Advanced Vanadium Flow Batteries and Applications for Renewable Integration

Vanadis Power GmbH

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Dr. Andreas Luczak

Personal data

44 years old

Education

Dr. rer. nat (PhD) in Physics

Professional experience

1994-1996:	Research Associate Laser Laboratory Goettingen
1996-1999:	Software Engineering Siemens Power Generation
1999-2003:	Innovation Manager Siemens Industrial Services
2003-2008:	Head of R&D group Siemens Automotive Projects
2008-2012:	Business Development & Project Management Siemens PV Inverters
2012-2013:	Head of Siemens Energy Storage Solutions
Since 2013:	**Managing Director of Vanadis Power GmbH**

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Vanadis Power GmbH

Vanadis was founded end of 2012 to bring to the European market **Advanced Vanadium Flow Batteries** for integration of renewable energy & other applications.

Through innovation, expertise and global strategic partnerships, **Vanadis**' **mission** is to become a leader in large- and medium-scale energy storage in Europe.

Our activities are sales, project management, system deployment (focus on PCS and grid integration) and services.

Origin of the company name:

„**Vanadis**" is the name of a goddess associated with beauty.

Vanadium was called after this goddess due to the many beautifully colored chemical compounds it produces.

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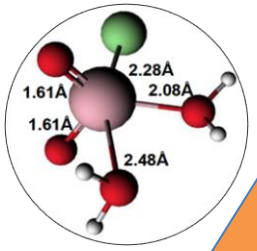
Vanadis‘ strategic partnerships

UniEnergy Technologies

NEW ELECTROLYTE

- ✓ 2X power and energy density
- ✓ –5°C to +60°C

Pacific Northwest NATIONAL LABORATORY



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RONGKE POWER

FIELD EXPERIENCE

5MW/10MWh wind firming installation and numerous others

BNM
BOLONG NEW MATERIALS

PRODUCT PACKAGING

6200m² design & manufacturing facility in Seattle, USA

ELECTROLYTE PRODUCTION

Electrolyte production capacity >**1.5GWh**/year

STACK PRODUCTION

More than 6 years design & production experience
Up to **30MW/year** stack capacity in 2013

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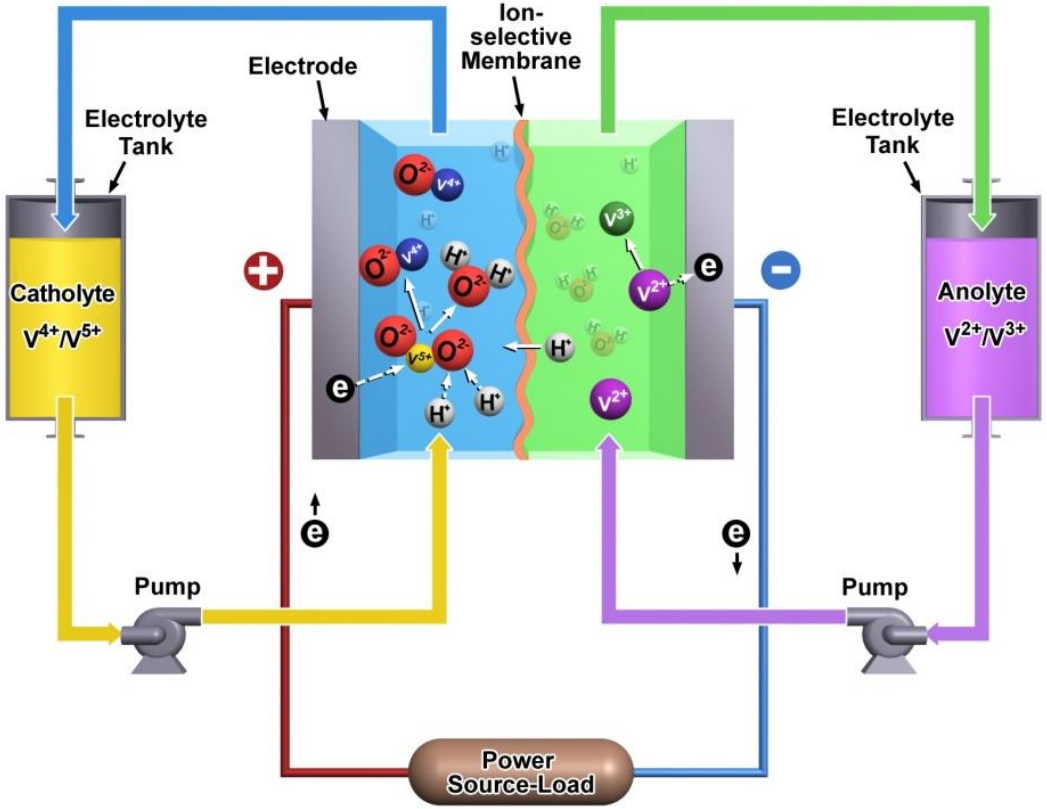
Conventional vanadium redox flow battery (VRFB) – Basic electro-chemistry



$$VO_2^+ + 2H^+ + e^- \leftrightarrow VO^{2+} + H_2O$$

$$V^{2+} \leftrightarrow V^{3+} + e^-$$

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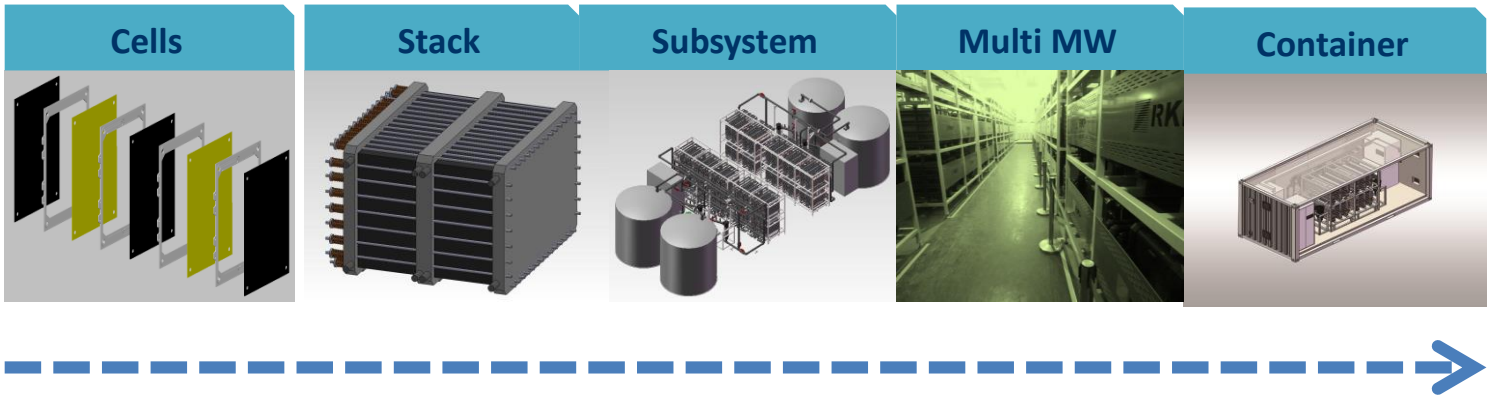
Conventional VRFB's have many advantages

- Separation of power (KW) -stacks - and energy (KWh) – electrolytes -> each can be individually sized according to application needs
- Adding additional energy just requires bigger electrolyte tanks which is simple and quite cheap
- No self discharge in electrolyte tanks
- "Inert" electrodes – no structural changes or stress buildup

  - long cycle life & shelf life, independent of state of charge/depth of discharge
- Inherent active heat management – flowing electrolytes carry away heat generated from electro-chemical reactions -> Uncontrollable fire known with NaS, Lead Acid and Li-Ion applications not possible
- Environmentally friendly since electrolyte only changes the ion valence during operation and can be virtually be reused forever
- Highly dynamic in the millisecond range with high overload capacity
- Capable of storing large quantities of energy (MWh's) for long periods and discharging upon need

Modular system architecture enables high scalability



- Cells with optimized design & materials, in powerful reliable & efficient stacks
- Standard stack subsystems for ease of installation and operation
- Turn-key Multi MW and Container solutions

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One of R&D focus is to increase stack power rating to reduce costs

Stack development of

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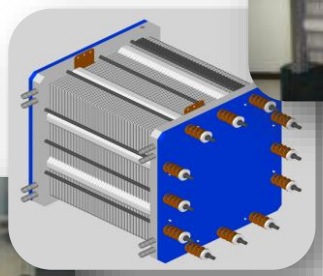
32kW Stack in 2013

22kW Stack in 2011

10kW Stack in 2010



5kW Stack in 2008

2kW Stack in 2008

1kW Stack in 2006

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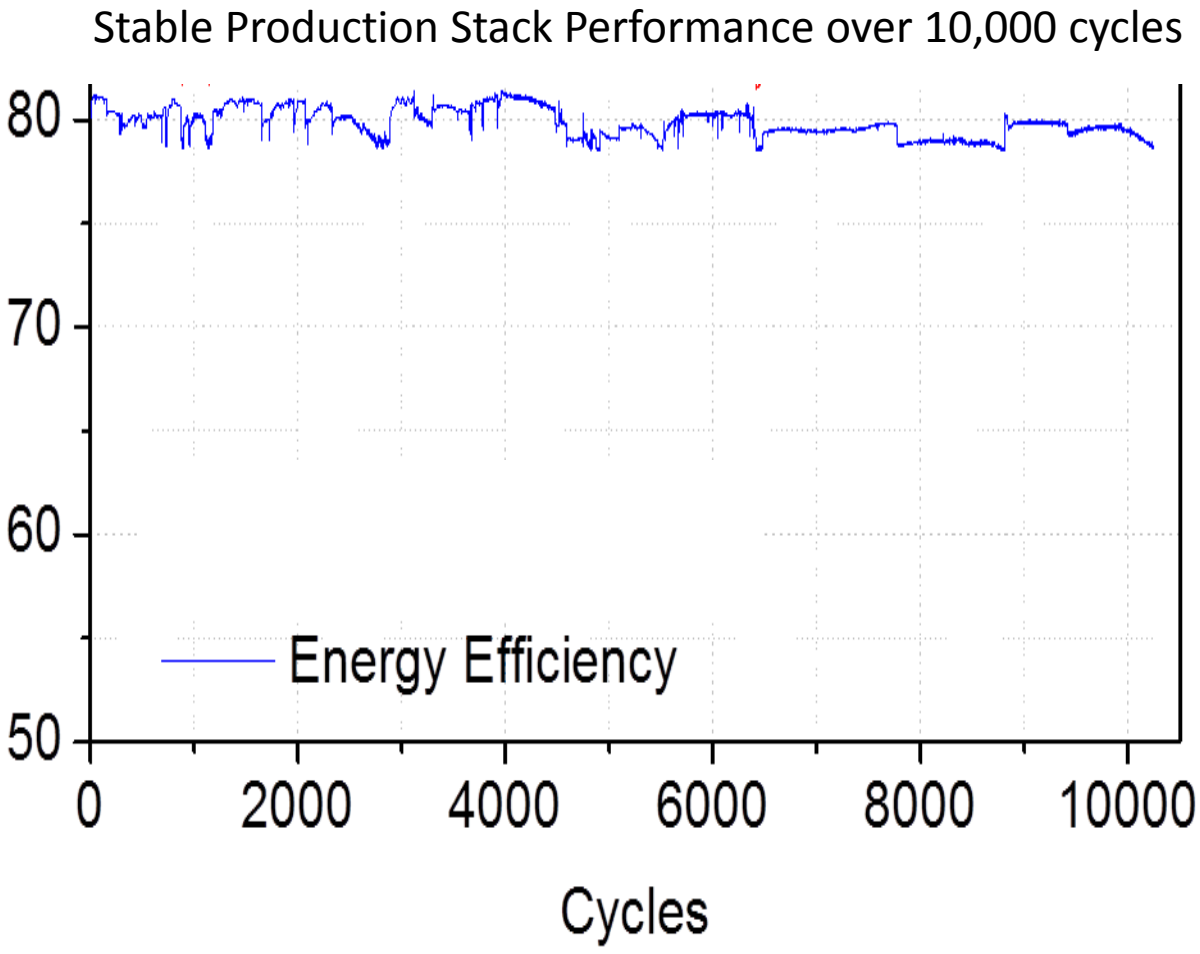
Stable 22kW stack performance over 10,000 cycles



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The mature production hardware provides solid stability over extended cycling, requiring no electrical balancing procedures

Test parameters:

Electric current:	320A
Temperature:	22-25°C
Cooling:	Liquid
E'lyte Temp:	<40°C
Cycles:	10,000

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Some of the world largest flow batteries (all Vanadium-based!)

Application	Output Capacity	Year of Installation	Country
Wind farm operation support	5MW/ 10MWh	2012	China
Wind farm operation support	4MW/6MWh	2005	Japan
Wind farm operation support	3MW/6MWh	2013 (in progress)	China
Demonstration project in conjunction with CPV	1MW/5MWh	2012	Japan
Load leveling at university	0,5MW/5MWh	2001	Japan
Wind farm operation support	1MW/4MWh	2013 (in progress)	Germany
Industrial Peak Shaving	0,6MW/3,6MWh	2012	USA
Demonstration with Wind/PV	0,2MW/1,2MWh	2013	Germany

Field Deployed Systems (Rongke Power)

#	Year	Projects	Applications	Power	Energy
1	2008	China Electric Power Res. Inst.	Distributed energy storage	100kW	200kWh
2	2008	Tibet Electric Energy Res. Inst.	PV integration	5kW	50kWh
3	2009	Green Residential House	Off grid storage	3.5kW	50kWh
4	2010	Green Office Building	Off grid storage	60kW	300kWh
5	2010	EV Charging Station	Peaking capacity, power quality	60kW	600kWh
6	2010	Telecom Station	Remote Area Power Supply	3.5kW	54kWh
7	2011	Island Keeper House	Off grid storage	10kW	200kWh
8	2011	Telecom Station	Remote Area Power Supply	3.5kW	48kWh
9	2011	Ningxia Electric Power Group	Off grid storage	3.5kW	14kWh
10	2012	Wind Turbine Supplier	Smart microgrid storage	200kW	800kWh
11	2013	Wind Farm near Shenyang	Wind smoothing	5MW	10MWh
12	2013	Wind Farm	Wind smoothing	3MW	6MWh
13	2013	Wind Farm	2013 installation pending	7MW	14MWh
			TOTALS	15.5MW	32.3MWh

Rongke Power *has built the most powerful and mature electrode stack in the world. Integration with* ***UET****'s electrolyte technology and packaging yields a highly compelling MW-class energy storage solution.*

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Example: 5MW/10MWh system at Longyuan wind farm

Time	August, 2012
Location	Faku County, Liaoning Province
Owner	Longyuan Group
Function	Scheduled operation following; Wind output smoothing; Voltage support, etc.

Main parameters of energy storage system	
Power	5 MW
Capacity	10 MWh
Voltage Range	DC 400-620V
Rated Current	DC 640A
Ambient Temperature	5-35℃

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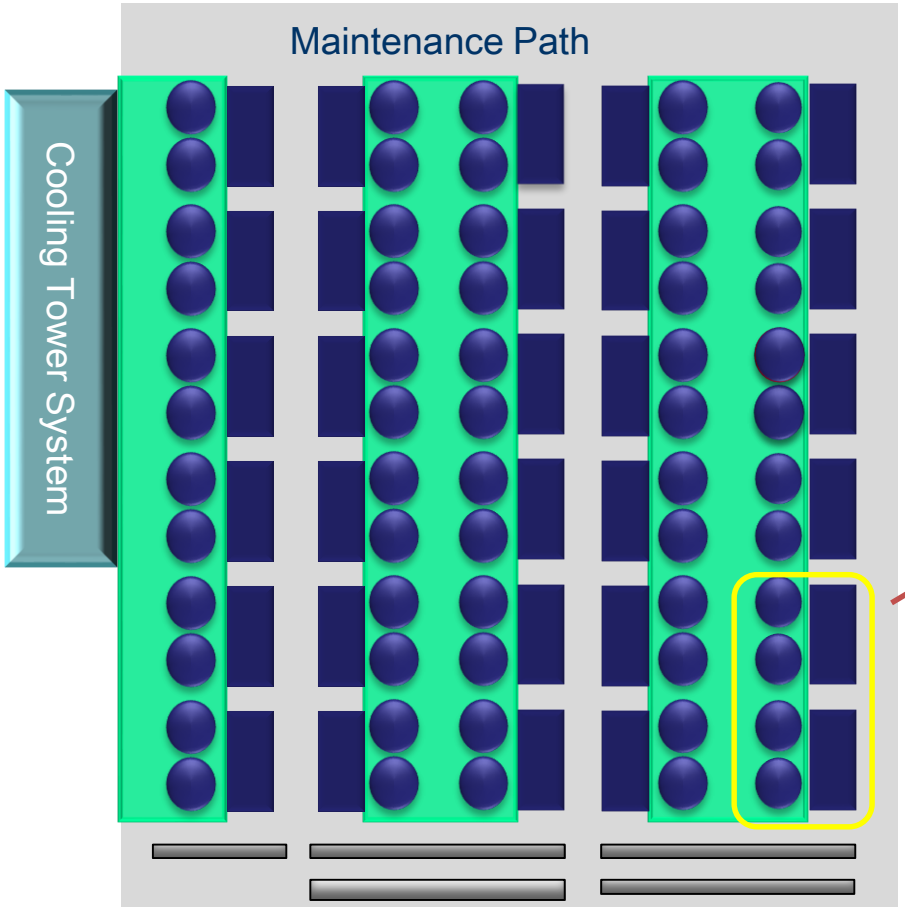
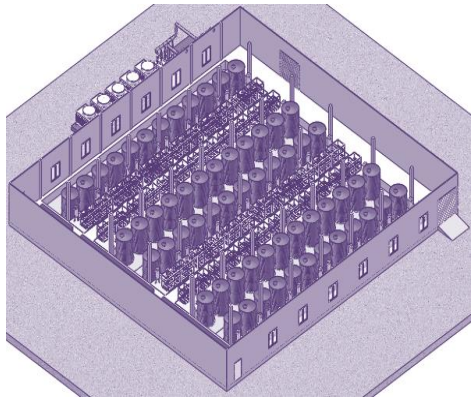
5MW/10MWh system layout



Space : 2,300 ㎡



352kW Sub-system

Electrolyte Tank

Cell Stacks

DCS & Inverter

Electrolyte Sink

Maintenance Path

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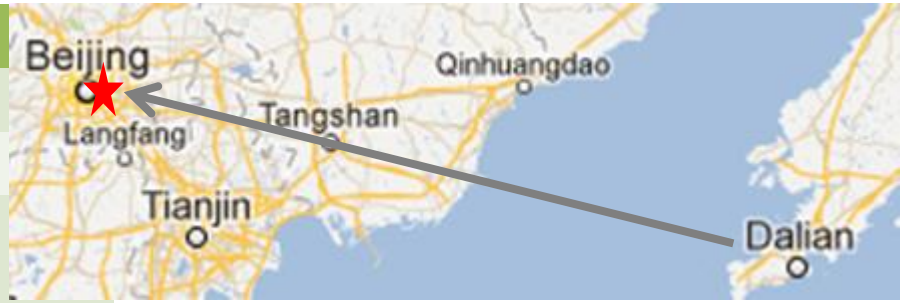
Example: Goldwind smart grid

Time	October, 2011
Location	Yizhuang, Beijing
Owner	Goldwind Corporation
Function	Smooth wind output; Improve power quality; Increase grid reliability, etc.



Main parameters of energy storage system	
Power	200 kW
Capacity	800 kWh
Voltage Range	DC 250-388V
Rated Current	DC 640A
Ambient Temperature	5-35℃

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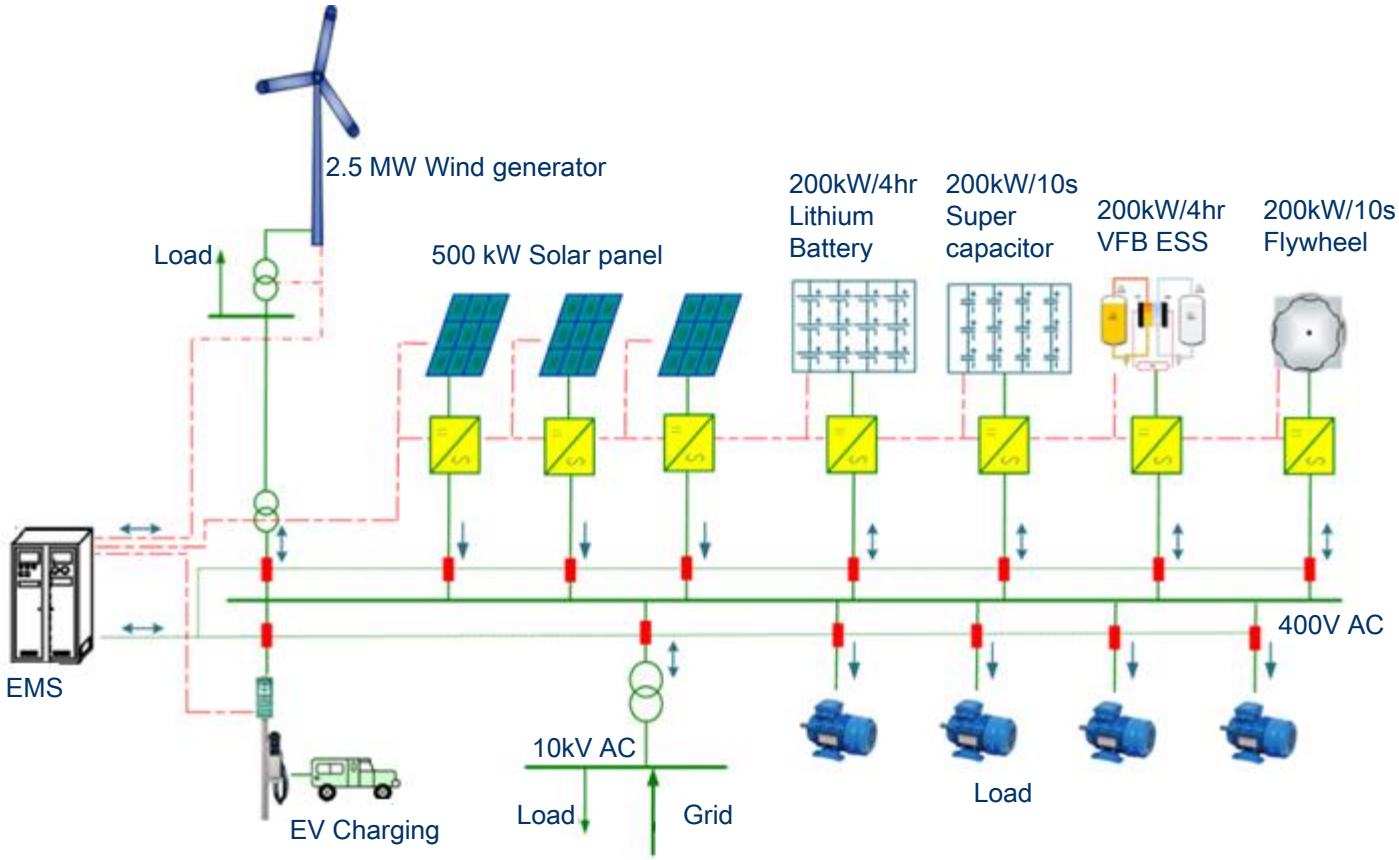
Site Design Overview



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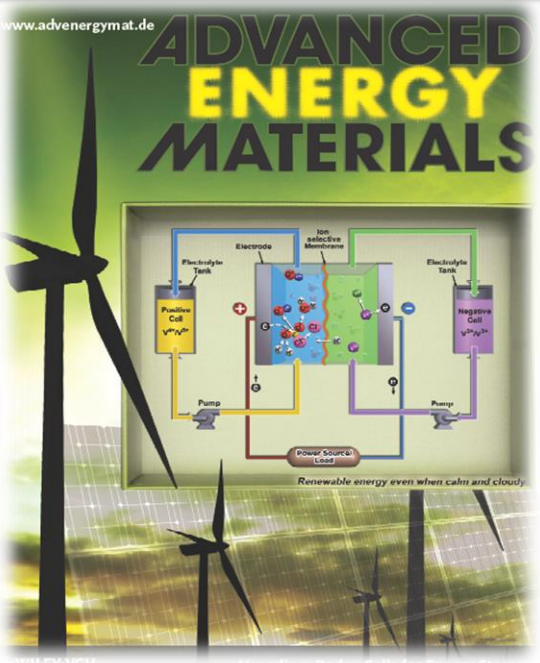
Challenges of conventional VRFB's

- Fundamental chemistry challenge:
  - Limited stability of conventional VRFB electrolyte chemistry
  - >~35^{o}C or <~10^{o}C, V^{n+} compounds precipitate out
  - Limited Vanadium concentration: <1.5 M vanadium

- Consequences:
  - Low energy density ~15Wh/L, limiting battery design and siting
  - Operation limited to ~10^{o}C - ~35^{o}C, requiring strict heat management and associated cost and efficiency loss
  - Low current densities (≤80 mA/cm^{2}), limiting stack power and reduction in $/kW

UET Technology: New Generation Chemistry

- New gen vanadium electrolyte chemistry - substantially improved performance and economics:
  - Doubled energy & power density
  - Wide operating temperature, -10 to +60°C
  - Improved efficiency, durability, and reliability
  - Simplified system and reduced cost



Li et al, *Advanced Energy Materials*, 2011

- Original developed at PNNL, with support from US DOE-OE Storage Program
- Won U.S. Federal Lab Consortium Award
- World-wide license from PNNL
- Improved by UET, protected by patents and trade secrets

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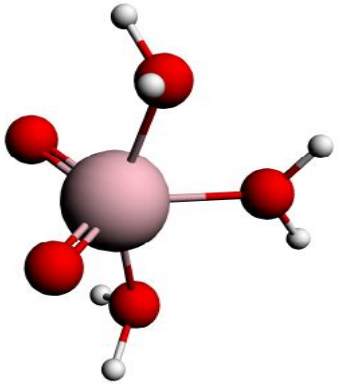
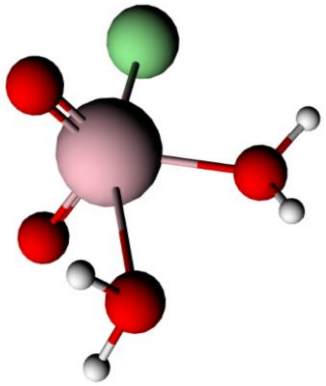
New electrolyte chemistry – vanadium mixed acid



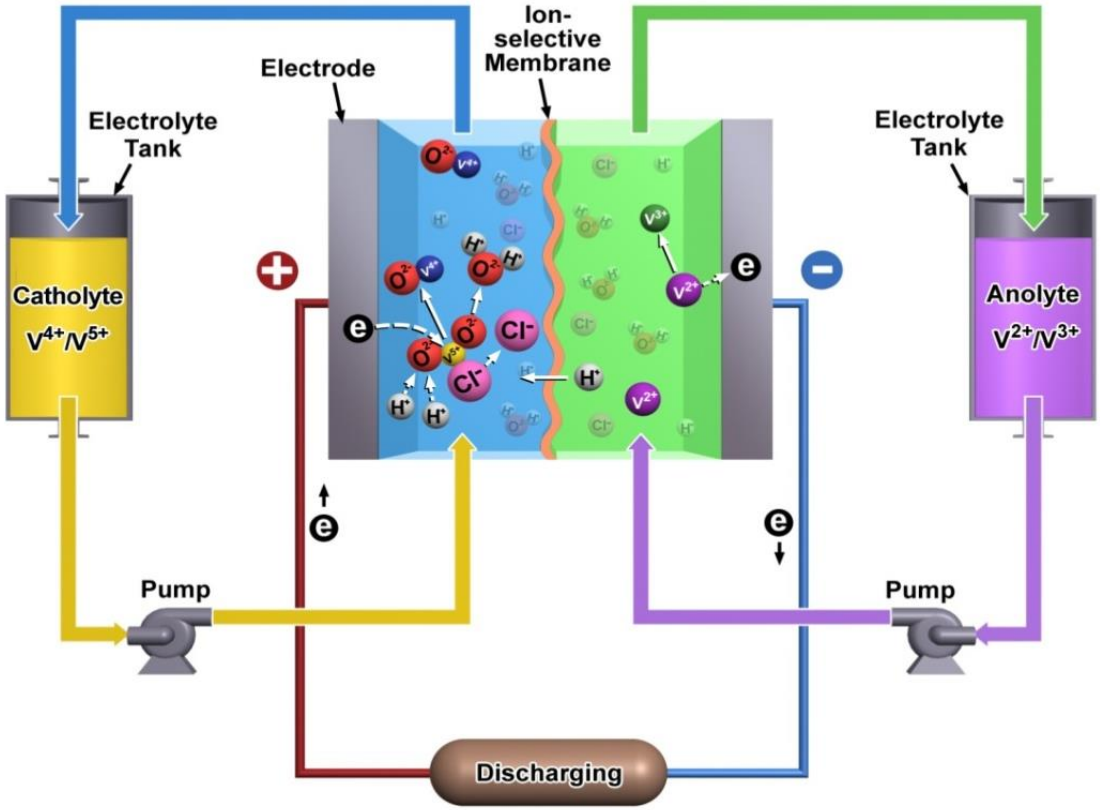
V^{5+} in sulfuric acid --
$[VO_2(H_2O)_3]^+$



V^{5+} in mixed acids --
$VO_2Cl(H_2O)_2$

- Substantially improved chemical stability
- V^{n+} up to 2.5M, practically double energy capacity (30Wh/L, due to a higher utilization as well)
- Stable ~-5°C↔~60°C without irreversible solid phase precipitation, minimizing thermal management
- Improved performance, durability, and reliability with reduced capital and levelized costs

Advanced VRFB's



- V^{n+} concentration ~2.5M; 2x increase in energy and power density
- Stability window extended to ~-5°C - ~60°C, minimizing heat management
- Stable operation without frequent balancing
- Reduction in capital and levelized cost by factor of 2 or even 3

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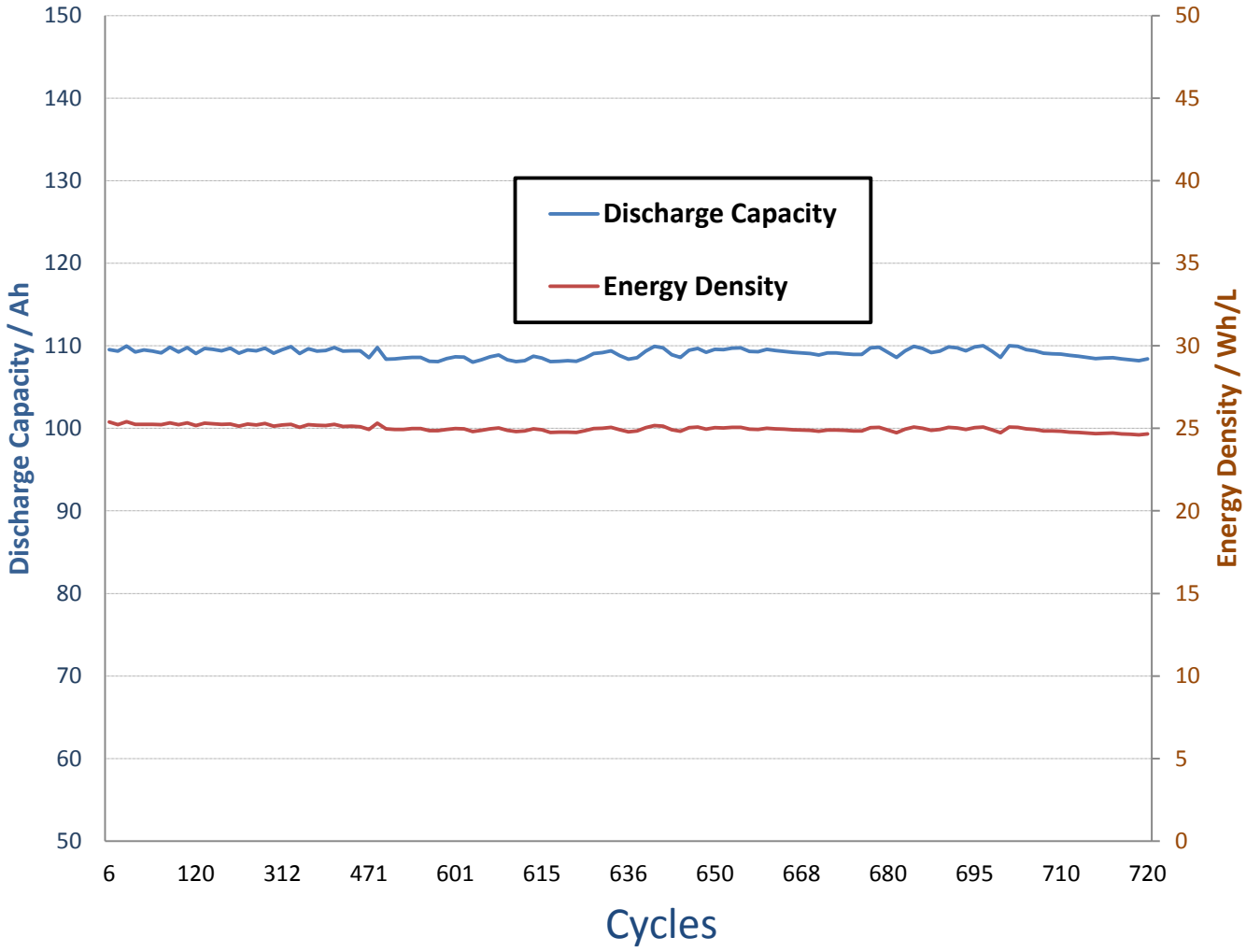
Validation of advanced chemistry by UET

Two 2kW systems operating in series at UET's facilities in Seattle

2kW systems in series testing – capacity analysis



Test Conditions

- Systems in Series
- Constant Power cycling
- Started Jan 4th, 2013
- 3.5h cycles
- Ongoing cycling

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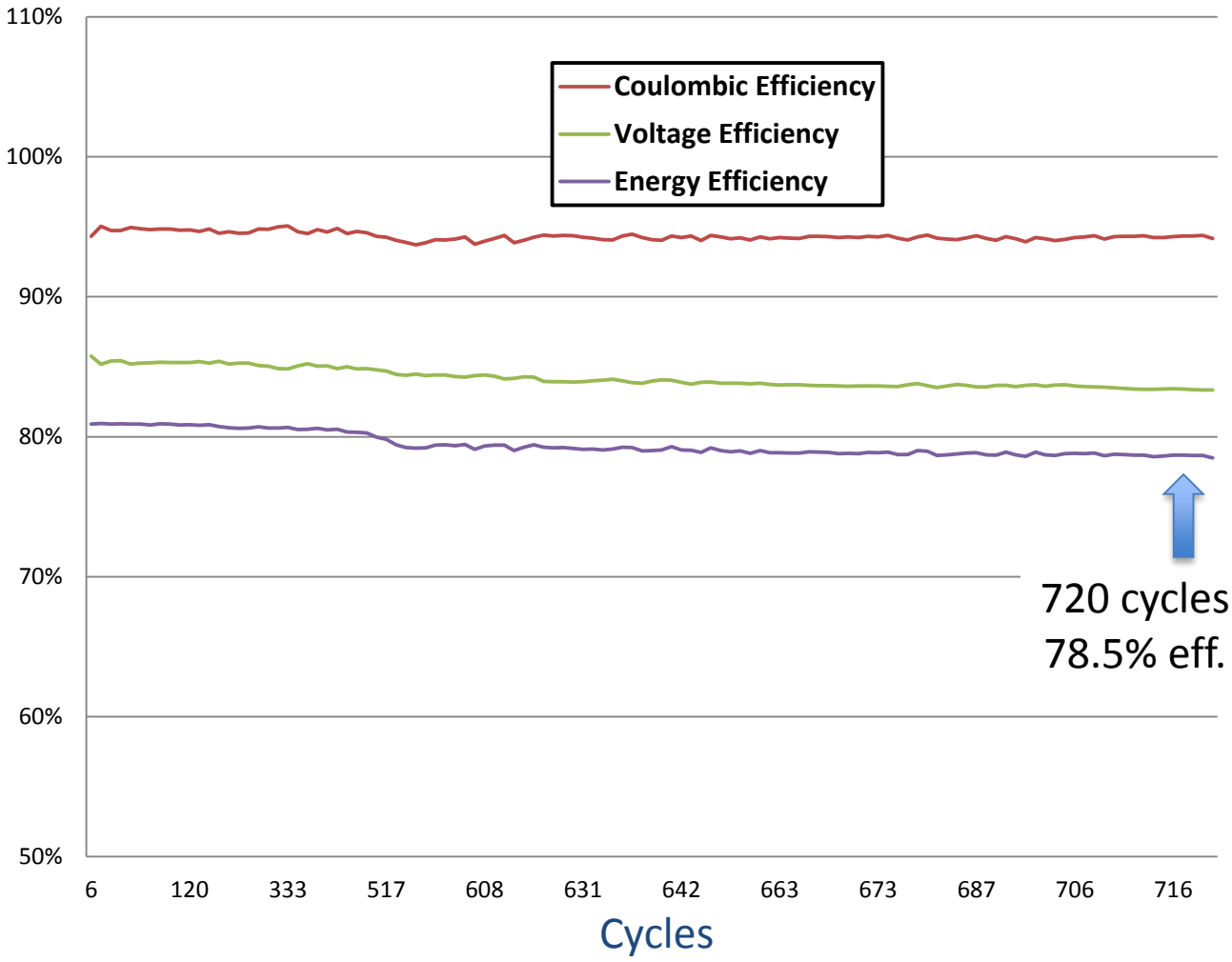
2kW systems in series testing – efficiency analysis



Test Conditions

- Systems in Series
- Constant Power cycling
- Started Jan 4th, 2013
- 3.5h cycles
- Ongoing cycling test

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Full-scale advanced VRFB testing at UET

33 kW system operating at UET's facilities in Seattle

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UET's Modular Container: 100 kW_{AC}, 4 hours

- Excellent safety
  no thermal runaway
- >95% availability
  minimal downtime
- SOC agnostic
  full operational flexibility
- Factory integration
  precision assembly & QC
- Plug & Play
  rapid deployment
- 15-year design life
  unlimited cycles
- 100% recyclable
  disposal contract included

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UET's Modular System, 500 kW_{AC}, 4 hours

Standard 20' ISO containers

- no step-in, side or rear access needed

- Systems scalable to multiple MW's
- Grid interconnection ready power interface and controls

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Representative Data for 500 kW_{AC} System

Parameter	Value
Power	500 kW continuous, 750 kW peak
Energy	4 hours duration
Efficiency	~70%, AC round trip at the inverter
Self-Discharge	<5%/year, in standby mode
Cycle Life	Unlimited cycles within system design life
System Design Life	15 years
DC Voltage Range	750V-1200V DC
AC Voltage Output	480V AC 3-phase
Power Factor Range	Available option
Power Control Modes	Dispatch and Autonomous, 50ms system response time
Standards Compliance includes	IEEE 519 IEEE 1547 available
Communications & Data Protocols	Modbus DNP3.0 IEC 61850, available
Ambient Temperature	-20°C to 50°C, active cooling for extended operation >35°C
Footprint	960 ft^2, double stacked, 15' aisle

Advanced electrolyte allows better packaging with less cooling

Example of 1MW/4MWh with electrolyte integrated in container

195m^2 footprint (***5kW/m^2***)

Can be further increased by stacking

Standard 20' containers

8 x 125kW/500kWh battery modules
(no step-in, side or rear access needed)

500kW power & control module

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Footprint of containerized solution with advanced electrolyte is significantly smaller than previous installations

1MW/5h “classic” System

1MW/4h UET System

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UET UniEnergy Technologies

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BNM BOLONG NEW MATERIALS

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Thank you!