Electrochemical Energy Storage

For Renewable Integration and Grid Applications

Z. Gary Yang

UniEnergy Technologies, LLC

WCTA Panel Discussion,

August 2, 2012

UniEnergy Technologies, LLC

UET is a Washington-based clean energy company scaling up to be a leading developer and provider of energy storage solutions.

- Founded by leading scientists in redox flow batteries, motivated to commercialize advanced technologies developed at labs
- Scaling up new generation V redox flow batteries in engineering, operations, and marketing
- Located in Mukilteo, nearby to Seattle and Bellevue

25 miles north of Seattle

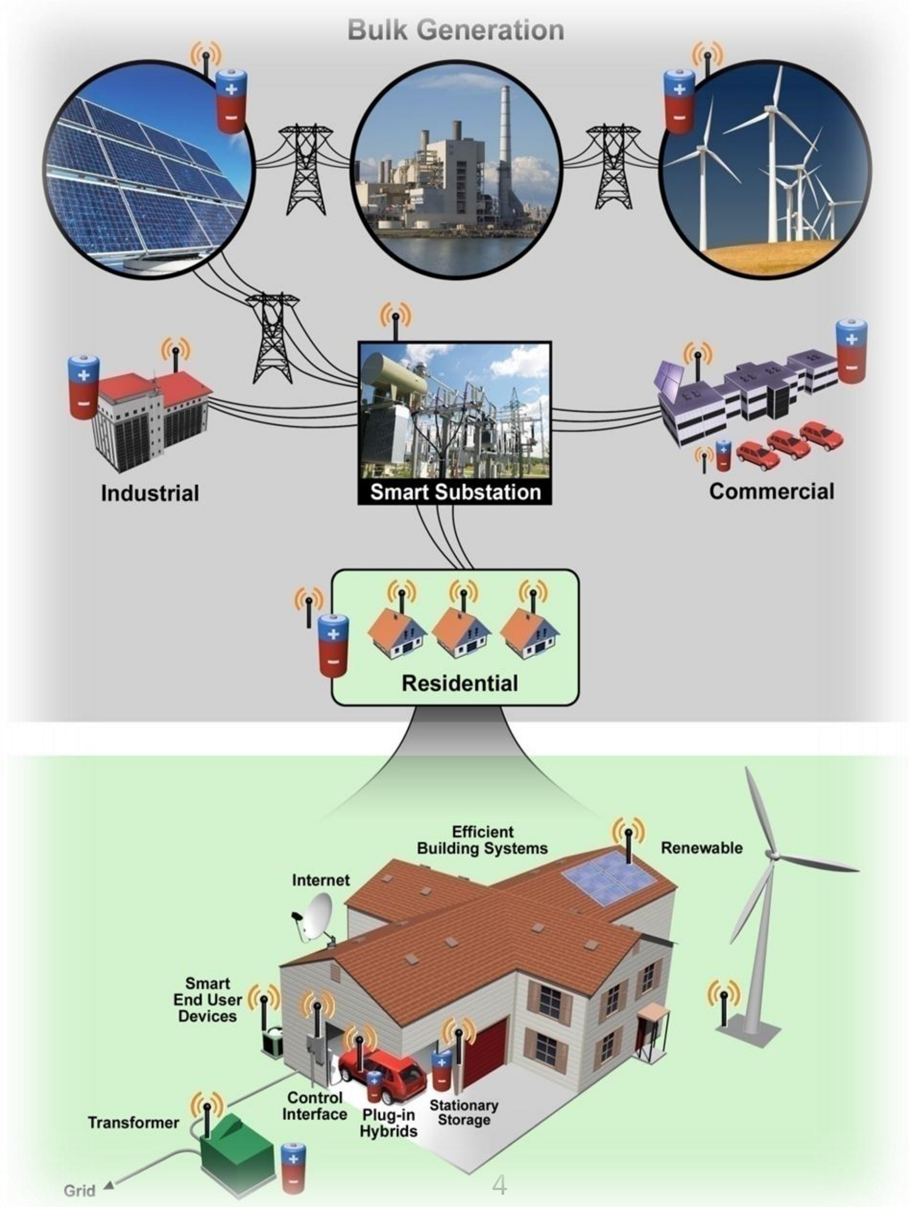
Electrical energy storage (EES)- A key component of the future grid

Bulk generation
10s MW ~ GW

Transmission-substation
MW ~ GW

Community storage
10s kW ~ 100s kW

End user storage
few kW



- *Dispatch renewable*
- *Improve grid reliability*
- *Enhance value of utility assets*
- *Enable smart grid, electrified transportation*
- *……*

UniEnergy Technologies

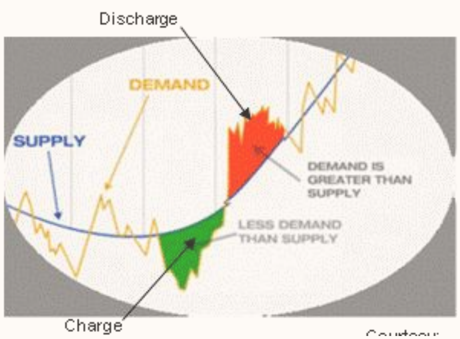
EES Applications – Time Scales

Seconds to Minutes

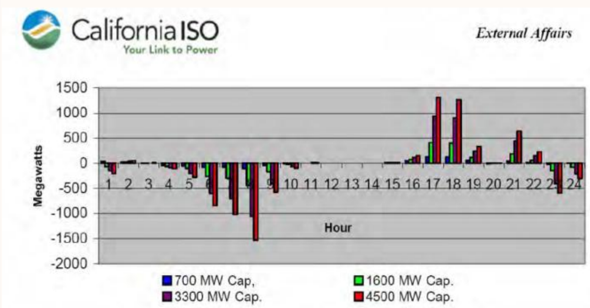
Minutes - one Hour

Several Hours - one Day

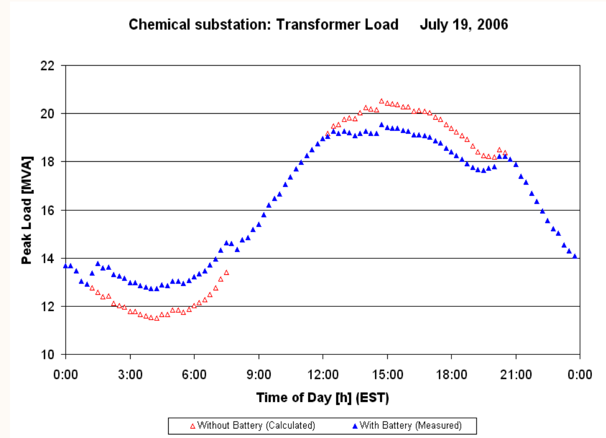
Regulation



Ramping



Peak shaving, load leveling



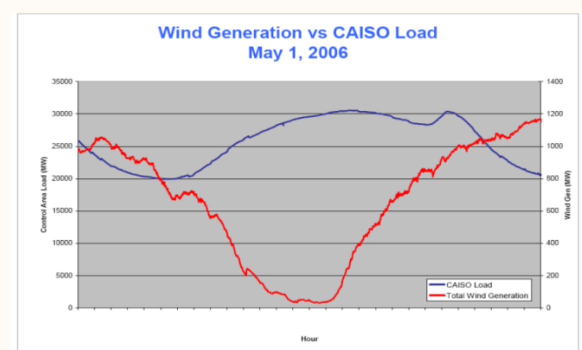
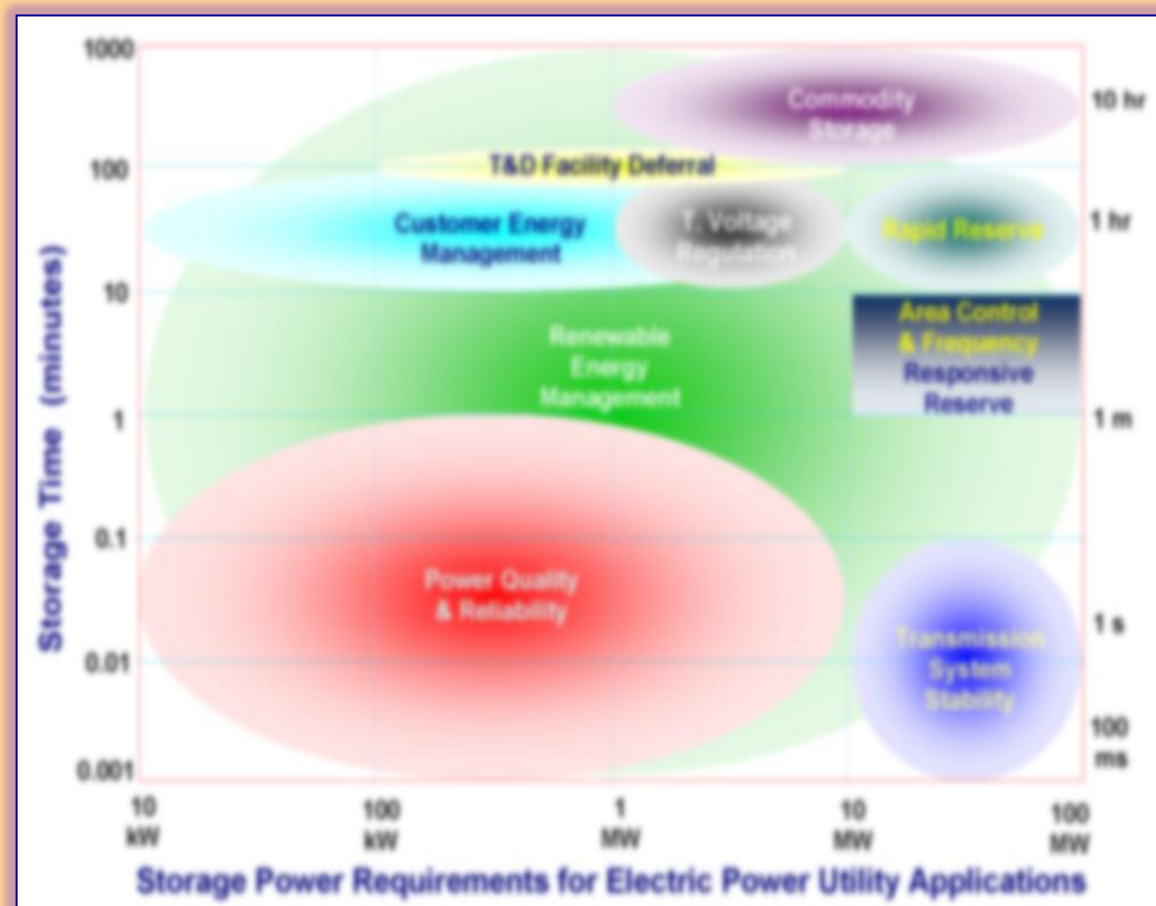


Figure 11: Total Wind vs. CAISO Load

Different Time Regimes
will Require
Different Storage Solutions

Performance and economic requirements



http://electricitystorage.org/

- **Energy/power, or discharge duration:** seconds ~ hours, depending on applications;
- **Quick response** seconds or sub-seconds
- **Efficiency**: High, preferable;
- **Life**: >10yrs, >4,000 deep cycles, higher for shallow cycles, depending on applications;
- **Safety**
- **Costs**: low capital cost, levelized cost over life, social cost (considering carbon effects)

UniEnergy Technologies

EES technology options

Yang, et al, *Chemical Reviews*, 111, 3577, 2011

Direct storage

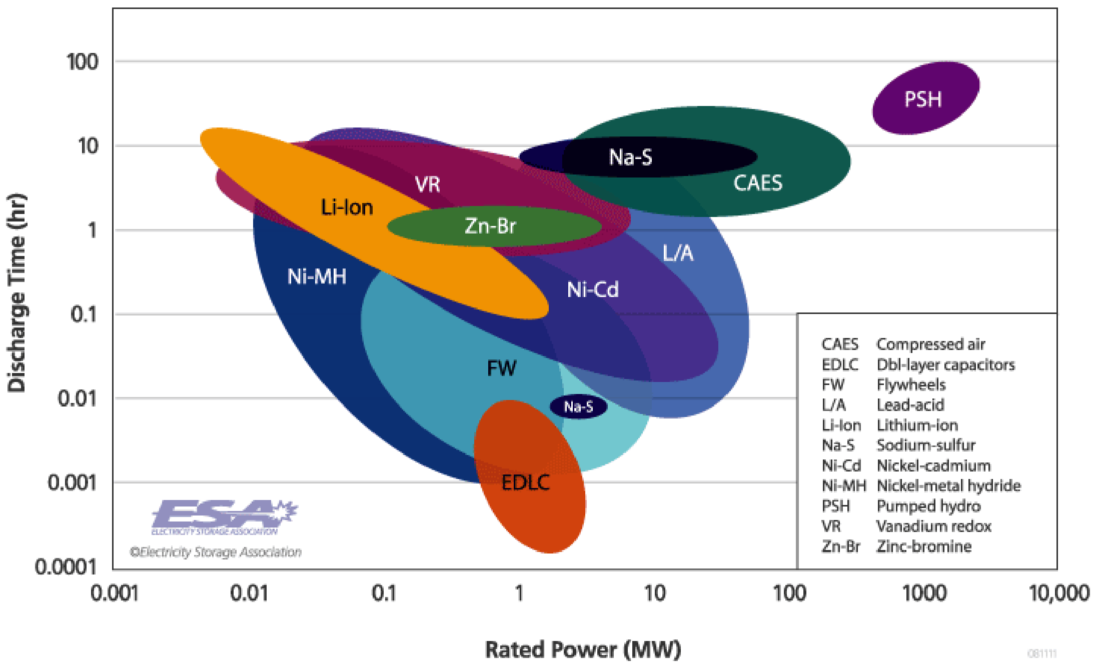
Indirect storage (via energy conversion)

Electrical charges: Capacitors

Potential energy: pump hydro, compress air

Kinetic energy: flywheels

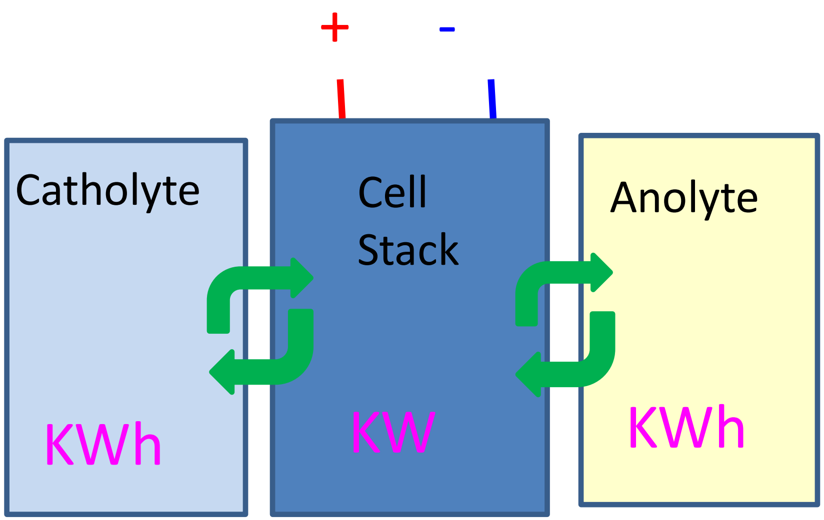
Chemical energy: batteries



- Free energy of chemicals converted into electrical energy or vice versa: without "Carnot" cycles
- Prompt uptake and release of electrical energy according to power and energy demands

UniEnergy Technologies

Redox flow battery (RFB)
- regenerative fuel cell



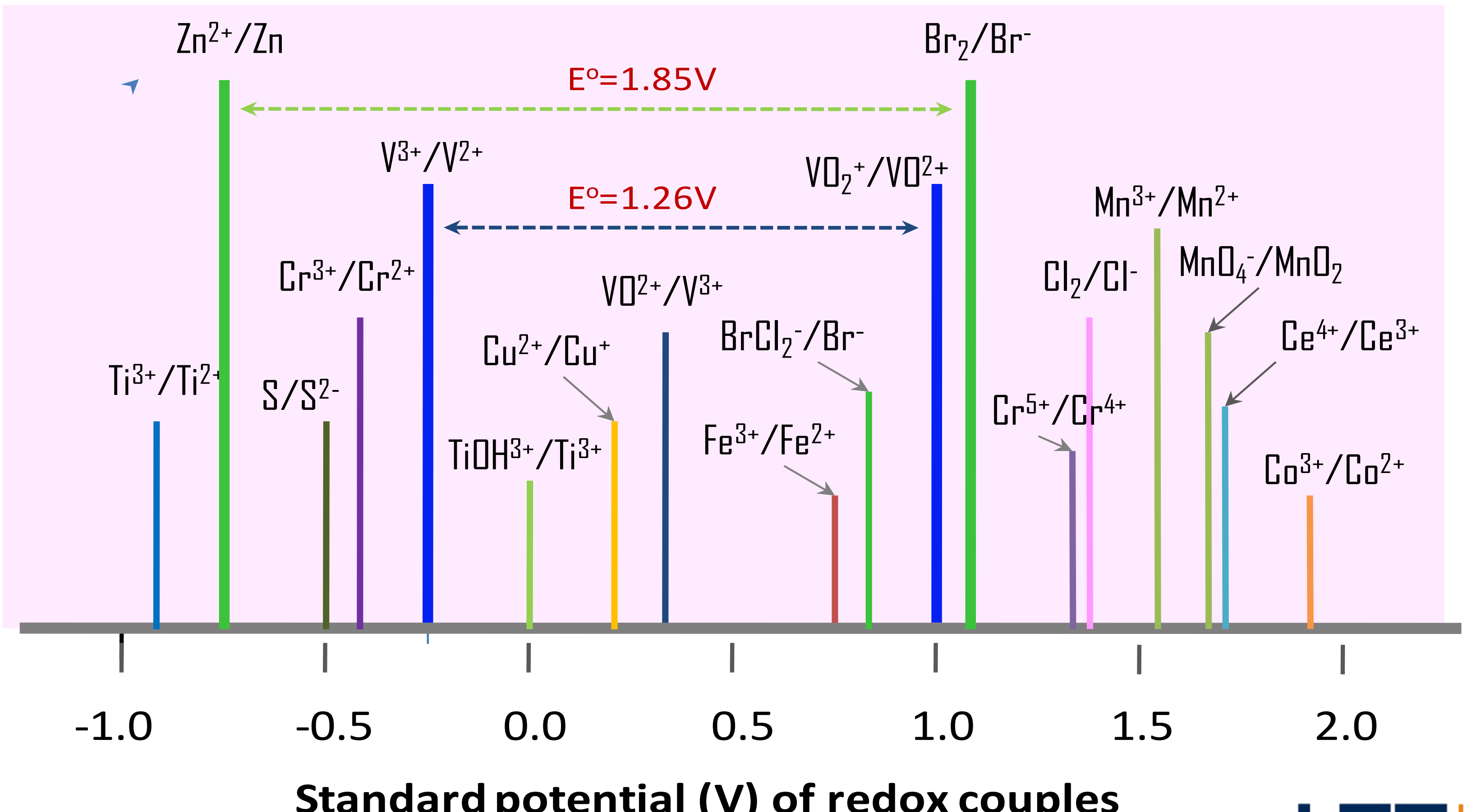
- Separate design of
  - energy (KWh) – electrolytes
  - power (KW) – cell stack
- "Inert" electrodes – no structural changes and stress buildup in electrodes
  - potential long cycle life
  - cycle life independent of SOC/DOD
  - High fuel utilization
- Active heat management – flowing electrolytes carry away heat generated from ohmic heating and redox reactions-super safe
- Capable of storing a large energy/power (MWs/MWs) in a simple design, for durations up to 12 hours
- **Challenges to be discussed**

Wang, Li, Yang, *Adv. Functional Mater.*, in press, 2012.

UniEnergy Technologies

Existing RFB chemistries

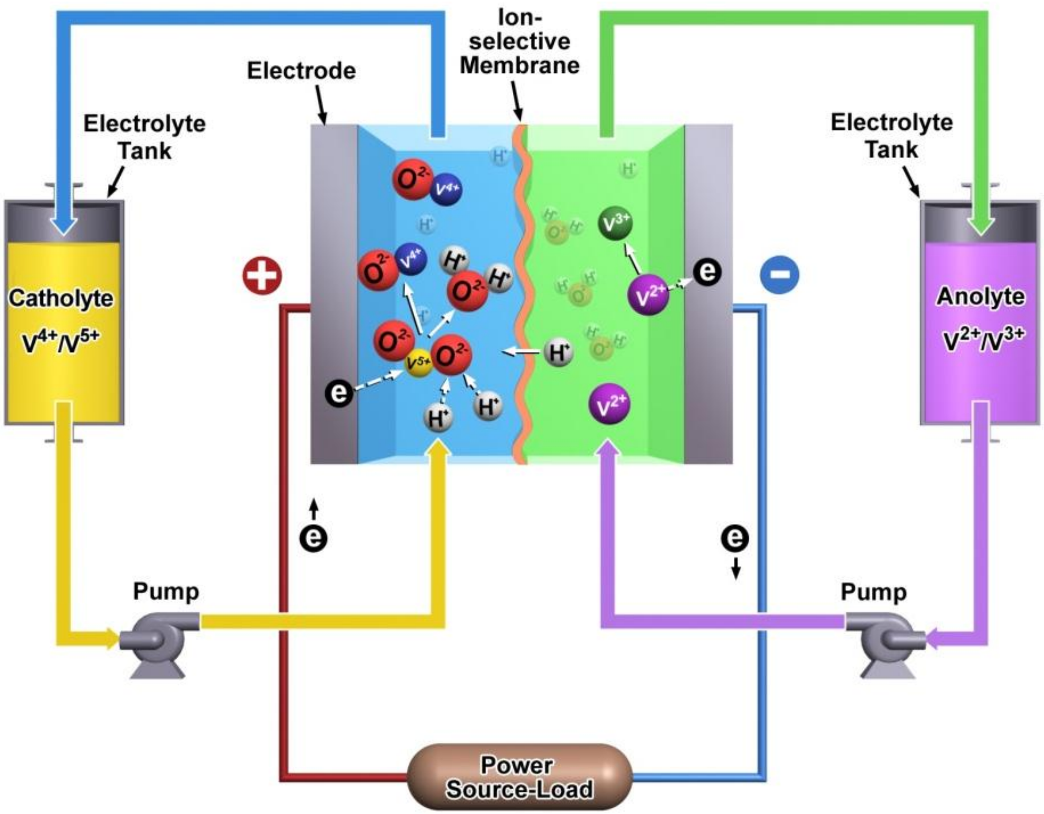
- Varied redox couples studied
- Dominated by aqueous supporting electrolytes, SO_4^{2-}, Cl^-, Br^-, …
- A few non-aqueous electrochemistries explored



Yang, et al, *Chemical Reviews*, 111, 3577, 2011

UniEnergy Technologies

All vanadium (V) RFBs



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

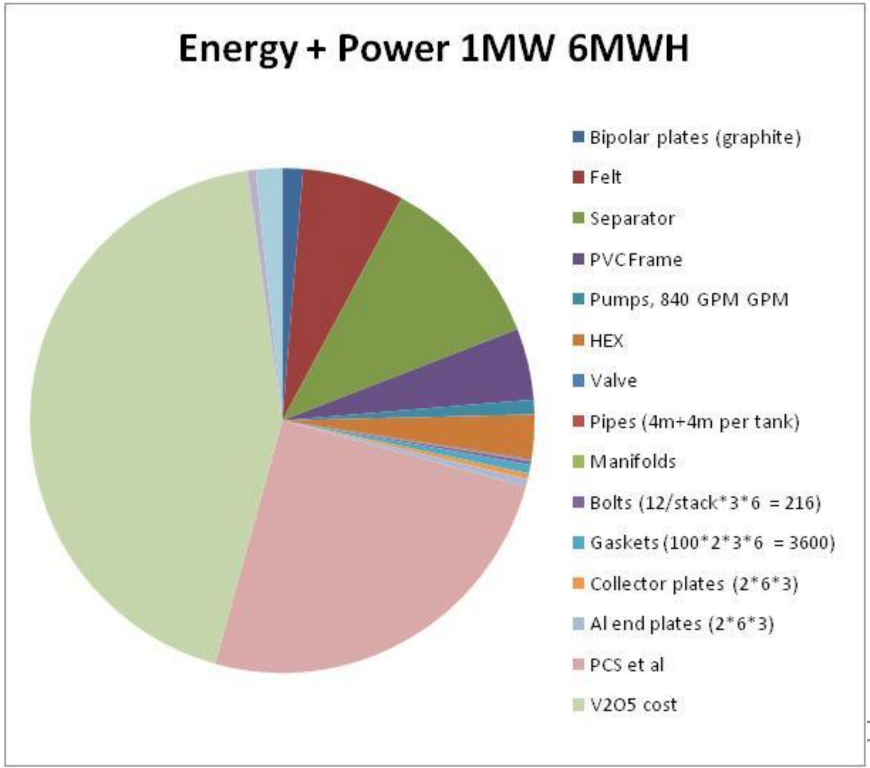
- Same active element (V) at both negative and positive sides, mitigating cross-transport
- Trace back to efforts by Dr. Larry Thaller at NASA in 1970s
- First demonstrated by Prof. Maria Skyllas-Kazacos in 1980s
- Up to multi-MWs demonstrated
- Unlimited cycle life, 270,000 cycles demonstrated

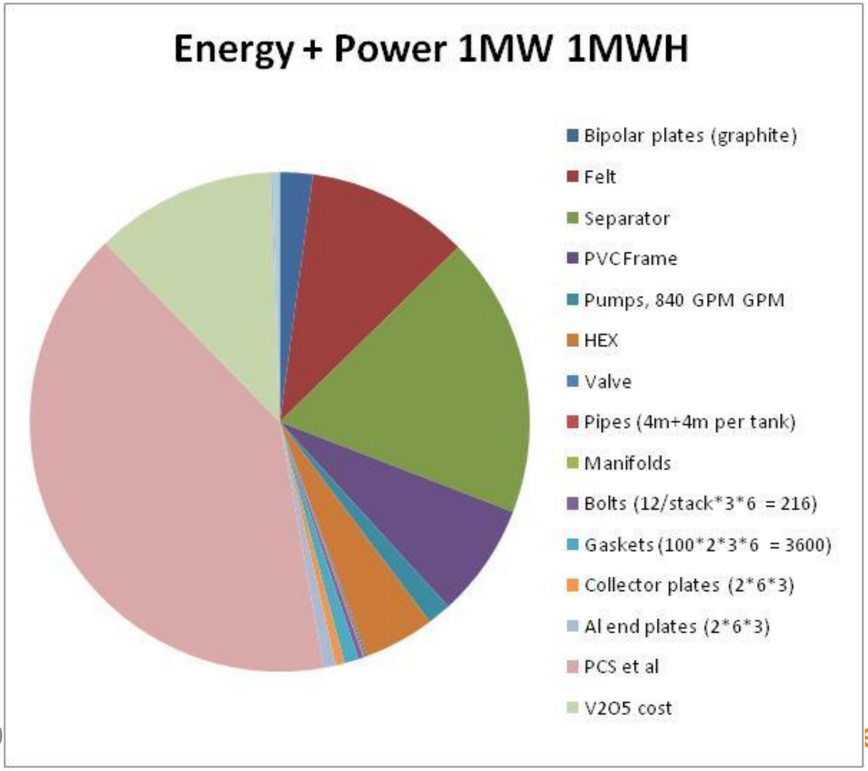
Wang, Li, Yang, *Adv. Functional Mater.*, in press.

UniEnergy Technologies

Challenges of V RFBs

- Performance:
  - -Low energy density 20~33 Wh/liter; specific energy 15~25 Wh/kg
  - -Heat management, frequent balancing, ……
  - -Long term durability/reliability
  - -System energy efficiency <60%
- Economics:
  - - Capital cost >$3,000/KW or >$600/kWh for a six hr system
  - - >20¢/kWh (levelized over life time)

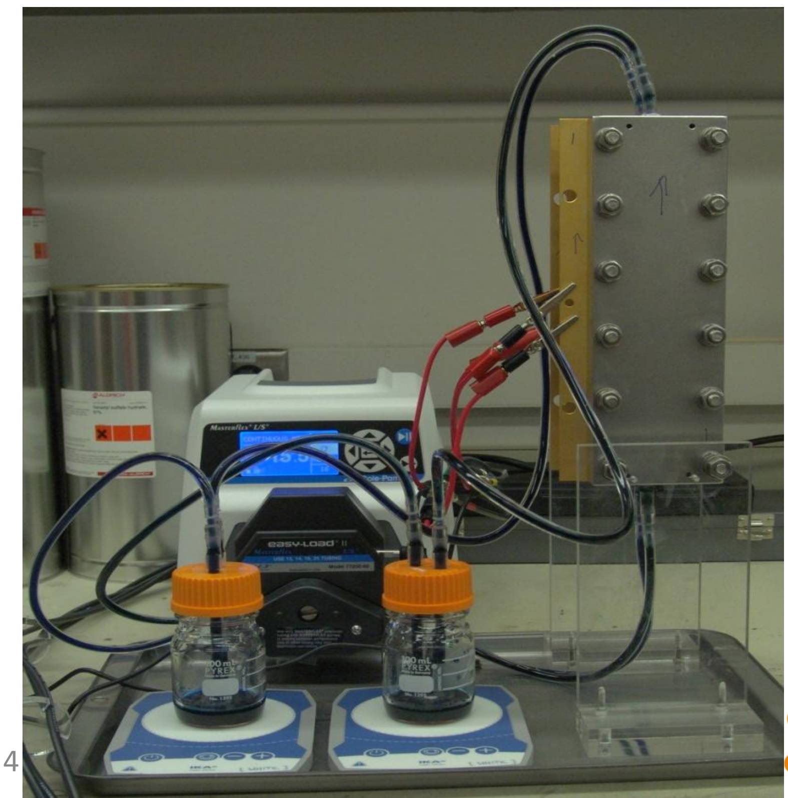




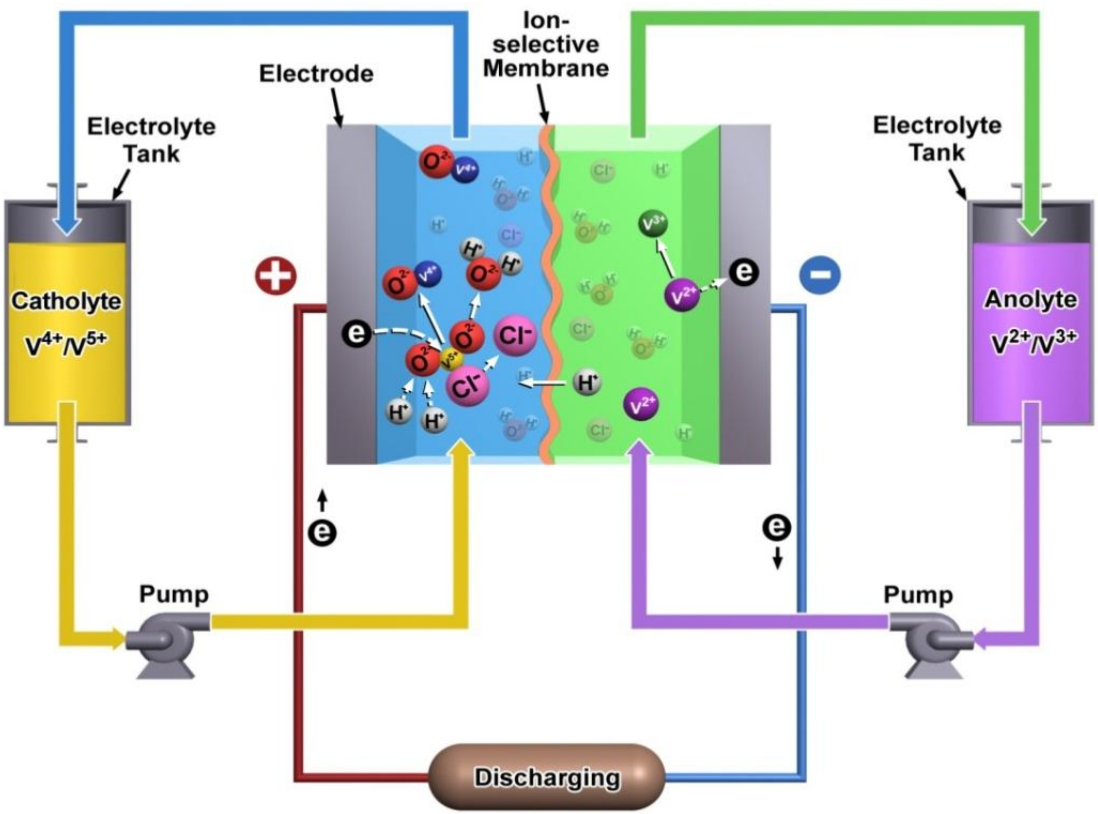
es

Fundamental issue: limited chemical stability

- Issue of stability: >40^{o}C, V^{5+} precipitates out; other V^{n+} out at RM or low temperatures
- Limited energy capacity <1.75 M in the sulfate systems
- Operation temperature window, 10~40^{o}C, requiring active heat management
- Frequent balancing due to the reaction mechanisms



New generation vanadium RFB



- V^{n+} concentration >2.5M, 80% increase in energy capacity
- Stability window extended to -5~60^{o}C, easing or potentially eliminating heat management
- Stable operation without frequent balancing
- 2~3 times of reduction in capital and levelized cost

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

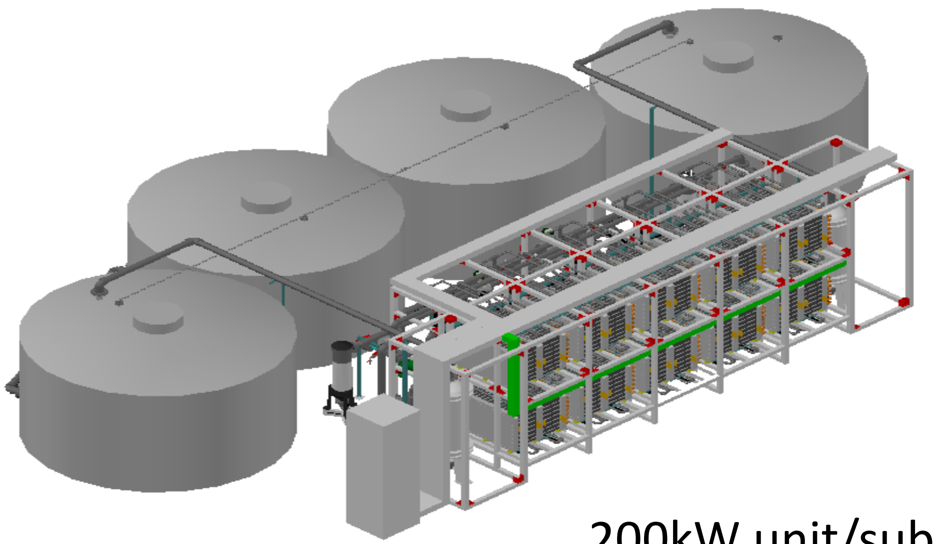
Anolyte: $V^{3+} + e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+}$

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

UniEnergy Technologies

UET Missions

- Demonstrate and commercialize new generation RFBs
- Develop and produce a series of RFB systems built from 25 kW modules scaling up to multi-MWs in 2 years, through innovation and strategic partnerships with BIC and its affiliates
- Together build a world-leading EES product development company and manufacturing chain
- Become a major provider in the EES markets in the US, Europe, South Asia, and China
- Leverage technology leadership of strategic partners to establish an US industry in RFBs and enhance its competitiveness in EES and clean energy



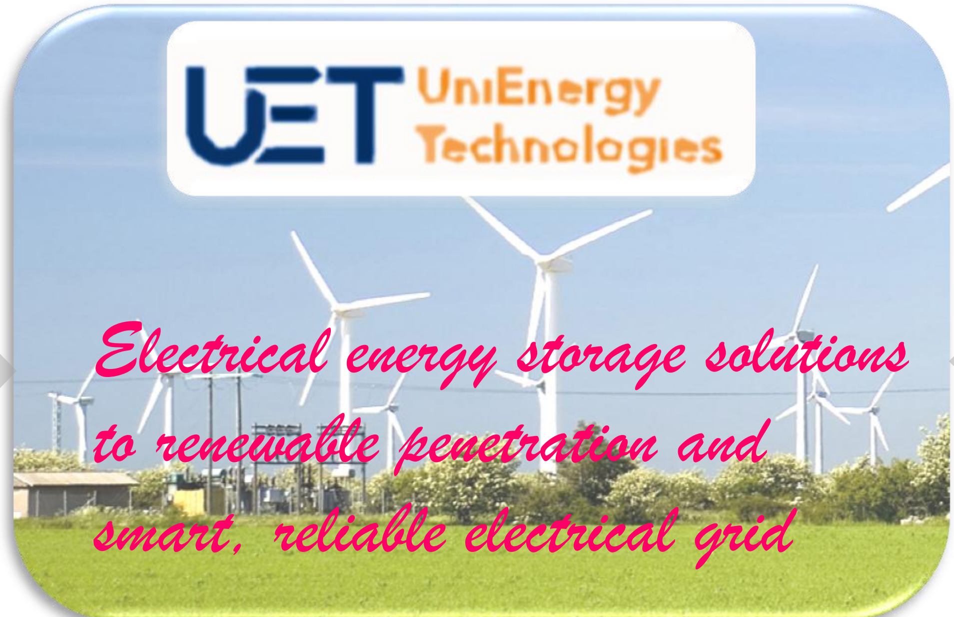
200kW unit/sub-system

UniEnergy Technologies

UET partnerships

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Tech transfer



Market, R&D support

KEMA DNV

Partnerships

融科储能 RONGKE POWER

BNM BOLONG NEW MATERIALS

…

Establish a renewable & grid integration center

- Build a generation and storage station to simulate integration of wind or solar power
- Establish market needs and economic indicators
- Evaluate UET modules and products
- Collaborate with US utilities, national labs and/or universities
- Look for collaborations with utility and renewable industries

THANK YOU

UET UniEnergy Technologies