Newfoundland and Labrador Hydro
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September 29, 2023

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: Jo-Anne Galarneau
Executive Director and Board Secretary

Re: Reliability and Resource Adequacy Study Review – Battery Energy Storage System Study

At the technical conference on the *Reliability and Resource Adequacy Study Review* proceeding ("*RRA Study Review*") on May 1 and 2, 2023, Newfoundland and Labrador Hydro ("Hydro") provided an overview of all of the reports, studies, and analyses underway or planned for fulsome consideration of the next supply resource for the province. Following the technical conference, in correspondence dated May 5, 2023, the Board of Commissioners of Public Utilities ("Board") directed Hydro to file a number of updates regarding the studies and analyses ongoing within the *RRA Study Review*. In particular:

1) Hydro shall file by May 19, 2023 a comprehensive list of all reports, studies and analyses it has currently underway or planned with respect to the reliability of the LIL, potential alternative generation resources, the load forecast, and any other issues raised in the 2022 RRAS Update and the May 1-2, 2023 technical conference. This list shall include a description of the scope of each study, report and analysis, the consultant or group undertaking the work and the schedule for completion.

2) Hydro shall file with the Board a copy of each report, study or analysis listed in response to number 1 above as it is completed.[1]

On May 25, 2023, Hydro provided the Board with a list of all reports, studies, and analyses currently underway or planned to support future filings in relation to the RRA Study Review.[2] Enclosed with this letter is an overview of the Battery Energy Storage System Study, which includes attachments containing the study performed by Wood Canada Ltd.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Shirley A. Walsh
Senior Legal Counsel, Regulatory
SAW/sk

[1] "Newfoundland and Labrador Hydro - Reliability and Resource Adequacy Study Review - To Parties - Further Process," Board of Commissioners of Public Utilities, May 5, 2023, p. 2.
[2] "*Reliability and Resource Adequacy Study Review* – Listing of Planned Reports, Studies, and Analyses," Newfoundland and Labrador Hydro, May 25, 2023, Table 1 and att. 1.

Encl.

ecc:

Board of Commissioners of Public Utilities
Jacqui H. Glynn
Cheryl Blundon
Maureen Greene, KC
PUB Official Email

Labrador Interconnected Group
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Bernice Bailey, Browne Fitzgerald Morgan & Avis

Battery Energy Storage System Report

Overview

September 29, 2023

A report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro

Contents

List of Attachments

Attachment 1: "BESS Project Preliminary Cost Estimate 258257-0000-DF00-STY-0001," Wood Canada Limited, rev. September 22, 2023 (originally issued June 23, 2023).

Attachment 2: "Long Duration Battery Energy Storage System Report 258259-0000-DF00-STY-0001," Wood Canada Limited, rev. September 22, 2023 (originally issued June 30, 2023).

1.0 Context within the RRA Study Review

Newfoundland and Labrador Hydro ("Hydro") filed the "Reliability and Resource Adequacy Study" ("2018 Filing") with the Board of Commissioners of Public Utilities ("Board") in November 2018.[1] Since the 2018 Filing, Hydro has filed regular updates to the Reliability and Resource Adequacy Study, numerous technical notes, additional studies, and third-party reports. The *Reliability and Resource Adequacy Study Review* proceeding ("*RRA Study Review*") has included five rounds of requests for information and four technical conferences, providing for substantial discourse and exchange of information between Hydro, the Board, and the parties. Further, there are additional studies and reporting underway and upcoming throughout the next year.

The regulatory record for this proceeding is robust, with good reason. The provincial electrical grid is in the midst of unprecedented change—it is evolving from an isolated to an interconnected system, some of the assets the province has historically relied on most are aging and nearing retirement, there are significant new assets integrated into the electrical system and being proven reliable, and the province is facing a material increase in load driven by global transitions from fossil fuels to renewable energy sources.

In the coming years and decades, Hydro will have to make significant investments to maintain its legislative obligation of safely and reliably providing electrical service in an environmentally responsible manner to Newfoundlanders and Labradorians.[2] As such, through the *RRA Study Review*, Hydro is modelling its system expansion in consideration of various forecast scenarios and within the context of continuously evolving energy policy. The numerous studies that Hydro has completed and planned are all necessary to validate and justify the information that Hydro feeds into its models that produce critical information on which timely, prudent decisions are to be made.

While the enclosed study provides valuable, necessary information, it cannot and should not be considered independent of the rest of the studies and analyses ongoing through the *RRA Study Review*. Rather, the study is an input that will—along with other studies completed and ongoing—inform Hydro's broader system resource planning process now and into the future.

[1] "Reliability and Resource Adequacy Study," Newfoundland and Labrador Hydro, rev. September 6, 2019 (originally filed November 16, 2018.
[2] *Electrical Power Control Act*, 1994, SNL 1994, c E-5.1, s 3(b)(iii).

2.0 Background

In its May 25, 2023 correspondence to the Board, Hydro advised that it had engaged Wood Canada Limited ("Wood") to complete a study that includes updated information on the feasibility of Battery Energy Storage System ("BESS") technology as it pertains to capacity constraints on the Avalon, including updated cost information for modelling purposes.[3] Wood's final report is divided into two phases—Phase 1 (provided as Attachment 1) and Phase 2 (provided as Attachment 2), known collectively as the "BESS Report." The two phases of the BESS Report are:

- **Phase 1**: An update of the 2022 battery study,[4] which focused on the development of a battery storage project on the Avalon Peninsula, including an update to the AACE[5] Class 5 cost estimates, for the following two options:
    - **Option 1**: 20 MW with a four-hour reserve; and
    - **Option 2**: 50 MW with a four-hour reserve.

  These options were selected to be representative of a small and a large battery project and can be scaled to represent larger battery projects.[6]

- **Phase 2**: Investigate batteries with larger storage capacities, likely from newer battery technologies (e.g., iron air, flow, etc.) with potential storage capacities of up to 50 to 100 hours and with capacities of 20 MW to 50 MW. The consultant was asked to provide guidance on storage capacities for any identified options, as well as a jurisdictional scan to see if there are other utilities using the identified technologies and assess the maturity of the technology.

It is important to note that the BESS Report is not intended to and does not make recommendations as to whether short- or long-duration batteries are an appropriate solution to meet the needs of the electrical system. This determination will be made in consideration of all matters being contemplated

[3] "*Reliability and Resource Adequacy Study Review* – Listing of Planned Reports, Studies, and Analyses," Newfoundland and Labrador Hydro, May 25, 2023.
[4] The 2022 battery study—"BESS Project Preliminary Cost Estimate 254388-000-DF00-STY-002," Wood Canada Limited, rev. August 22, 2022 (originally issued July 12, 2022)—was provided as Attachment 3 to Hydro's response to PUB-NLH-288 of this proceeding.
<http://pub.nl.ca/applications/NLH2018ReliabilityAdequacy/rfis/PUB-NLH-288.PDF>.
[5] American Association of Cost Engineering ("AACE").
[6] The cost for larger storage capacities increases proportionately to the increase in MWh capacity, on average. The study also provided a cost estimate approximation for an 8-hour BESS system and a 12-hour BESS system.

within the *RRA Study Review*. Rather, the BESS Report provides valuable information that will serve as input and improve the quality of Hydro's resource planning model. It is a prudent, necessary step in the evaluation of existing and emergent BESS technology.

The purpose of this overview report is to provide a high-level summary of Wood's findings and recommendations, as well as Hydro's assessment of those findings and planned next steps.

3.0 Summary of Wood's Findings

3.1 Phase 1: Short-Duration BESS

Phase 1 of the BESS Report provides an update to the 2022 battery study to validate equipment pricing and lead times for the following options:

- **Option 1**: 20 MW with a four-hour reserve; and
- **Option 2**: 50 MW with a four-hour reserve.

BESS technology can be used to store surplus energy generated from wind, solar, and hydro, which can then be used to provide short-duration backup as well as firm up intermittent renewable sources, such as wind generation. The four-hour duration options can also be scaled to 8-hour and 12-hour BESS systems, depending on system requirements.

The cost summary table included in Attachment 1 to this overview[7] provides a detailed comparison between the 2022 and 2023 cost estimates, with the 2023 cost estimate for each option included in Table 1.

[7] "BESS Project Preliminary Cost Estimate 258257-0000-DF00-STY-0001," Wood Canada Limited, rev. September 22, 2023 (originally issued June 23, 2023), p. 6.

Table 1: Estimated Class 5 Project Cost ($000)[8,9]

Project Cost	20 MW BESS (4-hour at 20 MW)	50 MW BESS (4-hour at 50 MW)
Engineering and Permitting	940	1,040
BESS Area	39,310	84,950
Terminal Station Upgrades (69 kV)	5,034	5,780
Contingency (10%)	4,981	10,094
Owner Cost (10%)	4,528	9,177
Total	**54,794**	**111,044**

The installed cost of the 20 MW and 50 MW options have increased by 28% and 14%, respectively, largely due to major electrical equipment price increases, such as the transformers and the 35 kV switchgear. The update did not identify any changes in technology that would impact project cost.

The delivery lead times for the BESS units have not increased; however, the lead times for the major electrical equipment have increased considerably, resulting in a project duration of five years from the start of FEED[10] analysis to the completion of construction for both options. Currently, the lead times for power transformers and circuit breakers—43 months and 23 months, respectively—are exceptionally long. The indicative project schedule considers these long lead times.

3.2 Phase 2: Long-Duration BESS

Phase 2 of the BESS Report includes an investigation of long-duration battery storage technologies that are available in the market with 50 to 100 hours of storage capability for 20 MW and 50 MW capacities. Long-duration energy storage ("LDES") can be used to store surplus energy generated from wind, solar, and hydro, which can then be used to provide multi-day power backup as well as firming-up intermittent renewable sources, such as wind generation.

Manufacturers are investigating various types of technologies for LDES and a review of the market was completed to identify manufacturers with new technologies, such as iron-air and flow batteries. Seventeen major energy storage manufacturers were contacted to assess technical and commercial

[8] The total estimated cost is presented in 2023 dollars and does not include escalation, land costs, transmission upgrades, or any additional project costs that may be required.
[9] Numbers may not add due to rounding. Please refer to Attachment 1, Appendix B to this overview for a detailed cost breakdown of both options.
[10] Front-end engineering design.

details of their products, such as battery chemistry, power capacity, storage capacity, module sizes, land requirements, operating temperature range, existing installations, current phase of development, planned future projects, and product life. The key advantages of the technologies, the system components, cost, and current production facilities were also evaluated, if available.[11]

Due to limited information shared by manufacturers, Class 5 cost estimates for LDES project development could not be determined; rather, costs were determined based on publicly available information. Attachment 2 to this overview includes a summary of the long-duration technologies and associated parameters that were gathered.[12] At this time, Form Energy's iron-air battery is the only potentially cost-effective,[13] long-duration storage solution that is expected to be available within the next ten years; however, their first pilot project is not planned until 2024.

4.0 Conclusion and Next Steps

Should Hydro's planning process identify a need for short-duration battery storage technology, Hydro will proceed to study this option in more detail to provide the information necessary to support the appropriate supply decision for the province. At this time, there are no proven installations for long-duration storage batteries and, while promising, uncertainties remain with this technology. Hydro will continue to seek updates on any emerging technology trends for both short- and long-term battery storage technologies.

[11] Limited information is available at this time, as most of the products are in demonstration or early adoption stage and most manufacturers require non-disclosure agreements ("NDA") prior to sharing any significant technical or commercial information.
[12] "Long Duration Battery Energy Storage System Report 258259-000-DF00-STY-0001," Wood Canada Limited, rev. September 22, 2023 (originally issued June 30, 2023), sec. 7, p. 12.
[13] Form Energy did not provide any cost estimate for their batteries; however, they indicated they are targeting less than USD $20/kWh (USD $2,000/kW for a 100-hour project) by 2030. Please refer to Section 5.1.4 of Attachment 2 to this overview.

Attachment 1

BESS Project Preliminary Cost Estimate
258257-0000-DF00-STY-0001

Wood Canada Limited

Revised September 22, 2023

BESS Project Preliminary Cost Estimate

258257-0000-DF00-STY-0001

September 22, 2023

Wood Canada Limited
133 Crosbie Road
P.O. Box 9600
St. John's, NL, A1A 3C1

wood.

APPROVALS

Prepared by: Lewis Hann	September 22, 2023 Date
Checked by: Doug Walters	September 22, 2023 Date
Approved by: Lewis Hann	September 22, 2023 Date

Professional Stamp

REGISTERED PROFESSIONAL ENGINEER
LEWIS HANN
SIGNATURE
22-SEPT-2023
DATE
NEWFOUNDLAND & LABRADOR

PROVINCE OF NEWFOUNDLAND AND LABRADOR
pegnl
ENGINEERING PERMIT D0018
Wood Canada Limited
02020
Signature or Member Number (Member-in-Responsible Charge)

IMPORTANT NOTICE

REVISION HISTORY

Rev.	Description	Prepared By	Checked By	Approved By	Date
A	Issued for review	AP	LH	LH	June 23, 2023
0	Issued for Use	AP	LH	LH	July 07, 2023
1	Issued for Use	AP	LH	LH	July 28, 2023
2	Issued for Use	LH	DW	LH	September 22, 2023

Table of Contents

1. Executive Summary

Newfoundland and Labrador (NL) Hydro is looking for an opportunity to introduce AC coupled Battery Energy Storage Systems (BESS) into their existing infrastructure. Wood prepared an earlier estimate for development of a Battery Energy Storage System project on the Avalon peninsula of Newfoundland in August 2022, document no. 254388-0000-DF00-STY-0002 Rev C. This is an update to the 2022 report to validate equipment pricing and lead times. This latest estimate did not identify any changes in technology that would impact project cost, however the scope changes.

The options considered for the 2022 report and for this current report are as follows:

Option 1: 20MW with 4-hour reserve.
Option 2: 50MW with 4-hour reserve.

As was the case in the 2022 report, the BESS systems will support short-term power shortfall in contingency situations. The specific location of the battery storage system has not been determined, but it is anticipated that may be deployed on the Avalon Peninsula and interconnected at an existing terminal station on a 66kV/69kV bus.

The cost summary table in Section 4.3 provides a detailed comparison between the 2022 and 2023 estimates. The installed cost of SunGrid BESS package has increased by 28% for the 20MW option and 14% for the 50MW option. The overall increase in 69kV equipment cost is more than 80%. This is a result of major equipment price increases: the 20MVA step-up transformers has increased in by more than 300% and the 35kV switchgear has increased by more than 400%.

A more thorough analysis of the real-estate requirements indicates that BESS system will require a larger footprint than that which was assumed in 2022, per technical guidance provided by SunGrid. The total land requirement has increased by approximately 70% for both options. The increased footprint has increased the electrical and civil costs accordingly. Every vendor provides different MW/MWh capacity per container and as a result physical sizes will vary. Specific vendor considerations such as energy capacity per container may have a significant impact on the real-estate requirements and maybe one of the many factors in ultimate vendor selection.

The delivery lead times for the BESS units has not increased, however the lead times for the major electrical equipment has also increased considerably, for example the transformer lead time increased from 10 months to 43 months.

2. Purpose and Scope

The purpose of the report is to provide a recent indicative (Class 5) cost estimate for a 20MWac and 50MWac BESS system with 4-hour reserve. The BESS would be connected to the existing terminal station at 66kV/69kV bus. This estimate includes relevant MV substation interconnection components needed to integrate with the existing terminal stations. For the purpose of this estimate, 69kV voltage level shall be considered.

Wood has made assumptions based on industry standards and previous experiences with AC coupled BESS, as follows:

- MV collector system design including substation requirements.
- Project scheduling and major project milestones.
- Developmental activities such as field investigation (ex. Geotech report), desktop studies, permitting, preliminary & detailed engineering, environmental studies, licenses, etc.

- Major equipment costs.
- Supporting activities during the construction stage (Site management & monitoring, owner engineer costs, safety, equipment rental, etc.).
- Construction cost for both BESS and upgrades at the existing 69kV terminal station.

3. System Characteristics

This section describes technologies and technical characterises of the major components for AC coupled BESS package, MV collector system including associated cabling, substation components required at the terminal station (such as main power transformer, breaker, disconnect switch, protection, and metering).

3.1 Battery Energy Storage System (BESS)

The proposed BESS solution is AC coupled, where batteries are connected to a common MV bus at the substation. The system can store energy from any generation source with main purpose being to discharge during peak electricity use. Peak shaving concept is depicted on **Figure 1** below.

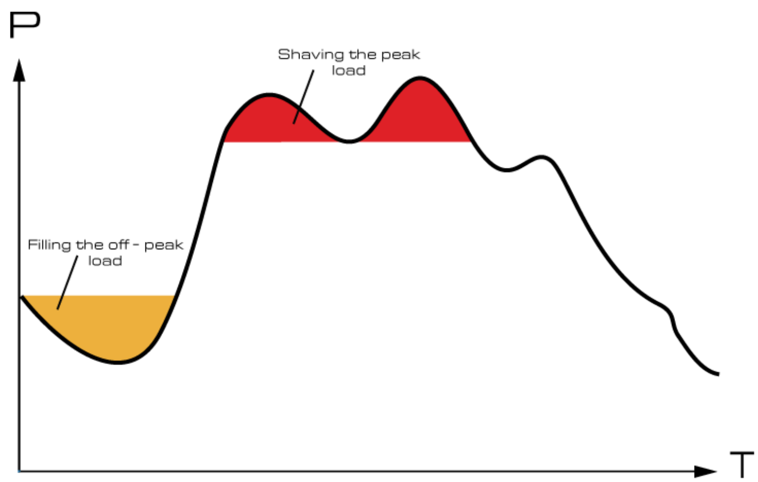


Figure 1: Peak shaving concept

AC coupled systems are generally considered for existing electrical infrastructure as they are easier to retrofit when compared to DC coupled solutions (typical for new solar PV installations). This is not applicable for BESS systems which are coupled to the AC source for the purpose of emergency backup or peak shaving. In AC coupled systems there is additional power conversion, from generating source to BESS and then from BESS to AC grid, resulting in additional efficiency losses. Both the PCS as well as the DC-DC convertors have efficiency of 99% (approx.). Resulting in an efficiency of 98%, excluding the MV transformer efficiency.

The typical industry standard for BESS lifespan is 20 years and standard warranties are 3 years. Extended warranties up to 20 years can be procured, however pricing for this was not available for this study.

3.2 Civil Engineering Considerations

A more thorough analysis of the real-estate requirements indicates that the BESS system will require a larger footprint than that which was assumed in the 2022 report, per technical guidance provided by SunGrid. Specific vendor considerations such as technology, energy capacity per container, clearances, topography, substation configuration, etc. may have a significant impact on the real-estate requirements and maybe one of the many factors in ultimate site and vendor selection. Additionally, 69kV expansion space in terminal station will also be required to accommodate terminal station interconnection equipment.

A typical BESS is housed in container with approximate dimensions: 9.340m (L) x 1.730m (W) x 2.600m (H) for the solution provided by Sungrid, however every vendor provides different MW/MWh capacity per container and as a result physical sizes will vary. Wood considered 0.6MW/2.637MWh for a typical container from Sungrid.

Containers required:

a) Option 1: 20MW, 4 hours reserve system would require 34 containers.
b) Option 2: 50 MW, 4 hours reserve system would require 84 containers.

A typical arrangement of containers is indicated below in **Figure 2 and Figure 3**:

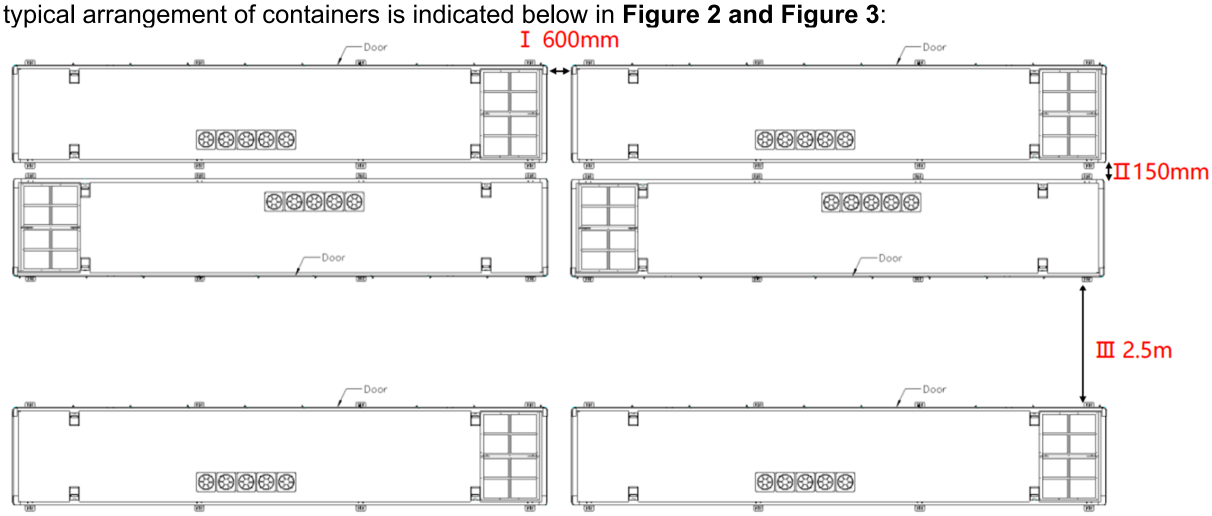


Figure 2: BESS Layout with clearances

The arrangement will require following area:

a) Option 1: 8 sets (4 containers each) x [(9.34+0.6+9.34+2.5)m x (1.73+0.15+1.73+2.5)m] + 20% contingency for PCS, Inverters, transformer, switchgear, roads, fencing, etc. **~ 1350 m²**

b) Option 2: 21 sets (4 containers each) x [(9.34+0.6+9.34+2.5)m x (1.73+0.15+1.73+2.5)m] + 20% contingency for PCS, Inverters, transformer, switchgear, roads, fencing, etc. **~ 3350 m²**

Figure 3: BESS Layout

3.3 MV collector system

Wood recommends having BESS system stepped up at 34.5kV level which is industry standard distribution voltage for the collector system in renewable sector; further this will be stepped up to 69kV level at the terminal station. A typical BESS package will consist of a DC battery pack, DC-AC inverter, and 34.5kV step-up transformer connecting to point of common coupling (PCC) as per **Figure 4** below.

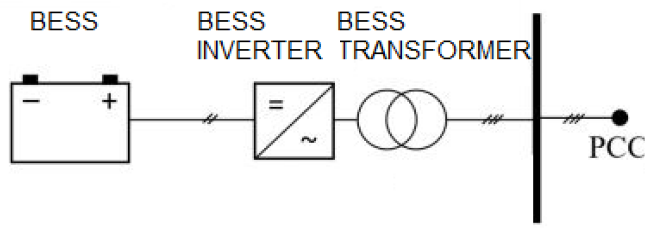


Figure 4: BESS SLD

As indicated above Wood assumed 0.6MW/2.637MWh block. Units will be daisy chained and connected to a dedicated 34.5kV switchgear at the terminals station as per sample single line noted in **Figure 5**. Depending on the size of the BESS system, additional feeder breakers may/may not be required. Further, design philosophy may dictate less BESS blocks in a circuit to ensure redundancy in case of trip or maintenance. With this approach, other blocks connected in a separate 34.5kV circuit can perform without interruption.

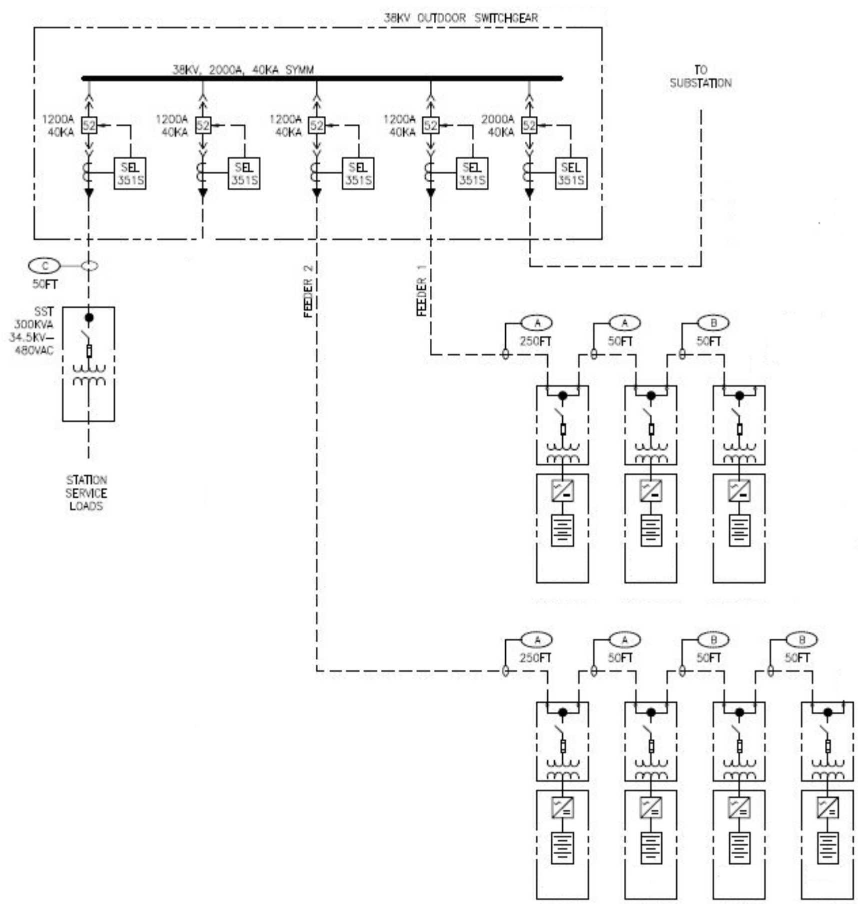


Figure 5: BESS AC arrangement

In addition to 34.5kV distribution, each BESS container will require external power supply for auxiliary loads (HVAC, controls, small power, etc.) and fiber optic connection to SCADA system.

3.4 Terminal Station interconnection

At the existing MV terminal station (69kV), it would be necessary to step up from 34.5kV switchgear to the terminal station voltage. For the interconnection, it will be necessary to interface with new 69kV breaker along with 69KV voltage transformer (for relay protection purposes), HV metering structure and main two stage fan cooled step-up transformer as follows:

- Option 1: 12/16/20MVA, 69kV-35kV
- Option 2: 30/40/50MVA, 69kV-35kV

A typical Single line diagram for the 69kV interconnection is indicated below in **Figure 6**:

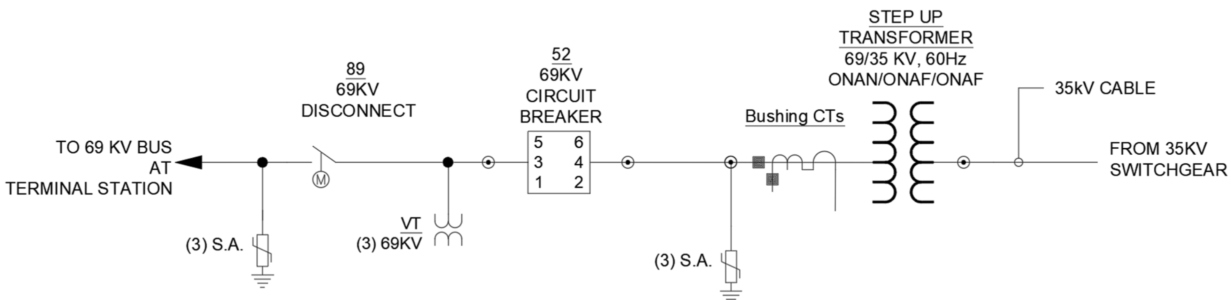


Figure 6: 69kV interconnection SLD

4. Cost and Schedule

4.1 Type of Estimate

This estimate is a Class 5 indicative estimate. This classification represents a rough order of magnitude estimate. It generally implies from -20% to -50% on the low side and +30% to up to 100% on the high side in accordance with AACE International Recommended Practices.

4.2 Project schedule

Project schedule is very important aspect in particular in today's volatile market and much longer lead time for equipment procurement. Addressing preliminary design at early stages and securing long lead items are critical for the overall project delivery. This in particular refers to: BESS packages, 69kV substation equipment such as main transformer, PTs & breakers.

Utility scale BESS are new in NL and availability of skilled resources and general labour may be limited. Construction activities shall ensure that all civil and electrical work occurs in spring to fall period. During winter months limited electrical work (such as LV wiring connections at protection building), commissioning activities and addressing minor deficiencies can occur.

Geotech field work must be performed as soon as possible so the project team can understand the proposed land features in order to plan for proper foundation design for BESS. For indicative project schedule please refer to **Appendix C**.

Project durations for BESS installations can range from approximately one year for accelerated commercial ventures to in excess of 2 years when pre-feed activities, permitting, project sanctioning, procurement of long lead items and construction season limitations are all taken into account. However, currently the lead times for power transformers (43 months) and circuit breakers (23 months) is exceptionally long. The indicative project schedule in Appendix C takes these elements into consideration.

Following is a list of typical sequential project activities:

a) Permitting and approval process
b) Geotech field work
c) Base engineering (needed for key equipment procurement)
d) Equipment procurement
e) Detailed engineering
f) Construction
g) Testing and commissioning
h) Post construction activities (deficiencies, warranty items, etc.)

4.3 Cost Summary

20 MW BESS (4hr @ 20 MW / 80 MWh)		June 2023	August 2022	Percentage change (approx.)
	Engineering and Permitting	$940,000	$940,000	No Change
	BESS Area	$39,310,000	$30,795,000	28% Increase
	Terminal Station Upgrades (69 kV)	$5,030,000	$2,675,000	88% Increase
	Owners Cost (10%)	$4,528,415		
	Contingency (10%)	$4,981,257	$3,500,000	42% Increase
	Total Estimated Cost	**$54,793,823**	**$37,910,000**	**45% Increase**

50 MW BESS (4hr @ 50 MW / 200 MWh)		June 2023	August 2022	Percentage change (approx.)
	Engineering and Permitting	$1,040,000	$1,040,000	No Change
	BESS Area	$84,950,000	$74,582,000	14% Increase
	Terminal Station Upgrades (69 kV)	$5,780,000	$3,190,000	81% Increase
	Owners Cost (10%)	$9,177,203		
	Contingency (10%)	$10,094,923	$7,500,000	34% Increase

	Total Estimated Cost	**$111,044,157**	**$86,312,000**	**29% Increase**

All figures are shown in Canadian Dollars.

For detailed breakdown for both 20MW/80MWh and 50MW/200MWh BESS please refer to **Appendix B**

The cost for larger storage capacities increases approximately proportional to the MWh capacity increase. A project with an 8 hour system (double the MWh capacity) would be approximately 1.9 times a 4 hour system and a 12 hour system would be approximately 2.8 times a 4 hour system. The cost of 69kV terminal station and the engineering cost would remain approximately same.

Operation and maintenance costs depend on a number of factors, site conditions, wind & ice conditions, proximity to corrosive impacts from ocean, scope of services, etc. In general the fixed O&M costs are in the range of $8-18/kW/year and variable O&M cost can be assumed to be approximately $0.0004/kwh/year.

APPENDICES

Appendix A

AC Coupled BESS package.

SunGrid
Better energy for tomorrow

wood.

Customer:	John Wood Group PLC		SunGrid Solutions
Name:	Igor Bozic		135 George St. N
Contact:	Igor.bozic@woodplc.com		Cambridge, ON, N1S 2M6
			www.sungridsolutions.com
Project:	BESS in NL	Contact:	Jacky Jiang
Prj. #:	570		jacky.jiang@sungridsolutions.com
Quote #:	02		647-865-5624
Size:	20MW, 95MWh / 50MW, 221MWh	Date:	24-May-23
Delivery:	Newfoundland and Labrador	Valid:	30 Days

SunGrid Proposal For Professional EPC Indicative Quote

	20MW, 95MWh	50MW, 221MWh	Notes
Description	**Total Price**	**Total Price**	Dischargeble Energy = 95MWh DC and 221MWh DC at Year 0
Engineering Services	**$ 602,000**	**$ 965,000**	
Interconnection (support only)	**TBD**	**TBD**	
Permits (support only)	**TBD**	**TBD**	
Equipment			- Delivery Date: TBD
Tier 1 BESS	Included	Included	
- Enclosures, HVAC, FSS, DC combiner, DC Cab	Included	Included	Payment Terms
- Battery Racks	Included	Included	- 10% LNTP - 15% NTP
PCS MV Skid	Included	Included	- 20% 60% Drawing
Tier 1 EMS Hardware	Included	Included	- 15% IF Drawing
MV Switchgear Equipment, Auxiliary Transformer/Panel, SCADA, CCTV, BOP Equipment	Included	Included	- 15% Site Mobilization - 10% MajorEquipment Delivery - 10% COD
Shipping Logistics	Included	Included	- 5% Substantial Completion
Total Equipment	**$ 23,511,000**	**$ 51,640,000**	
Construction/Install			
Civil(Fencing, Foundations, Piles, Vaults etc.)	Included	Included	
Civil Site Works/ Install	Included	Included	
Mechanical Installation	Included	Included	
Electrical install (all terminations)	Included	Included	
Total Construction/Install	**$ 4,251,000**	**$ 8,285,000**	
Commissioning	Included	Included	
Sales Tax	Not Included	Not Included	
Warranty and Performance Guarantee			
3-year workmanship	Included	Included	
Total	**$ 28,364,000**	**$ 61,457,000**	

Clarification

- Pricing is in $USD
- Import duties and sales tax not included
- Owner responsible for final BESS and PCS freight adjustment to site.
- Assumed clear site/road access to BESS
- Non-unionized labour
- Transfer trip not included
- POI located within BESS site
- Permit fees, application fees, etc. not included (support only)
- Final Interconnection not included
- Substation/HV work not included
- Water well or city water or city sewer connection
- Customer responsible for performing geotechnical studies
- Noise, biological, environmental, cultural, archeological studies not included
- Clear unobstructed site/road access to BESS worksite. Construction of access road to BESS site not included.
- Temporary construction storage and machine parking on worksite.
- Temporary equipment laydown area provided on worksite.
- No construction noise reduction requirements between 7AM and 7PM local time.
- Assumed not within official floodplain.
- Removal or relocation of any underground or overhead obstructions or utilities, not included.
- No extreme irregularities with soil quality upon geotechnical analysis.
- Water well or city water or city sewer connection not required and not included.
- Hydrant relocations have not been considered and are not included.
- Assumes no hazardous and or contaminated material removal, investigation, abatement, or removals.
- Assumes no storm water management, erosion control or dewatering of subsurface water.
- Assumes no removal of unknown underground obstructions (including existing buried steel plates, existing foundations, existing bedrock, existing structures, boulders, abandoned utilities) or underground storage tanks.
- Utility fees and/or interconnection costs for infrastructure upgrade not included.
- BESS aux power to site provided by others (480V-3p)
- Internet connection provided by others; GSM modem or hardwired within 20m of BESS site.
- Charge/Discharge signal/algorithm not included, Provided by Others.
- SunGrid not responsible for full site EMS software licensing and subscription.
- SunGrid providing BESS controller/system capable of accepting signal from others (site EMS, Utility, or manual)
- Onsite commissioning cost associated with owner caused delays not included.
- FAT - Factory Acceptance Testing witnessing is completed overseas.
- Utility Transfer Trip requirements and infrastructure not included.
- Utility fees and/or interconnection costs for infrastructure upgrade not included.
- Excludes any PV/Solar work/Wind work
- SunGrid Solutions Inc. (SGS) reserves the right to revise pricing based on market conditions. SGS shall provide written notice to Buyer of any price increase coming into effect: a) based on Nickle (Ni), Cobalt (Co), Manganese (Mn), Lithium Carbonate (Li_2CO_3), Copper (Cu), Aluminum (Al), and Iron (Fe) price fluctuations. b) based on supply chain fluctuations. c) based on product availability d) based on RMB¥ – USD$ exchange rate fluctuations.
- Pricing excludes extended product warranty, capacity guarantees, availability guarantees and site operation, to be determined and negotiated as part of an LTSA.

Appendix B

Cost Estimate

Class 5 BESS Estimate	20MWac BESS, 4 h reserve				
Size (MW)	20				
Duration (h)	4				
Size (MWh)	80				
Development Activities	***Description***		***Quantity***	***Total ($ CAD)***	***Comments***
Engineering and Permitting					
1	Interconnection Studies		1	$50,000	
2	Environmental Assessments		1	$50,000	
3	Permits and licenses		1	$50,000	
4	Site surveys		1	$50,000	
5	Geotech		1	$40,000	
6	Detailed Engineering		1	$480,000	Assumes 4000 hours with an average rate of $120/hour. Includes construction support and occasional site visits
7	Site management (site mtg, cost controller, safety		1	$160,000	
8	Owner Engineer Role		1	$60,000	Includes drawing review and approval, occassional site visit
	Subtotal - Engineering and Permitting			**$940,000**	
BESS area					**Installed costs**
1	AC BESS package	Quotes obtained from Sungrid solution dt. May 24, 2023. Attached as Appendix A.	1	$38,699,842	Quotes includes civil works, foundation, BESS MV transfomers, HVAC, enclosures, PCS, DC connections. USD$ 28,364,000*1.3644[#] = CAD$ 38,699,842.
2	AC/fiber cabling to Substation		175	$175,000	Assume $1000/meter. Cable length increased due to more footprint as per BESS dimensions from Sungrid
3	Civil Works		1	$335,000	Includes site clearing, service roads, grubbing, drainage, etc. Civil work increased due to more footprint as per BESS dimensions from Sungrid
4	BESS system commissioning		1	$100,000	Cost reference from another project.
	Subtotal - BESS Areas			**$39,309,842**	
Terminal area (69kV)					**Installed costs**
1	Main step up transformer		1	$2,351,160	Average of prices from Manufacturers:"PTI transformers" and "Delta star". Rating: 12/16/20MVA, 2 stage fan cooled, 35kV-69kV
2	69kV Motorized Disconnect Switch		1	$28,000	Quote from Aesco.
3	69kV Surge arresters		1	$24,650	Average of Quotes from CandC and AESCO
4	69kV circuit breaker		1	$250,000	Quote from CandC - Siemens.
5	69kV PT (for protection)		1	$80,000	Internal cost reference from another project.
6	69kV Revenue Metering		1	$150,000	Internal cost reference from another project.
7	Addition to existing protection and control building		1	$200,000	Protection relays & racking, LV DC/AC wiring. It is assumed that new protection equipment will fit within existing P&C building
8	69kV support steel structures		1	$315,000	Internal cost reference from another project.
9	Station service transformer		1	$162,500	Considered a 1 MVA tranformer for feeding the auxiliary loads of BESS containers
10	Low voltage switchgear		1	$168,000	Switchgear added for auxiliary power distribution
11	35kV pad mount switchgear		1	$435,000	Quote from Powell Industries
12	Substation Civil works and foundation		1	$270,000	Internal references (includes foundation for main transformer, MV breaker, pad mount switchgear and support structures)
13	Substation testing and commissioning		1	$100,000	
14	Indirect Costs		1	$500,000	Equipment rentals, tools, etc.
	Subtotal - Terminal Area			**$5,034,310**	
	Owners Cost		0.1	**$4,528,415**	
	Contingency		0.1	**$4,981,257**	Assumes 10% (reference from another project)
	TOTAL			**$54,793,823**	

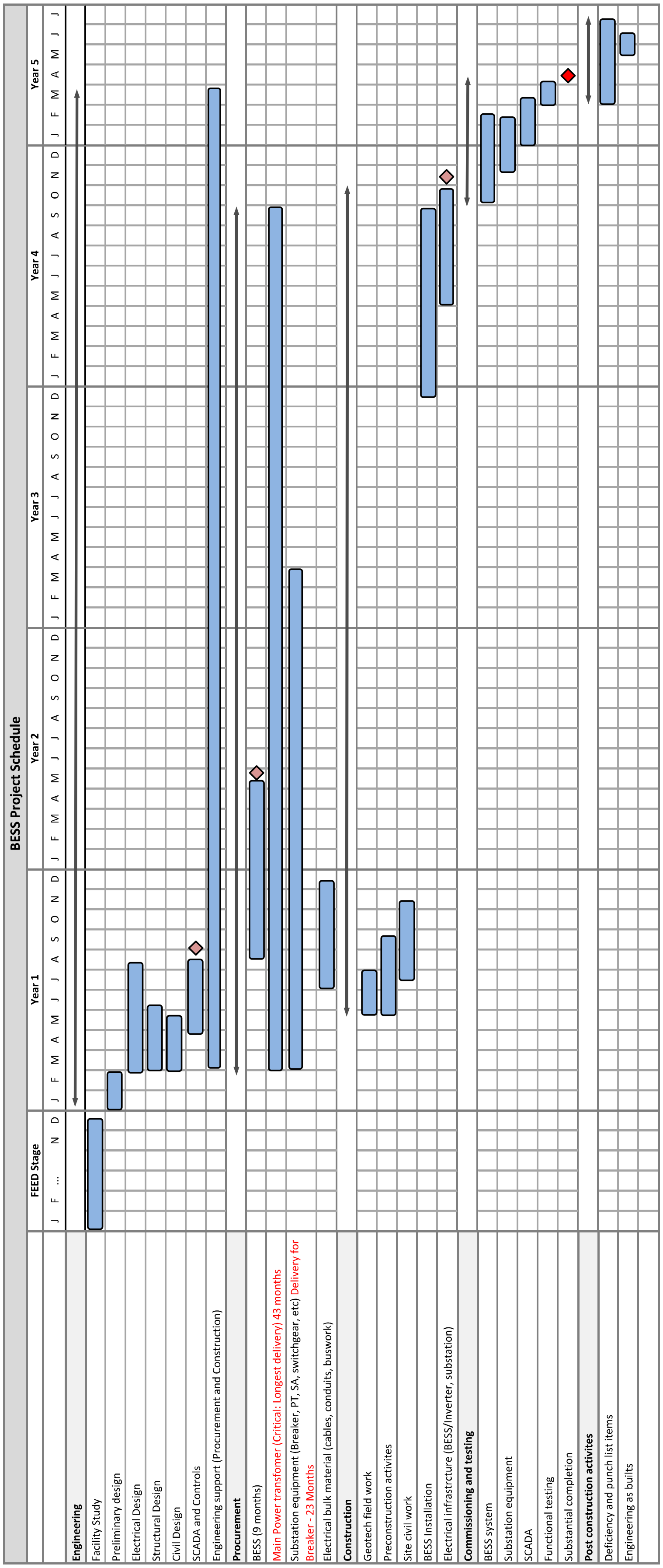
#USD to CAD exchange rate considered for BESS: **1.36**

Class 5 BESS Estimate	50MWac BESS, 4 h reserve				
Size (MW)	50				
Duration (h)	4				
Size (MWh)	200				
Development Activities	***Description***		***Quantity***	***Total ($ CAD)***	***Comments***
Engineering and Permitting					
1	Interconnection Studies		1	$50,000	
2	Environmental Assessments		1	$50,000	
3	Permits and licenses		1	$50,000	
4	Site surveys		1	$50,000	
5	Geotech		1	$40,000	
6	Detailed Engineering		1	$540,000	Assumes 4500 hours with an average rate of $120/hour. Includes construction support and occasional site visits
7	Site management (site mtg, cost controller, safety		1	$180,000	
8	Owner Engineer Role		1	$80,000	Includes drawing review and approval, occasional site visit
	Subtotal - Engineering and Permitting			**$1,040,000**	
BESS area					**Installed costs**
1	AC BESS package	Quotes obtained from Sungrid solution dt. May 24, 2023. Attached as Appendix A.	1	$83,851,931	Quotes includes civil works, foundation, BESS MV transfomers, HVAC, enclosures, PCS, DC connections. USD$ 61,457,000*1.3644# = CAD$ 83,851,931.
2	AC/fiber cabling to Substation		350	$350,000	Assume $1000/meter. Cable length increased due to more footprint as per BESS dimensions from Sungrid
3	Civil Works		1	$600,000	Includes site clearing, service roads, grubbing, drainage, etc. Civil work increased due to more footprint as per BESS dimensions from Sungrid
4	BESS system commissioning		1	$150,000	
	Subtotal - BESS Areas			**$84,951,931**	
Terminal area (69kV)					**Installed costs**
1	Main step up transformer		1	$2,815,950	Average of prices from Manufacturers:"PTI transformers" and "Delta star". Rating: 30/40/50MVA, 2 stage fan cooled, 35kV-69kV
2	69kV Motorized Disconnect Switch		1	$28,000	Quote from Aesco.
3	69kV Surge arresters		1	$24,650	Average of Quotes from CandC and AESCO
4	69kV circuit breaker		1	$250,000	Quote from CandC - Siemens.
5	69kV PT (for protection)		1	$80,000	Internal cost reference from another project.
6	69kV Revenue Metering		1	$150,000	Internal cost reference from another project.
7	Addition to existing protection and control building		1	$200,000	Protection relays & racking, LV DC/AC wiring, power plant controller. It is assumed that new protection equipment will fit within existing P&C building
8	69kV support steel structures		1	$315,000	Internal cost reference from another project.
9	Station service transformer		1	$292,500	Considered a 2.5 MVA tranformer for feeding the auxiliary loads of BESS containers
10	Low voltage switchgear		1	$224,000	Switchgear added for auxiliary power distribution
11	35kV pad mount switchgear		1	$525,000	Quote from Powell Industries
12	Substation Civil works and foundation		1	$275,000	Internal references (includes foundation for main transformer, MV breaker, pad mount switchgear and support structures)
13	Substation testing and commissioning		1	$100,000	Includes interconnection costs
14	Indirect Costs		1	$500,000	Equipment rentals, tools, etc.
	Subtotal - Terminal Area			**$5,780,100**	
	Owners Cost		0.1	**$9,177,203**	
	Contingency		**0.1**	**$10,094,923**	Assumes 10% (reference from another project)
	TOTAL			**$111,044,157**	

#USD to CAD exchange rate considered for BESS: 1.36

Appendix C

Project Schedule


BESS Project Schedule
FEED Stage
Year 1
Year 2
Year 3
Year 4
Year 5
Engineering
Facility Study
Preliminary design
Electrical Design
Structural Design
Civil Design
SCADA and Controls
Engineering support (Procurement and Construction)
Procurement
BESS (9 months)
Main Power transfomer (Critical: Longest delivery) 43 months
Substation equipment (Breaker, PT, SA, switchgear, etc) Delivery for Breaker - 23 Months
Electrical bulk material (cables, conduits, buswork)
Construction
Geotech field work
Preconstruction activites
Site civil work
BESS Installation
Electrical infrastrcture (BESS/Inverter, substation)
Commissioning and testing
BESS system
Substation equipment
SCADA
Functional testing
Substantial completion
Post construction activites
Deficiency and punch list items
Engineering as builts

Attachment 2

Long Duration Battery Energy Storage System Report 258259-0000-DF00-STY-0001

Wood Canada Limited

Revised September 22, 2023

newfoundland labrador hydro

Long Duration Battery Energy Storage System Report

258259-0000-DF00-STY-0001

September 22, 2023

Wood Canada Limited
133 Crosbie Road
P.O. Box 9600

wood.

APPROVALS

Prepared by: Lewis Hann	September 22, 2023 Date
Checked by: Doug Walters	September 22, 2023 Date
Approved by: Lewis Hann	September 22, 2023 Date

Professional Stamp

REGISTERED PROFESSIONAL ENGINEER
LEWIS HANN
SIGNATURE
22-SEPT-2023
DATE
NEWFOUNDLAND & LABRADOR

PROVINCE OF NEWFOUNDLAND AND LABRADOR
pegnl
ENGINEERING PERMIT D0018
Wood Canada Limited
02020
Signature or Member Number (Member-in-Responsible Charge)

REVISION HISTORY

Rev.	Description	Prepared By	Checked By	Approved By	Date
A	Issued for review	AP	LH	LH	June 30, 2023.
0	Issued for use	AP	LH	LH	July 28, 2023
1	Issued for use	LH	DW	LH	September 22, 2023

IMPORTANT NOTICE

Table of Contents

Page

1. Introduction

Newfoundland and Labrador (NL) Hydro have requested Wood to undertake investigation of long duration battery storage technologies that are available in the market (50-100 hours) for 20MW and 50MW capacities. Long Duration Energy Storage (LDES) can be used to store surplus energy generated from wind, solar and hydro, which can then be used to provide multi day power backup and can help in firming up intermittent renewable sources. LDES technology enables a cleaner grid and makes it more reliable and resilient. The specific location of such a project has not been determined yet. However, the sites are expected to be on the Avalon peninsula and interconnected to an existing terminal station on a 66kV/69kV bus in NL.

2. Background

Most energy storage systems today employ lithium-Ion batteries which provide excellent storage solution for short term storage and peak load shifting but they may not be the most economical solution for long term storage. Long duration storage can be used to discharge over multiple days when renewable generation is low. It can be used to shift month to month renewable variability by charging during excess renewable month and discharging during peak load season month. It can also be used to discharge in 8-12 hours bursts over low renewable generation during the daily 24 hours period. Long duration storage combined with an intermittent renewable energy system (wind, solar, run-of-the-river hydro), throughout the day, results in hybrid system that can divert any excess energy produced at times of low demand to storage. The storage can subsequently supply the grid at times of high demand, while also minimising the use of fossil fuels when attempting to match peak demand and overcome network constraints.

For long duration energy storage systems, manufacturers are investigating various types of technologies. Metal-air batteries consist of anode made up of pure metal (like Iron) which reacts with ambient air during discharging. During the charging phase, an external charging current, converts the rust back to iron. Such batteries can provide storage from 8 to 100 hours. Form Energy is a manufacturer involved in metal air technology.

Some manufacturers have flow battery technology in which chemical components are pumped through system on either side of membrane to charge/discharge the battery. VRB Energy, ESS, Invinity are few companies involved in this technology. These can have storage duration from 8 to 12 hours.

There are certain batteries which utilize the anode-cathode cell structure similar to lithium-Ion but substitute lithium with alternate materials. EnerVenue is a manufacturer which utilises Nickel hydrogen technology and have storage durations up to 12 hours. Ambri utilises liquid metal batteries with calcium & antimony electrodes and calcium-chloride salt electrolyte and are suited for storage duration of up to 24 hours.

3. Methodology

A review of the market was completed to identify manufacturers with new technologies, like iron-air, flow battery, etc., which can provide long duration energy storage technologies. The purpose of this report is to present the results of the analysis and provide a technical and commercial comparison of these technologies. Wood studied the product portfolios of major energy storage manufacturers and contacted 17 such manufacturers to enquire if they could provide long duration energy storage solutions and to provide technical and commercial details of their products. The manufacturers contacted were Form Energy, VRB Energy, EnerVenue, ESS Inc, Ambri, Sumitomo Electric, RedFlow, Zinc8, Enzinc, Hitachi Energy, Everflow Energy, Primus Power, Largo Inc., Cell Cube, Sungrid, Invinity and Tesla. Technical parameters provided, such as battery chemistry, power capacity, storage capacity, module sizes, land requirements, operating temperature range, existing installations, current phase of development, planned future projects and product life, were in turn analysed as the basis for this report.

The key advantages of the technologies, the system components, cost, and current production facilities were also evaluated.

Limited information was made available as most of their products are in demonstration or early adoption stage and manufacturers required NDA agreements to be in place before sharing any significant technical or commercial information. Out of the manufacturer's contacted, Form Energy, VRB Energy, EnerVenue and ESS Inc responded with details of their solutions. Ambri, Sumitomo Electric, RedFlow, Zinc8, Enzinc, Hitachi Energy, Everflow Energy, Primus Power, Largo Inc., and Cell Cube did not respond. Sungrid responded that they do not have any solution for long duration energy storage. Invinity and Tesla required NDA agreement to share information about their products.

4. Scope and Exclusions

Due to limited information shared by manufacturers, Class 5 estimates for complete LDES project development are beyond the scope of this report. Based on publicly available information and information provided by some of the manufacturers, section 5 of this report provides an indication of technology and prices for the following four manufacturers: Form energy (Iron Air battery chemistry), VRB energy (Vanadium redox battery chemistry), EnerVenue (Nickel Hydrogen battery chemistry) and ESS Inc. (Iron flow battery chemistry). The table in the summary in section 7 provides a comparison between the major parameters of these 4 manufacturers.

Balance of plant and station service supply requirements will vary considerably depending on the type of energy storage technology. For example, the iron air batteries will require water distribution system, pumps, HVAC, etc. The flow batteries may require extensive heating systems for the electrolyte during freezing conditions, pumping systems, etc. Details of such systems vary considerably with the technology, a thorough review of which is beyond the scope of this report.

Different storage technologies will have extremely varied land requirements. Some details about footprints are provided in section 6, however, a thorough review of land requirements is beyond the scope of this report.

Irrespective of the type of Long Duration Energy Storage technology used, the 69kV terminal station interconnection components will remain same. Wood's 2023 report "BESS Project Preliminary Cost Estimate" 258257-0000-DF00-STY-0001, can be referred for an indicative (Class 5) cost estimate of various MV substation interconnection components that are needed to integrate the energy storage with the existing terminal stations.

5. Technologies and Manufacturers

This section provides an overview of the various technologies for Long Duration Energy Storage solutions for which Wood was able to collect data without NDA agreements. The key aspects of the respective manufacturer's technology provided in this section are taken from the manufacturer's websites and inputs received from the manufacturers which are attached as Appendix A to D.

5.1 **Iron Air Battery by Form Energy**[1]

5.1.1 Overview of technology

The iron air battery is made up of low-cost iron, water, and air. The basic principle of operation is reversible rusting: while discharging, the battery breathes in oxygen from the air and converts iron metal to rust; while charging, the application of an electrical current converts the rust back to iron and the battery breathes out oxygen. A typical iron air battery cell is shown in **Figure 5.1.1**.

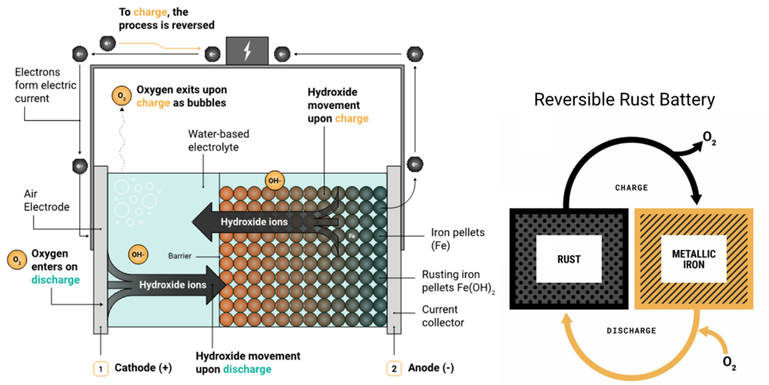


Figure 5.1.1: Iron Air Battery Cell.

Source[1]: "Pioneering multi-day energy storage technology" - Factsheet received from Form Energy.

5.1.2 Key Advantages

Form Energy's documents outlines the following advantages:

- Low cost. Manufacturer claims the cost is less than 1/10th the cost of lithium-ion battery technology.
- Modular and scalable.
- High recyclability.
- No risk of thermal run away. Does not use heavy metals. Non-flammable aqueous electrolyte.
- Multiple application. Discharge over multi-day during low renewable generation events. Shift month to month renewable variability by charging during excess renewable month and discharging during peak load season month. Discharge in 8-12 hours bursts over low renewable generation.

5.1.3 System Components

The building blocks of the battery are iron anode, air electrodes and water based high pH electrolyte. The balance of plant will consist of water distribution system, HVAC, air handling components and utility grade inverter. All the building blocks are shown in **Figure 5.1.2**. A 100MW/10GWh plant would cover a significant 50+ acres of land. Several projects with 10MW/100MWh and 15/150MWh capacities and in service dates within the next 2-4 years are currently under development. A detailed layout of a 2.5MW power block is indicated in **Figure 5.1.3**.

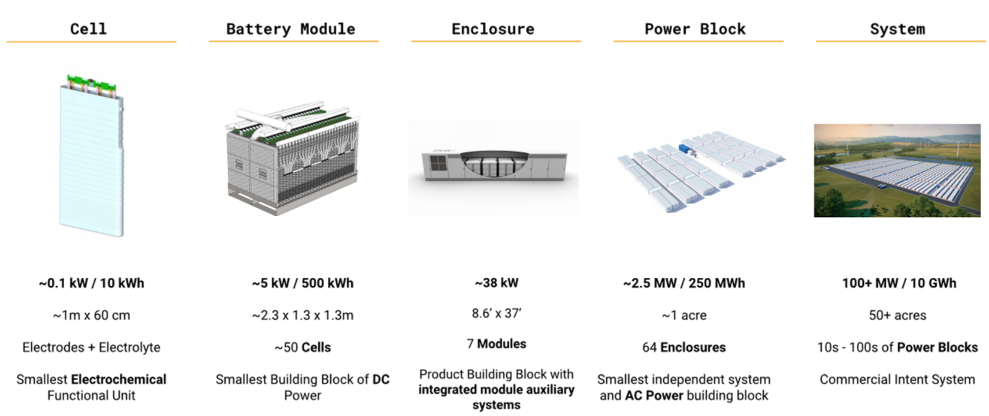


Figure 5.1.2: Building blocks of an Iron-Air long duration battery energy system.
Source[1]: Received from Form Energy.

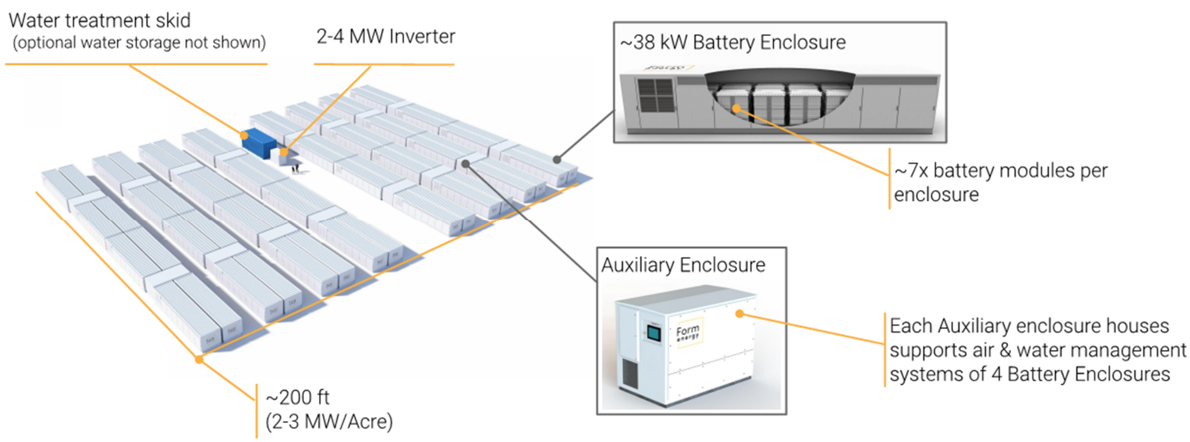


Figure 5.1.3: Sample power Block Layout
Source[1]: Received from Form Energy.

5.1.4 Cost

Form energy did not provide any estimates for their batteries, however, they informed they are targeting less than USD20/kWh (USD2000/kW for their 100-hour project) by 2030.

5.1.5 Production facility

Form energy is setting up a manufacturing plant in Weirton, West Virginia. The factory will have an annual production capacity of 500 megawatts of batteries when in full operation and should have capacity to build projects in the 20-50MW size range as early as 2026.

5.1.6 Planned Installations

Form energy do not have any existing installation. Their first pilot to prove technology at scale is planned in 2024 with a 1.5MW/150MWh Great River Energy project to be located in Cambridge, Minnesota to demonstrate value in real world environment. The company is also collaborating with Georgia power on a project up to 15MW/1500MWh to be located in the utility's service area. They are also partnering with Xcel Energy to deploy two 10MW/1000MWh multi day storage systems, one in Becker, MN and one in Pueblo, CO. They expect both projects to come online by 2025. New York State Energy Research and Development Authority, NYSERDA, has issued a grant for to Form Energy to develop and construct a 10MW/1000 MWh demonstration facility, project to be online by 2026.

5.2 Flow Batteries by VRB Energy[2]

5.2.1 Overview of technology

VRB Energy's VRB-ESS is an electrical energy storage system in which energy is stored chemically in different ionic forms of vanadium in an electrolyte. VRB-ESS are designed for durations of 4 to 8 hours with prefabricated tanks to form systems from 1MW/4MWh up to 100MW/800MWh. The cell stacks determine the power (MW) rating of the system. Adding extra energy (MWh) to a system is accomplished by adding tanks and electrolyte. A typical VRB-ESS system is shown in **Figure 5.2.1**.

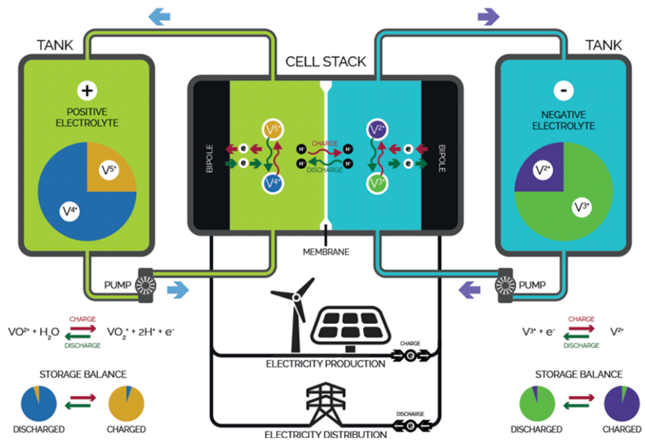


Figure 5.2.1: Typical VRB-ESS system

Source[2]: VRB Energy Brochure.

5.2.2 Key Advantages

VRB energy's VRB-ESS documents indicate the following benefits:

- 100% depth of discharge with no degradation results in low Life cycle cost of energy. As per manufacturer's website, VRB-ESS can be two to three times lower in LCOE compared to lithium-ion batteries when used in daily cycling applications.
- Components can be nearly 100% recycled at end-of-life, improving lifecycle economics and environmental benefits.
- Systems are non-flammable and operate at low temperature and pressure. Does not contain heavy metals. Electrolyte is nontoxic.
- Fast dynamic response as fast as 70ms.

5.2.3 System components

The standard VRB-ESS Power Modules, contain a series of cell stacks, pumps, and controls in a containerized format, combined with electrolyte storage tanks and power conversion systems.

Figure 5.2.2 Typical VRB ESS installation.

Source[2]: VRB Energy Brochure.

The system characteristics of a single VRB power module is indicated in **Figure 5.2.3**.

SYSTEM CHARACTERISTICS – SINGLE VRB® POWER MODULE

CHARACTERISTIC	VRB-G3-1000	NOTES
Nominal Output, AC	1000 kW AC	Active power only; see below for reactive component
Nominal output, DC	1080 kW DC	
Output, AC @ 95% SOC	1000 kW AC	
Output, AC @ 5% SOC	1000 kW AC	
DC voltage	500-810 V	Can be adjusted per site requirement
DC current	0-2500 A	Discharge current
Power factor	0.9	Nominal output at this power factory
AC connection voltage range	315-480 V, 3-Phase	+/-10% variation allowable; voltages below nominal may limit power capacity
Response time	50 to 100ms	Excluding signal latency, fast response option available
Efficiency	up to 85% DC, 75% AC	Nominal AC-in to AC-out, round-trip; efficiency varies as a function of operating conditions
AC connection frequency	50 / 60 Hz	± 5% variation allowable
AC current harmonics	Compliance with EN62103, IEEE519	
Operating ambient temperature	0°C to 50°C	Internal temperature regulated by active thermal management system to 42°C max
Calendar life	25 years	Refurbishment package available
Cycle life	25,000+	Minimum value
Availability	97%	Minimum value

Figure 5.2.3 System characteristics of a single VRB power module
Source[2]: VRB Energy Brochure.

5.2.4 Cost

VRB energy provided an indicative price of USD140Million for the battery system alone for a 500MWh system. This equates to approximately USD280 per kWH.

5.2.5 Production facility

As per company website, VRB Energy is a North American company, offering manufacturing and vanadium sourcing in China.

5.2.6 Installations

As per VRB energy's brochure they have a 2MW/8MWh solar-wind-storage demonstration project in Zhangbei, China which passed the State Grid Corporation of China' performance test requirements for renewable smoothing, frequency regulation, peak shifting and microgrid support. The system achieved 100% availability during the 240-hour acceptance test and has since demonstrated over 10 years of reliable performance. Based on publicly available information, they have 40MWh of installed capacity and 750MWh of projects under development

5.3 <u>Nickel Hydrogen Batteries by Enervenue</u>[3]

5.3.1 Overview of technology

EnerVenue's battery product is the Energy Storage Vessel which is based on nickel hydrogen chemistry. Technical & cost details were not provided by the manufacturer unless an NDA is signed. The details in here are obtained from the manufacturer's website.

5.3.2 Key Advantages

The manufacturers datasheet indicates the following benefits:

- Energy Storage Vessels can cycle up to 3 times per day.
- No risk of thermal runaway or fire propagation. Energy Storage Vessels have completed UL9540A testing.
- The estimated environmental impact of the battery is comparable to a number of competitors, but significantly lower than lithium ion.
- Manufactured with non-toxic, earth abundant materials and almost fully recyclable at end of life.
- The manufacturer offers a capacity assurance warranty for stationary energy storage batteries.

5.3.3 System Components

As per EnerVenue's documents, ESV (Energy Storage Vessel) battery technology is for assets requiring between 2 and 12 hours of storage. 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. **Figure 5.3.1** illustrates the battery technology.

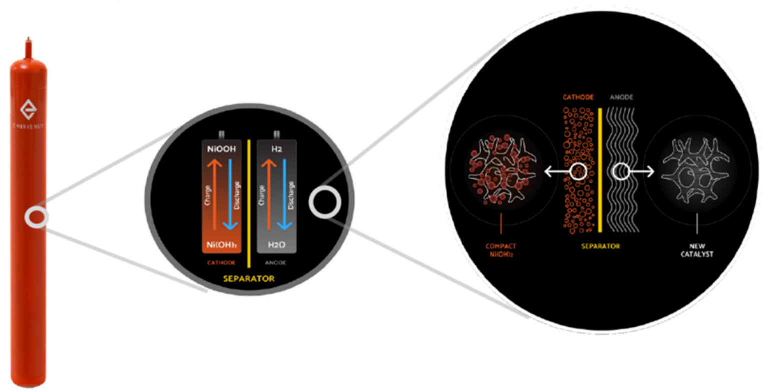


Figure 5.3.1: Representation of EnerVenue (ESV) battery system
Source[3]: www.enervenue.com

5.3.4 Cost

Costing details were not received from manufacturer. However, details were obtained from cost comparison sheet between the EnerVenue's ESV and Li-ion (LiFePo4) batteries prepared by Storlytics[5]. For a specific overbuild high cycle count deep discharge case, the cost per unit energy (USD/kWh) for EnerVenue (ESV) is USD350/kWh. The comparison for the specific case is indicated in **Figure 5.3.2**.

	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**

Figure 5.3.2 Financial comparison between EnerVenue(ESV) and the Li-Ion (LiFePO4) systems.
Source[5]: www.storlytics.net

5.3.5 Production facility

As per the Storlytics[5] document, the manufacturer, EnerVenue, is backed by, Schlumberger, to support large-scale deployment of nickel-hydrogen battery technology across selected global markets. Current production volume is 60MWh/year, however planned facilities soon to be under construction will result in exceeding 2GWh/year by the end of 2024.

5.3.6 Planned Installations

As per company website, EnerVenue will supply a 25 MWh order of Energy Storage Vessels (ESVs) for High Caliber Energy's client, an energy company based in the Southeastern United States. Delivery on the ESV order is planned to be fulfilled by Q4 2024.

5.4 <u>Iron flow battery by ESS Inc</u>[4]

5.4.1 Overview of Technology

ESS Inc provides battery energy storage solutions with Iron flow battery chemistry. They offer two products, Energy Warehouse and Energy Center. Energy Warehouse is designed to serve commercial and industrial customers and each unit delivers over 5 hours of energy at the rated power. The Energy Center is created for utility-scale applications, this solution delivers up to eight hours of energy at rated power that is flexible and scalable. Energy Center is a front of the meter solution and is currently in development stage. The shipping for this product is planned in Q4 2023. During charging iron collects(electroplates) on the negative electrode and during discharging iron dissolves back into solution. The Electrochemistry is indicated in **Figure 5.4.1**.

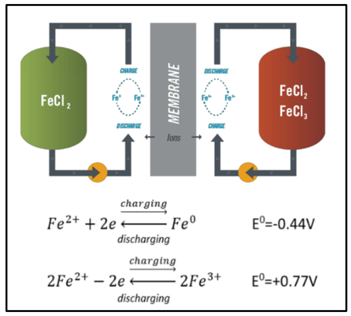


Figure 5.4.1. **Iron flow battery electrochemistry.**
Source[4]: ESS presentation received from ESS Inc.

5.4.2 Key Advantages

The manufacturers datasheet indicates the following benefits:

- Provides duration up to 8 hours with no capacity and power fade.
- No augmentation is required.
- Safe and nontoxic. Has recyclable components.
- Manufacturer provides 10-year extended warranty.

5.4.3 System Components

Iron flow batteries circulate liquid electrolytes to charge and discharge electrons via a process called a redox reaction. ESS indicates that their chemistry remains stable for an unlimited number of deep-cycle charge & discharge cycles. The **Figure 5.4.2** shows the building blocks of the Iron flow batteries.

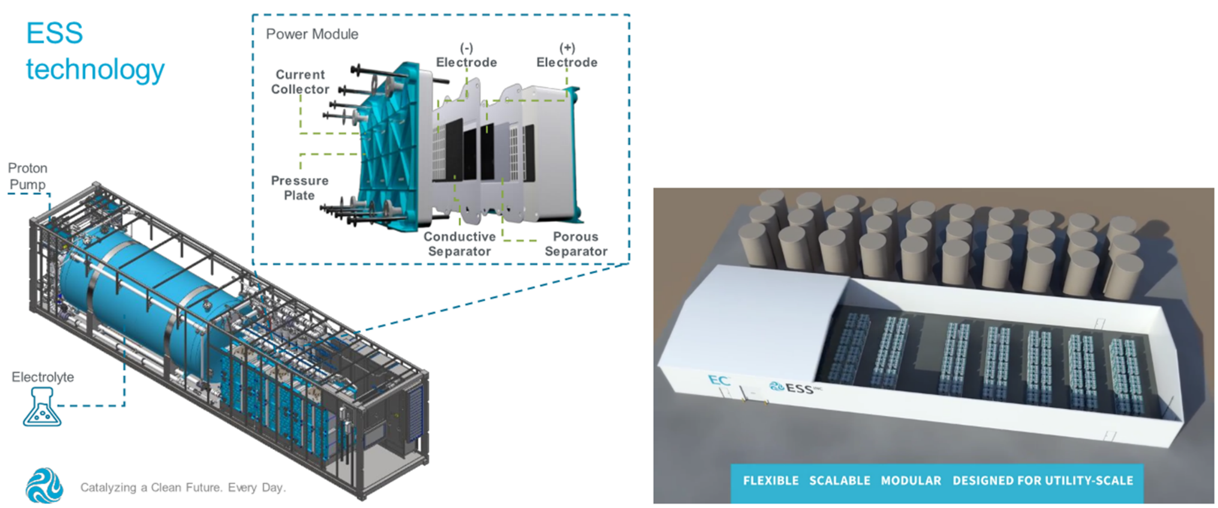


Figure 5.4.2 Building blocks of the Iron flow batteries.
Source[4]: ESS presentation received from ESS Inc.

The key parameters of the Energy center are indicated in **Figure 5.4.3**

	Energy Warehouse	Energy Center
Target Customer	C&I; medium-duration storage	Front-of-the-meter; long-duration storage
Rated Discharge Power	75kW	145kW
Peak Charge Power	90kW (1 hour)	174kW
Peak Energy (kWh)	500kWh	1450 kWh
Rated Energy (kWh)	400kWh	1160 kWh
Rated Energy (hours)	5.3 hours	8 hours
Voltage	AC - 400-480VAC | DC - 880VDC	DC - 880VDC
Blackstart Capability	Included in DC	Site requirement as needed
Ambient Temperature	-5°C to +40°C 15% de-rate to +45°C	-5°C to +40°C standard; -15°C option 15% de-rate to +45°C
Secondary Containment	Site requirement as needed	Included, integrated
Technology (Benefits)	Iron Flow Battery (non-toxic, no thermal runaway)	Iron Flow Battery (non-toxic, no thermal runaway)
Expected Life	25 years	25 years

Figure 5.4.3 Energy Center key parameters.
Source[4]: ESS presentation received from ESS Inc.

5.4.4 Cost

The cost details were not provided by the manufacturer.

5.4.5 Production facility

As per ESS Inc's brochure, it has manufacturing facility in Oregon with 250,000 ft^2 plant currently scaling to 2GWh annual production.

5.4.6 Planned Installations

For utility grade application, Energy Center is the product offered by ESS. However, it is in development stage and the shipping for this product is planned in Q4 2023. Some of the projects indicated in the ESS documents include: Microgrid powering the White Pigeon gas compression facility at White Pigeon, Michigan; Standalone LDES storage for large-scale renewable integration for SMUD at Sacramento County, CA.

6. BESS System Interconnection

6.1 MV Collector System

Wood recommends having BESS system stepped up at 34.5kV level which is industry standard distribution voltage for the collector system in renewable sector; further this will be stepped up to 69kV level at the terminal station. Irrespective of the BESS technology, the typical BESS package will consist of a DC battery pack, DC-AC inverter, and 34.5kV step-up transformer connecting to point of common coupling (PCC) as per **Figure 6.1.1** below.

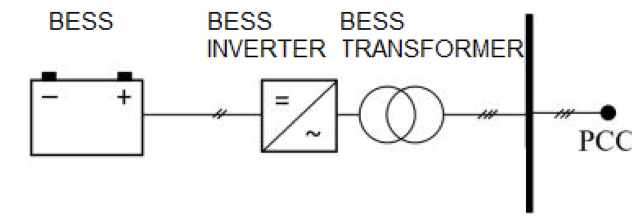


Figure 6.1.1: BESS SLD

Each BESS system would have BESS battery blocks. These units will be daisy chained and connected to a dedicated 34.5kV switchgear at the terminals station as per sample single line noted in **Figure 6.1.2**. Depending on the size of the BESS system, additional feeder breakers may be required. Further, design philosophy may dictate less BESS blocks in a circuit to ensure redundancy in case of trip or maintenance. With this approach, other blocks connected in a separate 34.5kV circuit can perform without interruption. The single line diagram would depend on the type of technology selected.

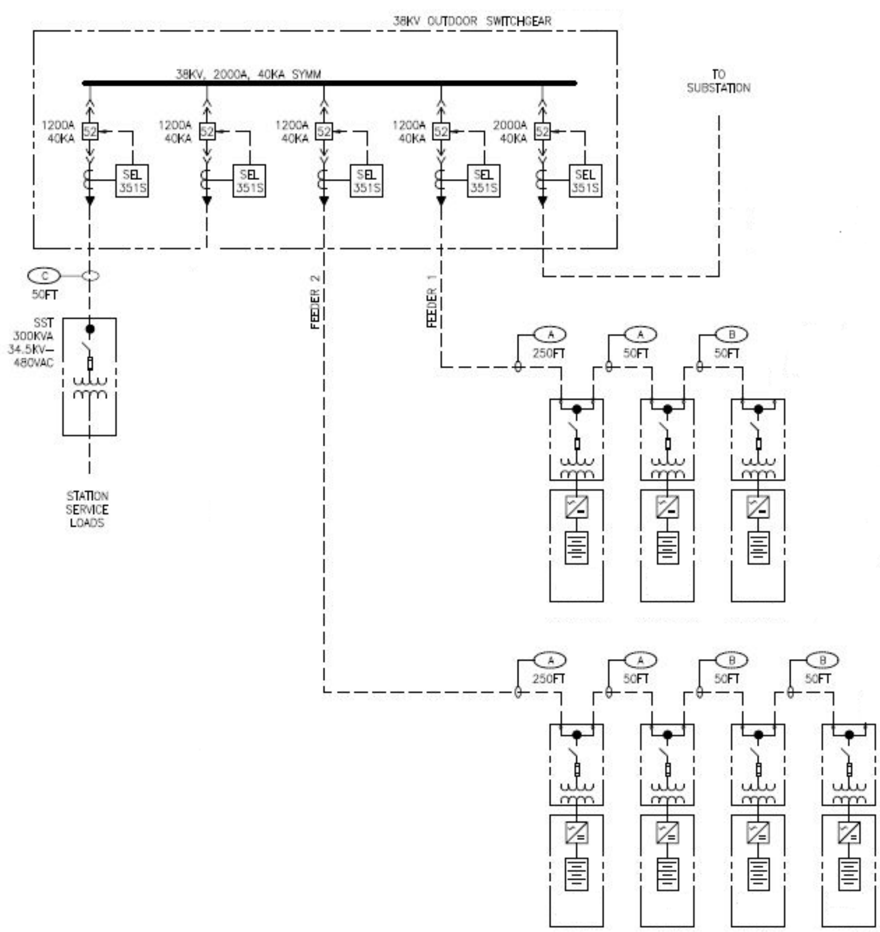


Figure 6.1.2: BESS AC arrangement

6.2 Terminal Station Interconnection

At the existing MV terminal station (69kV), it would be necessary to step up from 34.5kV switchgear to the terminal station voltage. For the interconnection, it will be necessary to interface with new 69kV breaker along with 69KV voltage transformer (for relay protection purposes), HV metering structure and main two stage fan cooled step-up transformer as follows:

- Option 1: 12/16/20MVA, 69kV-35kV
- Option 2: 30/40/50MVA, 69kV-35kV

A typical Single line diagram for the 69kV interconnection is indicated below in **Figure 6.2.1**:

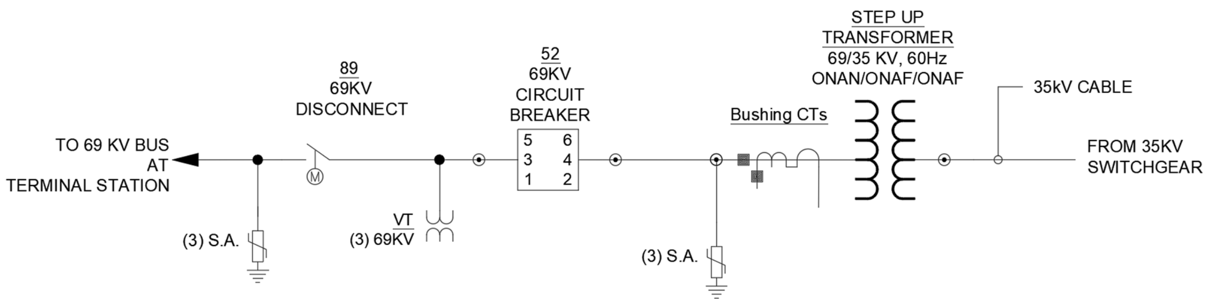


Figure 6.2.1: 69kV interconnection SLD

7. Summary

With regards to battery technologies for 50-100 hours duration, Form Energy was the only manufacturer which responded with a product with up to 100 hours storage. Ambri's websites indicate storage solution in the range of 4 to 24 hours but responded with minimal information. EnZinc and Zinc8 have zinc-based chemistries but did not respond to enquiry on their website. Form Energy's Iron Air battery is the only cost-effective long duration storage solution available within the next 10 years, however, their first 1.5MW/150MWh pilot project is planned in 2024. Hence there are no proven installations and many uncertainties associated with this technology.

Manufacturers of these long-term storage solutions claim that their systems have a lower environmental impact than lithium ion and have recyclability at end of life.

The table below provides a comparison between the major parameters of the 4 manufacturers provided in this report.

Parameter	Form Energy	VRB Energy	Enervenue	ESS Inc
Chemistry	Iron-Air battery	Vanadium redox battery	Nickel hydrogen chemistry	Iron flow battery
Maximum Power capacity	Up to 100MW	Up to 100MW	Not provided (Tubular format 560W per vessel)	Not provided
Storage capacity	100 hours	4 to 8 hours	2 to 12 hours	8 hours

Parameter	Form Energy	VRB Energy	Enervenue	ESS Inc
Risk	No risk of thermal runaway	Systems are non-flammable and operate at low temperature and pressure	No risk of thermal runaway	No risk of thermal runaway
Cost (USD/kWH)	Targeting USD20/kWh (USD2000/kW for their 100-hour project) by 2030	USD140 Million for 500MWh i.e. USD280/kWh for BESS alone (Approx.)	USD350/kWh (Approx.)	Not provided
Module size	2.6m x 11.3m for a 38kW module	Not provided	Tubular format. Module size not available	Not provided
Land requirement	Significant 50 acres for 100MW/10GWh	80 m^2 for a 500kW, 4 hour containerized version	Not provided	Not provided
Operating temperature range	-40^{0}C to 50^{0}C	0^{0}C to 50^{0}C	-15^{0}C to 55^{0}C	-5°C to +40°C
Existing Installations	None	Yes	None	None
Phase of development	1.5MW/150MWh Great River Energy project to be in Cambridge, Minnesota planned in 2024	2MW/8MWh demonstration project in Zhangbei, China. Demonstrated over 10 years of performance	25 MWh Energy Storage Vessels (ESVs) for High Caliber Energy's, Florida	Product in development stage & shipping planned in Q4 2023
Other planned future projects	10MW/1000MWh in Becker, MN, 10MW/1000MWh in Pueblo, CO, 15MW/1500MWh for Georgia power 10MW/1000 MWh for NYSERDA	40MWh of installed capacity and 750MWh of projects under development	Not provided	Not provided for Energy center. Energy Warehouse: White Pigeon, Michigan and Standalone LDES for SMUD at Sacramento County, CA
Lifetime	20 years with repowering in year 10	25 years	30 years	25 years

8. References

1. "Pioneering multi-day energy storage technology" received from Form Energy. Other details from https://formenergy.com/.

2. VRB Energy Brochure, VRB-ESS 500kW/2000MWh product specification and other details from https://vrbenergy.com/.

3. Resource from the Enervenue website. https://enervenue.com/.

4. Resource from the ESS Inc. website https://essinc.com/ and from ESS overview presentation shared by ESS Inc.

5. US based power systems modeling software company, https://www.storlytics.net/.

APPENDICES

Appendix A

Manufacturer’s brochures from Form Energy

Form energy

PIONEERING MULTI-DAY ENERGY STORAGE TECHNOLOGY

Our first commercial product is a rechargeable iron-air battery capable of storing electricity for 100 hours at system costs competitive with legacy power plants. Made from iron, one of the most abundant materials on Earth, this front-of-the-meter battery will enable a cost-effective renewable energy grid year-round.

ENABLING A 100% RENEWABLE GRID

To run the grid reliably and affordably, we need new cost-effective technologies capable of storing electricity for multiple days during renewable energy lulls. We conducted a broad review of available technologies and have reinvented and optimized the iron-air battery for the electric grid. Iron-air batteries are the best solution to balance the multi-day variability of renewable energy due to their extremely low cost, safety, durability, and global scalability.

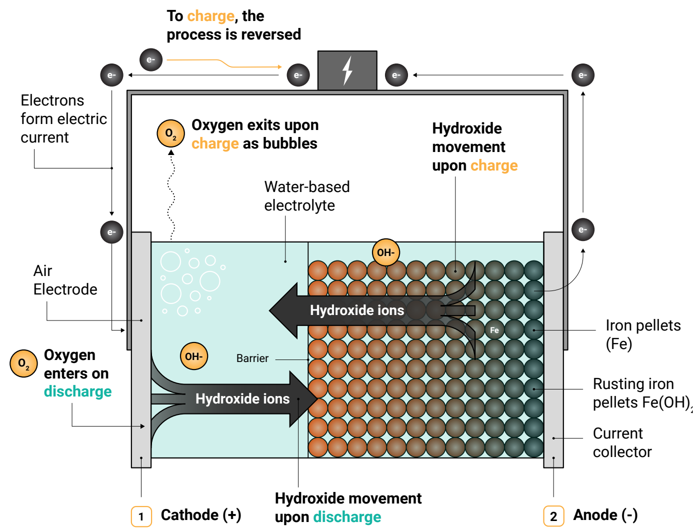
Technology Applications

- **Firmed Renewables** over any weather event or season
- **Transmission Optimization** without new wires
- **Reliability** without thermal generation
- **Resilience** during multi-day grid events

HOW OUR MULTI-DAY ENERGY STORAGE SYSTEM WORKS

The active components of our iron-air battery are some of the safest, cheapest, and most abundant materials on the planet — low-cost iron, water, and air. The basic principle of operation is reversible rusting: while discharging, the battery breathes in oxygen from the air and converts iron metal to rust; while charging, the application of an electrical current converts the rust back to iron and the battery breathes out oxygen.

Each individual battery module is about the size of a side-by-side washer/dryer set. These battery modules are grouped together with auxiliary systems in weatherized, factory-assembled enclosures. Hundreds of these modules make up a modular, megawatt-scale power block.



With this technology, we are tackling the biggest barrier to deep decarbonization: making renewable energy available when and where it's needed, even during multiple days of extreme weather, grid outages, or periods of low renewable generation.

KEY ADVANTAGES OF OUR BATTERY TECHNOLOGY

LOW-COST

Less than 1/10th the cost of lithium-ion battery technology.

OPTIMIZABLE

Pairs well with lithium-ion batteries and renewable energy resources to enable optimal energy system configurations.

RELIABLE

100-hour+ duration required to make wind, water, and solar reliable, year round, anywhere in the world.

MODULAR

Can be sited anywhere for utility-scale needs.

SCALABLE

Materials and designs with global scale needed for zero carbon economy.

SAFE

No risk of thermal runaway. No heavy metals. High recyclability.

Energy Storage for a Better World

CONTACT

info@formenergy.com
30 Dane St. Somerville, MA 02143
www.formenergy.com

BREAKTHROUGH LOW-COST, MULTI-DAY ENERGY STORAGE

May 2023

Form energy

Energy Storage
For A Better World

The Challenge

The electrical grid needs to fundamentally transform to meet the challenges posed by climate change

- Intermittency of renewable assets create periods of undersupply
- Carbon mandates require retirements and risk stranding fossil assets
- Extreme weather events become more frequent and disruptive to customers
- Increased transmission congestion and long interconnection queues

Multi-day storage can provide a range of possible benefits

RENEWABLE FIRMING

- Capable of "firming" renewable profiles at both the asset- and system-level, including over multi-day generation lulls.
- Can shape renewable output to meet any load profile, including flexible and fast ramping needs.

FOSSIL REPLACEMENT

- Pave the way to retire legacy fossil assets by providing a clean, firm, and dispatchable alternative to existing fossil units.

TRANSMISSION OPTIMIZATION

- Reduce uneconomic renewable energy curtailment, reduce transmission grid congestion, increase the total amount of low-cost renewable energy that flows across transmission boundaries, reduce needs for new transmission lines.

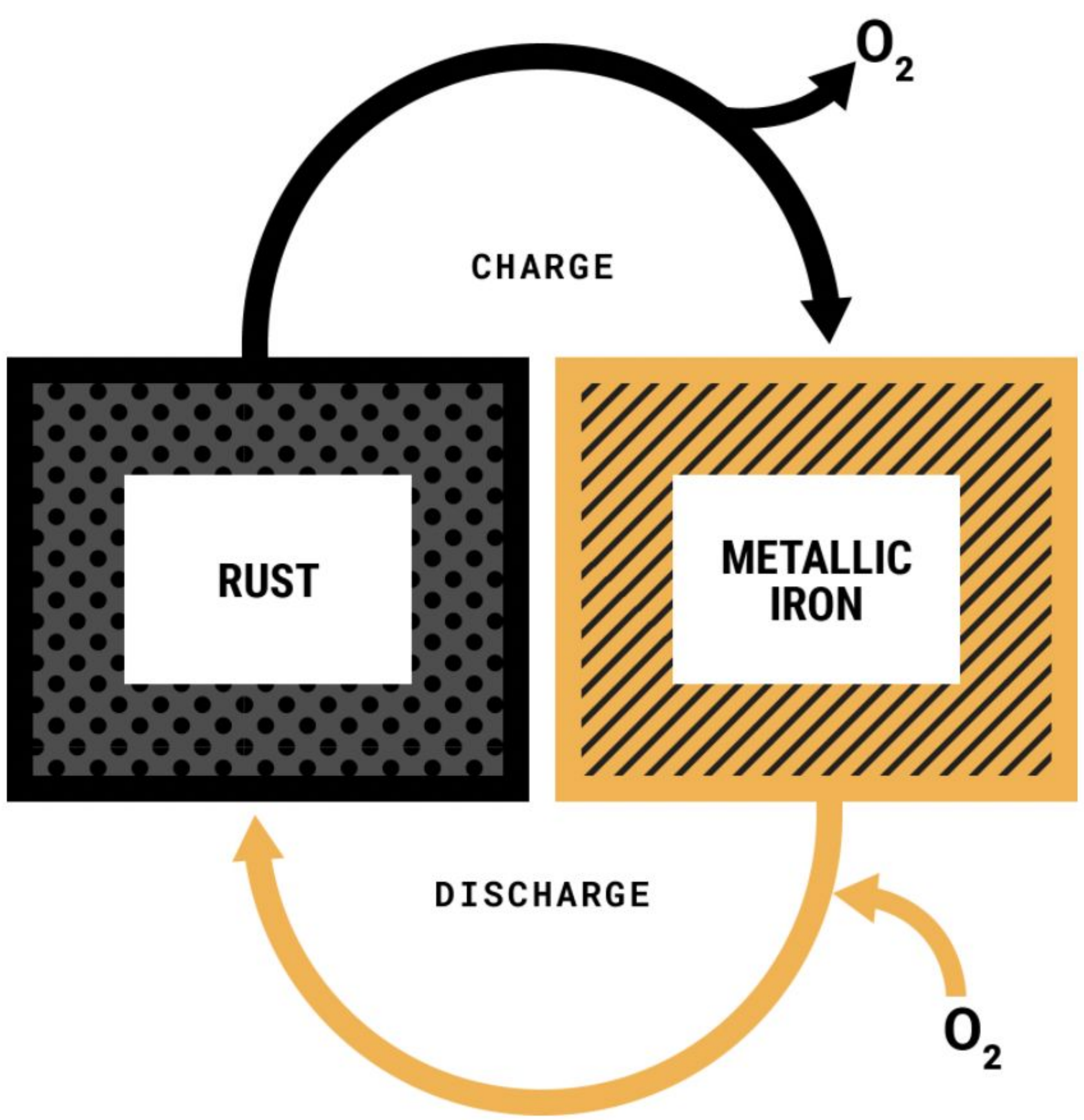
RESILIENCY

- Bolster grid reliability and system resiliency as severe, multi-day weather events increase in frequency.
- Provide ancillary and grid services, including black start.

Technology Overview

Rechargeable iron-air is the best technology for multi-day storage

Reversible Rust Battery



COST
Lowest cost rechargeable battery chemistry.
Less than 1/10th the cost of lithium-ion batteries

SAFETY
Non-flammable aqueous electrolyte. No risk of thermal runaway. No heavy metals.

SCALE
Uses materials available at the global scale needed for a zero carbon economy. High recyclability.

RELIABLE
100+ hr duration required to make wind, water and solar reliable year round, anywhere in the world.

Form energy

Our rechargeable, static iron-air battery leverages globally abundant materials and off-the-shelf components

SYSTEM BUILDING BLOCKS

Iron Anode

- Highly abundant
- Very low cost metal
- Non-toxic
- Highly recyclable

Air Electrodes

- Commercially proven air electrodes
- Readily scalable production

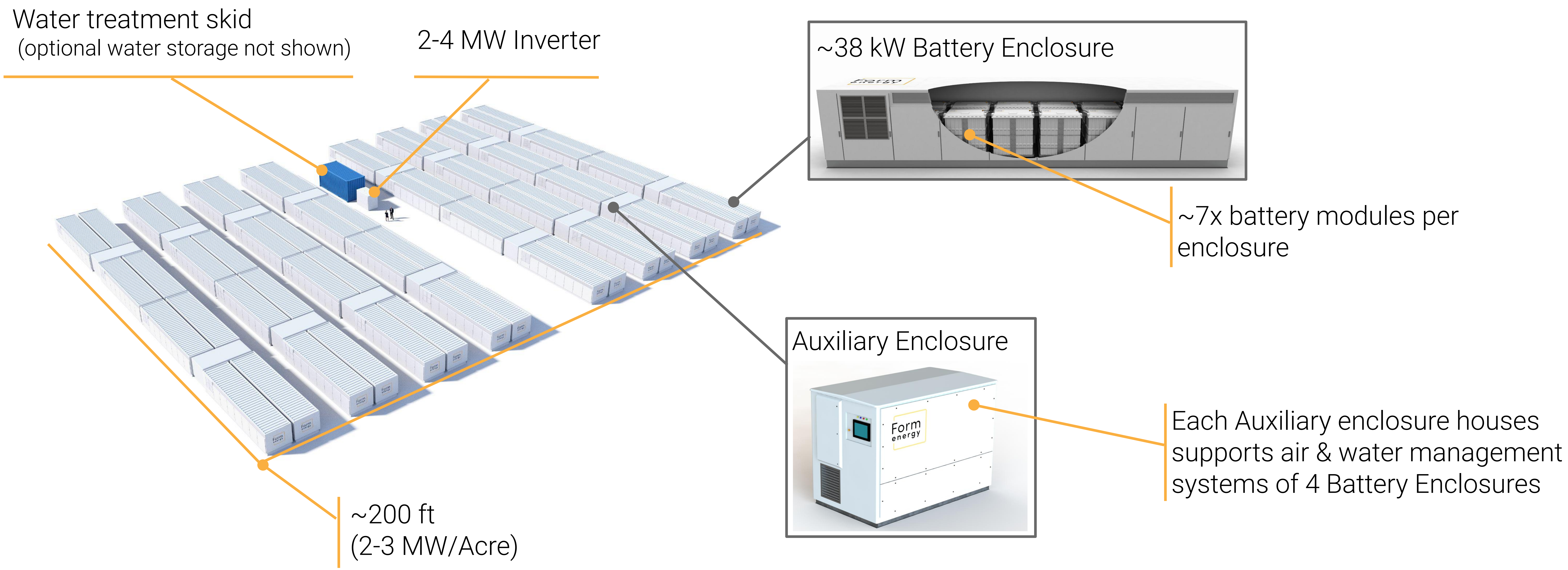
Water based electrolyte

- High pH (similar to AA batteries)
- Non-flammable
- No heavy metals

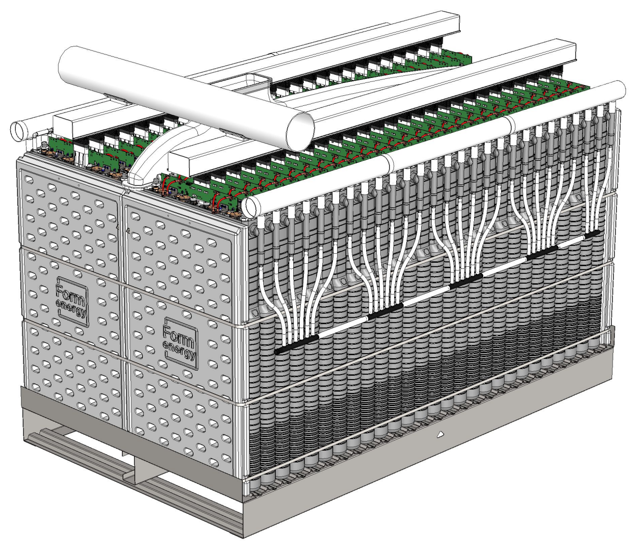
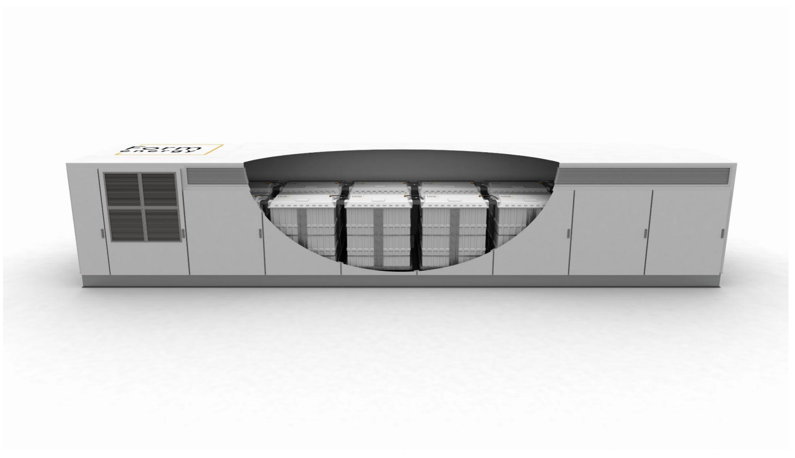
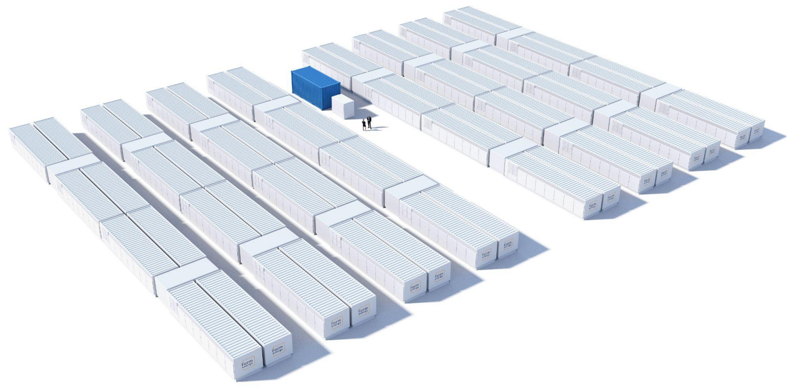
Balance of System

- Off-the-shelf water distribution, HVAC, & air handling system components
- Standard utility-grade inverter

Form Energy's 100hr multi-day energy storage system
Sample Power Block



Form Energy's modular 100hr multi-day energy storage system

Cell	Battery Module	Enclosure	Power Block	System
				
~0.1 kW / 10 kWh	**~5 kW / 500 kWh**	**~38 kW**	**~2.5 MW / 250 MWh**	**100+ MW / 10 GWh**
~1m x 60 cm	~2.3 x 1.3 x 1.3m	8.6' x 37'	~1 acre	50+ acres
Electrodes + Electrolyte	~50 **Cells**	7 **Modules**	64 **Enclosures**	10s - 100s of **Power Blocks**
Smallest **Electrochemical** Functional Unit	Smallest Building Block of **DC** Power	Product Building Block with **integrated module auxiliary systems**	Smallest independent system and **AC Power** building block	Commercial Intent System

Form Energy 100hr Storage delivers grid-scale reliable capacity year-round

System Overview

Rated AC System Power	10 - 500+ MW
System Capacity	1 - 50 GWh
Repeatable Power Block	2.5 MW / 250 MWh
Discharge Duration	100 hr
Round Trip Efficiency*	35%
Ramp (offline to full power)	< 10 minutes
Areal Energy Density	> 200 MWh/acre
Operating Temperature	-40°C to 50°C
System Lifetime	20 years

**AC-AC round-trip efficiency, full charge and full discharge at rated power; inclusive of losses from power conversion and auxiliary loads*

Form energy

Formware Capacity Expansion & Dispatch Model

What should we build? How should it operate?

Inputs

Project-Specific Constraints
Site capacity, target availability, ...

Sophisticated Storage Models
$/kWh, $/kW, RTE, ...

Market Conditions
PPA price, capacity prices, energy and ancillary prices, RPS, ...

Grid Data
Transmission limits, load forecasts, retirements, ...

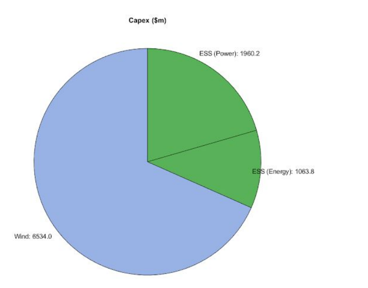
Generator Data
Capex, opex, start costs, heat-rates, fuel costs, solar & wind resource, ...

Formware™
Capacity expansion & dispatch model

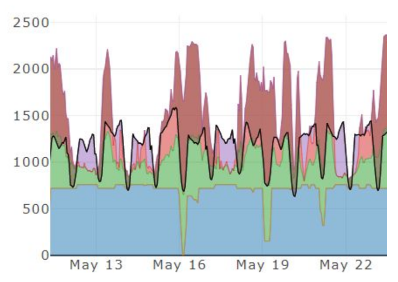
Differentiators

- **Granularity:** 8760+ model captures price and resource volatility
- **MDS Modeling:** Can capture dynamics of multiday storage operation
- **Scenario Modeling:** Multi-scenario optimization validates solution across range of conditions
- **Model Customization:** Customizable model allows Form to deliver bespoke analyses on-demand

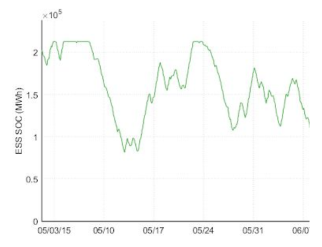
Outputs



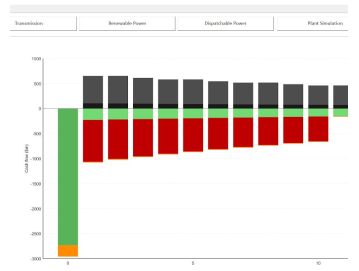
Recommended Energy Asset Sizing
Power, energy capacity



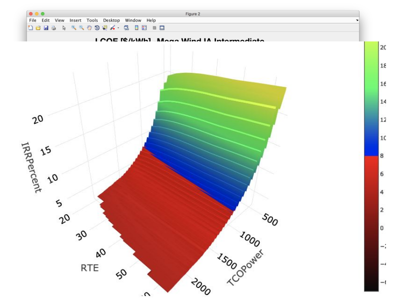
Hourly Operational Profiles
8760+ by energy asset



Storage "Duty Profile"
Cycles/yr, peak power



Project Financials
LCOE, FCF, IRR



Sensitivity Analysis
Risks and trade-offs from input uncertainties

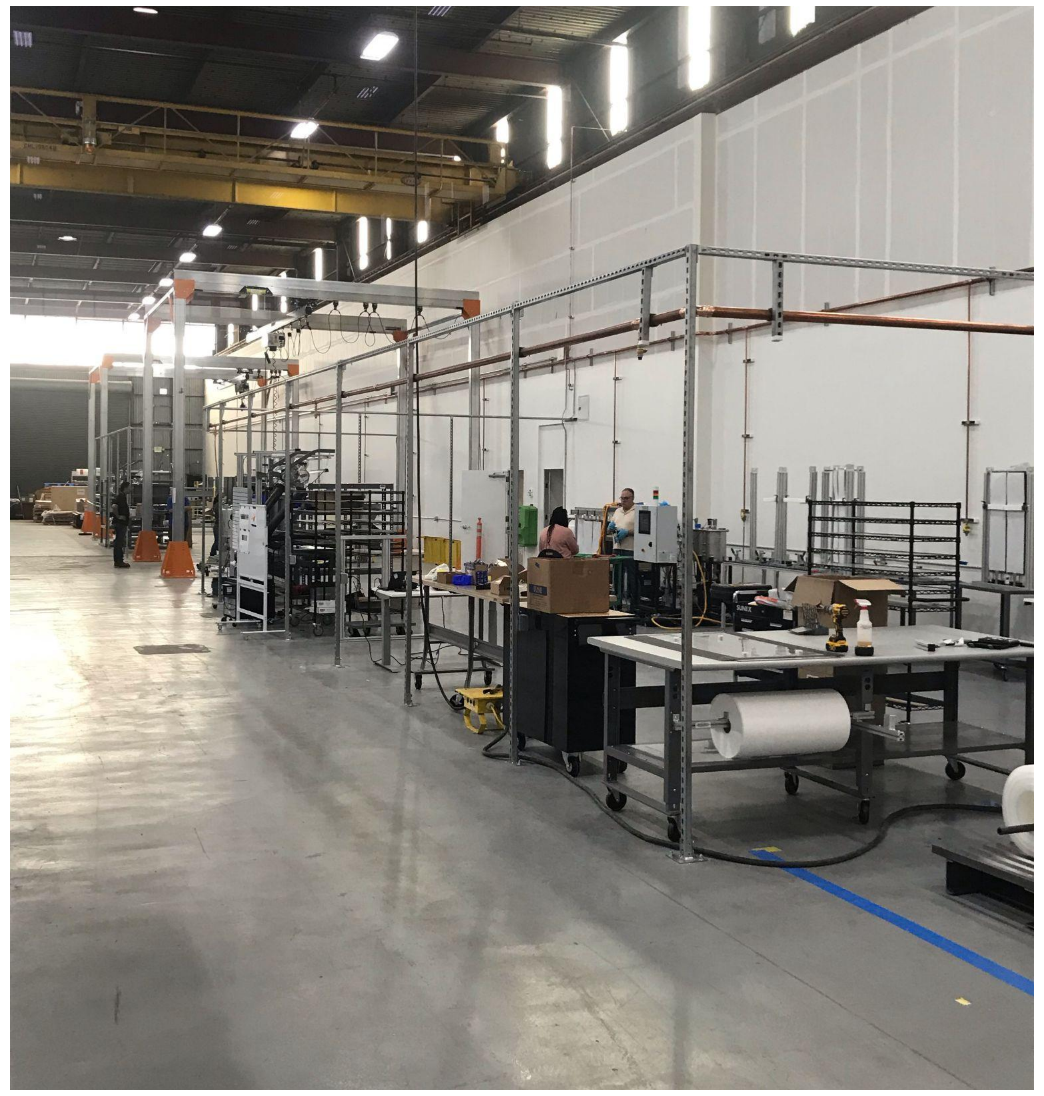
Form energy

Three manufacturing sites to ramp to commercial scale

Eighty Four, PA (near Pittsburgh)
Electrode Pilot Manufacturing

- Pilot manufacturing of electrodes
  - Anode
  - Discharge cathode
  - Charge cathode

Berkeley, CA
Cell, Module, Enclosure Pilot



- Manual cell, module, & enclosure assembly
- Supply to support internal testing & validation

Production Site 1 (Weirton, WV)
Commercial Scale Manufacturing

Building rendering

- Semi-to-fully automated cell, module, & enclosure assembly
- Ability to scale production in modular blocks

Form Energy's path to transform the global grid

2024
- **Prove Technology at Scale**
- 1.5 MW GRE project
- Demonstrate value in real world environment

2025
- **Initial Commercial Projects**
- 5-15 MW scale projects
- Demonstrate bankability

2026
- **Full Scale Installations**
- 20-100+ MW scale projects
- Bankable firm clean capacity

2030s
- **Deep Decarbonization**
- GW-scale projects
- Meet carbon goals and manage risk

Piloting → Scale-Up → Expansion → Global Transformation

30 years after commercial availability, global lithium-ion manufacturing capacity was 500 GWh/yr in 2020.

Form Energy will exceed that scale before 2030.

Over 3 GWh of Commercial Contracts

Georgia Power

Collaborating with Georgia Power on a project application of **up to 15 megawatts/1500 megawatt hours (MW/MWh)** of energy storage systems to be located in the utility's service area

"At Georgia Power, we know that we must make smart investments and embrace new technologies now to continue to prepare for our state's future energy landscape," said **Chris Womack, Chairman, President and CEO of Georgia Power.** "We're excited to have Form Energy as a partner to help us build on Georgia's solid energy foundation."

GREAT RIVER ENERGY™

Partnering with Great River Energy to deploy a first-of-its-kind **1.5 megawatt/150 megawatt hour** multi-day energy storage project in Cambridge, Minnesota in 2024

"Great River Energy is excited to partner with Form Energy on this important project. Commercially viable long-duration storage could increase reliability by ensuring that the power generated by renewable energy is available at all hours to serve our membership," said **Great River Energy Vice President and Chief Power Supply Officer Jon Brekke.**

Xcel Energy®

Partnering with Xcel Energy to deploy **two 10 MW / 1,000 MWh** multi-day storage systems; one in Becker, MN and one in Pueblo, CO. Both projects are expected to come online as early as 2025

"As we build more renewable energy into our systems, our partnership with Form Energy opens the door to significantly improve how we deliver carbon-free energy so that we can continue to provide reliable and affordable electric service to our customers well into the future." said **Bob Frenzel, Xcel Energy President and CEO.**

Appendix B

Manufacturer’s brochures from VRB Energy

VRB-ESS®

Sustainable, Scalable and Safe Energy Storage

PRODUCT OVERVIEW : VRB-ESS GEN3-1000

About VRB-ESS

VRB Energy's VRB-ESS is an electrical energy storage system based on the patented vanadium redox battery (VRB®) that converts chemical to electrical energy. Energy is stored chemically in different ionic forms of vanadium in an electrolyte.

The electrolyte is pumped from storage tanks into cell stacks where one form of electrolyte is electrochemically oxidized and the other is reduced on either side of an ion exchange membrane. This creates a current that is collected by electrodes and made available to an external circuit.

The reaction is reversible, and the electrolyte never wears out, allowing the battery to be charged, discharged and recharged a nearly infinite number of times.

VRB-ESS® DISTINGUISHING FEATURES

Low LCOE
100% depth of discharge with no degradation yields low LCOE.

Reliable
Proven performance and robust design yield high availability and low maintenance costs.

Recyclable
The electrolyte can be fully recycled at end of project lifetime, saving cost and avoiding the expensive disposal costs of other

Flexibility
Operation at partial states of charge (SOC) has no impact on life, allowing effective upward and downward ramp control.

System Safety
Systems are non-flammable and operate at low temperature and low pressure.

Fast Response
Fast dynamic response for transition between charge and discharge or between operating power levels as fast as 70ms.

LCOE Matters

25,000+
PRODUCT LIFE CYCLES AT FULL CAPACITY

100%
DEPTH OF DISCHARGE (DOD)

30+
YEARS OF OPERATIONAL LIFE

VRB ENERGY

SYSTEM DESCRIPTION

The VRB-G3 Power Modules have a nominal rating of 1000 kW AC, and have charge and discharge characteristics suitable for heavy duty, full-cycle energy management. Each Power Module can be combined with almost any volume of electrolyte, according to the requirements of a particular application. Typical configurations use four to eight hours of storage.

SYSTEM CHARACTERISTICS – SINGLE VRB® POWER MODULE

CHARACTERISTIC	VRB-G3-1000	NOTES
Nominal Output, AC	1000 kW AC	Active power only; see below for reactive component
Nominal output, DC	1080 kW DC	
Output, AC @ 95% SOC	1000 kW AC	
Output, AC @ 5% SOC	1000 kW AC	
DC voltage	500-810 V	Can be adjusted per site requirement
DC current	0-2500 A	Discharge current
Power factor	0.9	Nominal output at this power factory
AC connection voltage range	315-480 V, 3-Phase	+/-10% variation allowable; voltages below nominal may limit power capacity
Response time	50 to 100ms	Excluding signal latency, fast response option available
Efficiency	up to 85% DC, 75% AC	Nominal AC-in to AC-out, round-trip; efficiency varies as a function of operating conditions
AC connection frequency	50 / 60 Hz	± 5% variation allowable
AC current harmonics	Compliance with EN62103, IEEE519	
Operating ambient temperature	0°C to 50°C	Internal temperature regulated by active thermal management system to 42°C max
Calendar life	25 years	Refurbishment package available
Cycle life	25,000+	Minimum value
Availability	97%	Minimum value

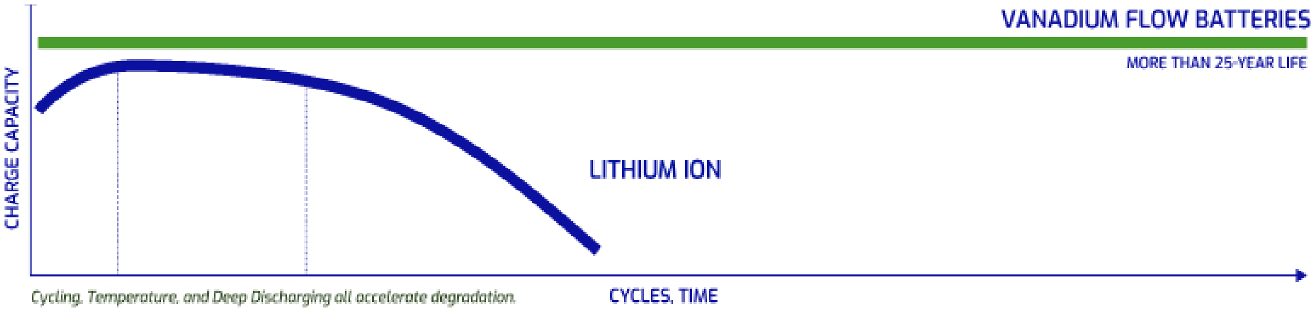
This document provides indicative performance figures only.
Actual figures will depend on the intended application, environmental conditions, and options required at a particular site.

SUPPORT & WARRANTY

- On-site support for assembly and installation of the VRB-ESS, as well as commissioning of equipment by VRB Energy personnel.
- Safety and operational training for all on-site personnel and operators.
- Ten year comprehensive warranty covering Capacity, Availability and Efficiency.

QUALITY

VRB-ESS have been reviewed and are in compliance with European system quality and safety guidelines.



VRB® TECHNOLOGY VS. LITHIUM-ION

While lithium-based batteries are well suited to consumer electronics and electric vehicles, their lifetimes can be limited. VRB® Energy's VRB® technology can be discharged over an almost unlimited number of charge and discharge cycles without wearing out. This is an

To find out more, check out www.vrbenergy.com or contact us by email at sales@vrbenergy.com.

VRB® ENERGY
Vanadium Redox Battery Solutions

China:

Suite 12-13, 5th Floor, West Tower
World Financial Center
No. 1 Dong San Huan Zhong Lu
Chaoyang, Beijing, China

T: +86.10.6150.3560

North America:

Suite 606, 999 Canada Place
Vancouver BC, Canada
V6C 3E1

T: +1.604.648.3900

India:

T: +99.5880.9722

@VRB-Energy @ThinkVRB

VRB ENERGY

THE MOST **RELIABLE**, **LONGEST-LASTING VANADIUM FLOW** BATTERY IN THE WORLD

WWW.VRBENERGY.COM

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ABOUT VRB ENERGY

VRB Energy is a fast-growing, global clean technology innovator. We have developed the most reliable, longest-lasting vanadium flow battery in the world, with over 750 MWh of systems deployed and in development, and over 1,000,000 hours of demonstrated performance. VRB Energy is the technology leader in the field, and the combination of our proprietary low-cost ion-exchange membrane, long-life electrolyte formulation and innovative flow cell design sets us apart from other providers.

Our vanadium redox batteries (VRB®) store energy in liquid electrolyte in a patented process based on the reduction and oxidation of ionic forms of the element vanadium. This is a nearly infinitely repeatable process that is safe, reliable, and non-toxic. Components can be nearly 100% recycled at end-of-life, dramatically improving lifecycle economics and environmental benefits compared to lead-acid, lithium and other battery systems.

VRB ENERGY OWNERSHIP

VRB Energy is 90% owned by Ivanhoe Electric Inc., a United States minerals exploration and development company with a focus on developing mines that can deliver the critical metals necessary for electrification of the economy. For more information on VRB Energy please visit our website at www.vrbenergy.com.

STORAGE IS ENABLING THE RENEWABLE **ENERGY REVOLUTION**

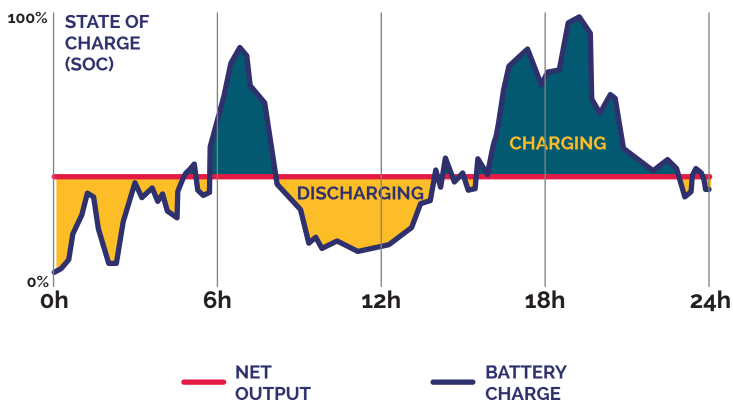
RENEWABLE ENERGY INTEGRATION

More energy from the sun reaches the earth in a single hour than humanity uses in an entire year. Photons hit the silicon in a solar panel and dislodge electrons as an electric current. The sun's rays also warm the earth, causing air to rise and generating wind currents that we can harness with wind turbines.

We can capture this variable energy with energy storage, and convert this free fuel into nearly limitless clean electricity. VRB Energy's Vanadium Redox Battery Energy Storage Systems (VRB-ESS®) are ideally suited to charge and discharge throughout the day to balance this variable output of solar and wind generation.

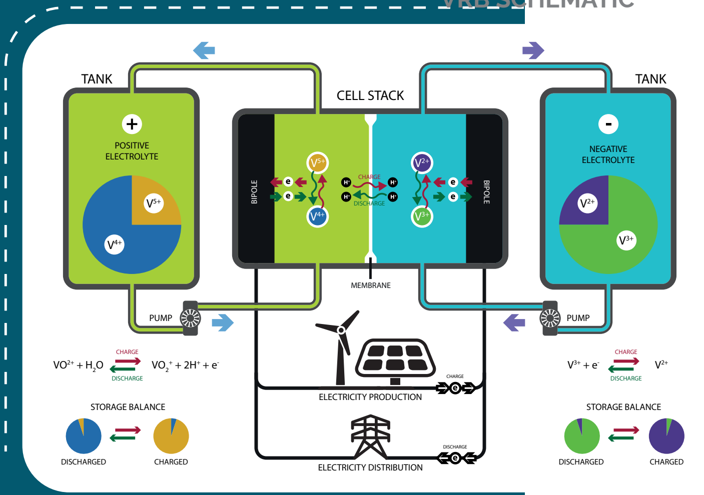
VRB-ESS are a type of flow battery, which are poised to dominate the utility-scale storage market for wind and solar integration. The technology is fundamentally better suited to these deep discharge applications that require four to eight hours of storage per day. VRB-ESS deliver an almost infinite number of cycles over more than 25 years, yielding the best, most sustainable lifecycle economics.

STORAGE SMOOTHS VARIABLE WIND OUTPUT TO KEEP THE GRID STABLE



PROPRIETARY **LOW-COST** ION-EXCHANGE MEMBRANE, **LONG-LIFE** ELECTROLYTE FORMULATION, **INNOVATIVE** FLOW CELL DESIGN

VRB SCHEMATIC



PRODUCT PERFORMANCE

MODULAR DESIGN

The standard VRB-ESS Power Modules, contain a series of cell stacks, pumps, and controls in a containerized format, combined with electrolyte storage tanks and power conversion systems.

MW-CLASS

Based on a 500kW containerized module, these systems are typically 1 MW / 4 MWh up to 100 MW / 800 MWh in size installed at utility, commercial and industrial sites, in support of solar or wind farms, or in isolated microgrids.

GW-class systems are also available on a custom-engineered basis.

VRB ENERGY

AN ALMOST **INFINITELY REPEATABLE** PROCESS

SAFE, RELIABLE, NON-TOXIC

VIRTUALLY **100% RECYCLED** AT END-OF-LIFE

APPLICATIONS

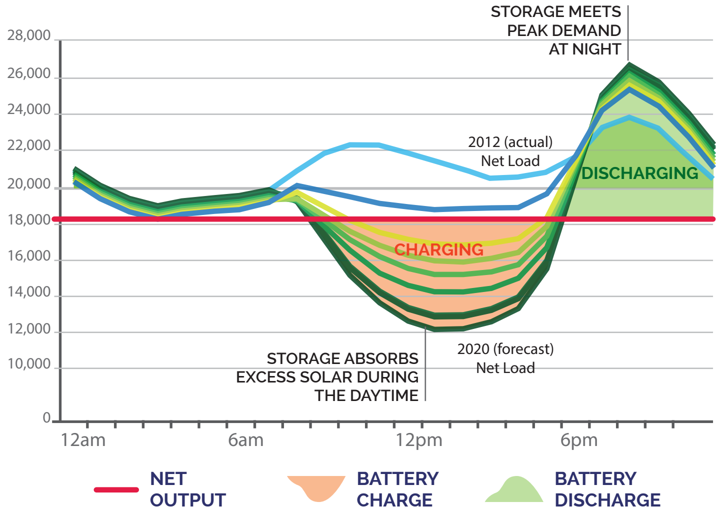
UTILITY OPTIMIZATION

Peaker Plant Replacement and T&D Deferral

VRB-ESS can respond to grid conditions within ½ cycle, providing frequency and voltage support in real time, while simultaneously serving longer-duration energy needs.

VRB-ESS enable utilities to balance loads, make more efficient use of existing infrastructure and operate smart microgrids. VRB-ESS can replace peaker plants, and investments in transmission and distribution (T&D) can be deferred.

Example: Net system load in California drops dramatically mid-day due to increasing solar penetration. Storage is needed to balance and stabilize.



SOURCE: CALIFORNIA CAISO

COMMERCIAL AND INDUSTRIAL (C&I)

On-Site Energy Optimization

Installed "behind-the-meter" at C&I facilities, VRB-ESS reduce operating expenses through multiple benefit streams:

- Reduction of peak demand charges from utilities.
- Integration and optimization of on-site renewable energy.
- Provision of backup power that reduces losses in the event of utility outages.
- Reduction of wear on equipment through improvement of power quality.

MICROGRIDS

System Balancing and Energy Optimization

Microgrids combine a diverse set of generation and loads on a system isolated from the main utility grid. They are typically either remote, islanded systems or special zones designed to connect or disconnect from the main utility grid for economic or power quality reasons.

On isolated diesel grids, VRB-ESS balance loads, maintain power quality, and reduce fuel use. On grid-connected systems, VRB-ESS allow seamless connect/disconnect from the main utility grid on-command. With the dramatically reduced cost of solar power, the combination of photovoltaics and VRB ("PV + VRB") is now three to five times cheaper than traditional diesel generation.

CHINA STATE GRID'S ZHANGBEI DEMONSTRATION SITE, THE **LARGEST FLOW BATTERY** FOR THE **LARGEST UTILITY IN THE WORLD**

SOLAR-WIND-STORAGE DEMONSTRATION PROJECT AT 2 MW X 8 MWH

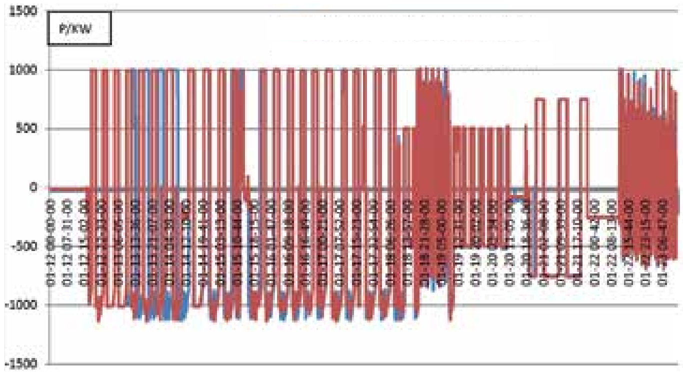
VRB Energy has completed the rigorous acceptance testing and approval process administered by State Grid Corporation of China, the world's largest electric utility company.

The 8 MWh VRB-ESS installed at State Grid's cutting-edge 500 MW solar-wind-storage project in Zhangbei (which helped supply 100% clean energy for the 2022 Winter Olympics) achieved all of the performance test requirements for:

- Renewable Smoothing
- Frequency Regulation
- Peak Shifting
- Microgrid Support

The system achieved 100% availability during the rigorous 240-hour acceptance test, and has since demonstrated over 10 years of reliable performance.

Two 1 MW units, C010 (red line) and C011 (blue line): power-time curve throughout the 240 hour test.



PERFORMANCE EXCEEDED EXPECTATIONS ACROSS ALL MAJOR METRICS:

AVAILABILITY:	100% of Test Hours
POWER RATING:	120% of Target
EFFICIENCY:	110% of Target
RESPONSE TIME:	< 20 ms Target

LOWEST LIFECYCLE COST OF ENERGY (LCOE) WITH **PROVEN PERFORMANCE AND SAFETY**

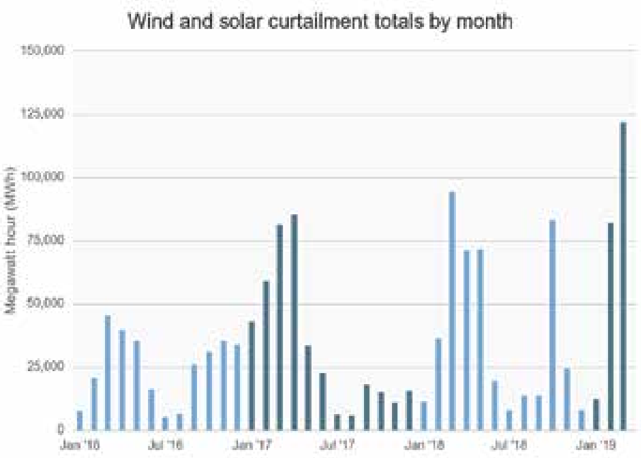
ENVIRONMENTAL BENEFITS

Air emissions from fossil-fuel fired power generation plants are a major source of environmental degradation worldwide, and air pollution has significant costs in terms of human health. Solar and wind energy are now widely recognized as the lowest cost of power generation in most locations around the world; however they cannot always meet all peak energy demand.

California alone, still utilizes natural gas to meet nearly one third of its electricity demand, while at the same time renewable resources are often curtailed in periods of low demand .

By utilizing VRB-ESS, solar and wind energy can be stored and discharged to meet peak energy demand, ensuring that the clean power is not wasted.

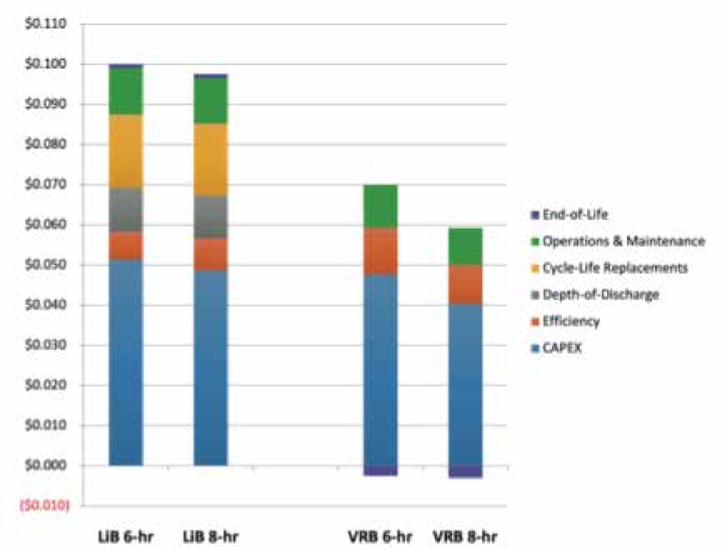
Adding VRB-ESS equal to 20% to 50% of the capacity of a typical wind or solar farm can optimize the use of "free" and clean energy, helping reduce global carbon dioxide emissions and harmful local air pollution.



LIFECYCLE BENEFITS

VRB Energy's proprietary all-vanadium electrolyte is the same on both the positive and negative sides of the battery. It is safe, non-combustible, and never wears out. At the end of 25 or more years of project life, the electrolyte can be reused in another battery, or recycled; and the other components can be recycled. This helps lower lifecycle costs and is a significant environmental benefit compared to other types of battery systems.

Levelized Cost of Energy (LCOE) $/kWh



The above comparison is based on Bloomberg and VRB Energy estimates for 2023, assuming one cycle per day, a 25-year project life, LiB replacement in year 10 at 50% of original cost, and a 5% discount rate.

The up-front capital costs for lithium batteries (LiB) is not an accurate metric for value, as it does not include replacement costs after 2,000 – 4,000 cycles, depth-of-discharge limitations imposed by warranty terms (typically resulting in a loss of 20% of capacity), or end-of-life disposal costs (recycling will always be more expensive compared to the high residual value of vanadium).

VRB ENERGY IS THE **TECHNOLOGY LEADER** IN THE FIELD

ECONOMICS

Lithium-based batteries have inherently shorter lifetimes and are not well suited for longer duration storage (4+ hours). Vanadium outperforms lithium on depth-of-discharge (DoD), cycle life, and end of life value (lithium carries a disposal cost). VRB-ESS are two to three times lower in LCOE.

PROPRIETARY TECHNOLOGY

VRB Energy is the technology leader in the field. The combination of our proprietary low-cost ion-exchange membrane, long-life electrolyte formulation and innovative flow cell design sets us apart from other providers.

SAFETY

Unlike other large battery systems, VRB-ESS contain no heavy metals such as lead, nickel, zinc or cadmium. The liquid electrolyte is non-toxic, non-flammable and is 100% reusable. VRB-ESS operate at low temperature and pressure and are an inherently stable and safe design.

PROVEN PERFORMANCE

With over 1,000,000 hours of operation, and millions of cycles on systems in our R&D labs and in the field, VRB Energy has the most proven technology and reliable products in the industry today.

SYSTEM QUALITY COMPLIANCE

VRB-ESS have been reviewed and are in compliance with European system quality and safety guidelines.

VRB ENERGY

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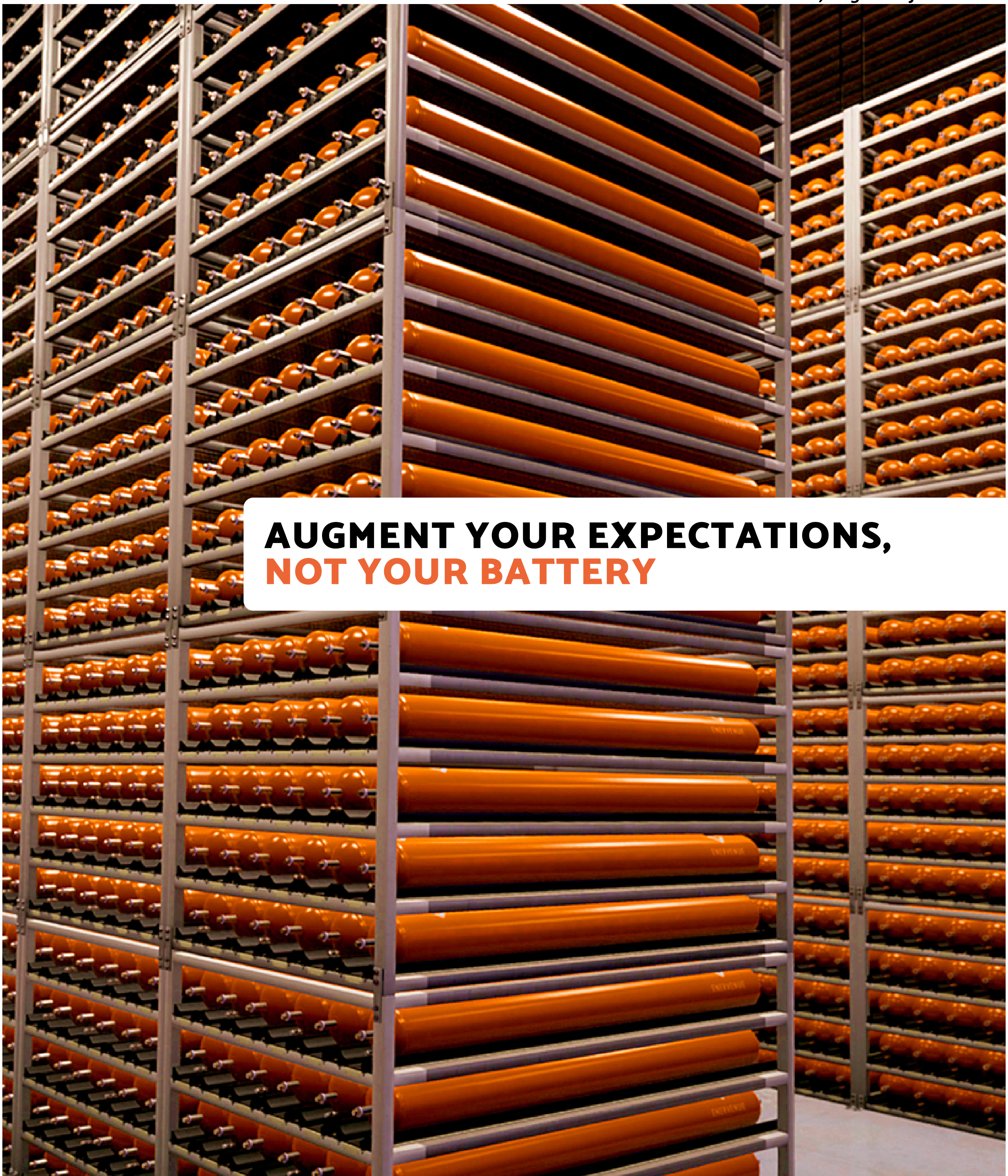
Appendix C

Manufacturer's brochures from Enervenue



AUGMENT YOUR EXPECTATIONS, NOT YOUR BATTERY

ENERVENUE | ENDURING ENERGY

ENERVENUE

PREPARE to challenge everything you know about stationary battery storage. Technology pioneered by NASA and proven in space is now shattering the status quo here on Earth. Revolutionary battery chemistry combined with the industry's best warranty is setting a new standard in projects across the globe.

NASA
First developed in the 1980s, nickel-hydrogen technology would reliably serve in many notable aerospace applications including the Mars Rover, Hubble Telescope, and the International Space Station.

Stanford University
In 2017, Stanford University professor Yi Cui, one of the world's leading material scientists, and his team of researchers redesigned the traditional nickel-hydrogen vessel, improving performance at a reduced cost, and paving the way for commercialization of the technology.

EnerVenue
Established in 2020, EnerVenue is

backed by visionary energy investors. The company's research was validated in 2022, when it achieved commercial deployments. While other non-lithium battery storage technologies are still waiting for a lab breakthrough, EnerVenue is currently producing Energy Storage Vessels via its automated pilot line in the heart of Silicon Valley and will achieve volume production at a U.S.-based manufacturing facility in 2024. Product for international markets may ship from alternative sites.

TECHNOLOGY TIMELINE

- **1980s** — NASA: Metal-Hydrogen technology deployed by NASA
- **2017** — Stanford University: Stanford Professor Yi Cui refines NASA battery technology
- **2020** — EnerVenue founded to commercialize the technology

The workhorse of our solutions: the Energy Storage Vessel™
EnerVenue Energy Storage Vessels feature an exceptionally long lifespan, eliminating the need for augmentation or oversizing. Energy Storage Vessels can be easily mounted in racks, containers or stacked in custom warehousing. Its unique chemistry eliminates the need for preventative fire suppression. Unlike the onerous HVAC conditions required by Li-ion solutions, it can reliably operate in a wide ambient temperature range with minimal or no auxiliary HVAC.

Energy Storage Vessels are the ideal companion to renewable energy generation facilities. Their flexibility allows system owners to capture numerous revenue streams from peak shaving to ancillary grid support services and everything in between.

ENERVENUE

ENERVENUE DELIVERS WHERE LITHIUM-ION CANNOT

FIRE SAFETY, limited lifespan and costly augmentation scenarios are among the critical risks that project owners and financiers must confront. The constraints associated with lithium-ion technology are well-known, and the dangers well-documented.

ENERVENUE IS THE FIRST COMPANY TO DELIVER:

Durability
- Lifetime of 30,000 cycles – 3 per day without rest for 30 years
- No augmentation needed throughout project lifespan

Versatility
- Superior operation in any climate with the lowest OPEX costs
- Ability to capture revenue streams in a multitude of applications

Safety
- No thermal runaway or fire propagation risk
- Absence of problematic fire suppression systems

Flexibility
- Dispatch from 2 to 12 hours in various use cases
- Unmatched deep cycle performance

Long-term security
- The market's longest and simplest warranty, Capacity Assurance™
- Guaranteed at least 88% battery capacity after 20 years/20,000 cycles

Sustainability
- Manufactured with non-toxic, earth abundant materials
- Almost fully recyclable at end of life

ENERVENUE

DIVERSE SOLUTIONS TO ADDRESS ALL MARKET SEGMENTS

TOMORROW'S electrical grid will not look like today's. As the global clean energy transition pushes towards ambitious targets, energy storage solutions that can provide power and support services for the grid will become increasingly important. Pairing low-cost, decentralized renewable energy with grid-scale storage will speed decarbonization. Therefore, it is paramount energy users adopt storage technologies that deliver on their promise to be flexible, safe, and long-lasting. Today, EnerVenue's metal-hydrogen solutions are redefining what can be expected from battery storage.

Grid-Scale

- EnerVenue Energy Storage Vessels can address the application needs of any system owner/operator from frequency and voltage regulation to capacity firming
- No augmentation or gross oversizing is necessary, securing large-scale project profitability for the lifetime of the system
- Significantly lower OPEX can be achieved versus Li-ion systems, eliminating the variables that can threaten consistent revenue stacking
- While Li-ion supply chain volatility can endanger project pipelines, Energy Storage Vessels are made from common materials found in abundance

Commercial & Industrial

- The ideal solution for demand charge avoidance, resiliency and achieving corporate sustainability goals
- Energy Storage Vessel's industry leading safety behavior allows for use in areas never considered before for C&I energy storage projects
- Unique, building-integrated solutions make the most effective use of commercial space
- Vessels can be stacked in a way that Li-ion batteries cannot, offering countless new ways to efficiently deploy storage in C&I markets
- Vessels can be easily integrated into basements, underground or even directly within the walls/structure of new construction

Residential*

- Great for backup power during outages or for energy management to reduce utility bills
- Unlike Li-ion batteries, EnerVenue solutions do not need to be placed in regularly serviceable areas like attics or basements
- Their groundbreaking safety achievements pave the way for storage integration in existing homes as well as new building scenarios
- They can be installed out of sight and mind, since no maintenance is needed
- Long lifetime offers homeowners the greatest peace-of-mind for their energy security

*In development

Energy Storage Vessels

dramatically reduce operational costs and feature a much lower cost-per-cycle compared to lithium-ion chemistries. They also require no augmentation over their 30 year/30,00 cycle lifetime, securing long-term profitability for asset owners without the investment risk inherent in lithium-ion technologies.

ENERVENUE

All projects carry some risk but only EnerVenue offers Capacity Assurance – the industry's longest, simplest and most straightforward extended warranty for stationary energy storage batteries. Plant owners can significantly manage risk and backstop their investments with Capacity Assurance, which offers a 20-year/20,000 cycle warranty extension.

What is even more remarkable, at the end of the 20-year/20,000 cycle period, system owners are guaranteed at least 88% battery capacity. No other battery manufacturer would dare match such a guarantee because their technology simply cannot perform to those standards.

CONTACT INFORMATION

EnerVenue.com | linkedin.com/company/enervenue | MADE IN USA

Energy Storage Vessel™

ENERVENUE

The industry's most durable, safe, and versatile building block for grid-scale and C&I energy storage applications

3/30/30,000

Energy Storage Vessels can cycle up to 3 times per day without rest and boast an expected lifetime of 30 years / 30,000 cycles – enabling unique applications and business models for developers, integrators, and owners.

NO FIRE RISK

Unlike Li-ion chemistries, EnerVenue batteries exhibit no risk of thermal runaway or fire propagation. Energy Storage Vessels have completed UL9540A testing.

LONG-TERM SECURITY

With the battery market's longest and simplest extended warranty available – Capacity Assurance™ – system owners are guaranteed at least 88% capacity after 20 years/20,000 cycles. The warranty safeguards a project's most critical years and helps ensure expected returns are achieved.

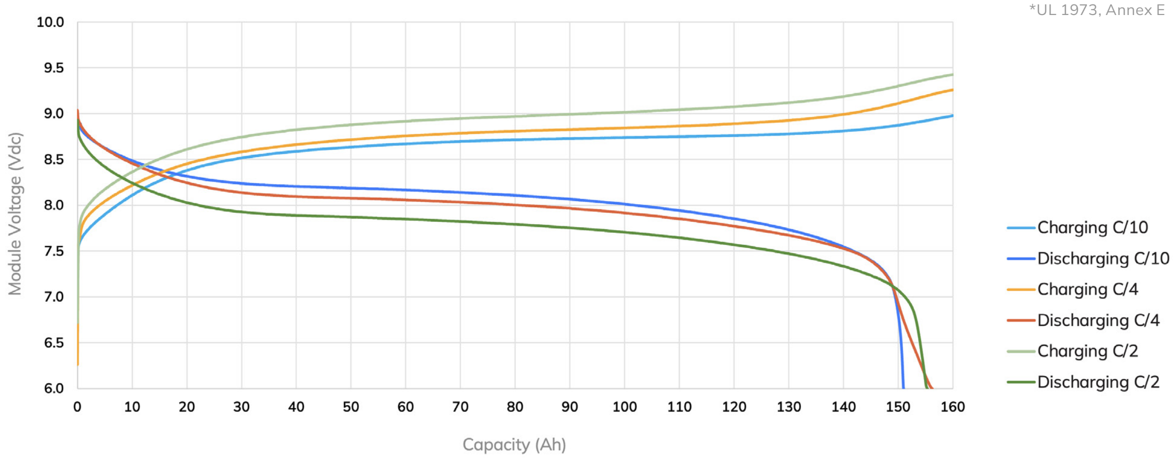
Based on proven technology used by NASA for more than 30 years, EnerVenue Energy Storage Vessels feature an exceptionally long lifespan, eliminating the need for augmentation or oversizing. Energy Storage Vessels can be easily mounted in racks, containers or stacked in custom warehousing. Its unique chemistry eliminates the need for preventative fire suppression. It can also reliably operate in a wide ambient temperature range without supplementary HVAC. Energy Storage Vessels dramatically reduce OPEX and feature a much lower cost-per-cycle compared to lithium-ion chemistries.

Model: Energy Storage Vessel ESV-E

TYPE	DESCRIPTION	SPECIFICATION
Mechanical	Dimensions (Diameter x Length)	142 mm x 1806 mm
	Format	Tubular
	Type	Large Format Battery
	Weight	40 kg / 88 lb
	Operating Temperature	-15 °C to +55 °C
	Cooling Type	Convection
Electrical	Nominal Amp-hour Charge/Discharge	160 Ah/152 Ah @ 25 °C
	Nominal Energy Capacity	1200 Wh @ 25 °C
	Voltage Range	6.6 Vdc - 9.6 Vdc across full range of SOC (0 - 100%) @ 25 °C
	Nominal Power	560 W
	C-Rates	C/2 - C/12
	Peak RTE	90% @ 25 °C
	Expected Capacity Retention	86% after 30,000 cycles
	Chemistry	$Ni-H_2$
	Modes	Constant Current, Constant Power
	BMS	EnerVenue BMS
Performance	Warranty	3-years standard, extendable to 20 years
Regulatory	Certifications	UL 1973*
	Tests Completed	UL 9540A
	Product Name	ESV-E

*UL 1973, Annex E

Module Level Charge and Discharge Curves @ 25 °C



67-00025 Rev B. All products claims and technical data are subject to change at any time without notice. The customer is responsible for verifying all applicable information at the time an order is placed. All information represented is believed to be accurate, but it is presented without guarantee, warranty, or responsibility of any kind, expressed or implied.

CONTACT INFORMATION

EnerVenue.com linkedin.com/company/enervenue

ENERVENUE

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

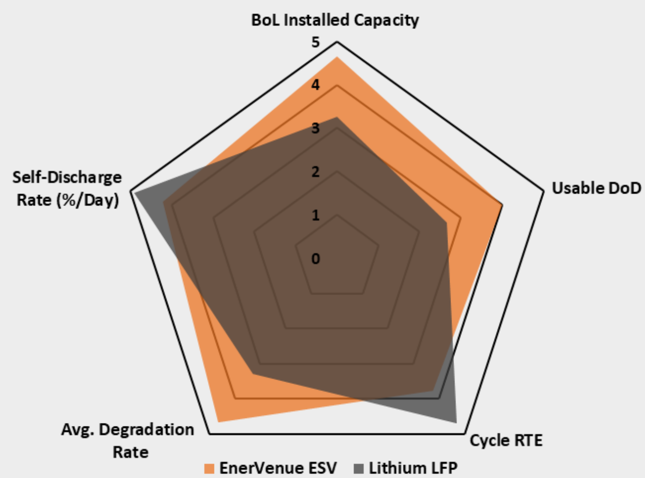


Figure 1. Radar chart for technical comparison

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

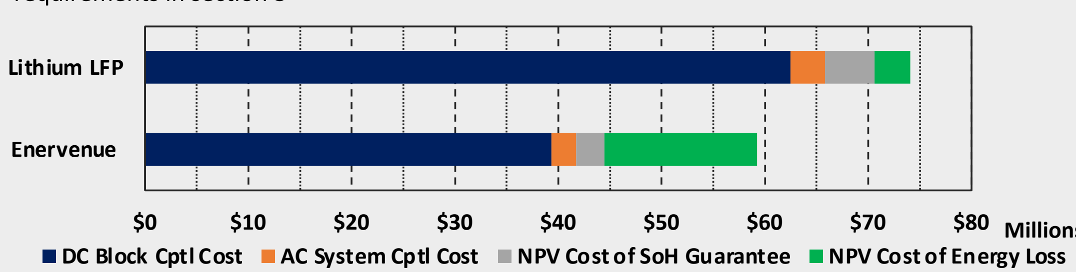


Figure 2: EnerVenue cost of ownership benchmark

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

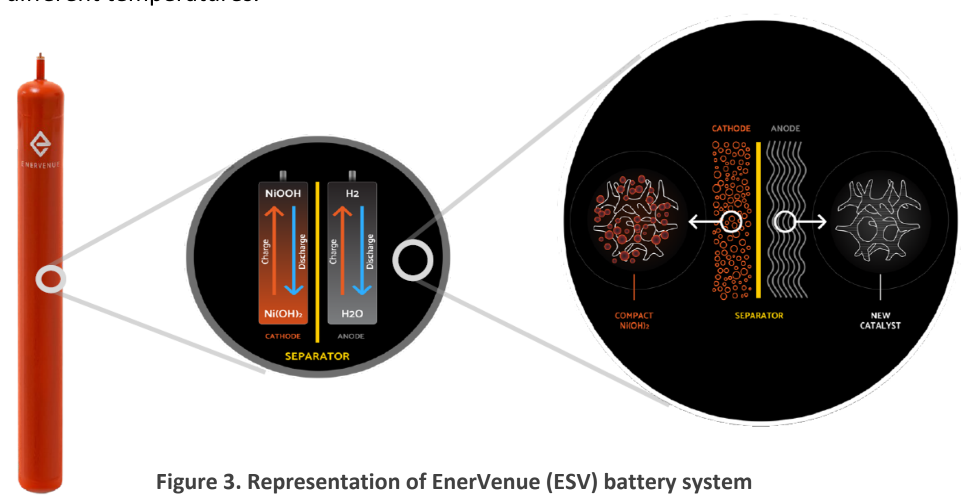


Figure 3. Representation of EnerVenue (ESV) battery system

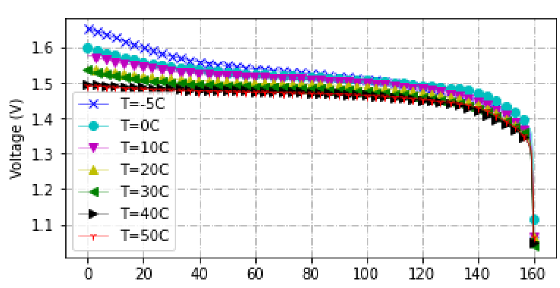


Figure 4.a. Charge cycle cell voltage vs. dsch. Energy

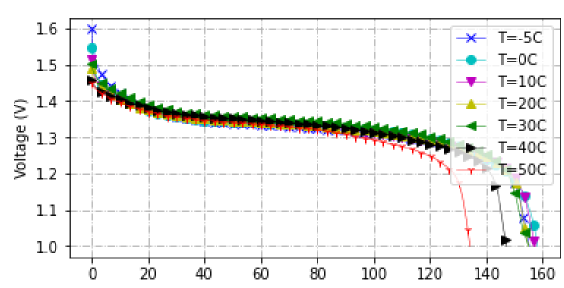


Figure 4.b. Discharge cycle cell voltage vs. dsch. Energy

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%

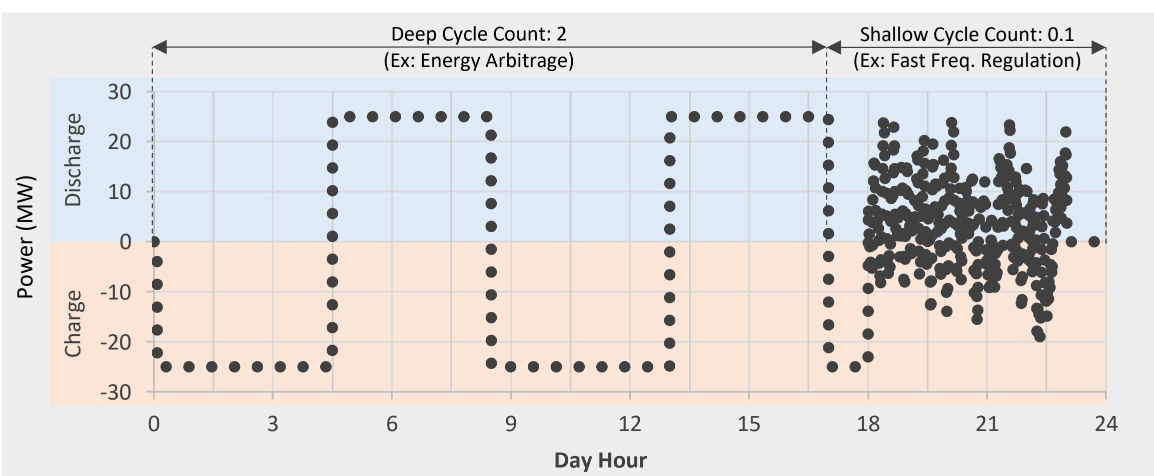


Figure 5. Point of Interconnection (POI) profile for both Li-Ion ($LiFePO_4$) and EnerVenue (ESV) systems

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

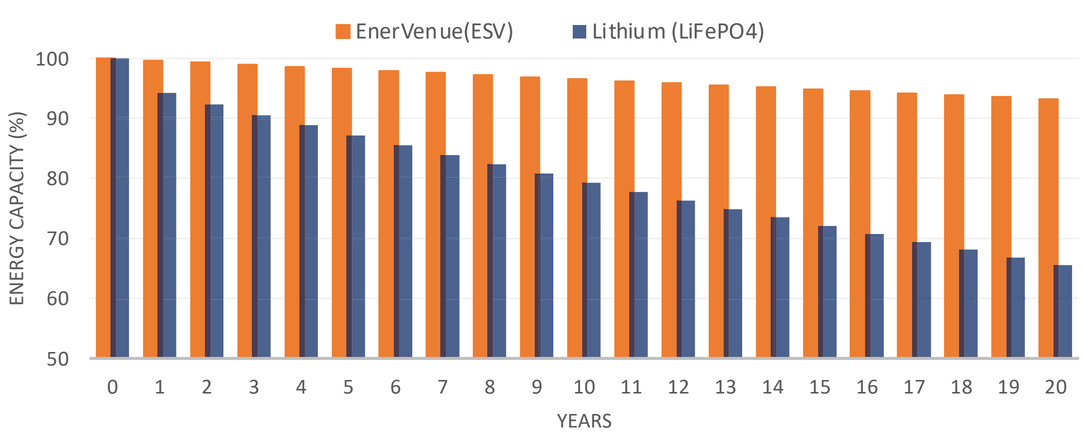


Figure 6. Energy capacity degradation comparison between EnerVenue (ESV) and Li-Ion ($LiFePO_4$)

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.

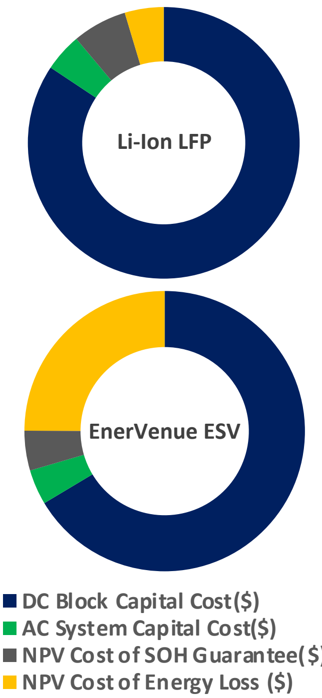


Figure 7. Ownership cost distribution of both systems.

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

Appendix D

Manufacturer's brochures from ESS Inc.

Catalyzing a Clean Future. Every Day.

February 2023

ESS: An Enduring Value Proposition

Creating the reliable, resilient and safe renewable energy future is one of the greatest challenges of our time.

ESS delivers the safe and sustainable solutions that empower our customers to make their clean energy vision a reality and achieve their legacy.

Flexible Technology

ESS' scalable solutions serve a variety of needs and will underpin the decarbonized energy system of the future.

ESS LDES solutions enable our customers to provide clean energy 24/7, maintain a safe, stable and resilient grid, and meet the needs of their customers.

Powered by Nature

Iron. Salt. Water.
Simple ingredients provide a natural, sustainable solution.

With the lowest lifecycle carbon footprint of any storage technology, an inherently reusable design and highly recyclable materials, ESS technology is in harmony with the emerging circular economy.

Responsible and Equitable

Safely deliver benefits to communities worldwide.

ESS' safe and nontoxic IFB systems are the safest possible choice for distributed energy storage applications, providing safe, clean and resilient energy for communities that need it.

By manufacturing and sourcing in the United States, ESS is driving thousands of jobs and millions of dollars in domestic economic activity, playing a key role in the sustainable American industrial renaissance.

ESS Iron Flow Battery Factory

Company Overview

Company profile

ESS	Founded in 2011 with mission to develop lowest cost long-duration energy storage technology
Headquarters	Wilsonville, OR
Facilities	250,000 ft^2 manufacturing plant Robotized production line currently scaling to 2GWh annual production
Employees	250+
Technology	Iron flow battery for utility-scale and commercial applications
Publicly traded	NYSE: GWH

Manufacturing facilities in Oregon


Agenda
The Global Energy Transition
ESS Iron Flow Batteries
Benefits of Iron Flow Batteries
Case Studies
Next Steps

The Global Imperative to Transition to Renewable Energy

Extreme climate-driven weather events are now the norm. Deadly extreme weather for US cost at least $145 billion in 2021.

The world's appetite for electricity is growing unabated. Global electricity demand rose by 6% or 1,500 terawatt hours (TWh) in 2021.

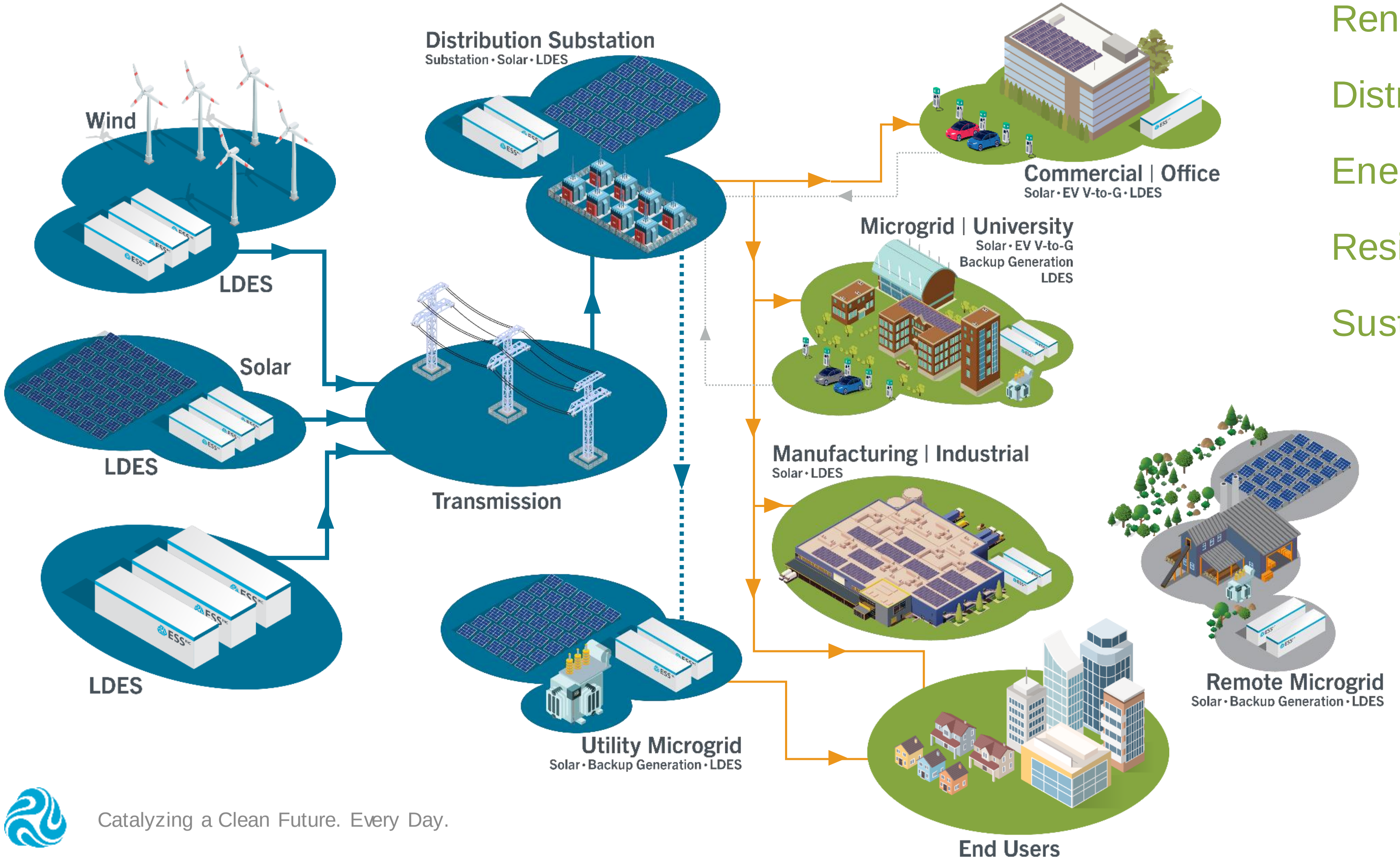
The risks of today's aging energy infrastructure are readily apparent – and more dangerous. Today's solutions need to last for decades.

Increasing concern for energy and national security.

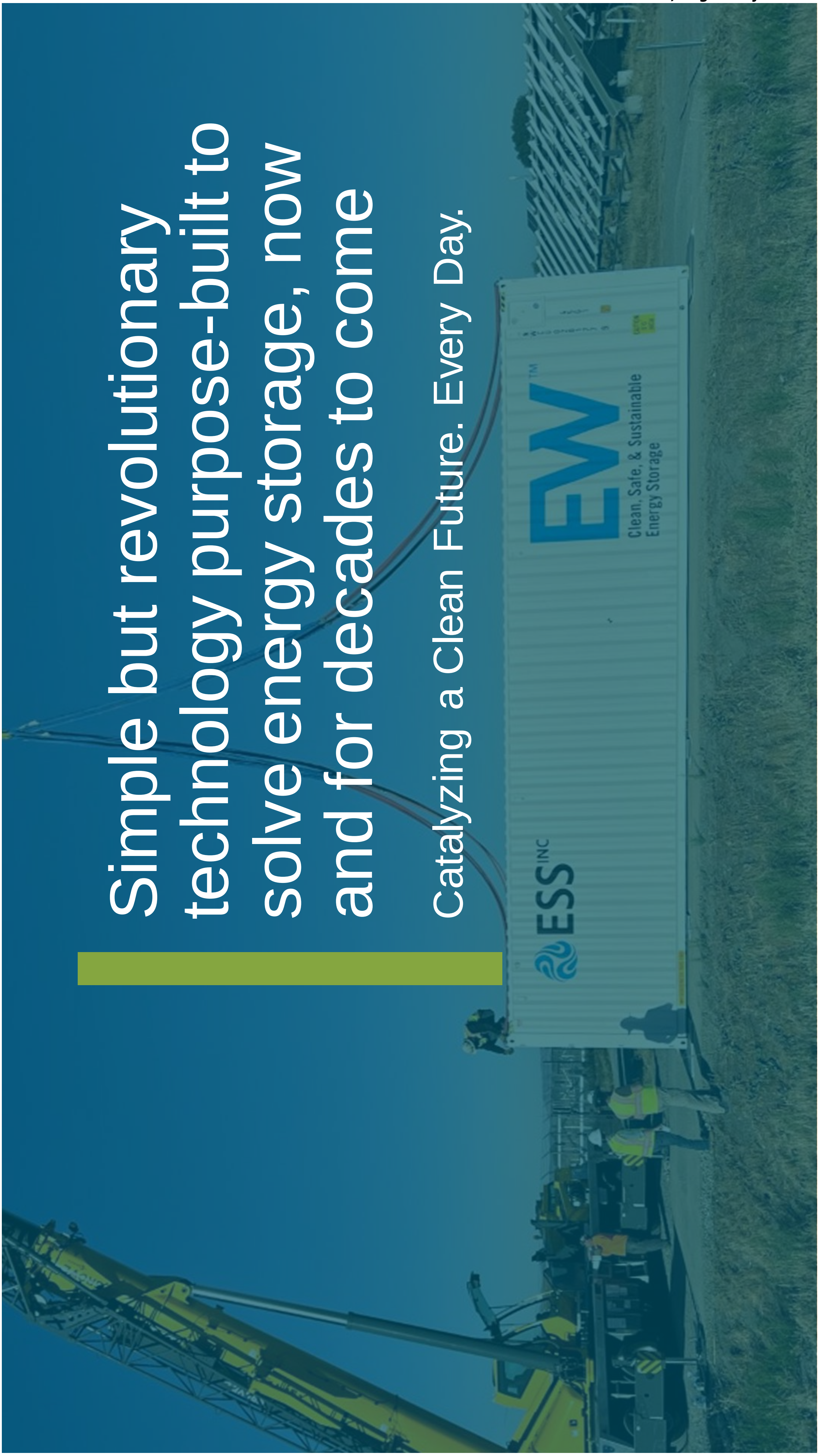
The cost for utility-scale solar PV power has declined 82% since 2010 and the costs for onshore and offshore wind have declined 39% and 29%, respectively *(both are now cheaper than fossil fuels).*

A global transition to a decarbonized world is underway. To preserve a livable climate, greenhouse-gas emissions must be reduced to net 0 by 2050.

How Long-Duration Energy Storage (LDES) Fits into Our Energy System



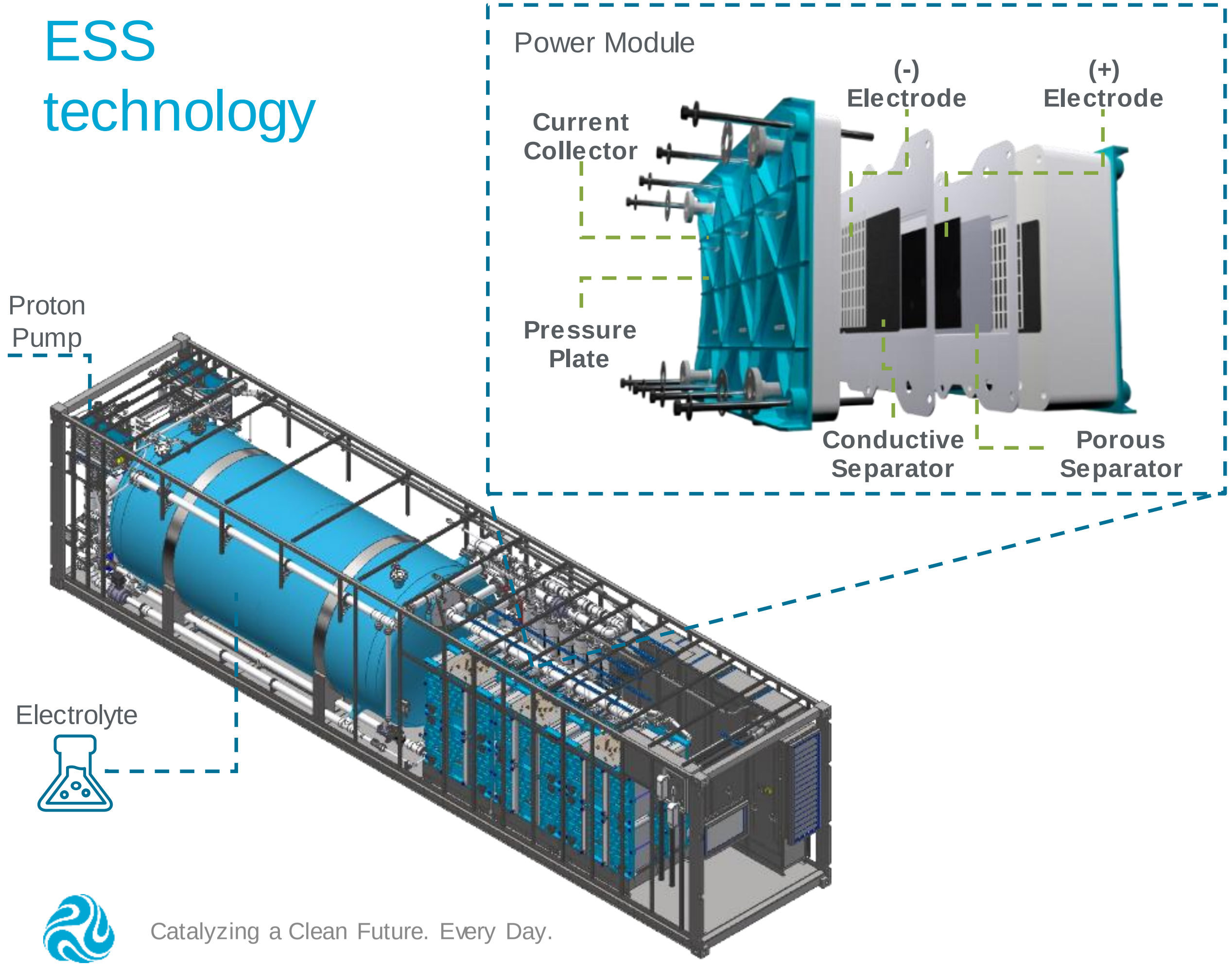
- Renewable energy smoothing
- Distributed energy resources
- Energy cost savings
- Resiliency and reliability
- Sustainability goals


Simple but revolutionary technology purpose-built to solve energy storage, now and for decades to come
Catalyzing a Clean Future. Every Day.
EW
Clean, Safe, & Sustainable Energy Storage
ESS INC

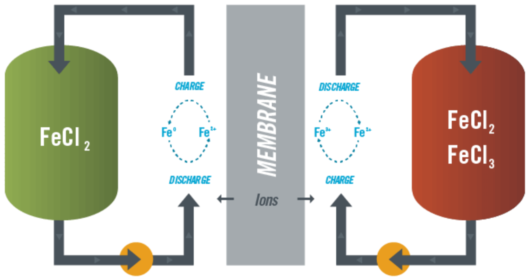
ESS Iron Flow Batteries

ESS Battery Technology

ESS technology



Electrochemistry



$$Fe^{2+} + 2e \underset{discharging}{\overset{charging}{\rightleftarrows}} Fe^{0} \qquad E^{0}=-0.44V$$

$$2Fe^{2+} - 2e \underset{discharging}{\overset{charging}{\rightleftarrows}} 2Fe^{3+} \qquad E^{0}=+0.77V$$

- During charging iron collects (electroplates) on the negative electrode
- During discharging iron dissolves back into solution
- Passive design proton pump continuously refreshes electrolyte in closed-loop system

Energy Warehouse™ Overview

- First commercial deployment in 2015
- Generation II launched in 2020
- Containerized fully-integrated design
- Fast to deploy and commission

Specifications

Nominal Power	75kW
Peak Energy Capacity	500kWh
Rated Energy Capacity	400kWh
Response Time	<1 second
Module Cycle Life	>20,000 cycles
Ambient Temperature	-5°C to +40°C
Expected Life	25-year design life
Warranty	1-year comprehensive defect warranty, 10-year warranty backstop underwritten by Munich Re

Energy Center Overview

- Front-of-the-meter solution
- Shipping Q4 2023
- Modular design for utility-scale applications

Specifications

Configurable Range	Customizable up to GW scale; 145kW DC increments
Rated Capacity	8MWh per MW installed
Total Capacity	10MWh per MW installed
Ambient Temperature	-5°C to +40°C standard; -15°C to +40°C option; both 15% derate to +45°C
Expected Life	25-year design life
Secondary Containment	Integrated into tank container to volume of largest tank
Warranty	1-year comprehensive 10-year extended warranty on battery modules and electrolyte management system

ESS Product Comparison

	Energy Warehouse	Energy Center
Target Customer	C&I; medium-duration storage	Front-of-the-meter; long-duration storage
Rated Discharge Power	75kW	145kW
Peak Charge Power	90kW (1 hour)	174kW
Peak Energy (kWh)	500kWh	1450 kWh
Rated Energy (kWh)	400kWh	1160 kWh
Rated Energy (hours)	5.3 hours	8 hours
Voltage	AC - 400-480VAC | DC - 880VDC	DC - 880VDC
Blackstart Capability	Included in DC	Site requirement as needed
Ambient Temperature	-5°C to +40°C 15% de-rate to +45°C	-5°C to +40°C standard; -15°C option 15% de-rate to +45°C
Secondary Containment	Site requirement as needed	Included, integrated
Technology (Benefits)	Iron Flow Battery (non-toxic, no thermal runaway)	Iron Flow Battery (non-toxic, no thermal runaway)
Expected Life	25 years	25 years

Investment Grade Warranty

Industry-leading warranty

Product cover

10-year extended warranty on entire technology stack

Project cover

Assignable warranty provides additional surety to owners and financiers

Bankability

Warranty backed by investment grade insurer, Munich RE, that covers every product, everywhere.

US Export-Import Bank Qualified
Pre-qualified financing available for overseas buyers

Munich RE

"The ability to ensure battery performance is a key piece of the puzzle in decarbonizing our energy sector."

- Peter Röder, Member of the Board of Management, Munich RE

Benefits of Iron Flow Batteries

ESS Benefits

What Customers Demand	ESS INC	How ESS Transforms the Grid
Longer duration	• Up to 10 hours • No capacity fade • No power fade	• Can replace coal and gas with solar and wind • Designed for utility-scale applications
Low cost	• Lower LCOS than other technologies • No augmentation required	• The first truly low-cost flow battery • In commercial production today
Power on demand	• <1 second response time • >20,000 cycle life – $0 marginal cost per cycle • Flexibility allows multiple revenue streams	• Improved grid resiliency and flexibility • Enables multiple use cases
Safety, reliability, and bankability	• Safe and non-toxic • Wide operating temperature range • Munich Re insures technology risk	• Can deploy in a wide range of geographies • No HVAC needed – cuts CAPEX and OPEX
Sustainability	• Easily sourced materials; recyclable components • “Plug and play” with 25-year design life	• Environmentally sustainable • Accelerates clean energy transition

How Iron Flow Batteries Stack Up

	Iron Flow	Li-Ion	Vanadium, Zinc Bromine	Sodium Sulfur	Compressed Air	Pumped Hydro
Low LCOS	●	○	○	○	●	●
Earth abundant materials	●	○	●	●	●	●
Unlimited cycling	●	○	○	○	●	●
Zero capacity face	●	○	○	○	●	●
Deployable anywhere	●	●	●	●	○	○
Wide operational temperature range	●	○	●	○	●	●
Scalable	●	●	○	○	○	○
No thermal runaway	●	○	●	○	●	●

Note Internally developed table based on company data and publicly available information.

Sustainability Advantages

Sustainability focus areas	ESS Iron-flow batteries
Responsibly sourced materials	Earth-abundant iron, salt and water
Global warming potential (GWP)	67% lower CO_2 emissions than Li-Ion[1]
Recyclability	Contains no toxic materials Easily sourced materials Recyclable components

Note GHG impact is dependent on specific Li-Ion chemistry.

1 He, H. et al. "Flow Battery Production: Materials Selection and Environmental Impact." Journal of Cleaner Production. Vol. 269. 1 October 2020.

Noguera, E., Comparative LCA of stand-alone power systems applied to remote cell towers, 2014.

Use Case

San Diego Gas & Electric

Community resiliency for PSPS events and wildfires

Project location

California

Use case

- Microgrid to mitigate Public Safety Power Shutdown events
- Market participation during non-PSPS events
- Distribution system support

Project benefits

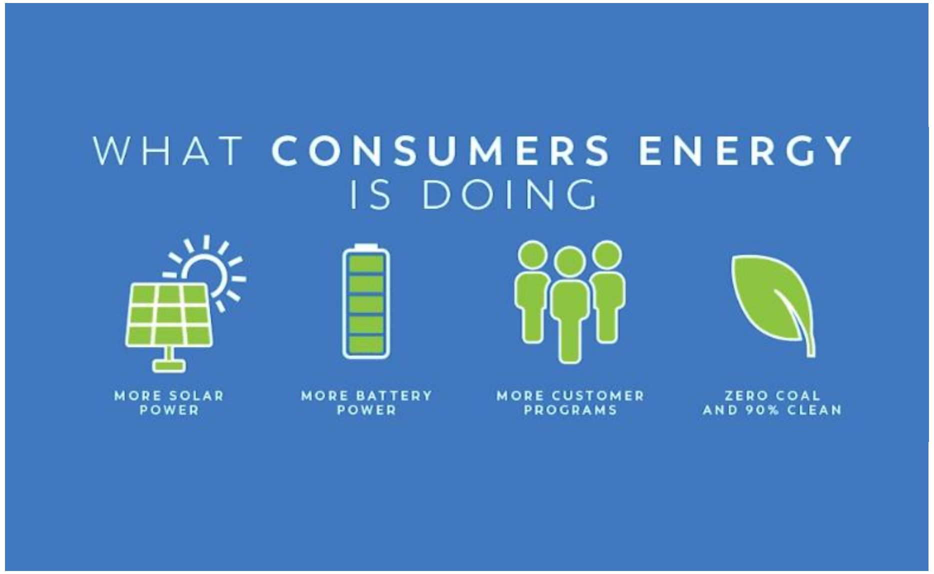
- Provides multi-day resiliency for remote community
- Powers critical community infrastructure including healthcare, community centers, and commercial businesses during PSPS events

Why ESS won

- Safety:
  no risk of thermal runaway
- Ability to provide grid ancillary services and participate in CAISO market during non-PSPS events

Use Case
CMS

Energy shifting and critical load management



Project location
White Pigeon, Michigan

Use case
- Microgrid powering the White Pigeon gas compression facility

Project benefits
- Resiliency: Ensures the safe, dependable operation of critical infrastructure
- Sustainability: Delivers on customer goal of producing, storing and utilizing increased clean, renewable electricity

Why ESS won
- Battery safety. Li-on eliminated due to safety and compliance concerns
- Long asset life
- Unlimited cycling with no degradation

Use Case
SMUD

Enabling 2030 Zero Carbon Plan – 2GWh by 2028

Project location
Sacramento County, CA

Use case
- Standalone LDES storage for large-scale renewable integration
- DER for community resiliency and environmental justice

Project benefits
- Enables SMUD's ambitious 2030 Zero Carbon plan
- Safe and non-toxic technology can be sited near communities most in need of reliable energy
- Eventual elimination of natural gas generation
- Economic development opportunities

Why ESS won
- Safe and non-toxic technology
- Unlimited cycling and long-duration enables elimination of fossil fuel generation
- Commitment to local assembly and workforce development partnership

Use Case
TerraSol Energies, Inc.

Decarbonizing recycling

TerraSol Energies, Inc.

SYCAMORE

Project location
West Grove, Pennsylvania

Use case
- Behind the meter microgrid owned by customer
- Customer is an electronics recycling facility
- Energy shifting, load management

Project benefits
- <5 yr. payback on energy cost savings
- >$800K in resiliency benefits (over 10 years)

Why ESS won
- Resiliency benefits of long duration storage
- Battery safety. Li-on eliminated due to safety and compliance concerns

ESS INC

Making Renewable Energy On Demand Energy. All Night. Every Day.

Flexible

One long-duration energy storage solution that addresses multiple use cases

- Reliability and renewable integration
- Resiliency and ancillary services

Durable

25-year design life, no capacity fade

Cost effective

Lowest cost of storage

Easy

Easy to site and deploy.
Easy to augment, increase capacity (just add water)

Safe

Non-toxic
Earth abundant materials
No thermal runaway