Final Technical Report

Flow Battery Solution for
Smart Grid Applications

Award DE-OE0000225

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Submitted by

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Contents

List of Figures

1 Introduction

To address future grid requirements, a U.S. Department of Energy ARRA Storage Demonstration program was launched in 2009 to commercialize promising technologies needed for stronger and more renewables-intensive grids. Raytheon Ktech and EnerVault received a cost-share grant award from the U.S. Department of Energy to develop a grid-scale storage system based on EnerVault's iron-chromium redox flow battery technology.

2 Project Overview and Objectives

This project demonstrates the performance and commercial viability of EnerVault's novel redox flow battery energy storage systems (BESS), the EnerVault's Vault-20 (250 kW, 1 MWh). The four-year project culminated in the deployment of the only MW-hr scale Iron-Chromium redox flow battery in the world. The system was deployed in California's central valley. In Phase I, site assessment and compliance was completed as well as development and laboratory testing of a 2.5 kW prototype system and a 30 kW Alpha stack (full scale). In Phase II, lessons learned from the Alpha stack evaluation were used to complete the development, design, and construction of a Vault-20 Beta system. Phase III was composed of commissioning the Vault-20 system at the demonstration site and operating the system for several months.

Figure 1 - EnerVault installation in Turlock, CA.

The project team included Raytheon Ktech and EnerVault Corporation. Raytheon Ktech provided controls and automation and systems engineering and EnerVault led the battery development, fabrication, and commissioning and operation of the fielded system.

The primary objective of the project was to combine a proven redox flow battery chemistry with a unique, patented design to yield an energy storage system that meets the combined safety, reliability, and cost requirements for distributed energy storage. Redox flow batteries (RFB) are a subclass of electrochemical energy storage devices called flow batteries. Flow batteries are batteries where at least one of the reactants flows through the system rather than being contained in a cell. The separation of power and energy is a key distinction of RFBs compared to other electrochemical storage systems. The system energy storage capacity is based on the volume of electrolyte solution. The power capacity of the system is determined by the size of the stack of electrochemical cells.

The iron-chromium chemistry is used in EnerVault's long-duration, grid-scale energy storage systems. The iron-chromium redox flow battery (Fe-Cr RFB) energy is stored by employing the Fe^{2+}- Fe^{3+} and Cr^{2+} - Cr^{3+} redox (reduction-oxidation) couples:

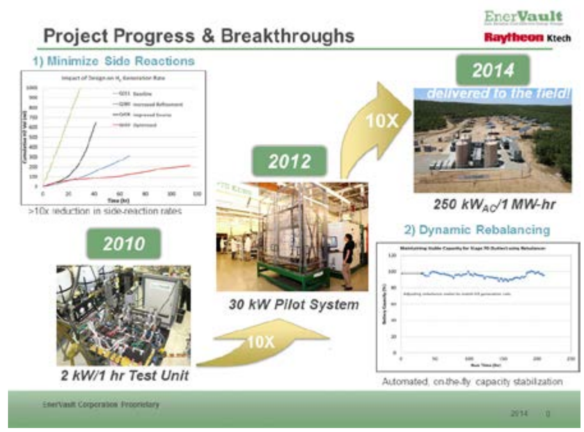
Discharging: $Fe^{3+} + e^- \Leftrightarrow Fe^{2+}$ (reduction)
$Cr^{2+} \Leftrightarrow Cr^{3+} + e^-$ (oxidation)

Charging: $Fe^{3+} \Leftrightarrow Fe^{2+} + e^-$ (oxidation)
$Cr^{3+} + e^- \Leftrightarrow Cr^{2+}$ (reduction)

The active chemical species are fully dissolved in the aqueous electrolyte at all times. Like other RFBs, the power capacity and energy storage capacity ratings of the iron-chromium system are completely independent of each other, and each may be optimized separately for each application

This project delivered the first demonstration of a MW-scale Fe/Cr redox flow battery.

3 Schedule and Key Milestones



Several breakthroughs were achieved during this project including minimizing side reactions and automating the rebalancing process.

The prototype system was scaled up 10 times from the previous iteration to create a production scale, 30 kW test system, PTS Echo which was installed in April 2012.

The 30 kW Echo test system was fabricated by Ascension Industries and the *Engineered Cascade*™ power modules were manufactured on an EnerVault pilot manufacturing line in Sunnyvale, CA.

The results from the sub-scale system Bravo were used to predict the results of the production scale model, systems Charlie, Delta, and Echo. When the actual test was conducted, results were as predicted by the design model. Figure 2 shows the cascade power compared to the cascade current.

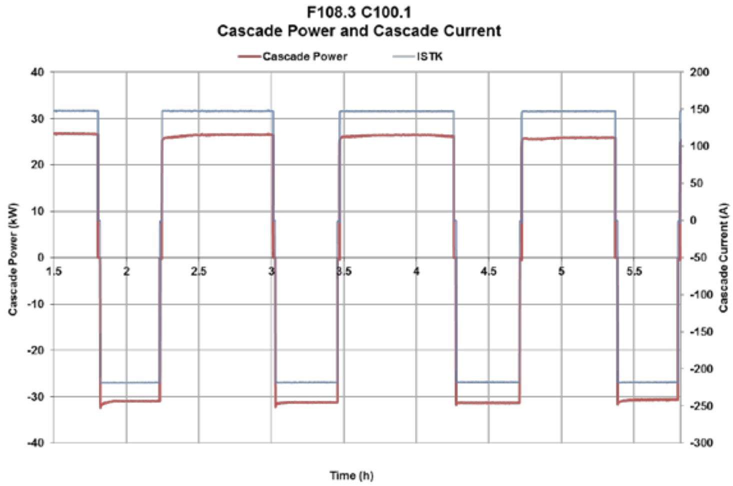


Figure 2 - Cascade Power vs. Current

After completing the installation of the 30 kW prototype system, PTS Echo in April 2011, the project focused on completing the system design, designing the site, beginning the permitting and interconnection process, and building the system.

In order to scale the system to 250 kW (1 MW-hr), nine 30 kW cascade flow batteries were integrated into one unit. This was part of the assembly process that took place between November 2013 and March 2014.

The 250-kW-system included the first hydraulic and electrical integration of multiple cascades. The balance of system, including the hydraulic plant module and power unit enclosure was designed to EnerVault's specifications. This module included pumps, valves, filters, container modifications, ventilation, safety systems, sensors, software, and controls.

The Turlock Site design consists of the EnerVault Fe-Cr RFB, an existing solar photovoltaic system, an irrigation pump, and connection to the power grid via a medium voltage - low voltage distribution transformer.

Figure 3, Figure 4, Figure 5, and Figure 6 show the main sub-systems of EnerVault Turlock. The Power Unit, Figure 3, was installed as nine 30 kW cascades. Figure 4 shows the Hydraulic Plant Module being installed. Figure 5 shows the Energy Unit consisting of four electrolyte tanks. Figure 6 shows the inverter.

Figure 3 - 30 kW_{DC} cascades installed (9 in total)

Figure 4 - Skid-mounted Hydraulic Plant Module

Figure 5 - Electrolyte Tanks

Figure 6 - Inverter

After completing the physical installation and receiving operating permits, the Turlock test system began performance testing in May 2014. Initially the system was tested at 50% energy levels (i.e., up to 2 hour discharge) to generate more full cycle testing data. Power was ramped to the full 250 kW net AC and the remaining electrolyte added to bring the system to full capability in October 2014.

A summary of project milestones and actual dates milestones were achieved is shown in Table 1 below.

Table 1. Project Milestones

Milestone No.	Milestone Title	Completion Date
M1	Achieve Initial Performance Targets	05/30/2010
M2	2-5 kW Prototype System Demo	08/31/2011
M3	Demonstrate Full Scale Stack Design	01/27/2012
M4	Demonstration of 21 kW Alpha stack for 1 month	05/26/2013
M5	Completion of 250 kW Vault-20 Beta Unit	05/22/2014
M6	Beta Field Demonstration	03/30/2105
M7	Final Report to DOE	05/14/2015

A summary of cumulative project costs, including Federal and Cost Share contributions, is shown in Figure 7. In 2009, the original project budget was estimated at $9.5M. Scaling this technology from laboratory to fielded full-scale system resulted in total costs of approximately $23.5M. Project milestones are also shown according to milestone completion date.

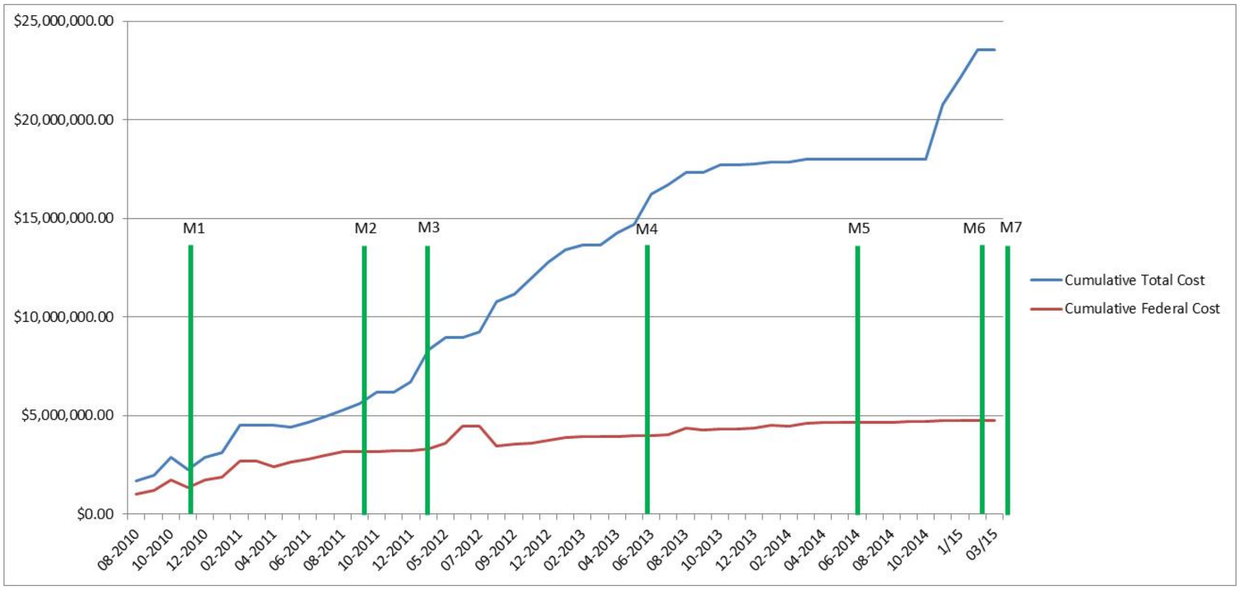


Figure 7 - Spend Plan

4 Performance Metrics

The key benefits of EnerVault's iron-chromium redox flow battery technology is that it uses plentiful, low cost, environmentally safe, and low hazard electrolytes allowing low production costs and low mitigation costs. As the power and energy can separately be sized, the technology provides a high degree of flexibility to tailor the set-up to the needs of the application. Since adding more energy storage involves only increased tank sizes and a larger volume of low cost electrolytes, the marginal installed cost of an additional kW-hr of energy can be under $100 / kW-hr, making long duration applications cost effective.

Test results are displayed in the following figures. Figure 8 shows the cell voltage uniformity over charge and discharge cycles. Cell voltages are shown for each of the six stages of the nine 30 kW cascades. The flow and current distribution among stacks is purely passive balancing by design. All cells measured within a range of approximately 20 mV. This result indicates an excellent degree of electrical and reactant flow uniformity throughout the system.

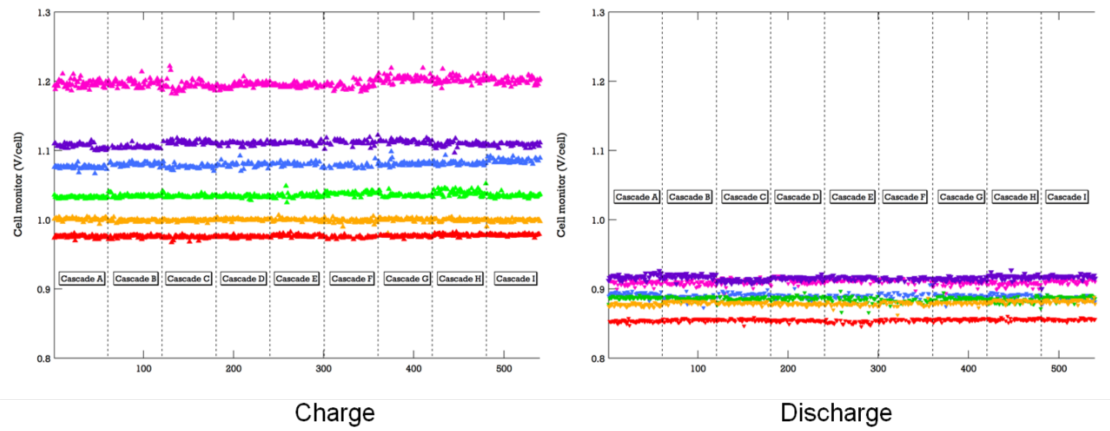


Figure 8 - Cell Voltage Uniformity

Figure 9 shows the system performance profile and uniformity over three shorter duration charge and discharge cycles at 250 kW AC net. The multi-colored lines shows voltage from each 120 cell stage, normalized to the cell count. Each color has nine plot points, one for each of the nine cascades that make up the system. The narrow width of each plot is another indicator of the excellent electrical and hydraulic uniformity in the stages and cascades. The black line plots the cascade current for each of the nine cascades. The blue line shows the system flow rate as measured at multiple points within the hydraulic system.

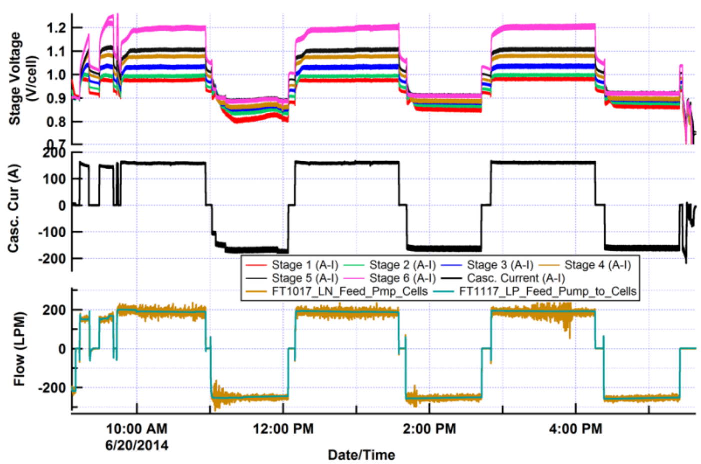


Figure 9 - Uniformity over Multiple Cycles

Figure 10 shows the full energy cycle performance from testing conducted over November 20 – 21, 2014. Charge power was adjusted to ensure adequate stored energy for subsequent steady discharge at 250 kW AC net for 4 hours, a goal that Figure 10 shows was achieved. The EnerVault Turlock system ramped from idle to full charge and to full discharge power (250 kW AC net) within 30 seconds.

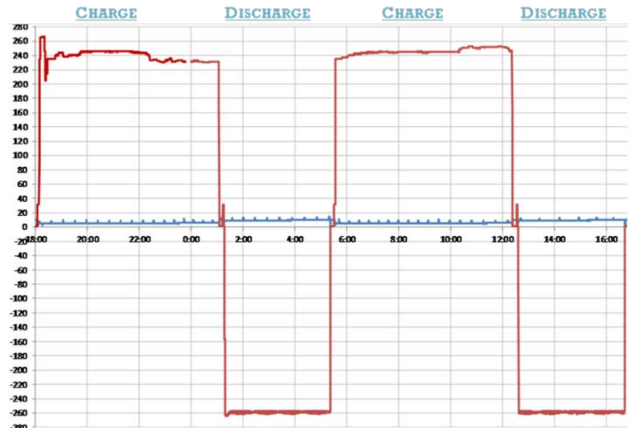


Figure 10 - Full Energy Performance Cycle

4.1 PNNL Test Protocol

EnerVault conducted tests according to DOE PNNL-22010 Rev. 1 Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems. Test results were verified by DNV GL Energy, Inc.

- The four stored energy capacity (SEC) cycles averaged 248.9kW for 4.1 hours resulting in 1.018 MWH delivered with an average efficiency of 60.7%.
- Two roundtrip efficiency (RTE) duty cycles of 6 and 4 hours of discharge yielded 56.0% and 54.5% efficiency respectfully. The 2-hour discharge cycle efficiency result is not application for this redox flow battery design.
- The response time and ramp rate (RESP) test yielded a system response time <30s (or 0.5 MW/min) from standby to 98% of rated charge power and 98% of rated discharge power.

Cycle	Charge Time (h)	Charge Energy (kWh)	Discharge Time (h)	Discharge Power (kW)	Discharge Energy (kWh)	Roundtrip Efficiency (%)
SEC1 Cycle 1	6.8	1,656	4.0	248.4	1,012	61.0
SEC1 Cycle 2	6.9	1,714	4.1	248.8	1,020	59.5
SEC2 Cycle 1	6.9	1,644	4.1	249.2	1,017	61.9
SEC2 Cycle 2	7.2	1,689	4.1	249.1	1,021	60.5
Sum	27.8	6,704	16.3	995.5	4,070	242.9
Average	7.0	1,676	4.1	248.9	1,018	60.7

- All cycles had similar input and output energies with an average efficiency of 60.7%.
- Ambient temperature and barometric pressure during the tests were approximately 56°F and 30.1" Hg.

Figure 11 - Stored Energy Capacity and Roundtrip Efficiency at Rated Power

Duty Cycle	CHG Time (h)	CHG Power (kW)	CHG Energy (kWh)	Float Energy (kWh)	DSG Time (h)	DSG Power (kW)	DSG Energy (kWh)	% Rated Power During Discharge	Duty Cycle Roundtrip Efficiency (%)
A	6.8	239.5	1,689	148.1	6.1	169.8	1028	67.9	56.0
B	6.8	249.8	1,697	178.8	4.1	249.3	1022	99.7	54.5
C	6.8	252.5	1,717	207.3	2.0	248.4	509	95.3	*

Figure 12 - Duty-Cycle Roundtrip Efficiency

Cycle	Discharge Energy (kWh)
SEC1 Average	1,016
SEC2 Average	1,019
Difference (%)	+0.3%

Figure 13 - Stored Energy Capacity Stability

Response Time on Charge

- T-1 11/25/2014 12:55:41 PM Set pumps
- T0 11/25/2014 12:56:31 PM Set CHG power
- T1 11/25/2014 12:57:06 PM Start of Ramp
- T2 11/25/2014 12:57:34 PM 98% of rated CHG power achieved
- Flow development= T0-T-1= 50s
- Communication latency= T1-T0= 25s
- Charge response time = T2-T1= 28s
- Charge ramp rate = 0.58 MW/min and 230% rated power/min

Response Time on Discharge

- T-1 11/25/2014 01:05:05 PM Set pumps
- T0 11/25/2014 01:06:34 PM Set DSG Power
- T1 11/25/2014 01:07:00 PM Start of Ramp
- T2 11/25/2014 01:07:24 PM 98% of rated DSG power achieved
- Flow development= T0-T-1= 89s
- Communication latency= T1-T0= 26s
- Discharge response time = T2-T1= 24s
- Discharge ramp rate = 0.61 MW/min and 246% rated power/min

Figure 14 - Response Times

4.2 Charge/Discharge Cycles

The following summarizes the charge and discharge cycles for the period of 6/3/2014 through 12/3/2014:

Charge Cycles	31
Discharge Cycles	27
Charge Hours	148
Discharge Hours	79

4.3 Economic Performance Parameters

Metric	Expected	Actual	Unit of Measure	Definition
Development	6,700,000	11,701,203	$	Development cost
Engineering and Design Costs	1,050,000	1,223,346	$	Cost associated with engineering and design for the demonstration project implementation.
Capital cost (e.g. equipment capital and installation	2,150,000	3,089,133	$	Total installed first cost of fielded system, breaking out major categories including equipment (i.e., major equipment costs, related support equipment, associated with shipping, site preparations, installation and commissioning.
Capital Cost $/kWh	2,150	3,089	$/kWh	Total installed first cost of fielded system, normalized by energy storage capacity and peak power optput
Capital Cost $/kW	8,600	12,357	$/kW	
End of Life disposal Cost		$350,000	$	Total cost of dismantling and removing the fielded system, including (if applicable) decontamination long-term waste storage, environmental restoration and related costs.
End of life value of plant and Equipment		0	$	Resale or salvage value of plant and all associated equipment.
Operating cost (activity based,non-fuel, by application plus monitoring)		NA	$/kW-month	Activity based, average monthly total of all direct and indirect costs incurred in using the system,excluding cost of purchased electricity and including third-party monitoring if applicable.
Maintenance cost (by cost category)		NA	$/kW-month	Activity based, average monthly cost of maintaining the fielded system.

4.4 Technical Performance Parameters

Metric	Expected	Actual	Unit of Measure
Round-trip efficiency (RTE)	Cycle efficiency measured per DOE PNNL 22010 R1: 60% cycle efficiency 54% duty cycle efficiency for cycle B	60	%
Capacity degradation	No change measured per DOE PNNL 22010R1 stored energy capacity test before and after duty cycle testing		%

Other parameters were not predicted or measured because this project was part of the 2.5 "Promising technology demonstration" program.

4.5 Results Summary

- Demonstrated full system power rating of 250 kW net AC in charge and discharge modes
- Demonstrated full power, constant discharge of 250 kW net AC over 4 hours
- Demonstrated full system energy rating of 1 MW-hr
- Demonstrated cycling capability at full power and energy from the original set of cascades
- Demonstrated a high degree of cell voltage uniformity throughout the system
- Validated the ability to consistently manufacture precision, high quality stages due to a robust engineering of cells, stages, and cascades
- Validated thoroughness of factory acceptance testing protocols
- Demonstrated the ability to integrate system components including nine *Engineered Cascades*™ power unit

5 Interoperability and Cyber Security

The architecture of the BESS control system was based on the architecture of the battery, the functional subsystems, and the operational environment. Individual battery modules are controlled by a programmable automation controller. These controllers are connected via an internal TCP/IP network to a primary control computer. This primary control computer system acquires sensor data used to monitor the overall health and effectiveness of the BESS, and manages charge and discharge rates and times.

The BESS provide threes mechanisms for information exchange: e-mail notifications, web services, and remote login.

- The BESS provides e-mail notifications in the event of process excursions or other noteworthy system events. These addresses are specified in the BESS configuration. E-mails are sent via SMTP.
- The BESS provides a set of web services to allow access via HTTPS to various monitoring, control, maintenance and reporting functions.
- The BES provides for remote login with authentication and authorization security controls.

6 Lessons Learned

Utility Interconnect. Connecting an energy storage system to the grid is new for everybody involved – allow lots of time. We began the application process with Pacific Gas and Electric (PG&E) in October 2012. There were many iterations as additional information was requested by numerous people within PG&E; more detail on single line drawing, application for service needed in addition to interconnect agreement, certification of inverter, and then in September 2013 we were notified we would have to go through Net Energy Metering/Multiple Tariff (NEM/MT) application process. After much effort, it was determined that PG&E had not had very many opportunities to work with bi-directional systems, especially at large scale capacities and it was unclear as to how and where it fit in their connection application process. Prior to applying for an application with a utility company, it would be wise to make sure that the equipment being tied to the grid has the proper UL and/or CSA certifications, and the site chosen can readily accommodate the grid loading necessary for full scale operation.

The lesson learned is the need for planning sufficient time for proposing, negotiating, and closing on utility interconnects. Acquiring a utility interconnect will be a new process for most emerging technologies and can be a difficult process. Energy storage technologies must apply for interconnect early during the execution of their project.

New Technology. When evolving a new technology, provide room in your project schedule for additional risks and unknowns. Taking a new technology from the laboratory, through the scaling up process, interim testing including materials, and out to the field for demonstration is a complex process and unknowns should be expected and planned for.

Permitting. Early involvement of local authorities is a key part of smooth permitting. Local legislative bodies will have different requirements regarding permitting and must be communicated with, openly.

Remote Site. Another lesson learned is using shop-fabricated, modular construction. Fabricating modular units that are electrically and hydraulically connected on-site at standardized locations will reduce field time and cost. Do as much in your fabrication shop as possible to reduce time in the field as well as costs. This is even more critical when the installation site is remote with limited communications and other resources nearby.

7 Energy Storage Applications and Smart Grid Functions

EnerVault is promoting the wide-scale use of energy storage to enable the expanded use of renewable energy, make fossil fuel power plants more efficient, reduce the costs of grid infrastructure, and increase the reliability of electric service to commercial and industrial users.

EnerVault is targeting applications with demand for large amounts of energy. Our ability to reduce costs significantly in applications where megawatts of power are required for several hours makes our approach ideal for supporting renewables, peak shifting in commercial and industrial facilities, or enabling operation and increasing fuel efficiency in micro-grid. Technical and economic benefits include:

- Time shifting peak demand management
  - Transform variable renewable sources into dispatchable resources
  - Improve grid stability
- Enable 6–12 hours of energy in the $250/kWh price range
- Safe, clean electricity
- Low cost as compared to other for long-duration energy storage solutions (4+ hours)
- Abundant materials (not relying on rare earth metals, etc.)
- Full rated power for full discharge time

Figure 15 - EnerVault ribbon cutting ceremony May 2014.

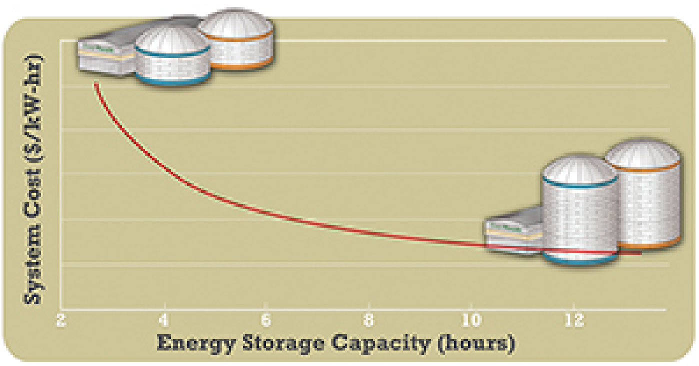
Renewable Energy

EnerVault's energy storage systems offer grid operators a two-way resource that can both store renewable energy when abundant and deliver that energy to the grid after the sun sets or the wind abates. Redox flow batteries can offer ancillary services similar to a gas combustion turbine, but uniquely offer the valuable capability of long-duration energy storage.

Utility

EnerVault's system can be integrated into the transmission systems of utilities to reduce grid infrastructure improvements and replace fossil fuel peaker plants currently used. The result is lower costs, higher reliability, and—by using more efficient, lower costs sources of baseload energy—a reduction in greenhouse gas emissions.

7.1 Grid Efficiency

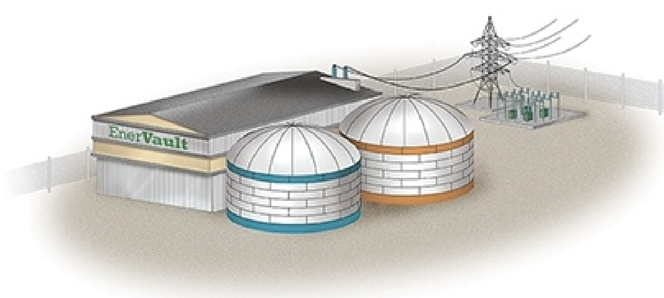


EnerVault grid-scale, long-duration energy storage systems allow grid operators to manage electricity production and delivery, creating a grid that is modern, flexible and can use renewable resources efficiently and effectively. Without energy storage systems, increasing the amount of renewable energy on the grid would result in a less stable grid.

7.2 Micro-Grid

EnerVault's energy storage systems can be used in combination with renewables and conventional power sources to assure reliable energy delivery while running generation sources at their peak efficiency. Microgrid operators reduce costs by maximizing renewable energy delivery and reducing fossil fuel consumption.

7.3 Commercial and Industrial



Commercial and industrial companies can use large-scale, long-duration energy storage systems to optimize their load profile to minimize expenses by storing energy off-peak and using it to later meet peak load.

7.4 Customer Benefits

- Full rated power for full rated discharge time
- Unparalleled safety, reliability, and low cost
- Power and energy matched to application

EnerVault's combination of RFB system architecture and low-cost reactants translates to a marginal cost for an additional hour of discharge (at the system's nameplate power capacity) of less than $100/kW-hr on an installed basis.

The iron and chromium chemistry is environmentally benign compared to other electrochemical systems because the utilized iron and chromium species have very low toxicity, and the dilute water-based electrolyte has a low acid content and very low vapor pressure. Additionally, a unique feature from the presence of iron and chromium in both positive and negative electrolytes is that the electrolytes become chemically identical at zero state-of-charge (SOC) thereby making the cells, and stacks of cells, electrically neutral without damaging the system's operability. In other words, electrical hazard can be eliminated in an EnerVault Fe/Cr RFB system by fully discharging it; then the system can be recharged safely and rapidly. These factors combine to make the iron-chromium RFB one of the safest systems for energy storage.

Program Impact

Energy storage systems can provide cost-effective benefits to the grid and reduce the cost of sure and secure electricity. Grid instability can be caused by changes in frequency and energy storage is fast and accurate to respond to small changes. Improving grid stability will reduce blackouts.

Cleaner, healthier environment

- Provide clean peak electricity
- Promote retiring once-through cooling (OTC) plants

Electricity price predictability

- Transform variable renewable sources into dispatchable resources
- Supports State Renewable Portfolio Standards (RPS) which reduce energy price volatility, reduce emissions, and help during droughts when less hydro power is produced

Potential Impact: Our project represented the first opportunity to demonstrate the use of a flow battery in a renewable energy application. The demonstration will hopefully lead to the wide deployment of this technology. The power and energy aspects of flow batteries lead to a highly efficient capitalization for the various sizes of energy storage and specific power levels required by renewable energy technologies.

7.5 Benefits to California

EnerVault's energy storage technology offers many benefits for saving money, improving the environment, and increasing grid resiliency. EnerVault's technology mitigates:

- Rising fossil fuel costs
- Intolerable environmental impacts from fossil fuel
- Differences between peak and base load
- Transmission & distribution constraints

EnerVault's technology leverages the:

- Cost effectiveness of photovoltaic and wind renewables
- Increased value of energy security

EnerVault's technology provides for lower energy costs and greater reliability by:

- Enabling peak demand management
- Avoiding costly transmission and distribution projects over sensitive areas
- Providing backup power
- Delivering clean peak electricity
- Improving grid efficiency
- Increasing renewables penetration capacity
- Eliminating renewables curtailment

8 Summary

The world's first megawatt-hour class, Fe-Cr RFB system was commissioned in May 2014 and successful system demonstration was completed in March 2015. System achievements include:

- Delivery of 250 kW of power (as designed).
- Delivery of 1 MW-hr of energy (as designed).
- Successful testing against DOE PNNL-22010 Rev. 1 protocol
- Demonstration of numerous full 4-hour discharge cycles
- Obtained operation permits
- Underwent Rule 21 interconnection process
- Co-location and connection in parallel to 480 V common AC bus with 150 kW_{AC} solar photovoltaic system driving 260 kW groundwater irrigation pump, connected to 21 kV PG&E distribution circuit.

Numerous EnerVault innovations were demonstrated throughout the project including:

- Full power delivered for the full duration delivers the full rated energy
- Fe-Cr Electrolytes
  - Readily available commodities iron and chromium mined broadly around the world
- Uses low cost, high reliability micro-porous separators – 1/100th of the cost of ionic membranes used in conventional flow batteries
- Low vulnerability - Due to the low hazard and environmental risks, the costs of mitigation and site preparation are significantly reduced
- Enables a lower cost system with fewer restrictions and additional site related costs
  - No thermal runaway
- Our project is the first MW-hr scale Fe/Cr redox flow battery demonstration
- Development, integration and build of 250 kW_{AC}/1 MW-hr system is complete
  - Upscaling functional building blocks to MW_{AC} system

- Ribbon cutting held May 22, 2014, field demonstration completed March 2015
- Successful demonstration of EnerVault's 250 kW_{AC}/1 MW-hr system in this application provides pathway to broad deployment for smart grid and renewable generation

This project overcame numerous difficult challenges associated with bringing new technologies to market and resulted in a system that will provide significant benefits in the making of a sustainable, clean, and resilient utility grid.

The project provided significant benefit to California in developing a technology that has demonstrated the capability to enable California to meet its renewables and decarbonized grid goals, all while enabling more effective use of existing generation and transmission assets.

The project was successful in scaling up the technology and EnerVault sees a need for pilot programs to learn the operational and market optimal requirements of a grid-connected energy storage system. EnerVault has identified particular applications where the future need is high and the fit for long duration energy storage systems like EnerVault's is optimal. EnerVault hopes to have the opportunity to further address these needs; however, the state of the company is currently unknown.

Attachment A - Project Status Reports Summary

Month/Year	Project Status Summary
08-2010	Contract received. PMP and I&SC plans under development. Flow battery under development.
09-2010	Project plan updated and resource loaded. Baseline set through Phase 1, October, 2011. Preparing first invoice, then actual costs will be entered into Project Plan to generate PVMS statistics. PMP completed and in final review and format. Program review presentation under development for November 2-4 conference in DC. Project kick-off meeting scheduled for October 22, 2010. Flow battery under development.
10-2010	Final Project Management Plan being reviewed by DOE NETL. Metrics and Benefits Reporting plan final draft completed. Flow battery under development, prototype scale achieved on in-house test bed. Scale-up underway.
11-2010	Project Management Plan being reviewed by DOE NETL. Program review completed in DC, November 2-4. Metrics and Benefits Reporting plan drafted and in review. Submittal planned for December 23. I&CS plan comments received from DOE NEL. Plan updates being completed. Submittal planned for December 21. Flow battery under development, prototype scale achieved on in-house test bed. Scale-up underway.
12-2010	Final Project Management Plan being reviewed by DOE NETL. Metrics and Benefits Reporting plan final draft completed. Flow battery under development, prototype scale achieved on in-house test bed. Scale-up underway.
01-2011	Final PMP, I&CS and M&BR plans are being reviewed by DOE NETL. Flow battery under development, scale-up continues with initial full-scale hydraulic modeling. Packaged plant test bed construction complete, startup planned for end of February.
02-2011	Final PMP and I&CS and M&BR plans approved. M&BR under review by DOE NETL. Flow battery under development, scale-up continues with initial full-scale hydraulic modeling. Packaged plant test bed construction complete, startup planned for end of February. Control system design progressing. Baseline data plan completed.
03-2011	Baseline data capture plan completed and installation of meter is scheduled for April 21. Flow battery under development, scale-up continues with conceptual design work of full-scale cells. Packaged plant test bed commissioning nearly complete, startup planned for early April. Control system design progressing.
04-2011	Baseline data being captured. Flow battery under development, scale-up continues with design work of full-scale cells and testing of new design features for full-scale cells at prototype scale before fabrication at full scale. Packaged plant test bed commissioning completed, and battery system performance characterization under way with prototype scale stack. System design progressing. Design meeting held at EnerVault in Sunnyvale, CA, April 20-22.
05-2011	Baseline data being captured. Flow battery under development, scale-up continues with design work of full-scale cells and testing of new design features for full-scale cells at prototype scale before fabrication at full scale. Packaged plant battery test system performance characterization under way with prototype scale stack. Test system modifications underway based on early findings. System detailed design is progressing.
06-2011	Control software issues in the packaged plant test system have been resolved. Lessons learned have been carried over into next generation test system designs. Total impact on timing for milestones 6.3 estimated at 8 week slippage.
07-2011	M&BRP rev 3 submitted. Test tank designed and being manufactured. Conceptual mechanical design underway.
08-2011	M&BRP approved. Test tank being tested; new baffle to be machined. Mechanical design proceding well. System controller design underway.

Month/Year	Project Status Summary
09-2011	M&BRP approved. Test tank being tested; new baffle to be machined. Mechanical design proceding well. System controller design underway.
10-2011	System specification Rev 1 complete. Mechanical draft design, P&ID draft design and control software state charts ready for PDR. PDR is Nov. 17-18.
11-2011	System specification Rev 1 complete. PDR completed Nov. 17-18. Mechanical draft design, P&ID draft design and control software state charts completed. Inverter research, comparison, analysis complete.
12-2011	System specification Rev 1 complete. EV finalizing stack configuration. Finalizing mechanical design, based on final stack config. Inverter options documented. Tank options documented. BMS and system controller detailed design underway.
03-2012	System specification Rev 1 complete. P&ID 98% complete. Electrical drawings 20% complete. Mechanical drawings 75% complete. Flow model complete and analysis underway. Inverter selected, vendor setup in process. PG&E connection line drawings being finalized. BMS and system controller detailed design in process.
05-2012	System specification Rev 1 complete. "P&ID 99% complete. Electrical drawings 90% complete. Mechanical drawings 95% complete. Transportainer quote requested. Flow model and analysis complete. Inverter ordered. PG&E connection line drawings being finalized. BMS and system controller detailed design nearly complete; coding to begin."
06-2012	Activities completed in Q2 2012 include mechanical drawings (80% complete), P&ID (99% complete), electrical drawings (50% complete); interconnect agreement in process; permitting in process; BMS and system controller detailed design. (80% complete).
07-2012	Activities completed in Q2 2012 include mechanical drawings (95% complete), P&ID (Rev A under chagne control), electrical drawings (60% complete); interconnect agreement in process; permitting in process; BMS and system controller detailed design. (85% complete).
08-2012	System specification Rev 1 complete. Activities completed in August 2012 include mechanical drawings (98% complete), P&ID (Rev B under change control), electrical drawings (75% complete); interconnect agreement in process; permitting in process; BMS and system controller detailed design. (85% complete). Due to delays in test system and subsystem specs, revised schedule for Dec-Jan installation and commissioning. Detailed Design Review completed, Aug. 28-29.
09-2012	System specification Rev 1 complete. Activities completed in Sept 2012 include mechanical drawings (98% complete), P&ID (under change control), electrical drawings (80% complete); interconnect agreement in process; permitting in process; BMS and system controller detailed design. (90% complete); control system development underway. Civil engineering underwar. Due to delays in test system and subsystem specs, revised schedule for Feb installation and Mar commissioning.
10-2012	System specification Rev 1 complete. Activities completed in Oct 2012 include mechanical drawings (99% complete), P&ID (under change control), electrical drawings (99% complete); interconnect agreement in process; permitting in process; BMS and system controller detailed design. (90% complete); control system development underway. Civil engineering underway. Transportainer ordered. Tank quotes received.
12-2012	Activities completed in Dec 2012 include mechanical drawing modifications, P&ID completed, electrical drawings completed and reviewed; interconnect agreement completed; power upgrade application submitted to PG&E; civil engineering draft plans complete; BMS and system controller development 50% complete. Transportainer delivered. Tanks ordered. Detailed Design Review completed, Aug. 28-29.

Month/Year	Project Status Summary
01-2013	Activities completed in Jan 2013 include transfer of all techanical drawings and documentation to EnerVault to provide to Noram. Working out revised schedule and will re-baseline in March. Interconnect agreement completed; site service upgrade application submitted to PG&E; civil engineering draft plans complete.
02-2013	Activities completed in Feb 2013 include coordination with EnerVault and Noram; arranging for transport of container and misc items to Noram; reworking schedule; modifications to civil engineering work. Detailed Design Review completed, Aug. 28-29.
03-2013	Activities completed in Mar 2013 include coordination with EnerVault and Noram; transporttainer shipped to Noram; reworking schedule; modifications to civil engineering work. Detailed Design Review completed, Aug. 28-29.
04-2013	Activities completed in April 2013 include coordination with EnerVault and Noram; transportainer and other hardware shipped to Noram; completed Baseline 3, revised/updated schedule; issued mod on tanks; requested quote for additional civil engineering work needed. Detailed Design Review completed, Aug. 28-29.
05-2013	Working with ETM on inverter and power supply status; inverter met specs in testing; will go through certication in July. Working to export new project plan baseline to XLS with montly spend information.
06-2013	Tanks completed and will be shipped when site is ready; ETM inverter in certification; milestone 6.7 completed.
07-2013	ETM inverter almost through UL certification. Final report will go to PG&E for final grid connect acceptance. Production build of battery modules continues and preparation of site for civil work complete. Electrolyte supply for field demonstration secured.
08-2013	ETM inverter completed UL certification.
09-2013	ETM inverter completed UL certification. Container build-out is progressing.
10-2013	ETM inverter completed UL certification. Working through final issues with PG&E for grid connect acceptance. Civil works done and tanks installed and insulated. Electrochemical stacks and cascades 50% complete. BOP module will be set and anchored in early Nov, then cascades installed.
11-2013	Working with PG&E on system interconnect requirements. Some changes required from original EnerVault plan, but these will not affect the planned ability to demonstrate 250 kW charge/discharge and 1 MWh storage as part of the program. Installation progress continues with focus on piping and mechanical installation under way in November. All major equipment modules delivered and anchored in place; NORAM engineers visiting 3-4 times per month now to guide installation and interconnection of the modules. Cascades are 6/9 completed, cascade testing going well with cascades meeting requirements. Stack yield less than expected on a first pass basis, but nearly 100% with minor re-work. December will continue focus on mechanical installation and beginning of electrical installation. Some HazOp action items required modification of some electrical hardware and purchase of a few additional components. These are all on order and will be delivered in January.
12-2013	Submitted system interconnect mod to PG&E. Installation progress continues; 85% on piping interconnects complete, 7 of 9 cascades completed and testing, electrical interconnect 15% complete, electrolyte for first fill (40% of total capacity) produced and tested.
01-2014	Electrical installation began. BOP skid and tank system are in water commissioning - running pumps, resolving issues with instruments and control loops; basic function is proven on main electrolyte feed pumps, all recirculation loops, and the cooling water system. Heaters tested and functioning as expected. Instrument calibration and troubleshooting of control loops.
02-2014	In final stretch of installation. Final shop fabricated process skid (a subsystem) delivered and set in place. Power and instrument wiring underway and final interlocks installed. Testing with water oingoing and making progress with configuration verification, flow and level calibrations, and software verification. Inspection from Merced County and a conditional operating permit expected early March. Plan to start cycling (testing with electrolyte) about end of March.
03-2014	Commissioning work with water testing of system states and operating modes was completed. Rebalance system installation was completed. Temporary power supply with a generator for main inverter power was established (will be replaced when PG&E interconnect is completed). Cascade modules were installed in container. First fill (50%) of electrolyte was received and loaded on the last day of March.
04-2014	Ran flowing charge and discharge at 45 kW last week. Expect to ramp up to 125 kW early May. Working on control system debugging and script writing. Utility connection completed.

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05-2014	System operating with slow ramping up of power and energy; have demonstrated 250 KW gross discharge power for 1.5 hours. Next step is to add more electrolyte and extend the discharge duration, ultimately to 4 hours; need to get up to about 265 kW for a net 250 kW dispatch. Rebalance system is performing well with over 90% efficiency. Developing automated scripts for system operations. Ribbon cutting ceremony held May 22.
06-2014	System running with all nine cascades in standard configuration; continuing to ramp power and energy. Work continues on the rebalance system. Additional software updates completed to correct for results some bugs and for instrument noise; automation scripts completed.
07-2014	System running with all nine cascades in standard configuration; continuing to ramp power and energy. Work continues on the rebalance system. Additional software updates completed to correct for results some bugs and for instrument noise; automation scripts completed. We have begun planning for testing the system to PNNL/SNL 22010 protocol for "peak shaving" per Section 5.1. Submitted first metrics and benefits report; limited system data available for first report. We have drafted outline for final technical report.
08-2014	Continuous, overnight operation of the rebalancer underway. Power monitors have been installed to measure system auxiliary loads. Minor modifications and upgrades to process plant (filters), and software. Preparation for the PNNL/SNL 22010 protocol for "peak shaving" per Section 5.1 continues. Started to prepare annual program review presentation for Peer Review Drafting report outlines for final technical report and other close-out reports.
09-2014	System demonstrated full power operation at 250 kW Net AC discharge. Software communication bugs and instrument noise bugs solved. Developing automated scripting and automated rebalance system operation. Next month plan - take delivery of remaining electrolyte and begin full power/full energy test runs in preparation for the PNNL/SNL 22010 testing in November. Completed annual program review at Peer Review in DC. Starting on final technical report and other close-out reports.
10-2014	Received full delivery of electrolyte. System demonstrated at 244kW for 4 hours, 976kWh. Continue to develop automated scripting and automated rebalance system operation. Working on final technical report and other close-out reports. Identifying specific system data for reports, and gathering cost information
11-2014 / 2015	System demonstration continues.