Resilient Molecules to MWs:

An Update on Commercialization of New Generation Vanadium Redox Flow Batteries

Gary Yang, UniEnergy Technologies

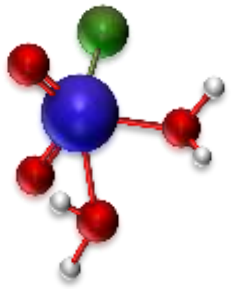
NATTBATT 2019 Annual Meeting & Conference

March 11-14, Litchfield Park, Arizona

UniEnergy Technologies (UET)

A Leading VRFB Systems and Service Provider in the multi-hour energy storage market

Technologies:



$VO_2Cl(H_2O)_2$

Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Working with SNL, PNNL to advance reliability

INNOVATION + QUALITY + PARTNERSHIPS

Chemours™

Membrane development and production, advancing stacks

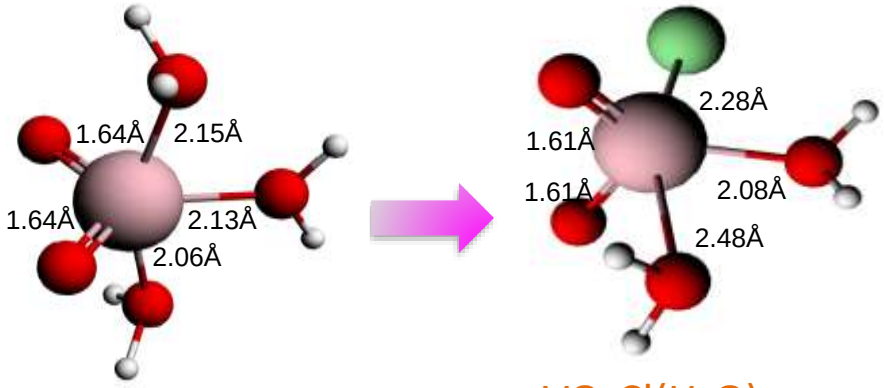
EcoPartners:

10 years stack field experience, ramping up GW production capacity

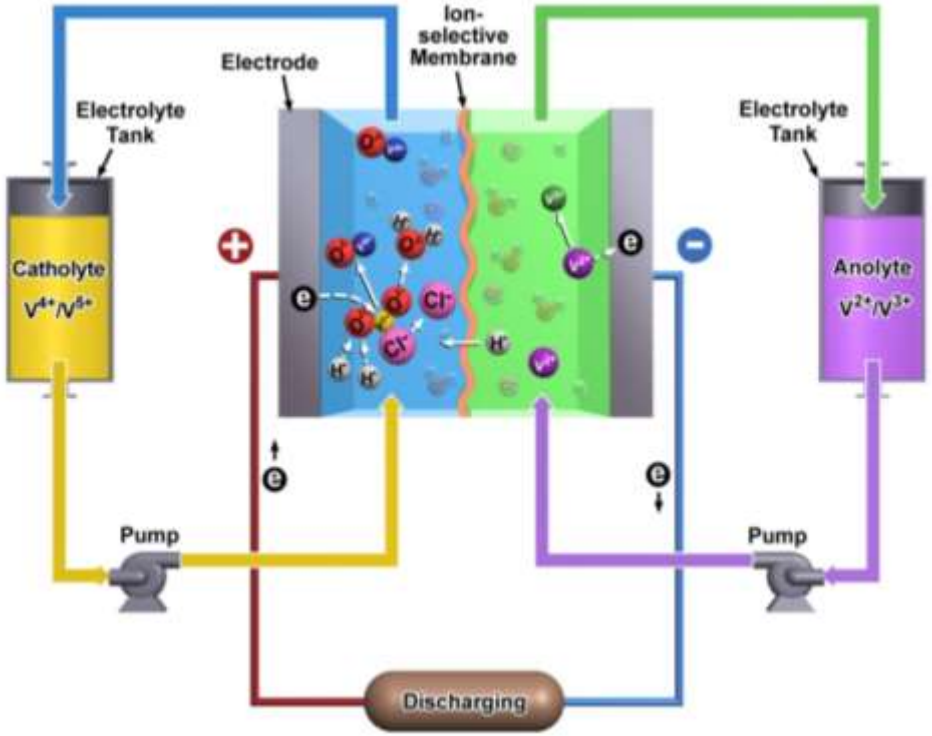
BNM BOLONG NEW MATERIALS

Electrolyte production: 1.5 GWh/yr capacity

Field proven new gen vanadium redox flow battery (VRFB)



$[VO_2(H_2O)_3]^+$ $VO_2Cl(H_2O)_2$



Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Developed at PNNL and optimized at UET. Won the highest US Government Award for Excellence in Technology Transfer and 2017 Presidential Green Chemistry Award

- ❑ More stable electrolyte chemistry:
  - ➢ 2x energy density
  - ➢ Up to 50°C or higher
- ❑ Optimized electrochemistry:
  - ➢ Inhibiting oxygen activity, mitigating electrode degradation
  - ➢ Easing electrochemical balancing
- ❑ Higher chemical activity:
  - ➢ Less sensitive to impurities
  - ➢ High chloride activity, more corrosive

Advancing products: From Uni.System™ to ReFlex™

- Valuable learnings from field demonstration of Uni.Systems
- Rolling out 2nd generation product – ReFlex systems through value engineering

2012, 2013, 2014

IP DEVELOPMENT
- Electrochemical, Mechanical, Power & Controls Engineering

2015, 2016, 2017

PRICELESS FIELD EXPERIENCE
- Understanding Customers
- Contract Manufacturing

2018

PIVOT TO **REFLEX™**
- Customer Driven Design
- Flexible, Modular, Resilient

2019

100kW C&I PROJECTS
- High System Availability
- Industrial Design

2020

ELECTRICITY WAREHOUSING
- E'lyte Leasing
- Storage-as-a-Service

Up to MWs demonstrated and deployed around the globe

From C&I, Microgrid to T&D, plus renewable integration








Great learnings from early deployments!!!

Learnings from early demonstrations: inherent safe

No fire accident reported for RFB' !!!

noncombustible

nonreactive

- Non-flammable aqueous electrolytes
- No thermal runaway
- As thus without danger of releasing exposed to a sustained external fire

UET VRFB approved by NY Fire Dept with letter of no objection, only after Pd-acid

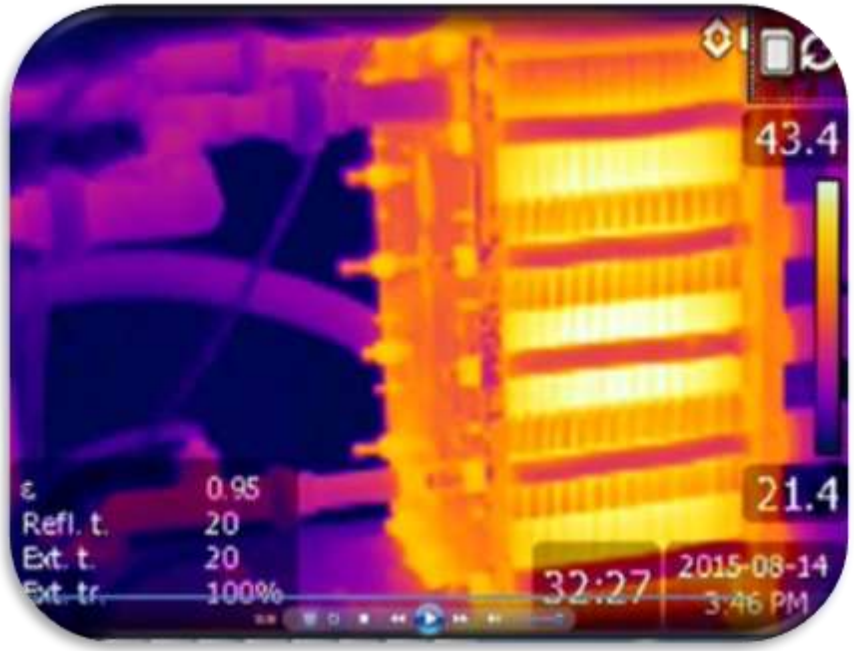
Numerous fire accidents reported for Li-ion

After a fire was contained, this photo captures the initial explosive re-ignition of a 2.5MWh lithium battery, severely injuring 3 experienced firefighters in ***Hilden, Germany***

Over 1GWh of Li-ion deployed in south Korea 2018, but 16 fire accidents reported.

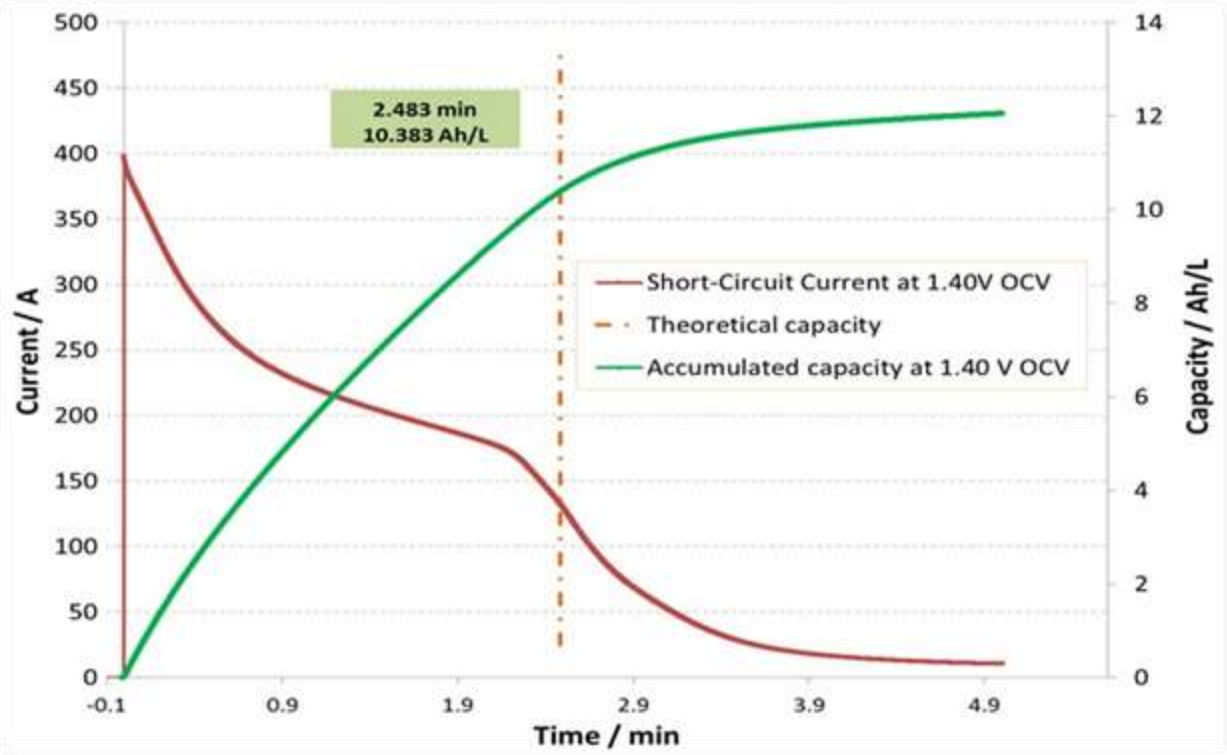
https://www.youtube.com/watch?v=uyuiWywTL8Q http://www.e2news.com/news/articleView.html?idxno=200025

No thermal runaway

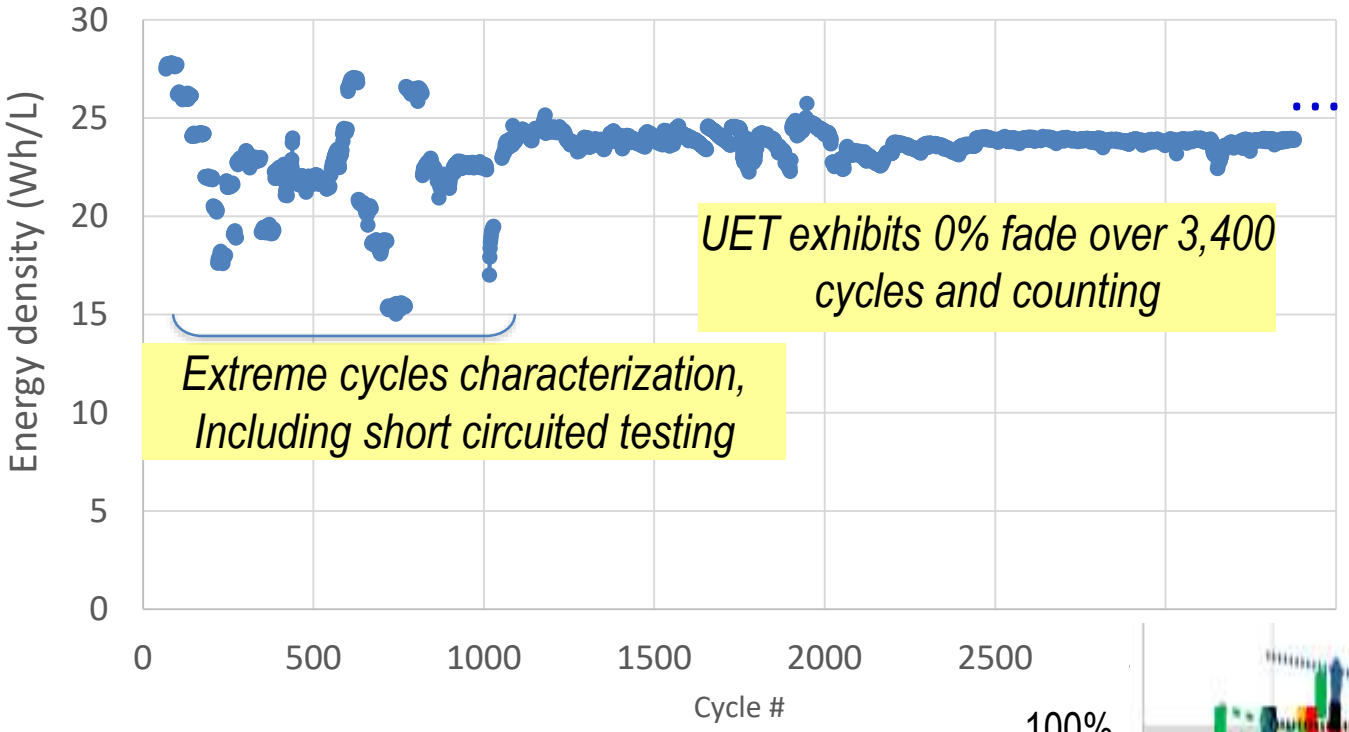


- ✓ Shorted cell stack produces no lasting damage
- ✓ No spontaneous reactions when shorted
- ✓ Limited temperature increase
- ✓ Justified simplified cooling

- 9.1 °C increase in surface temperature was measured after 29 minutes during an intentional short-circuit at full charge
- At fully charged, mixing of electrolytes would raise temperature less than 20°C.



Proved no or negligible degradation over a long life

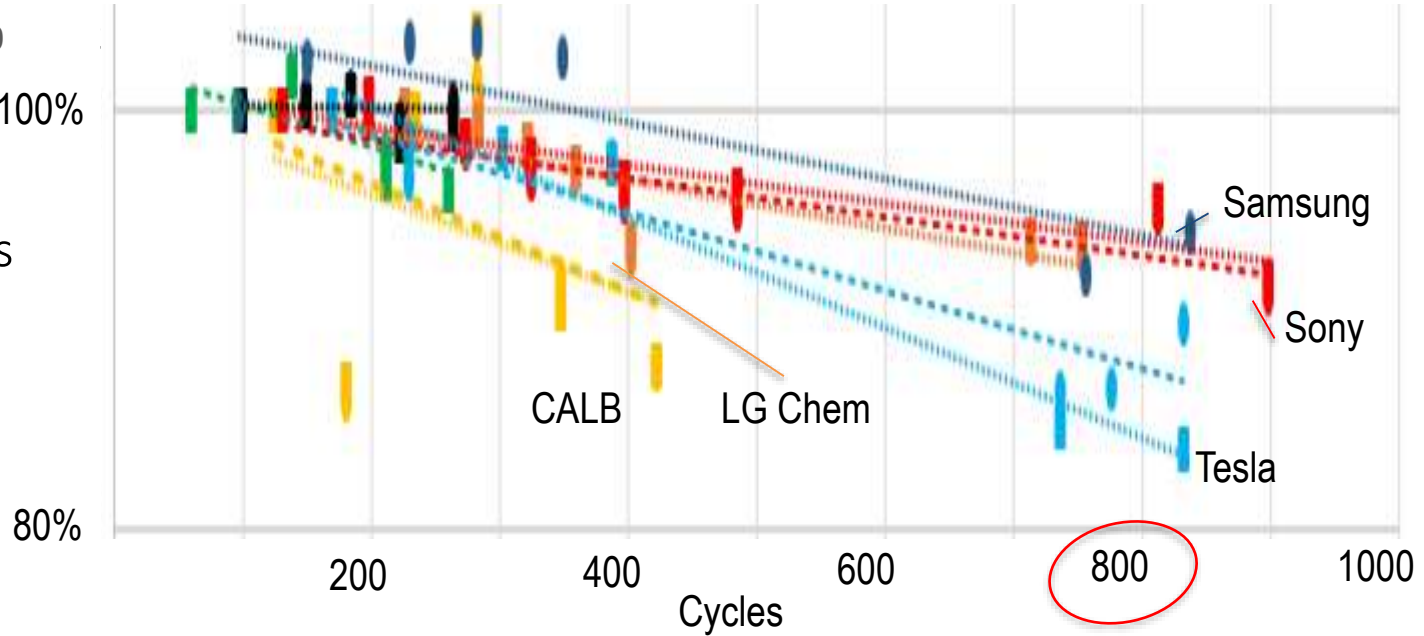


… 100% access to rated capacity, with unlimited cycles (over 12,000 cycles achieved under 100%SOC

ARENA ITP Report: Ongoing Battery Testing

***Source**: http://batterytestcentre.com.au/wp-content/uploads/2017/07/Battery-Testing-Report-November-2017-2.pdf*

- Li-ion, Pb-acid degrading in capacity, even under developer' recommended SOC ranges
- Typically 70~80% of rated at the end of life, partial access to rated capacity



Fully recyclable

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

Electrolyte (2 options)
- 100% reusable (no decay) for next ReFlex™
- 100% Vanadium recycling & reused for other purposes

Stacks (separate components)
- Plastics
- Painted Steel & Copper
- Carbon

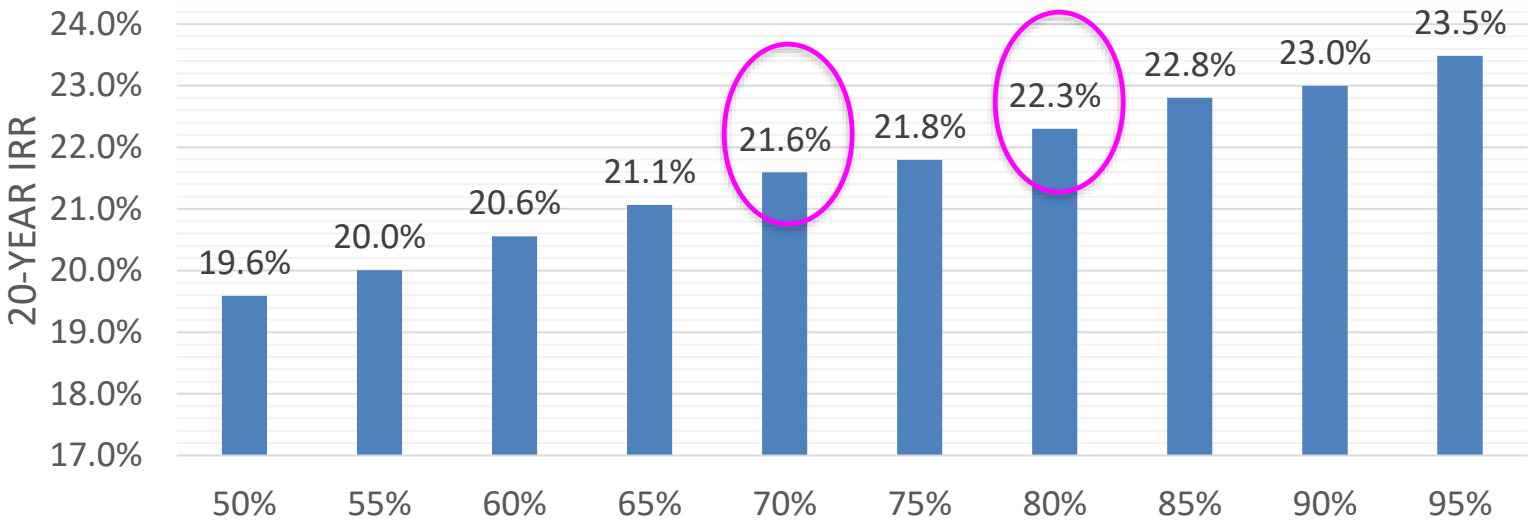
Plastics
- Tanks
- Piping
- Other

Full recycling or reuse of electrolytes facilitates leasing electrolytes, reducing CapEx at the up-front and conserving vanadium resources

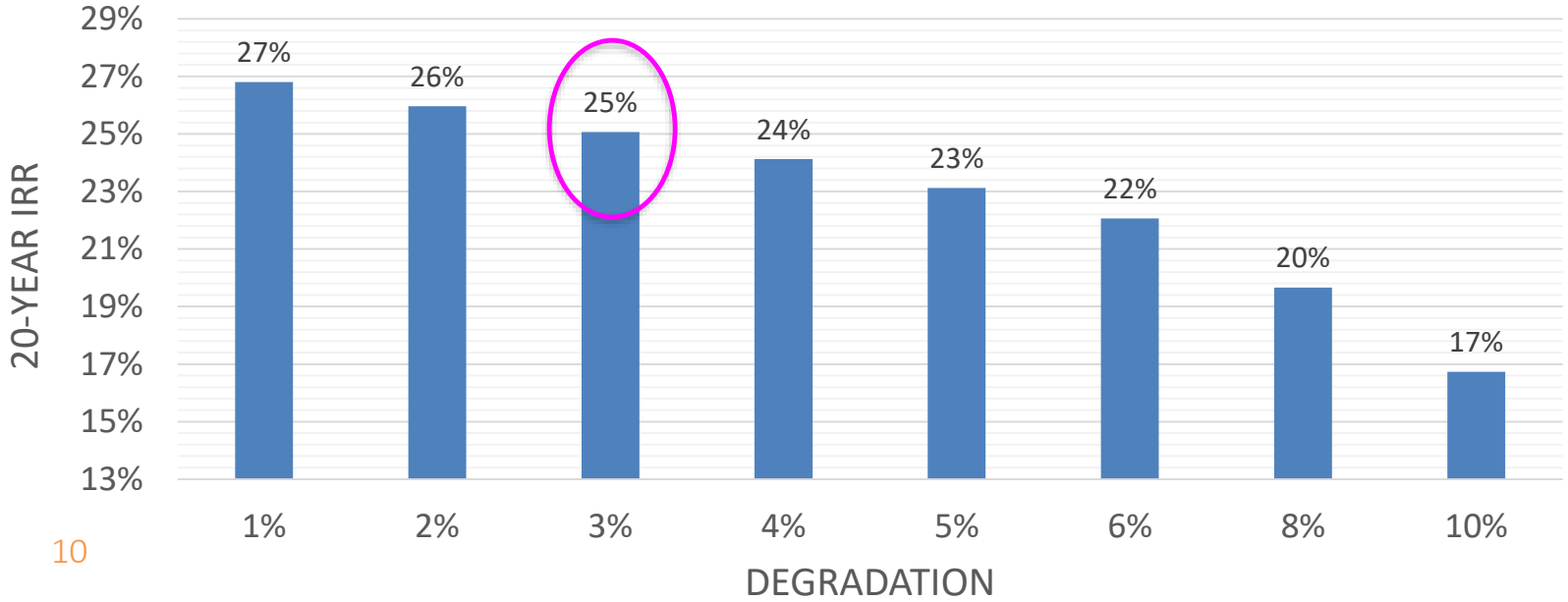
Competitive value propositions

Case Study: xxx
Location: CA
Tariff: PG&E E-20
System Size: 125 kW / 450 kW ESS
Incentives: SGIP + MACRS
System Installed Cost: $550/kWh
Replacement: Yr. 10 @ 70% original CAPEX

20-Year IRR vs. Battery Efficiency



20-Year IRR vs. Degradation



Economic return more sensitive to degradation than efficiency

Challenges – Take money, time and efforts to establish a full industry

- Billions invested and well established industry chains in Li-ion, though most for vehicle and electronics applications.
- But limited on emerging technologies including RFB', slowing down product maturation and hindering cost reduction.

System

Modules

Stacks

Raw materials

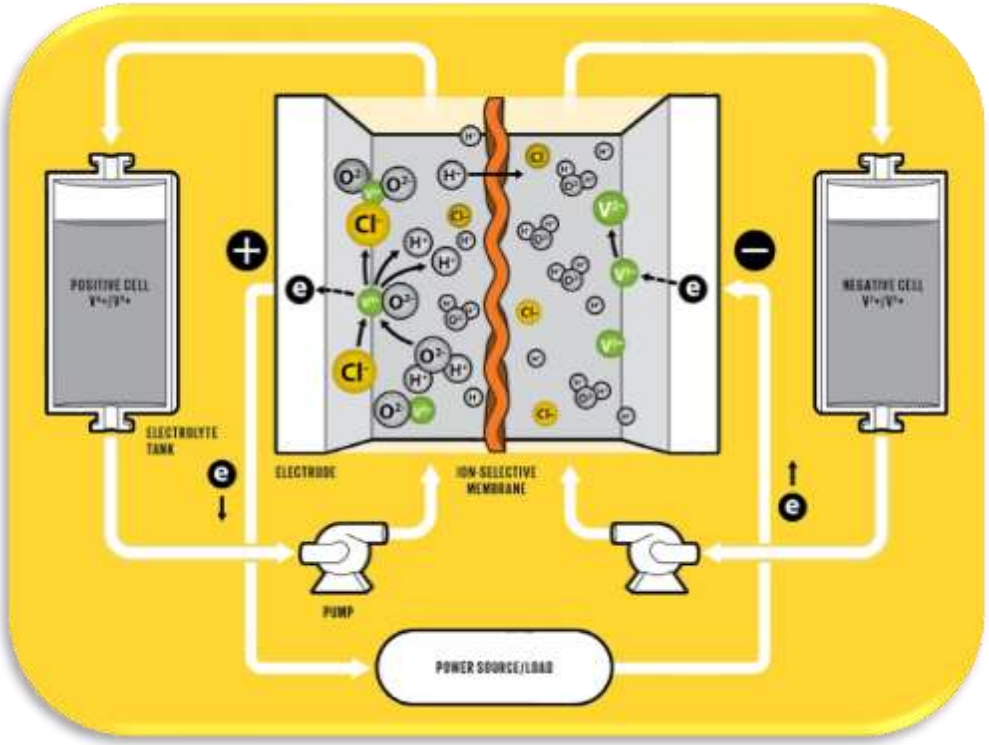
Electrolytes

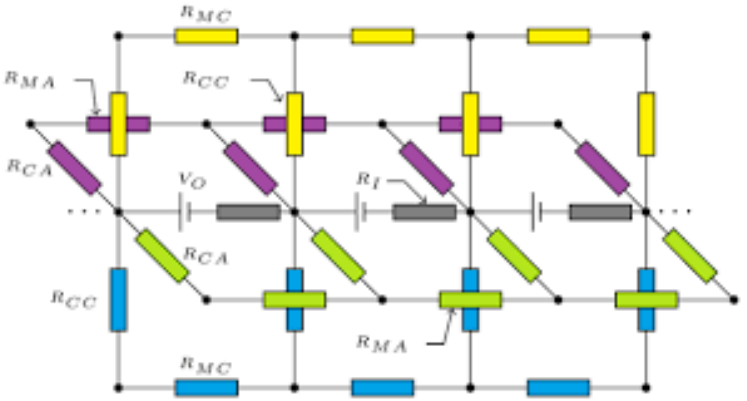
Needs of improving availability and reliability

While the new gen VRFB proven in technology, early deployments/demonstrations indicated needs of improving reliability:

- Shun current – a parasitic current causing failures of stacks
- Mis-balancing electrolytes across positive/negative side, leading to overcharged, gassing, etc.
- Lack of out of shelf reliable power electronics, such as PCS
- Lack of module redundancy, reducing system availability
- Challenges in quality control, logistics management at limited scale production

- Further improve performance and value propositions





ReFlex™ - 2nd generation product

Leverages a decade of field experience and is driven by customer needs and hard-won field experience

- Green
  - Common recyclable industrial materials
  - Vanadium sourced from waste & mines
  - No operational emissions or pollutants
- Safe
  - No risk of explosion or thermal runaway
  - No flammable materials or toxic fumes
  - Has a chemical off-switch!
- Flexible and Durable
  - Run any duty cycle without invalidating warranty
  - Maintain full performance over 20 years
  - Enables Storage-as-a-Service for any use case

ReFlex™ is 150X more available than containerization

2MWh STATIONARY STORAGE SYSTEM

Availability of a 2MWh containerized systems

- 4 containers in series deliver 2MWh
- With no redundancy, a single container failure shuts down the entire system
- A module failure probability of 1% yields a **4%** possibility the system will shut down in a given period

$p := 0.01$ Probability of failure
$n := 4$ Number of modules on site
$m := 1$ Number of failed modules required to cause site failure

$$Pr(a,b) := \frac{a!}{b!\,(a-b)!}\,p^{b}\,(1-p)^{(a-b)}$$

$$Pst := 100\sum_{i=m}^{n} Pr(n,i) = 3.94$$ % Probability of site failure

ReFlex™ Improvements:

- ✓ Over 25% higher V utilization
- ✓ 5X fewer parts
- ✓ Seamless bypass
- ✓ Eliminated shunt risk
- ✓ Surface cooling
- ✓ No electrolyte onsite fill
- ✓ 50% simpler hydraulics
- ✓ 50% lower pressure
- ✓ Fewer sensors
- ✓ Insulated enclosure

Availability of a 2MWh ReFlex™

- 60 modules arranged in 5 strings of 12 provide n+2 redundancy in delivering 2MWh
- If 3 modules fail, discharge duration will shorten 4 minutes without effecting power
- Assumes neither of the first 2 ReFlex™ are repaired before the 3rd fails
- A module failure probability of 0.2% yields only a **0.025%** possibility the system will only de-rate in the same given period

$p := 0.002$ Probability of failure
$n := 60$ Number of modules on site
$m := 3$ Number of failed modules required to cause site failure

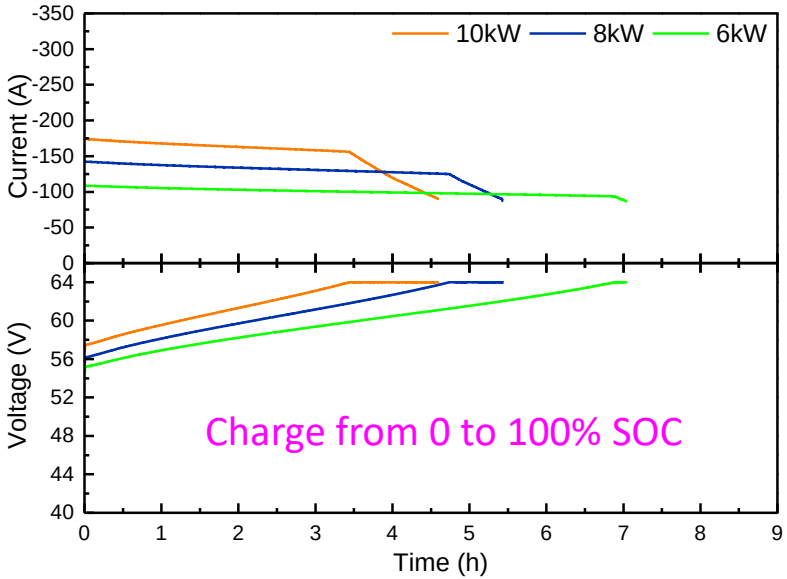
$$Pr(a,b) := \frac{a!}{b!\,(a-b)!}\,p^{b}\,(1-p)^{(a-b)}$$

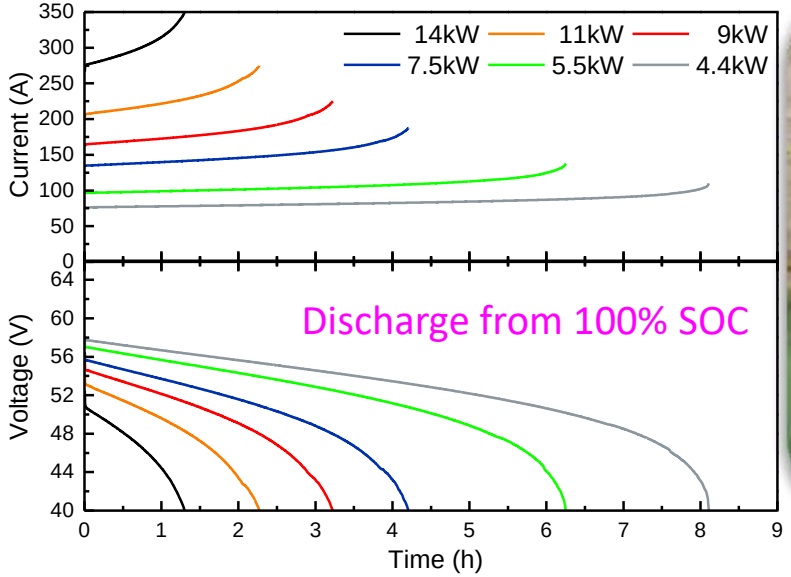
$$Pst := 100\sum_{i=m}^{n} Pr(n,i) = 0.02514$$ % Probability of site failure

Performance of ReFlex™

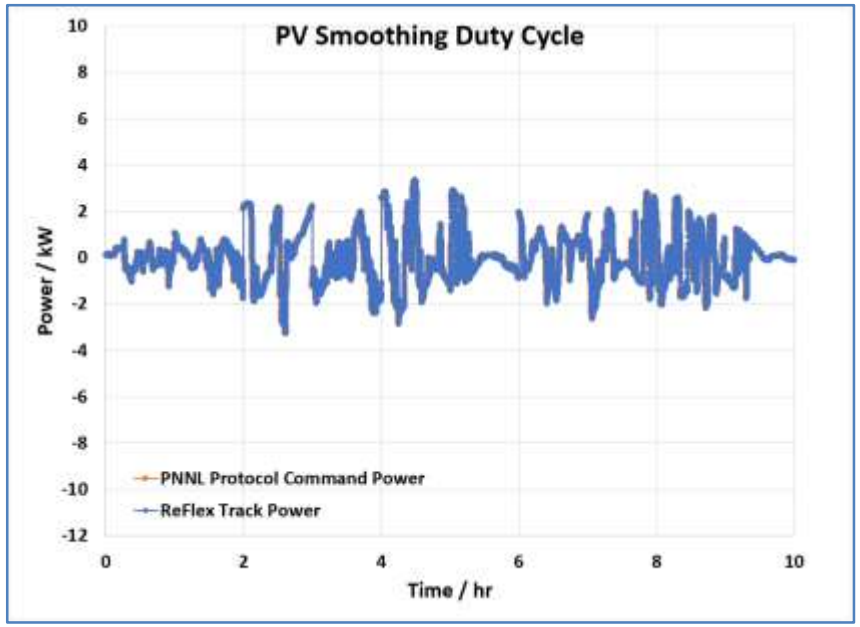
Duration	Power	Energy	DC Efficiency	AC roundtrip efficiency (including Aux consumption)
2h	11kW	22kWh	77%	68~69%
3h	9kW	27kWh	79%	69~70%
4h	7.5kW	30kWh	81%	70~71%
6h	5.5kW	33kWh	83%	70~71%
8h	4.4kW	35kWh	85%	69~70%

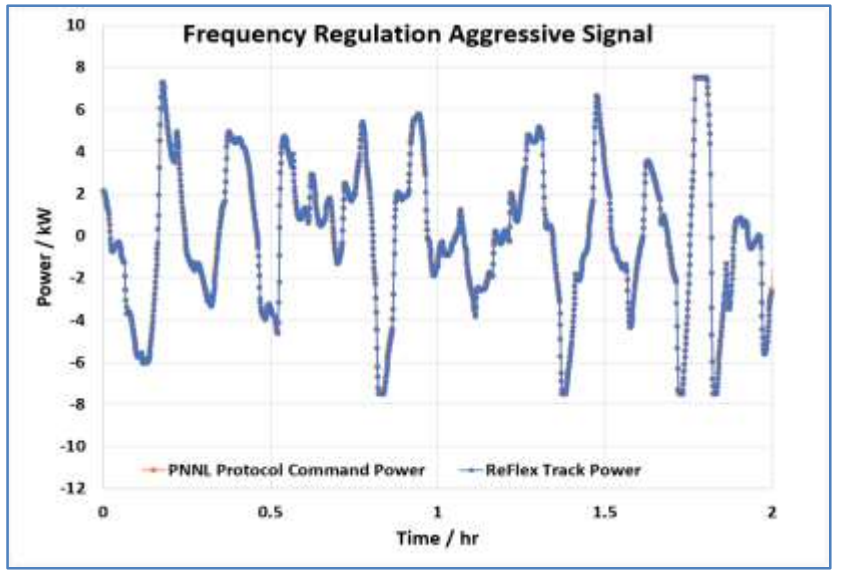
25% improvement in vanadium electrolyte utilization!!!

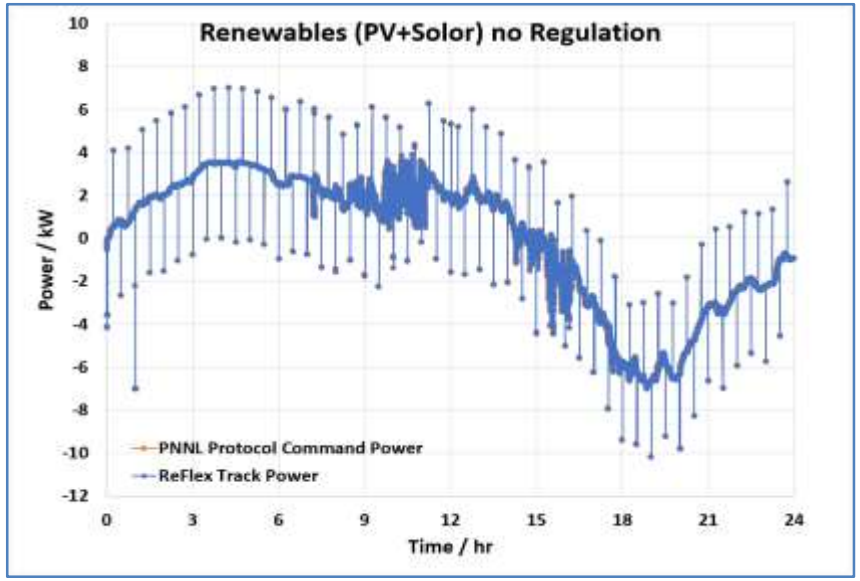


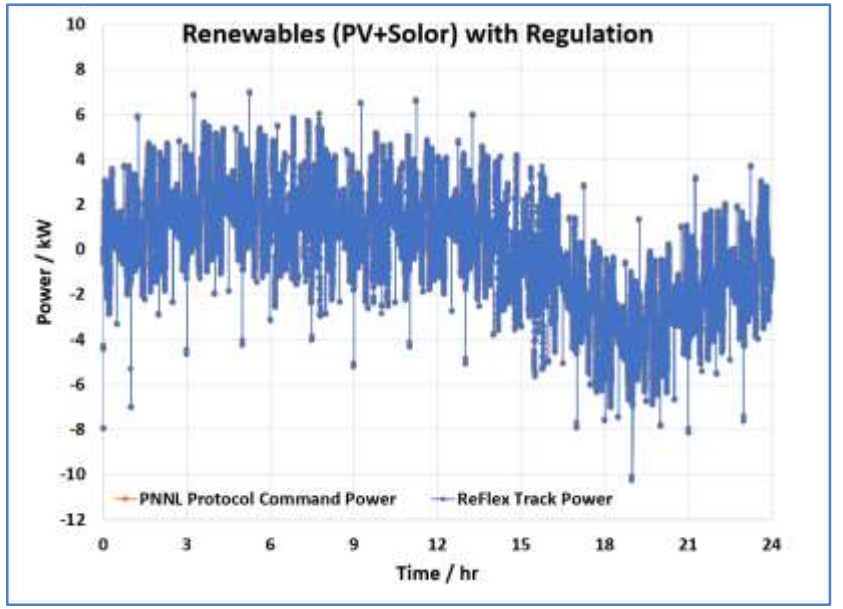


Application case test (PNNL/SNL test protocols)

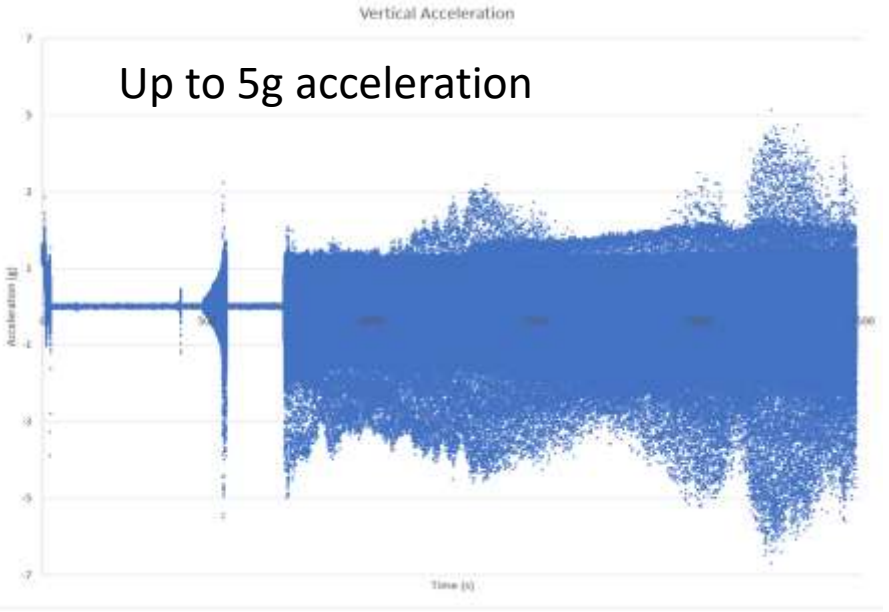








Being certified: UL, DOT, …



Features of ReFlex™

- ✓ Compact foot print
- ✓ Short & long duration
- ✓ Zero degradation
- ✓ Unlimited cycles
- ✓ 20+ Year lifetime
- ✓ Non-flammable
- ✓ No thermal runaway
- ✓ Shipped ready to run
- ✓ Highly recyclable

Acknowledgement

- US DOE OE Energy Storage Program, Dr. Imre Gyuk
- Pacific Northwest National Lab, Sandia National Lab
- Industry partners: BNM, RKP, Chemours, etc.