High-Performance Vanadium Flow Battery (VFB) Electrolyte and Cell Stacks are the Key to Low Cost VFB Systems

IFBF Meeting| 06.26.25

Mike L. Perry/ Technical Fellow

Who is Storion Energy

Stryten's scaled battery manufacturing expertise, complemented by Largo's direct vanadium supply chain & strong VRFB patent position combine to form Storion Energy

STRYTEN ENERGY

U.S.-Based Energy Storage Manufacturer

Technology agnostic, large-scale manufacturing of the right battery technology and the right cost for each application.

+

STORION ENERGY

Established February 2025

LARGO

Vanadium (Critical Mineral) Sourcing, Patented Purification Technology

$160mm (CAD) Market Cap

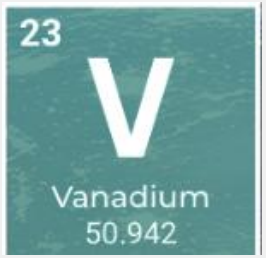
20 Year Est. Total Mine Life

10,396 Tonnes V_2O_5 Sold in 2023

6.1MWh VRFB Deployment in 2023

Vanadium is Uniquely Well-Suited for LDES

Earth-Abundant



- Fifth most abundant transition metal in the Earth's crust
- Vanadium reserve base to support > 10 TWh of VFB
- Similar deposit levels to Cu, Ni
  - With lower mining capacity

https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust
www.doi.org/10.1016/j.jpowsour.2010.08.056

VFBs are Real-World Proven

- + 500MWhrs in single installations
- High Response Time
- Unparalleled Lifetime – 20+ Years
- Unmatched Cycling capability (100%DoD with >95% Capacity retention)
- > 99% Operability

www.doi.org/10.1016/j.est.2024.111790
https://pv-magazine-usa.com/2023/07/11/sumitomo-reveals-testing-results-of-redox-flow-battery-project-in-california/,
https://www.ess-news.com/2025/03/03/sumitomo-electric-launches-vanadium-redox-flow-battery-with-30-year-lifespan/

Highly Recyclable

Flexible Options at End of Life (EOL)

- Renew Lease
- Return Electrolyte for Recycling

99⁺% vanadium recovery at EOL = strong candidate for leasing.

Circular Economy of Lead Batteries - Battery Council International

Key Attributes of VFBs

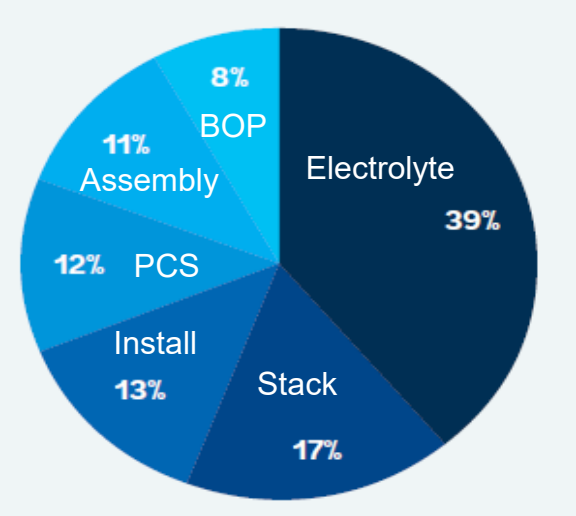
Most mature RFB chemistry, due to multiple inherent attractive attributes:

- Single species enables simple crossover-mitigation strategies
- Excellent stability of active materials
  - No capacity losses due to V-species degradation within controlled temperature range
- Relatively facile redox kinetics on carbon electrodes
- OCV is ≈ 1.55 V (at conventional V concentrations)
  - Located in aqueous-stability window (minimal HER)
- Decent solubility (≈ 1.6 M)
  - Theoretical energy density of ≈ 30 Wh/L
- Unlimited electrolyte recyclability
  - Reuse in VRFBs, or convert back to commodity product (e.g., V2O5)

Capital Cost of VFB Systems

Lower costs are required to be competitive with Li-ion batteries (even for LDES)

VFB Cost Break Down for a 4- to 6-h battery*



From: World Bank Group, "Vanadium battery storage report," (2024)

* Electrolyte costs can be as high as 80% for 10+ hour batteries

VRFB Systems at a present-day disadvantage:

100 MW, 10 Hour Installed BESS Costs	
VFB	**LFP System**
$446/kWh	**$379/kWh**

Source: A. Hollas, *et.al.*, "Adoption Readiness Level Assessment of RFBs," PNNL-36780 (2024)

This disadvantage can be retired by**:

- **Economies of scale**
- **Technological advancements**
- **Lower electrolyte pricing**
- **Manufacturing-efficiency improvements**

** VFB System costs can be < $200/kWh at > 2-GW/y production volumes per the US DOE JCESR's techno-economic models

Vanadium Electrolyte Production

Historical

70+ Million Liters/ Year of High Purity, Sulfuric Acid Based Electrolyte Produced for Lead Acid Battery Markets

2024

Proprietary Vanadium Electrolyte Manufacturing Developed

Pilot Line Commissioned

MAKEIT Prize Phase 2 Awarded to Scale Production

2025

Rapidly Scale Production Capacity

MAKEIT Prize Supports Production of 50 MWh/year

Scale to Market Demand

Roadmap

Large Scale Commercialization Exceeding Annual Capacity of 1GWhr

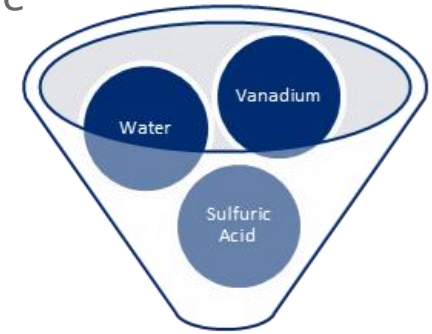
SECURING AMERICA'S VANADIUM ELECTROLYTE (SAVES)

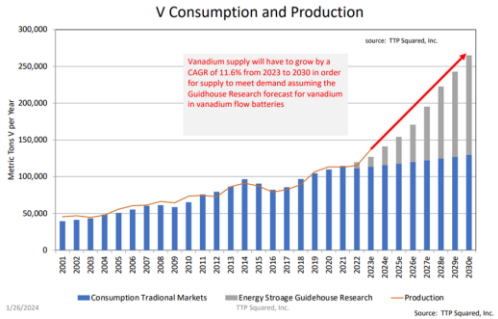
AMERICAN MADE
U.S. DEPARTMENT OF ENERGY

Electrolyte Purification Broadens Available Sources

Storion produces some of the purest and most effective vanadium electrolyte

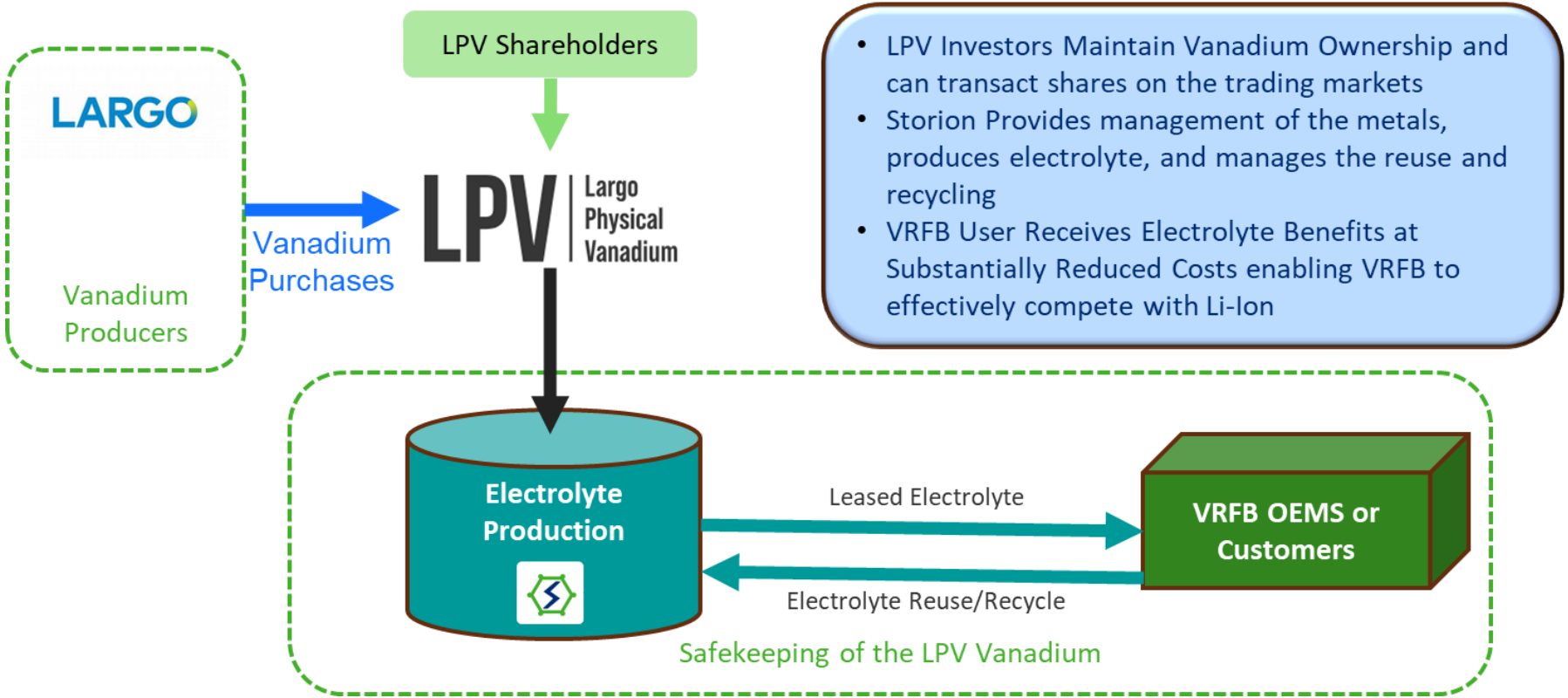
- Our patented purification process is simple and highly effective
  - Enables using lower-purity feedstocks
- Enables 20+ years of operation with no performance degradation





Storion Annotation:
100,000 metric tons V Supports >20 GWh of storage capacity

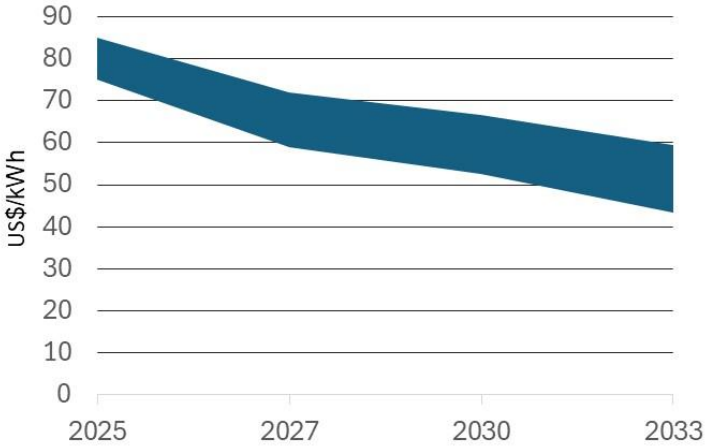
Storion's Innovative Leasing Models for Vanadium Electrolyte



- LPV Investors Maintain Vanadium Ownership and can transact shares on the trading markets
- Storion Provides management of the metals, produces electrolyte, and manages the reuse and recycling
- VRFB User Receives Electrolyte Benefits at Substantially Reduced Costs enabling VRFB to effectively compete with Li-Ion

Storion's Leasing Model Dramatically Lowers Up Front Costs

- Storion is the Safekeeper for LPV vanadium
- Standard leasing terms:
  - Twenty-year lease
  - Fixed annual lease payment is <$10/kwh/year
  - Low up-front conversion costs



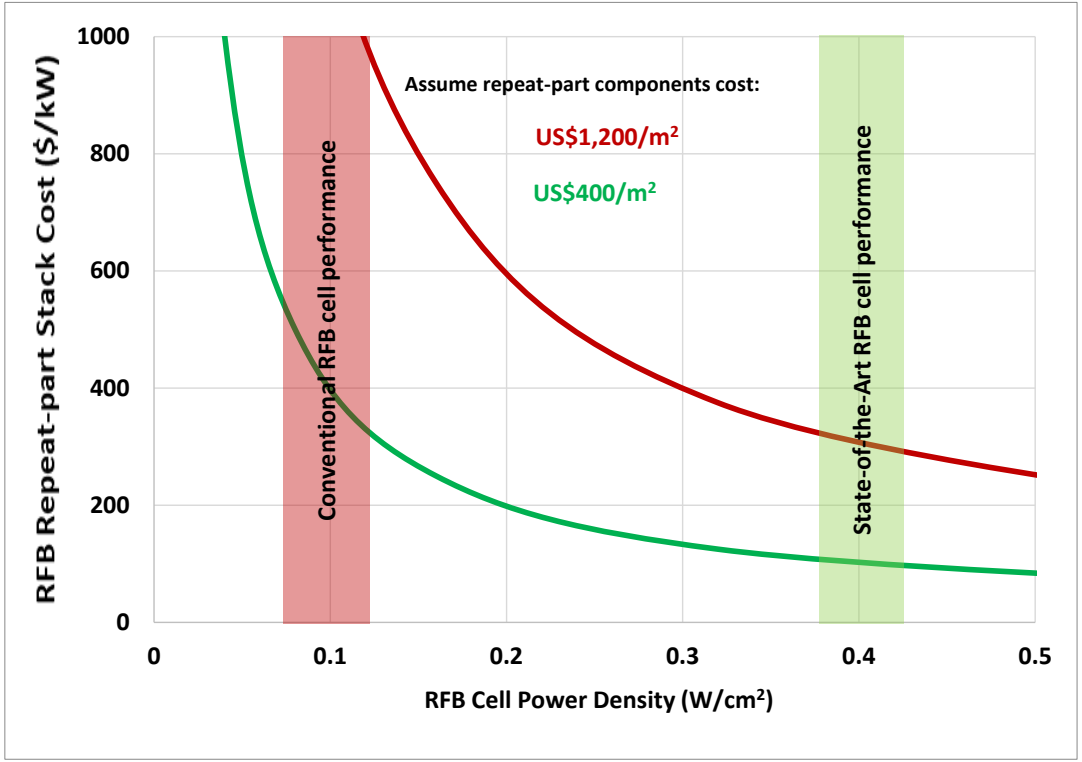
Vanadium Electrolyte Up-Front Costs	
Purchase	Lease
<$200/kWh	<$85/kWh

This assumes 18.2 kWh/L of VFB electrolyte, which is 57% of theoretical capacity of 1.7 M VFB electrolyte

Stack Cost

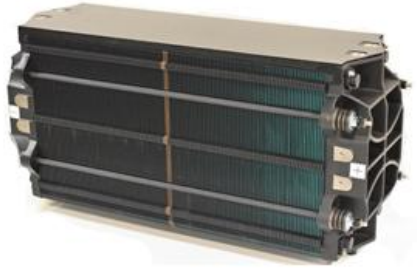
High cell power densities enable substantial cost reduction

- Reduce total m^2 required for all stack components per kW capacity
- At high production volumes repeat-part costs :
  - Membranes ≈ $200/$m^2$
  - Electrodes (X2) ≈ $50/$m^2$ (each)
  - Bipolar plates ≈ $100/$m^2$
- Even higher cost at current volumes
- This is for stack-repeat parts only, also need to include:
  - Non-repeat components
    - Ex: End plates, tie rods
  - Stack assembly labor



Larger, High-Performance Stacks are Desirable

- Higher kW/stack enables:
  - Fewer non-repeat components
    - Ex: End plates, tie rods
    - Reduced stack assembly labor
  - Fewer plumbing connections in MW-scale systems
    - Reduced # of potential leak paths
    - Reduced BOP cost & assembly
- Key Challenges:
  - Shunt currents
  - Pressure drops



125-cell stack; ≈ 40-kW with ≈ 80% RTE

Capital Cost of VRFB Systems

Costs can be competitive with Li-ion batteries with Storion Energy's components

100 MW, 10-Hour Installed BESS Costs (US$/kWh)			
	Conventional state-of-the-art VFB System	*VFB System with Leased Electrolyte*	LFP System
Active Materials	$180/kWh	$75/kWh	$90/kWh
Installed System	$446/kWh	$341/kWh	$379/kWh

- These attractive costs are enabled by:
  1. Lower electrolyte costs, and
  2. High-performance stacks
- Storion Energy is focused on delivering these two key enablers via:
  - Innovative electrolyte-leasing models
  - Continuous electrolyte-manufacturing process, including simple electrolyte purification
  - High-power density cell stacks
- Future cost reductions projected with economies of scale

Summary

- VFBs are the most mature RFB systems
  - The simplest known RFB technology with many attractive attributes
  - Proven real-world lifetime (project system lifetimes of > 20-years)

- *Storion Energy* is focused on being an exceptional RFB-component supplier
  - Initially focused on: high-purity VFB electrolyte & high-performance RFB stacks

- VFBs are commercially-viable, with lower capital costs
  - Lower capital costs can be realized by partnering with *Storion Energy*, who offers:
    - Innovative business models (*e.g.*, leased electrolyte with V owned by LPV),
    - Manufacturing efficiency (*e.g.*, continuous electrolyte production with low-cost feedstock)
    - Advanced technology (*e.g.*, high-performance cell stacks, and simple electrolyte purification)
    - Continuous future improvements resulting from economies-of-scale and ongoing R&D

Questions?

Mike.Perry@storion.com

Acknowledgement

Some of the material presented here is based upon work supported by the U.S. DOE as part of:

- The Flow Battery Systems Manufacturing Program under the Advanced Materials & Manufacturing Technologies Office (AMMTO), award number DE-EE0009792, and
- DOE "Manufacture of Advanced Key Energy Infrastructure Technologies (MAKE IT) Prize