Advances in Soluble Lead Redox Flow Battey Technology : From Fundamentals to stack development and Life cycle assessment studies

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Introduction

Soluble Lead Redox Flow Battery (SLRFB)[1]

Anode : $Pb^{+2}_{(aq)} + 2e^- \rightleftharpoons Pb_{(s)}$ $\quad E^0_{-ve} = -0.13$ V vs. SHE

Cathode : $Pb^{+2}_{(aq)} + 2H_2O_{(l)} \rightleftharpoons PbO_{2(s)} + 4H^+_{(aq)} + 2e^-$ $\quad E^0_{+ve} = +1.49$ V vs. SHE

Cell Reaction : $2Pb^{+2}_{(aq)} + 2H_2O_{(l)} \rightleftharpoons PbO_{2\,(s)} + Pb + 4H^+_{(aq)}$ $\quad E^0_{cell} = 1.62$ V

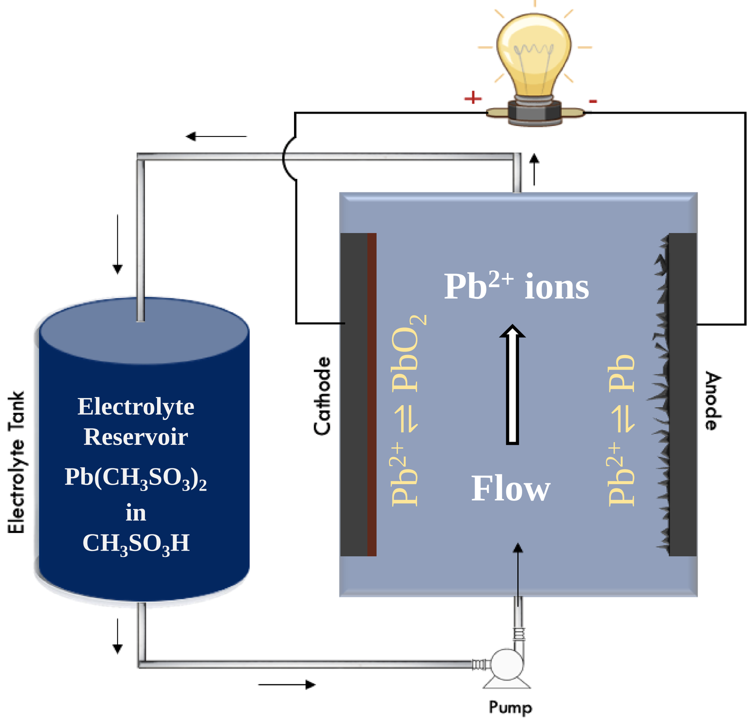
Advantages

Cost effective flow battery

- Single electrolyte
- No cost-intensive ion exchange membrane
- Widely abundant low-cost active materials

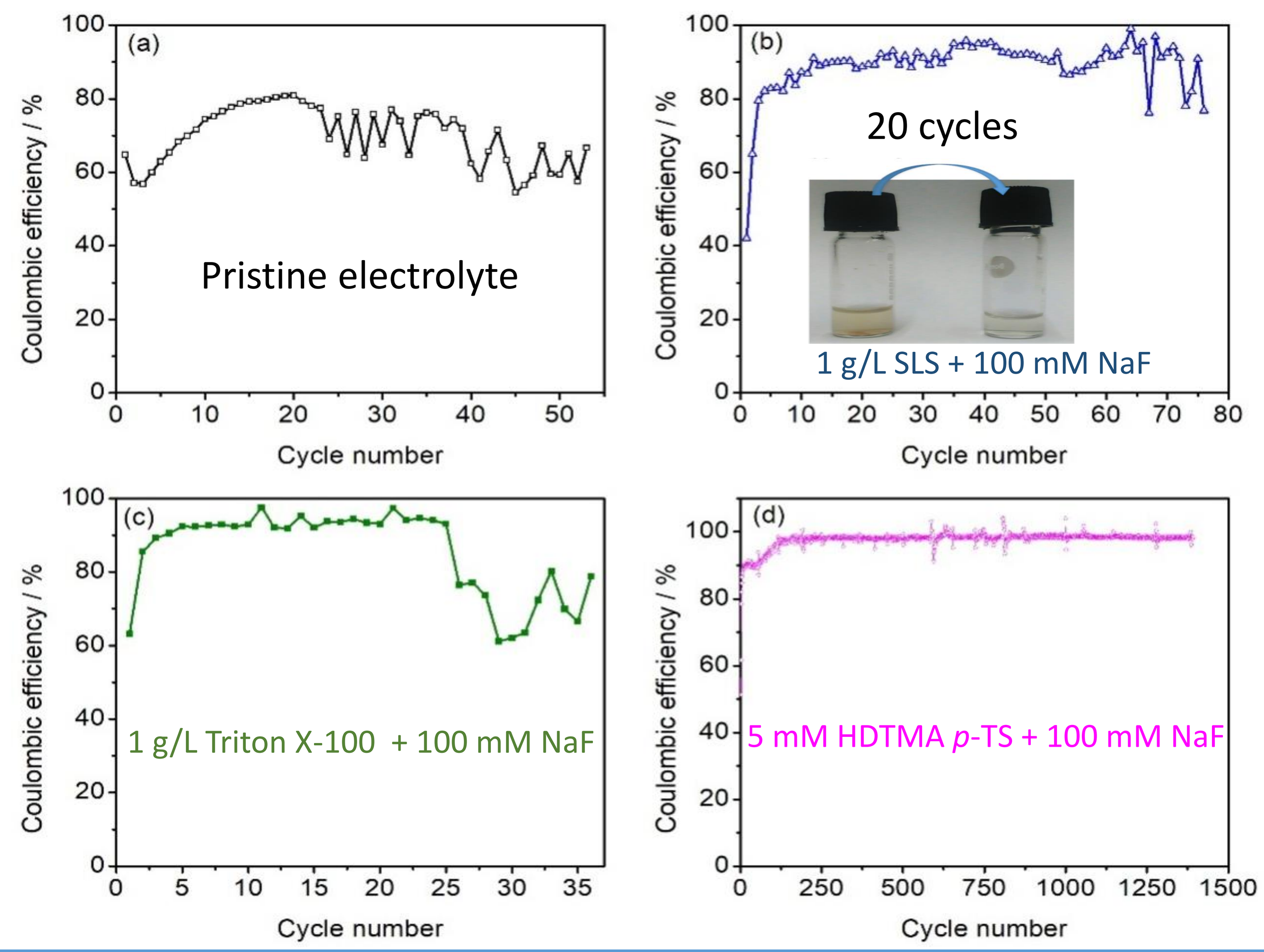
Challenges

- Pb dendrite formation on anode
- O_2 evolution reaction on cathode
- PbO_2 sludge formation
- Sluggish electrode kinetics of cathode
- Stack engineering of SLRFB and mitigation of



Results and discussion

Cycle life study[1]



Shunt current (ionic leakage current) in RFBs[2,3]

- Shunt currents are observed in stacks of electrochemical cells with common electrolyte manifold.
- Shunt currents are undesired since they reduce charge and energy efficiency.

Methods to determine shunt current

1. Equivalent circuit model
2. Experimental methods
   - Magnetic field detectors
   - Voltage drop along channel and manifold

Internal current distribution

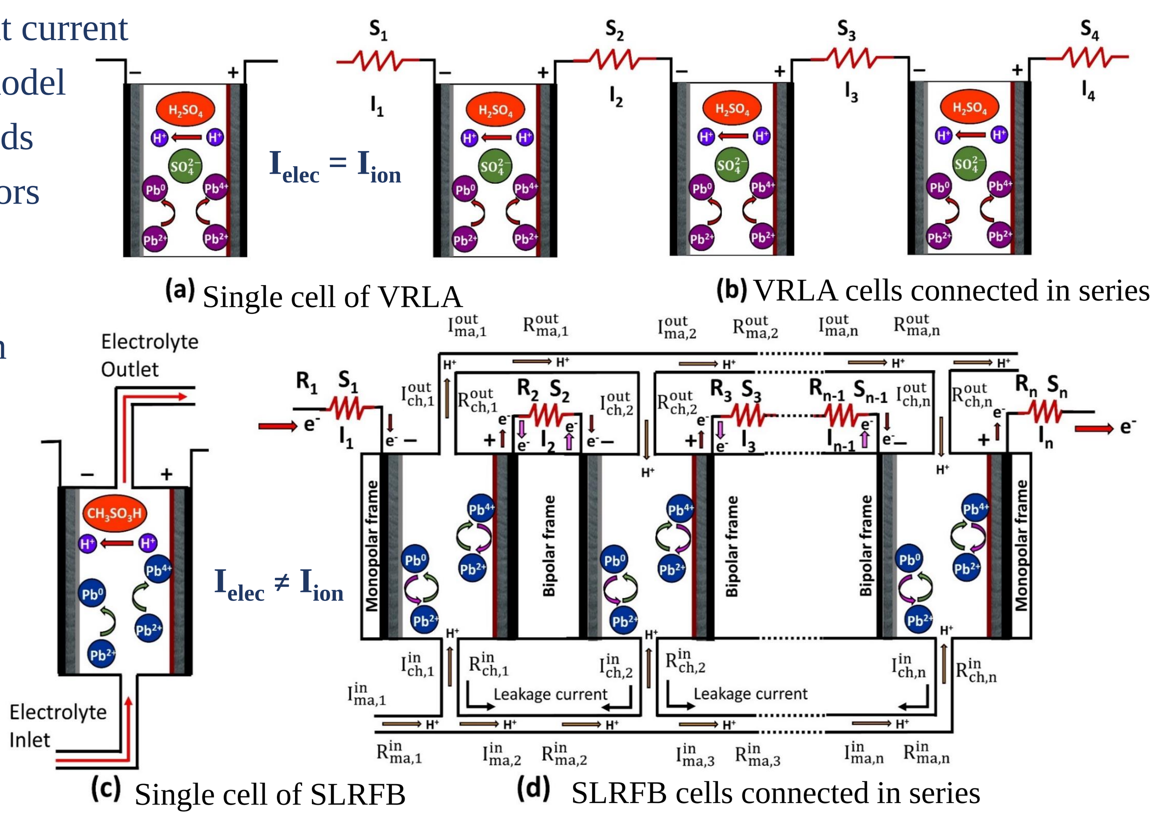
$I_1 - I_2 = I^1_{ch+ma}$

$I_1 - I_3 = I^2_{ch+ma}$

Ionic leakage current of each cell

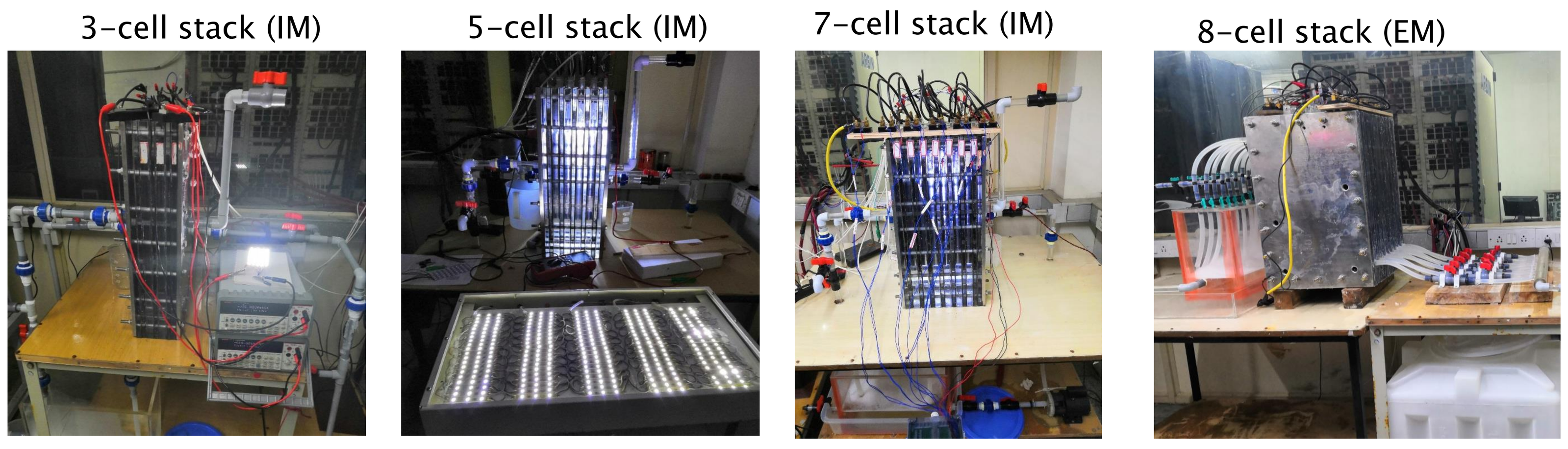
$I_1 - I_2 = I^1_{lc}$

$I_2 - I_3 = I^2_{lc}$



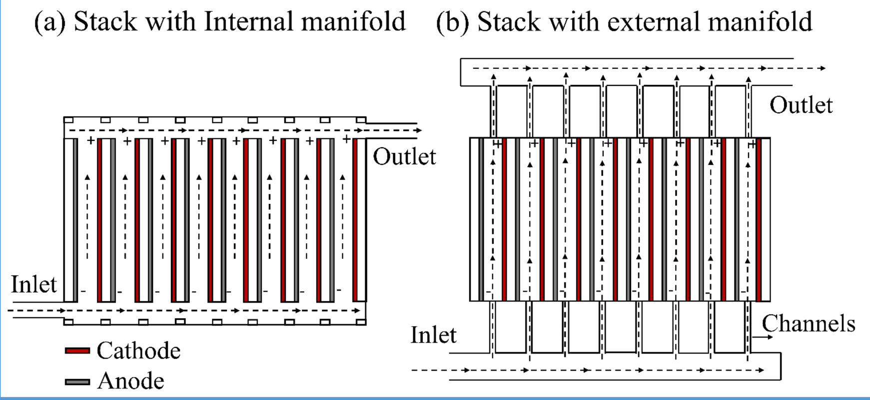
(a) Single cell of VRLA (b) VRLA cells connected in series (c) Single cell of SLRFB (d) SLRFB cells connected in series

SLRFB Stacks with internal and external manifold



4.8 V - 3-cell stack | 8 V - 5-cell stack | 11.5 V - 7 cell stack | 13.5 V - 8 cell stack

What is internal and external manifold



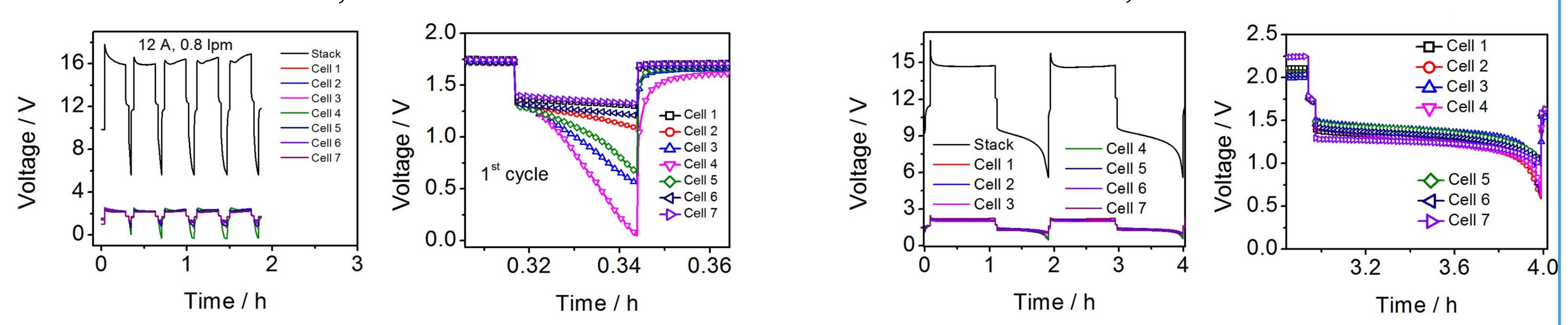
Shunt current can be minimized by…

- Increasing electrolyte pathlength by long and narrow channels

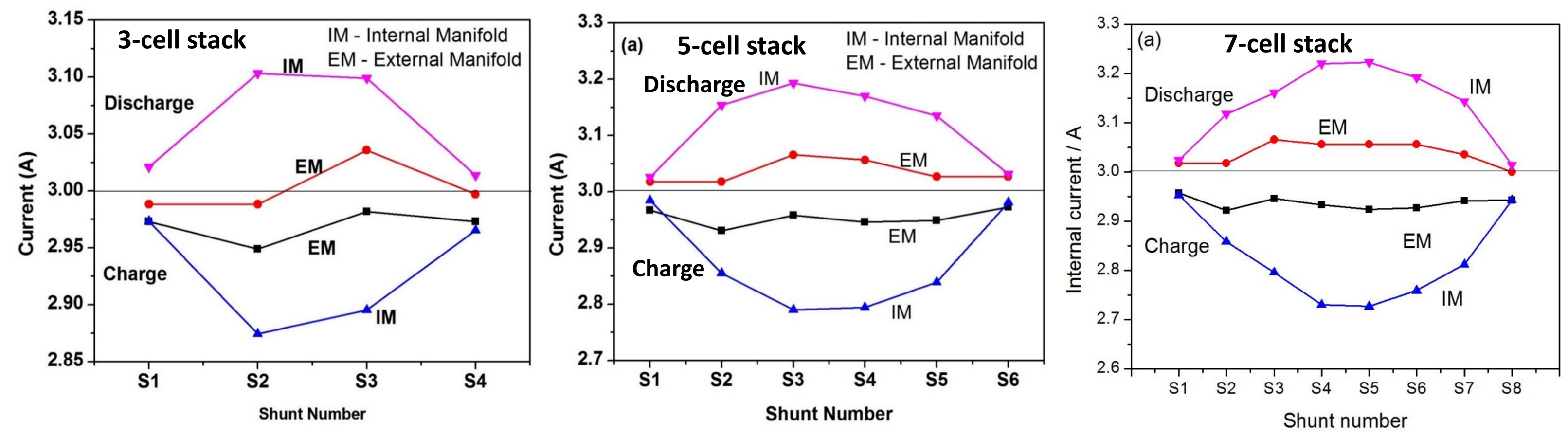
$$R = \rho \frac{l}{A}$$

R = Resistance, ρ = resistivity, l = length
A = cross sectional area

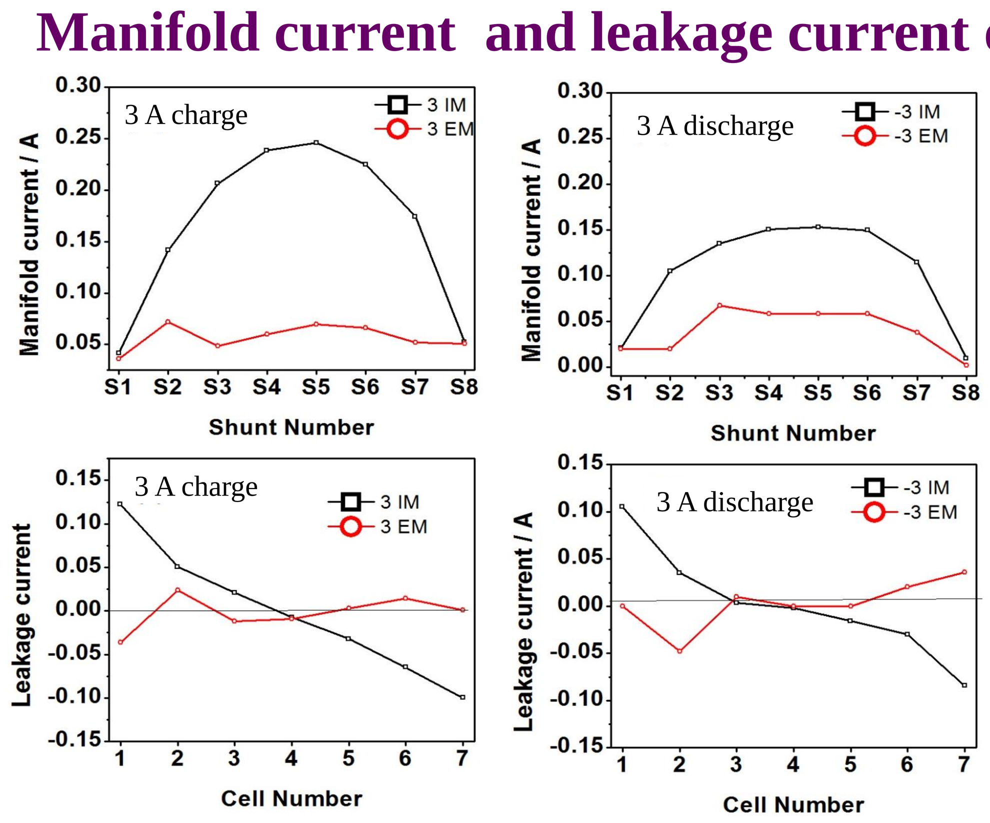
1h charge-discharge of 7-cell stack



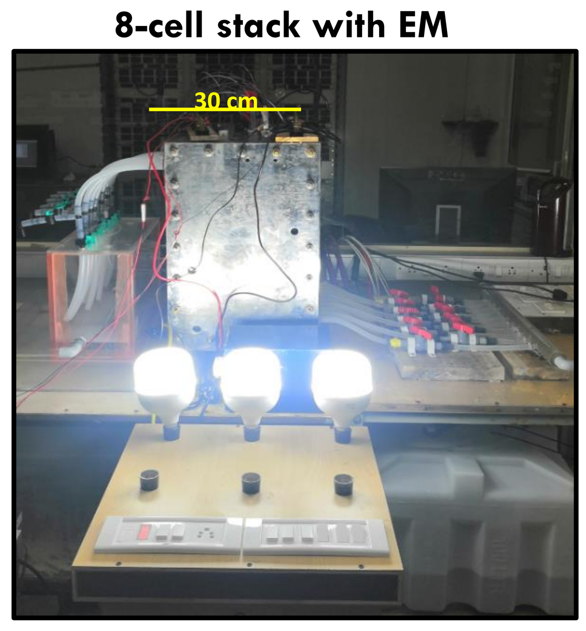
Internal current distribution in 3, 5 and 7-cell stacks



Manifold current and leakage current distribution in 7-cell stack

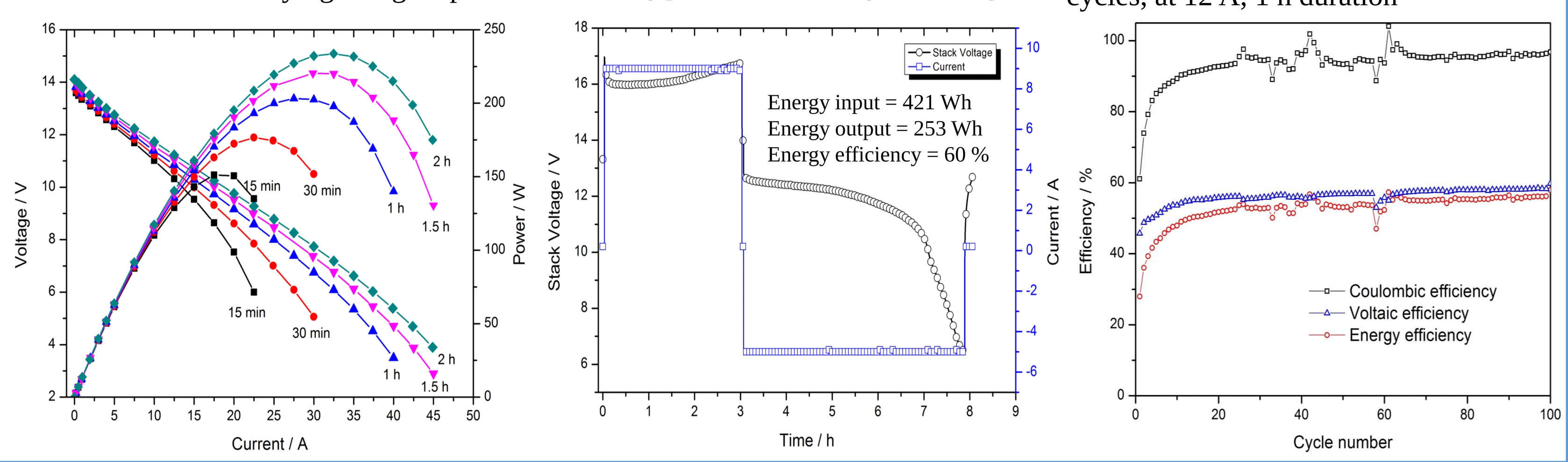


Shunt minimized 12 V – 250 Wh 8-cell stack with EM



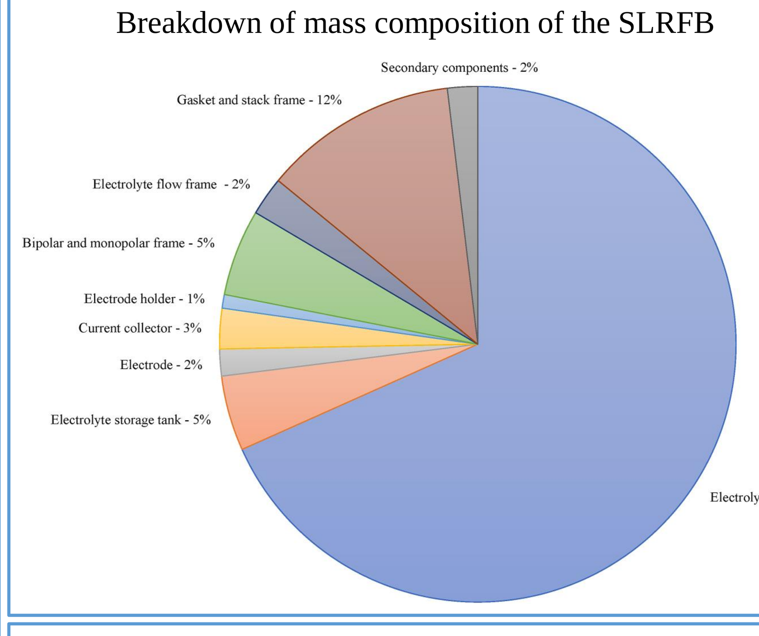
Performance characteristics of 8-cell stack with EM design

I-V curves with varying charge input | Long period (3 h) charge-discharge | Efficiency data for 100 charge-discharge cycles, at 12 A, 1 h duration

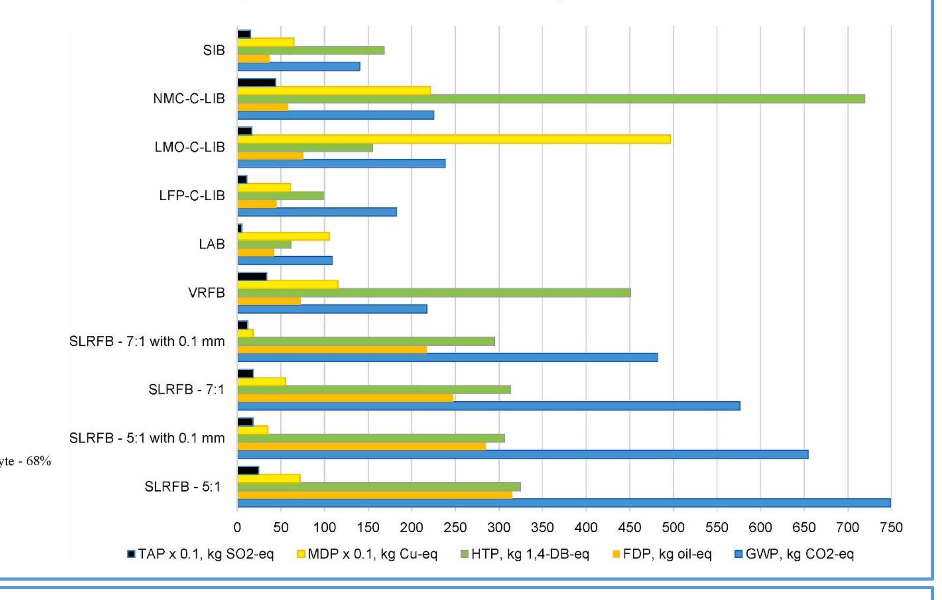


Life-cycle assessment studies[4]

Breakdown of mass composition of the SLRFB



Environmental impact of SLRFB and Comparison with other Batteries



Conclusions

- HDTMA *p*-TS and NaF binary additive system helps in controlling the Pb dendrite formation and shown the cycling stability of 1392 cycles without failure.
- Shunt current in the middle cells of 3, 5, 7-cell stacks were found to be 3.3%, 6% and 8.5% respectively of total input current. Whereas for the external manifold design it is about 1.5 % .
- A 12 V / 50 W – 250 Wh battery has been demonstrated for the first-time maximum power output of 232 W upon 24 Ah input and showed stable cycling behaviour for more than 100 cycles at 24 mA/cm^2 , 1h duration charge-discharge with > 95% coulombic efficiency.
- The environmental impacts of SLRFB shows promising results compared to other station application exhibiting one of the lowest depletion of material resources of all compared batteries, including Lithium-ion batteries, lead acid batteries and sodium ion batteries.

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2. Suman, R.; Yadav, S. P.; Ravikumar, M. K.; Patil, S.; Shukla, A. K. *J. Electrochem. Soc.* **2021**, *168* (12), 120552.
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