RESILIENT POWER

A project of CleanEnergyGroup

Improving Energy Resiliency with Flow Batteries

September 15, 2016

CleanEnergyGroup

Innovation in Finance, Technology & Policy

Northeast Electrochemical energy storage Cluster

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 previous Resilient Power Project webinars, online at:

www.resilient-power.org

Clean Energy Group (CEG)

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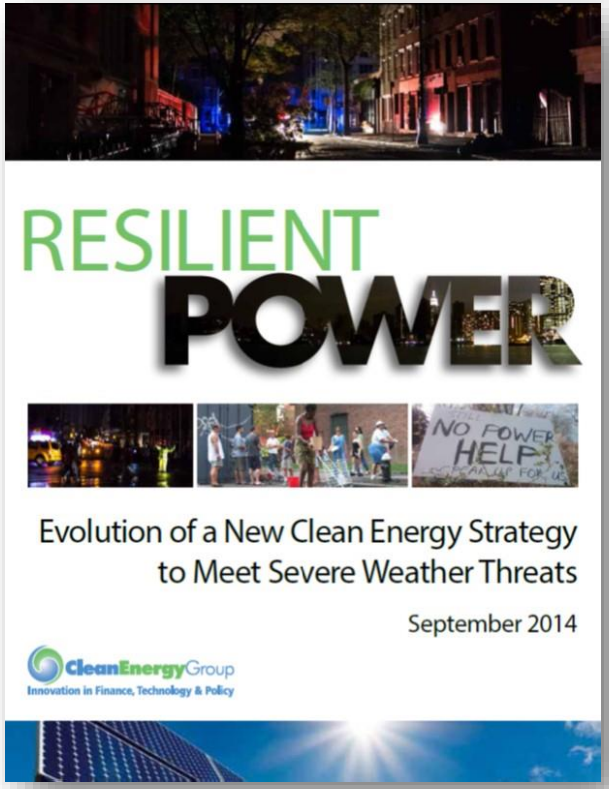
Innovation in Finance, Technology & Policy



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SURDNA FOUNDATION
Fostering sustainable communities in the United States

www.cleanegroup.org

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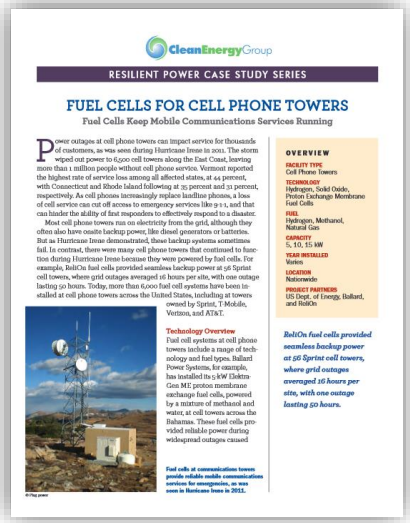
CEG's Resilient Power Project

- Increase public/private investment in clean, resilient power systems
- Engage city officials to develop resilient power policies/programs
- Protect low-income and vulnerable communities
- Focus on affordable housing and critical public facilities
- Advocate for state and federal supportive policies and programs
- Technical assistance for pre-development costs to help agencies/project developers get deals done
- See www.resilient-power.org for reports, newsletters, webinars, and more.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RESILIENT POWER CASE STUDY SERIES

FUEL CELLS FOR CELL PHONE TOWERS

Fuel Cells Keep Mobile Communications Services Running

Power outages at cell phone towers can impact service for thousands of customers, as was seen during Hurricane Irene in 2011. The storm wiped out power to 6,500 cell towers along the East Coast, leaving more than 1 million people without cell phone service. Vermont reported the highest rate of service loss among all affected states, at 44 percent, with Connecticut and Rhode Island following at 35 percent and 31 percent, respectively. As cell phones increasingly replace landline phones, a loss of cell service can cut off access to emergency services like 9-1-1, and that can hinder the ability of first responders to effectively respond to a disaster.

Most cell phone towers run on electricity from the grid, although they often also have onsite backup power, like diesel generators or batteries. But as Hurricane Irene demonstrated, these backup systems sometimes fail. In contrast, there were many cell phone towers that continued to function during Hurricane Irene because they were powered by fuel cells. For example, ReliOn fuel cells provided seamless backup power at 56 Sprint cell towers, where grid outages averaged 16 hours per site, with one outage lasting 50 hours. Today, more than 6,000 fuel cell systems have been installed at cell phone towers across the United States, including at towers owned by Sprint, T-Mobile, Verizon, and AT&T.

OVERVIEW

FACILITY TYPE
Cell Phone Towers

TECHNOLOGY
Hydrogen, Solid Oxide, Proton Exchange Membrane Fuel Cells

FUEL
Hydrogen, Methanol, Natural Gas

CAPACITY
5, 10, 15 kW

YEAR INSTALLED
Varies

LOCATION
Nationwide

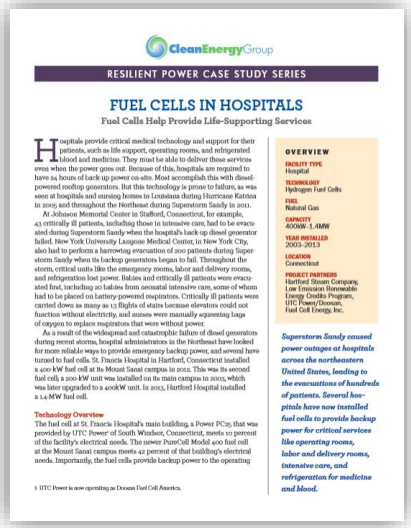
PROJECT PARTNERS
US Dept. of Energy, Ballard, and ReliOn

Technology Overview

Fuel cell systems at cell phone towers include a range of technology and fuel types. Ballard Power Systems, for example, has installed its 5 kW Elektra Gen ME proton membrane exchange fuel cells, powered by a mixture of methanol and water, at cell towers across the Bahamas. These fuel cells provided reliable power during widespread outages caused

ReliOn fuel cells provided seamless backup power at 56 Sprint cell towers, where grid outages averaged 16 hours per site, with one outage lasting 50 hours.

Fuel cells at communications towers provide reliable mobile communications services for emergencies, as was seen in Hurricane Irene in 2011.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RESILIENT POWER CASE STUDY SERIES

FUEL CELLS IN HOSPITALS

Fuel Cells Help Provide Life-Supporting Services

Hospitals provide critical medical technology and support for their patients, such as life support, operating rooms, and refrigerated blood and medicine. They must be able to deliver those services even when the power goes out. Because of this, hospitals are required to have 24 hours of back up power on-site. Most accomplish this with diesel-powered rooftop generators. But this technology is prone to failure, as was seen at hospitals and nursing homes in Louisiana during Hurricane Katrina in 2005 and throughout the Northeast during Superstorm Sandy in 2012.

At Johnson Memorial Center in Stafford, Connecticut, for example, 43 critically ill patients, including those in intensive care, had to be evacuated during Superstorm Sandy when the hospital's back-up diesel generator failed. New York University Langone Medical Center, in New York City, also had to perform a harrowing evacuation of 200 patients during Superstorm Sandy when its backup generators began to fail. Throughout the storm, critical units like the emergency rooms, labor and delivery rooms, and refrigeration lost power. Babies and critically ill patients were evacuated first, including 20 babies from neonatal intensive care, some of whom had to be placed on battery-powered respirators. Critically ill patients were carried down as many as 13 flights of stairs because elevators could not function without electricity, and nurses were manually squeezing bags of oxygen to replace respirators that were without power.

As a result of the widespread and catastrophic failure of diesel generators during recent storms, hospital administrators in the Northeast have looked for more reliable ways to provide emergency backup power, and several have turned to fuel cells. St. Francis Hospital in Hartford, Connecticut installed a 400 kW fuel cell at its Mount Sanai campus in 2012. This was its second fuel cell, a 200 kW unit was installed on its main campus in 2005, which was later upgraded to a 400kW unit. In 2013, Hartford Hospital installed a 1.4 MW fuel cell.

OVERVIEW

FACILITY TYPE
Hospital

TECHNOLOGY
Hydrogen Fuel Cells

FUEL
Natural Gas

CAPACITY
400kW- 1.4MW

YEAR INSTALLED
2003-2013

LOCATION
Connecticut

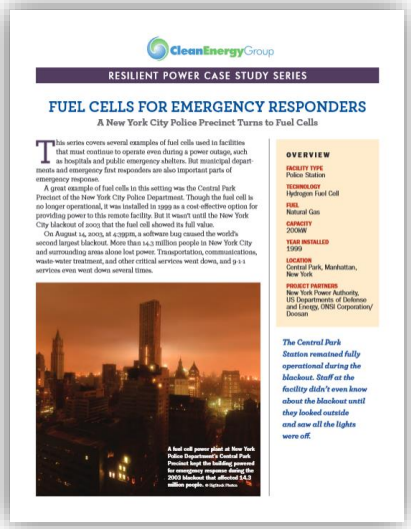
PROJECT PARTNERS
Hartford Steam Company, Low Emission Renewable Energy Credits Program, UTC Power/Doosan, Fuel Cell Energy, Inc.

Technology Overview

The fuel cell at St. Francis Hospital's main building, a Power PC25 that was provided by UTC Power of South Windsor, Connecticut, meets 10 percent of the facility's electrical needs. The newer PureCell Model 400 fuel cell at the Mount Sanai campus meets 42 percent of that building's electrical needs. Importantly, the fuel cells provide backup power to the operating

1 UTC Power is now operating as Doosan Fuel Cell America.

Superstorm Sandy caused power outages at hospitals across the northeastern United States, leading to the evacuations of hundreds of patients. Several hospitals have now installed fuel cells to provide backup power for critical services like operating rooms, labor and delivery rooms, intensive care, and refrigeration for medicine and blood.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RESILIENT POWER CASE STUDY SERIES

FUEL CELLS FOR EMERGENCY RESPONDERS

A New York City Police Precinct Turns to Fuel Cells

This series covers several examples of fuel cells used in facilities that must continue to operate even during a power outage, such as hospitals and public emergency shelters. But municipal departments and emergency first responders are also important parts of emergency response.

A great example of fuel cells in this setting was the Central Park Precinct of the New York City Police Department. Though the fuel cell is no longer operational, it was installed in 1999 as a cost-effective option for providing power to this remote facility. But it wasn't until the New York City blackout of 2003 that the fuel cell showed its full value.

On August 14, 2003, at 4:10pm, a software bug caused the world's second largest blackout. More than 14.3 million people in New York City and surrounding areas alone lost power. Transportation, communications, waste-water treatment, and other critical services went down, and 911 services even went down several times.

A fuel cell power plant at New York Police Department's Central Park Precinct kept the building powered for emergency response during the 2003 blackout that affected 14.3 million people. © Peyton Hoyt

OVERVIEW

FACILITY TYPE
Police Station

TECHNOLOGY
Hydrogen Fuel Cell

FUEL
Natural Gas

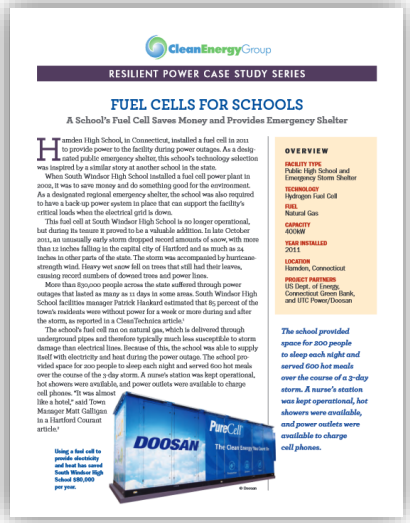
CAPACITY
200kW

YEAR INSTALLED
1999

LOCATION
Central Park, Manhattan, New York

PROJECT PARTNERS
New York Power Authority, US Departments of Defense and Energy, ONSI Corporation/ Doosan

The Central Park Station remained fully operational during the blackout. Staff at the facility didn't even know about the blackout until they looked outside and saw all the lights were off.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RESILIENT POWER CASE STUDY SERIES

FUEL CELLS FOR SCHOOLS

A School's Fuel Cell Saves Money and Provides Emergency Shelter

Hamden High School, in Connecticut, installed a fuel cell in 2011 to provide power to the facility during power outages. As a designated public emergency shelter, this school's technology selection was inspired by a similar story at another school in the state.

When South Windsor High School installed a fuel cell power plant in 2010, it was to save money and do something good for the environment. As a designated regional emergency shelter, the school was also required to have a back-up power system in place that can support the facility's critical loads when the electrical grid is down.

This fuel cell at South Windsor High School is no longer operational, but during its tenure it proved to be a valuable addition. In late October 2011, an unusually early storm dropped record amounts of snow, with more than 12 inches falling in the capital city of Hartford and as much as 24 inches in other parts of the state. The storm was accompanied by hurricane-strength wind. Heavy wet snow fell on trees that still had their leaves, causing record numbers of downed trees and power lines.

More than 830,000 people across the state suffered through power outages that lasted as many as 11 days in some areas. South Windsor High School facilities manager Patrick Haskard estimated that 85 percent of the town's residents were without power for a week or more during and after the storm, as reported in a CleanTechnica article.[1]

The school's fuel cell ran on natural gas, which is delivered through underground pipes and therefore typically much less susceptible to storm damage than electrical lines. Because of this, the school was able to supply itself with electricity and heat during the power outage. The school provided space for 200 people to sleep each night and served 600 hot meals over the course of a 3-day storm. A nurse's station was kept operational, hot showers were available, and power outlets were available to charge cell phones. "It was almost like a hotel," said Town Manager Matt Galligan in a Hartford Courant article.[1]

OVERVIEW

FACILITY TYPE
Public High School and Emergency Storm Shelter

TECHNOLOGY
Hydrogen Fuel Cell

FUEL
Natural Gas

CAPACITY
400kW

YEAR INSTALLED
2011

LOCATION
Hamden, Connecticut

PROJECT PARTNERS
US Dept. of Energy, Connecticut Green Bank, and UTC Power/Doosan

The school provided space for 200 people to sleep each night and served 600 hot meals over the course of a 3-day storm. A nurse's station was kept operational, hot showers were available, and power outlets were available to charge cell phones.

Using a fuel cell to provide electricity and heat has saved South Windsor High School $80,000 per year.

Northeast Electrochemical Energy Storage Cluster (NEESC)

NEESC is a network of industry, academic, government and non-governmental leaders working together to help businesses provide energy storage solutions.

Northeast Electrochemical energy storage Cluster

www.neesc.org

Today's Guest Speaker

Adam Rauwerdink
Director of Sales Engineering
VIONX Energy

VIONX™ ENERGY

TRANSFORMING THE GRID

Proven Long Duration Energy Storage

Improving Energy Resiliency with Flow Batteries

Adam Rauwerdink, Director of Sales Engineering

Proven Long Duration Energy Storage

20 YEAR LIFETIME

Bankable, utility-grade asset designed for the long run.

6 - 10 HOUR RUNTIME

Operational flexibility and endurance for multiple applications.

LASTING CAPACITY

No degradation.
No augmentation.
No replacement.

160 kW / 640 kWh System at Ft Devens

Leveraging World-Class Strategic Partners

DEEP EXPERIENCE IN TECHNOLOGY, ENERGY, MANUFACTURING AND FINANCE

EQUITY OWNERS

STARWOOD ENERGY GROUP

United Technologies

VANTAGE POINT CAPITAL PARTNERS

STRATEGIC & TECHNOLOGY PARTNERS

SIEMENS
EPC & PCS Equipment

3M
Membrane

JABIL
System Fabrication

United Technologies Research Center
System Optimization, Ongoing R&D

LARGO RESOURCES
Vanadium Supply

Leveraging World-Class Technology

DECADES OF TECHNOLOGY AND MATERIALS VALIDATION BY UTC & 3M

United Technologies

INTERDIGITATED FLOW FIELD

High Power

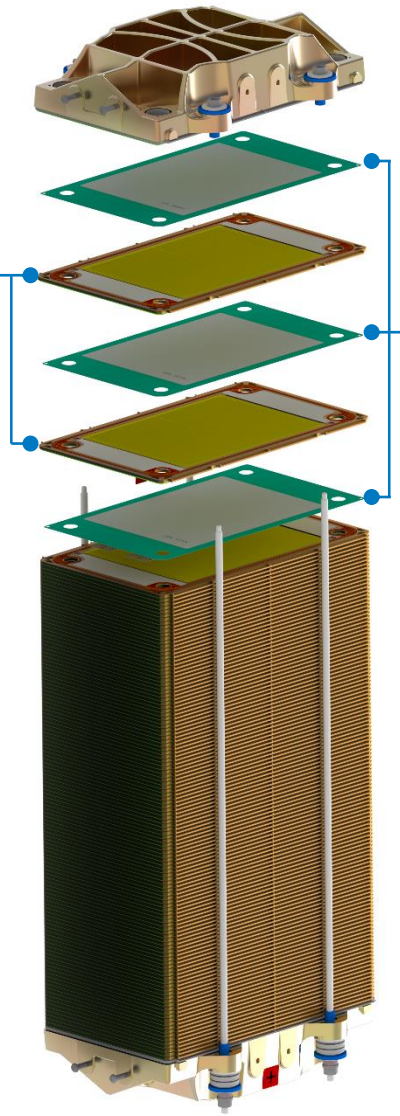
Twice the power density of traditional stacks through an advanced flow field design

High Reliability

Low pressure operation enables 20-year stack life and maximizes reliability

Low Cost

Half the stack cost of other flow batteries and no replacement costs



3M

UNIFIED ELECTRODE ASSEMBLY

Proven Materials & Performance

Decades of performance validation and established volume manufacturing

No Degradation. No Cycle Limits.

Maintains performance over a 20-year life with no limitations on how often the system is cycled

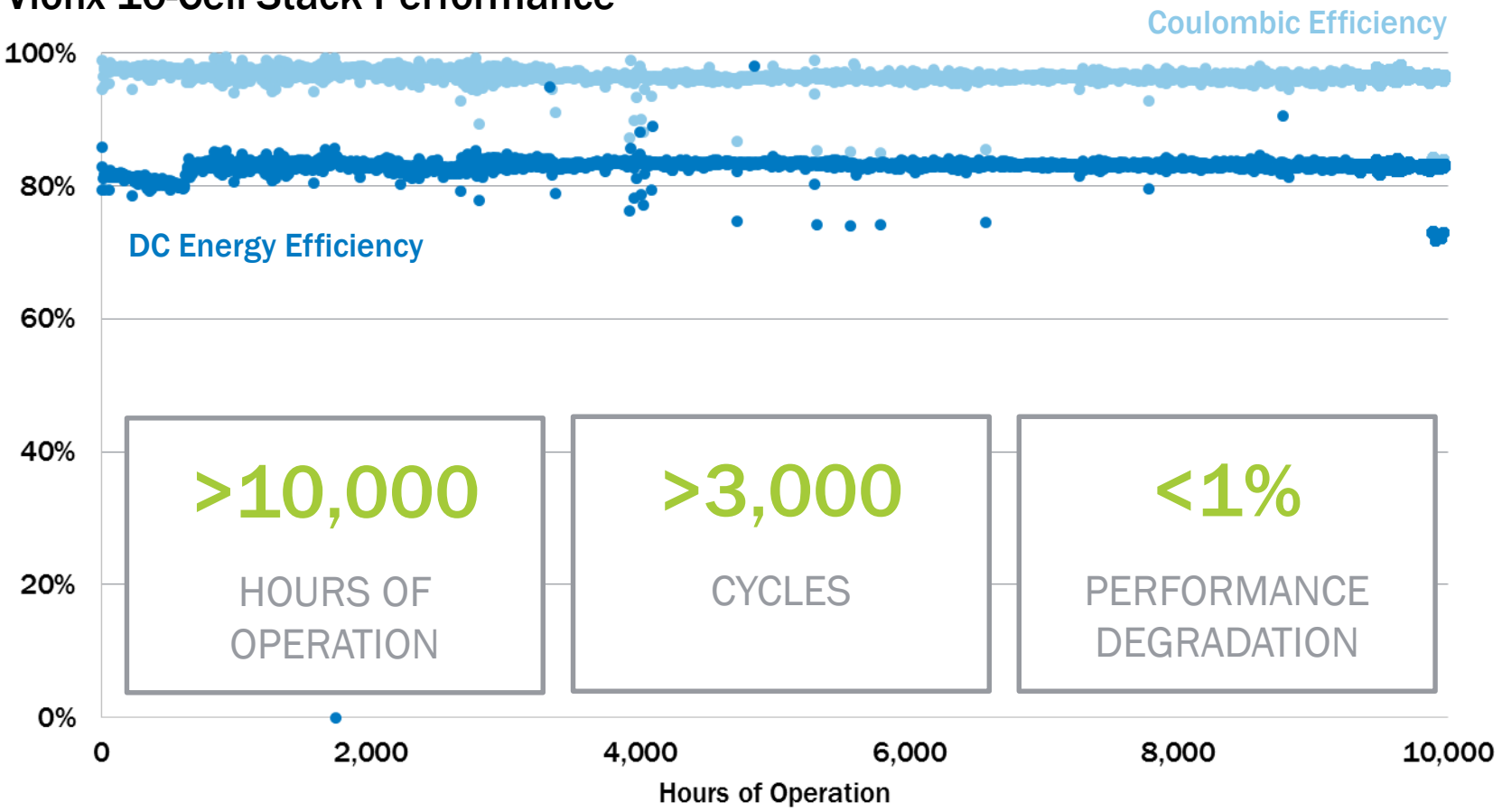
INDEPENDENTLY EVALUATED

DNV·GL

VIONX™ ENERGY

No Performance Degradation With Cycling or Time

Vionx 10-Cell Stack Performance



The Superior Technology for Long Duration

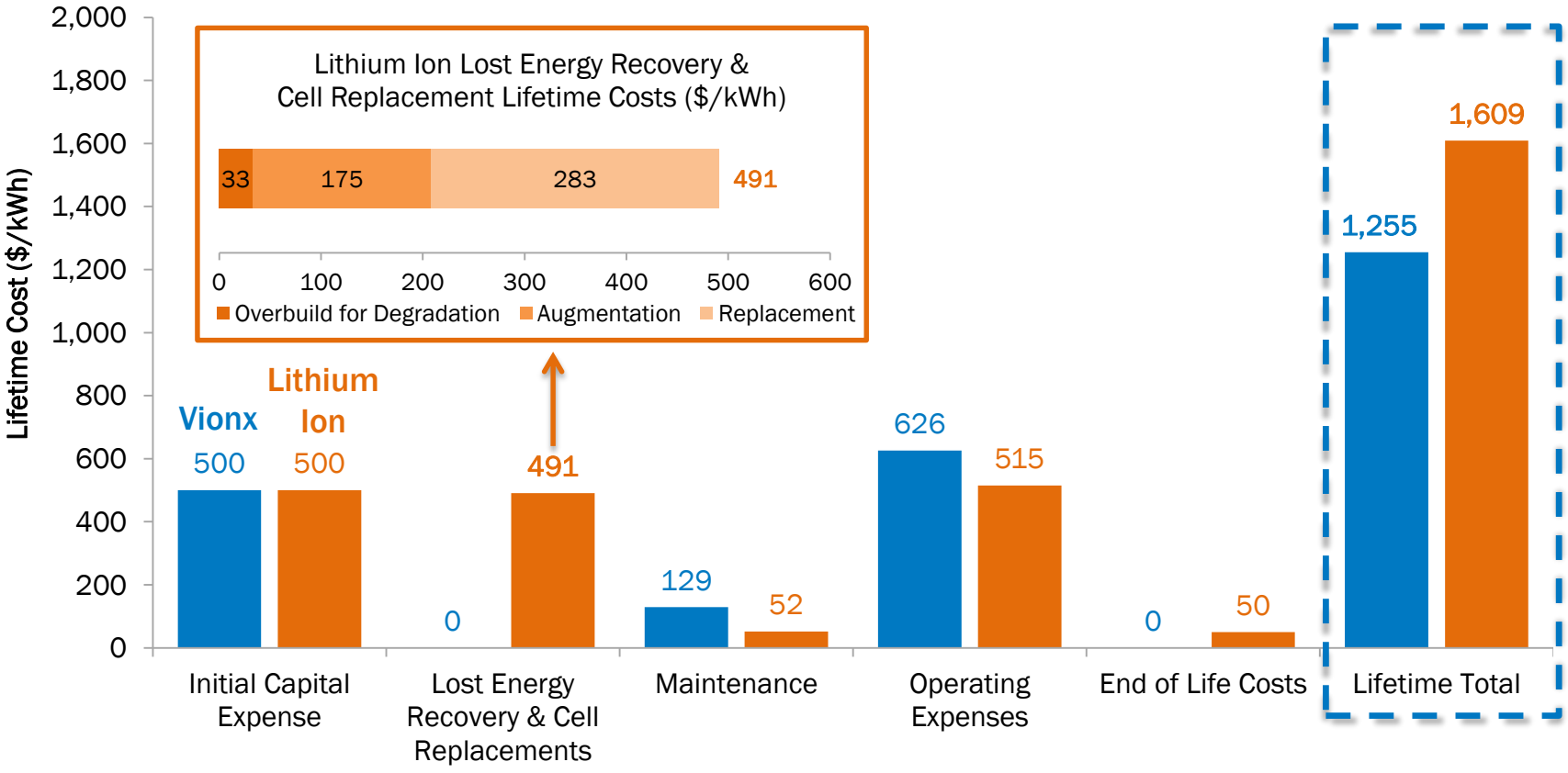
Strong | Medium | Weak

Storage Technology	Vanadium Redox Flow Battery	Lithium Ion Battery	Other Flow Batteries	Sodium Sulfur Battery	Compressed Air Energy Storage	Pumped Hydro
Economic Runtime	6 - 10 hours	0.5 - 4 hours	1 - 5 hours	6 hours	8 hours	6 - 20 hours
20 Year LCOE ($/MWh)	$216 - $260	$260 - $270	N/A	$400 - $500	$120 - $210	$188 - $274
Installed AC System Cost ($/kWh)	$500 - $700	$500+	$350 - $1,500	$500 - $2,500	$200	$250 - $350
Lifetime	20 years	10 years	Unproven	5 - 15 years	20+ years	20+ years
Capacity Degradation	None	Yes ~30% in 10 years	Unproven	Yes	Limited	Limited
Siting : Size (MWh/acre) & Restrictions	100 Limited Restrictions	200 Limited Restrictions	50-75 Limited Restrictions	200 Limited Restrictions	N/A Geographic Restrictions	N/A Geographic Restrictions
Track Record	Demonstration/ Deployment	Commercial	R&D / Demonstration	Commercial	Commercial	Commercial
Safety	Stable, non-flammable	Fire Hazard	Stable, non-flammable	High Operating Temperature	High Pressure	Safe
Competitors	VIONX ENERGY, UET UniEnergy Technologies, SUMITOMO ELECTRIC	TESLA, Panasonic, LG Chem, SAMSUNG	EOS, ViZn ENERGY, PRIMUS POWER	GE, NGK, FIAMM	LightSail Energy, DRESSER-RAND	–

Sources: Company; DOE/EPRI 2013 Electricity Storage Handbook; JPM Energy Storage Primer, 12/7/15; Lazard Levelized Cost of Storage Analysis, 11/15/15

Vionx VRB Beats Li-Ion Lifetime Cost

LITHIUM ION CAPACITY LOSS AND REPLACEMENTS DRIVE 20 YEAR LIFETIME COST



Grid-Scale Validation

✓	**Military & Microgrids** (Ft. Devens, MA) Operational		**160kW / 640 kWh System** ✓ Micro-Grid Control Compatibility ✓ Time-of-Use Rate Reduction ✓ Demand Charge Reduction
Q3 2016	**Wind Integration** (Worcester, MA) Under Construction		**500kW / 3,000 kWh System** ✓ Wind Integration (600kW Wind) ✓ Time-of-Use Rate Reduction ✓ Demand Charge Reduction
Q4 2016	**Solar Integration** (Everett, MA)		**500kW / 3,000 kWh System** ✓ PV Integration (605kW Solar) ✓ Voltage Support ✓ Load Following

VNX1000 SERIES

1,000 kW / 6-10 Hours

Modular Architecture

Independent scaling of power and energy

- Optimal system sizing for each application
- Flexibility to add power or energy as project needs change over time

Shown: 1 MW / 8 MWh DC System

Simplicity

Maximizes power density & minimizes footprint to reduce material and site costs

- Reduces container spacing & pipe runs
- Reduces wetted electrolyte surfaces, minimal propensity for leaks
- Minimizes moving components via centralization of all pumps, controls, etc. in stack container
- Electrolyte containers have no moving parts

Durable, Quality Components

Maximize system life and minimize operational expense

- Materials meet chemical industry standards
- Containers are marine grade for maximum climate resistance
- Electrolyte 100% double walled/contained

VNX1000 Specifications

Energy Storage Module	VNX1000-6	VNX1000-8	VNX1000-10
Energy Storage (MWh)	6 MWh	8 MWh	10 MWh
Usable Depth of Discharge	100%	100%	100%
Life	20 years (unlimited cycles)		
Power Rating	1 MW AC (2 Stack Containers)		
DC Footprint	185 m^2 / 2,000 ft^2	195 m^2 / 2,100 ft^2	205 m^2 / 2,200 ft^2
DC Efficiency (stack)	78%	78%	78%
DC Voltage	500V-800V DC operating range		
AC Efficiency	68%	68%	68%
Signal Response	<1 Second electrolyte pumps ON • <1 Minute electrolyte pumps OFF		
Interconnection Standard	IEEE 1547		
Operating Ambient Temperature	-40°C to +45°C / -40°F to 113°F		
Relative Humidity	0 to 100%		

Proven Long Duration Energy Storage Solution

Renewables Integration and Microgrids

- Dispatchable renewable power
- Increased capacity value and optimized energy delivery
- Improved thermal generation efficiency and reliability

T&D Deferral

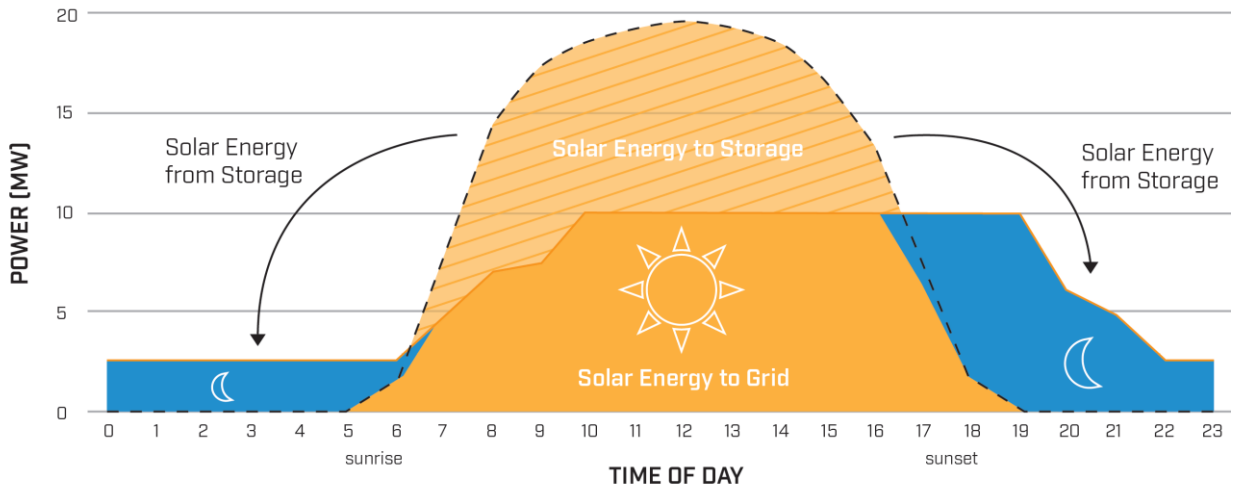
- Flexible and capital-efficient grid design
- Rapid deployment and simplified siting
- Increased utilization of existing assets

Commercial and Industrial

- Improved utilization of local solar
- Lower demand charges and more reliable power
- Revenue from grid services

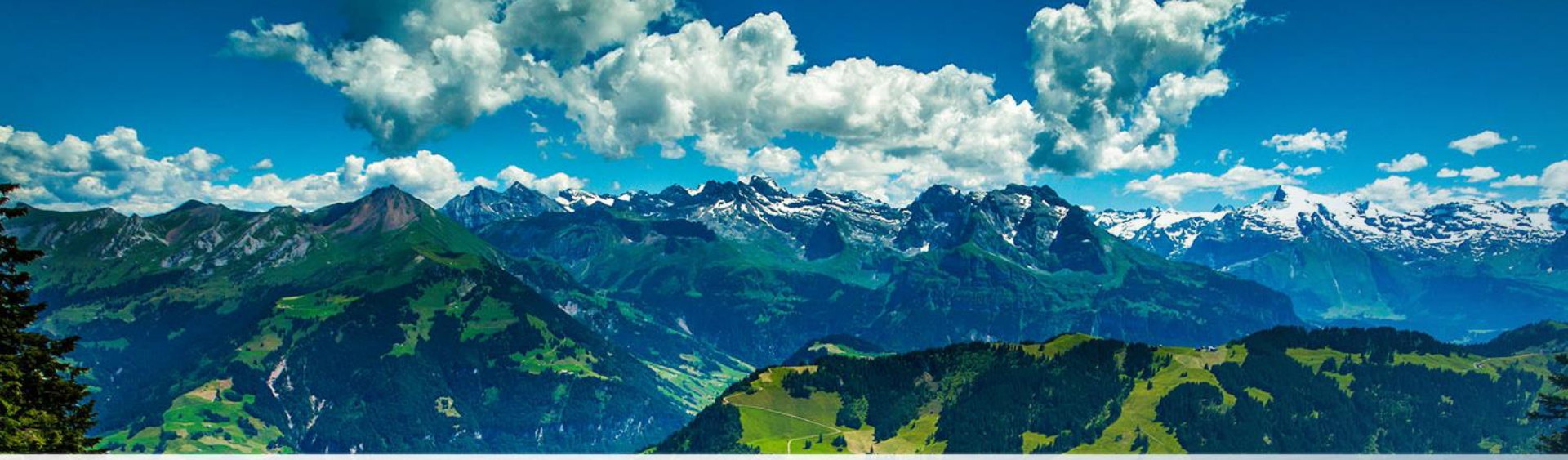
Dispatchable 24x7 Solar Power

Solar + Vionx Long-Duration Storage = Dispatchable Power at 15¢/kWh Today and 10¢/kWh by 2020



- Solar + Vionx storage is cost effective today
- Leverage existing or new low-cost PV solar to create a complete clean energy system
- Reliable, independent, dispatchable power generation for remote users
- Enables more efficient T&D operations for renewable energy integration
- Eliminates or optimizes fossil fuel-fired generation
- No air emissions or water consumption

Note: Lazard methodology used for LCOE calculation. 80% debt and 20% equity. 16% pre-tax cost of equity. Solar installed cost of $1,600/kW in 2017 dropping linearly to $1,000/kW in 2020. Vionx DC costs declining commensurate with projections. 20 year project life. Solar data from NREL PVWatts.



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