EnerVault

Safe, Reliable, Cost-Effective Energy Storage

Raytheon Ktech

LONG-DURATION, GRID-SCALE IRON-CHROMIUM REDOX FLOW BATTERY SYSTEMS

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2014 DOE Energy Storage Peer Review

Disclaimer

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Addressing A Global Need and Market

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Major Announcements: All About Long Duration Energy Storage

	Size (Power)	Duration (Energy)	Description
	⊙ 1,360 MW	⊙ 2-4 hrs	⊙ California procurement decision AB 2514 (October 2013)
SOUTHERN CALIFORNIA EDISON An EDISON INTERNATIONAL Company	⊙ 50 MW	⊙ ≥ 4 hrs	⊙ RFP issued (October 2013)
LIPA Long Island Power Authority	⊙ 150 MW – 650 MW	⊙ 12 hrs	⊙ RFP issued (November 2013)
ほくでん	⊙ 12 MW	⊙ 5 hrs	⊙ Contract awarded (July 2013)
Terna Rete Elettrica Nazionale	⊙ 130 MW	⊙ 2-4 hrs	⊙ Contract awarded (May 2013)
SDGE	⊙ 25 MW – 800 MW	⊙ ≥ 4 hrs	⊙ RFP issued (September 2014)

EnerVault Company Overview

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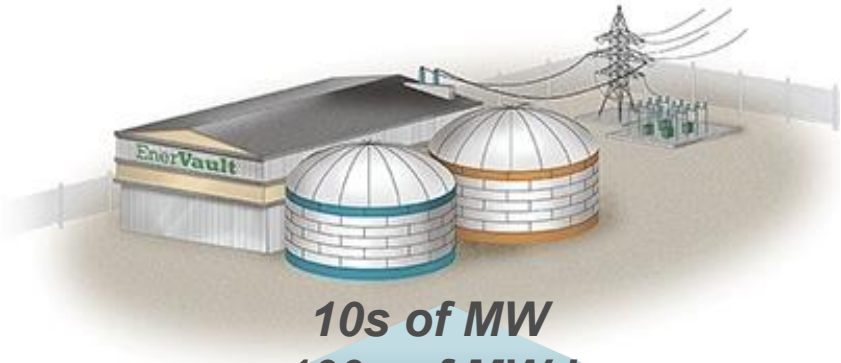
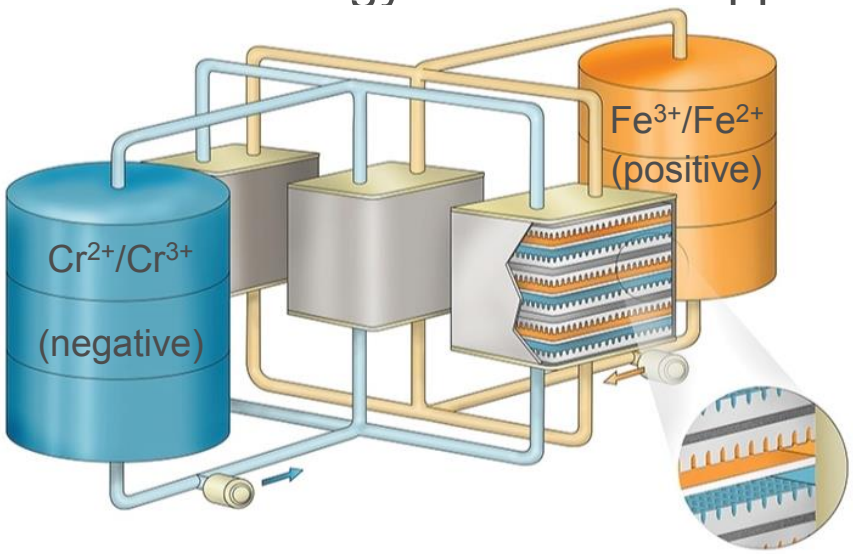
Market Focus:

- *Long-duration = 4-12⁺ hours discharge*
- *"Grid Scale" = power in megawatts*



Customer Benefits:

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



10s of MW
100s of MW-hr

250 kW_{AC}
4 hour

EnerVault Technology

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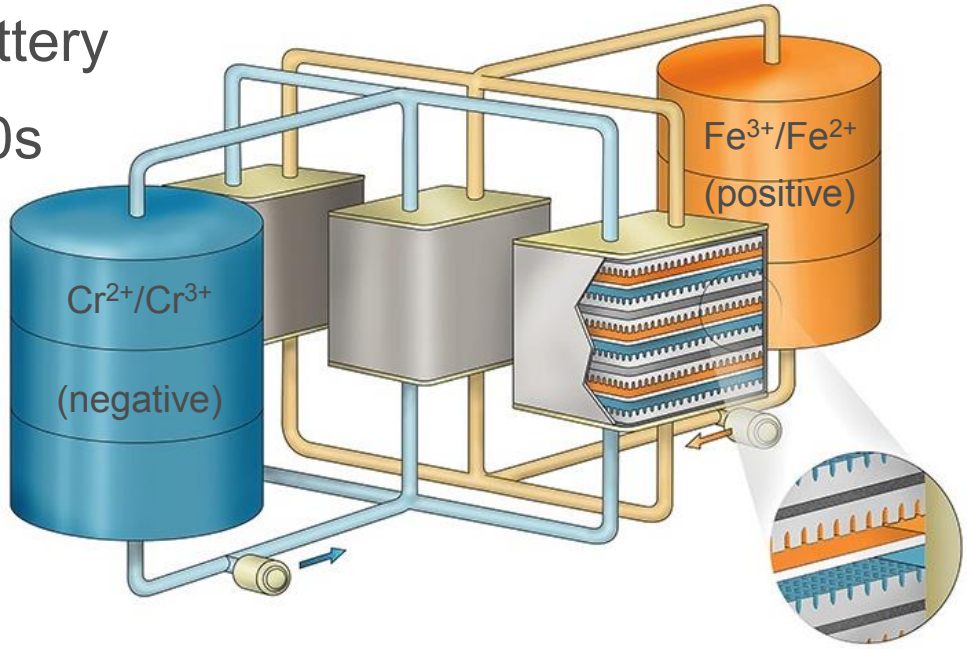
Iron-Chromium Redox Flow Battery

First studied by NASA in 70s/80s

- + low cost
- + robust
- + abundant
- + safe

EnerVault

- + novel architecture for sustained power
- + innovations that make Fe/Cr commercial



Discharge reaction

$Cr^{2+} \rightarrow Cr^{3+} + e^-$

$Fe^{3+} + e^- \rightarrow Fe^{2+}$

Charge reaction

$Cr^{3+} + e^- \rightarrow Cr^{2+}$

$Fe^{2+} \rightarrow Fe^{3+} + e^-$

Project Goal

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Bring a Promising Energy Storage Technology to the Field!

Applications: time-shift, increase value of PV

Project Overview

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- Phase 1, Dec. 2009 – Jan. 2012
  - Develop EnerVault's energy storage technology into a 30 kW utility-scale system building block
  - Complete preliminary design of the Vault-250/1000 system
- Phase 2, Feb. 2012 – June 2014
  - Final design and build Vault-250/1000
  - Install and commission system
- Phase 3, July 2014 – Nov. 2014
  - First Ever Design and Operation of MWh-scale Fe/Cr RFB System
  - Commission and demonstrate Vault-250/1000 system

Project Locations

EnerVault
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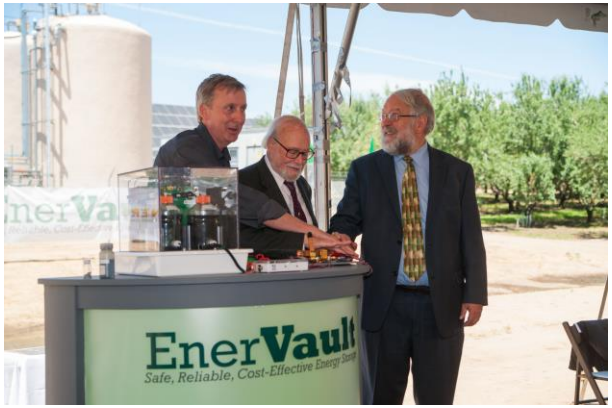
Project Milestones

Achieve initial performance targets	Complete
2 kW prototype system	Complete
Full scale 30kW design, Engineered Cascade™	Complete
Engineered Cascade™ demonstration	Complete
Completion of Vault-250/1000 beta system	Complete
Vault 250/1000 field demonstration	Began June 2014
Final report to DOE	November 2014

First-ever grid scale FeCr system is fielded!



Project Progress & Breakthroughs

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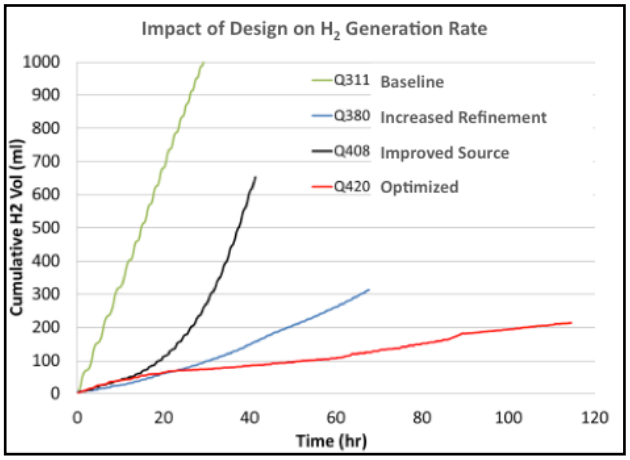
1) Minimize Side Reactions



>10x reduction in side-reaction rates

2010

2 kW/1 hr Test Unit

10X

2012

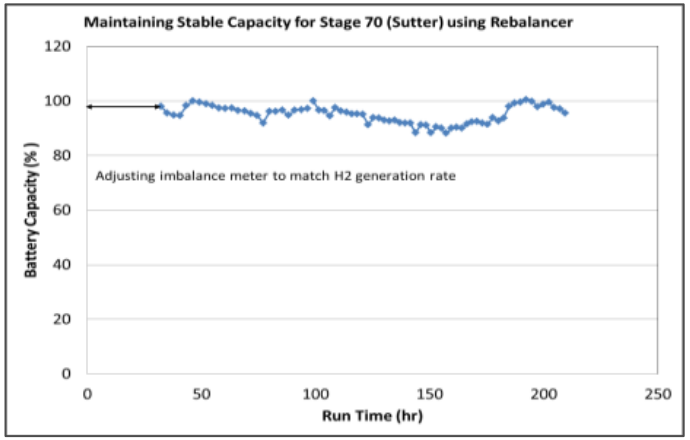
30 kW Pilot System

10X

2014

250 kW_{AC}/1 MW-hr

2) Dynamic Rebalancing



Automated, on-the-fly capacity stabilization

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$

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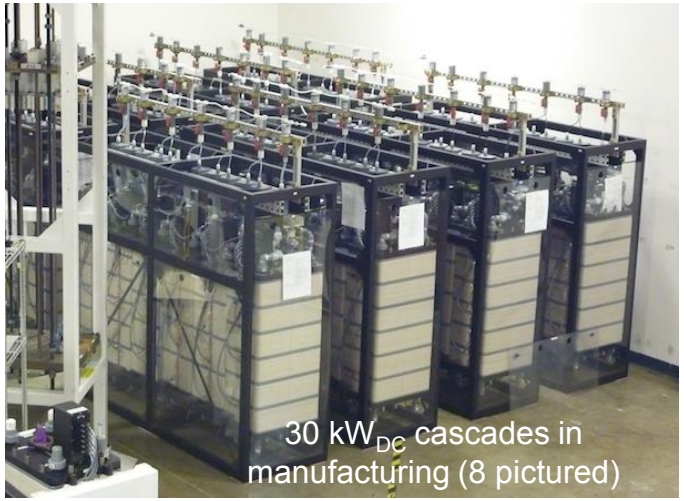
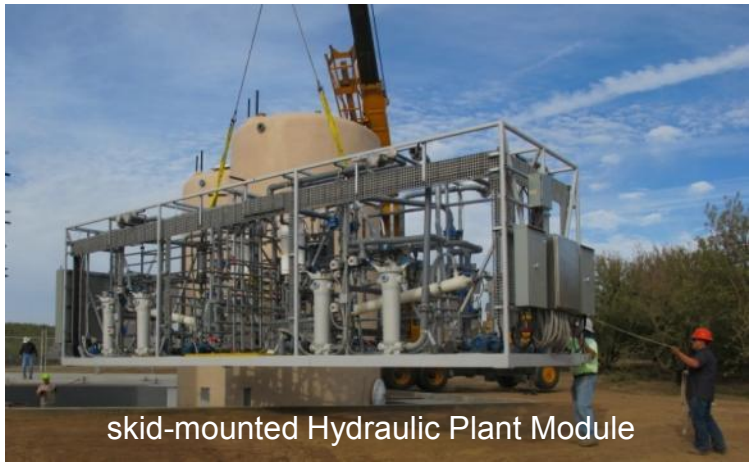
Key System Components Implemented in the Field


30 kW_{DC} cascades in manufacturing (8 pictured)

9 each, 30 kW_{DC} cascades installed

cascade module


skid-mounted Hydraulic Plant Module


Electrolyte Storage Tanks


Inverter

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$

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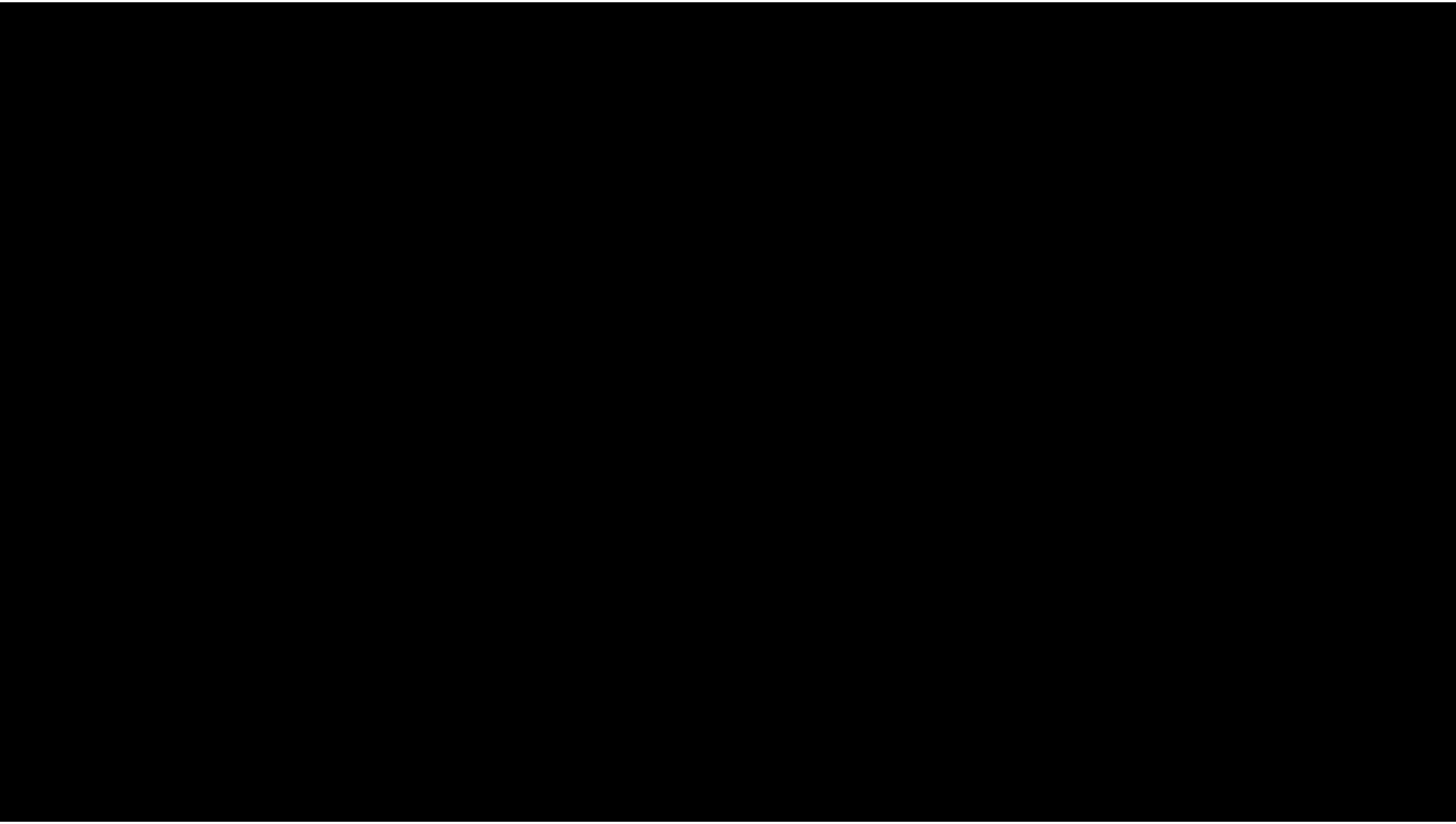

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$

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Design-Build Time Line

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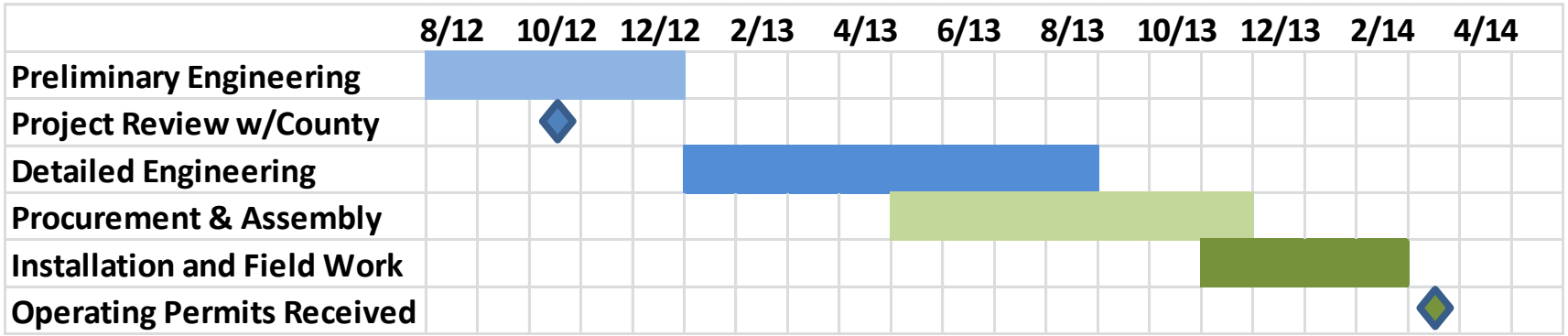
First plant: time line dominated by NRE; concurrent development



- 20-Month Design/Build Project
  - EnerVault scope: system design, specifications, build stacks, integration
  - Partners' scopes: detailed engineering, procurement, assemble, install
- Early involvement of local authorities is key to smooth permitting
- Shop-fabricated, modular construction for reduced field time/cost
- Utility interconnect: it's new for everybody involved – allow time

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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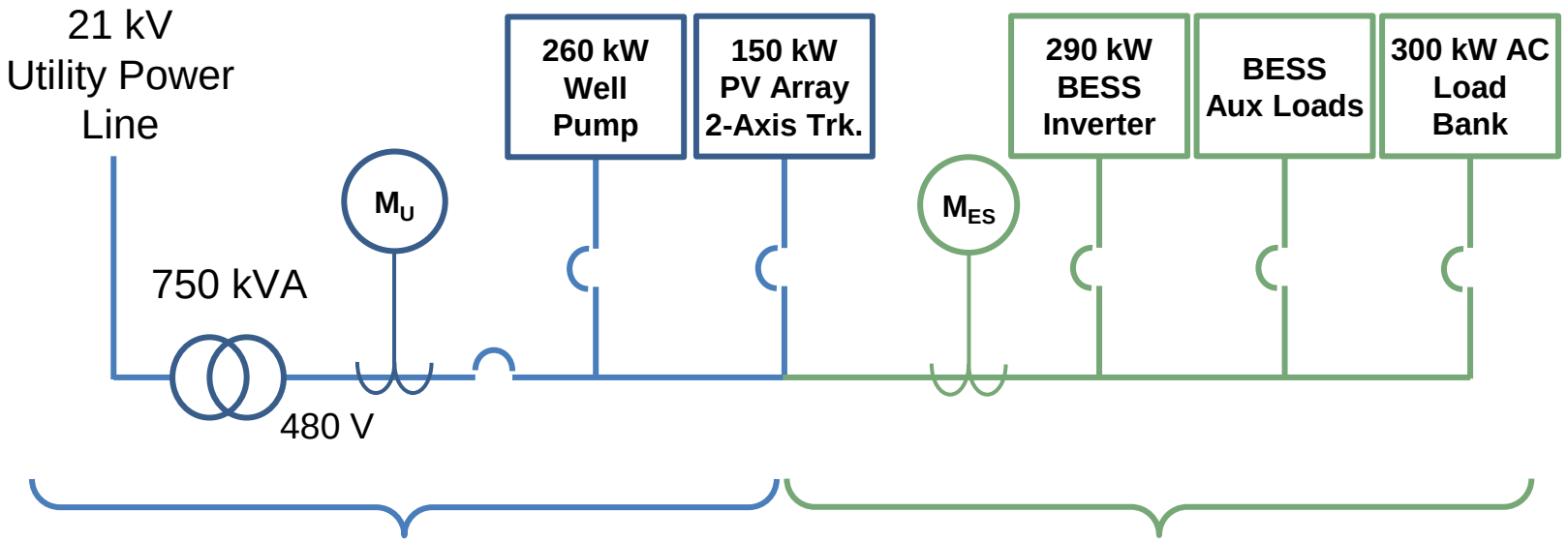
Site Single Line Diagram



Original Site Installation
Well pump plus 2- axis PV; TOU tariff

Addition of Fe-Cr RFB for
Time shifting, peak demand management

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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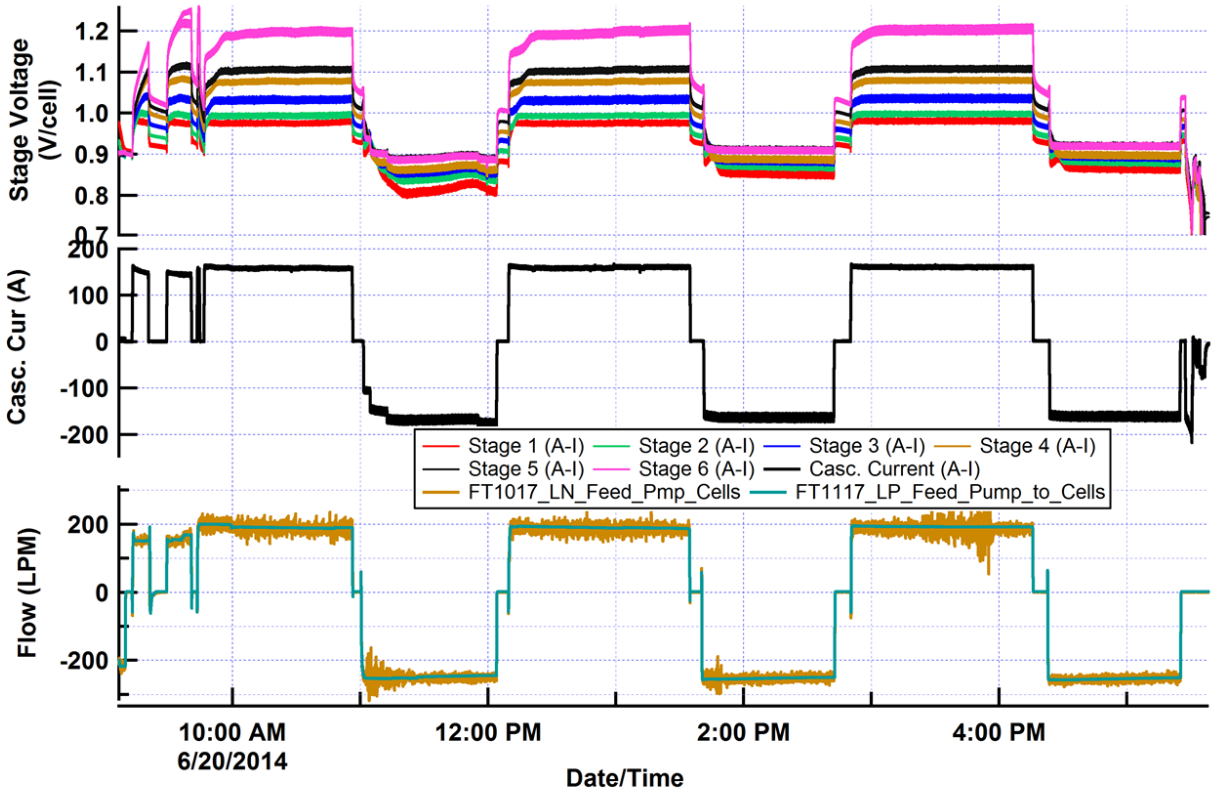
Example Cycle results, 20 June, 2014 – 220 kW – 1 hr

- First cycle used to establish flow-current-voltage targets at 220 kW power
- Subsequent cycles verify stability, validate model
- Short cycles – long enough for steady state; short enough for quick progress



Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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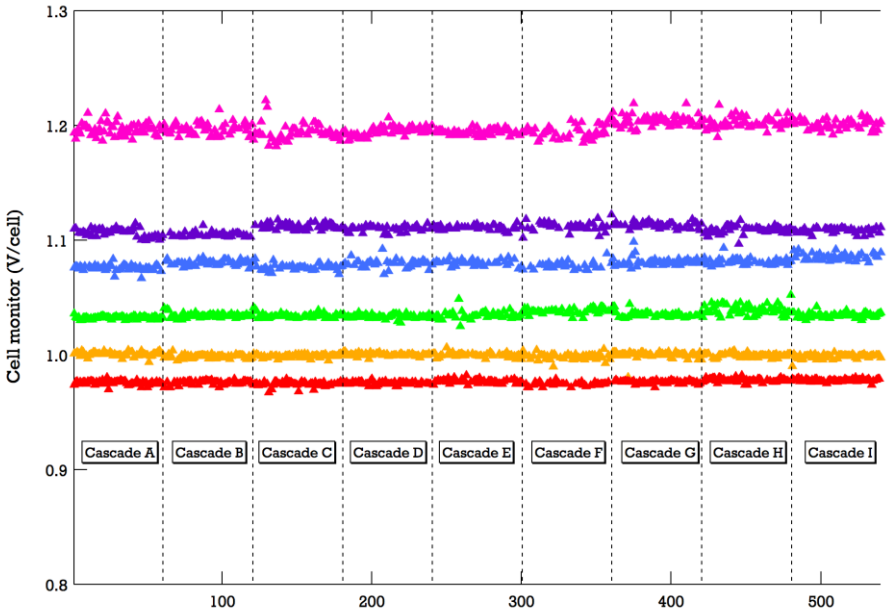
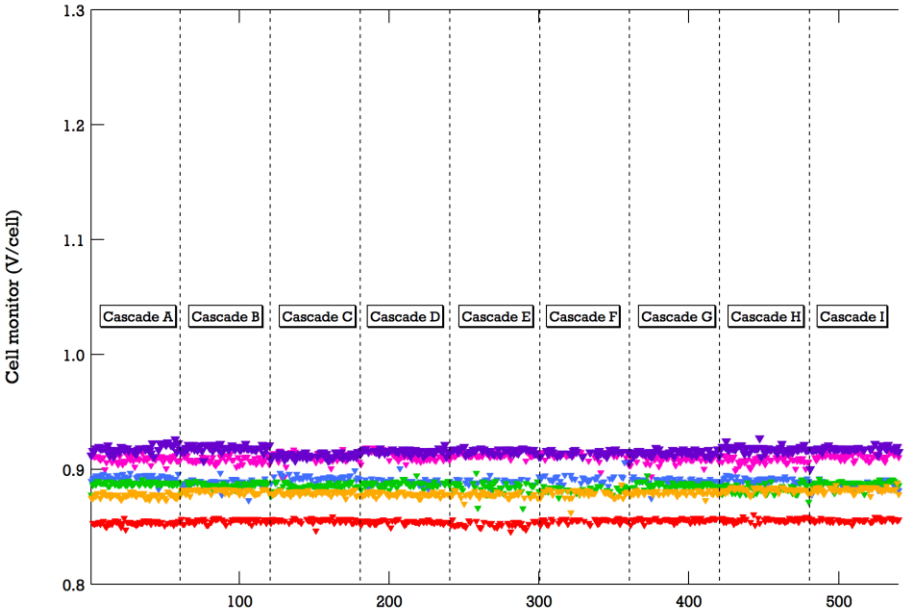
Cycle results: Cell Voltage Uniformity – Charge and Discharge Cycles

- Showing Cell voltages by stage in each of nine, 30 kW cascades
- All cells within ~20 mV – excellent cell uniformity; excellent flow uniformity
- Flow and current distribution among stacks is purely passive balancing by design and quality of manufacturing and factory acceptance testing



Charge



Discharge

Progress & Plans

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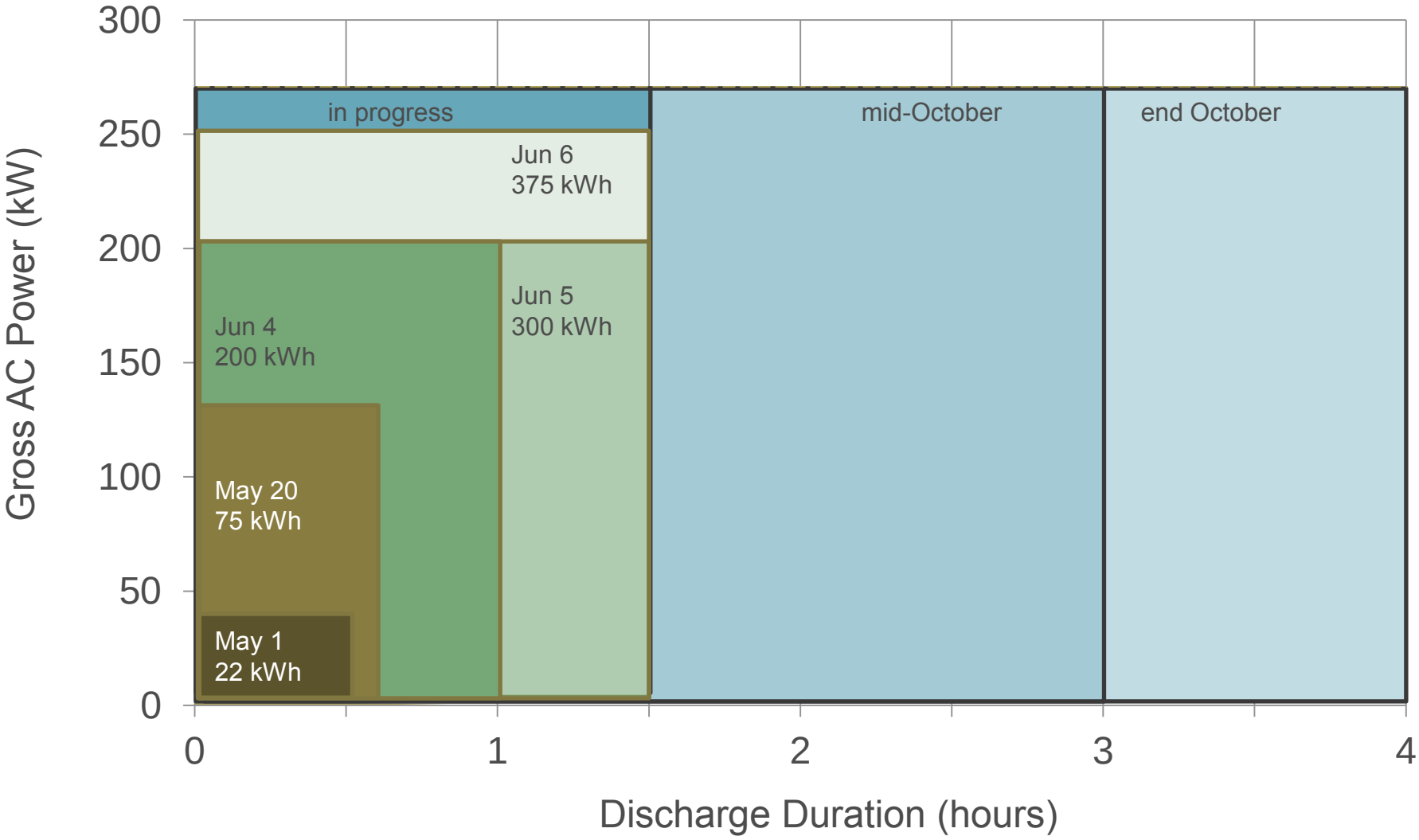

Certification Testing

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US DOE ESS Performance Measurement Protocol PNNL 22010:

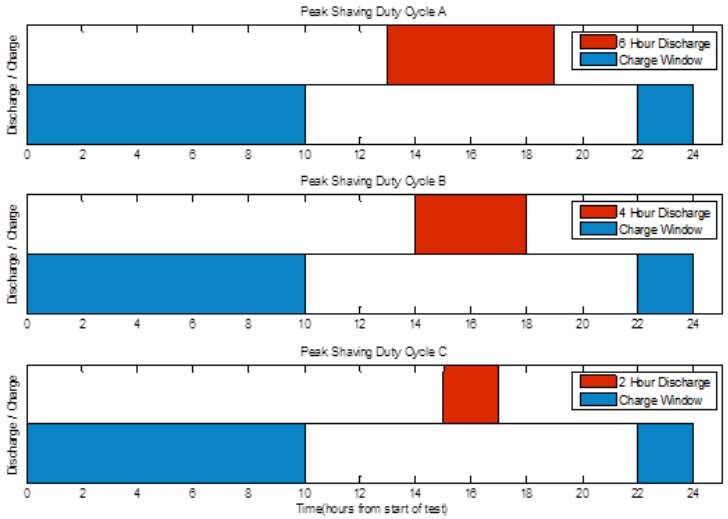

Figure 5.1.3. Peak-Shaving Duty Cycles

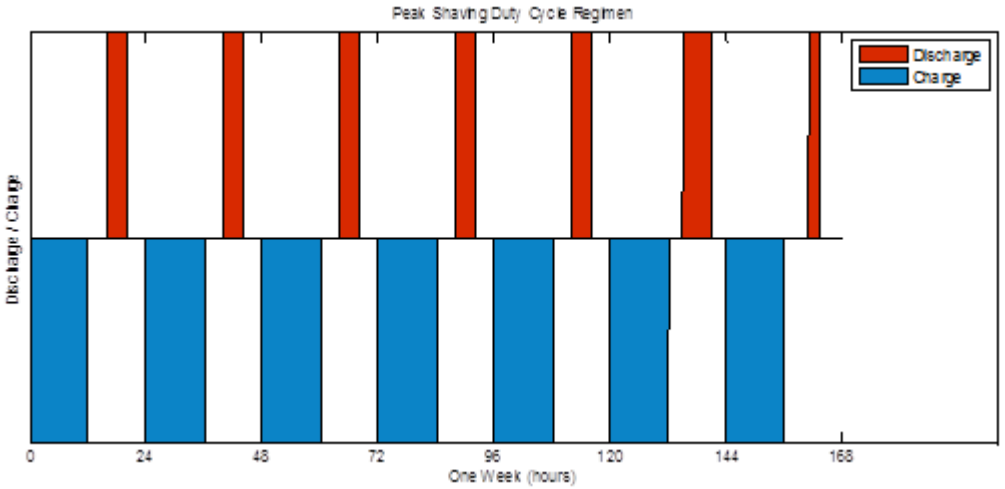

Figure 5.1.3.4. Peak Shaving (Management) Duty-Cycle Regimen

- Defined protocols for system energy, efficiency, and ramp rate
  - Clear definition of the system boundaries for efficiency calculation
  - Clearly defined duty cycle and test regimen for multi-cycle performance
- True AC-AC efficiency measured over multiple cycles

Source: US Department of Energy, Protocol for Uniformly Measuring and Expressing Performance of Energy Storage Systems, PNNL 22010, Nov., 2012

EnerVault Commercialization Timeline

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Flexible, Bi-Directional Power Generation Plants

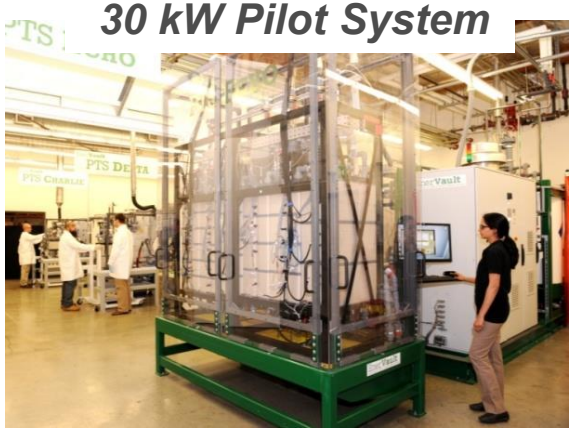
2 kW/1 hr Test Unit

250 kW/1 MW-hr

25 MW / 100 MW-hr

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

30 kW Pilot System



2 MW / 12 MW-hr

Constant Power + Low Marginal Energy Cost

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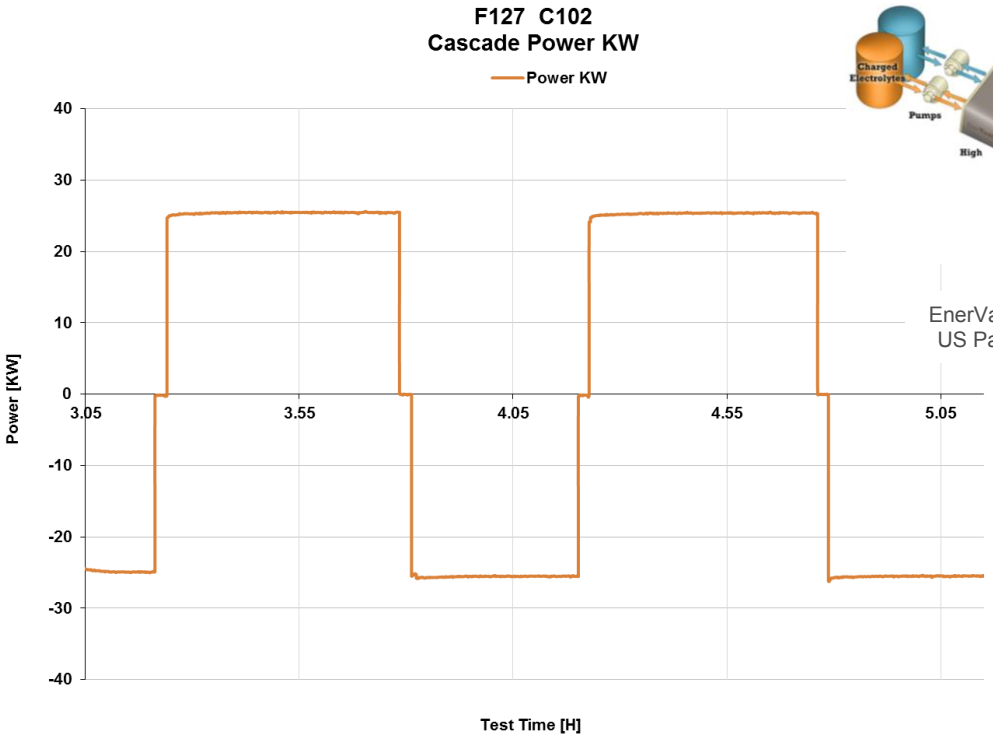
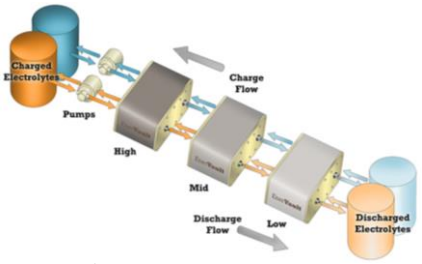
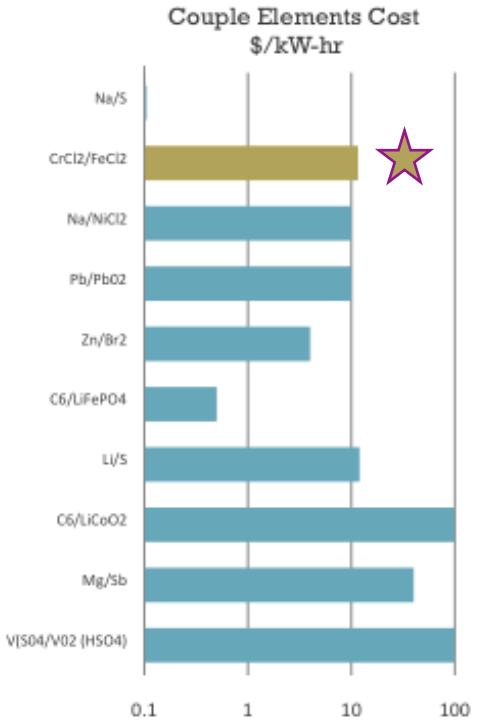
Engineered cascade delivers constant power discharge, rapid switch (seconds) between charge and discharge



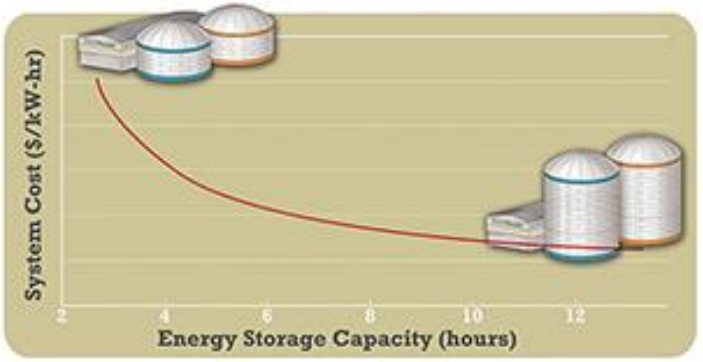


EnerVault's Unique Design
US Patent No. 7,820,321



adapted from: Wadia et al., *J. Power Sources* **196**(2011)1593-1598

- *Enables 6-12 hours of storage in the $250/kW-hr total price range*



Program Impact

Reduce the cost of sure and secure electricity

- reduced blackouts
- improve grid stability
- optimize existing T&D network

Cleaner, healthier environment

- provide clean peak electricity generated w/in distribution network
- retire OTC plants (CA leading)

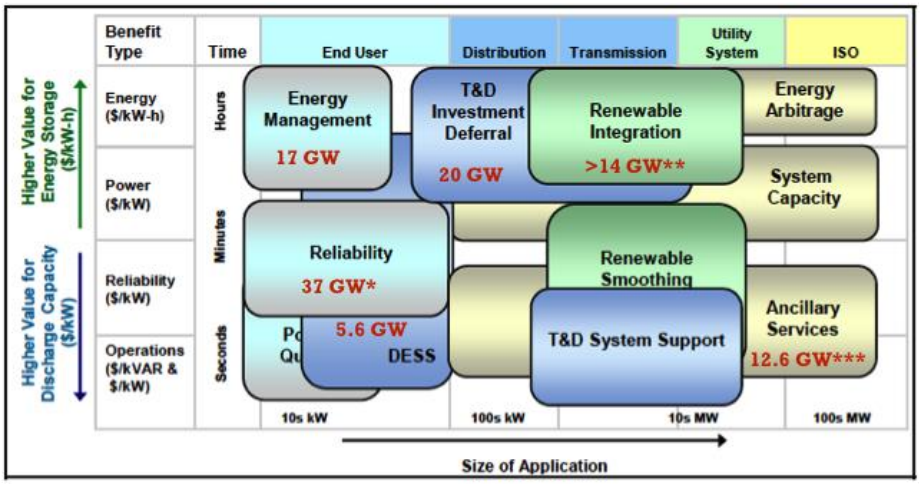
Electricity price predictability

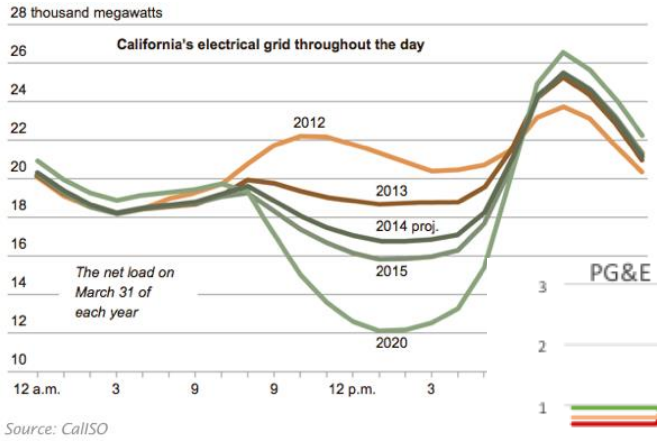
- transform variable renewable sources into dispatchable resources
- state RPS become price hedge fossil prices, emissions, drought

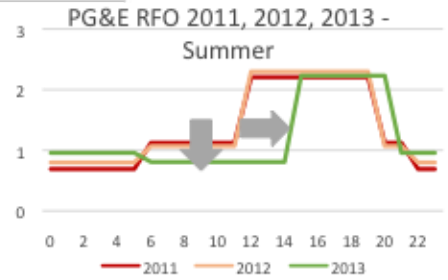
US jobs

- KEMA: over 110,000 jobs

Source: *Electric Energy Storage Technology Options: A White Paper Primer on Applications, Costs and Benefits*. EPRI, Palo Alto, CA, 2010. 1020676.







Summary

- 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, 2104, field demonstration underway
- 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

Thanks to Our Partners, Investors, & Sponsors

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Partnerships and industry relationships are key to our success

investors

TOTAL
MITSUI GLOBAL INVESTMENT
EREN Group
3M
OCEANSHORE VENTURES
TOKYO ELECTRON
COMMERCIAL ENERGY
Your Best Choice

recognition & associations

theguardian cleantech Global Cleantech 100 we're on the list.
ESA Energy Storage Association
ADVANCED ENERGY ECONOMY
GoingGreen Global 200 -WINNER-
GoingGreen Silicon Valley 100 Winner
UTILITY TECHNOLOGY CHALLENGE TOP UTILITY SOLUTION
CalCharge
CESA CALIFORNIA ENERGY STORAGE ALLIANCE
BVES BUNDESVERBAND ENERGIESPEICHER

financial grant awards

DEPARTMENT OF ENERGY
STATE OF CALIFORNIA ENERGY COMMISSION
nyserda Energy. Innovation. Solutions.

partners

Raytheon Ktech
JKBENERGY CAPTURING THE POWER OF NATURE
NORAM
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Q & A

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