40 Years of Vanadium Flow Battery Research and Development at UNSW

Maria Skyllas-Kazacos

School of Chemical Engineering

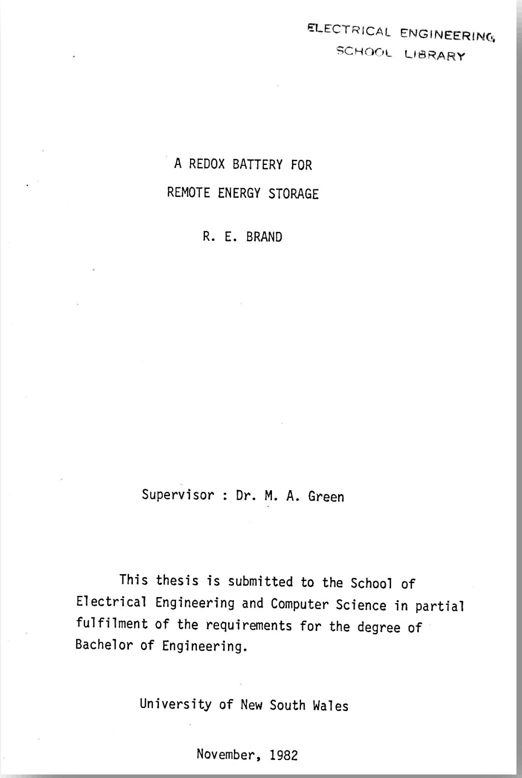
UNSW Sydney, NSW, AUSTRALIA

The original seed – NASA's Fe/Cr flow cell project by Martin Green's Student Bob Brand


Larry Thaller (NASA)


Martin Green


Bob Brand



A REDOX BATTERY FOR
REMOTE ENERGY STORAGE

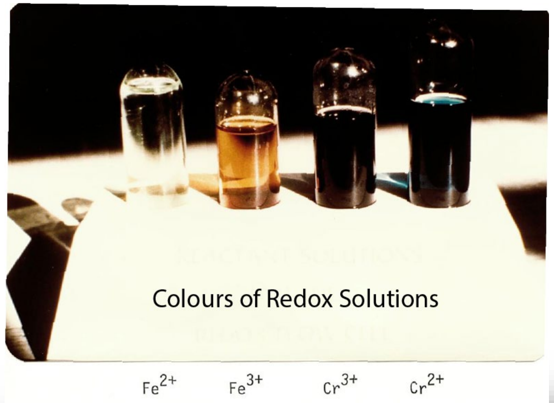
R. E. BRAND

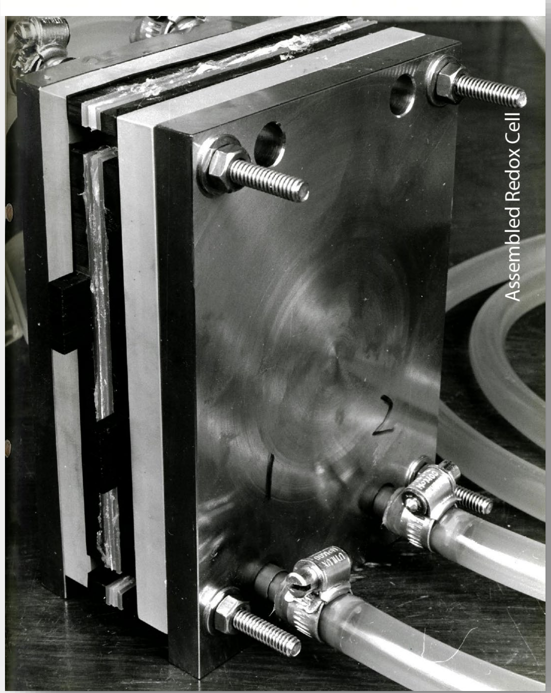
Supervisor : Dr. M. A. Green

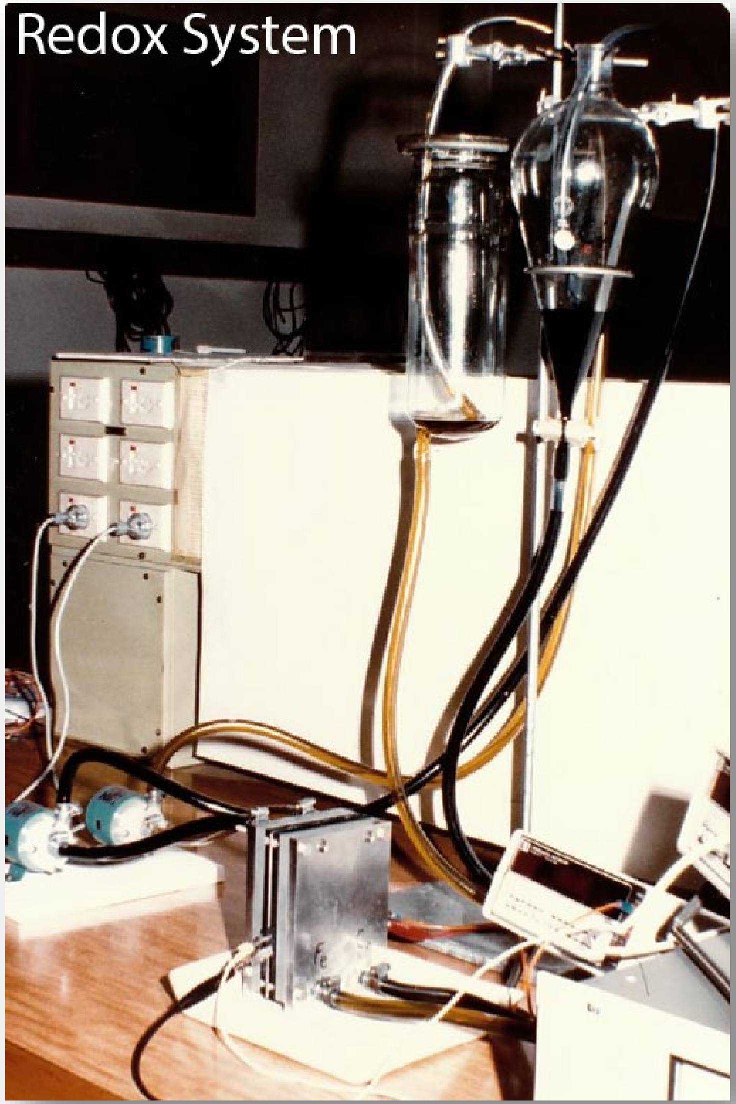
This thesis is submitted to the School of Electrical Engineering and Computer Science in partial fulfilment of the requirements for the degree of Bachelor of Engineering.

University of New South Wales

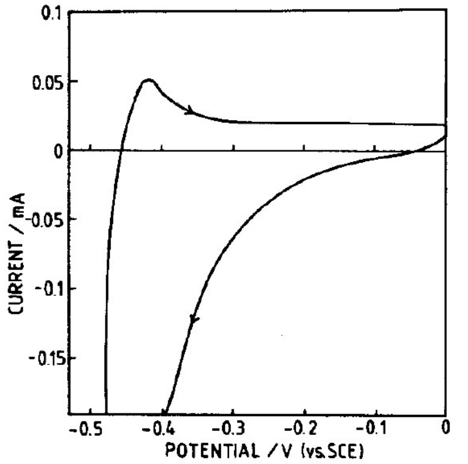
November, 1982







First Electrochemical Experiments of Vanadium Redox Couples – Elaine Sum 1984



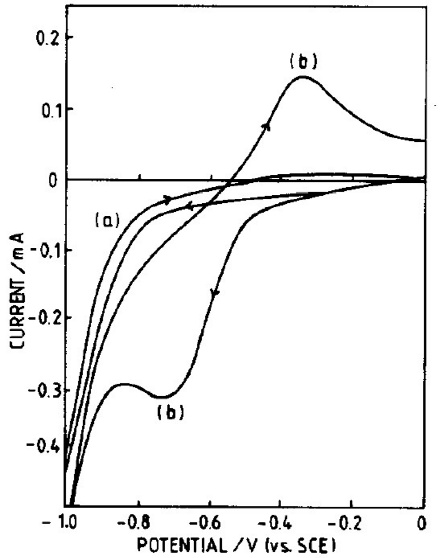


Fig. 1. Voltammogram of gold (area 0.45 cm^2) in 0.015M VCl_3 + 0.1M H_2SO_4; sweep rate 2 V min^{-1}.

Fig. 2. Effect of electrode polishing on voltammograms for glassy carbon in 0.08M VCl_3 + 1.8M H_2SO_4; scan rate 5 V min^{-1}. (a) Electrode prepared with P1200 sandpaper, 0.3 μm alumina, 45 min ultrasonic cleaning; (b) electrode polished on P1200 sandpaper.

A study of the V(II)/V(III) redox couple for redox flow cell applications, E. Sum and M. Skyllas-Kazacos, J. Power Sources, **15**, 179-190 (1985).

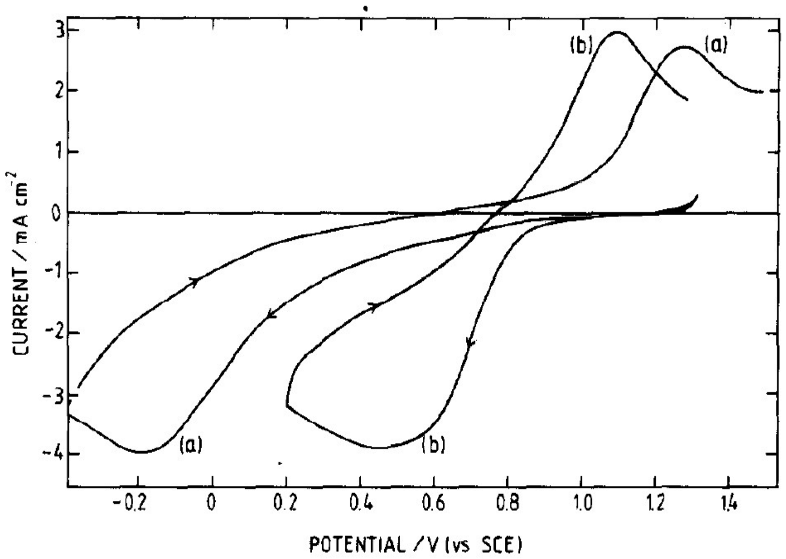


Fig. 2. Effect of surface preparation on voltammograms for glassy carbon in 0.055 M V(V) + 1.8 M H_2SO_4 solution; scan rate = 4 V min^{-1}. (a) Electrode prepared with P1200 paper, 0.3 μm alumina, and ultrasonic cleaning for 1.5 h. (b) Electrode polished with P1200 paper.

Investigation of V(V)/V(IV) system for use in positive half-cell of a redox battery, E. Sum, M. Rychcik and M. Skyllas-Kazacos, J. Power Sources, **16**, 85-95 (1985).

First Flow Vanadium Cell Tests

JOURNAL OF THE ELECTROCHEMICAL SOCIETY

ACCELERATED

BRIEF COMMUNICATIONS

MAY 1986

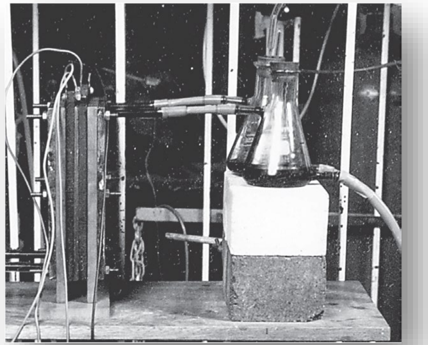
New All-Vanadium Redox Flow Cell

M. Skyllas-Kazacos,* M. Rychcik, R. G. Robins, and A. G. Fane

School of Chemical Engineering and Industrial Chemistry, University of New South Wales, Kensington, New South Wales 2033, Australia

M. A. Green

School of Electrical Engineering and Computer Sciences, University of New South Wales, Kensington, New South Wales 2033, Australia



First All-Vanadium Flow Cell fabricated by Franz Grossmith in 1986

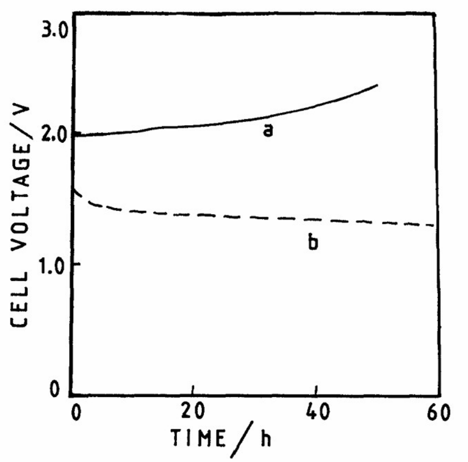
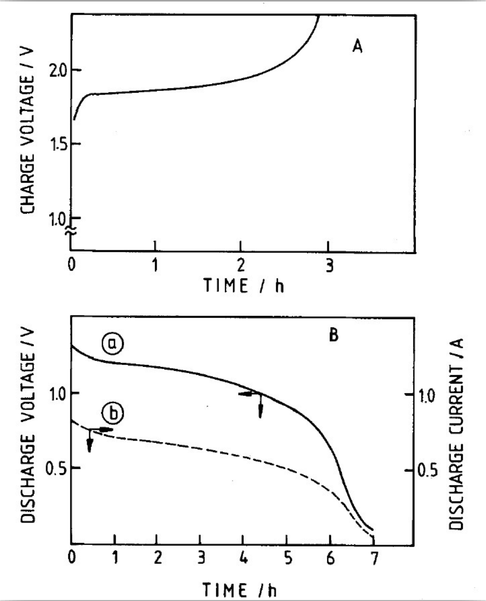
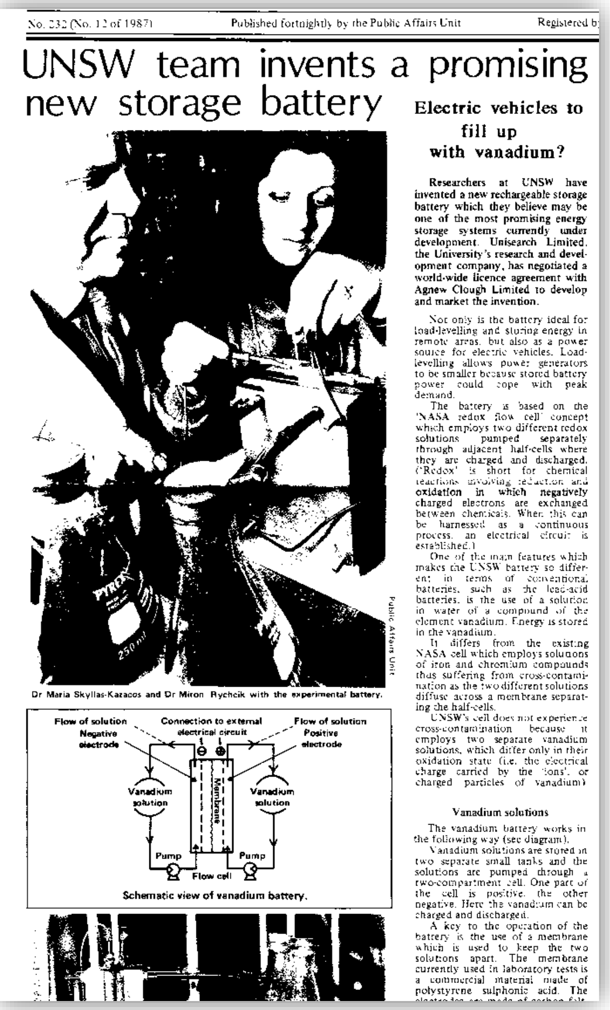


Fig. 1. a – Change of voltage during charging: b – Stability of open circuit voltage of charged cell.



Efficient vanadium redox flow cell, M. Skyllas-Kazacos and F. Grossmith, J. Electrochem. Society., **134**, 2950 (1987).

1987 - Discovered by the media and 1st licence



No. 232 (No. 12 of 1987) Published fortnightly by the Public Affairs Unit Registered by

UNSW team invents a promising new storage battery

Dr Maria Skyllas-Kazacos and Dr Miron Rychcik with the experimental battery.

Schematic view of vanadium battery.

Public Affairs Unit

Electric vehicles to fill up with vanadium?

Researchers at UNSW have invented a new rechargeable storage battery which they believe may be one of the most promising energy storage systems currently under development. Unisearch Limited, the University's research and development company, has negotiated a world-wide licence agreement with Agnew Clough Limited to develop and market the invention.

Not only is the battery ideal for load-levelling and storing energy in remote areas, but also as a power source for electric vehicles. Load-levelling allows power generators to be smaller because stored battery power could cope with peak demand.

The battery is based on the 'NASA redox flow cell' concept which employs two different redox solutions pumped separately through adjacent half-cells where they are charged and discharged. ('Redox' is short for chemical reactions involving reduction and oxidation in which negatively charged electrons are exchanged between chemicals. When this can be harnessed as a continuous process, an electrical circuit is established.)

One of the main features which makes the UNSW battery so different in terms of conventional batteries, such as the lead-acid batteries, is the use of a solution in water of a compound of the element vanadium. Energy is stored in the vanadium.

It differs from the existing NASA cell which employs solutions of iron and chromium compounds thus suffering from cross-contamination as the two different solutions diffuse across a membrane separating the half-cells.

UNSW's cell does not experience cross-contamination because it employs two separate vanadium solutions, which differ only in their oxidation state (i.e. the electrical charge carried by the 'ions', or charged particles of vanadium)

Vanadium solutions

The vanadium battery works in the following way (see diagram).

Vanadium solutions are stored in two separate small tanks and the solutions are pumped through a two-compartment cell. One part of the cell is positive, the other negative. Here the vanadium can be charged and discharged.

A key to the operation of the battery is the use of a membrane which is used to keep the two solutions apart. The membrane currently used in laboratory tests is a commercial material made of polystyrene sulphonic acid. The

Exclusive world-wide licence being granted to Agnew Clough Pty Ltd. Company funded further research at UNSW for 3 years, but relinquished licence during Asian financial crisis.

Sir Robert David Garrick Agnew, CBE (21 September 1930 – 3 August 1987) . Australian competition swimmer and businessman. Represented Australia at the 1948 and 1952 Summer Olympics, as well as the 1950 British Empire Games. After retiring from swimming he entered business, becoming involved in resources industry in Western Australia. Partnered with Clough to establish Agnew Clough Pty Ltd – vanadium mine in WA.

The UNSW All-Vanadium Flow Battery

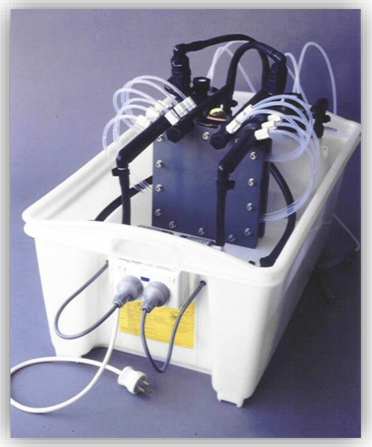
- **1984**: First practical VFB demonstrated at the University of NSW
- **1986**: Patents filed in Australia, USA and Japan
- **1984-2000**: Extensive R&D effort at UNSW covering all aspects of cell materials, electrolyte characterisation and production, stack design, modelling, fabrication and testing, sensor and control system development etc.
- Early UNSW field trials in solar house in Thailand, electric golf cart and submarine applications in mid-1990s.
- Early projects funded by Australian national and state government bodies interested in energy storage for remote area power systems (NERDDC, ERDC, NSW Office of Minerals and Energy, ARC).
- Initially licensed to Thai Gypsum, Mitsubishi Chemical Corporation in mid-1990s and Sumitomo Electric Industries in 2001.

VRB Progress at UNSW 1984-1990

- First All-Vanadium Flow Battery patent filed by UNSW in 1986
- Basic chemical and electrochemical studies
- Screening, characterisation and selection of membranes, electrodes, cell materials
- Development of vanadium electrolyte processes.
- Early stack design and development

Rui Hong, Jim Wilson, Dennis Yan, Michael Kazacos, John Chieng, Djen Kasherman, Peter Wegner

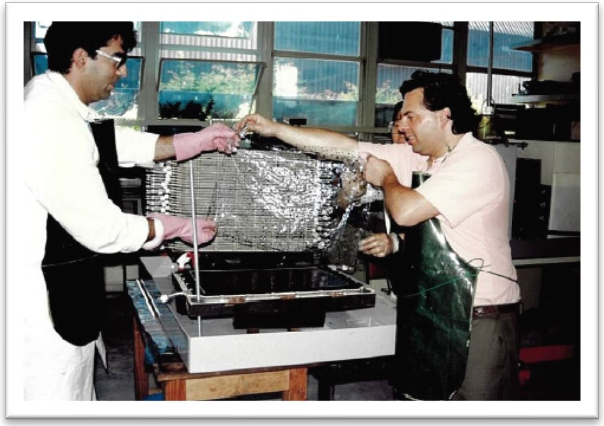
First VFB flow cell: 1986



Early VFB multi-cell: 1988

First 1 kW VFB multi-cell stack: 1988

First 2.5 kW VFB stack: 1989

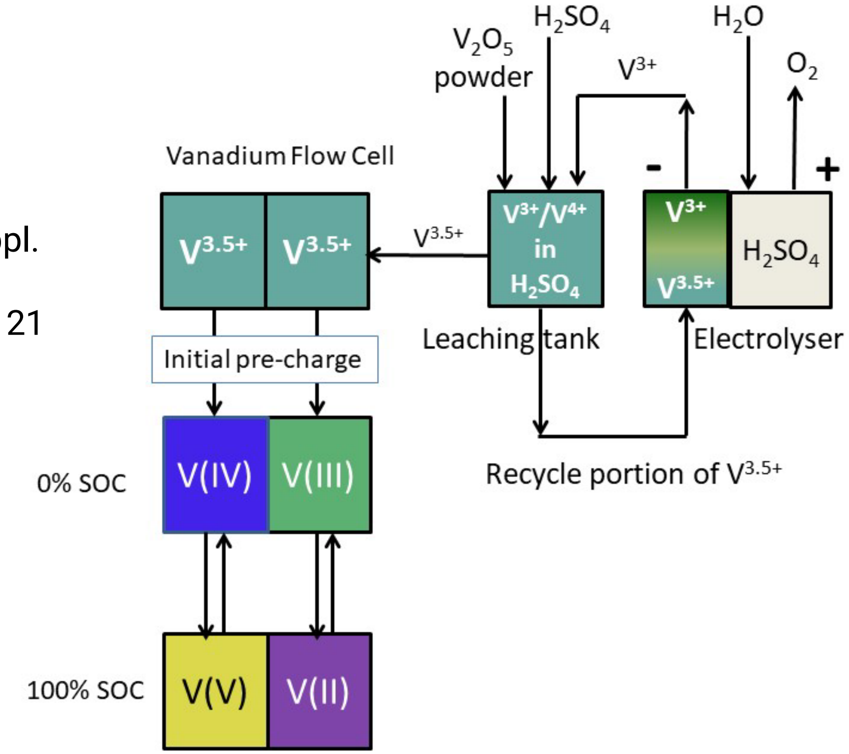


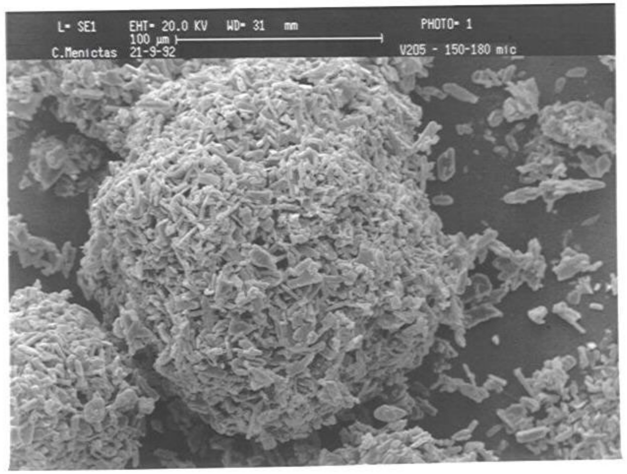
Early UNSW R&D Projects: Vanadium Electrolyte Production

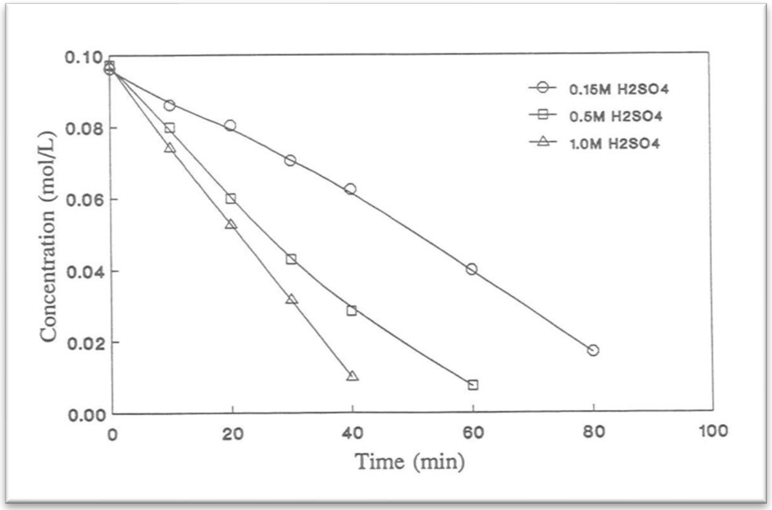
Investigation of V_2O_5 processes:

- **Suspended powder electrolysis**
- **Chemical reduction – eg H_2SO_3, oxalic acid**
- **Leaching eg with V(III)**
- **V2O5 + V2O3 reactive dissolution**

"Vanadium salt dissolution process", M. Skyllas-Kazacos, R. McDermott and M.Kazacos, Patent Appl. No. PCT/AU88/00471.
“Vanadium Redox Battery Electrolyte Process” M.Skyllas-Kazacos, Prov. Patent Application, PR 5143, 21 May, 2001, PCT Application, PCT/AU02/00613, May, 2002, US Applic No 2004/0241552 A1.







C. Menictas PhD thesis, UNSW, 1993

Chris Menictas, Rod McDermott, Rui Hong, Jim Wilson, Alex Stefos

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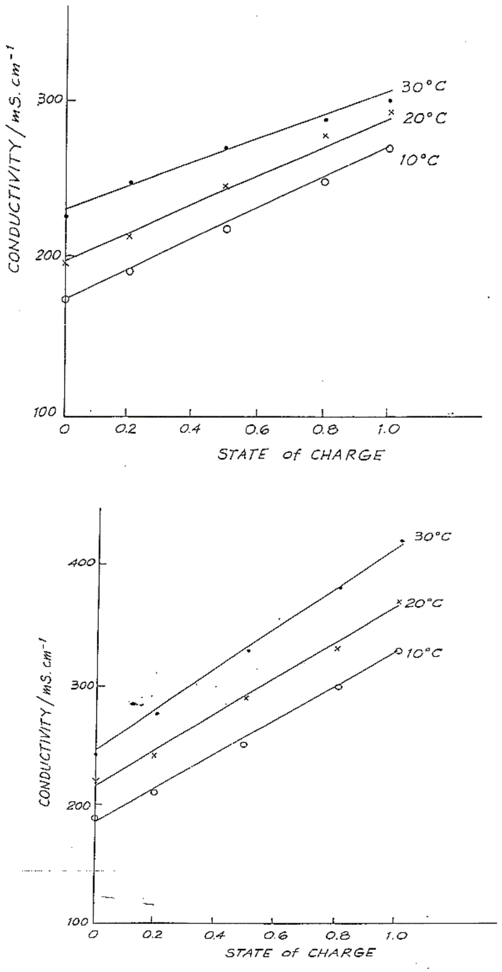
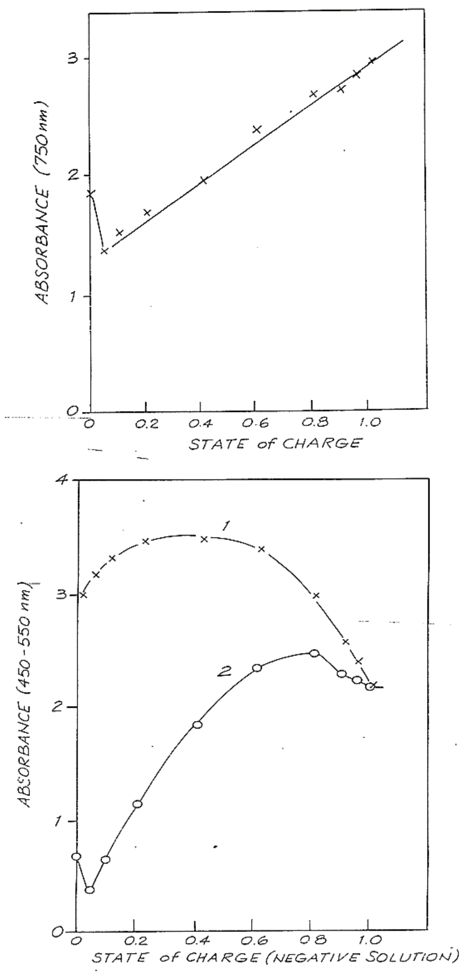
Early UNSW R&D Projects: SOC Monitoring and Control

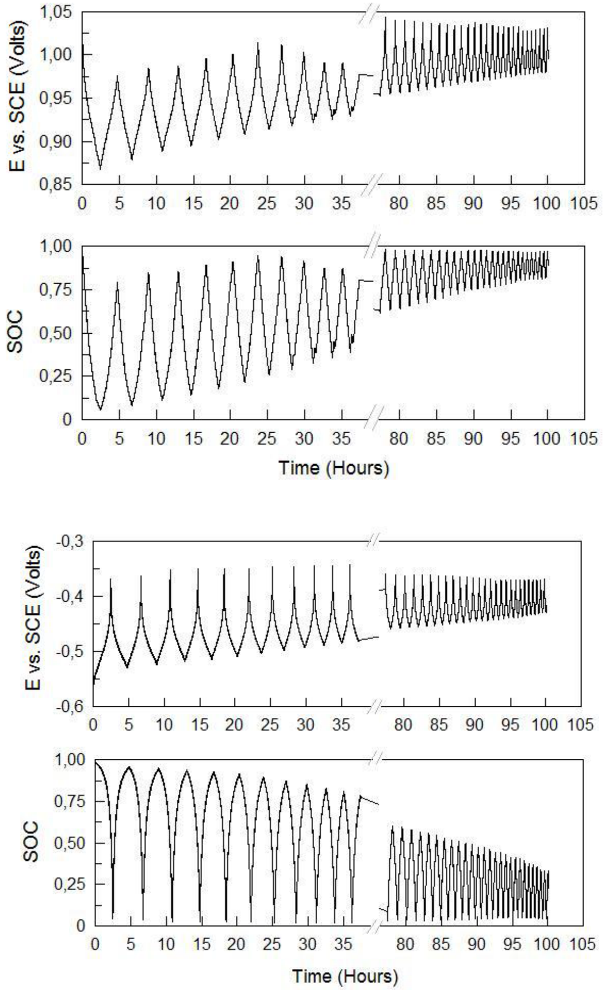


Conductivity vs SOC



Absorbance vs SOC

Michael Kazacos MSc Thesis, UNSW 1889



S. Corcuera et al Eur. Chem. Bull. 2012, 1(12), 511-519

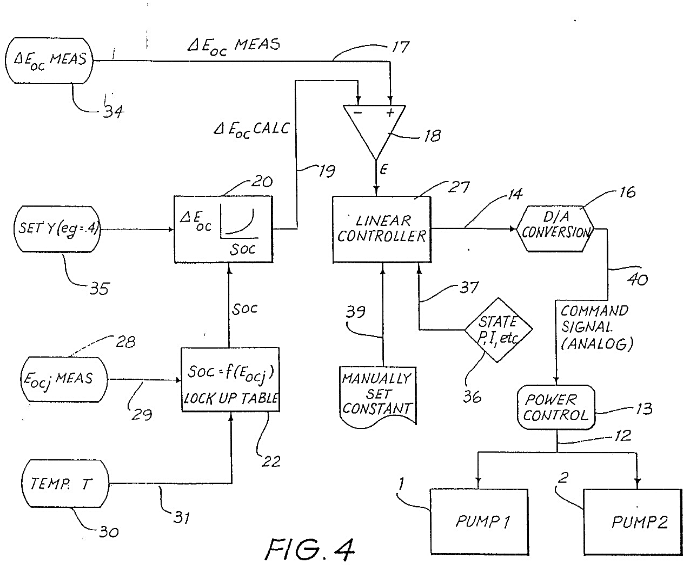


FIG. 4

"State-of-Charge of Redox Cell", by M. Skyllas-Kazacos, M. Kazacos, J. Joy and B.G. Madden, Patent Appl. No. PCT/AU89/00252, June 1989.

Early Battery Controller Development: Barry Madden, Rob Largent, Luke McDermott, Yifeng Li

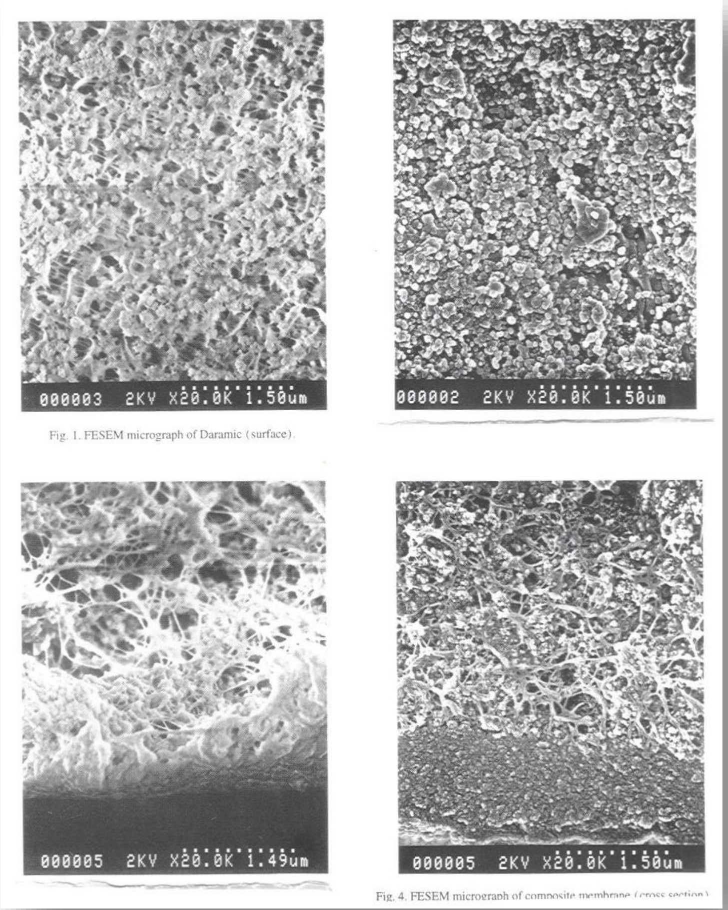
Early UNSW R&D Projects:
Membrane Screening and Modification

1. Wide range of commercial membranes screened for:
    - electrical conductivity
    - permeability
    - chemical stability in V(V)
    - water transfer behaviour

2. Developed membrane modification processes to reduce water transfer

3. Novel low-cost composite membrane based on "Daramic" separator.

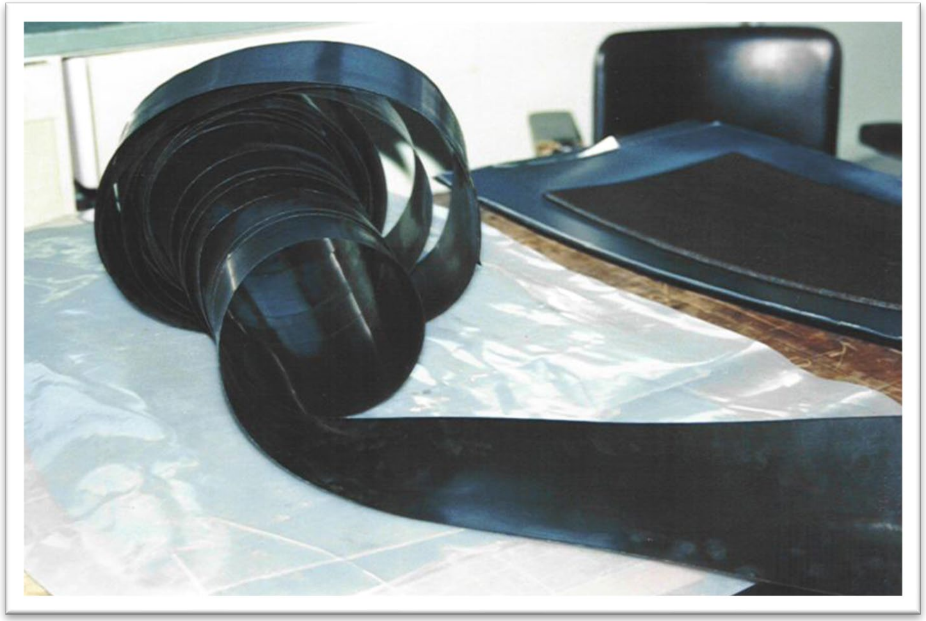
4. Developed methods to measure membrane diffusion coefficients



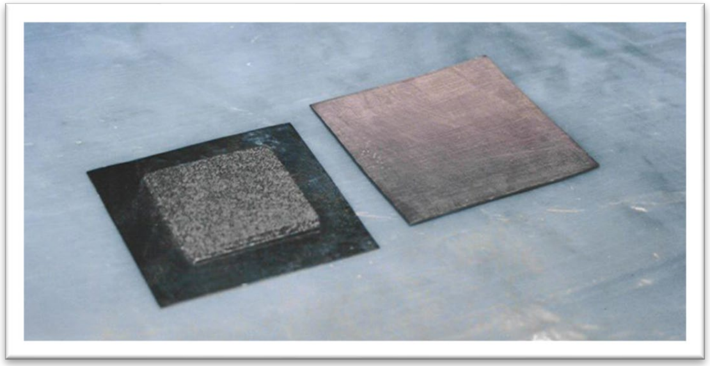
From T. Mohammadi PhD thesis UNSW, 1995

John Chieng, Toraj Mohammadi, Theresa Sukkar, Helen Prifti, George Kazacos (V-Fuel)

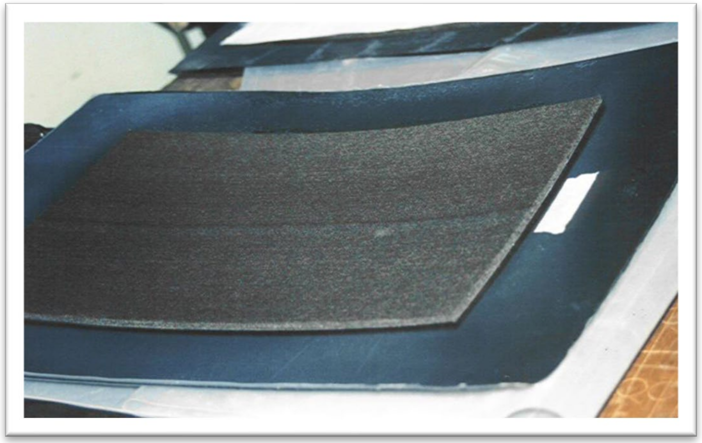
Early UNSW R&D Projects: Bipolar Electrode Development



Conducting plastic substrate - carbon filled PE/PP/rubber blends



End electrodes



Bipolar electrode

S.Zhong, PhD thesis UNSW, 1992, V. Haddadi-Asl PhD thesis, UNSW, 1995
Jim Wilson, Michael Kazacos, Chris Menictas, Christoph Hagg, Nick Kazacos (V-Fuel)

Graphite Felt Electrode

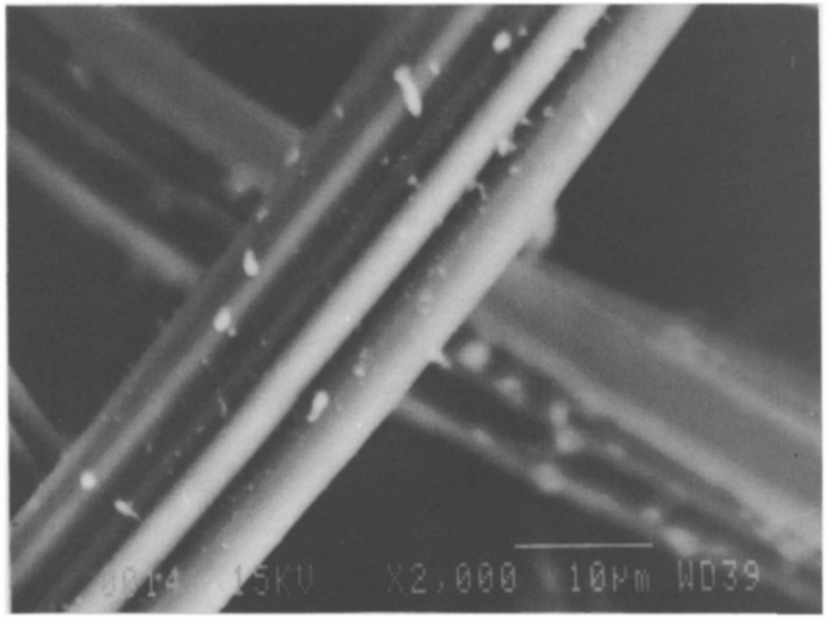
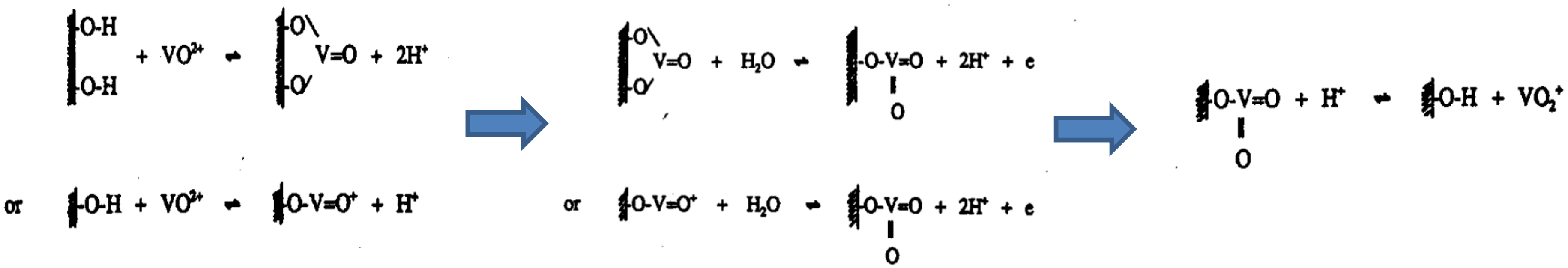


Fig. 6. The surface morphology of graphite felt treated at 400°C for 30 h.

Thermal, chemical and electrochemical treatments of graphite felt found to improve cell performance by introducing surface functional groups that provide active sites for the vanadium reactions and increasing hydrophilicity



Sun and Skyllas-Kazacos, Electrochemica Acta 1992

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Graphite felts and felt activation

(a)Thermal treatment (b) Acid Treatment

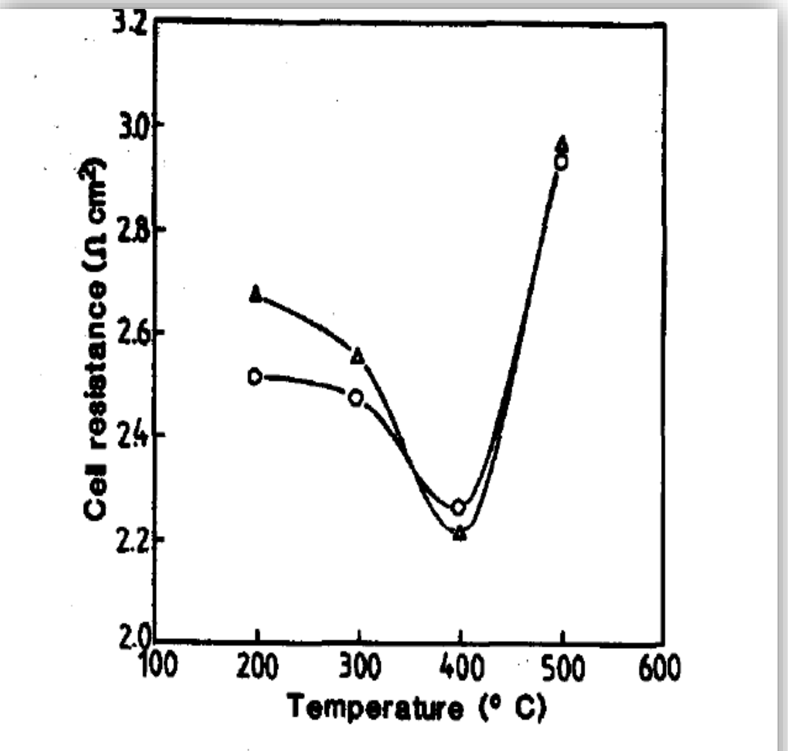


Fig. 2. Effect of treatment temperature on the cell resistance for activated graphite felt, (○) charge and (△) discharge.

Sun & Skyllas-Kazacos Electrochim Acta, Vol. 37, No. 13, pp. 1253-1260. (1992)

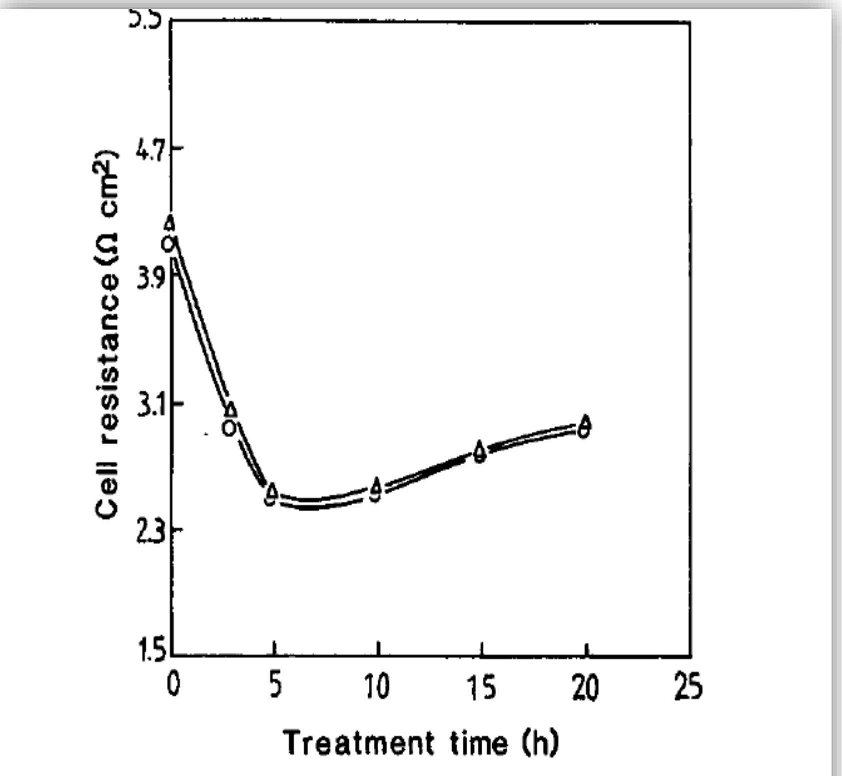


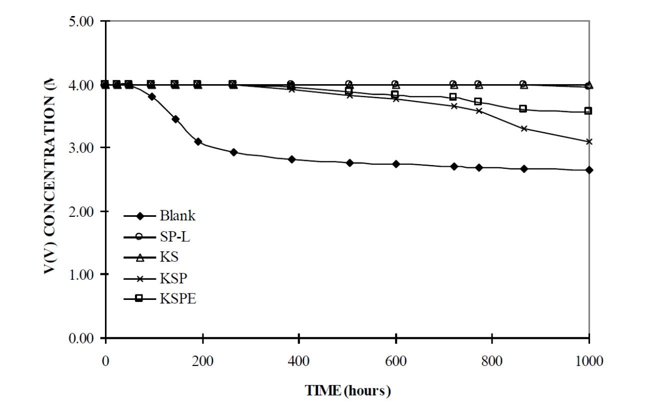
Fig. 1. Influence of treatment time on the cell resistance of a vanadium redox cell employing graphite felt electrodes

Sun & Skyllas-Kazacos, Electrochim. Acta, 37. (1992), pp. 2459- 2465.

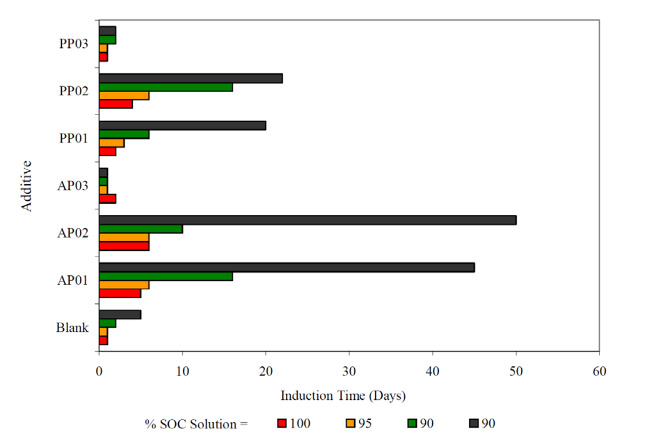
Improved G1 VRB with supersaturated solutions and precipitation inhibitors

- In mid 1990s, Skyllas-Kazacos and co-workers patented use of precipitation inhibitors to stabilise up to 4 M vanadium electrolytes concentrations and increase energy density (PCT/AU94/00711, 1994)
- Wide range of additives identified as good precipitation inhibitors to stabilise highly concentrated vanadium solutions over wide temperature range

Early precipitation inhibitor screening by Min Chen 1991, Michael Kazacos 1992, Chris Menictas 1995, Faizur Rahman 1998, Nadeem Kausar 2002, Asem Mousa 2003



Faizur Rahman UNSW PhD thesis 1998



Nadeem Kausar, UNSW PhD thesis 2002

Solution	Induction time (day)	Degree of Precipitation
Blank	4	4
Ammonium Sulfate	38	1
Ammonium phosphate†	> 52	Nil
Ammonium oxalate	10	3
Phosphoric acid	10	2
Potassium triphosphate	8	2
Sodium triphosphate	**30**	3
Sodium Pyrophosphate	30	4
Potassium Sulphate	10	3
Potassium persulphate	9	2
Sodium Sulfite	30	3
Boric acid	5	5
Tungstic acid†	> 52	Nil
Sodium Tungstate†	> 52	Nil
M1*	10	3
M2*	14	1

Asem Mousa UNSW PhD thesis 2003

UNSW SYDNEY

1992 - Moving out of the laboratory - first Thailand...

Vanadium battery agreement signed with Thai Gypsum

After seven years of research and development, Unisearch Ltd has signed an option agreement with Thai Gypsum Products Co Ltd for development of its unique vanadium battery technology.

Unisearch is the research, development, training and technology transfer company of UNSW and is the owner, by assignment, of the vanadium battery technology that has been developed at UNSW.

In return for a major investment in the commercial development of the technology, Thai Gypsum will acquire a licence to make, market and develop the vanadium battery for end-user domestic applications in much of South-East Asia.

The agreement between Unisearch and Thai Gypsum was reached after a recent visit to Australia by **Mr Krisada Kampanatsanyakorn**, the Managing Director of Thai Gypsum.

The vanadium battery technology was invented at UNSW by **Associate Professor Maria Skyllas-Kazacos** of UNSW's School of Chemical Engineering and Industrial Chemistry, **Dr Myron Rychcik** and **Professor Robert Robins**.

Other engineers and researchers who have played a significant role in the development of the vanadium battery technology include **Dr Djen Kasherman, Michael Kazacos,**

nitely; and batteries may be recharged instantaneously by pumping out spent electrolyte and replacing with charged electrolyte. Construction, running and maintenance costs have been shown to be more than competitive with other power storage systems.

Mr David Hogg, Unisearch's Intellectual Property Business Manager, said: "The development of this technology has received support from government research funding and private industry in Australia.

"Although this technology has enormous potential, we at Unisearch and UNSW have had, until now, difficulty in attracting a major industrial partner, so we are very pleased to be able to collaborate with Thai Gypsum.

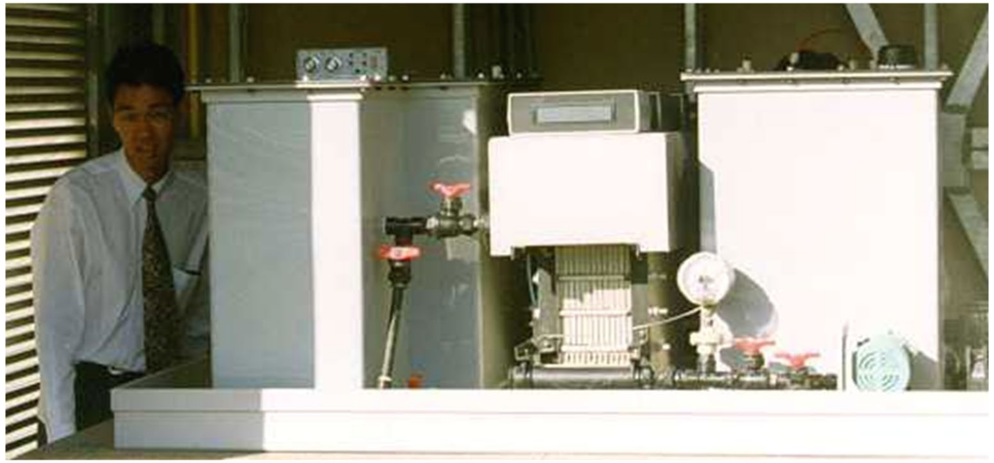
"We are looking forward to working with Thai Gypsum and confidently expect the project to benefit both companies. We are also pleased that this association will establish our battery technology on a large scale in South-East Asia, a region where we see strong growth creating great demand for this type of energy-efficient and pollution-minimising technology."

High commercial viability

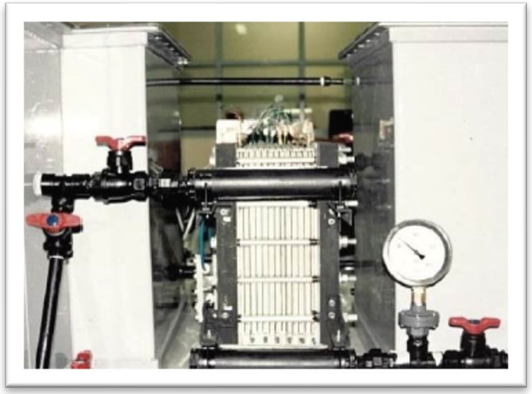
Mr Krisada said: "With environmental concern now a global issue, renewable energy sources combined with energy-efficient applications

Pictured during an inspection of UNSW's Centre for Photovoltaic Devices and Systems laboratory (from left): Mr Ted Spooner, a Project Scientist from UNSW's Department of Electric Power Engineering; Ms Kirsten Murray, Projects Manager for Unisearch's Consulting and Research Division; Professor Robert Excell, Chairman of the Division of Energy Technology at the Asian Institute of Technology, Bangkok; Mr Krisada; Mr William Cecchini, Project Director for Thai Gypsum; Mr Largent; Dr Sunt Techakumpuch, Chairman of Thai Engineering Consultants Co Ltd; Mr Hogg.

Thailand to test the battery under ... volts and will have a capacity of 15 ... cessing, provided technical assist-



Thai Solar House Project 1993-94



To save energy, pump control system designed to turn pumps on only when current > 20 A. When stack voltage dropped below pre-set value, pumps turned on for 3 minutes to replenish solution in stack.

Improved *PV* System Performance Using Vanadium Batteries" by Robert L. *Largent*, Maria *Skyllas-Kazacos* and John Chieng, Proceedings *IEEE*, *23rd Photovoltaic* Specialists Conference, Louisville, *Ky*., May *1993*

Battery fabricated by Rui Hong, Chris Menictas, John Chieng, Michael Kazacos, Jim Wilson; Electrolyte produced with in-house pilot process – controller designed and built by Rod McDermott; Battery controller designed and built by Rob Largent

...then Japan.

Vanadium battery receives backing

Continued from page 1

tion of Asia, Australia and New Zealand.

The intent of the agreement with Mitsubishi and Kashima-Kita is to bring the technology to the stage where it can be used for load levelling – storing electricity produced by power utilities during periods of reduced demand so it can be released at times of peak demand.

In the short term, this allows peak demand to be met without increasing electricity generating capacity. In the longer term it will postpone the need to build further expensive electricity generators.

Because the battery uses two liquid electrolytes, the battery's storage capacity can be raised by increasing the size of the storage tanks. The technol-

At the signing of the agreement between Unisearch and Mitsubishi Petrochemical and Kashima-Kita (standing, from left): Mr Hogg; Mr Kanji Sato, Chief Manager of Kashima-Kita's Vanadium Battery Development Division; Mr Hirokazu Takahashi, Power Systems Department, Mitsubishi Corporation; (and sitting from left) Mr Akira Shibata; Mr Richard Kaan, Managing Director of Unisearch; Mr Fuji Shigematsu, Representative Director of Kashima-Kita Electric Power Corp; and Professor Skyllas-Kazacos.

Australian Defence Department Project 1997

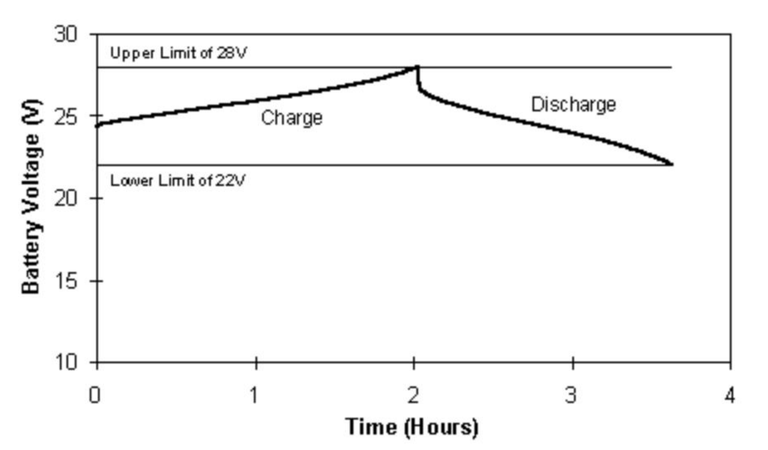


Fig. 7 Voltage profile for charge/discharge across 17/19 cells at 100A.

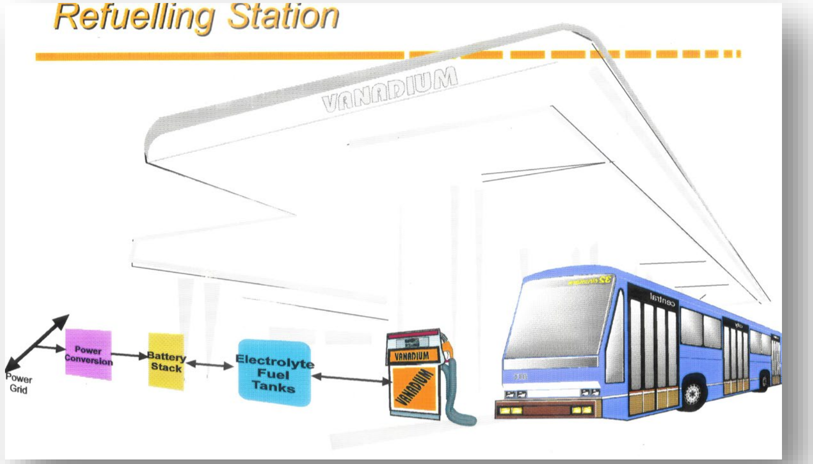
M. Skyllas-Kazacos and C. Menictas, Proceedings INTELEC'97, Melbourne, 19-23 October,1997. (https://ieeexplore.ieee.org/document/645928/)

Tapping Cell Utilisation

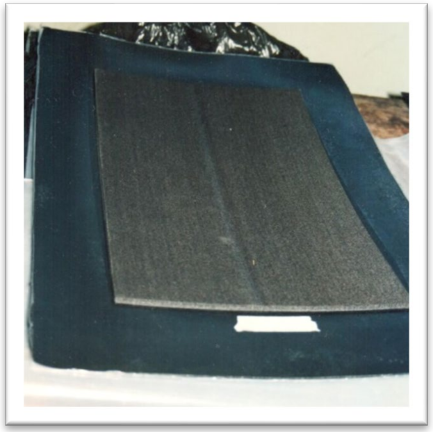
- Two 19-cell stacks connected in parallel.
- Tapping cell in each stack at cell 17.
- Purpose to allow charging across 17 cells and discharging across 19 cells thus limiting the difference between charge and discharge voltages.
- Charging battery across 17 ensured total battery stack voltage < 28 V.
- Battery discharged across 19 cells until total battery stack voltage reached 22 V.
- Two tanks share common wall with anti-syphoning pipe to transfer solution back to other side whenever electrolyte level exceeded.
- Typical voltage profile for 17 cells charge - 19 cells discharge at 100 A illustrated in Figure.

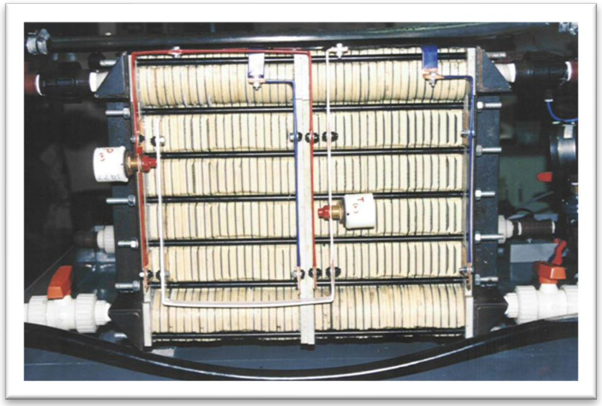
Design and fabrication team: Rui Hong, Chris Menictas, Denis Yan, Jim Wilson, Michael Kazacos

Bill Wentworth - Local advocate for UNSW VFB-powered light rail for Sydney in 1990s

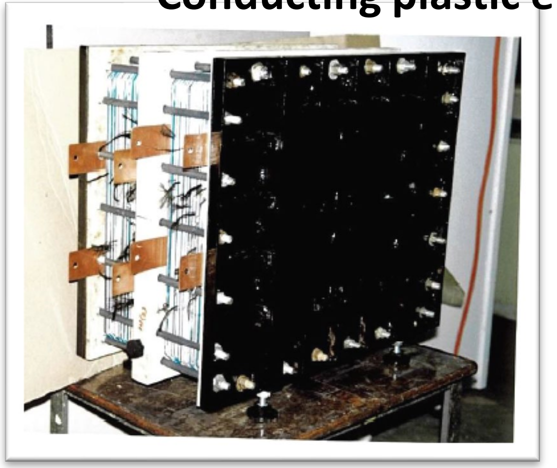


UNSW Electric golf cart project 1996-97





Conducting plastic electrode stack + 2 M electrolyte – typical Rcell = 3.2 ohm.cm2

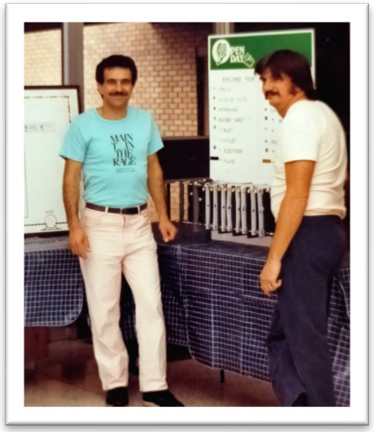


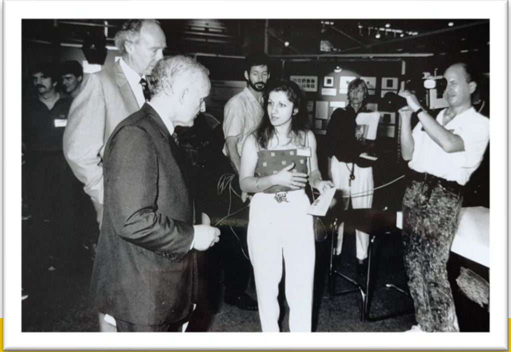
Glassy carbon electrode stack + 3 M vanadium electrolyte – Rcell = 2 ohm.cm2

Team: Rui Hong, Dennis Yan, Jim Wilson, Chris Menictas, Michael Kazacos, David Hogg, Wal Lamberth

Electrolyte Additives for 3 M solution: Michael Kazacos, Chris Menictas, Asem Mousa, Nadeem Kausar, Faiz Rahman, Sarah Roe

Exhibitions and Visitors





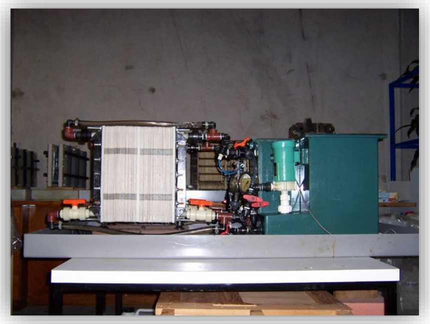
VRB Technology moved off-shore

- UNSW VRB patents sold to Pinnacle in 1997.
- Hostile take-over in 2001, Pinnacle and VRB patents taken over by Canadian company VRB Power.
- 2001 VRB licensed by Pinnacle to Sumitomo Electric - first began manufacturing and installing VRBs in 1990s.
- After Global Financial Crisis, Canadian company assets bought by Prudent Energy.
- Original UNSW VRB patent expired in 2006.

Gen 2 V/Br patented by UNSW in 2003

2005: Spin-off V-Fuel, established by Michael, Nicholas & George Kazacos with investment funding from CEGT and Newchris

2010: V-Fuel folds due to lack of investment



Commercial VFB Systems & Installations in Early 2000s

1 MW/5 MWh VRB - Sumitomo - Japan

5 MW/10 MWh Rongke Power - China

Gildemeister - Germany

300 kW/3.6 MW Prudent - California

VFB SYSTEM FOR UNSW TYREE BUILDING

- $129.7 million grant awarded to AGL Energy and First Solar under Solar Flagships Program in 2012
- $40.7 million to University of Queensland and UNSW to conduct related research.
- Part of UNSW funds for installation of 30 kW/ 120 kWh VFB unit in new Tyree Energy Technology Building at UNSW
- Installation of Cellcube VFB completed June 2015
- VFB system used to store solar energy from PV array on roof of building, while also allowing research on different energy storage applications.

Sumitomo 60 MWh VFB in Hokkaido

30 MW/ 60 MWh VFB

Location: Hokkaido, Japan

Started: December 2015

Grid Use:

- **Suppress WT and PV output fluctuations**
- **Load Frequency control**
- **Suppress long-period fluctuations**
- **Over generartion measures**
- **Hybrid operation of Long and Short period fluctuations**

Shibata et al, IFBF 2017, Manchester UK.

UNSW Basic VFB patent expired in 2006, allowing universal freedom to operate.

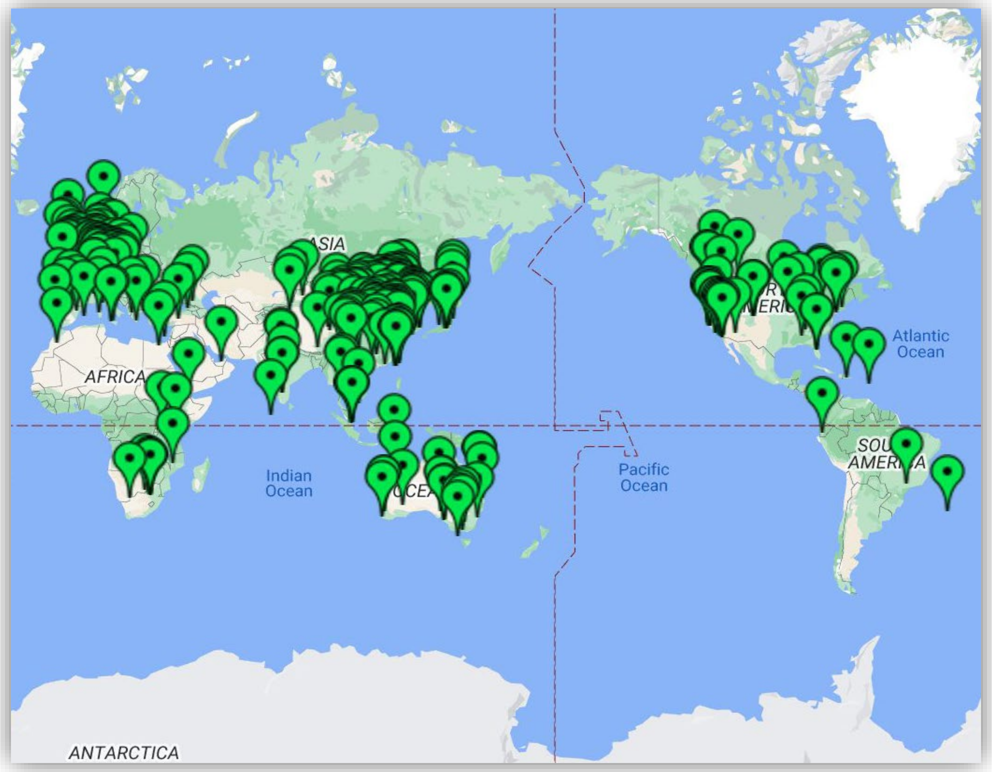
Since 2006, VRB manufactured by companies in Japan, China, USA, Germany, Austria, UK, Canada, Korea, India.

But for next 15 years, market still not ready.

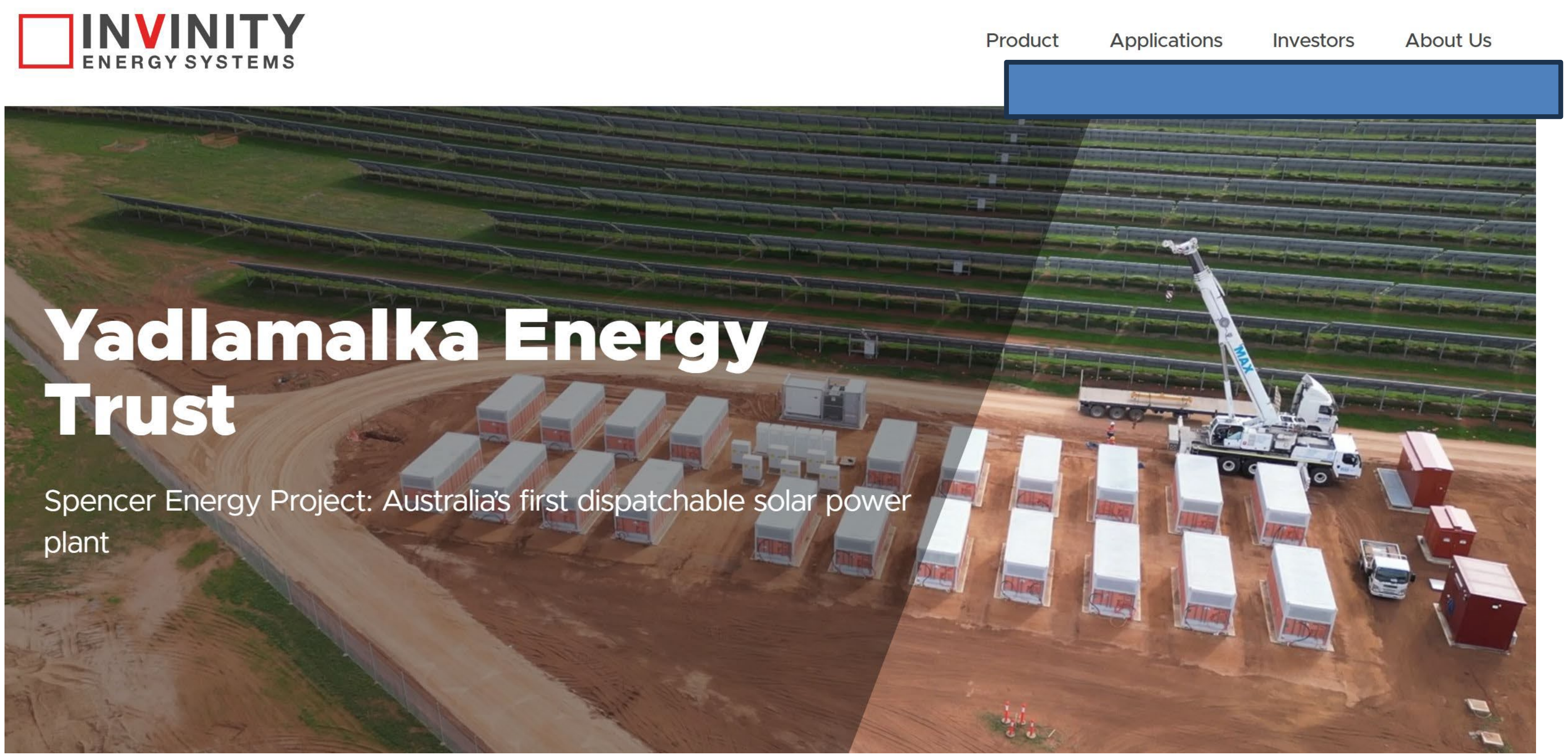
This changed in recent years and the UNSW VFB currently manufactured by more than 20 companies.

100s of MWhs of VFBs installed around the world. Several companies being established in Australia to manufacture and install VFB systems and produce vanadium electrolyte for local market.

Installed and Announced VFB installations in 2023



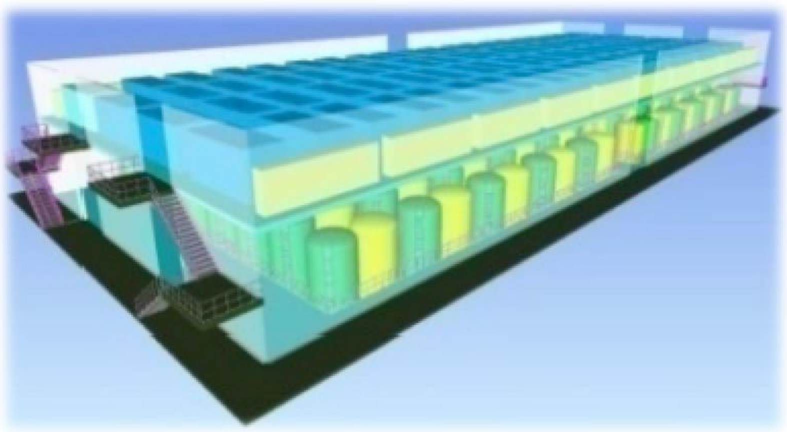
Largest VFB project in Australia to date



Invinity currently creating Australia's first dispatchable solar power plant with an 8 MWh (VFB), coupled with a 6MWp solar array in South Australia.

800 MWh Rongke Power Dalian Project and GigaFactory

200MW/800MWh VRFB Project



Location: Dalian City, CHINA

The first floor :	Electrolyte tank
The second floor:	Power unit + control unit
The third floor:	PCS + Transformer

Huamin Zhang, IFBF 2017, Manchester, UK

First 100 MW/400 MWh system commissioned in 2022. Phase 2 under construction

Rated Power: 200 MW

Rated Capacity: 800 MWh

AC efficiency > 70%

Components:

Battery: 500 kW/2 MWh x 400

Rongke Power, LinkedIn 2024

Many GWh of VFB storage projects in pipeline in China

Global Vanadium Production and

By 2030, the cumulative installed capacity of electrochemical energy storage will reach 100GW, and the market share of VFBs is estimated to be about 30%, which is 30GW. If the average storage time of VFBs is 6 hours, it will be about 180GWh.

The 180GWh electrolyte requires 1.5 (1.44 million) tons of V2O5.

- Prof Huamin Zhang, Vanitec Conference, China 2023

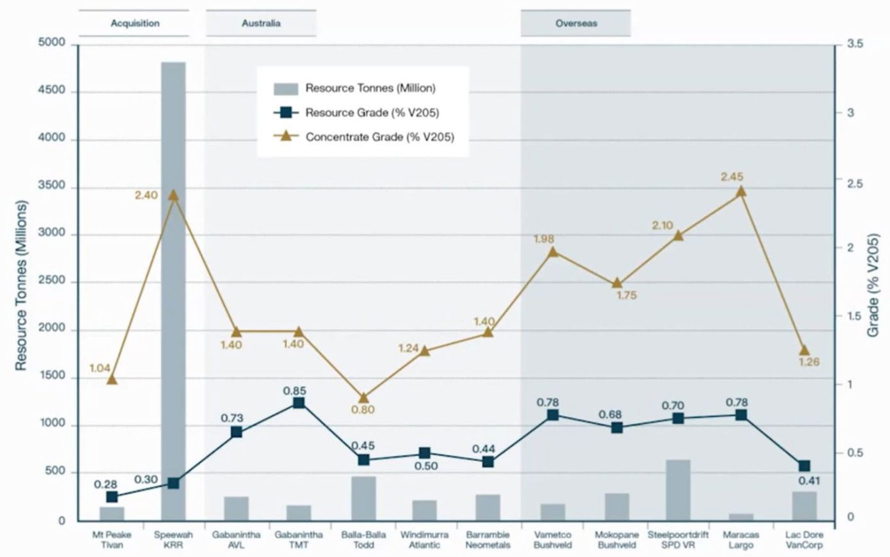


Figure 5: Vanadium in titanomagnetite resources, peer comparison. Prepared in accordance with ASX Compliance Update, 19 September 2018. Update No 08/18, Section 3. Link is available here. The full dataset with relevant sources and notes is included in Appendix 1.

Vanadium supply forecasts – Tivan Pty Ltd

Australia can be a major global supplier of this critical mineral and potentially establish a significant battery manufacturing capability

40 years of team effort …..

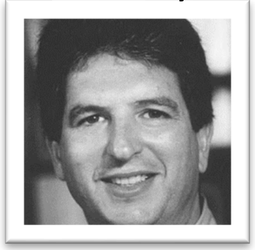
Bob Robins and Tony Fane

Bob Brand

Franz Grossmith, Michael Kazacos, Maria S-K, Rod McDermott

Rui Hong

Chris Menictas



Martin Green

Elaine Sum

Jim Wilson

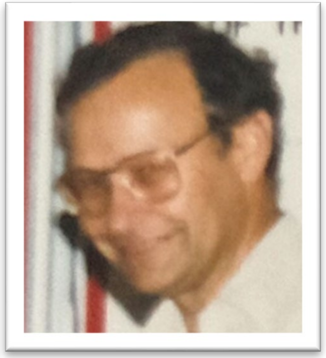
Jie Bao

Rob Burford

Miron Rychcik

and many many more…

Rob Largent



Peter Wegner

Tuti Lim

Bao, Jie
Brungs, Mike
Burford, Rob
Brand, Bob
Chau, Andrew
Dobrinski, Elizabeth
Fane, Tony
Fell, Chris
Fletcher, John
Fynch, Mike
Giddy, Alan
Green, Martin
Hogg, David
Howe, Russell
Lamberth, Wal
Largent, Rob.
Lim, Tuti
Liyadipitiya, Gamini
McCann, John
Meng, Ke
Menictas, Chris
Nasev ,Katia
Tomazic Gerd
Tran, Tam
Trimm, David
Wainwright, Mark
Walker, Richard
Welch, Barry

Adam, Jeffrey
Akter, Md. Parvez
Alvin, Leonhard
Arcidiacono, Alfio
Banzato, Amadeo
Becker, Ashley
Benson, Craig
Borman, Michael
Cao, Liuyue
Channing, Amanda
Chau, Andrew Hung
Che Mat, Norfamila
Cheng, Min
Cheung, Winnie Cheuk
Chieng, S.C. John
Choi, Nak Heon
Choong, Petrina
Cohen, Elizabeth
Corcuera, Sara
Eadie, Ben
Estornés, Jon
Furner, Nicholas
Gerber, Anthony
Godiwala, Shail
Goh, Leesean
Goulet, Marc-Antoni
Grossmith, Franz
Guan, Xinjie
Haddadi-Asl, Vahid
Hagg, Christoph
Holme, Sue
Hong Anh, Wendy

Hong, Rui
Jeffrey, Adam
Joy, Jaqui
Ju, Jesse-Yizhou
Kasherman, Djen
Kausar, Nadeem
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Kazacos, Nicholas
Kazacos, George
Kenyon, Rebecca
Kiat, Meng
Koh, Bing Sen
Kronander, Anders
Lee, Anna
Lee, En Leng
Leonardi, Alvin
Leong, Tween Teng
Li, Jui-Ko
Li, Jun
Li, Yifeng
Liao, Hannah
Lim, Tuti
Limantri, Yuni
Ling, Lionel
Lisinio, Lisboa
Llewellyn, Paul
Ma, Elisha
Marston, Susan
McAuley, Robert
McDermott, Luke
McDermott, Rod
McKay, David
McCloy, Ryan

McKinley, Sarah
Milne, Nicholas
Mohammadi, Fereidoon
Mohammadi, Toraj
Morabito, Joe
Moses, Michael
Murphy, Kristina
Navaphol, Tharathon
Olansathit, Janephum
Olney, Kathryn
Padeste, C.
Peng, Christina
Pennisi, Paul
Poon, Grace
Priest, Matthew
Prifti, Helen Vafiadis
Rachmat, Ryana
Rahman, Faizur
Reid, Nicola
Risbud, Mandar
Roe, Sarah
Rychcik, Miron
Saeed, Mohammed Kahlid
Sani, Agus
Shu, Bing
Sim, Yaw Lim
Siyu, Yuan
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Stefos, Alex
Stiel, Andrew
Sukkar, Theresa
Suld, Sulide

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Sun, Longgang
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Tang, Chung Hang
Tham, Andrew
Tian, Yuheng (Carolyn)
Timbrell, P.
Ting, Simon
Tio, Kitiono
Tjokrowidjaja, Mariana
Trinh, Phan
Tuerah, Mery
Turney, Robert
Veersema, Hugh
Vierkant, John
Vijayaratnam, Pujith (PJ)
Wah, Tay Kian
Weber, Logan
Wegner, Peter
Wei, Lai
Wen, Bingyi
Widjaja, Melinda
Wilson, Jim
Xie, Jiangzhou
Yan, Yitao
Yan, Z.H. Dennis
Ye, Zuyu
Yi, Zuyu
Zhang, Xinan
Zhong, Shihuang

UNSW SYDNEY

Thank you

Maria, Nick, George, Michael and Anthony Kazacos

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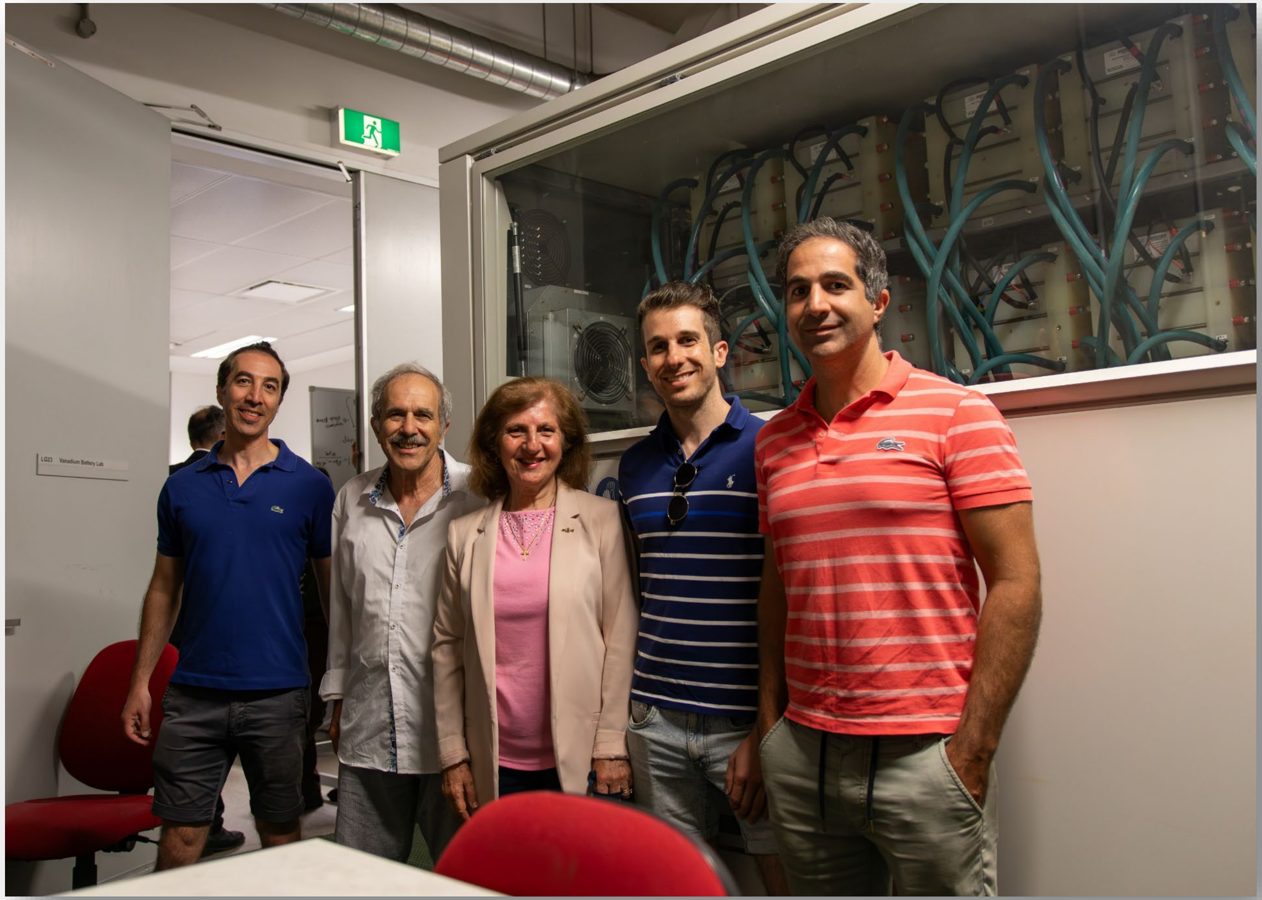

Nick, Michael, Maria, Anthony and George Kazacos

2024