UniEnergy Technologies

New Generation VRFB for Electrical Grid and Utility Applications

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IEA Workshop on "The Role of Storage in Energy System Flexibility", October 23, 2014, Berlin

Outlines

- *Introduction of UET*
- *Discuss RFB and VRFB in particular*
- *Journey of commercialization: From molecules to MW*
- *Status and challenges*
- *RD&D needs*
- *Acknowledgements*

UniEnergy Technologies

Mission: Be a major global provider of bulk energy storage products through

Innovation + Partnerships + Quality

We are accomplishing this by commercializing break-through vanadium redox flow batteries with:

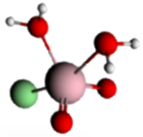
- ✓ *High performance electrolytes & electrode stacks*
- ✓ *Industrial engineering of fully integrated system products*
- ✓ *State-of-the-art controls & power electronics*
- ✓ *Value-added field services*

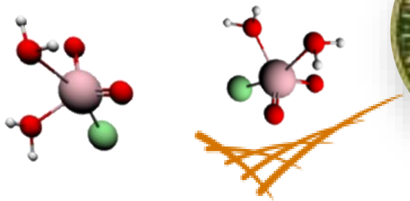
$250M Invested in UET's DNA & Corporate Group

UET

NEW ELECTROLYTE

- ✓ 2X energy density
- ✓ –40°C to +50°C
- ✓ Improved reliability





Pacific Northwest
NATIONAL LABORATORY

DOE

PRODUCT ENGINEERING AND MANUFACTURING

67,000ft^2 design, development & manufacturing facility in Seattle

STACK PRODUCTION

- ✓ 108,000 ft^2 manufacturing facility
- ✓ 100MW production capacity (scale up 300MW in 2016)
- ✓ ISO9000/14000, GB/T28001 Certified

RONGKE POWER

BNM
BOLONG NEW MATERIALS

ELECTROLYTE PRODUCTION

- ✓ 1,324,000 ft^2 production facilities
- ✓ Electrolyte production capacity > 1.5GWh/year
- ✓ ISO9001:2008 Certified

FIELD EXPERIENCE

- ✓ 5MW/10MWh wind firming installation
- ✓ Numerous MW-class micro-grid sites

VANADIS POWER GMBH

Field engineering, installation, service, marketing, sales in Europe

Broad Partnerships and Manufacturing Chain

Poka-yoke

AsahiKASEI · REDOXWER · BNM BOLONG NEW MATERIALS · 融科储能 RONGKE POWER · Pacific Northwest NATIONAL LABORATORY · COMSOL MULTIPHYSICS · SolidWorks · AEG POWER SOLUTIONS · SIEMENS · OSI · arena · ISO 9001 · CIMC

- **Materials**
  - Vanadium
  - Electrolyte
  - Carbon felt
  - Membranes
  - Compatible Plastics
- **Components**
  - Stacks
  - Pumps
  - Containers
  - Tanks
  - Manifolds
- **Development**
  - E'lyte Development
  - Optimized Conditions
  - Power Density & Efficiency
  - Chemical Utilization
  - Control Methodology
- **Engineering**
  - Engineering Prototypes
  - Fluid &Thermo dynamics
  - Thermo Dynamics
  - Design for Manufacture
  - Design for Serviceability
- **Control**
  - Power Electronics
  - Battery Management
  - Site Controller
  - Application Algorithms
  - Data Storage & Analysis
- **Manufacturing**
  - Business Process Software
  - Quality Supply Chain
  - Just in Time logistics
  - Lean Manufacturing
  - Quality Control & ISO9001

Delivering MW Scale Uni.System™

- ❑ Modular, highly integrated, containerized, plug &play

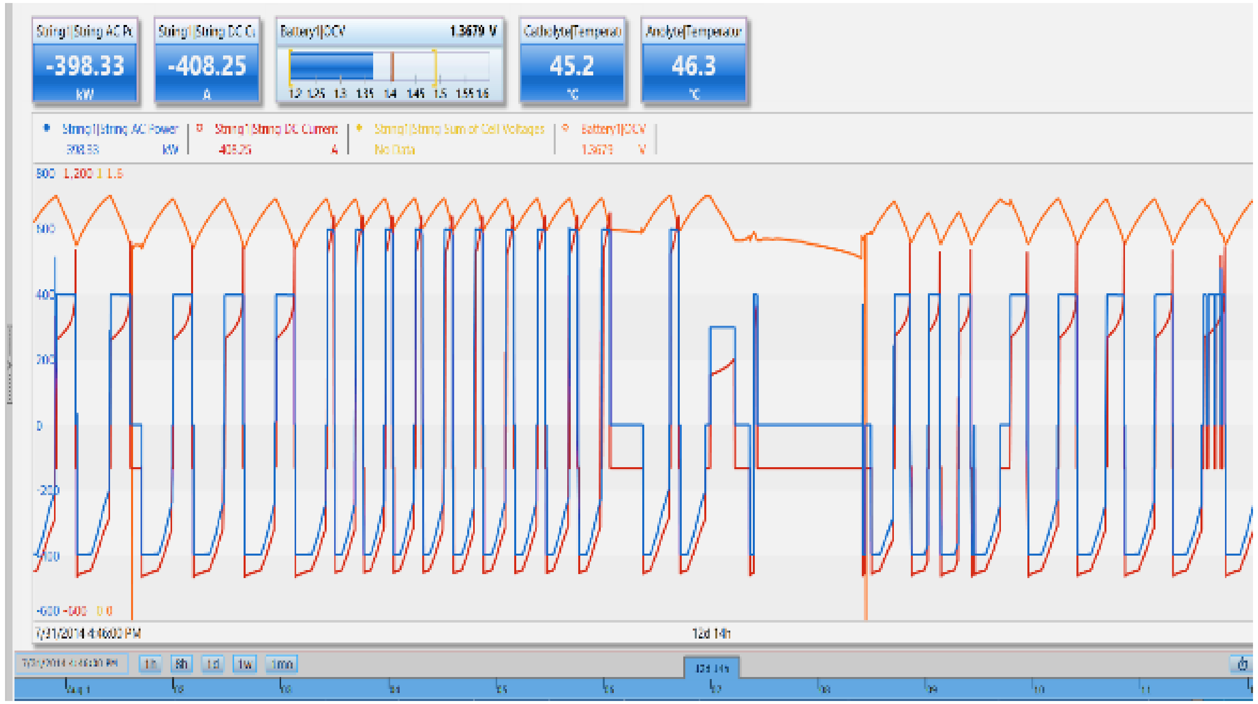
0.5MW; 2.0MWh

Ribbon-cutting with Governor Jay Inslee and Madam Secretary Pat Hoffman on July 8, 2014

Safe, Reliable, Flexible, Affordable

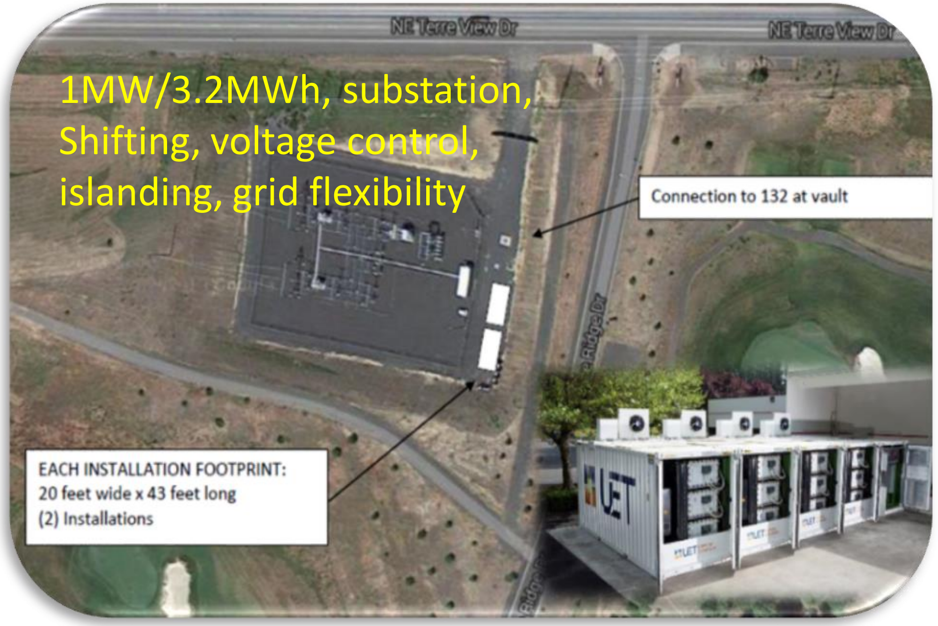
Performance Validation

- 180MWh Dispatched into local grid, analyzed with OSI Coresight™
- 3rd party validation testing from
  - ☑ Storage Industry Expert
  - ☑ Sandia National Labs



	2015 Uni.System.AC™		
Peak Power	600 kW_{AC}		
Maximum Energy	2.2 MWh_{AC}		
Discharge time	2 h	4 h	8 h
Power	600 kW_{AC}	500 kW_{AC}	275 kW_{AC}
Efficiency	DC >80%; AC system 70%		
Voltage	12.47kV +/- 10%		
Current THD (IEEE 519)	<5%THD		
Response Time	<100ms		
Reactive Power	+/- 450kVAR		
Humidity	95%RH noncondensing		
Footprint	820 ft^2		
Envelope	41'W x 20'D x 9.5'H		
Total Weight	170,000 kg		
Cycle and Design Life	Unlimited cycles over 20 year life		
Ambient Temp.	-40°C to 50°C (-40°F to 122°F)		
Self Discharge	Max capacity loss: <2%		

Deployment and Application Partners



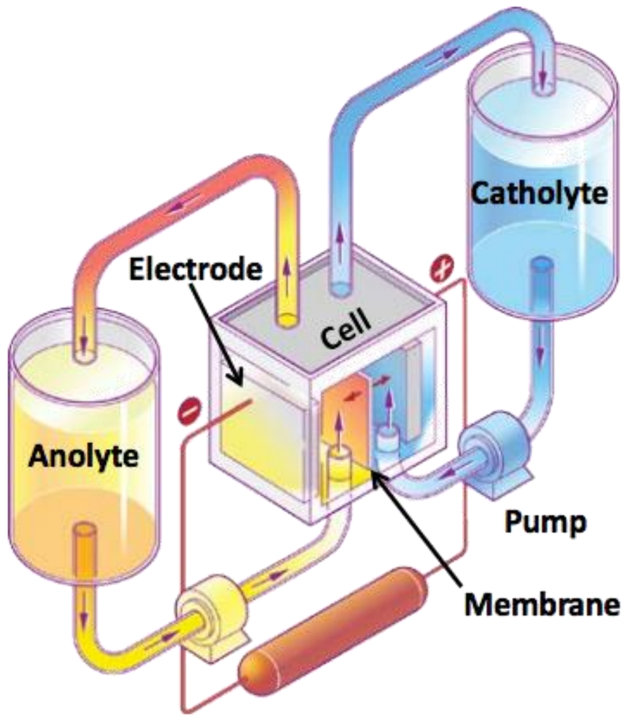
BOSCH

AVISTA Utilities

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

PG&E Pacific Gas and Electric Company®

Redox Flow Battery (RFB) – Reversible Fuel Cell



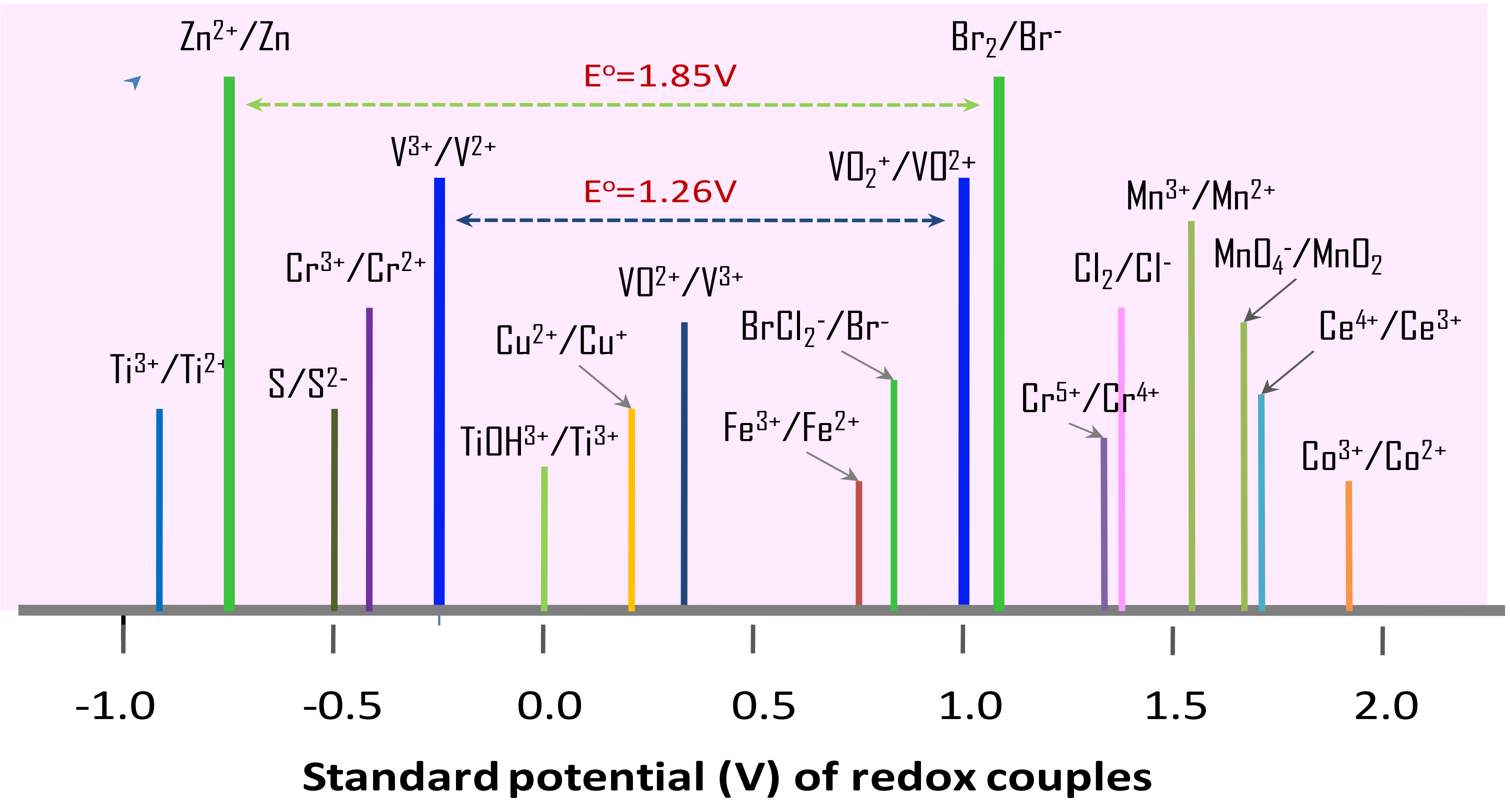
- Decoupling of power (kW) and energy (kWh)
  - » power (KW) determined by cell stacks
  - » energy (KWh) determined electrolytes
- "Inert" electrodes – no structural change, stress buildup or undesirable reactions with electrolytes, e.g., SEI layer in Li-ion
  - » Potential long cycle life independent of SOC/DOD
  - » High electrolyte utilization (0-100%SOC)

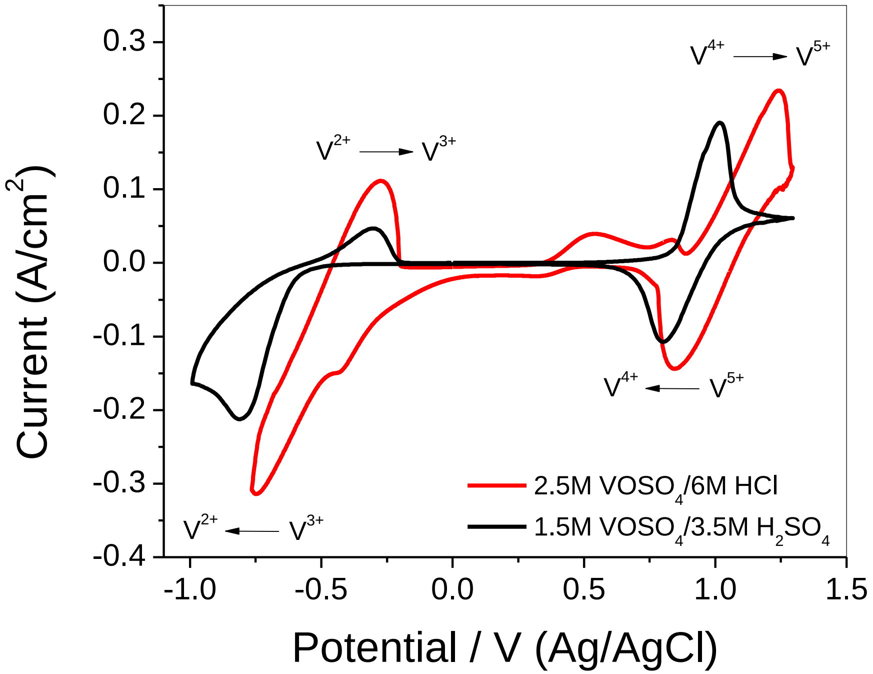
Devices	Sites of reactants/products	Electrolyte conditions
Flow battery	Liquid electrolytes in tanks	Liquids flowing through cells
Static battery	Active materials in electrodes	Static and held within cells
Fuel cell	Gaseous or liquid fuel plus air	Solid polymer/ceramics within cells

- Storing large amounts of power (MW) for hours (MWh)- significantly simpler in a RFB with large tanks than actively managing the SOCs of thousands of static batteries

Vanadium RFB or VRFB of Best Electrochemical Activity

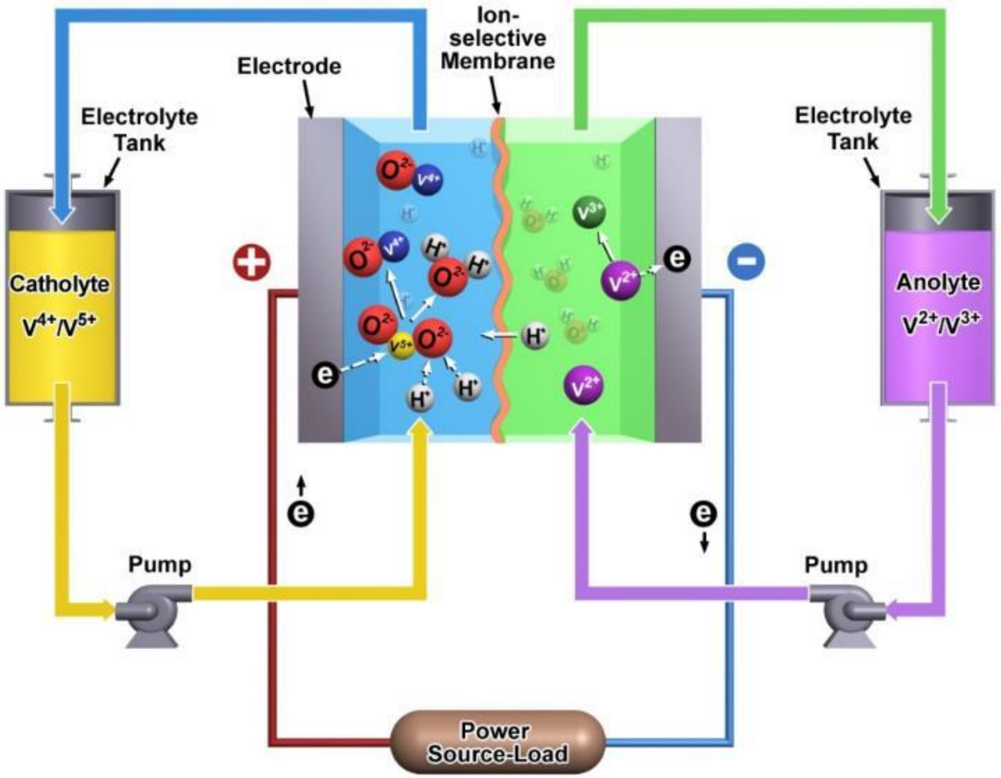
- Various redox couples have been developed
- Dominated by aqueous supporting electrolytes, SO_4^{2-}, Cl^-, Br^-, …
- A few non-aqueous electro-chemistries explored





Traditional VRFB

V^{5+} V^{4+} V^{3+} V^{2+}



Cathode: $VO_2^+ + 2H^+ + e^- \xrightarrow{\text{Discharge}} VO^{2+} + H_2O$

Anode: $V^{2+} - e^- \xrightarrow{\text{Discharge}} V^{3+}$

Cell: $VO_2^+ + V^{2+} + 2H^+ \xrightarrow{\text{Discharge}} VO^{2+} + V^{3+} + H_2O$ E_o=1.26 V

- ✓ Same element (V) both sides, mitigating cross-contamination
- ✓ Excellent reversibility - unlimited cycle life, (270,000 deep cycles demonstrated)
- ✓ Unmatched safety – aqueous, fire extinguishing electrolytes; room temperature operation; no thermal run away
- ✓ Fully recyclable of vanadium electrolytes

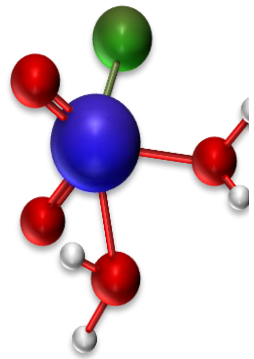
But:

- × Low energy density, large foot print, etc.
- × Limited chemical stability to operate between 10-35°C
- × Engineering must be improved to lower maintenance

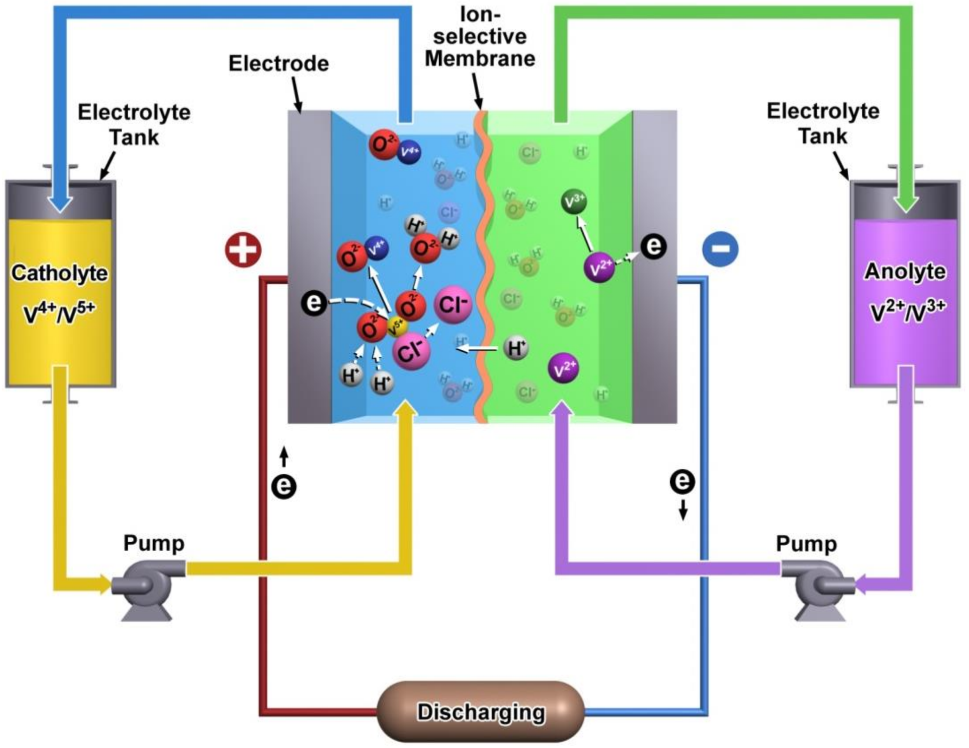
UET Next Gen VRFB Chemistry

Pacific Northwest NATIONAL LABORATORY

UET



$VO_2Cl(H_2O)_2$



Cathode: $VO_2Cl + 2H^+ + e^- \leftrightarrow VO^{2+} + Cl^- + H_2O$

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

Cell: $VO_2Cl + V^{2+} + 2H^+ \leftrightarrow VO^{2+} + V^{3+} + Cl^- + H_2O$ E_o=1.26 V

Developed at and licensed from PNNL, world-wide covering

- Over 8 years RD&D, optimization and stack/system validation
- Won the US Government's highest Award of Excellence in Technology Transfer to UET
- Extraordinary electrolyte stability, stable from -40°C to +50°C
- 2X energy density improvement

  → 5X product footprint reduction
- Improved reliability and performance and deployment flexibility through containerization and power electronics

Production of High Quality Electrolytes

German-engineered

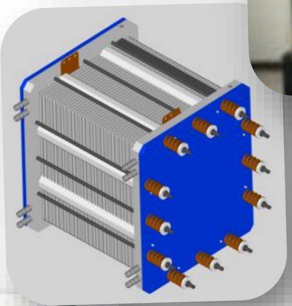
- 6 years of process optimization and quality control
- One of the world's leading producers of vanadium products
- BNM produces 70% of the world's vanadium electrolyte
- Vertically integrated with vanadium mining operations
- 10-year stable pricing visibility
- ISO9001:2008 Certified
- 1,324,000 ft^2 production facilities
- **1.5GWh** annual electrolyte capacity

Proven Stacks: 14 years in R&D and Production

9 years of field-driven stack development

1kW Stack in 2006

2kW Stack in 2008



5kW Stack in 2008

10kW Stack in 2010

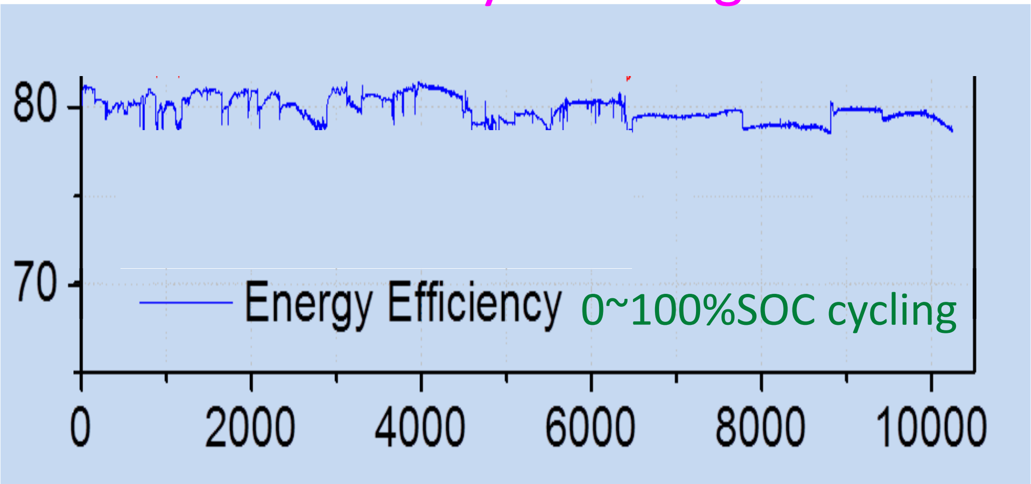
22kW Stack in 2011

25kW Stack in 2012

31.5 kW Stack in 2014

- ✓ Mature, powerful stack
- ✓ ISO9000/14000, GB/T28001 Certified
- ✓ Individual cell voltage data
- ✓ 108,000 ft^2 facility
- ✓ 100MW annual stack capacity, scale up to 300MW in 2016

Over 6 yrs testing!



Fully Integrated, Modular, Containerized Design

- **Factory Integration**
  - ✓ System level quality and performance testing
  - ✓ Factory integrated for rapid field deployment
  - ✓ On-site assembly versus on-site engineering
- **Modular Subassemblies and System Architecture**
  - ✓ Efficient and cost-effective production
  - ✓ Compact and flexible site arrangements
  - ✓ Scales to meet the application: up to 50MW
  - ✓ Incremental field capacity upgrades
- **Containerized Plug & Play Deployment**
  - ✓ Built-in secondary containment
  - ✓ Engineered with seismic strength and anchoring
  - ✓ More rapid permitting
  - ✓ Transportable
  - ✓ Possible lease financing as non-fixed asset

20’ standard container

Advanced Power Electronics and Control

- Optimized Software Architecture
  - ✓ Designed for scalability and pre-configured for deployment
  - ✓ Stand-alone control for multiple use cases
  - ✓ Software tools for third party integration and control
- Optimized Control Architecture
  - ✓ Siemens hardware and software platforms
  - ✓ UET proprietary embedded software puts focus on energy delivery
  - ✓ Single customer point of control
- Communications and Control
  - ✓ Industry standard command protocols
  - ✓ Multiple options for secure communications and data transfer
- Proprietary Self-Balancing and Battery Management
  - ✓ Simplified design
  - ✓ Reduced maintenance

Sophisticated Value-Added Data Analysis and Reporting

OSI PI

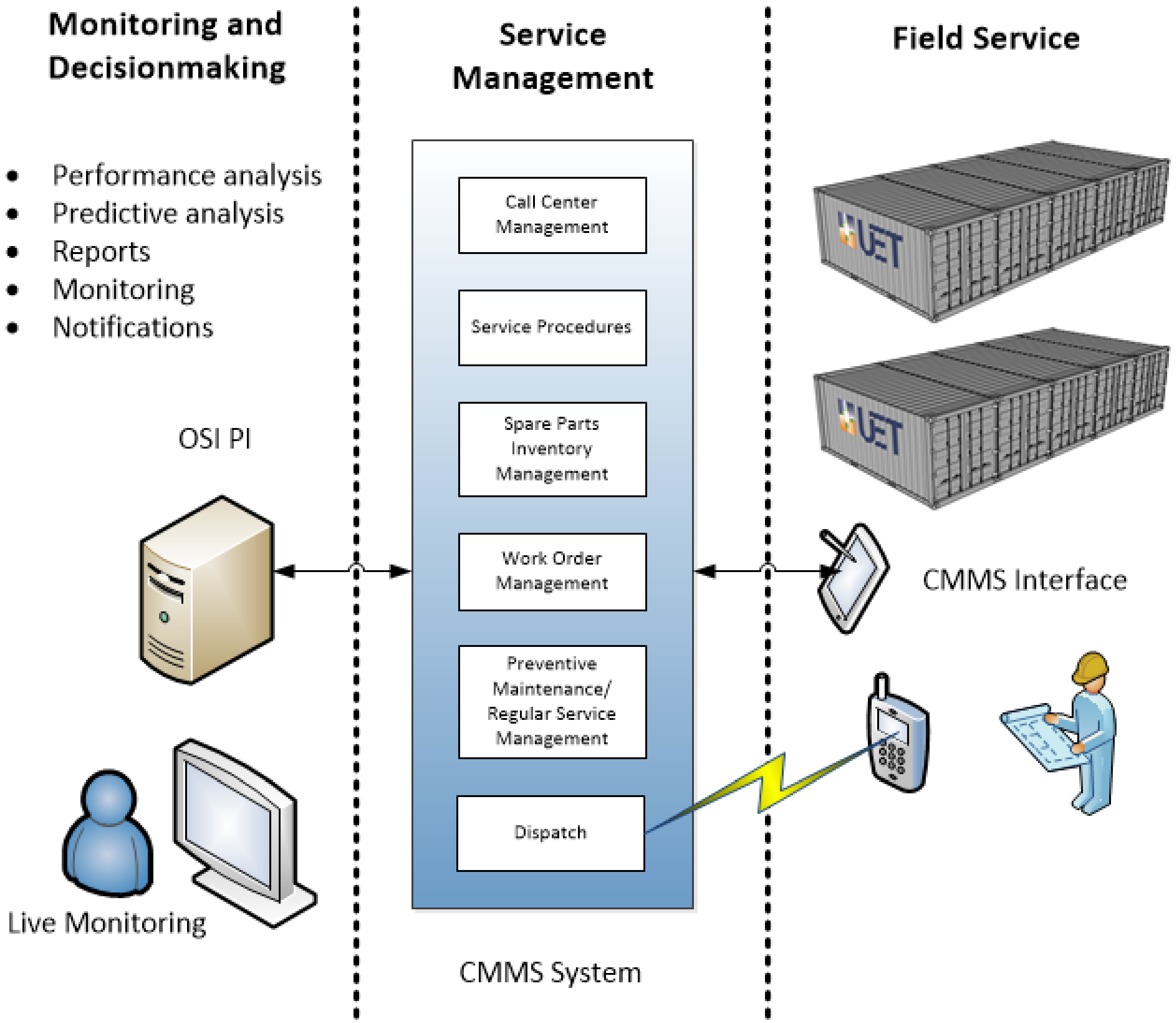
- ✓ Industry standard data historian
- ✓ Custom analysis tools and templates
- ✓ Event notifications
- ✓ Real-time monitoring
- ✓ System cloning for rapid deployment

Maintenance Management System

- ✓ Warranty and work order tracking
- ✓ Service procedures and costs

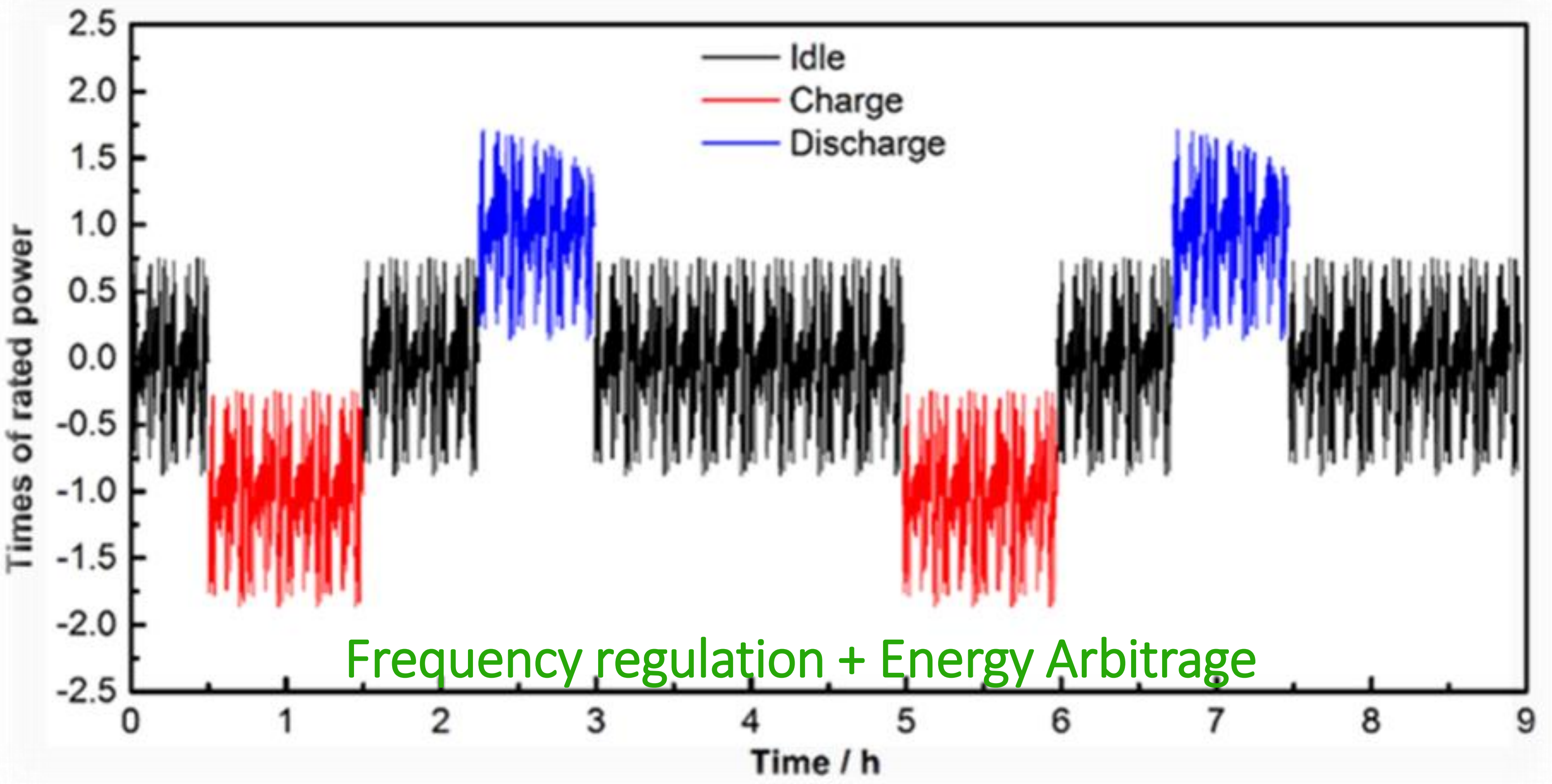
Value-Added Services

- ➢ Optimized asset utilization
- ➢ Stand-alone use-case economic analyses



Energy (long duration) + Power (short duration) Functions

Uni.System^{TM} stores hours of energy that can be released for a duration of hours or even days, with very limited self-discharge loss, while simultaneously supporting short duration power functions



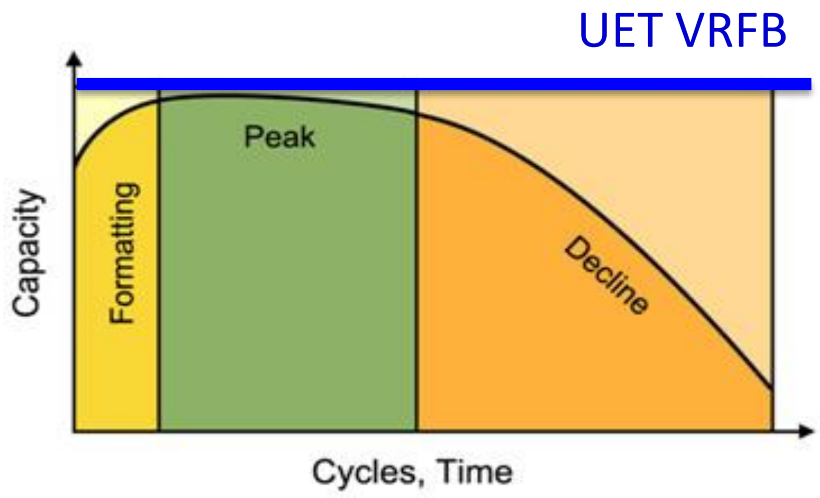
Deliver Multi-Applications & Benefits for Maximized Value

	Use Case	Primary Benefit	Conventional Technology	Value Basis
T-Connected Bulk Storage	Peaker Alternative	Capacity, Energy, A/S	CT	PPA, Mkt Rev, Avoided cost savings
	T&D Support	Deferral, Added Capacity, Reliability	Line & Substation Expansion	Avoided cost savings, FTR revenue
Distribution Energy Storage	Distributed Peaker	Resource Services, Resiliency, Microgrids	Circuit & Sub Expansion, CT, DG	PPA, Mkt Rev, Avoided cost savings
	Substation-Sited Storage	Deferral, Resiliency, Microgrids	Circuit and Substation Expansion, DG	Avoided cost savings
	Renewable Integration	Renewable Curtailment Reduction	none	PPA, Energy arbitrage w/ ‘0’ cost
Behind-the-Meter Energy Storage	Behind the Meter	Bill Reduction, Power Quality	DR, DG	Customer bill shared savings
	Behind the Meter Utility Controlled	Bill Reduction, Avoid Cost, Market $, Grid Rel	Circuit Upgrade, DR, DG	Bill savings, Avoided Cost

Competitiveness in Performance and Value

- ✓ Unmatched safety, aqueous electrolytes, no thermal run away
- ✓ Full rated capacity access (0~100% SOC), no cycling limitations
- ✓ No capacity fading over life time (targeting 20 yrs)
- ✓ Acceptable efficiency, DC 80-85%; AC-AC system 70%
- ✓ Fairly competitive capital costs
- ✓ Lower deployment cost (20~25% of battery, compared to 50~100% others)
- ✓ Highly competitive in LCOC or LCOE
- ✓ Capable of a long duration, while covering short-time power functions
- ✓ Flexible to deliver multiple benefits for maximized value

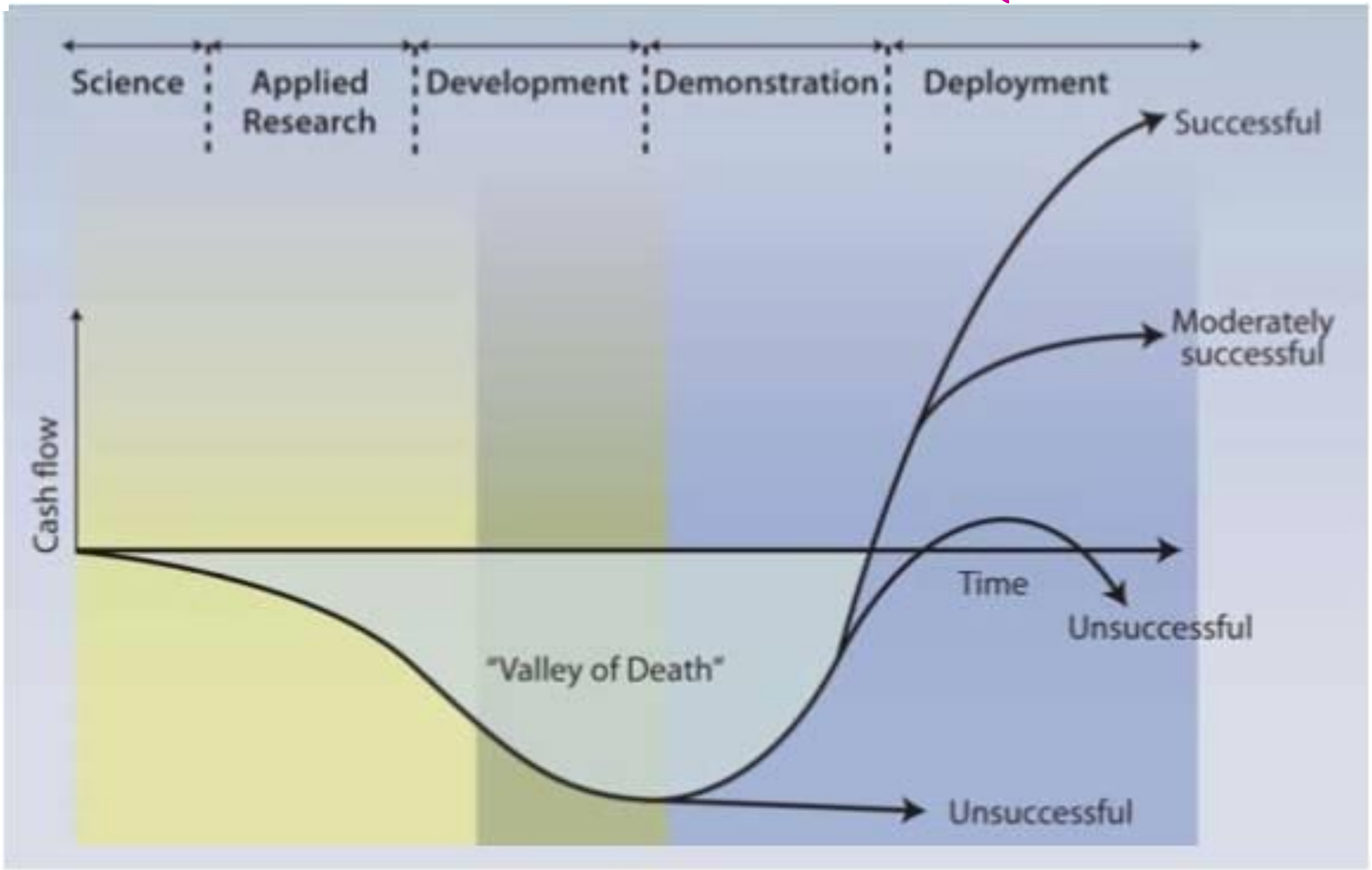
Fire accidents reported on varied batteries at large scales



Capacity degrades over cycling for traditional batteries

Molecules to Megawatts through Valley of Death

✓ ✓ ✓ ✓ 4Q14



http://www.energy.ca.gov/research/buildings/demonstrations.html

Status and Challenges

- ☑ There is strong customer interest in energy storage products
- ☑ Technology maturity
  - While most emerging chemistries are still in their experimental phase, some very high performance and reliable technologies are available today
- ☐ Product maturity
  - We are beginning to see products with the required seamless integration of chemical, mechanical, thermal, electrical, and controls engineering to deliver affordable, reliable & safe systems
  - Product maturity also requires tremendous investment of engineering and manufacturing resources into field demonstrations to prove out reliability and value propositions
- ☐ Bankability
  - More full-scale, profitable field deployments are needed to establish low financial risk
  - Regulations are slowly facilitating utilities to capture the value of grid storage assets

RD&D Needs

RFB or VRFB has existed over 3 decades, but never been as widely invested as Li-ion, fuel cells, etc.

- Further improve battery stack performance capability, durability and reliability – 1,000 mA/cm^2 of fuel cell vs 100 mA/cm^2 of RFB
- Extend electrolyte energy capacity and improve utilization
- Optimize power electronics and control, and battery management
- Lack of mature integration tools and energy management
- Need of standardization
- Government and industry collaboration on demonstration

Acknowledgements

- DOE-OE Energy Storage Program, Dr. Imre Gyuk
- Pacific Northwest National Laboratory
- RKP, BNM, Vanadis, all other partners
- UET employee, contractors