

Strategic Metals & Rare Earths Letter

INTERNATIONAL

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VANADIUM redox flow batteries to benefit from the EV revolution

Vanadium is rarely mined on its own, often occurring in vanadium magnetite iron ore, is used to produce high-strength steel and chemical catalysts, but most potential future demand stems from its role in **vanadium redox flow batteries (VRFBs)** as a result of the electric car revolution. VRFBs have reached a stage of larger-scale commercialization, as demonstrated by Rongke Power's Dakan project. While the technology is becoming increasingly sensitive, it remains highly price sensitive and in a position to compete with lithium-ion technology.

Vanadium also shows potential to be used in other forms of batteries, with lithium vanadium oxide a potential high-density anode for lithium-ion batteries, while vanadium phosphates could be used as a cathode in lithium vanadium phosphate batteries, another form of lithium-ion battery.

As vanadium flow batteries use a liquid electrolyte rather than the more familiar solid "cell" construction they are very easy to "scale" up or down, you simply change the size of the plastic tank used to house the electrolyte. That means you can double the size of a vanadium battery and reduce the cost of electricity storage, while if you did the same thing for a lithium battery that storage cost would have doubled.

Currently 85% of the world's vanadium is produced by 3 countries: China, Russia and South Africa. The bulk of the metal is either mined or produced as a by-product of steelmaking, meaning that changes in iron ore and steel market dynamics can impact vanadium production.

Vanadium is also found in bauxite (used to produce alumina and finally aluminium) and in deposits of crude oil, coal, oil shale and tar sands.

That means that a lot of current vanadium deposits are owned by companies whose main purpose is to mine or extract something very different such as bauxite, iron ore, gold, copper or uranium.

Global mining giants are: BHP, Rio Tinto and Alcoa, which increase or begin vanadium production when it is economic. As a by-product many companies might not even acknowledge they have vanadium.

On the high-profile pursuits private firm **High Power Exploration**, with Robert Friedland its CEO, has a controlling interest in Beijing-based **Pu Neng**, which has invested about \$ 90 million in VRFB systems.

In late September 2017, the China National Development and Reform Commission released a policy document called "Guidance on the Promotion of Energy Storage Technology and Industry Development" to move away from coal-fired power plants towards renewable energy sources in order to reduce emissions and improve air quality.

The document calls for the launch of pilot projects such as multiple 100-MW-scale vanadium flow batteries by the end of 2020.

As part of the policy, Pu Neng was awarded a contract in November 2017 to build the largest vanadium flow battery in China.



► **Dalian Rongke Power** is a jointly established company by Dalian Boleng Holding Group and Dahan Institute of Chemical Physics, Chinese Academy of Sciences. The company is a vertically integrated processing independent R & D and production capacity of vanadium flow battery industry chain and has developed the second generation of containerized portable products in 2013, significantly reducing the cost of the production.

Regarding the expansion in international energy storage market, **Rongke Power** has seized the opportunity and developed an international strategy. In March 2012, the establishment of UniEnergy Technologies (UET) in the United States, aiming at fostering the innovation capability and expanding the US market. The Company has won the Top Science and Technology Award of the US Department of Energy.

At present, UET has made great break-through's in product design, system integration and business model demonstration. In addition, great business opportunities have emerged in the Japanese and European market. Rongke Power received orders of key materials of more than 100 MW in Japan and Europe.

Rongke Power started the construction of the larger-scale manufacturing base in 2014. The layout is divided into three parts: A. build R & D center in Dalian High-Tech Zone's; B. construct the new equipment manufacturing base in Dalian Puwan New District with the capacity of 300 MW/year in Phase I; C. upgrade the key material manufacturing base in Zhuanghe Huayuankou Economic zone; D. based on the existing cases, establish a complete set of solutions for large-scale energy storage application.



The world's largest battery:

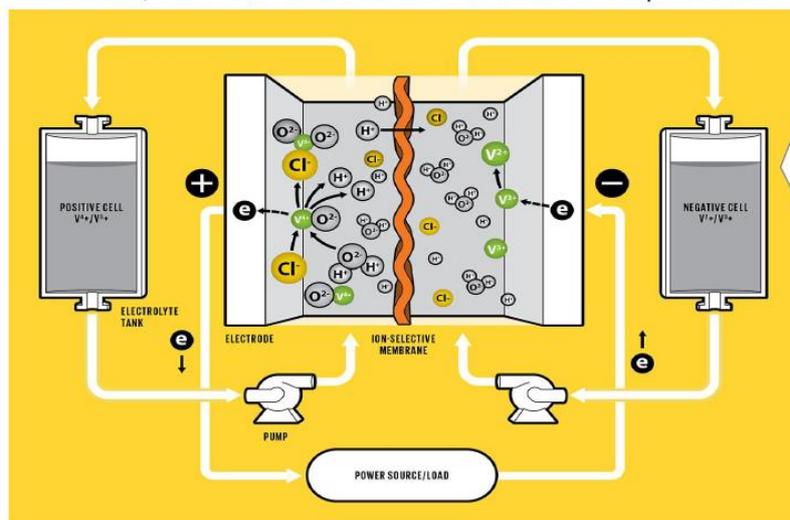
Rongke Power's 800MWh vanadium flow battery factory in Dalian, China

Vanadium is the simplest and most developed flow battery



How does a vanadium redox flow battery (VRFB) work?

- A flow battery was first developed by NASA in the 1970s and is charged and discharged by a reversible reduction-oxidation reaction between the two liquid vanadium electrolytes of the battery
- Unlike conventional batteries, electrolytes are stored in separated storage tanks, not in the power cell of the battery
- During operation these electrolytes are pumped through a stack of power cells, or membrane, where an electrochemical reaction takes place and electricity is produced



- Vanadium can exist in four different states, allowing for a single element to be used
- Benefits include simplicity and no cross-contamination
- In 2010, US DoE funded research at PNNL yielded an improved electrolyte formula

SOURCE: IEEE Spectrum: It's Big and Long-Lived, and It Won't Catch Fire: The Vanadium Redox-Flow Battery, 26 October 2017

► Vanadium price trends

On August 17, 2017, the Chinese Ministry of Environmental and Protection posted an announcement on its website that all four types of metal slag containing vanadium will be “forbidden” for import into China under regulation that have entered in force after December 31, 2017.

China primarily imports slag from Russia and New Zealand. Metal Bulletin predicts that scrap import will cut 4,500 to 5,500 tonnes from China’s V2O5 production annually.

Vanadium prices were on the rise in 2017 on supply side changes with top vanadium produced in China. Enforcement of environmental regulations meant that more vanadium was being produced from ore instead of a by-product steelmaking in early September 2017.

Ferro vanadium (FeV) prices averaged \$ 25 per kilogram in Q1 2017 and more than doubled since then.

On June 19, 2018, owing to low availability Fob China vanadium prices rose on domestic tightness as the trend continues European ferro-vanadium market strengthened once again amid supply concerns.

Currently, mainstream prices for ferro-vanadium 50% min have risen to RMB 223,000 – 226,000/t (US\$ 68.90-69.82/kg V) up sharply by RMB 13,000/t (US\$ 4.02/kg V) from last week.

Shagang Group Anyang Yongxing Iron & Steel Co. opened bidding starting on June 19th, 2018 to purchase 40 t of vanadium-nitrogen alloy with the delivery to be made on June 20th.

Meanwhile, **vanadium pentoxide (V2O5)** prices increased in 2017 from \$ 5.75 per pound to \$ 9.50 per pound mid-July to mid-August in Europe. In China, V2O5 prices ranged from \$ 12.30 to \$ 13 on August 17, 2017 – that was an 88% increase from \$ 6.40 to \$ 7 just a month earlier.

The current V2O5 price is about US\$ 15.80.

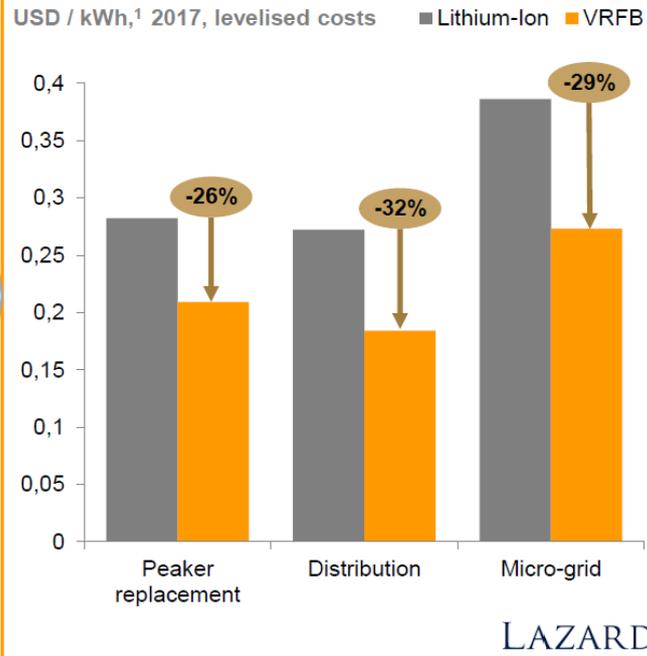
When used daily, VRFB technology has significant benefits, including being cheaper than lithium ion

VRFBs are ideal for large stationary applications

- + Long life and minimal reduction in performance during its life
 - + 100% depth of discharge
 - + Nearly unlimited number of cycles
- + Lowest cost per kWh when fully used once daily (or more frequently)
- + Easily scalable, as energy and power ratings are independent
- + Safety (no fire) and sustainability (100% of vanadium is reused at end of life)

VRFB is an excellent fit for daily, multi-hour, deep cycle storage (e.g. with solar PV), grid support (e.g. peak shaving, system balancing) and off-grid installations (e.g. mines, farms, islands)

Investment bank Lazard analysis shows that VRFBs already have the lowest costs in the industry



SOURCE: Lazard's Levelised Cost of Energy Storage Analysis – Version 3.0 (November 2017); Bushveld Energy

Especially in Asia, VRFBs are used in large scale energy storage projects

I. 60 MWh VRFB from Sumitomo in Hokkaido, Japan

HEPCO PJ (online @Dec, 2015)

- Size : 15 MW / 60 MWh (max. capacity: 30 MW)
- Application: Multi-purpose
 - Renewable generation mitigation
 - Frequency control, etc
- Funded by Japanese government

2nd Fl.: Battery cubicles
1st Fl.: Electrolyte tanks & PCS

II. 800 MWh VRFB by Rongke Power in Dalian, China

Location: Dalian City, CHINA

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

Specification:
Rated power: 200MW
Rated capacity: 800MWh
AC Efficiency: >70%

Components:
Battery: 500kW/2MWh×400
PCS: 550kVA×400
Transformer: 2500kVA×100
EMS: 1 unit
SCADA: 1 unit

III. 400 MWh VRFB from Pu Neng in Hubei, China

- 3-phase project to be finished by 2020
- Cornerstone of a new smart energy grid in Hubei Province.
- Will serve as a critical peaker plant, deliver reliability and reduce emissions

PUNENG
THE FUTURE OF ENERGY STORAGE



Containerised solutions are ideal for installations in the 500kWh to 50MWh sizes, as per Bushveld's current project with Eskom

SOURCE: Sumitomo; Rongke Power; Pu Neng; UET; Bushveld Energy



Bushveld Minerals (AIM – BMN) is an integrated vanadium producer with additional investments in coal power and tin. The Company has a current market valuation of £ 195 million. Its flagship vanadium platform includes a 59.1% t controlling interest in Bushveld Vametco Alloys (Pty) a primary vanadium mining and processing company.

Operating the Vametco Vanadium Mine and processing plant in Brits, South Africa, the Company is producing more than 3% of world's vanadium.

Controlling multiple other large, open cast deposits with a 439.6 million tonnes combined resource (including about 55 million tonnes combined reserves in South Africa), **Bushveld** is host to the world's largest high-grade primary vanadium resources.

An energy storage solutions company owned by **Bushveld** is exclusively focusing on vanadium redox flow battery technology (VRFB) with technical partner Uni Energy Technologies (UET) based in the US and are focused on energy solutions across Africa.

The Company is working with the Industrial Development Cooperation (IDC) to establish VRFB and electrolyte production in South Africa.

► Outlook for 2018

Vanadium demand in China is expected to rise following a revision to the standard tensile strength of rebar products in the country; the new standard increases the vanadium content in rebar products to make them stronger and is dedicated to increase earthquake resistance of rebar used in construction.

An official at the China Iron & Steel Research Institute said the move could increase vanadium consumption by 30%, or 10,000 tonnes per year.

Because of the revision, Chinese vanadium producers are expected to forgo their annual supply agreement with European buyers to prioritize domestic sales.

► Overview of vanadium related exploration companies

Energy Fuels (NYSE MKT – UUUU), as one of the four uranium producing US companies, also produces vanadium as a by-product of its uranium from certain of its mines on the Colorado Plateau.

Most ASX-listed junior companies related partly to exploration of vanadium are: **Australian Vanadium** (AVL) Australia; **Technology Metals Australia** (TMT) – Australia; **TNG** (TNG) – Northern Territory, Canada; **Tando Resources** (TNO) – South Africa; **Aura Energy** (AEE) – Sweden.

Junior uranium exploration companies listed in North America focused partly on vanadium include: **Prophecy Development** (TSX - PCY) – United States; **Cornerstone Metals** (TSX - CCC) – United States; **Western Uranium** (OTC US - WSTRF) – United States; **Blue Sky Uranium** (TSX.V - BSK) – Argentina.