Storlytics

STORLYTICS BATTERY SCORE SHEET

EnerVenue Energy Storage Vessel (ESV)

Use Case
Overbuild
High Cycle Count
Deep Discharge

1. THE STORLYTICS REVIEW

Overall, Storlytics found that the ESV is advantageous from a cost of ownership standpoint for the studied use-case. This is due to its superior cycle life compared to that of Li-Ion. Further, the rate of degradation of the ESV was found to be less than that of lithium. Both factors resulted in a smaller required BoL capacity for EnerVenue's system compared to that needed for Li-Ion. This led to considerable capital cost savings. The ESV does underperform against lithium in self-discharge, RTE and energy density. However, cost of lifetime energy losses was found to be much less than the capital cost premium that was required for the Li-Ion benchmark.

While Storlytics believes that the results of this report can be applicable to most battery projects with similar use-cases, we recommend that developers model their planned battery systems and use-cases in Storlytics' Software to determine expected efficiency, life cycle, degradation and resulting financial benefits (or lack thereof) of their specific case. This allows for project specific aspects like location, ambient temp., system configuration, use-case and deployment strategy to be considered.

IMPORTANT: Scores shown here are only indicative of the use-case shown in section 3. Simulation files have been made public in the link shown in the appendix. Developers should leverage these files and edit them to simulate their specific use-cases as results will vary.

Technical Scores

Scores are based on Enervenue battery performance of specified use-case in section 3

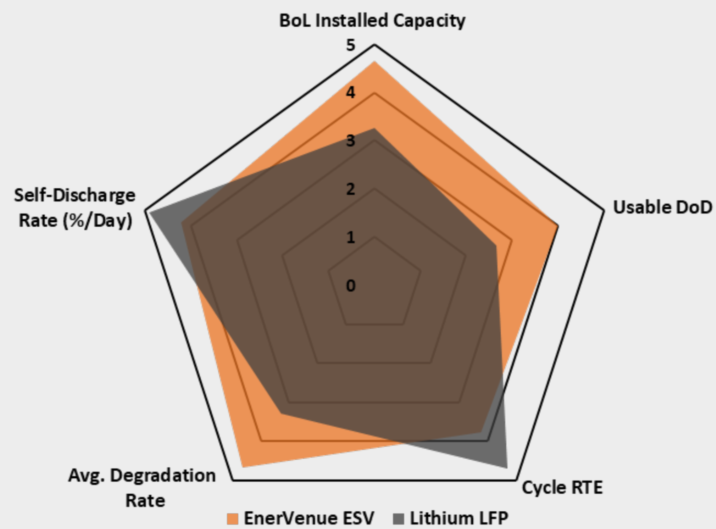

Figure 1. Radar chart for technical comparison

Table I. Technical Scoring

	EnerVenue ESV	Lithium LFP
BoL Instl. Capacity	4.7	3.3
Usable DoD	4	2.7
Cycle RTE	3.8	4.7
Avg. Deg. Rate	4.7	3.3
Self-Dsch Rate (%/Day)	4.2	4.9

Cost of Ownership Scores

Financial comparison below is based on project cost to meet use-case and performance requirements in section 3

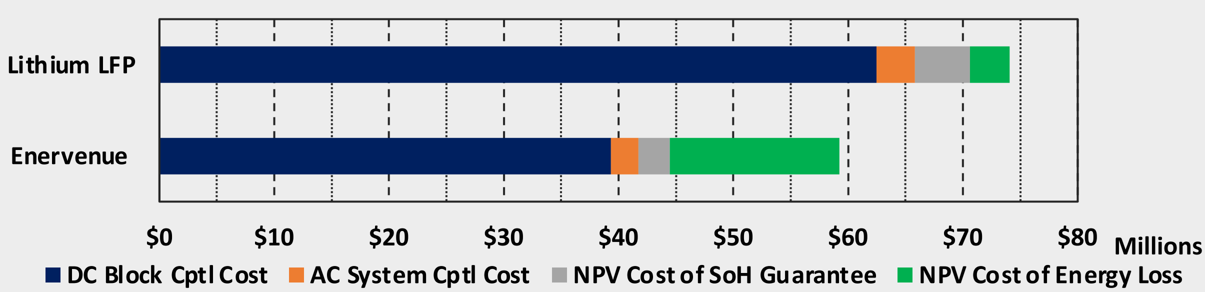

Figure 2: EnerVenue cost of ownership benchmark

STORLYTICS BATTERY SCORE SHEET

EnerVenue Energy Storage Vessel (ESV)

2. Battery General Specifications

EnerVenue's main battery product is the ESV (Energy Storage Vessel) large format module. A string is a collection of ESVs connected in series to produce the proper voltages necessary to connect to inverters, DC/DC converters and other power conversion systems. 1500 Vdc strings utilize up to 153 ESVs with a system voltage range of approximately 1010 - 1500 Vdc at 25°C. Fewer ESVs will be required in the string in colder climates. Table II shows the specification of the ESV, and Figure 3 illustrates the battery technology. Figures 4.a and 4.b illustrate charge and discharge cycles cell voltage variation at different temperatures.

Table II. EnerVenue (ESV) module specifications

Battery OEM	EnerVenue
Product Name	Energy Storage Vessel (ESV)
Product Dscrp.	Common Pressure Vessel (CPV) with 6 internal cells connected in series
Chemistry	Nickel Hydrogen
Rated Energy	1.2 kWh
Temp Range	-15 to 55°C
DoD Range*	97%
Perf. Guarantee Cycles**	20,000
Temperature Mgmt.	Convection forced air without active refrigeration cycle

*Based on operation at 0.25C at 20 °C

** Number of cycles covered by OEM performance guarantee

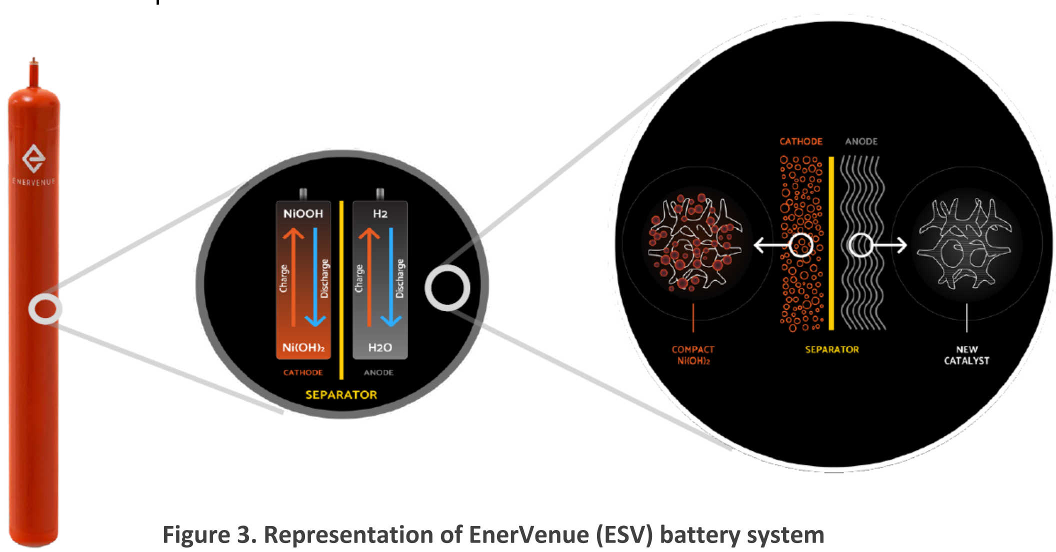

Figure 3. Representation of EnerVenue (ESV) battery system

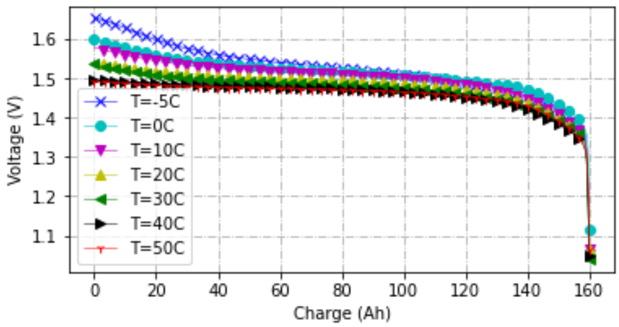

Figure 4.a. Charge cycle cell voltage vs. dsch. Energy

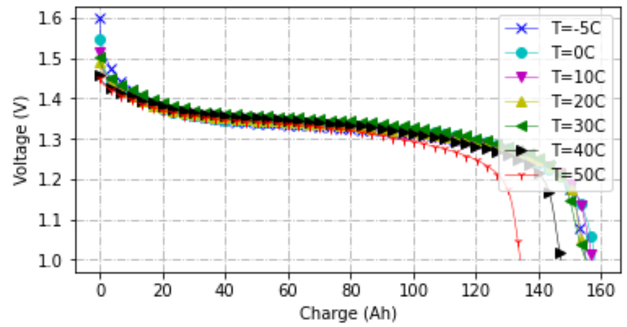

Figure 4.b. Discharge cycle cell voltage vs. dsch. Energy

STORLYTICS BATTERY SCORE SHEET

EnerVenue Energy Storage Vessel (ESV)

3. Scored Use Case

Technical and cost of ownership values were deduced based on performing the use-case described in this section. The use-case profile shown in Figure 5 is assumed to be executed daily, for the entirety of the project life. The Beginning of Life (BoL) energy capacity (for both EnerVenue batteries and the lithium benchmark) was sized to allow the system to maintain the Energy Capacity Requirement as outlined in Table III.

Table III. Performance requirements

Power Req. at POI	25 MW
Duration Req.	4 hours
EoL Dsch Energy Req. at POI	100 MWh
Project Life	20 Years
Cycle Count per Day	2.1 Cycles
Cycle Count per Asset Life	15,330 Cycles
Deployment Strategy	Overbuild
Applications	Energy Arbitrage PJM RegD , PV clipped Energy

Storlytics simulated both EnerVenue's (ESV) battery and a tier-1 Li-Ion ($LiFePO_4$) battery executing the POI profile shown in Figure 5. This simulation leveraged fully validated battery models developed within Storlytics software. Storlytics software's native file format for batteries is (.btt).

EnerVenue's battery model was developed and validated for operation at a temperature of 20°C.

The Li-Ion ($LiFePO_4$) model was developed and validated for 24°C cell temperature. The Li-Ion system degradation model was validated using SoH guarantee data from dozens of projects offered by a tier-1 Li-Ion battery OEM. Modeling accounted for variance in cycle DoD, C-rate, avg SoC, and project life. Table IV provides specifications required of both systems to meet performance requirements described in Table III.

Table IV. System specifications required to perform use-case

	EnerVenue (ESV)	Lithium (LFP)
Simulation Amb. Temp	20 °C	24 °C
Required BoL Energy	112.36 MWh	219.17 MWh
Max SoC	100%	96%
Min SoC	3%	3%

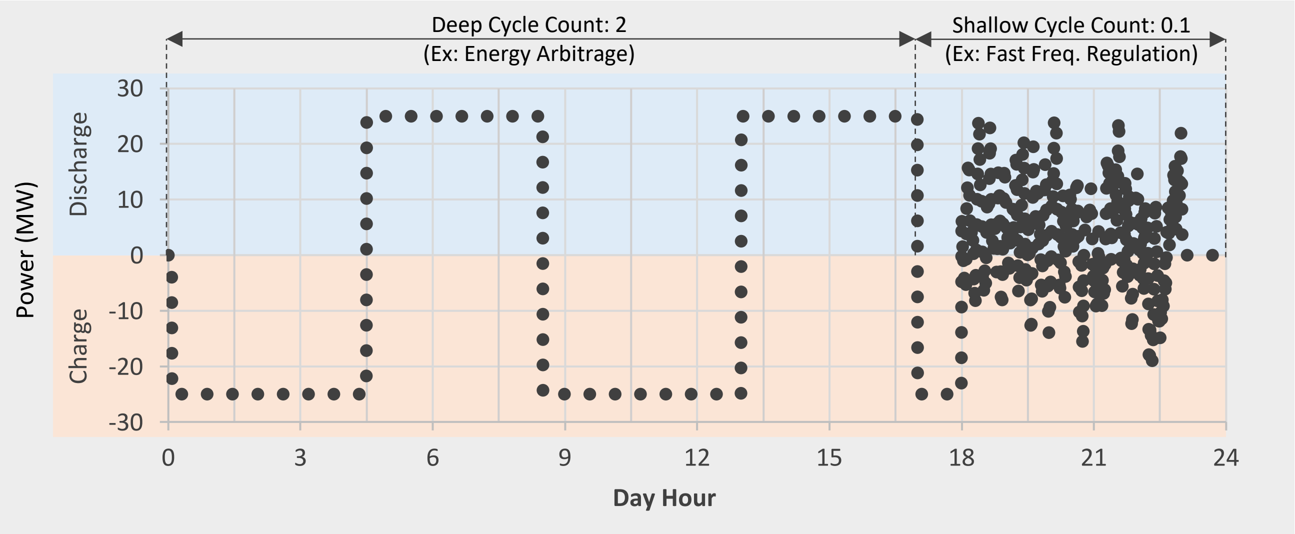

Figure 5. Point of Interconnection (POI) profile for both Li-Ion ($LiFePO_4$) and EnerVenue (ESV) systems

STORLYTICS BATTERY SCORE SHEET

EnerVenue Energy Storage Vessel (ESV)

4. Cell Degradation

Degradation of both battery systems was characterized by the following points:-

- It is noted that the EnerVenue system has significantly superior capacity degradation characteristics than the designed Li-Ion ($LiFePO_4$) system.
- Even after performing several cycles for 20 years, the EnerVenue system's state of health degrades only to 93.20%. On the contrary, the degradation rate of Li-Ion ($LiFePO_4$) systems is much higher and reaches close to its state of health limit of 65%, beyond which the Li-Ion OEM does not guarantee performance.
- Figure 6 and Table V indicate that the BoL capacity required for the Li-Ion ($LiFePO_4$) system (219.17MWh) is much greater than that required for the EnerVenue (ESV) system (112.36 MWh). This is to perform the same use-case described in section 3, for the same number of years.
- For Li-Ion ($LiFePO_4$) system if the BoL is reduced, the EoL capacity goes below the OEM minimum guaranteed SoH of 65%. To keep SoH greater than this value and meet throughput requirements of the use-case profile, the Li-Ion ($LiFePO_4$) system needed to be oversized. Table V shows the degradation of both systems.

Table V. Degradation comparison

	EnerVenue (ESV)		Li-Ion ($LiFePO_4$)	
Year	SoH (%)	DC Capacity (MWh)	SoH (%)	DC Capacity (MWh)
0	100.00	112.36	100.00	219.17
1	99.65	111.97	94.25	206.56
2	99.30	111.57	92.29	202.26
3	98.95	111.18	90.54	198.44
4	98.60	110.79	88.84	194.71
5	98.25	110.40	87.17	191.04
6	97.91	110.01	85.53	187.45
7	97.57	109.62	83.92	183.92
8	97.22	109.24	82.34	180.46
9	96.88	108.85	80.79	177.07
10	96.54	108.47	79.27	173.74
11	96.20	108.09	77.78	170.47
12	95.86	107.71	76.32	167.26
13	95.53	107.33	74.88	164.12
14	95.19	106.96	73.47	161.03
15	94.86	106.58	72.09	158.00
16	94.52	106.20	70.73	155.03
17	94.19	105.83	69.40	152.11
18	93.86	105.46	68.10	149.25
19	93.53	105.09	66.82	146.44
20	93.20	104.72	65.56	143.69

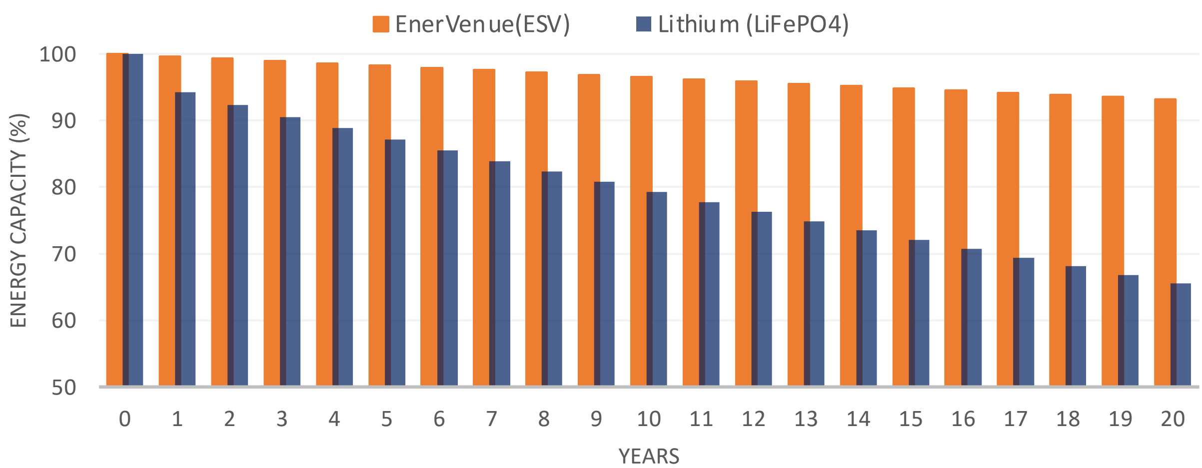

Figure 6. Energy capacity degradation comparison between EnerVenue (ESV) and Li-Ion ($LiFePO_4$)

STORLYTICS BATTERY SCORE SHEET
EnerVenue Energy Storage Vessel (ESV)

5. Cost of Ownership Results

The following major factors contributed to the EnerVenue system achieving a more advantageous lifetime cost of ownership cost.

- The EnerVenue (ESV) battery system has significantly superior capacity degradation performance compared to the Li-Ion ($LiFePO_4$) system.
- The EnerVenue system required an initial beginning-of-life capacity of 112 MWh compared to Li-Ion's 219 MWh.
- Accordingly, the capital cost of the EnerVenue system ($39 MM) was deduced to be less than that of the Li-Ion system ($ 62 MM).
- The EnerVenue system did however achieve a lower DC round-trip efficiency (RTE) of 90.25% compared to the Li-Ion (LiFePO4) system's 97.68%, for the same use case described in section 3.
- Accordingly, the annual cost of energy losses was deduced to be more for the EnerVenue system ($ 992,910) than that for the Li-Ion system ($230,742).

As a result of these factors, and as shown in table VI, and Figure 7, the total cost of ownership for executing this high cycle use-case was found to be more advantageous with the EnerVenue battery.

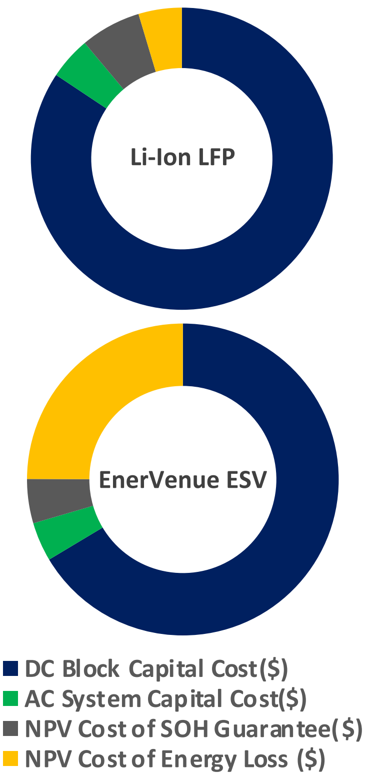

Figure 7. Ownership cost distribution of both systems.

Table VI. Financial comparison between EnerVenue (ESV) and the Li-Ion (LiFePO4) systems

	EnerVenue (ESV)	Li-Ion ($LiFePO_4$)
Project Life	20 years	20 years
Cost per unit energy ($/kWh)	350	285
Required BoL Energy Capacity (MWh)	112.36	219.17
DC Block Capital Cost($)	$ 39,326,000	$62,463,450
AC System Capital Cost($)	$ 2,400,000	$3,360,000
Total System Capital Cost($)	$ 41,726,000	$65,823,450
SoH Guarantee Cost per year ($)	$ 179,776	$317,797
NPV Cost of SOH Guarantee($)	$ 2,715,387	$4,800,087
Energy Loss Per Year (MWh)	9026.45	2,097.66
Cost of Energy Loss per Year($)	$ 992,910	$ 230,742
NPV Cost of Energy Loss ($)	$ 14,771,986	$ 3,432,859
NPV of Total Running Cost($)	$ 17,487,373	$ 8,232,946
Discount rate	3%	3%
Total Cost ($)	$ 59,213,373	$ 74,056,396
Required EoL Energy(MWh)	100	100
Effective Cost per Required EoL Energy($/kWh)	**$ 592**	**$ 741**

APPENDIX

Scoring Background

Storlytics Battery Score Sheets (BSSs) evaluate new ES technologies based on defined use cases. This is because performance characteristics of battery systems, like losses, auxiliary load, and degradation, vary widely based on the use case they execute over their lifetime. Additionally, most battery technologies are heavily affected by the meteorological conditions of install location. Therefore, it becomes imperative to associate battery technology ratings with use cases and any other tech-specific modeling details. This scoring compares the performance of the EnerVenue (ESV) energy storage system with a tier-1 Li-Ion($LiFePO_4$) storage system. The score sheet provides insights about the following features:-

- EnerVenue battery degradation compared to a tier-1 Li-Ion($LiFePO_4$) system for a multi-cycle per day use case
- EnerVenue energy storage system's efficiency compared to a Li-Ion($LiFePO_4$) system
- Overall cost of ownership of the EnerVenue system compared to the Li-Ion($LiFePO_4$) benchmark

Acronyms

BESS	Battery Energy Storage Systems
BoL	Beginning of Life
CPV	Common Pressure Vessel
DOD	Depth of Discharge
EoL	End of Life
ESV	Energy Storage Vessel
IPV	Individual Pressure Vessel
NPV	Net Present Value
SoC	State of Charge
SoH	State of Health
OCV	Open Circuit Voltage
LFP	Lithium Iron Phosphate
RTE	Round Trip Efficiency
PPC	Power Plant Controller

Full Report Access

The full report for this analysis is titled *"Technology Evaluation of Enervenue Nickel-hydrogen (ESV) 160ah Battery Cell"*. It consists of two main parts: -

1. *"Part I: Characterization & Modeling"*
2. *"Part II: Performance Benchmarking Against Li-Ion LFP Systems"*

The full report of this analysis is made available by Storlytics Energy Storage. To receive a copy, please contact support@storlytics.net.

Simulation Files

The simulation files used to deduce the results in this score sheet can be found through this link:
Download Simulation Files
To simulate your own use-case, simply download the simulation files, and edit the system sizing and POI Profile per your case.

About Storlytics

Storlytics is a US based consulting and software firm specializing in grid-tied energy storage systems. Our team of PhDs and professional engineers support and partner with industry leading integrators, battery OEMs ,utilities, Universities, and national labs to develop accurate models for conventional and new grid tied battery energy storage systems. This allows us to perfect our energy storage modeling software Storlytics® for our clients.
Our mission is simple, ***"Enable renewable energy developers, integrators, and utilities to easily design and optimize energy storage projects"***
Storlytics' engineers bring more than 20 years of combined energy storage industry experience into the simulation of grid tied battery systems within the Storlytics platform.
Recognizing major industry pain points in uncertainty of degradation and system loss profiles of battery energy storage systems, the Storlytics team built the Storlytics platform to accurately estimate expected degradation of battery energy storage systems, allowing our users to reduce project uncertainty and risk. This also allows our users to optimize project design and select the best battery technology and OEM for the user's specific case.
For more information about Storlytics software and consulting services, please reach out to support@storlytics.net.