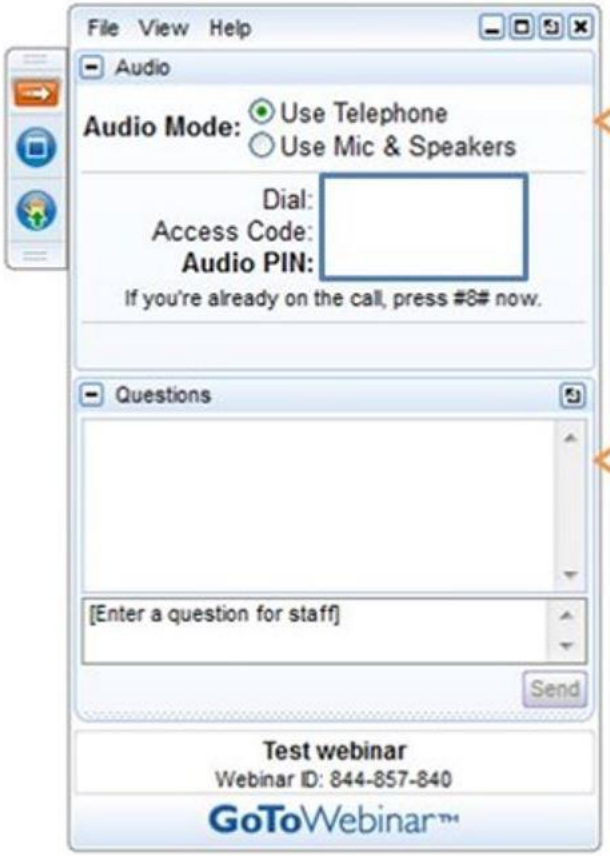
Energy Storage Technology Advancement Partnership (ESTAP) Webinar:

Flow Battery Basics, Part 2

October 29, 2014

Hosted by Todd Olinsky-Paul
ESTAP Project Director, CESA

Housekeeping



All participants are in "Listen-Only" mode. Select "Use Mic & Speakers" to avoid toll charges and use your computer's VOIP capabilities. Or select "Use Telephone" and enter your PIN onto your phone key pad.

Submit your questions at any time by typing in the Question Box and hitting Send.

This webinar is being recorded.

You will find a recording of this webinar, as well as all previous CESA webcasts, archived on the CESA website at

www.cesa.org/webinars

State & Federal Energy Storage Technology Advancement Partnership (ESTAP)

Todd Olinsky-Paul

Project Director

Clean Energy States Alliance

Thank You:

Dr. Imre Gyuk
U.S. Department of Energy,
Office of Electricity Delivery and
Energy Reliability

Dan Borneo
Sandia National Laboratories

CleanEnergy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

ESTAP is a project of CESA

Clean Energy States Alliance (CESA) is a non-profit organization providing a forum for states to work together to implement effective clean energy policies & programs:

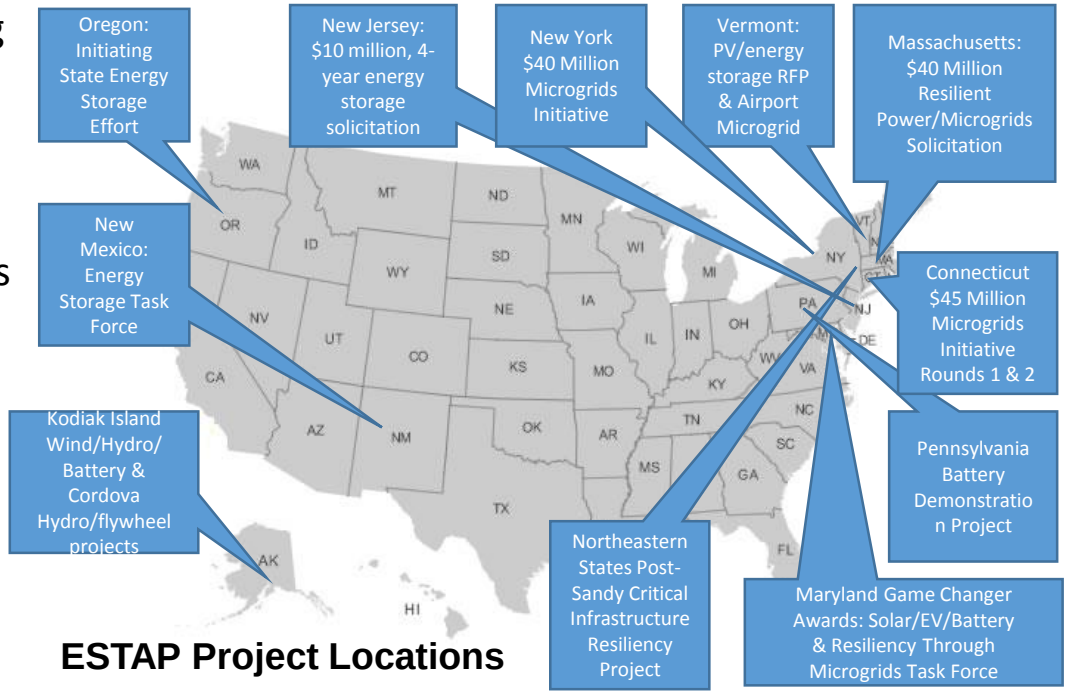
ESTAP is conducted under contract with Sandia National Laboratories, with funding from US DOE.

ESTAP Key Activities:

1. Disseminate information to stakeholders

   - ESTAP listserv >500 members
   - Webinars, conferences, information updates, surveys.

2. Facilitate public/private partnerships at state level to support energy storage demonstration project development



ESTAP Project Locations

CleanEnergy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Energy Storage Technology Advancement Partnership

More CESA Projects

Project Director: Todd Olinsky-Paul

Contact: Todd Olinsky-Paul, Todd@cleanegroup.org

SIGN UP FOR THE LISTSERV

The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by CESA, that aims to accelerate the deployment of electrical energy storage technologies in the U.S.

Project Objective

The project's objective is to accelerate the pace of deployment of energy storage technologies in the United States through the creation of technical assistance and co-funding partnerships between states and the U.S. Department of Energy.

ESTAP conducts two key activities:

1) Disseminate information to stakeholders through:

NEW RESOURCES

May 1, 2014
The Economics of Grid Defection
By Rocky Mountain Institute

April 4, 2014
ESTAP Webinar Slides: Microgrid Technologies
By ESTAP

April 4, 2014
ESTAP Webinar Recording: Microgrid

UPCOMING EVENTS

May 20, 2014
ESTAP Webinar: Commissioning Energy Storage,

More Events

LATEST NEWS

April 30, 2014
NYSERDA Announces Opening of Battery and

Today's Guest Speakers

Imre Gyuk, Program Manager, Energy Storage Research, Office of Electricity Distribution and Energy Reliability, U.S. Department of Energy, imre.gyuk@hq.doe.gov

Dan Borneo, Engineering Project Manager, Distributed Energy/Electrical Energy Storage, Sandia National Laboratories, drborne@sandia.gov

Andrew Marshall, Director of Utility Solutions, Primus Power, andrew.marshall@primuspower.com

Tracy Montoya, Lead Engineer for Energy Storage, Raytheon Ktech, tracy.l.montoya@raytheon.com

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Raytheon

PRIMUS POWER

Flow Batteries for Bulk Energy Storage

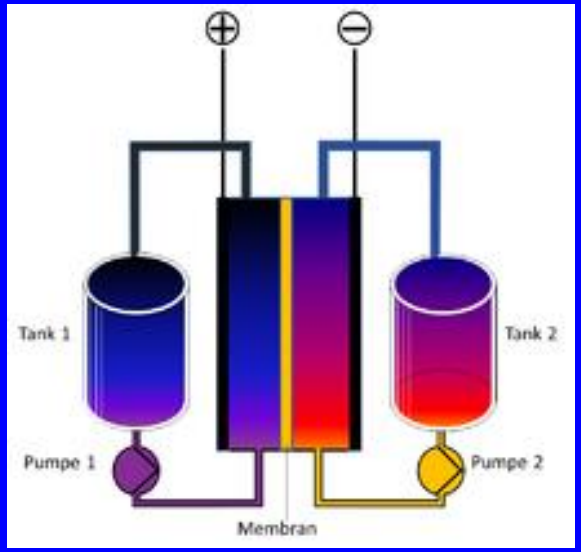
IMRE GYUK, PROGRAM MANAGER
ENERGY STORAGE RESEARCH, DOE

Flow Batteries decouple Power from Energy:

- Power is produced by a rechargable Electrochemical Cell
- Energy is stored in Tanks of electrolyte

This is analogous to a car:

- Power comes from the Engine
- Energy is in the gasoline Tank



Flow Batteries are primarily Energy Batteries.
They generally hold enough Energy
for 3-4 hours of discharge.

Particularly suitable for Peak Shaving
But also appropriate for Ramping
And Resilience Applications

Primus and Redflow utilize Zn-Br chemistry

- Electrochemical Potential is relatively large
- Cost of Electrolytes is relatively low
- Electrolytes allow deep discharge
- Cycle life is expected to be very long
- Aqueous Electrolyte is non-flammable
- Electrolyte is environmentally benign

ARRA- Primus Power:

25MW / 3hr battery plant for the Modesto, CA Irrigation District,
Providing equivalent flex capacity of a 50MW - $73M gas turbine

	Gas Turb	Storage
Cap Cost:	$73M	$50M
Ramp:	300 sec	5 sec
CO_2	66k met. tons	0
Area:	1 acre	¼ acre

2012- 50 Hottest Tech Startups
2011-GoingGreen Global 200

PRIMUS POWER

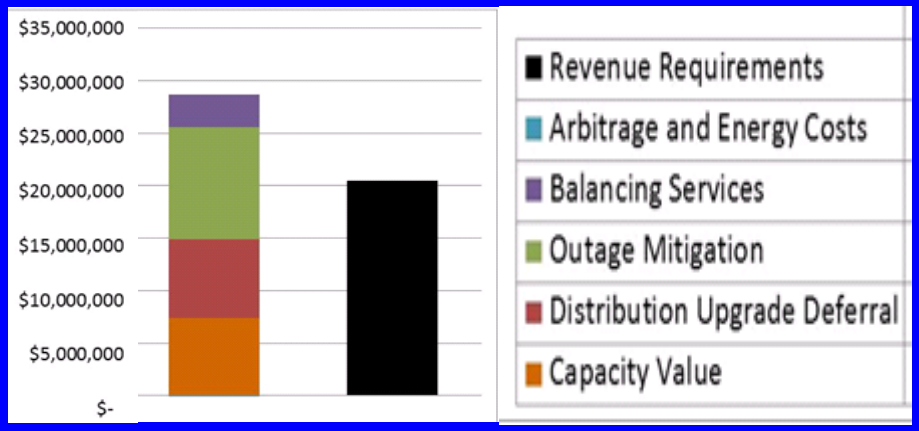
BOSCH

EnergyPod 250kW / 1MWh Power Box

BPA / Puget Sound Grid Project:

PNNL Analysis Program selects cost-effective site and scale to optimize Value Stream

Primus Power, developed under ARRA funding to install 500kW / 2hr ZnBr Flow Battery



Redflow has found Applications
for Distributed Storage in Australia

Redflow has also undergone testing at the
Sandia Energy Storage Systems Test Site.

Flowbatteries are well on the way towards commercialization and market share

Primus Power: Utility-grade energy storage

CESA Flow battery Webinar

Andy Marshall, Director of Utility solutions

October 2014

Agenda for today's discussion

Flow batteries: our market opportunity

Primus Power's flow battery solution

Potential development of flow batteries in the US

Current challenges are not easily addressed by existing solutions

Macro trends…		… present new challenges
	Renewable generation approaching parity convention generation	Integrating renewables is remains costly
	Emissions caps are becoming more stringent	Carbon emitting resources are more difficult to site
	Dynamics of customer load are changing and increasingly unpredictable	Infrastructure (“wires”) solutions are less effective and more expensive

PRIMUS POWER

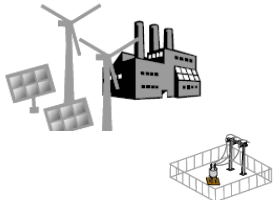
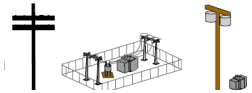
Flexibility is a key difference of energy storage vs. incumbent solutions

Characteristics	Ideal Flexible Generation Solution	Thermal Generation 	Primus Power 
Time to full power	Seconds	300 sec	<5 sec
Modular / transportable	Preferred	No	ISO shipping containers in sub-MW deployments
Footprint (ft^2)	Enable siting close to load	90,000	18,000
Emissions / noise	Enable siting close to load	NOx, CO, VOCs ~100 db	None <55 db(A)
Installation	Rapid	Years	Months

PRIMUS POWER

Energy storage is emerging as a key issue in the power industry as it has operational applications across the entire value chain

Minimum duration of output energy (continuous) by operational application

Location	Short (< 2 min)	Medium (2 min - 1 hour)	Long (1 hour +)
Generation 	Provide frequency regulation services	Provide spin/non-spin Provide ramping	Provide capacity "Firm" renewable output Shift energy Avoid dump energy Provide black start Provide in-basin generation
Transmission 	Smooth intermittent resource output Improve short-duration performance Provide system inertia	Improve system reliability	Avoid congestion fees Defer system upgrades
Distribution 	Improve power quality	Mitigate outages Integrate intermittent distributed generation	Defer system upgrades
End user 	Maintain power quality	Provide uninterruptible power supply	Optimize retail rates

SOURCE: SCE Whitepaper, Moving energy storage from concept to reality, 2011

PRIMUS POWER

“Hybrid” technologies can help fill the need for long duration near loads

Minimum duration of output energy (continuous) by operational application

Location	Short (< 2 min)	Medium (2 min - 1 hour)	Long (1 hour +)
Generation			**Long duration (6+hrs)** **Deep-discharge** **Not mobile or modular** • Pumped Hydro • CAES
Transmission	**Short duration** **Fast-reacting, shallow discharge** **Mobile and modular** ***e.g., Li-ion, Lead acid, Flywheels, Super capacitors*** **Li Ion** **Lead acid**		
Distribution			
End user			

SOURCE: SCE Whitepaper, Moving energy storage from concept to reality, 2011

“Hybrid” technologies can help fill the need for long duration near loads

Minimum duration of output energy (continuous) by operational application

Location	Short (< 2 min)	Medium (2 min - 1 hour)	Long (1 hour +)
Generation			Long duration (6+hrs) Deep-discharge Not mobile or modular • Pumped Hydro • CAES (NGK)
Transmission	Short duration Fast-reacting, shallow discharge Mobile and modular *e.g., Li-ion, Lead acid, Flywheels, Super capacitors* Li Ion: electrovaya, SAFT, SAMSUNG, A123 SYSTEMS, BYD Lead acid: Xtreme Power, AXION POWER INTERNATIONAL INC.		“Hybrid systems” Moderate duration (3-6+hrs) Fast-reacting, deep-discharge Mobile and modular Flow battery: EnerVault, UET UniEnergy Technologies, redflow, ZBB, PRIMUS POWER, GILDEMEISTER Other chemistries: AQUION ENERGY Modular CAES: LightSail Energy, SustainX, GENERAL COMPRESSION
Distribution			
End user			

SOURCE: SCE Whitepaper, Moving energy storage from concept to reality, 2011

PRIMUS POWER

Flow batteries can fit "hybrid" system needs, but have limited field experience

	Flow battery	Li ion	Lead Acid	NaS NaNiCl	Modular CAES
Commercial exp.	Limited	Extensive	Extensive	Extensive	Limited
Safety	Aqueous electrolytes	Pot. thermal runaway	Understood risks/mitigation	Extreme air sensitivity	High pressure ~3,000 PSI
Total cost trajectory	Med CAPEX, Low OPEX	Low CAPEX, Med OPEX	Low CAPEX, High OPEX	High CAPEX, Med OPEX	Low CAPEX, High OPEX
Durability, reliability	Some mechanical	Limited deep discharge	Limited in Partial SOC	Limited deep discharge	Mechanical-based
Design flexibility	Decouple power/energy	Chemistry flexibility	Limited	Limited	Decouple power/energy
Ease of installation	Some containerized	Containerized	Some containerized	Not containerized	Potential for containerized

SOURCE: Various whitepapers: 2010-present, literature, public company presentations, Primus analysis

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Agenda for today's discussion

Flow batteries: our market opportunity

Primus Power's flow battery solution

Potential development of flow batteries in the US

PRIMUS POWER

Primus Power is a recognized leader in energy storage

Technology validated by experts

BOSCH
Sandia National Laboratories
Raytheon

First utility and microgrid customers in 2014

Marine Base Miramar

PSE PUGET SOUND ENERGY
MID Modesto Irrigation District

Well funded by world-class investors

KPCB KLEINER PERKINS CAUFIELD BYERS
DBL INVESTORS DOUBLE BOTTOM LINE VENTURE CAPITAL
ANGLO PLATINUM
Chrysalix ENERGY VENTURE CAPITAL
I2BF

Winner $20M in competitive grants

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA
BONNEVILLE POWER ADMINISTRATION
arpa·e

Tested team with technical product design and launch experience

APPLIED MATERIALS
TESLA MOTORS
intel
United Technologies
Bloomenergy

PRIMUS POWER

Steady technical progress and important customer wins are helping Primus become a leading storage company

Grants

DOE $14M

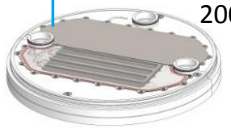
$2M

California Energy Commission $1M

$1M

Primus Power started Aug-09

Titanium electrode and catalytic coating proven Sep-11



200 mA/cm² proven Jun-10

1 kW EnergyCell May-12

2 kW EnergyCell Dec-12

Contact manufacturing agreement Feb-14 SANMINA

Material cost milestone Jul-14

17th patent granted Sep-14

20 kW β EnergyCell Sandia Natl Lab 3rd party test Sep-13

Customers

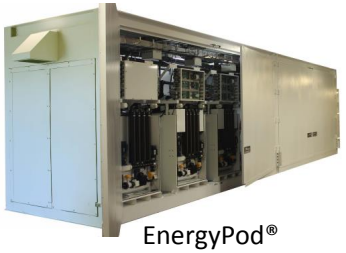
Modesto Muni • Q2-15

Puget Sound Energy • Q1-15

Miramar Microgrid • Q1-15

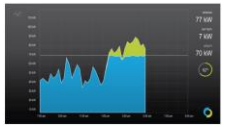
Israel Chemicals • Q1-15

Products



EnergyPod®
First ship: Q4-14

EnergyCell
First ship: Q1-15



PRIMUS POWER

EnergyPod®: safe, proven chemistry meets great engineering

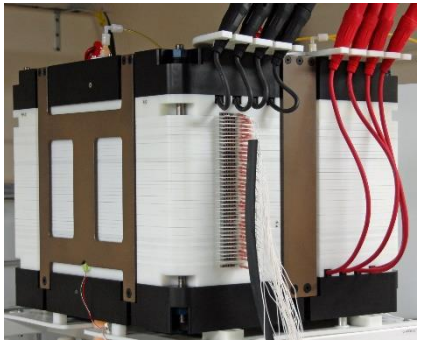
Electrode → Stack → EnergyCell 20-30 kW, 72 kWh → EnergyPod® 280-420 kW, 1,000 kWh

Power density at low cost

Innovative electrode design

- Metal electrode
- Industry-leading current density
- Multi-lane, multi-level flow control

Robust and durable



Patented electrode stack

- No separator
- Patented flow architecture
- Tested for 20-year life

Simple and reliable

Low cost system design

- Single flow loop
- Sized for high value storage applications
- Fully contained pump & controls

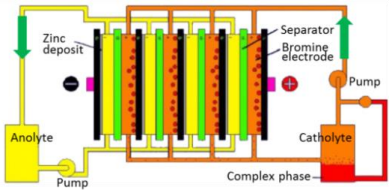
Rapid permitting and installation

Short customer "time to money"

- Factory built & tested
- Multipoint monitoring
- Seamless system integration
- Modular scalability
- Rapid installation

PRIMUS POWER

Primus Power's EnergyCell is a superior flow battery design

	Traditional flow batteries	Primus Power EnergyCell
		
Electrochemical couple (VDC)	$ZnBr_2$ 1.8 Vanadium 1.4 Fe_2Cr_3 1.2	1.8
Tanks / Flow loops / pumps	2 total for each	Only 1
Separator	Failure prone, polymer membrane	No expensive, life-limiting membrane
Electrodes	Plastic + graphite, felt	Non corroding metal
Current density (mA/cm^2)	$ZnBr_2$ Vanadium Fe_2Cr_3 <50	200
Stack and balance of plant	Separate	Integrated

Primus innovation enables:

- **Low cost**
- **High reliability**
- **Modularity**
- **Rapid installation**

Traditional flow battery diagram from ZBB website

EnergyCells and EnergyPods®: distributed storage at a low total cost of ownership

EnergyPod® - for utility customers
1,000 kWh • 280 kW nominal, 420 kW peak

EnergyCell – for commercial/ industrial customers
72 kWh
20 kW nominal, 30 kW peak

Primus Power's "only-liness"

Low total cost of ownership

Enabled by:

Capital cost

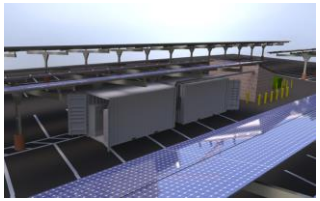
Cycles = 20 years

Roundtrip efficiency

Depth of discharge

PRIMUS POWER

Primus is shipping to utilities, microgrid developers and commercial/ industrial customers

Application	Deployment		Value
Microgrids & Energy management	**Marine Base at Miramar** Microgrid		**Pay back:** 10 yrs **IRR:** 9% Microgrid economics stronger with higher diesel prices
Capital Deferral of Distribution Substation	**Puget Sound Energy** Power dense arrays		**Pay back:** 7 yrs **IRR:** 14% PSE will own and rate base this project
Local Capacity & Renewable firming	**Modesto Irrigation District** Multi-MW arrays		**Pay back:** 7 yrs **IRR:** 12% MID will own and rate base the project
Demand Charge Management	**Israel Chemicals** Single EnergyCell		**Pay back:** 7 yrs **IRR:** 12% EnergyCell reduces utility demand charges

Agenda for today's discussion

Flow batteries in context

Lessons from Primus' experience

Potential development of flow batteries in the US

PRIMUS POWER

US market for long-duration flow batteries will rely on manufacturers removing costs

	Near-term horizon: Present-2015	Mid-term horizon: 2015-2018	Long-term horizon: Beyond 2018
"Killer" applications	• Military/Island microgrids • C&I energy management	• T&D deferral and reliability • High penetration solar mitigation • Microgrids	• Local capacity • T&D deferral • Home energy management • Microgrids
Deployment sizes	• <5 MW	• 2-10MW	• Up to 50MW
What you would have to believe	• Demonstrations meet expectations • Strategic partner support	• High penetration PV • Cohesive regulatory framework	• RPS targets met • High penetration PV • Favorable legislation (e.g. AB2514, Wyden ITC)
Potential show stoppers	• Accidents	• Incumbents (e.g., Li ion) reaching cost floor ahead of schedule	• Very low natural gas (e.g., <$4/MMBT)

SOURCE: Primus analysis

PRIMUS POWER

PRIMUS POWER™

Smart Grid Storage™

PRIMUS POWER™

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Raytheon

Customer Success Is Our Mission

Raytheon
Energy Storage Solutions

October 2014

Introduction

- Raytheon is a technology and innovation leader specializing in defense, homeland security, and other markets throughout the world.
- Raytheon provides state-of-the-art electronics, systems integration, and a broad range of mission support services.
- Raytheon Ktech, part of Raytheon Missile Systems, specializes in high-tech engineering, advance systems integration, and power and energy solutions.
- Energy storage expertise based on excellence in power and energy engineering and advanced control systems.

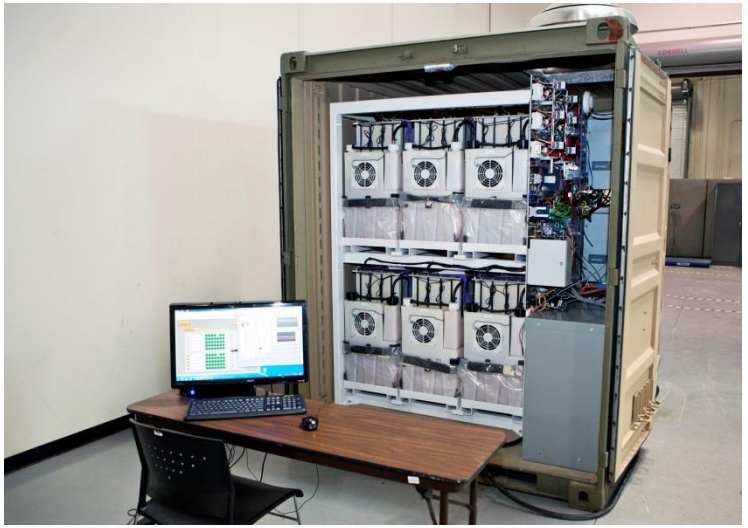
Energy Storage

- Energy storage is a key enabling technology for intelligent management of power & energy for smart grid technologies, increased deployment of renewable energy, and reduction of fossil fuels and emissions.
- Energy storage systems can reduce generator fuel consumption by more than 50%, simplify logistics, improve micro-grid management, and optimize renewables.
- Raytheon has developed energy storage systems that meet efficiency, safety, reliability, and flexibility requirements for smart grid technology:
  - RK30, 30 kW / 120 kWh, 3f/208 VAC
  - RK10, 5 kW / 20 kWh, 1f/240 VAC
- Our energy storage systems are built on proven flow battery technology with robust inverters and power electronics that meet field operational requirements.
- Our advanced technology systems can be off-grid, grid, or micro-grid connected and directly integrated with generators and renewable sources, optimally managing and controlling energy to efficiently distribute uninterrupted power.

Compelling Products for ES Requirements

Advanced solutions for energy storage and management:

- Superior performance
- Reliable source of power
- Versatile application support
- Scalable, flexible turnkey solution
- Sustainable optimization of renewables
- Enhancement to smart power grids



Raytheon Energy Storage Products

Specifications

- Integrates with PV and generators
- Grid or micro-grid connected
- Operating temperature range 14 to 122 F (-10 to 50 C)
- Long-lasting flow batteries
- Intelligent control system technology
- IEEE 1547 and UL 1741 compliant inverter
- NEMA 4 enclosure

RK30

RK30 Specifications

- Power: 30 kW
- Energy: 120 kWh
- Three-phase 208 VAC, 60 Hz
- TRL 6

RK10M and RK10

RK10 Specifications

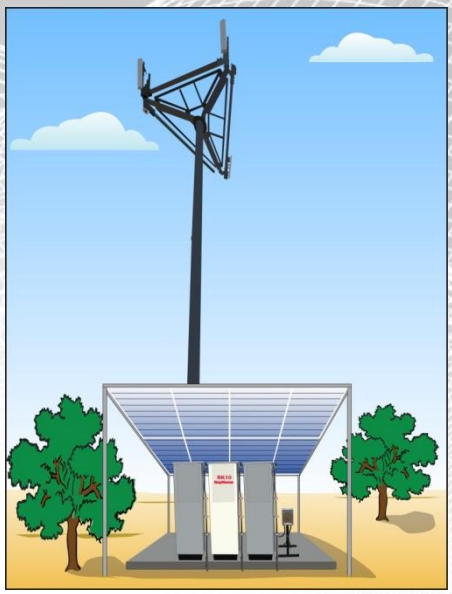
- Power: 5 kW
- Energy: 20 kWh
- Single-phase 240 VAC, 60 Hz
- Islanded mode operation
- Standalone and modular versions

ADVANCED MISSILE SYSTEMS

ES Product Features

Performance

- High-performance zinc bromide flow battery modules
- 100% capacity utilization; partial charge and discharge cycles
- Long life, lower life-cycle costs
- Superior operating temperature range



Reliability

- Uninterrupted power for remote locations, disaster recovery, critical operations
- Immediate and extended back-up power during grid outages
- Resilient power and energy

Versatility

- Configurable control system with advanced algorithms
- Multiple applications support: load following, peak shaving, back-up, firming, ramp control, time-shifting
- Turnkey integration with renewables, generators, and smart grids
- Modular and standalone models to fit all locations

ES Product Features (cont.)

Scalable

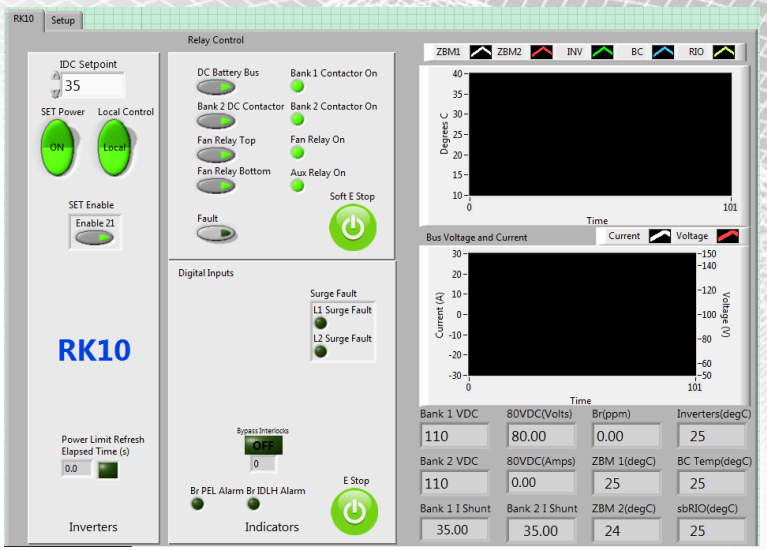
- Modular approach scales for higher power and increased energy
- 5 kW to 100 kW to meet customer specific power and energy requirements

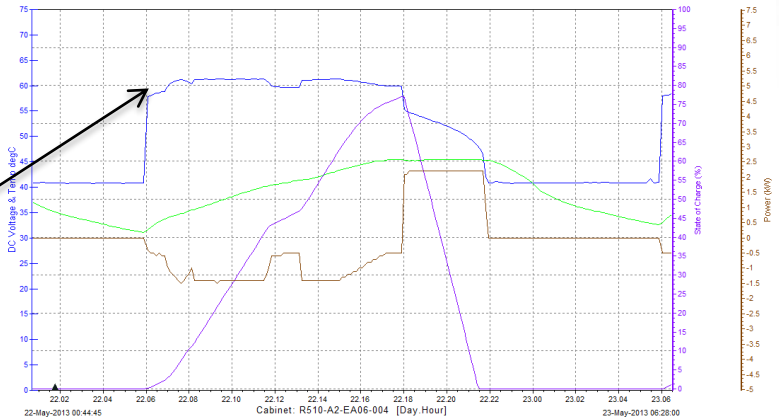
Sustainable

- Optimize solar and wind energy
- Reduce generator fuel consumption and run-time
- Store energy indefinitely
- Reduce emissions
- Recyclable

Advanced System Control

- **Configuration options to support multiple applications**
  - Load following
  - Peak shaving
  - Renewable firming and time-shifting
  - Back-up
- **Remote monitoring and control**
  - Automatic remote alerts
  - Check status, system health
  - Change application parameters
  - Perform maintenance, tests
  - Download data



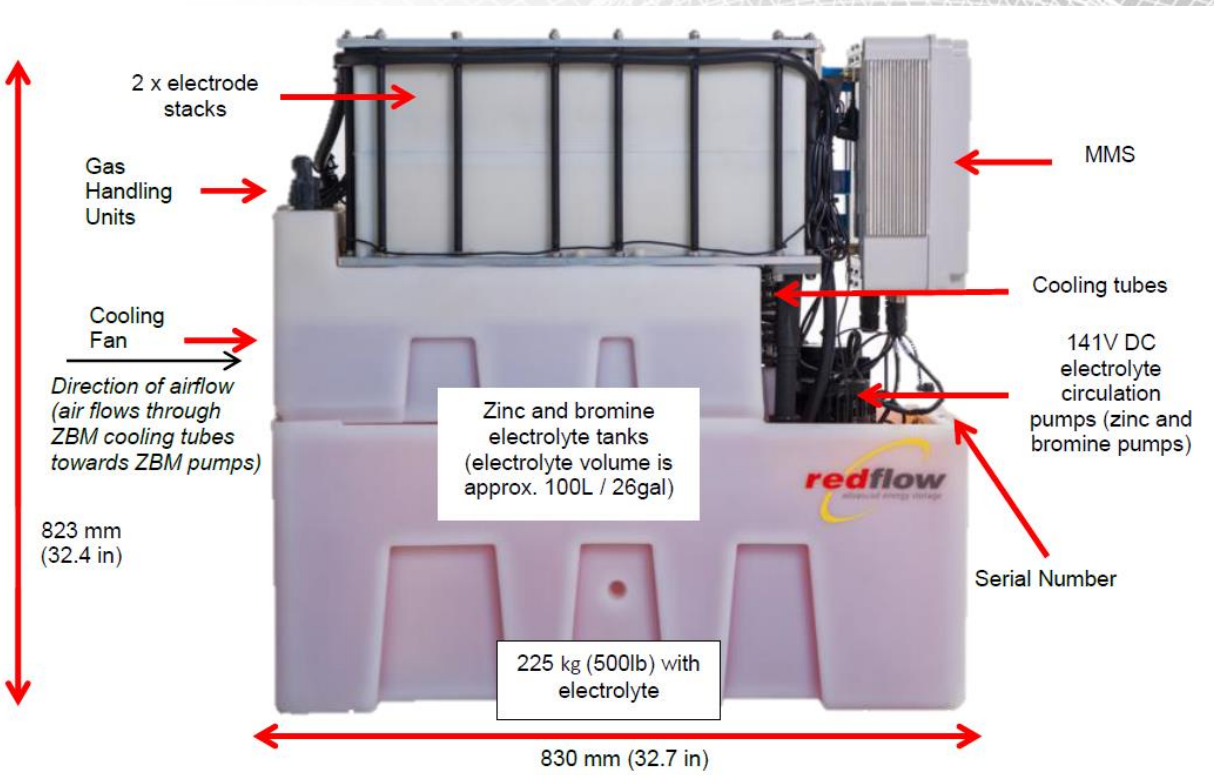


Consistent power output

Zinc-Bromide Flow Battery

Zinc Bromide Advantages Over Lead Acid

- 100% capacity utilization
- 50% the weight of lead acid at equal energy density
- Full or partial power charge and discharge without degradation
- Increased number of cycles
- Greater energy density
- Can be stored and transported in discharged state
- Environmentally safer



Gen 2.8 ZBM Zinc Bromine Battery Module

Energy Storage Addresses Numerous Challenges

Forward Operating Base	Microgrid	Remote Site

Load Following, Grid Resilience, Peak Shaving, Renewable Integration

- Significantly reduce TQG fuel consumption
- Improve TQG efficiency
- Reduces logistics support
- Reduce maintenance costs

- Secure and reliable power
- Critical services
- Communications
- Sustainability

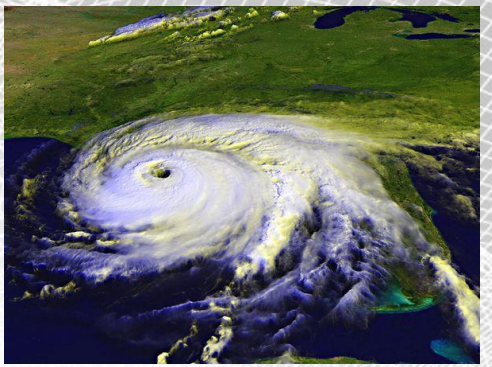
- Ensure reliable back-up power & improve generator efficiency
- Optimize renewable energy
- Support temporary sites in disaster situations

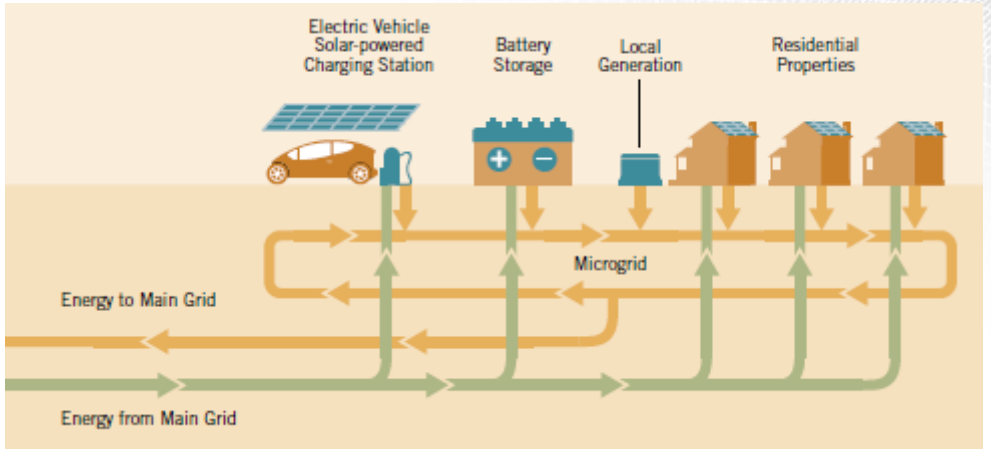
Energy Storage for Military

- **Support various theaters of operations**
  - Mobile communications systems
  - Tactical platforms
  - Forward and remote operating bases
- **Dramatically improve logistics**
  - Large, long-distance convoys dominated by water and fuel
  - Convoy routes are hazardous and transport is expensive
- **Enhance energy efficiency**
  - Generator utilization less than 50% nearly 75% of the time
  - Significantly reduce fuel consumption

Energy Storage for Regional Microgrid

- **Reliable energy security**
  - Advanced controls
  - Grid independence
- **Security of supply**
  - Natural disasters
  - Cyber security
  - Other threats
- **Efficiency**
  - Lower stress on T&D system
- **Sustainability**
  - Renewables
- **Quality**
  - Consistent charge/discharge cycles without battery degradation



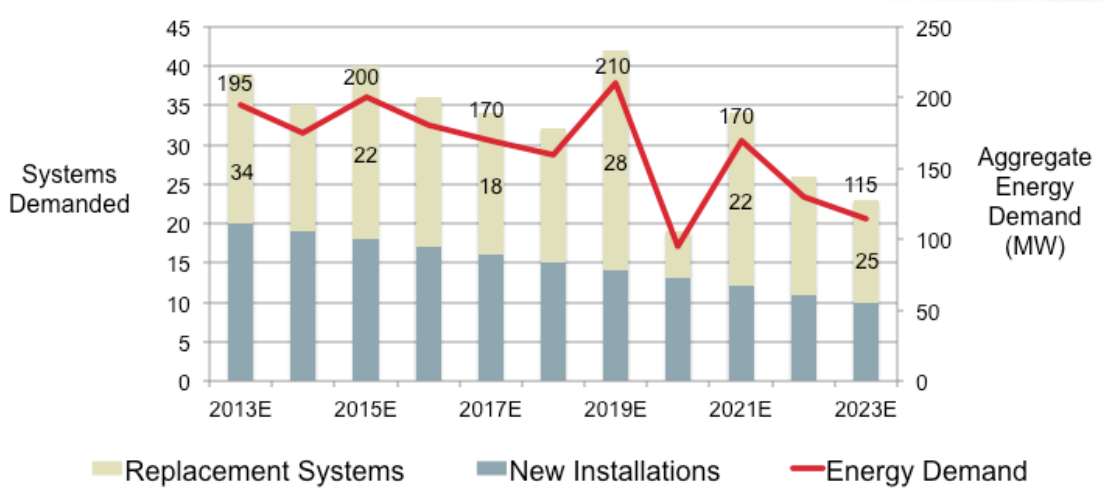


Energy Storage for Telecommunications

- US telecom annual energy demand is about 20 GW.
- Most are grid connected but off-grid sites are the fastest growing segment of new installations.
- PV is increasingly powering telecom sites.
- Potential market demand for the US telecommunications industry is 25,000 – 40,000 energy storage systems per year.

Customer Needs

- Extended back-up capability (48+ hours)
- “Green” solution
- Safe, reliable performance
- Remote monitoring
- Cost savings



ADVANCED MISSILE SYSTEMS

Raytheon ES Solutions

Differentiators	Description
AC Cooling	Lead Acid batteries require heavy cooling systems
Remote Monitoring	Cost savings from frequent visits of electrician to battery site
Preventative Maintenance	Cost savings from remote monitoring's identification of problems before they develop
String of Lead Acid Batteries Savings	If using Lead Acid batteries in a string, damage to one battery requires replacement of the entire string
Lead Acid Battery Disposal Cost	Savings from fee associated with battery disposal (every 3 years)
Lost Revenue Due to Dead Battery	Telcos currently facing lost revenue due to batteries dying, specifically in remote locations
Green	Use RK10 and renewables to provide greener solutions compared to Lead Acid

Discussion

Q & A

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Webinar Archive: www.cesa.org/webinars

ESTAP Website: http://www.cesa.org/projects/energy-storage-technology-advancement-partnership/

ESTAP Listserv: http://www.cesa.org/projects/energy-storage-technology-advancement-partnership/energy-storage-listserv-signup/

CleanEnergy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY