



POLITECNICO
MILANO 1863

Scaling Zn-Mn Flow Batteries: Performance & Economic Assessment

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SEELab
Surface and Electrochemical
Engineering Laboratory

Patents portfolio
in energy storage
(> 15)



Spin-off Polimi for
water treatment



Technologies
transfer and
commercialisation

Spin-off Polimi for
lithium batteries

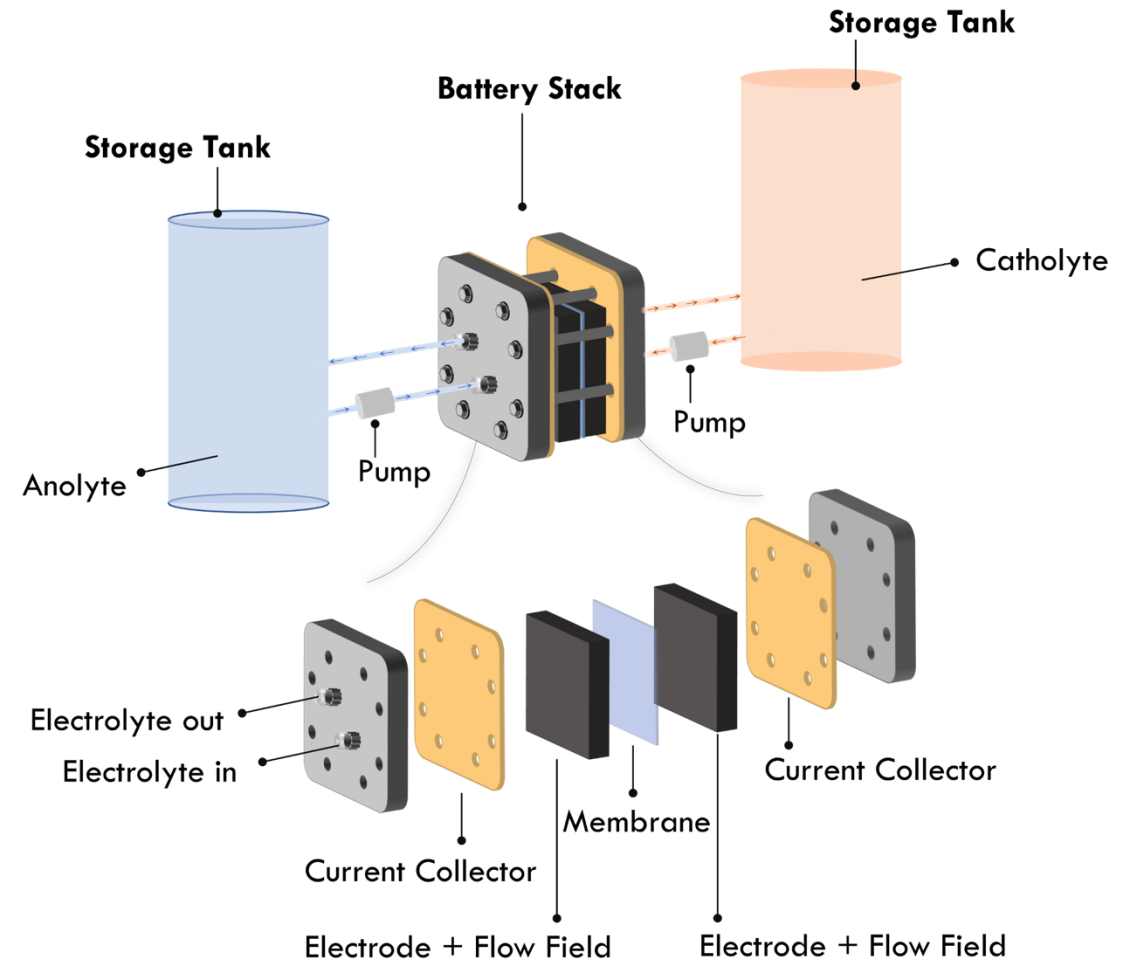


Why RFB for ESS?

- ✓ Long life-cycles (10-20 y)
- ✓ Lower maintenance costs
- ✓ Easy scalability

Energy and power are independent variables

Adjustable E/P (MWh/MW)



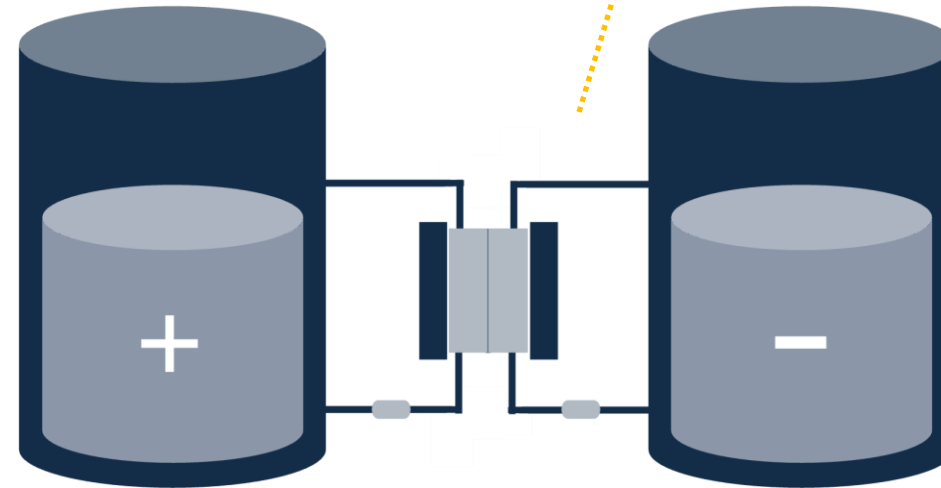
Zn-Mn Flow Battery: Structure

Manganese based electrolyte



$$E^0 = +0.64 \text{ V}$$

Foam Electrodes

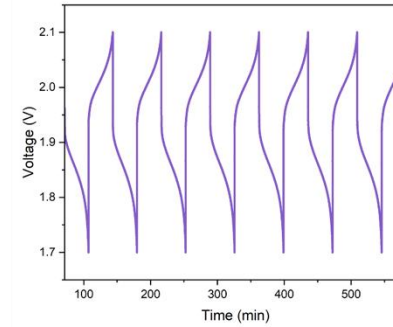
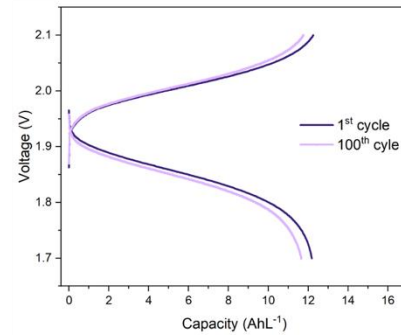


$$\text{OCV} = 1.97 \text{ V}$$

Zinc based electrolyte

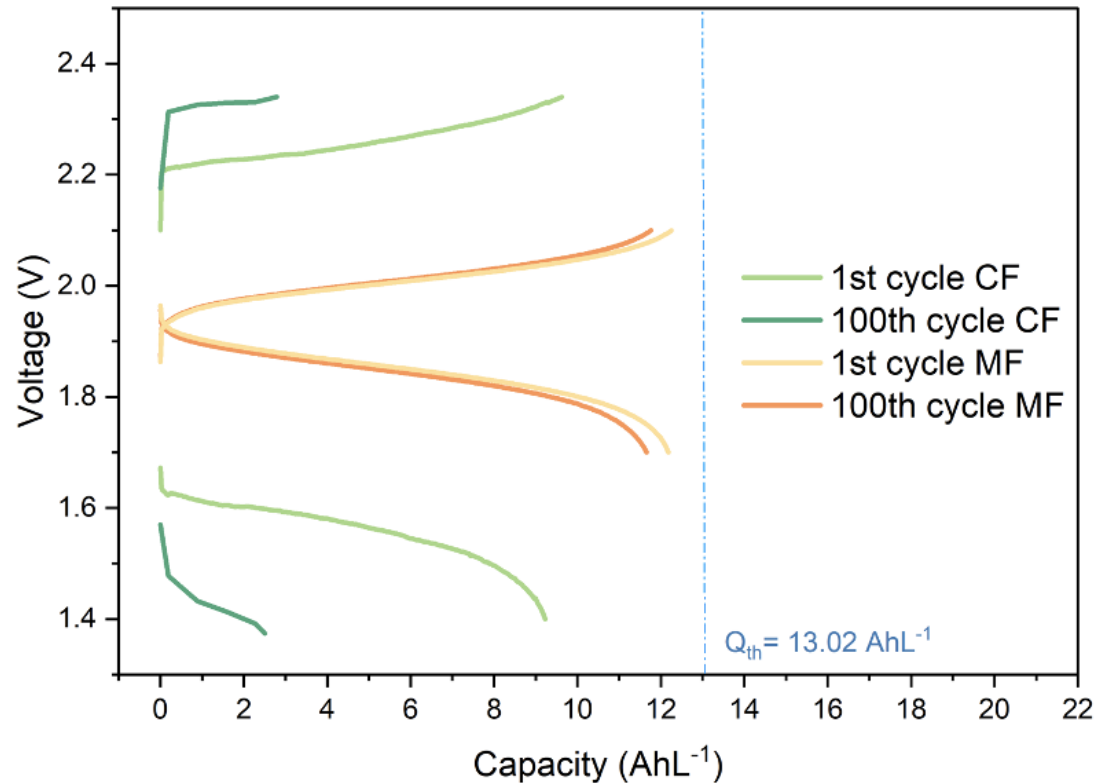


$$E^0 = -1.33 \text{ V}$$



The cell cycled stably with minimal capacity fade.
The **selection of materials** and **electrode design** enables reversibility and stability.

Zn-Mn Flow Battery: Carbon Felt vs Metal Foams

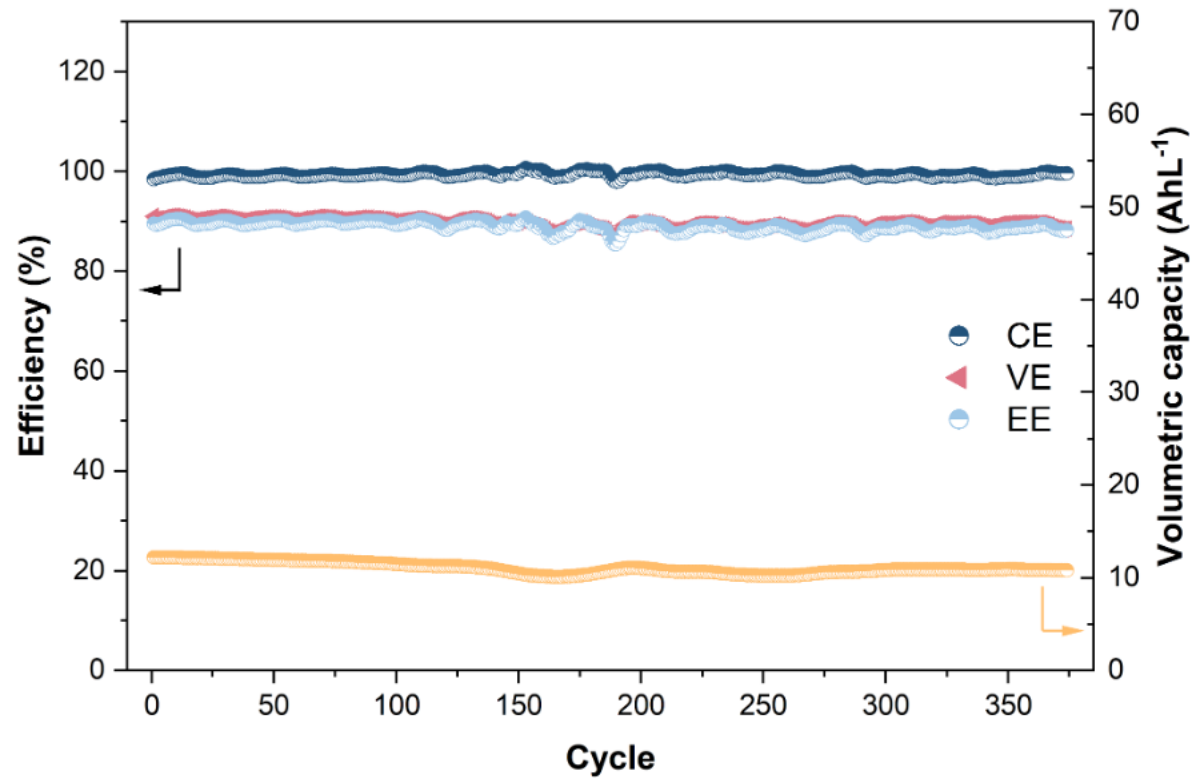


- The discharge cutoff voltage was limited to prevent MnO₂ formation
- The battery was able to discharge a total capacity of **13,02 AhL⁻¹** in the first cycle, corresponding to an electrolyte utilization of **94%**

Zn-Mn FB: Stack performance

The selection of materials and electrode design enables reversibility and stability

+3 weeks cycling test

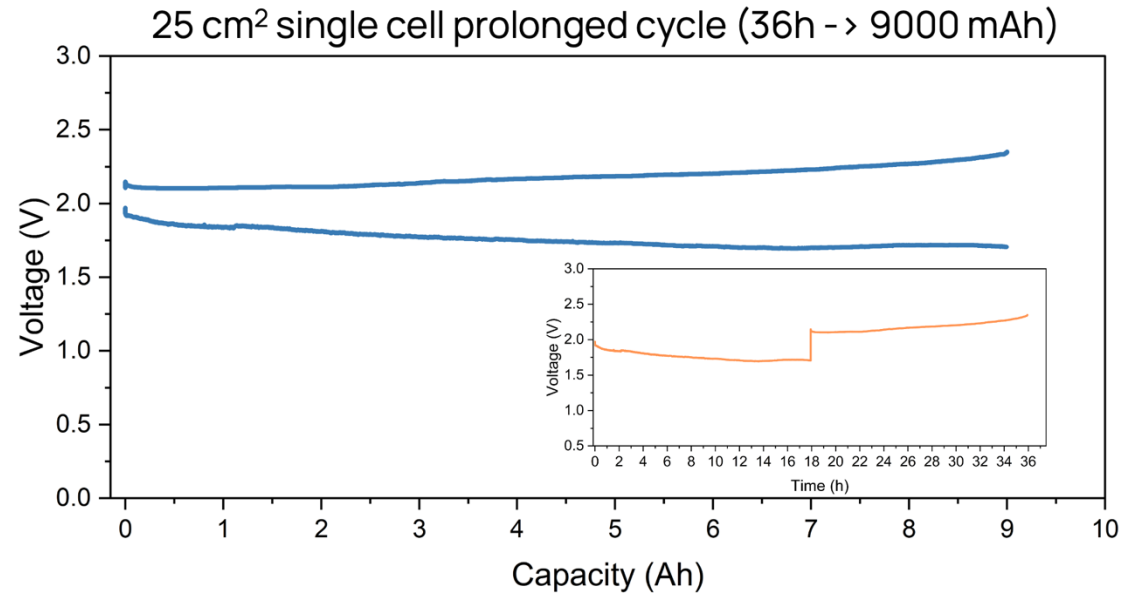


Coulombic Efficiency 99.4%

Energy Efficiency 89.9%

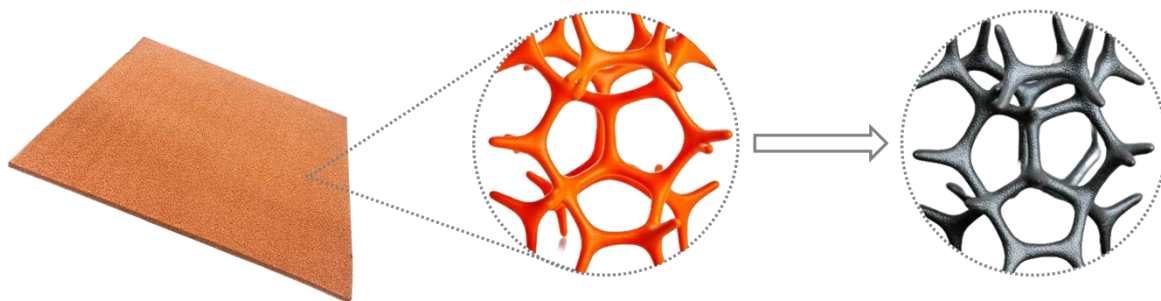
Electrolyte UR 94.0%

Capacity Fade 0.02%

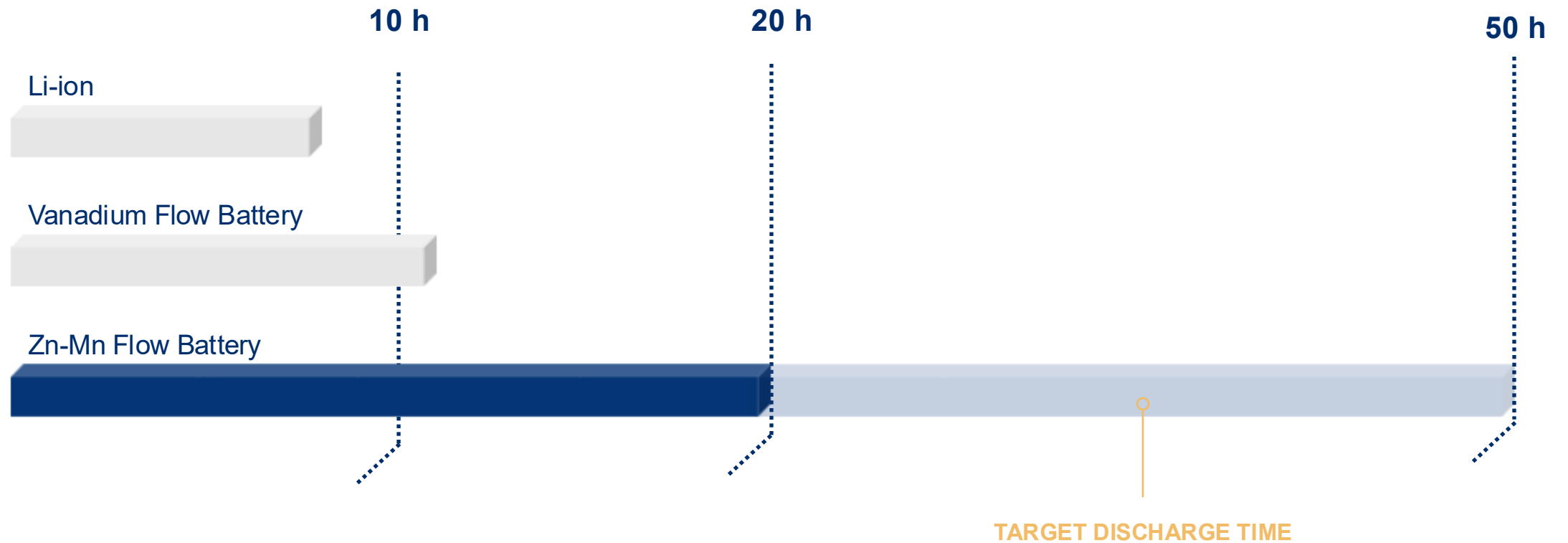


Foam electrodes advantages

- Stability in alkaline conditions
⇒ Higher cycle life
- High surface area and homogeneous electric field distribution
⇒ High load of zinc



Zn-Mn FB: LODES

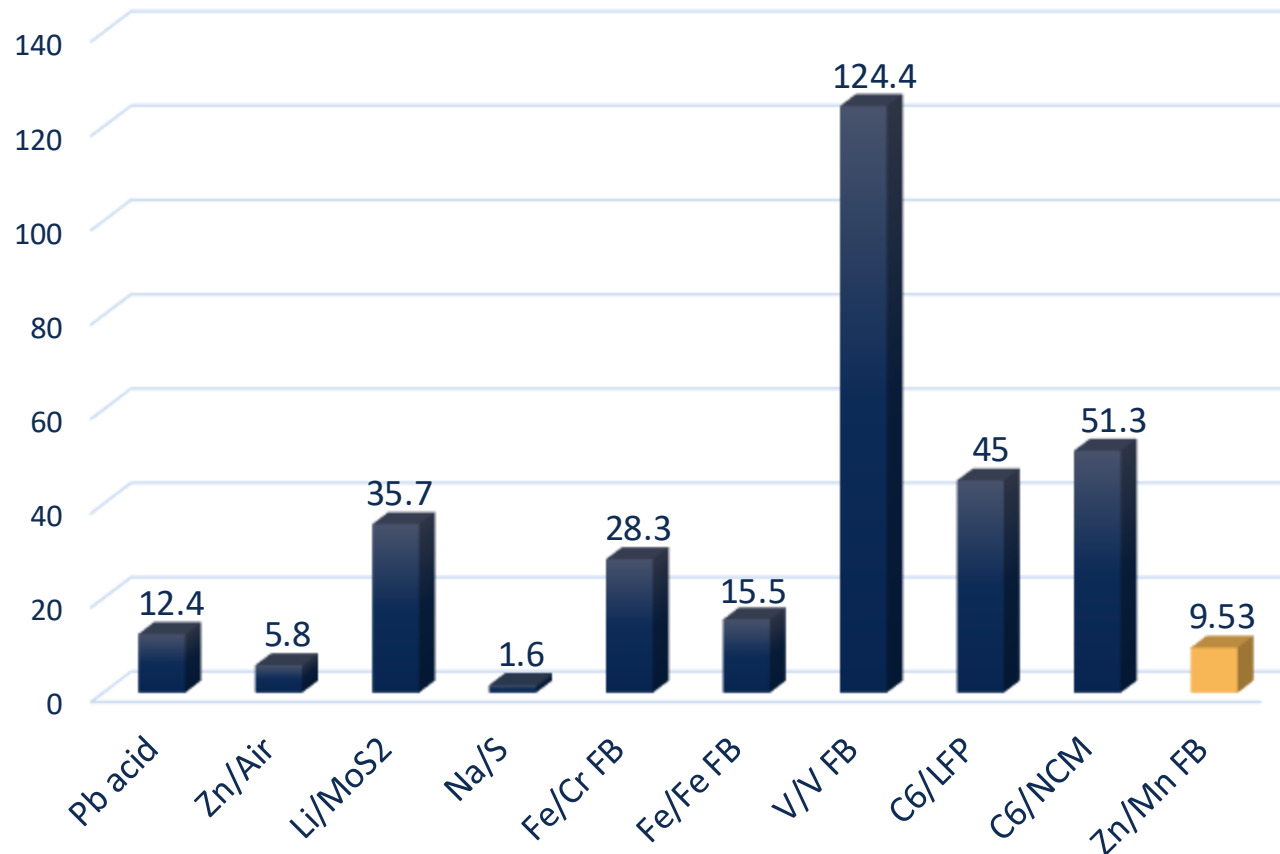


Chemical Cost Comparison

Chemical cost of storage (CCS): Total cost of the anode, cathode, and electrolyte normalized to the stored electrical energy (USD/kWh)

$$CCS \left(\frac{US\$}{kWh} \right) = \frac{\text{Redox Flow} \text{ Cost of Anolyte (US\$) + Cost of Catholyte (US\$)}}{\text{Voltage (V)} \times 1(\text{Wh}) \times 0.001 \left(\frac{kWh}{Wh} \right)}$$

$$CCS \left(\frac{US\$}{kWh} \right) = \frac{\text{Other Batteries} \text{ } m_a(\text{kg}) \cdot P_a \left(\frac{US\$}{\text{kg}} \right) + m_c(\text{kg}) \cdot P_c \left(\frac{US\$}{\text{kg}} \right) + m_e(\text{kg}) \cdot P_e \left(\frac{US\$}{\text{kg}} \right)}{\text{Voltage (V)} \cdot 1(\text{Ah}) \cdot 0.001 \left(\frac{kWh}{Wh} \right)}$$



Simplified expression for pre-commercial systems

Price of electricity p_c 100 USD/MWh

Discount rate r 10 % y^{-1}

$$LCOS \left(\frac{USD}{MWh} \right) = \frac{P_0}{E_d \omega} \frac{r}{1 - e^{-rt_L}} + \frac{p_c}{\varepsilon_{e,rt}}$$

Reagent purification and balance of plant costs were neglected

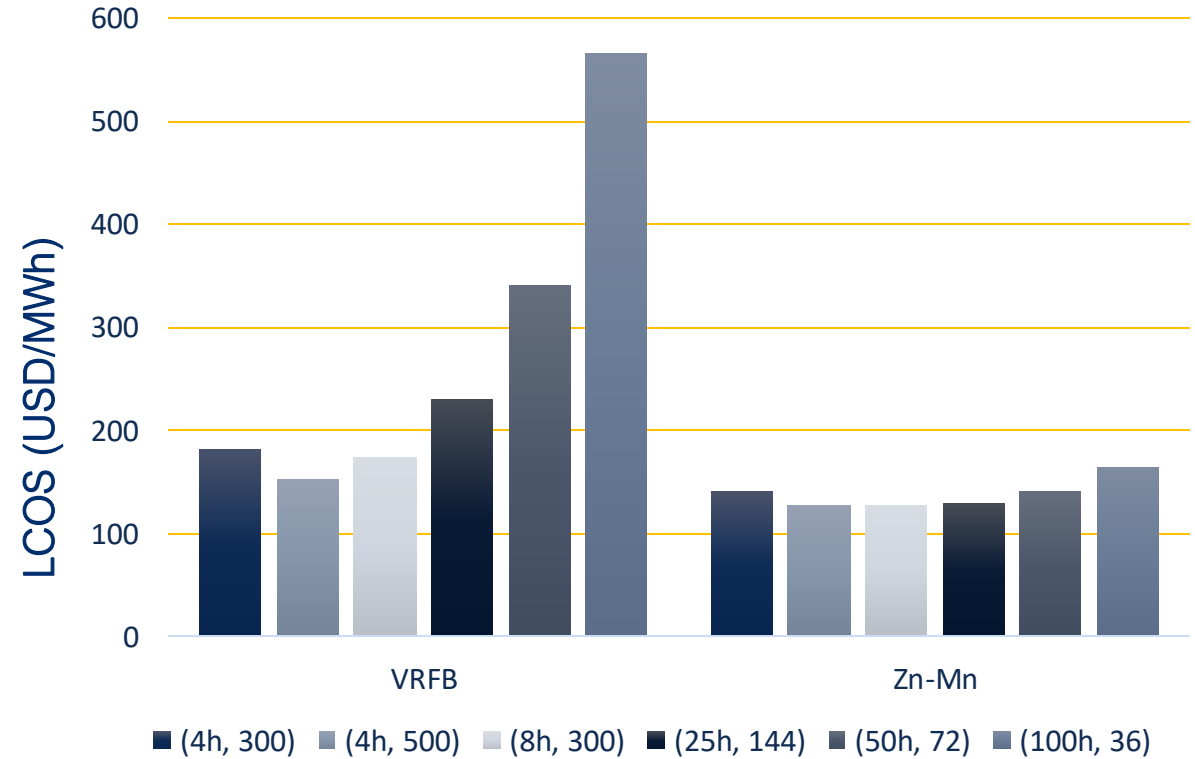
$$\frac{P_0}{E_d} = \text{Intrinsic Capital Cost} \left(\frac{USD}{kWh} \right) = C_{electrolytes} + C_{reactor} + \cancel{C_{BoP}} + \cancel{C_{additional}}$$

Multi-hour ES use cases considered:

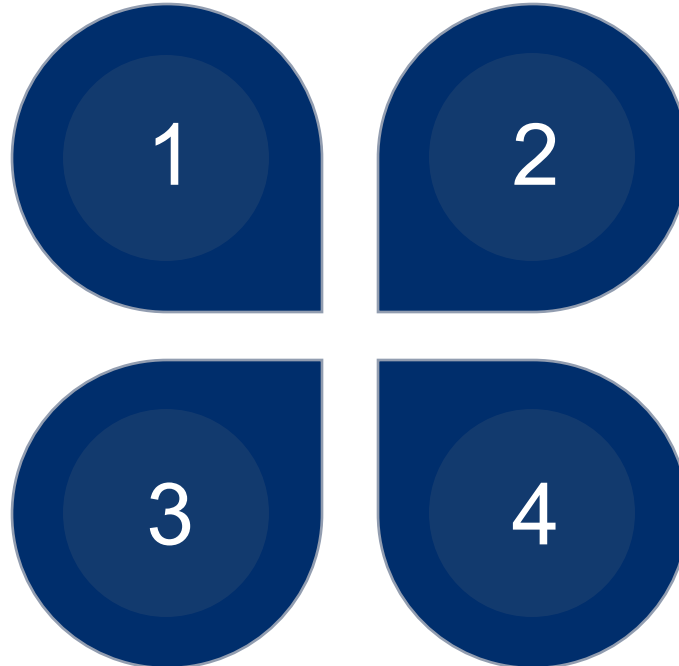
	t_d (h)	ω (y^{-1})
Energy Arbitrage	4	300
Network Operation	8	300
Power Quality	4	500
LDES	25	144
LDES	50	72
LDES	100	36

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Simple and safe
Aqueous
Not flammable or explosive

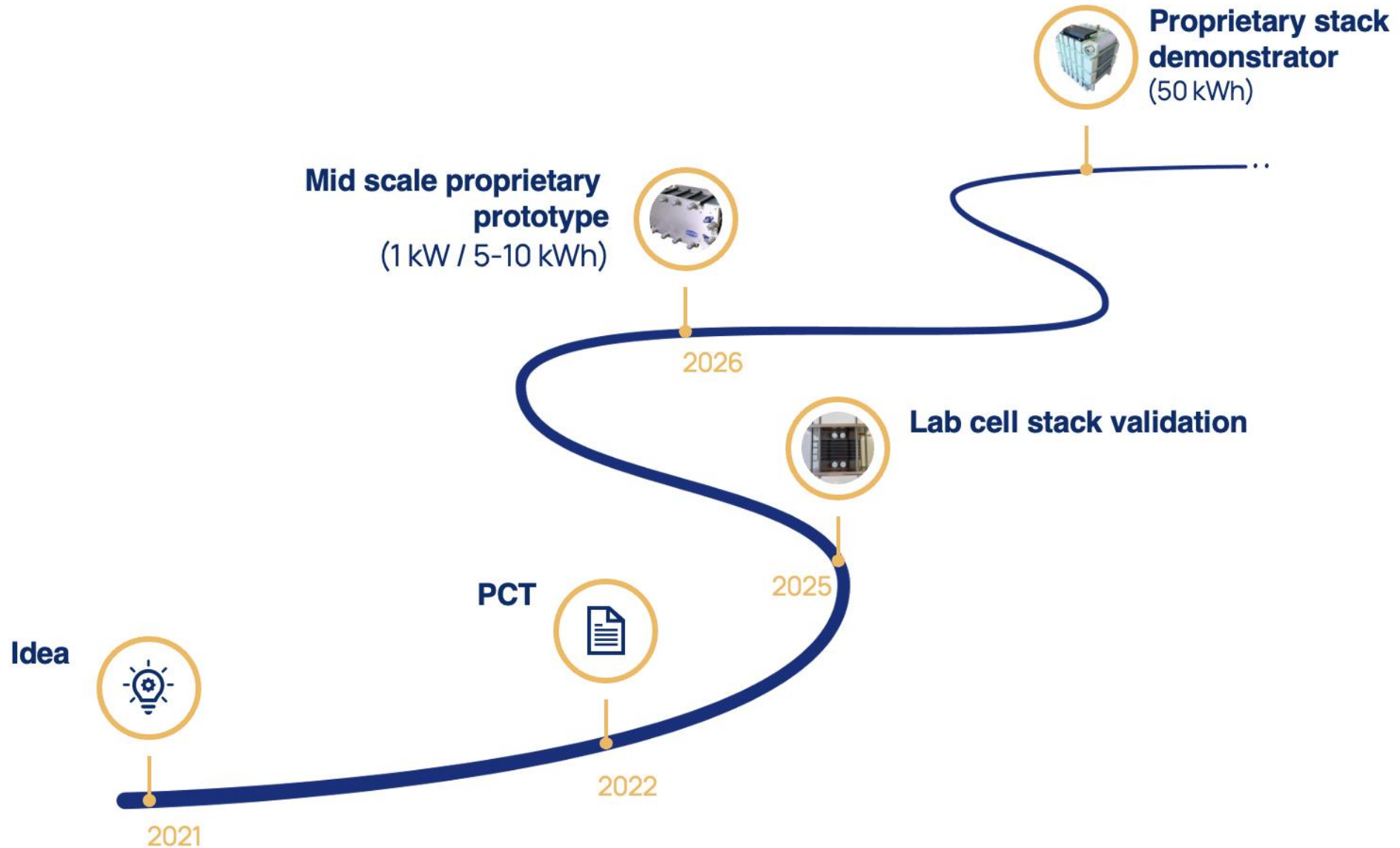


Scalable and modular
Capacity and performance can be expanded independently

Low-cost
Earth abundant materials
80-90% cheaper than VFB

High Energy Density
77 Wh L⁻¹
 $t_d > 18$ h

A clear roadmap





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Thank You For Your Attention

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