Sustainable Energy Storage Technologies: A Techno-Economic Analysis

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Introduction:

•The need for long duration energy storage is increasing along with the penetration of renewable energy in the grid. For providing more flexibility to the grid by helping in grid balancing and as backup for RE (Renewable Energy) sources.

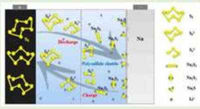
•The current state of the art technology is the lithium-ion battery, which is not suitable for storage durations over 6 hours. The supply of lithium is also constraint to geopolitical issues due to its limited availability.

•In this project, sustainable energy storage technologies based on cheap, locally available materials are explored. Over 45 technologies were analyzed, of which 6 were shortlisted based on target parameters decided from an RE project developer's point of view.

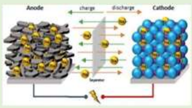
•The shortlisted technologies are: Room temperature sodium sulfur battery; sodium ion battery with Prussian White and Hard Carbon electrodes; Iron flow battery by ESS Inc.; Iron air battery by Form energy; liquid metal battery by Ambri; and thermochemical energy storage in nanocoated calcium hydroxide.

•The levelized cost of storage (LCOS) of these technologies was calculated based on their parameters and cost estimates for the year 2025, as these technologies are expected to commercialize around that time. (LCOS calculation could not be performed for thermochemical storage due to limitations of the LCOS calculation model)

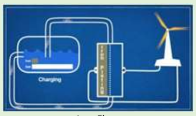
•Further, a sensitivity analysis was performed for the LCOS of these technologies to study how the various battery parameters affect the LCOS.



RT NaS

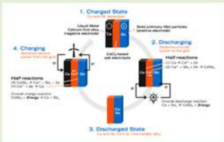


Na ion

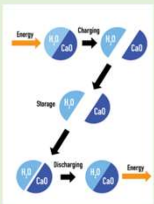


Iron Flow

Iron air



Liquid metal



Calcium hydroxide

Methodology:

•Over 45 energy storage technologies were analyzed, of which 6 were shortlisted based on the following list of target parameters decided from an RE developer's point of view.

S/N	Parameter	Developer Expectation	Comments
1	Cycle Life	>4000 cycles @0.25C, 1 cycle/day operation	We are looking at grid connected systems that will charge from RE – so low C-rate & high cycle life is the requirement
2	RTE	>90%	Comparable with LIB at cell level
3	Storage duration	>8 hr	Long duration storage
4	Safety	Safe operation in temperature range 0-50°C	• We are looking at a room temperature battery • Minimum dendrite formation at low temperature • Pouch cells must pass mechanical, electrical tests as per IEC/UL/other safety standards
5	Cost/kWh (Capex)	<100 $/kWh	At 1 GWh production scale, system level
6	Materials	Cheap & abundantly available in India	To safeguard against supply chain constraint

• LCOS of an energy storage technology is defined as the average of total cost of building and operating the asset (including CAPEX, OPEX, capacity degradation, EOL Cost, misc. charges, etc.) per unit of the total energy delivered over its entire lifetime. Its unit is [cost/unit of energy] The formula for calculating it is as follows: -

$$LCOS\left[\frac{\$}{MWh}\right]=\frac{\text{Investment cost}+\sum_{n}^{N}\frac{\text{O\&M cost}}{(1+r)^{n}}+\sum_{n}^{N}\frac{\text{Charging cost}}{(1+r)^{n}}+\frac{\text{End-of-life cost}}{(1+r)^{N+1}}}{\sum_{n}^{N}\frac{Elec_{Discharged}}{(1+r)^{n}}}$$

•In this project, the LCOS calculation model takes the following battery parameters as inputs: CAPEX; Round Trip Efficiency (RTE); Cycle Life; Depth of Discharge (DoD); End of life capacity; and Technical availability.

•Assumptions made for calculation of LCOS:

•Capacity = 100 MWh

•Storage duration = 8 hr

•Estimated capex at 1 GWh production scale

•Capex values do not include BCD, GST, other taxes

•Annual OPEX is estimated to be 2% of the CAPEX.

•Parameters for the shortlisted technologies for LCOS calculation:

Technology	Institute/Company	RTE	DOD	Cycle life	EOL Capacity	Technical availability	Total Capex /kWh
RT-NaS		90%	90%	3000	80%	98%	$110
Na ion (PW/HC)	CATL	95%	90%	4000	70%	98%	$130
Iron Flow	ESS Inc.	70-75%	100%	20000	100%	100%	$150
Liquid Metal	Ambri	80%	100%	8000	80%	98%	$240
Iron Air	Form Energy	50%	90%	10000	100%	98%	$120
Lithium ion	CATL	95%	90%	4000	70%	98%	$170

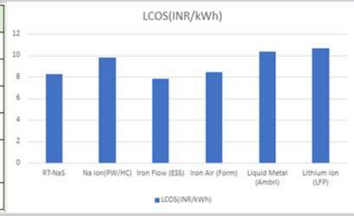
•The costs and energy delivered for a period of 25 years (Average lifespan of solar projects) are calculated and their Net Present Values (NPV) are taken at a discount rate of 10%. The ratio of the NPV of the total costs in the lifetime of the project to the estimated energy delivery for the same period gives the LCOS.

•After performing the LCOS calculations of the shortlisted technologies, a sensitivity analysis was performed by varying the battery parameters and observing how these variations affect the LCOS.

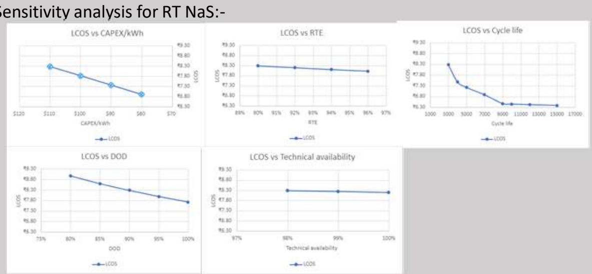
Results:

• LCOS calculations and comparison with Lithium-ion batteries: -

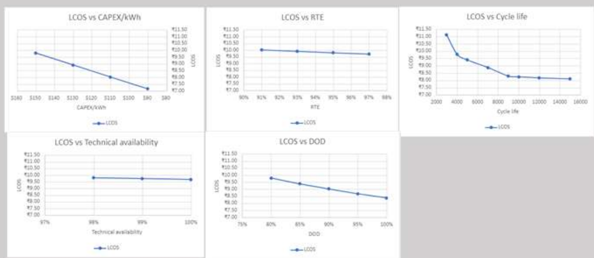
Technology	LCOS(INR/kWh)
RT-NaS	8.28
Na ion (PW/HC)	9.8
Iron Flow (ESS)	7.84
Iron Air (Form)	8.44
Liquid Metal (Ambri)	10.39
Lithium ion (LFP)	10.69



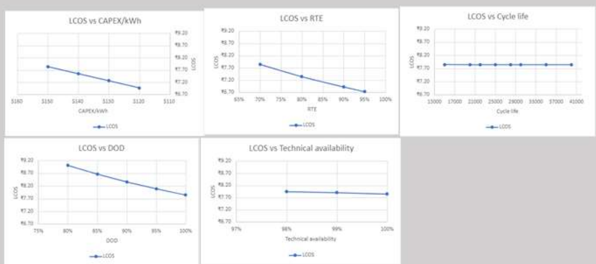
• Sensitivity analysis for RT NaS:-



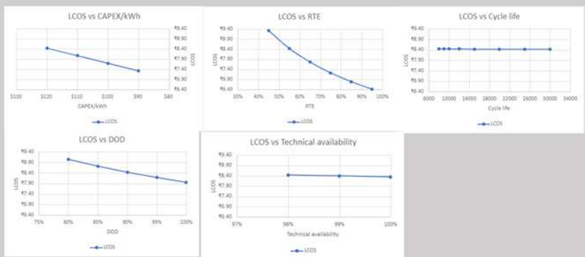
• Sensitivity analysis for Na ion:



• Sensitivity analysis for Iron Flow battery:



• Sensitivity analysis for Iron Air battery:-



• Sensitivity Anaysis for Liquid Metal Battery: -

Conclusions

- It is observed that the projected LCOS of the shortlisted technologies will be lower than that of Lithium ion batteries.
- Iron Flow and Room Temp. Sodium Sulfur batteries are expected to have the lowest LCOS.
- The sensitivity analysis reveals that CAPEX will always have a linear and significant impact on the LCOS.
- Increasing RTE will significantly lower LCOS if the initial efficiency is below 80%
- Increasing the DOD will always significantly lower the LCOS in a linear manner.
- Increasing cycle life to 9000-10000 will greatly lower the LCOS, and a plateau is observed after that due to elimination of replacement costs.
- Technical availability does not have a significant impact on the LCOS.
- This study can help in guiding research areas in battery technology with the objective of lowering the levelized cost.