FROM MOLECULES TO MWs:

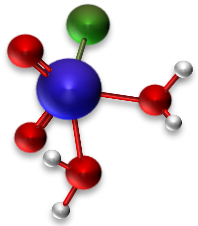
Experience & Progress in Commercializing New Gen VRFB

25 May 2016

UniEnergy Technologies

A Leading Systems and Service Provider in the accelerating large scale multi-hour energy storage market

Technology:



$VO_2Cl(H_2O)_2$

Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

INNOVATION + QUALITY + PARTNERSHIPS

North Seattle, 67,000ft^2, technology and product development, manufacturing, marketing & sales, services

EcoPartner:

10 yrs stack field experience, ramping up GW production capacity

Investment:

ORIX

BOLONG 博融控股集团

Electrolyte production: 1.5GWh/yr capacity

UET-RKP was just recognized to join the US-China EcoPartnership Program.

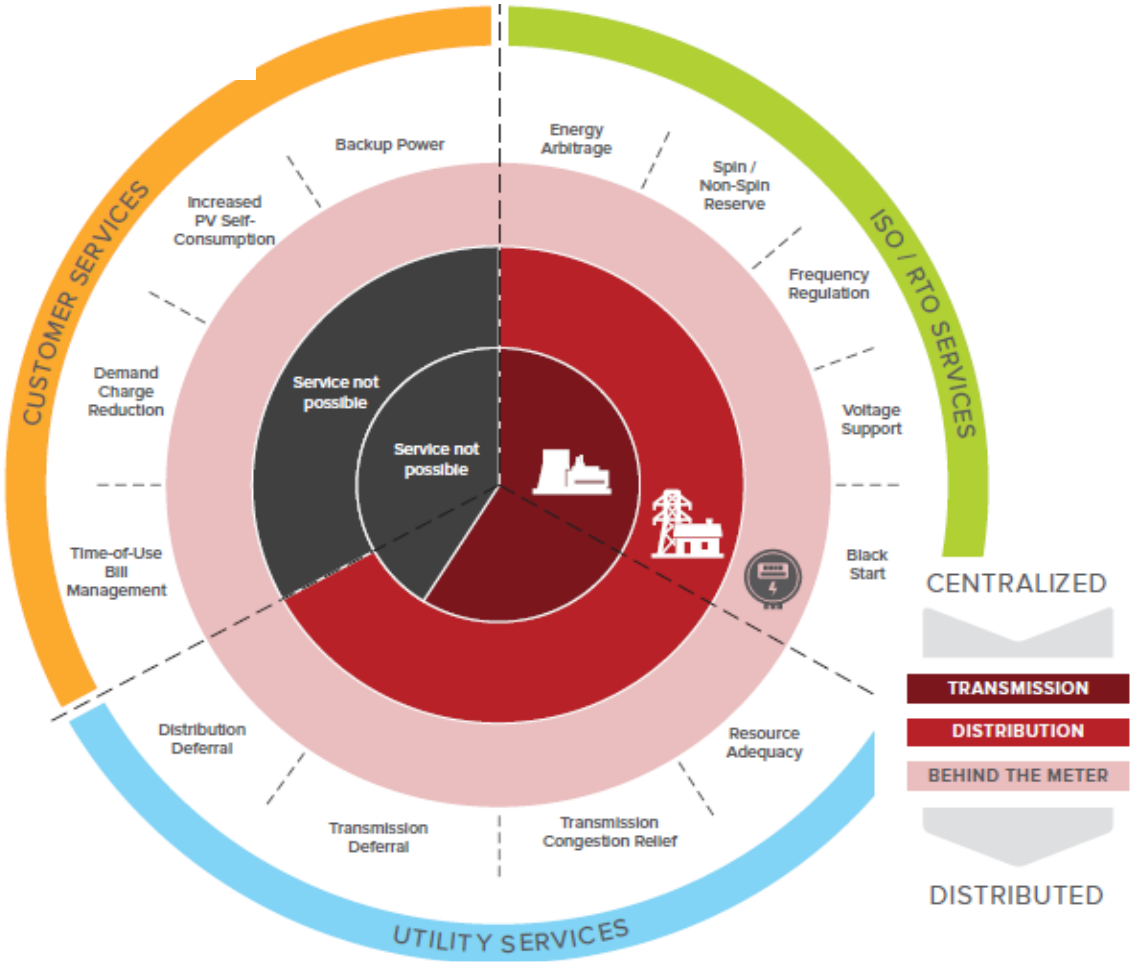
What Energy Storage Solution (ESS) Does to Electrical Grid?

Electricity is generated and consumed instantly, through transmission that moves electron to ***where*** *it is needed, without time scale.*

ESS adds the time dimension and helps deliver ***when*** *it's needed, adding value to utility assets by improving flexibility, resiliency and efficiency.*

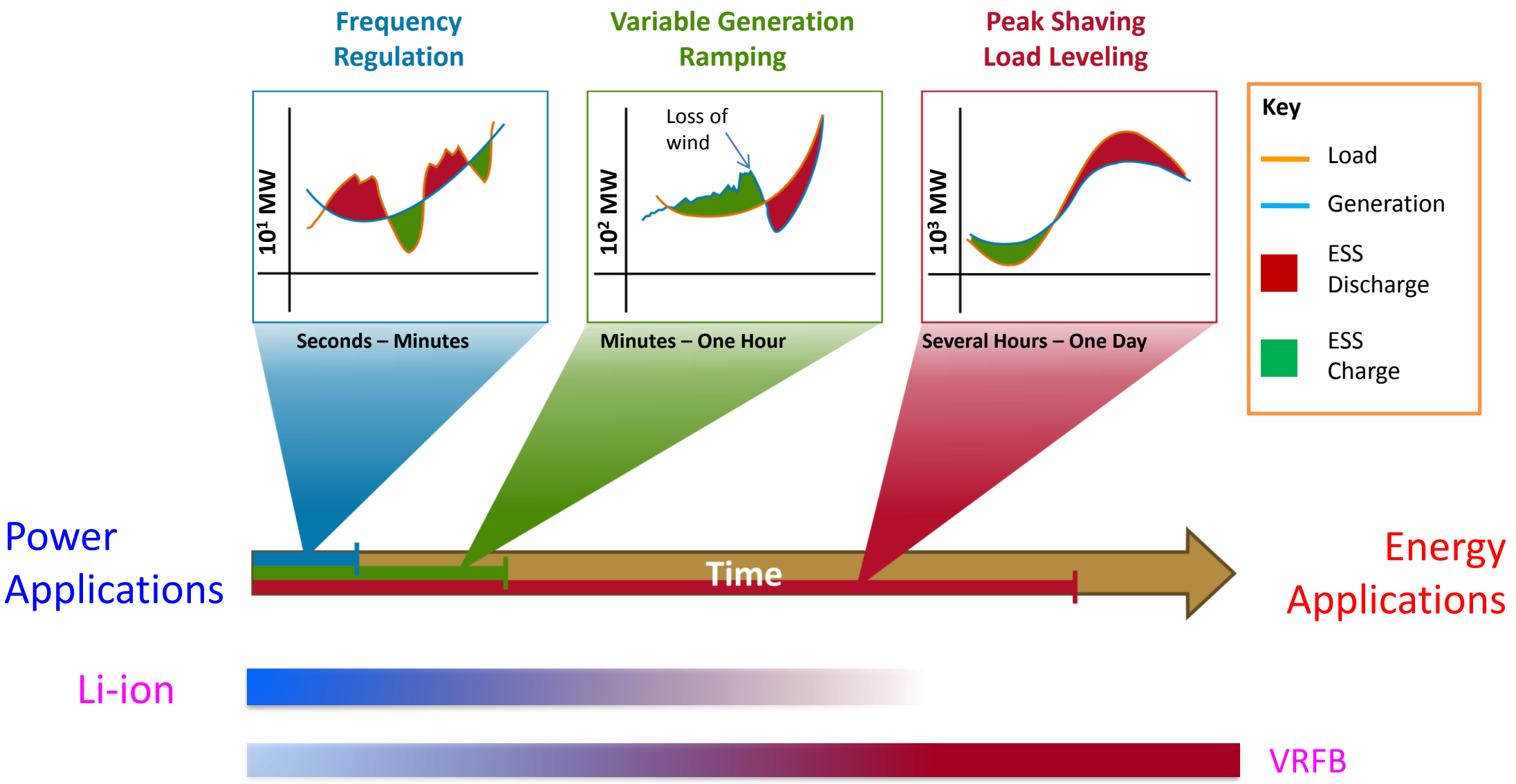
Applications and Benefits to Electricity Customers

- ISO/RTO
  - Energy arbitrage
  - Spin/non-spinning reserve
  - Frequency regulation
  - Voltage support
  - Black start
- Utility
  - Resource adequacy
  - Transmission congestion relief
  - Transmission deferral
  - Distribution deferral
- C&I
  - Time of use
  - Demand charge reduction
  - Increased PV self-consumption
  - Backup power



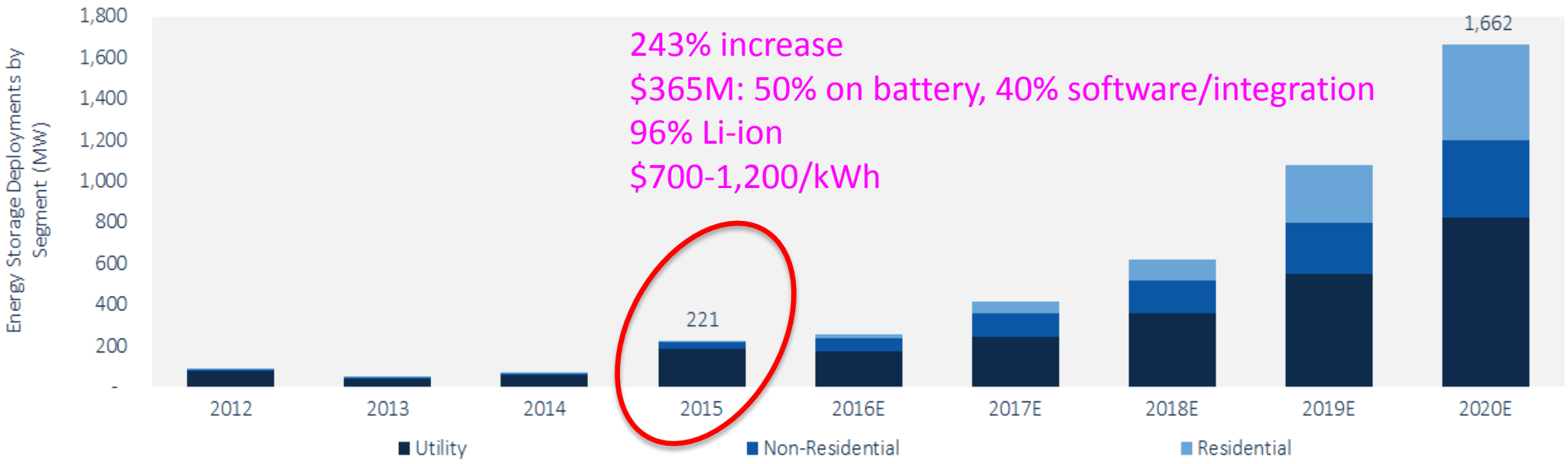
After RMI

Time Scales of Applications



ESS Market Trends

GTM ESS Monitor, US ESS (PHS, CAS, thermal ESS excluded) deployment 2012-20



In US, cumulative 5.86 GW/15.4 GWh projected for 2016-2021

In China, ESS highlighted in its 13th plan, projected to reach 14.5-24.5GW, plus 40GW PHS.; multiple 100MW, long duration projects start this yr.

ESS Technology Trends

Storage 1.0

Tech R&D
Commercialization
Early demonstration
Favorable regulations appearing

Storage 2.0

Li-ion matured,
Dominating early power apps
Energy apps, non-Li-ion growing
Project CapEx reaching $500/kWh

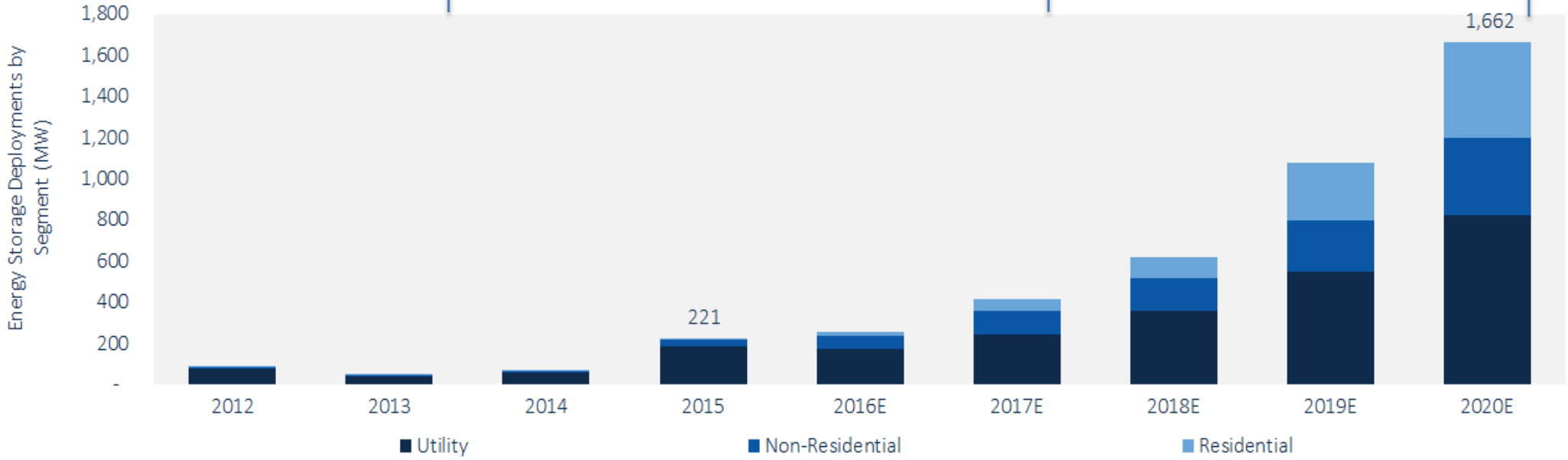
Storage 3.0

Non-Li-ion scaled up
Energy appls to expand
CapEx reaching $350/kWh
LOCS 6¢/kWh

Storage 4.0

Varied techs
Ubiquitous

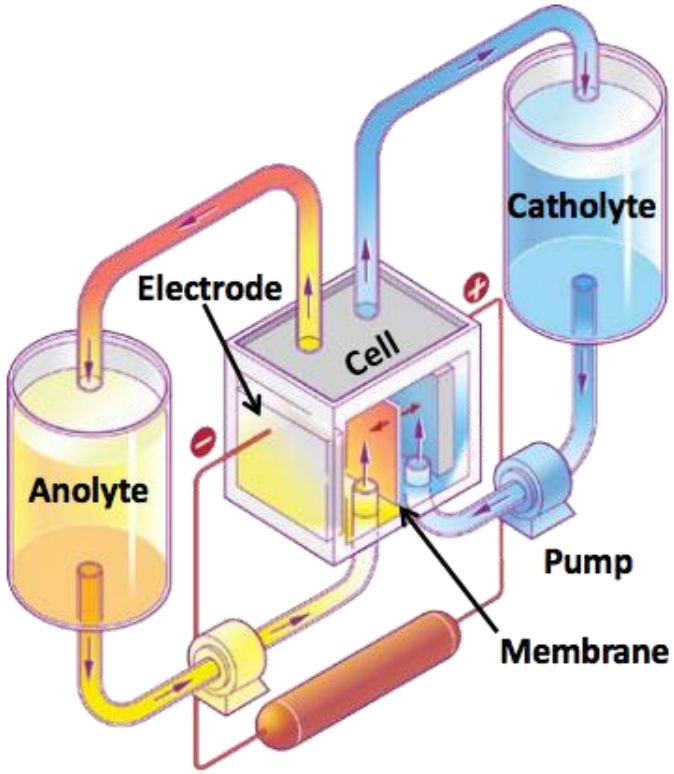
After Greg Horn



GTM ESS Monitor

Redox Flow Battery (RFB)

- Reversible Fuel Cell



- Conventional liquid RFB
  - Soluble liquid electrolytes at both anode and cathode side, i.e. anolyte and catholyte, respectively, e.g.
    - Fe-Cr (first demonstrated at NASA, 1970s),
    - All vanadium (first demonstrated at UNSW, Australia, mid-1980s)
- Hybrid RFB
  - Involving a solid phase either as a reactant and/or product, e.g.,
    - Elemental metal deposited on electrodes, e.g., Zn-bromide

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

https://en.wikipedia.org/wiki/Vanadium_redox_battery

Vanadium redox battery

From Wikipedia, the free encyclopedia

The **vanadium redox battery** (VRB) (or *Vanadium flow ba* ry that employs vanadium ions in different oxidation states to store chemical potential energy he ability of vanadium to exist in solution in four different oxidation states, and uses this prop electroactive element instead of two.[3] For several reasons, including their relatively bulky size, ed for grid energy storage, such as being attached to power plants or electrical grids.

The first successful demonstration of the all-vanadium redox flow battery which employed vanadium in a solution of sulfuric acid in each half was by Maria Skyllas-Kazacos at the University of New South Wales in the 1980s.[4] Her design used sulfuric acid electrolytes, and was patented by the University of New South Wales in Australia in 1986.[5] The possibility of creating a vanadium flow battery was explored variously by Pissoort in 1930's,[6] NASA researchers in the 1970s, and Pellegri and Spaziante in the 1970s,[7] but none of them were successful in demonstrating the technology.

Numerous companies and organizations involved in funding and developing vanadium redox batteries including Imergy (formerly Deeya), Vionx (formerly Premium Power), UniEnergy Technologies[8] and Ashlawn Energy[9] in the United States, Renewable Energy Dynamics Technology[10] in Ireland, Gildemeister AG (formerly Cellstrom GmbH in Austria) in Germany,[11] Cellennium in Thailand, Rongke Power and Prudent Energy in China,[12] Sumitomo in Japan and H2, Inc. in South Korea.[13]

The main advantages of the vanadium redox battery are:

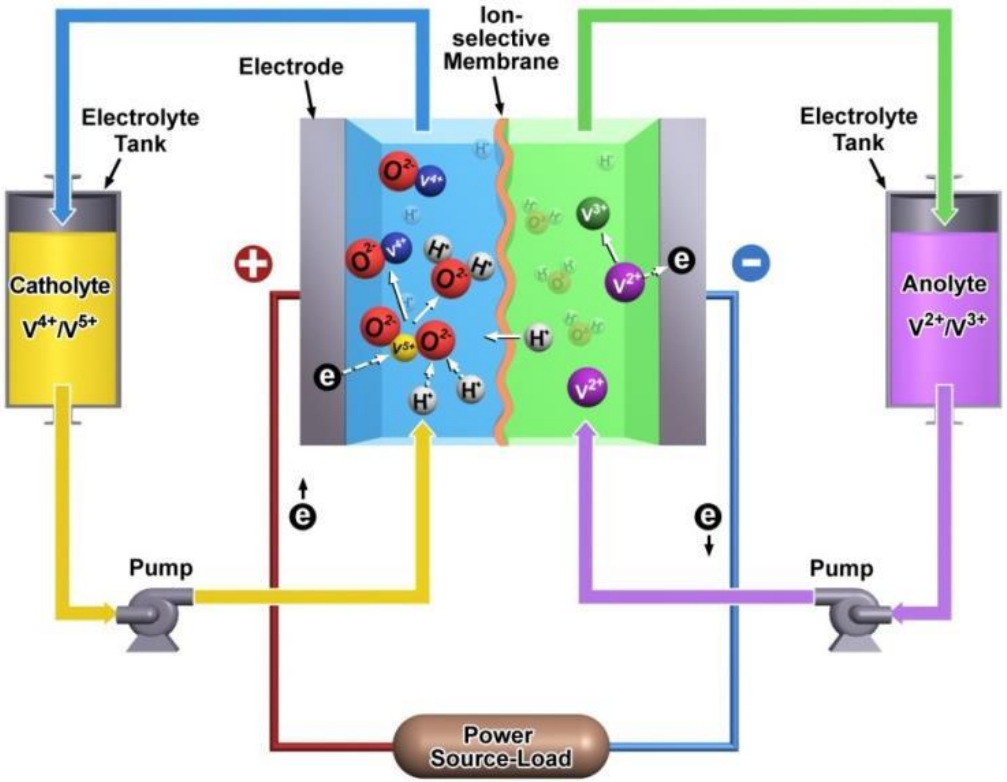
- It can offer almost unlimited energy capacity simply by using larger electrolyte storage tanks.
- It can be left completely discharged for long periods with no ill effects.
- If the electrolytes are accidentally mixed the battery suffers no permanent damage.
- A single state of charge between the two electrolytes avoids the capacity degradation due to a single cell in non-flow batteries.
- The electrolyte is aqueous and inherently safe and non-flammable.[14]
- The generation 3 formulation using a mixed acid solution developed by the Pacific Northwest National Laboratory operates at a high temperature allowing for passive cooling [15]

Vanadium redox battery

Specific energy	10–20 Wh/kg (36–72 J/g)
Energy density	15–25 Wh/L (54–65 kJ/L)
Charge/discharge efficiency	75–80%<.[1]
Time durability	20-30 years
Cycle durability	>100,000 cycles [citation needed]
Nominal cell voltage	1.15–1.55 V

1 MW 4 MWh containerized vanadium flow battery owned by Avista Utilities and manufactured by UniEnergy Technologies

Traditional Vanadium Redox Flow Battery (VRFB)



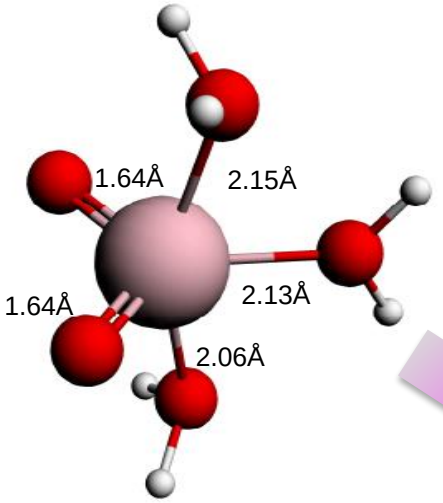
- Full separation of energy (kW, electrolyte) and power (kW, cell stacks)
- Vanadium ionic species in both catho-/ano-lytes
- Unlimited cycle life: 270,000 cycles, both shallow and deep, demonstrated at multi-MW levels
- 100% SOC; cycle life independent on SOC
- Safe: no thermal runway, use of non-flammable aqueous electrolytes
- V chemicals fully recyclable
- But limited in chemicals stability, operation, mass balancing, large foot print, …

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

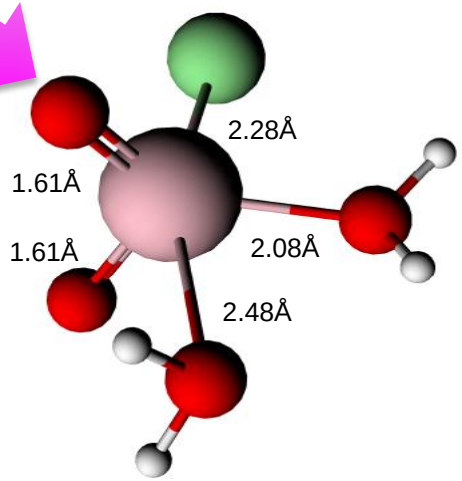
Anode: $V^{2+} - e^- \xrightarrow{\text{Discharge}} V^{3+}$

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

New (3rd) Gen VRFB Electrolyte Chemistry



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



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

Developed at and licensed from PNNL; Won highest US Government Award of Excellence in Technology Transfer

Improved Chemical Stability, leading to:

- Higher V solubility and energy density;
- Wider stable temperatures, -40 to 50°C;
- ……

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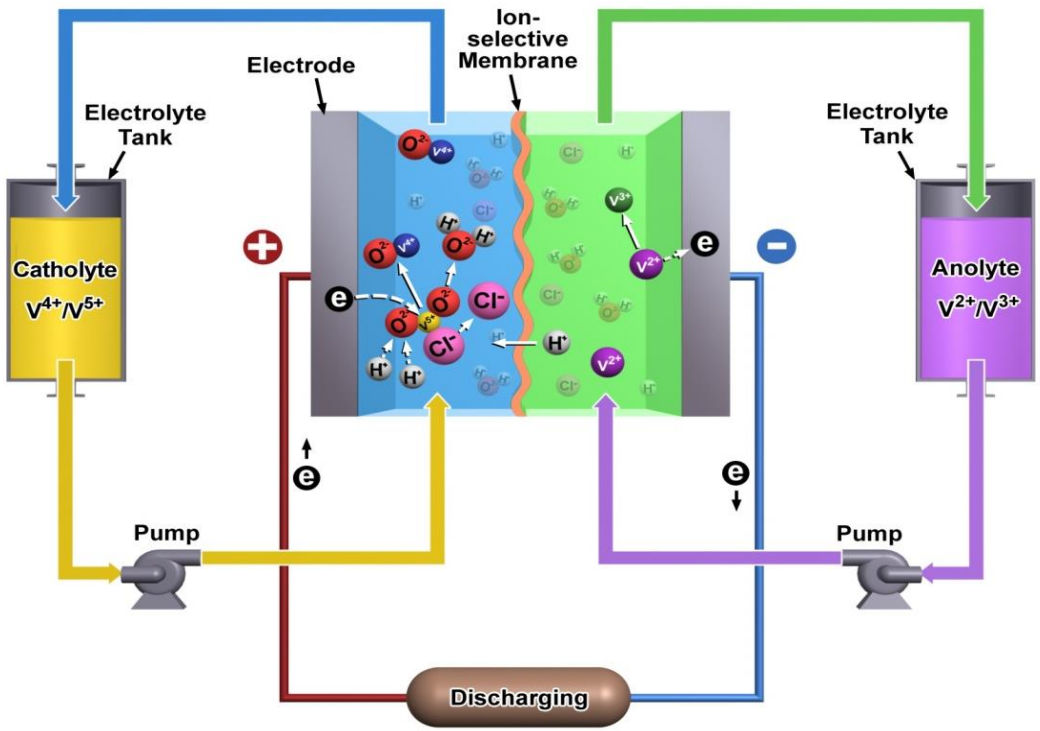
New (3rd) Generation VRFB



In addition to the benefits of traditional VRFB, the new gen VRFB allows for:

- Wide operation temperatures, ambient from -40°C to +50°C
- facilitate mass balancing to maintain 100% capacity and availability
- Mitigation of oxygen evolution to avoid "burning" positive electrode
- Over 2X energy density via 70% increase in solubility and improved utilization

  → 5X product footprint reduction

Catholyte: $VO^{2+} + Cl^- + H_2O - e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2Cl + 2H^+$ $\varepsilon_{co}=1.0$ V

Anolyte: $V^{3+} + e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+}$ $\varepsilon_{ao}=-0.25$

Overall: $VO^{2+} + Cl^- + H_2O + V^{3+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2Cl + 2H^+ + V^{2+}$ $E_o=1.25$ V

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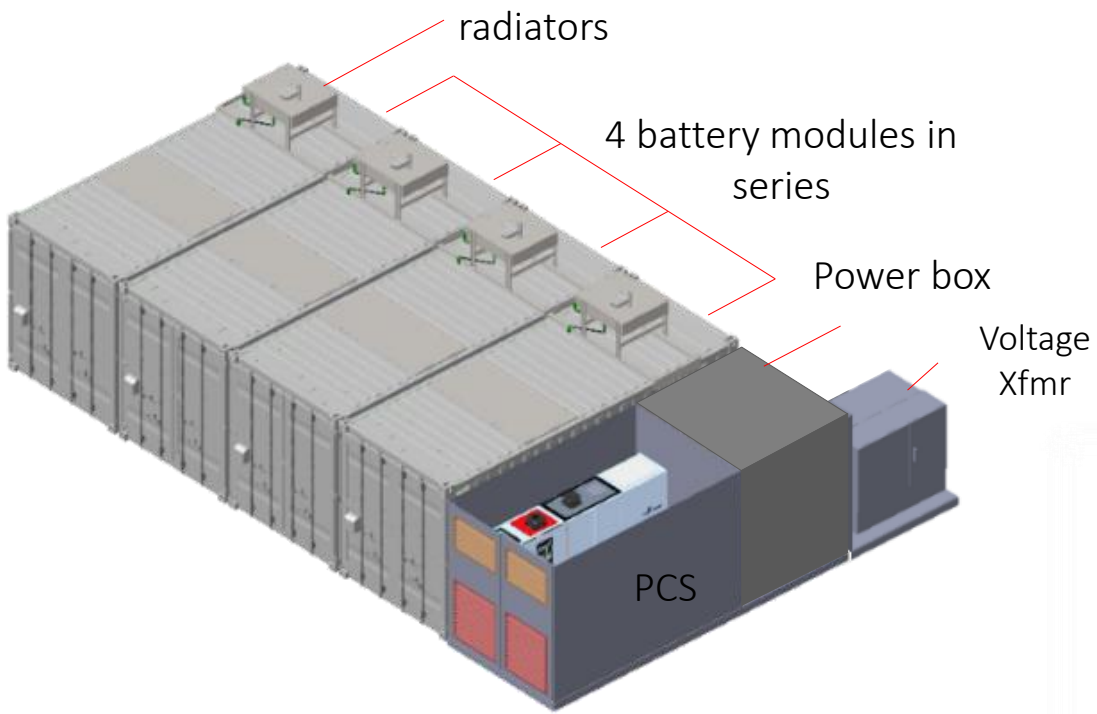
Fully Containerized, Plug & Play Products



- 20’ Container, Compact, Modular
- Full Factory Integration
- Optimized Power Electronics & Control
- Remote Monitoring, Cloud Base Data Management
- Plug-Play, Rapid Deployment

Uni.System™,
0.5MW/2MWh

ReFlex™,
100kW/400kWh

Features – Inherent Safe

- Aqueous electrolyte, a fire retardant, non-flammable
- No thermal spike, large thermal sink in electrolytes
- No Thermal runaway or spontaneous reactions leading to smoke or fire)
- Fire or smoke accidents reported on Li-ion, Na-S, others; None on VRFBs around the world

UET VRFB passed New York Fire Department examination – Only second after Pd-acid battery for C&I and unfenced applications.

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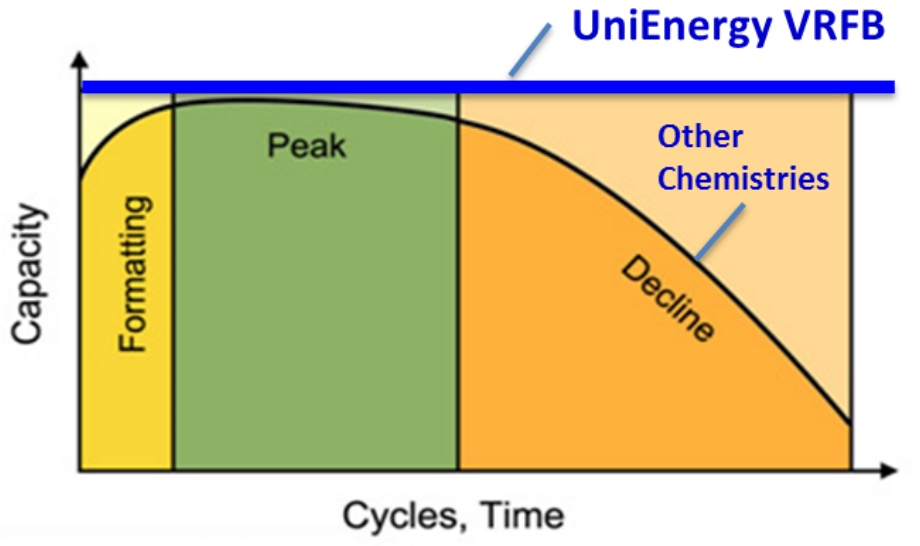
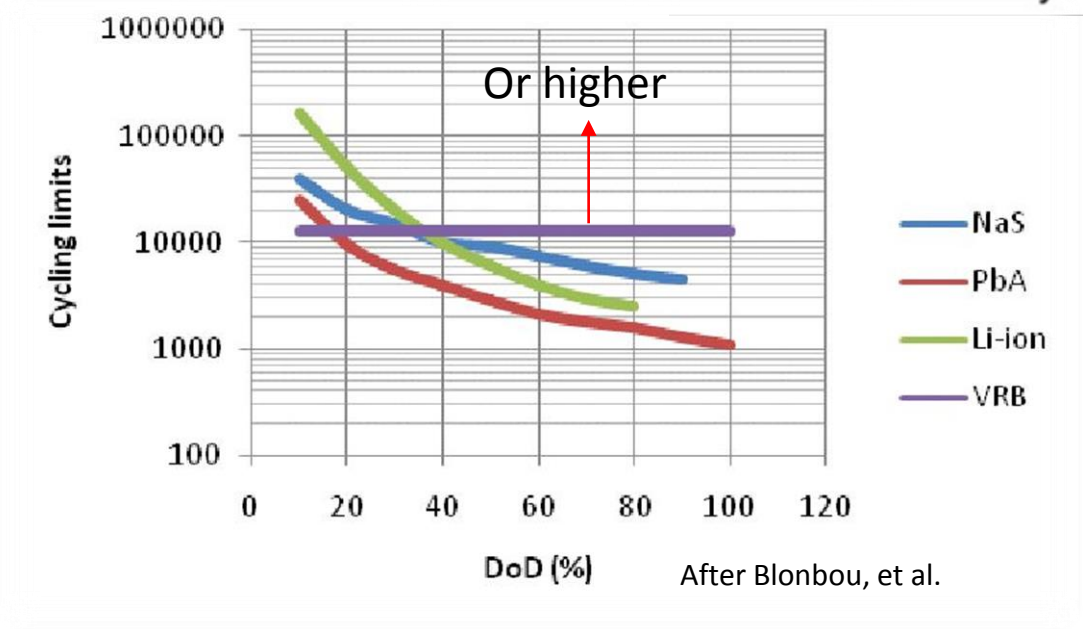
Features – Unmatched Flexibility

- Power(KW)/energy(kWh) decoupled, allowing separate design kW and kWh
- Practically unlimited cycle life that is independent of SOC and DOD
- 100% SOC and 100% capacity availability over life
- Operational at ambient -40°C to +50°C





After Blonbou, et al.

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Features – Value Propositions

- Excellent flexibility enabling multiple benefits

- Lowest levelized cost of system/energy LCOS/LCOE

$$\text{LCOE} = \frac{\text{Total costs over lifetime}}{\text{Electricity produced over lifetime}} = \frac{\sum_{i=0}^{N}\left[\frac{I_i + O_i + F_i - ITC_i - PTC_i}{(1+r)^i}\right]}{\sum_{i=0}^{N}\left[\frac{E_i}{(1+r)^i}\right]}$$

I_i	Investment costs in year i
O_i	O&M costs in year i
F_i	Fuel costs in year i
ITC_i	Investment tax credits in year i
PTC_i	Production tax credits in year i
E_i	Energy generated in year i
r	wacc
N	Lifetime of project (years)

- Competitive CaPex
- Installation 15% CaPex), 1-2% Opex
- Full capacity access, w/o cycle life limit
- Efficiency: DC >80%, AC≥70%
- V fully recyclable

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Applications and Benefits

Utilities/ Grid

- T&D deferral
- Flex capacity/ramping
- Load shifting
- Ancillary services

Microgrids

- Reliability (critical facilities, military)
- Remote communities & mining
- Integrating renewables
- Fuel savings ("Diesel off")

Commercial & Industrial

- Demand charge mitigation
- Time of use savings
- Integrating renewables
- Incentive programs

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Demonstrated Uni.System™

--First string 0.5MW/2MWh commissioned in April, 2014

Ribbon cutting by Governor Inslee, July 8, 2014

--over 250MWh discharged back to grid, free!!!

Commissioned the Largest VRFB

in North America and Europe

- $1MW_p$; $4MWh_p$ Uni.System™
- Grid connected and customer-side @ Schweitzer Engineering Labs
- Energized April, 2015
- Use cases:
  - Grid-tied and islanding operation
  - Avista smart grid enhancement
    - Energy shifting
    - Grid reliability
    - Improved distribution system efficiency
    - Enhanced voltage control
    - Optimized utilization of energy storage
- Project partners
  - AVISTA
  - UET
  - WA State Dept. of Commerce
  - PNNL

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10MW /40MWhs Installed or Ordered

1) Harbour Pointe Energy Storage Project (near Seattle, WA) May 2014 COD
   - 500kW/2MWh Uni.System™, demonstrating fully commercialized system with >250MWh discharged to Snohomish PUD grid and providing voltage support to distribution circuit
2) Citizens Wind Park (Braderup, Germany) Sept 2014 COD
   - 250kW/1MWh, exceeding performance requirements (tested over 1.25MWh) and buffering intermittency of wind generation, shifting energy, and providing park power & voltage support
3) Avista Energy Storage Project (Pullman, WA) June 2015 COD
   - 1MW/4MWh Uni.System, the largest capacity flow battery in North America & Europe (largest containerized in the world), grid-connected supporting distribution circuit and also customer-side islanding, black start, and seamless switching protecting Schweitzer Engineering Lab manufacturing
4) Terna Energy Storage Project (Italy) Q2 2016 COD
   - 500kW/2MWh Uni.System™, part of 35MW procurement providing solar integration, voltage support, and other utility applications
5) Mission Produce (Oxnard, CA) Q2 2016 COD
   - 500kW/2.0MWh Uni.System at packing & ripening center, providing peak-shaving, energy savings, and back-up power without diesel generators, integrating 1MW solar array and Powerit building energy management software
6) City of New York (NY, NY) Q3 2016 COD
   - 100kW/400kWh ReFlex™ system at Bronx hospital, providing peak-shaving, energy savings, and back-up power
7) Snohomish PUD Energy Storage Project (Everett, WA) Q4 2016 COD
   - 2MW/8.0MWh Uni.System at Everett Substation, providing balancing of wind procured as part of fossil-free policy in conjunction with hydro, supporting distribution circuit, and preparing for growth of rooftop solar & EV charging
8) …..

Challenges

From R&D to a mature product is a “Long March”

- Accelerate product maturation
  - Materials and component reliability
  - Software and integration
- Policy and regulation reform to facilitate monetization of EES benefits
- Business innovation to improve bankability

Acknowledgements

- UET all employee
- Pacific Northwest National Laboratory
- DOE-OE Energy Storage Program

THANK YOU