New Generation VRFB: Field Experience and Value Propositions

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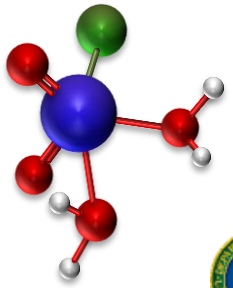
U.S.-South Africa Workshop on Energy Storage Standards, Conformance and Technology

February 21, Johannesburg

UniEnergy Technologies (UET)

A Leading 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

Investments:

BNM BOLONG NEW MATERIALS

ORIX

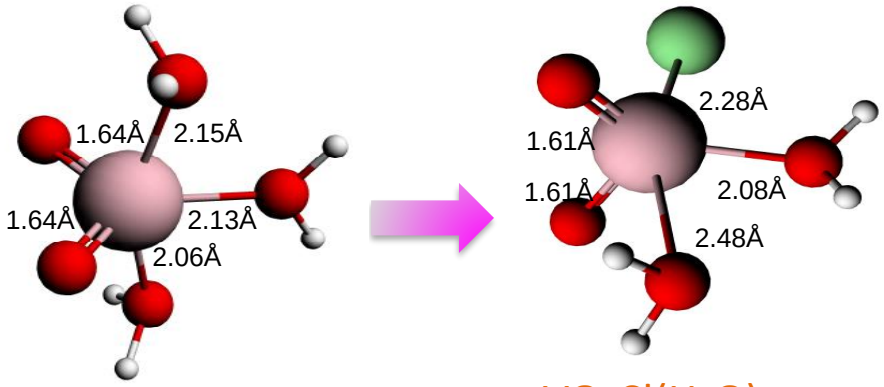
INNOVATION + QUALITY + PARTNERSHIPS

EcoPartners:

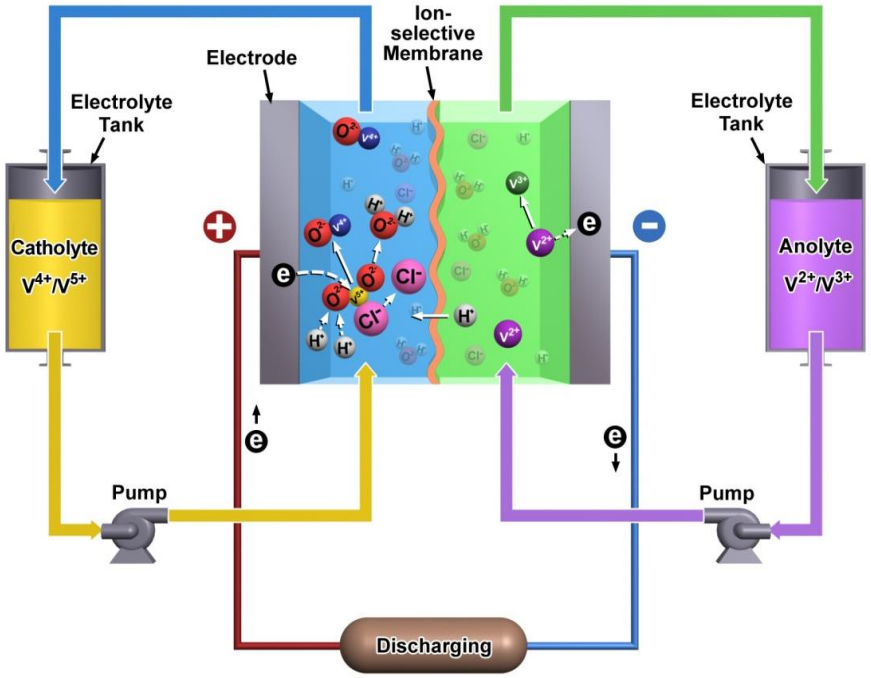
10 years stack field experience, ramping up GW production capacity

Electrolyte production: 1.5 GWh/yr capacity

New generation vanadium redox flow battery (VRFB)



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



Developed at PNNL and optimized at UET. Won the highest US Government Award for Excellence in Technology Transfer and 2017 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
  - ➢ More corrosive, high chloride activity

Advancing new gen VRFB products meeting market demands

- Scaling up
- Field demonstration
- Optimization through value engineering
- Building a chain through partnerships

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 String Configurations
- High System Availability
- Industrial Design

2020

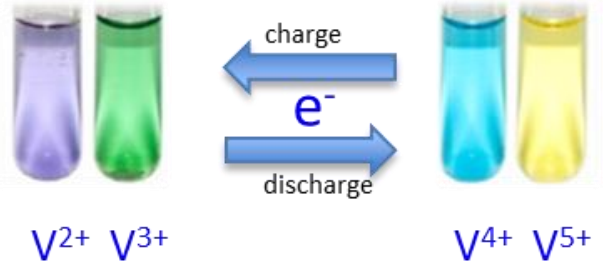
ELECTRICITY WAREHOUSING
- E'lyte Leasing
- Storage-as-a-Service

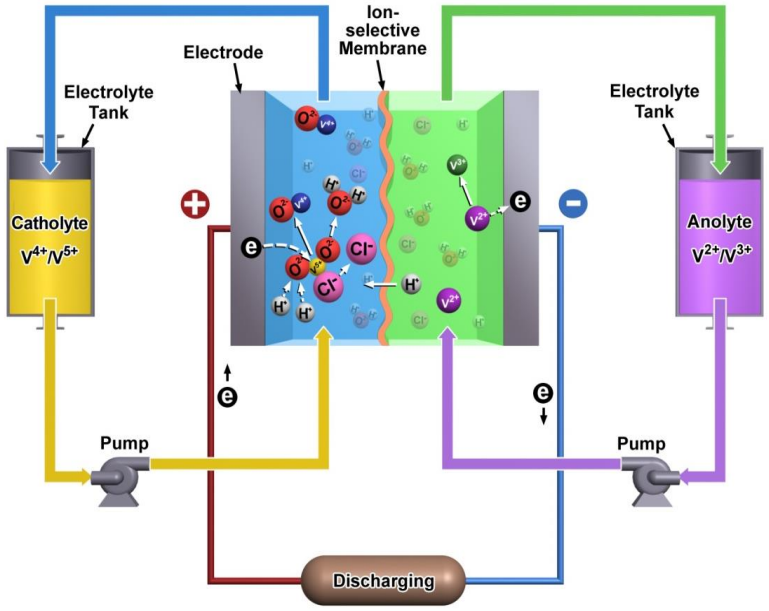
Up to MW scale deployments around the globe

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

Great learnings from early deployments!!!

Highly modulized, plug-play system products

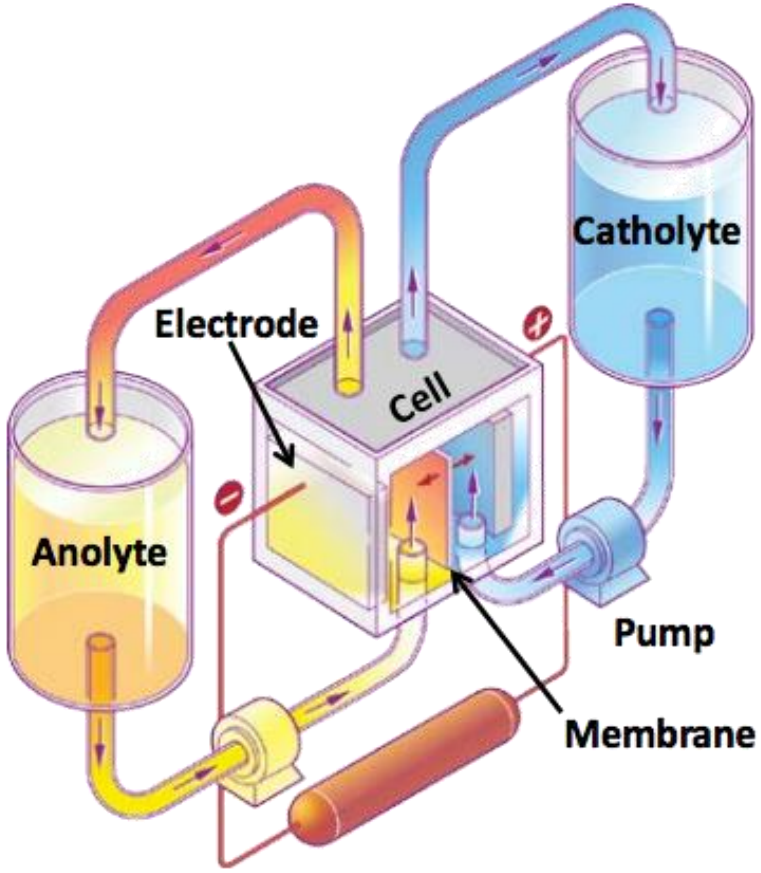




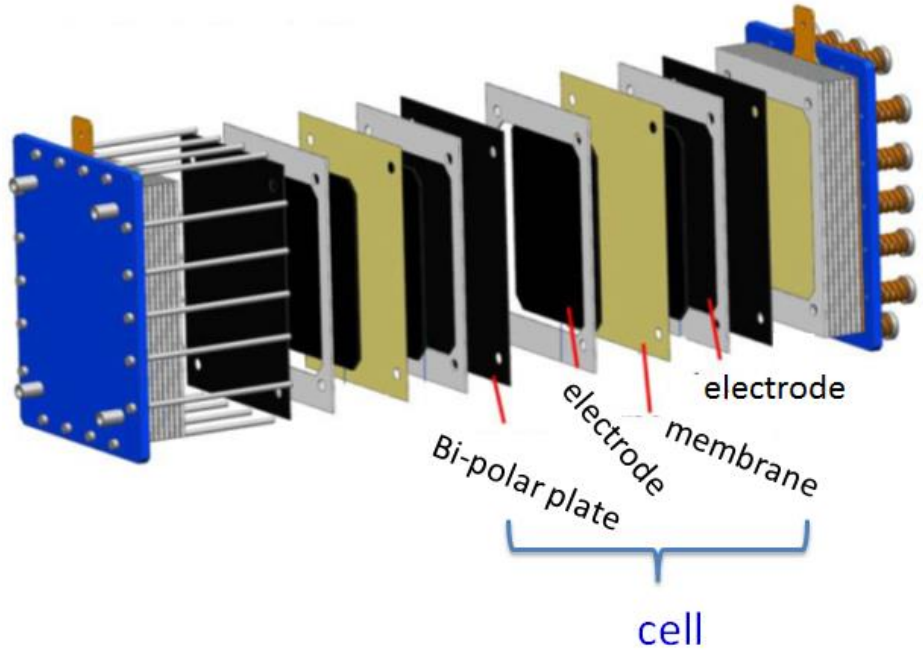
- ✓ Compact foot print
- ✓ Short & long duration
- ✓ Zero degradation
- ✓ Unlimited cycles
- ✓ 20+ Year lifetime
- ✓ Non-flammable
- ✓ No thermal runaway
- ✓ Shipped ready to run
- ✓ Highly recyclable

ReFlex™

VRFB' developed and built specifically for utility applications



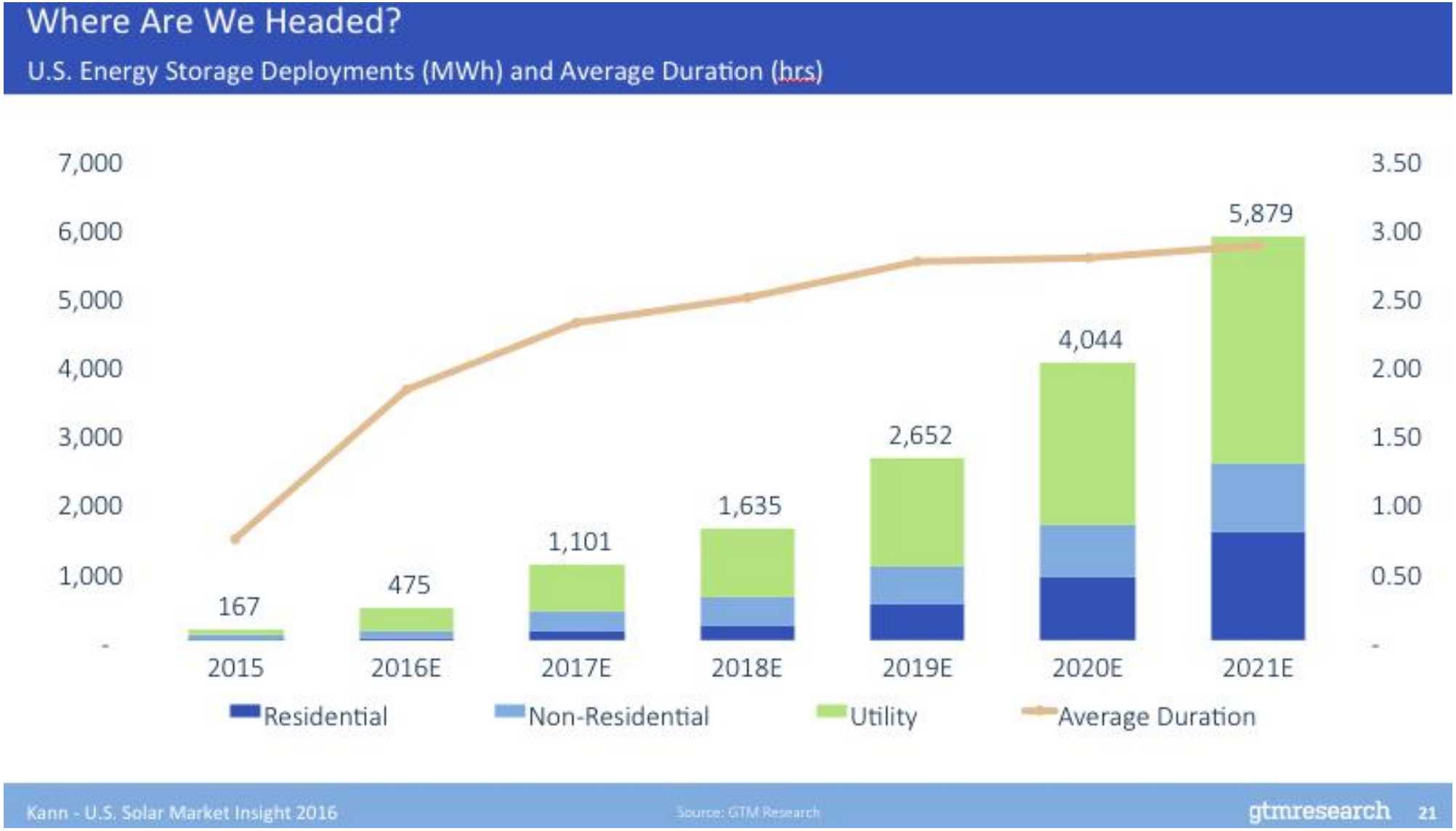
- Simple for big, each stack, from kWs to 10' kWs
- kW & kWh decoupled, longer durations by adding only electrolytes, self-discharge limited to only volumes in stacks
- "Inert" electrodes – no structural changes or strain/stress buildup



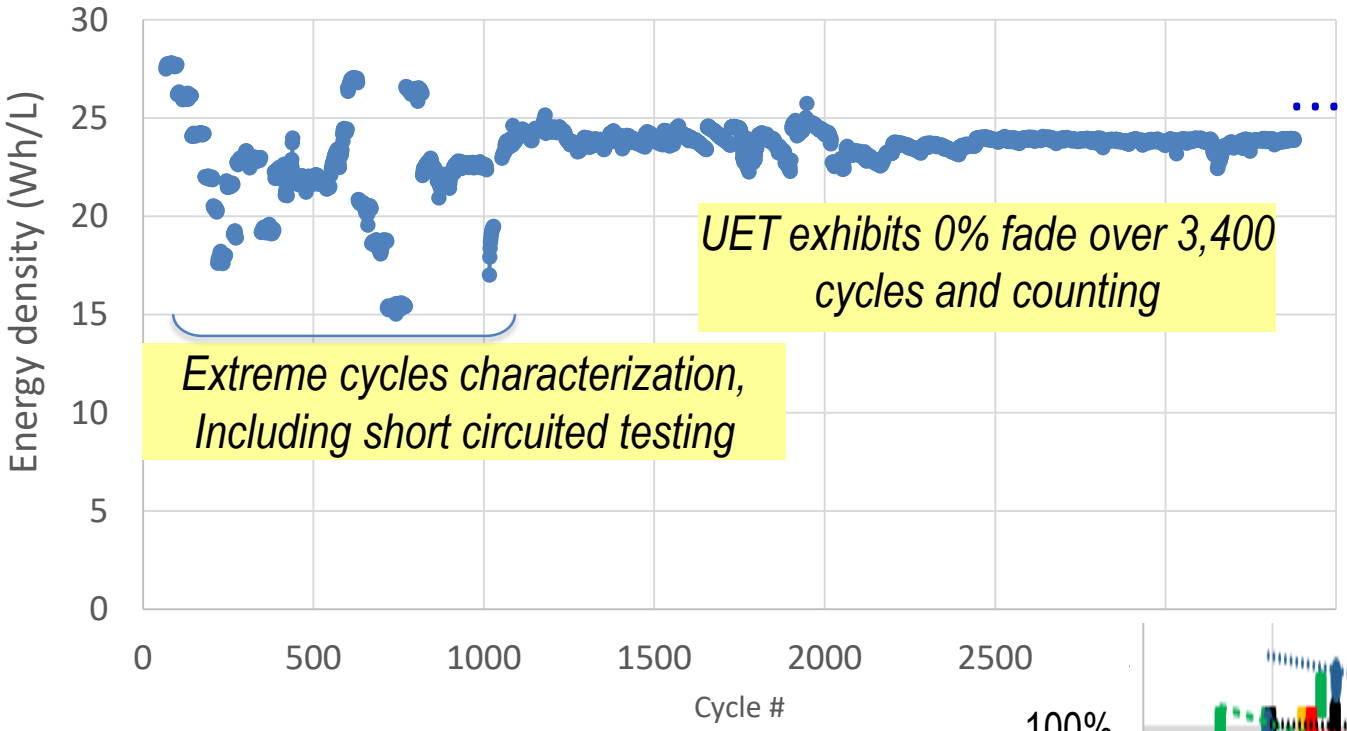
VRFB becoming the leader among emerging technologies

Over 100 projects, >1GWh deployed; more under construction

Meeting demands covering longer *duration* to better value propositions



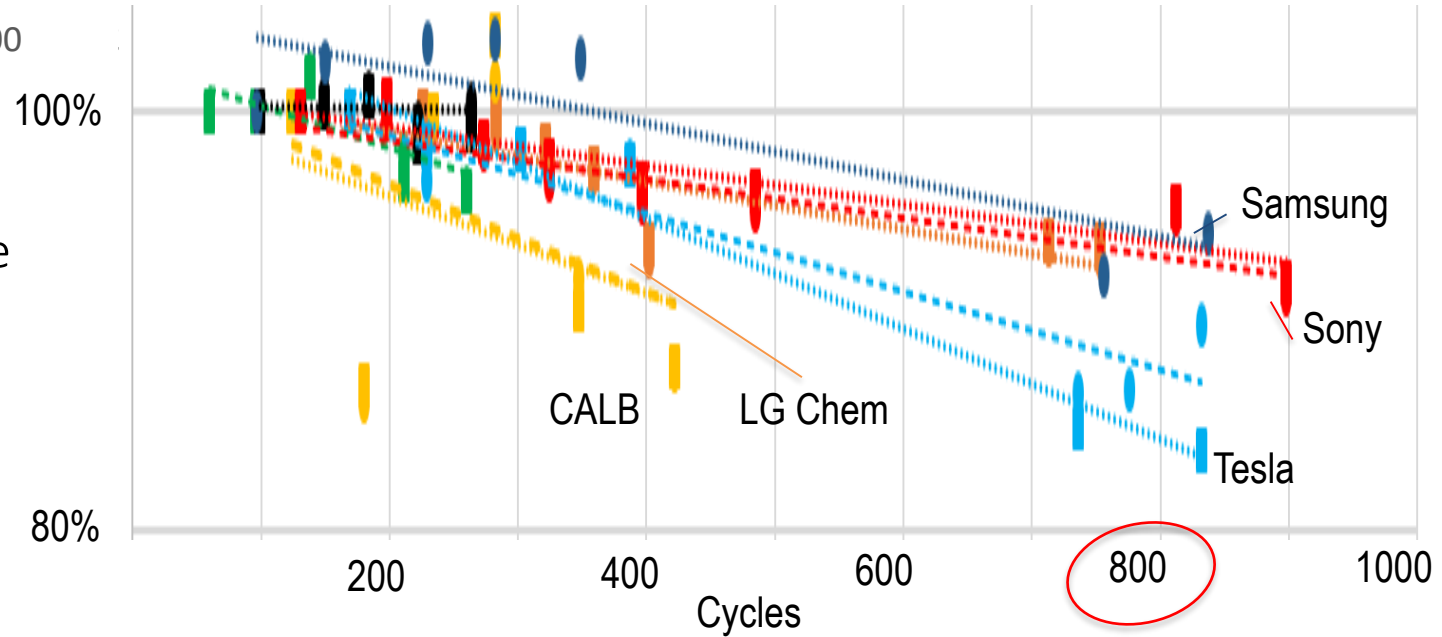
No or negligible degradation over life



… 100% access to rated capacity

ARENA ITP Report: Ongoing Battery Testing

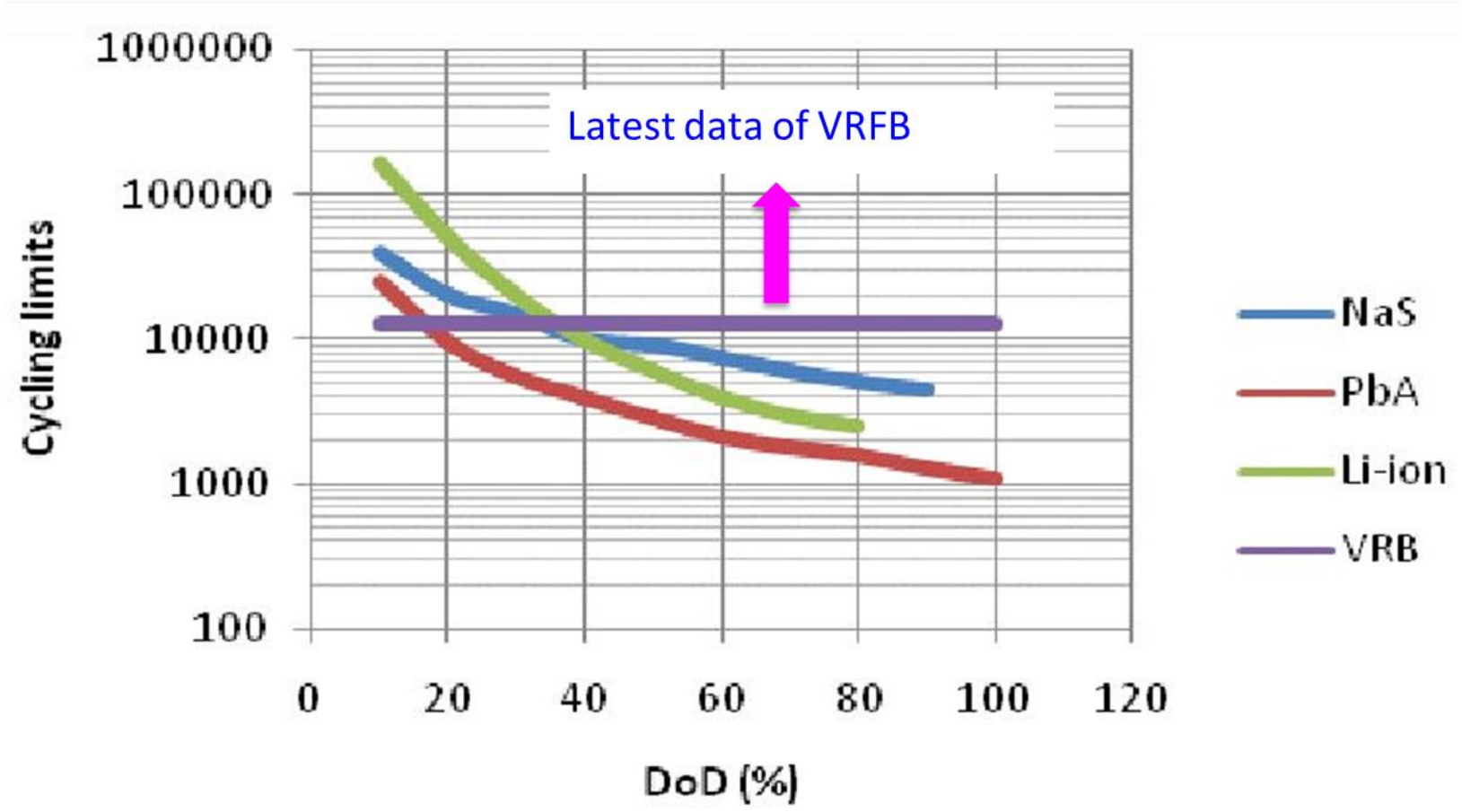
***Source**: http://batterytestcentre.com.au/wp-content/uploads/2017/07/Battery-Testing-Report-November-2017-2.pdf*



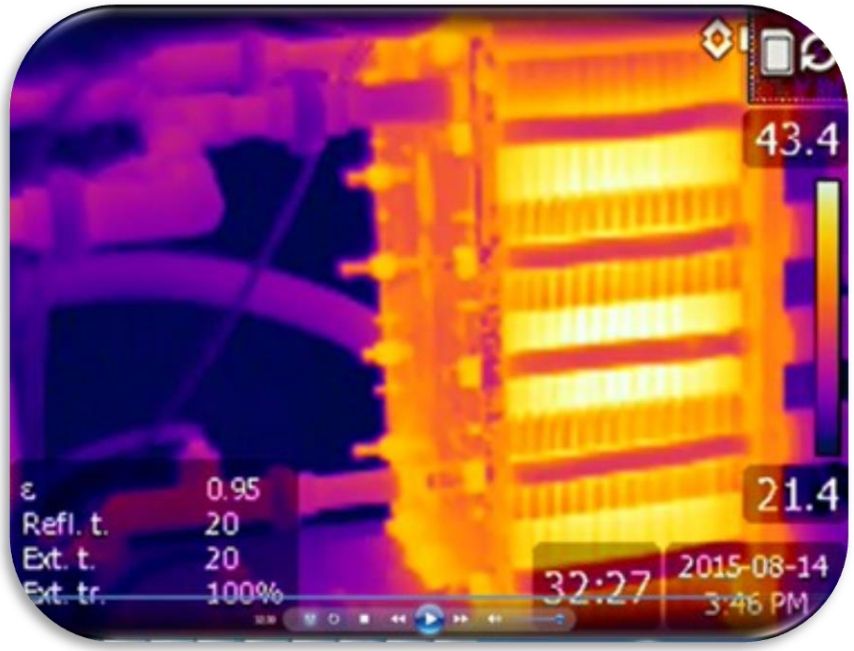
- Li-ion, Pb-acid degrading in capacity, even under developer' recommended SOC range
- Typically 70~80% of rated at the end of life, partial access to rated capacity

Unlimited cyclability and a long life

- Over 12,000 cycles achieved over a 6 yrs test at 100% SOC; 275,000 cycles in the field at varied SOC
- Life limited by shelf life, ≥20years

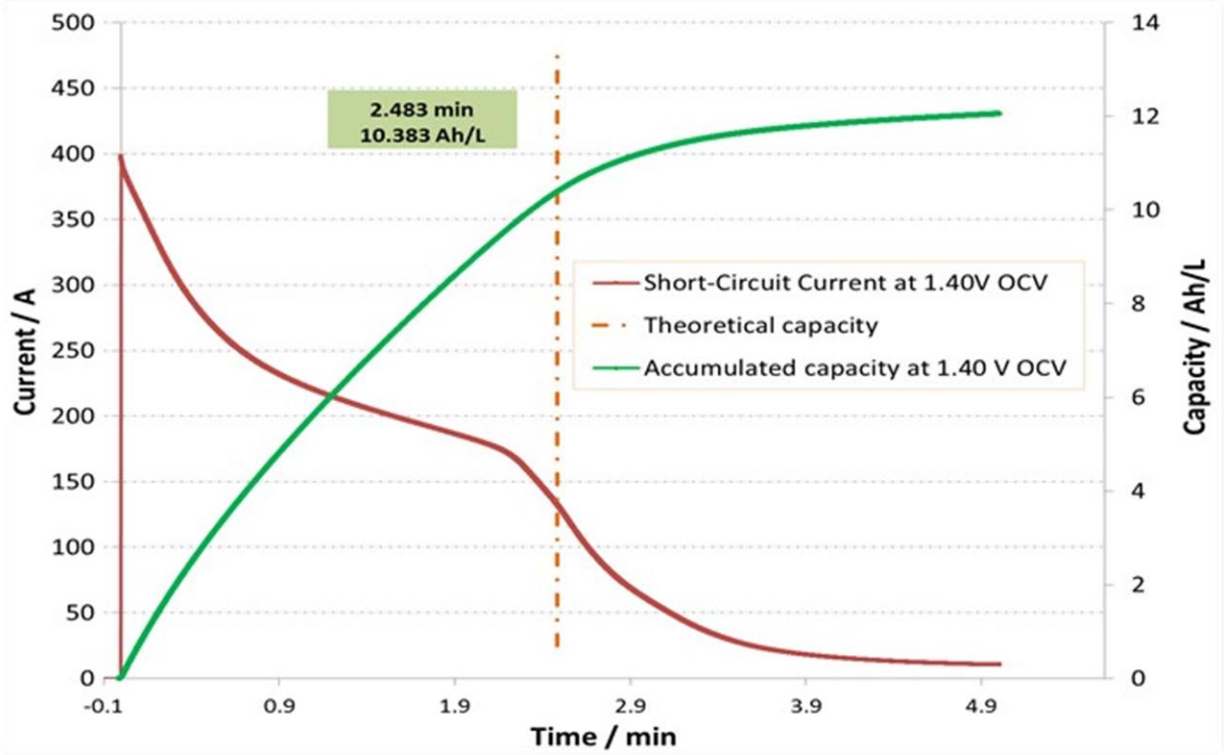


No thermal runaway



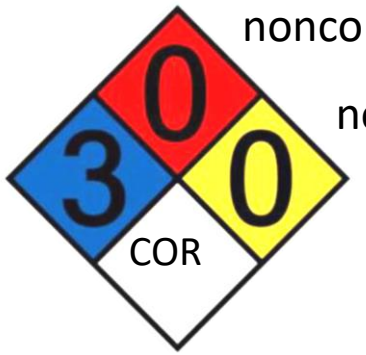
- Shorted cell stack produces no lasting damage
- No spontaneous reactions when shorted
- Limited temperature increase
- Justified simplified cooling, e.g. with heat exchanger

- 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.



Inherently safe

No fire accident reported for VRFB' !!!



noncombustible

nonreactive

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

New gen VRFB approved by NY Fire Dept, after only Pd-acid

A number of 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***

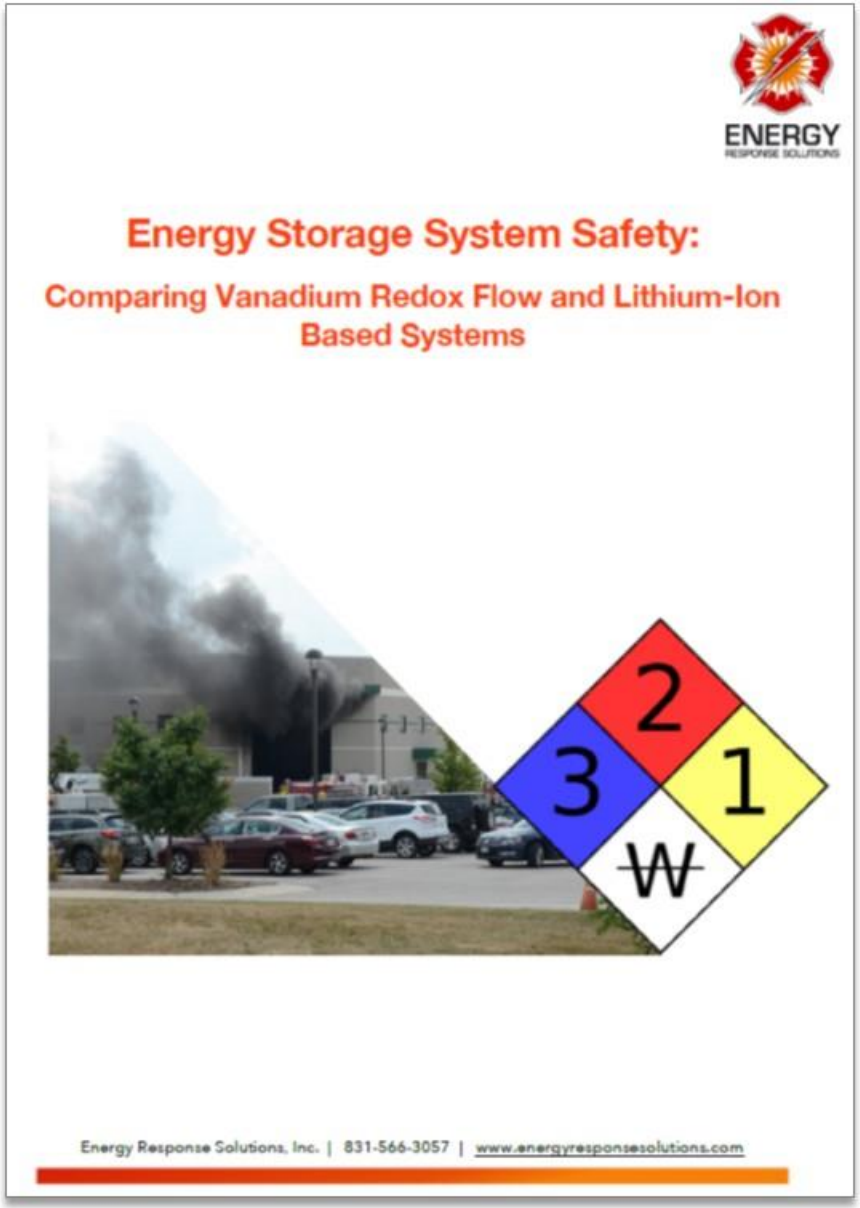
In Nov 2017, this lithium battery with state-of-the-art fire protection technology failed during commissioning, resulting in release of toxic fumes, closing freeways and evacuating citizens

Safety critical to utility applications as well!

SUMMARY

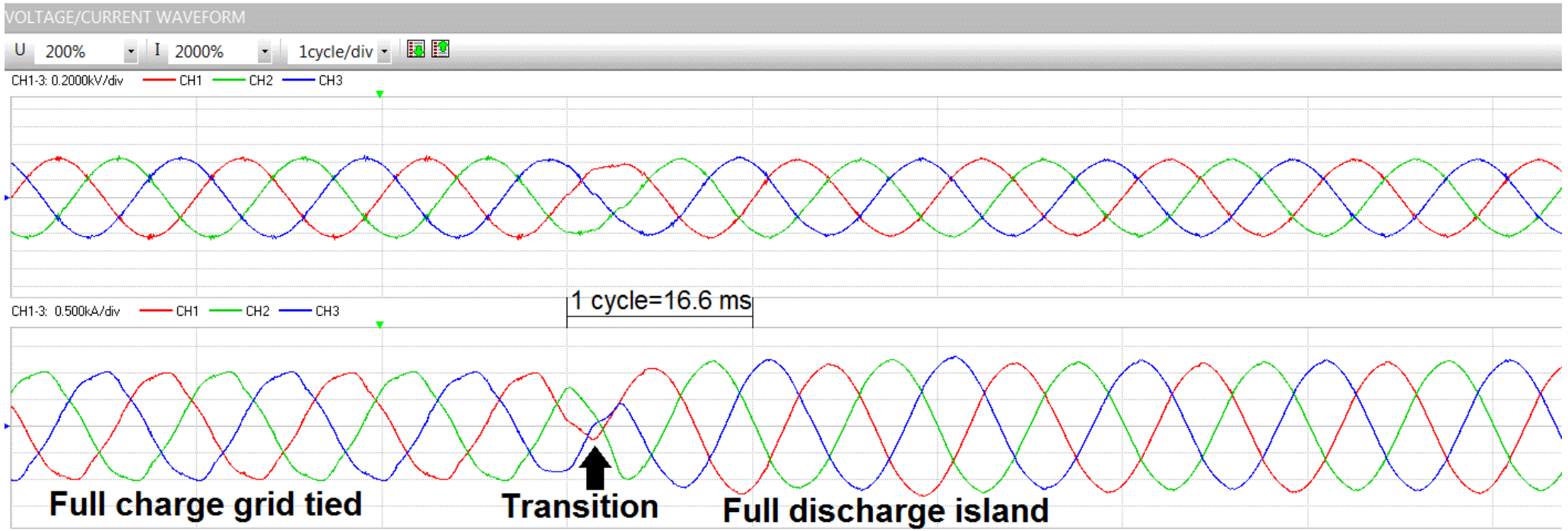
- Vanadium flow battery systems offer significant safety advantages relative to lithium-ion in the areas of short-circuit fault, arc-flash/blast, “stranded” energy, fire suppression, and deflagration. This can lead to a streamlined review and approval process for all stakeholders involved.
- When comparing available ESS technologies, many factors will affect the final system choice. From a safety perspective, significant questions remain unanswered when it comes to protecting Li-ion batteries from thermal runaway, even more so in an occupied structure. If codes continue developing along their current trajectory, many structures may not be suitable without significant modifications. As one designer of naval-based ESS explained, “A submarine must have a significantly higher level of safety than a land based structure, as escape is impossible”.. However, when looking at ESS installations inside high-rise apartment dwellings, these structures may be compared to submarines standing on end in terms of life hazard profiles

Risk	Lithium	Lead Acid	NaS	Vanadium
Voltage	X	X	X	
Arc-Flash/Blast	X	X	X	
Toxicity	X	X	X	X
Fire	X	X	X	
Thermal Runaway	X	X		
Stranded Energy	X	X	X	



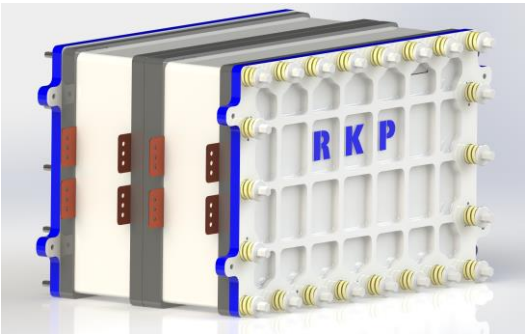
Advancement in integration

Successful Implementation of Islanding, realizing smooth transition



High Residual Value supports 100% Recycling

Plastics
- Tanks
- Piping
- Other



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

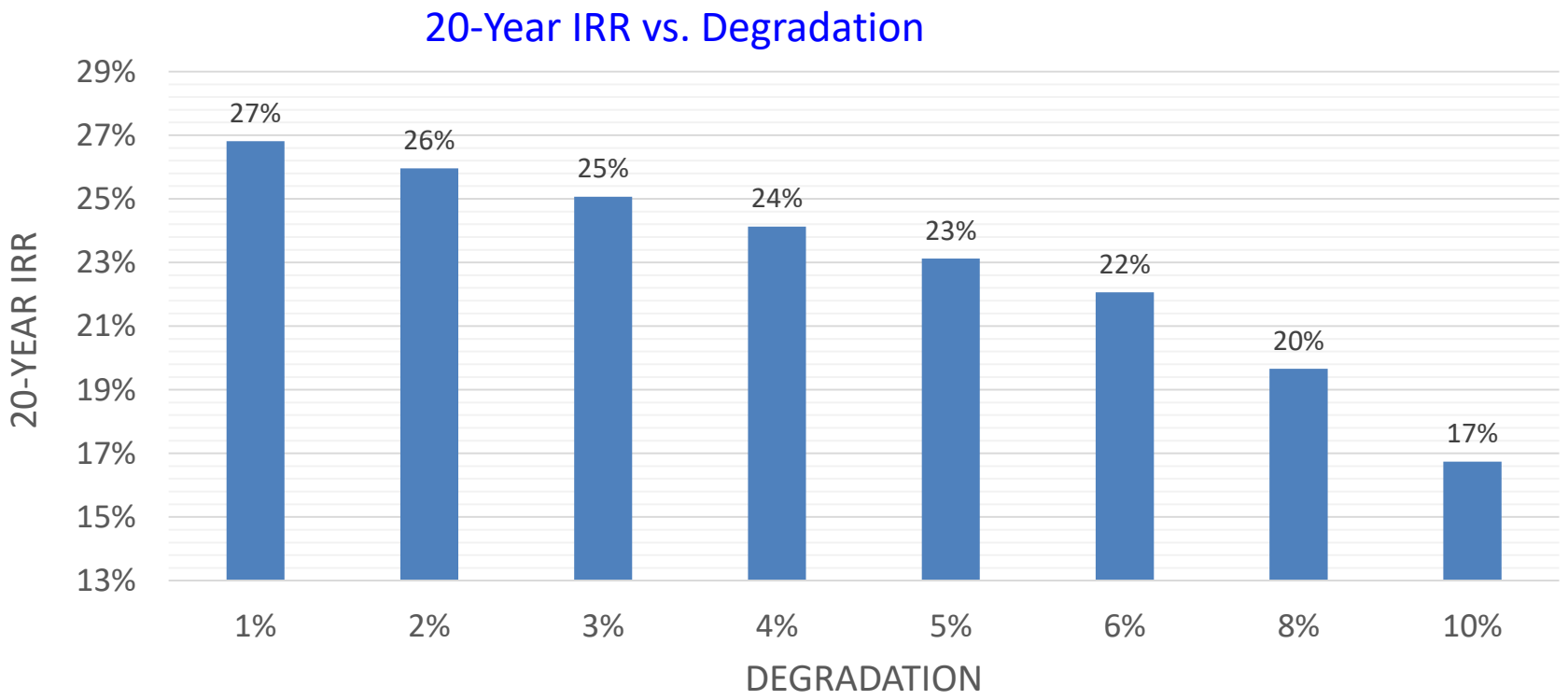
Steel Shell & BOP
- Steel shell
- Coated Metal frames
- Pumps
- Air Handler
- Electronics

Electrolyte (2 options)
1. 100% reusable (no decay) for next ReFlex™
2. 100% Vanadium recycling & reused for other purposes

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

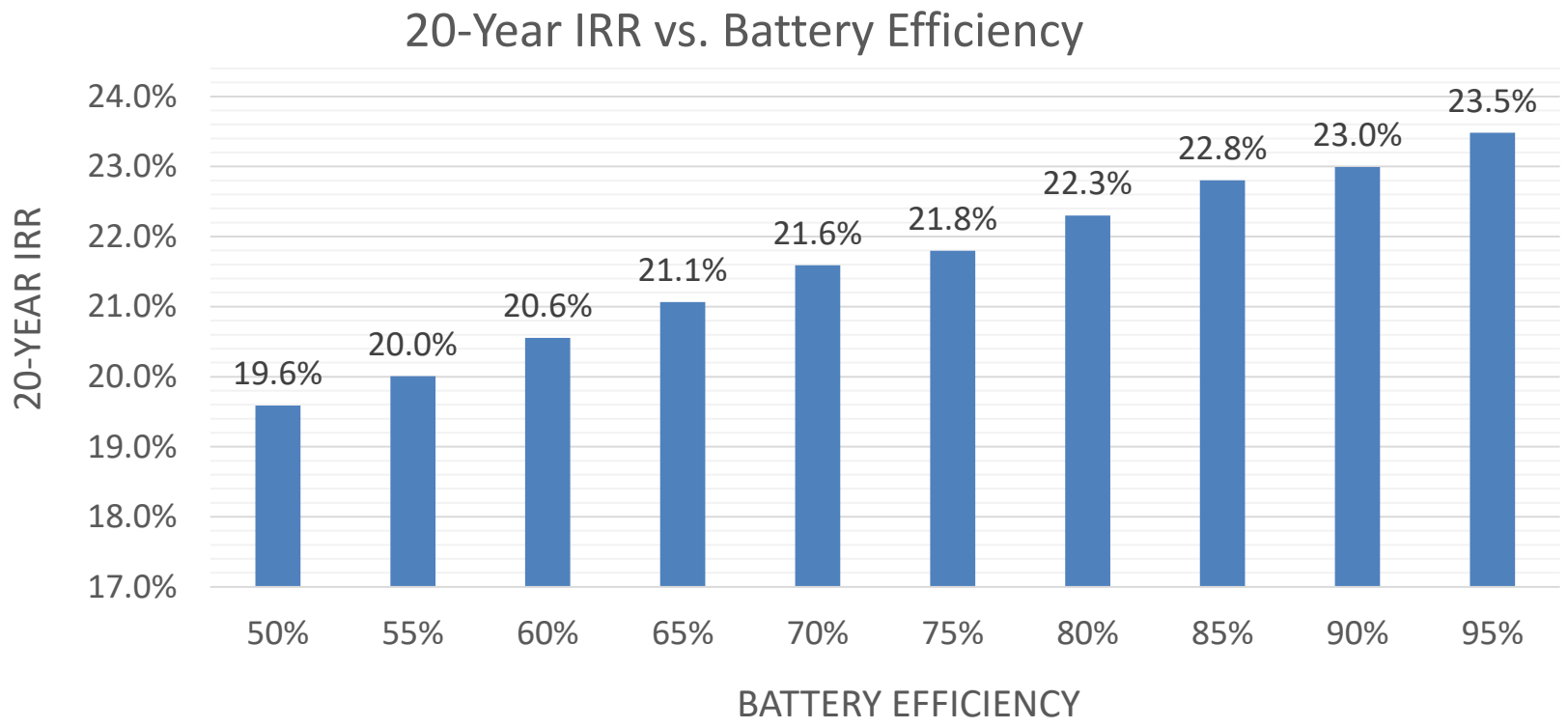
Economic return very sensitive to degradation



Competitive value propositions

Economic return less sensitive to efficiency

VRFB: 80~85% stack efficiency
70~75 AC system efficiency



Need to establish a full industry chain

- Billions invested and well established industry chains in Li-ion, though most for vehicle and electronics applications;
- Leading dramatic cost reduction in the past decade.
- But as emerging technologies, RFB' have yet established a full industry chain that is critical to further technology maturation and cost reduction.

System

Modules

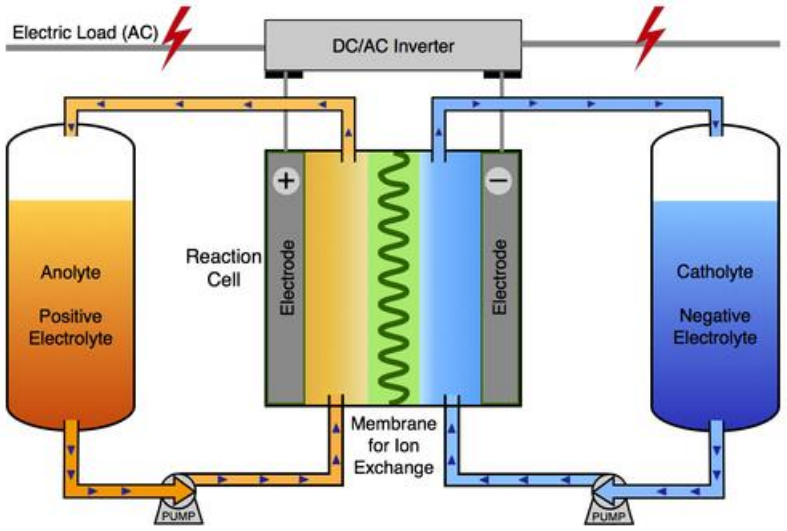
Stacks

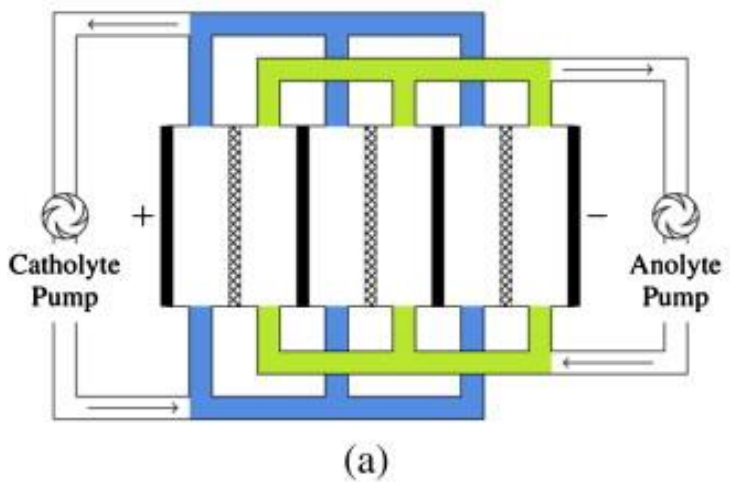
Raw materials

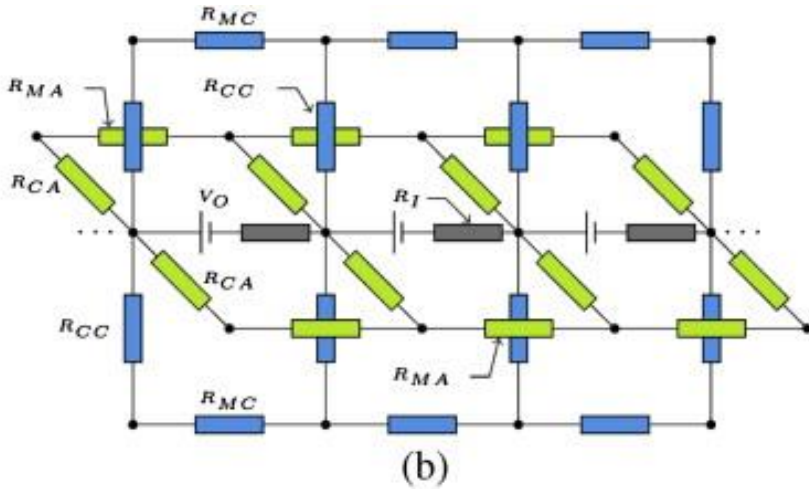
Electrolytes

Further improvement in value engineering

- **Shunt current** – parasitic current flowing through liquid-connected circuit, leading to potential materials and structural failures in stacks and pipes







Kim, et al., J Power Sources, 237, 1, 300.

- **Mass balancing** during operation – driven by electrochemical potential difference, mass (H^+, other ions too) transports through the membrane leading to mass-imbalance across anode and cathode and potential gassing and other damages, if not well managed during operation.

https://wernerantweiler.ca/blog.php?item=2014-09-28

Streamlining deployments and conformance with utilities

- Lack of standardization, as an emerging industry

  Some standards on batteries, power connection, integration, etc., BUT limited

- Not only batteries, but power conversion, integration including software all important to the applications

Details will be added

Thank You