ENERGY STORAGE IN UTILITY SYSTEMS

Hands-On Relay School 2019

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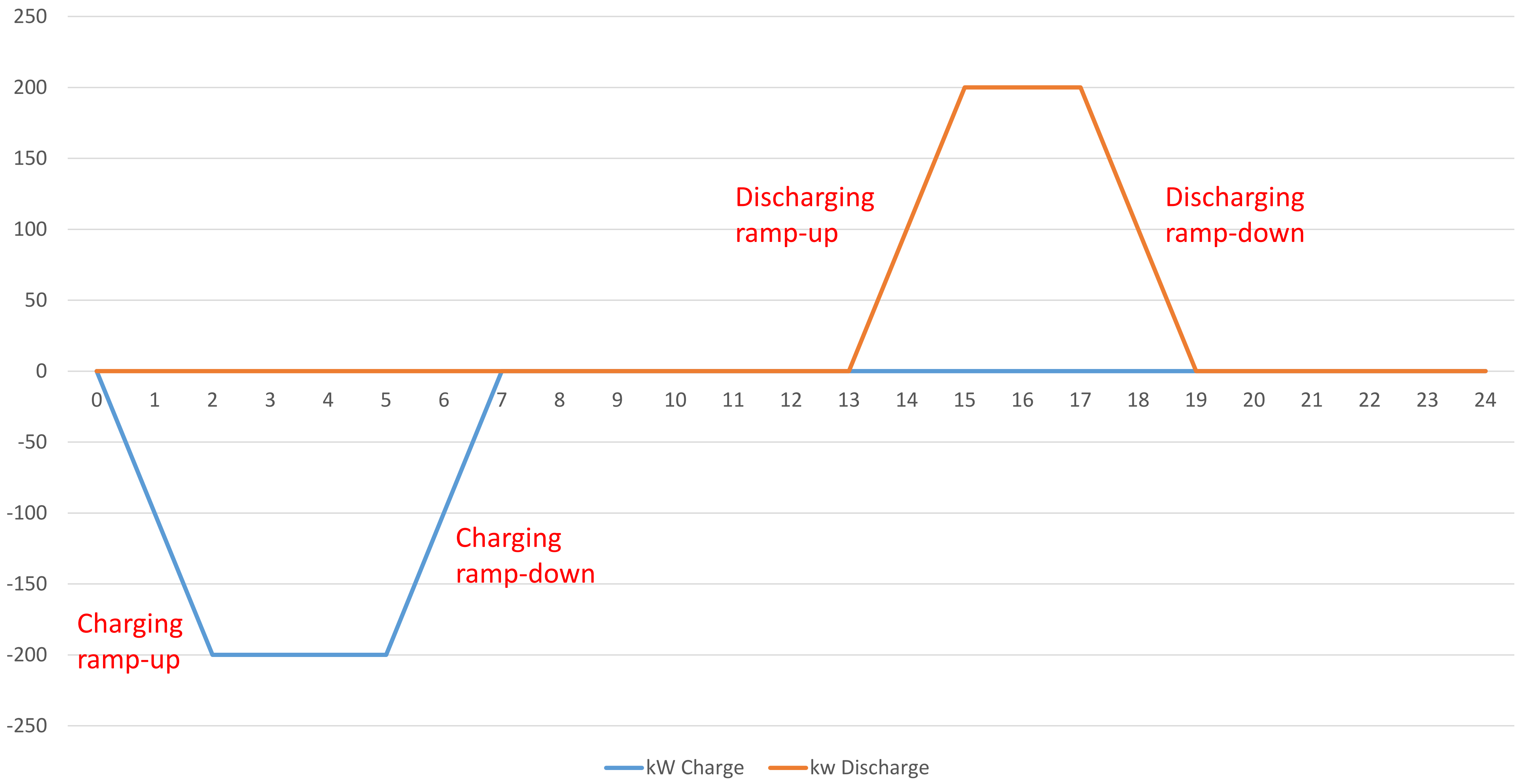
Snohomish County Public Utility District

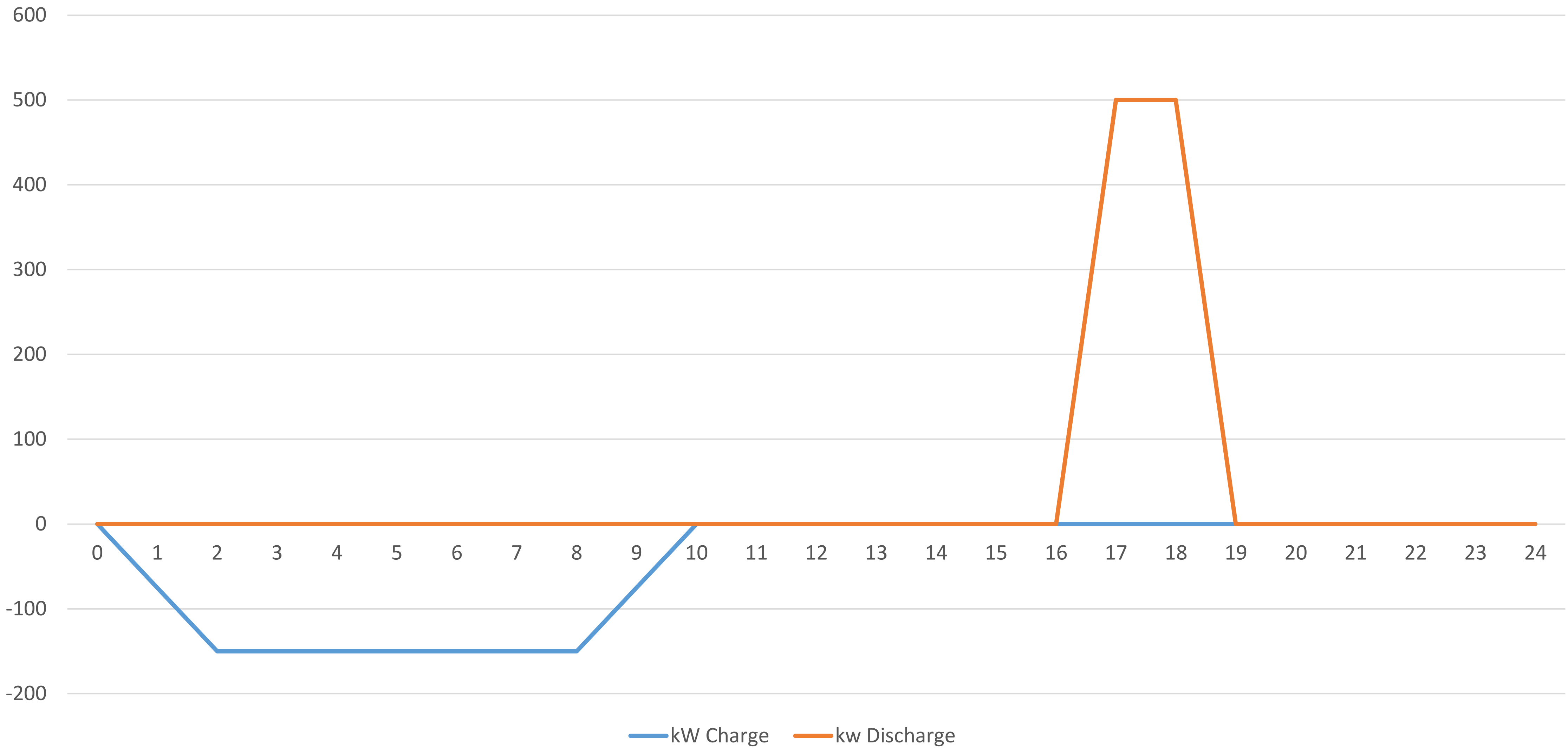
ENERGY & POWER MEASUREMENT

- Energy measurement
  - 1 Joule = Energy applied by a force of one newton through a distance of one meter
  - Joule is energy needed to lift one kilogram about 10 cm
  - Joule = one watt-second, a kWhr=3,600,000 Joules
  - AA Battery (alkaline) stores about 10^4 Joules, auto battery about $2*10^6$ Joules
  - Large systems measured in MW-hr, which is $3.6*10^9$ Joules
- Power measurement
  - 1 Watt = 1 Joule/second, 1 kW = 10^3 , 1 MW = 10^6 watts
  - DC power, P=V*I, AC systems $P = \sqrt{3} * V * I * pf$
- **Energy is Power * Time, Integral of power on a time plot**

Energy Storage – Charge 1000 kW-hr & Discharge 800 kW-hr



Slow Charge of 1200 kW-hr – Fast Discharge of 1000 kW-hr



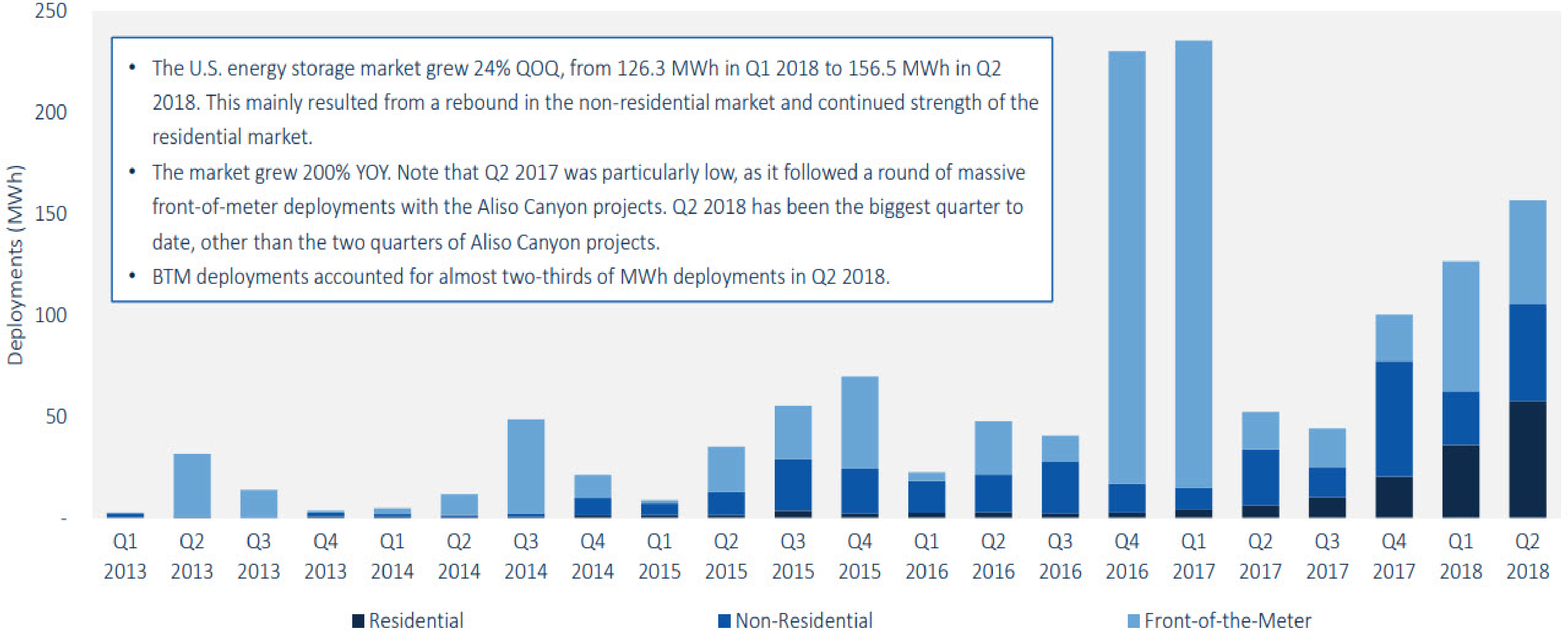
VALUE OF ENERGY STORAGE

- Energy storage allows generation of power to occur at a different time than the energy usage.
- Energy storage converts off-peak energy to on-peak energy, which increases value of the off-peak power production.

- Energy storage is important when generation is intermittent. By adding flexibility to dispatch, renewable sources can offer day-ahead guaranteed contracts to utilities, increasing profitability.
- Energy storage can provide improved frequency control and power quality for renewables.

ENERGY STORAGE DEPLOYMENT IN U.S.A.

U.S. Quarterly Energy Storage Deployments by Segment (MWh)



- The U.S. energy storage market grew 24% QOQ, from 126.3 MWh in Q1 2018 to 156.5 MWh in Q2 2018. This mainly resulted from a rebound in the non-residential market and continued strength of the residential market.
- The market grew 200% YOY. Note that Q2 2017 was particularly low, as it followed a round of massive front-of-meter deployments with the Aliso Canyon projects. Q2 2018 has been the biggest quarter to date, other than the two quarters of Aliso Canyon projects.
- BTM deployments accounted for almost two-thirds of MWh deployments in Q2 2018.

Source: GTM Research

MAP OF ENERGY STORAGE PROJECTS IN U.S.A. & CANADA

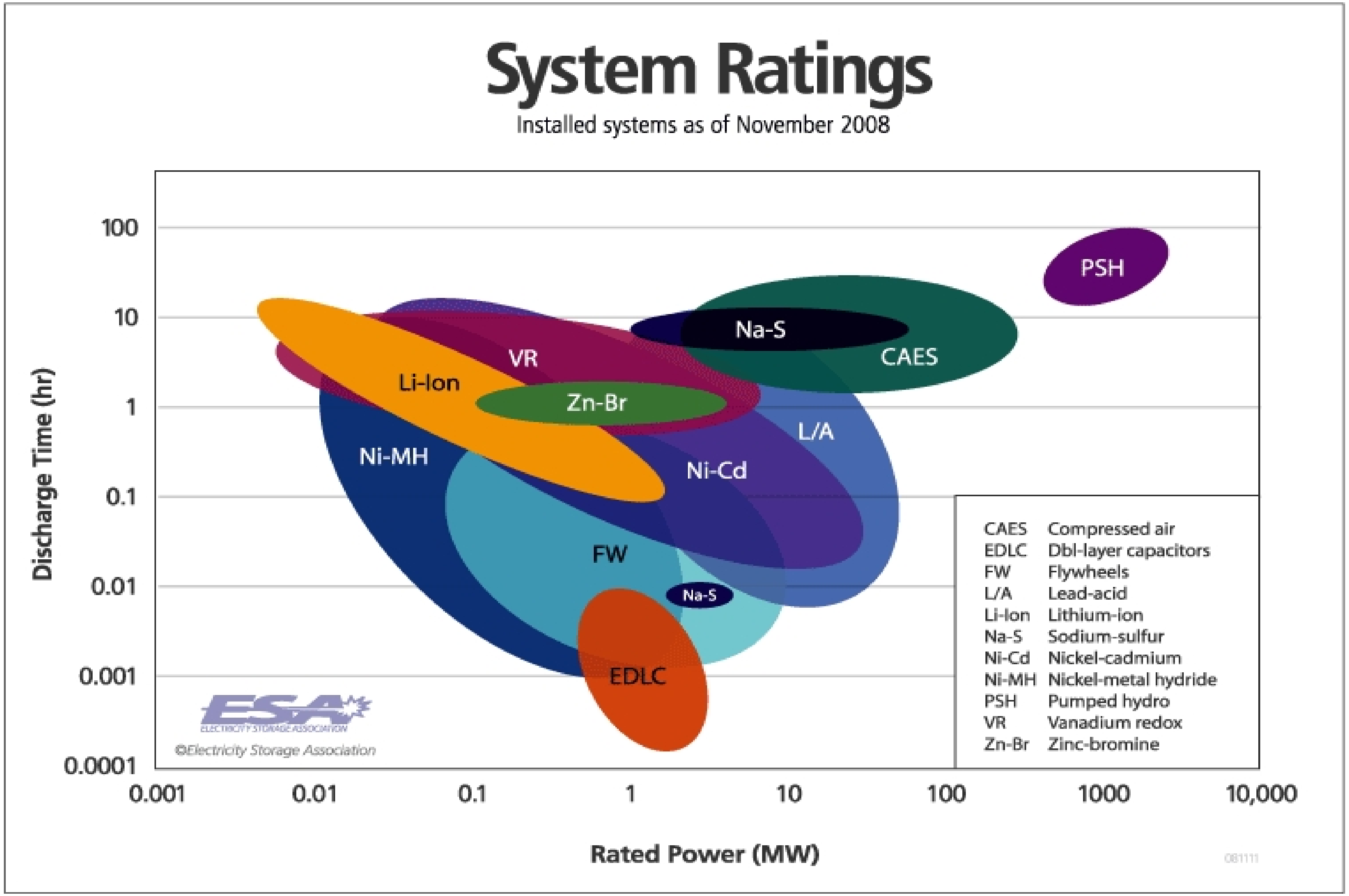
Red pin = 1 project
Blue circle = 2-10 projects
Yellow circle = 10-99 projects
Red circle (LA) = >100 projects

Source – USA DOE, Global Energy Storage Database

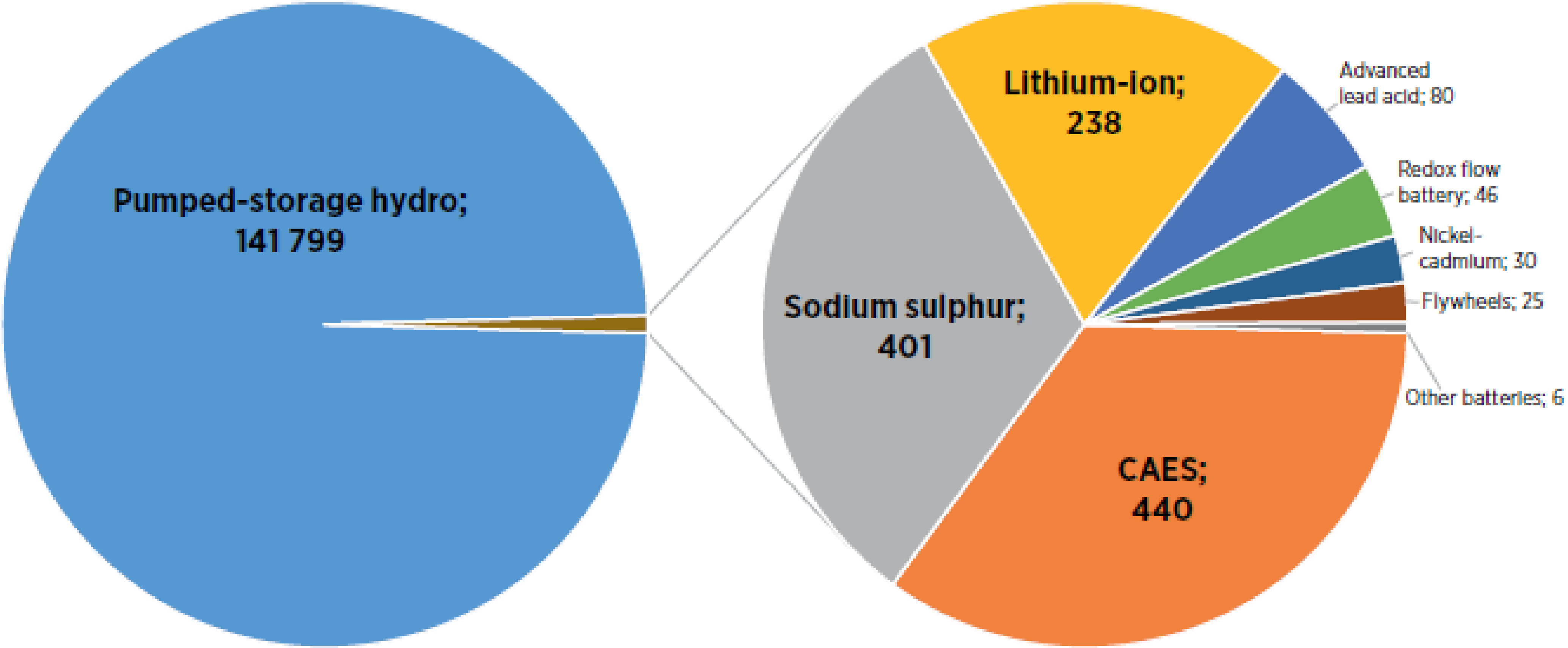
ELECTRIC ENERGY STORAGE OPTIONS

- Pumped Hydro – Elevation difference in a body of water creates stored energy
- Battery Energy Storage
  - ✓ Energy converted from electrical to chemical during charging, and from chemical to electrical during discharging
  - ✓ State of charge determined by the battery voltage
- Other types of Energy Storage
  - ✓ Compressed Air (CAES) – Large vessel stores compressed air, then a turbine generates power when air is released.
  - ✓ Hydrogen energy storage – Hydrogen produced through electrolysis, then re-electrified in fuel cells.
  - ✓ Flywheel – Kinetic energy stored in a rotating mass.
  - ✓ Thermal storage – Electrical energy drives a heat pump which pumps heat from the cold reservoir to the hot reservoir to store, then the heat pump is reversed to recover energy.

ENERGY STORAGE OPTIONS GRAPH, 2008



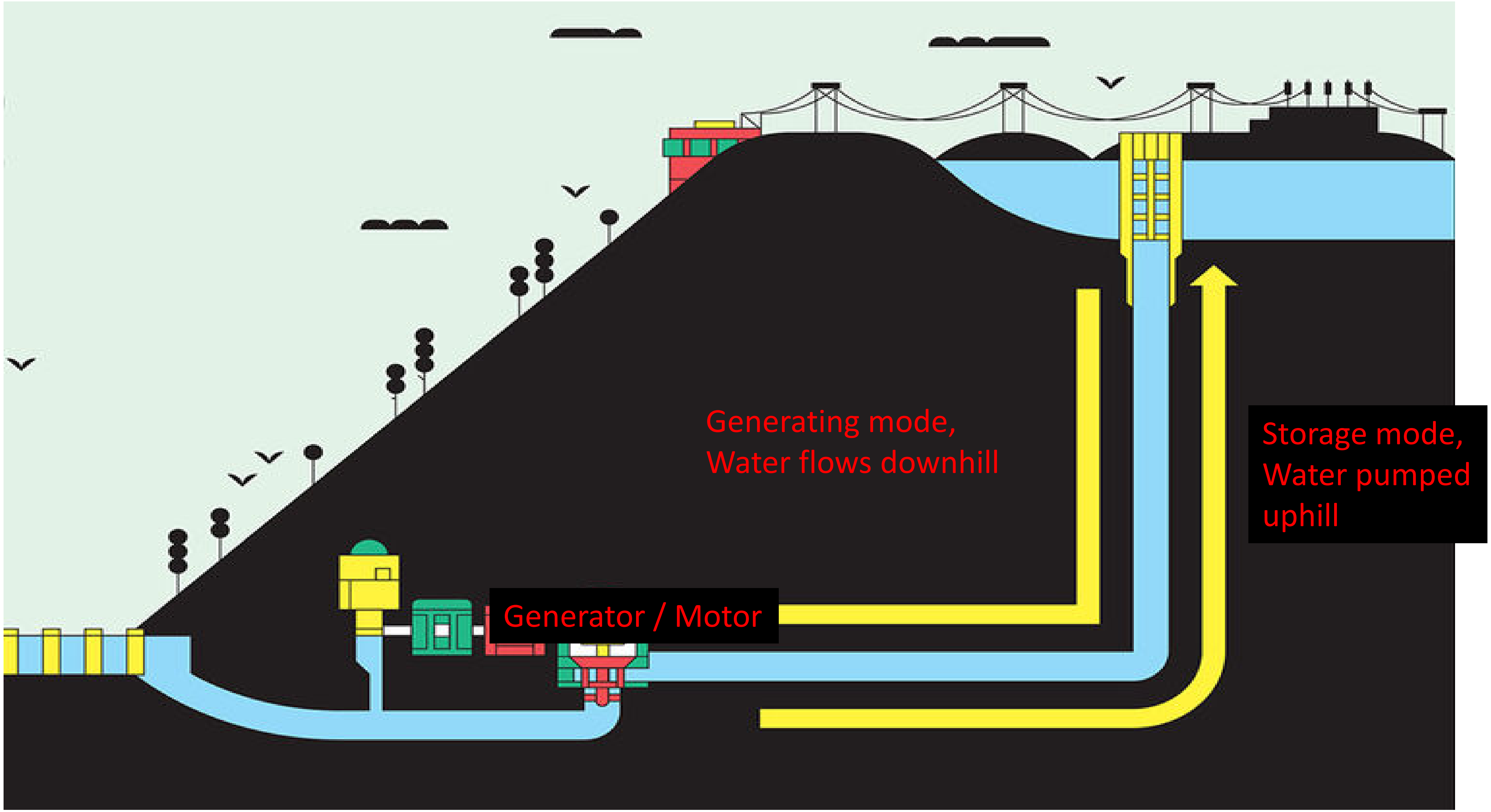
Pumped Storage Hydro Dominated Market in 2015



Source: Navigant Research (Dehamna, Eller & Embury, 2014) for installed battery capacity by type, and GlobalData (2015) for the pumped-storage hydroelectricity capacity.

Total Global MW installed as of 2014

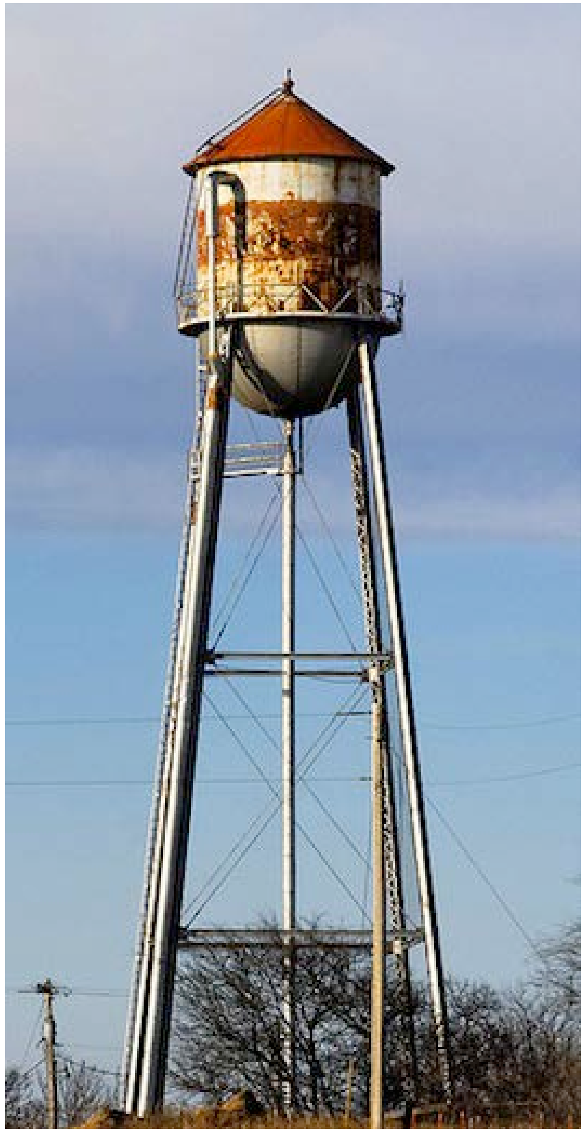
PUMPED HYDRO ENERGY STORAGE (PHES)



ELEVATION Δ CREATES STORED ENERGY

- Two water reservoirs are necessary, one at a higher elevation than the other.
- In the storage mode, water is pumped from the lower to the upper reservoir.
- In the generation mode, water flows from the upper through a turbine at the lower reservoir.
- Reversible pump-turbine/motor-generator assemblies can act as both pumps and turbines.
- Difference in potential energy is Mass * g * Height.
- Round-trip efficiency would be in the range of 80%.
- Over 100 GW of PHES installed world-wide.

EXAMPLE OF P.H.E.S. ENERGY CALCULATION



- One cubic meter of water weighs 1000 kg, or about 2,200 lbs.
- Put this in a tower 100 meters above the ground.
- Potential for energy generation is
  - M * g * H
  - 1000*9.8*100 = 980,000 Joules
  - Same as 0.272 kWhrs
  - Not very much!!
- P.H.E.S. requires either lots of water or big elevation difference
- Nearly all PHES systems installed are open-loop with reservoir at higher elevation.

JOHN W. KEYS PUMPING PLANT, ELECTRIC CITY, WA

Six pumps for irrigation, and
six turbine-pumps to transfer
water between two lakes.
Generation capacity is 314 MW.

Transfers water from Lake
Roosevelt, elevation 1290’
to Banks Lake elevation 1571’.

LOCATION OF P.H.E.S. IN U.S.A.

- ➢ Approx 25,000 MW in USA, six largest (by MW) are:
  - ✓ Bath County – 2100 MW
  - ✓ Ludington – 1872 MW
  - ✓ Racoon Mtn - 1530 MW
  - ✓ Castaic – 1440 MW
  - ✓ Helms – 1053 MW
  - ✓ Beinheim – 1000 MW
- ➢ First installed in CT, in 1929. Last installed in 1995 in GA.
- ➢ In 1980's & 1990's, PHES deployment in USA slowed to a halt, as a result of restrictions on land and water use.
- ➢ Best sites in USA have already been taken. Permitting new sites can be cost-prohibitive.
- ➢ In January 2019, FERC issued EIS for the proposed 393 MW Swan Lake PHES in Klamath County, OR.

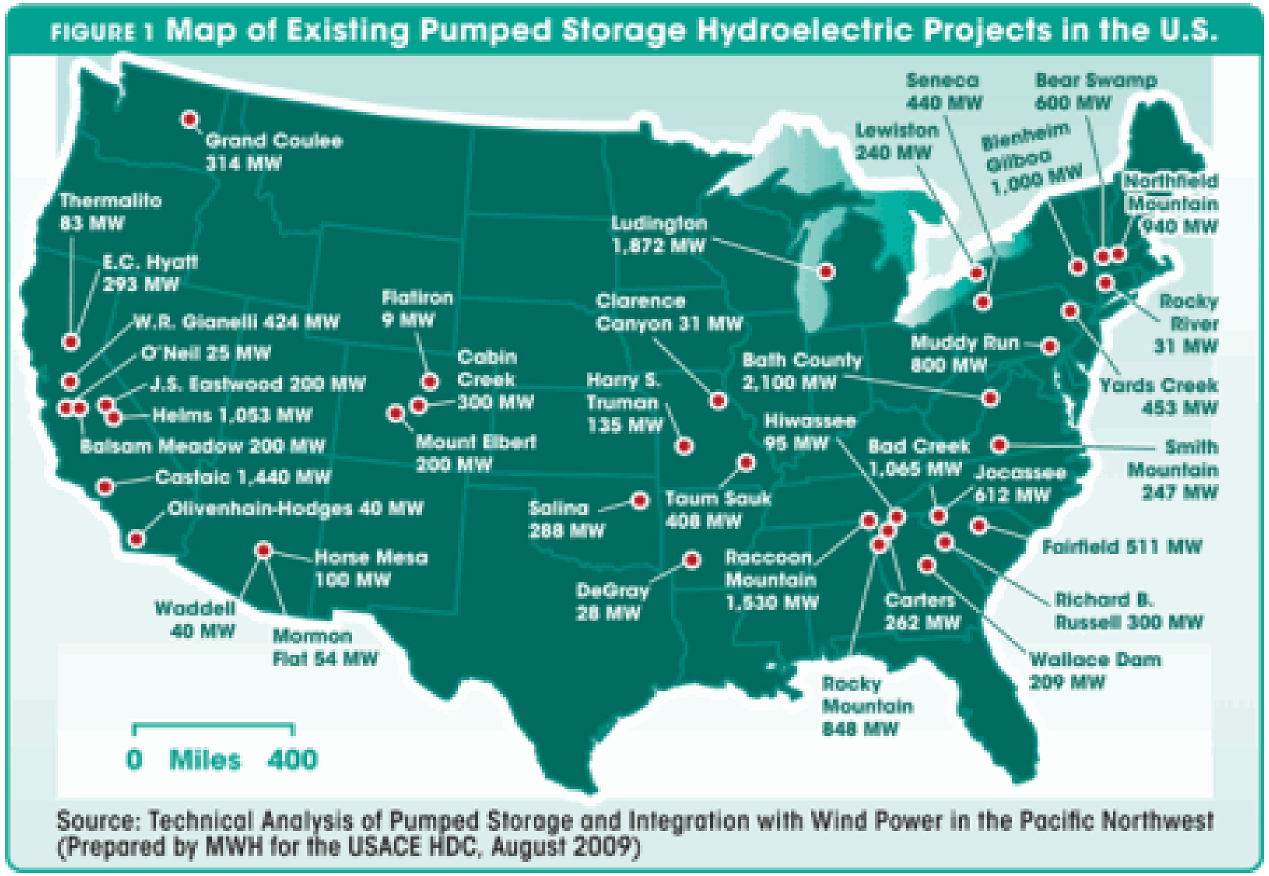
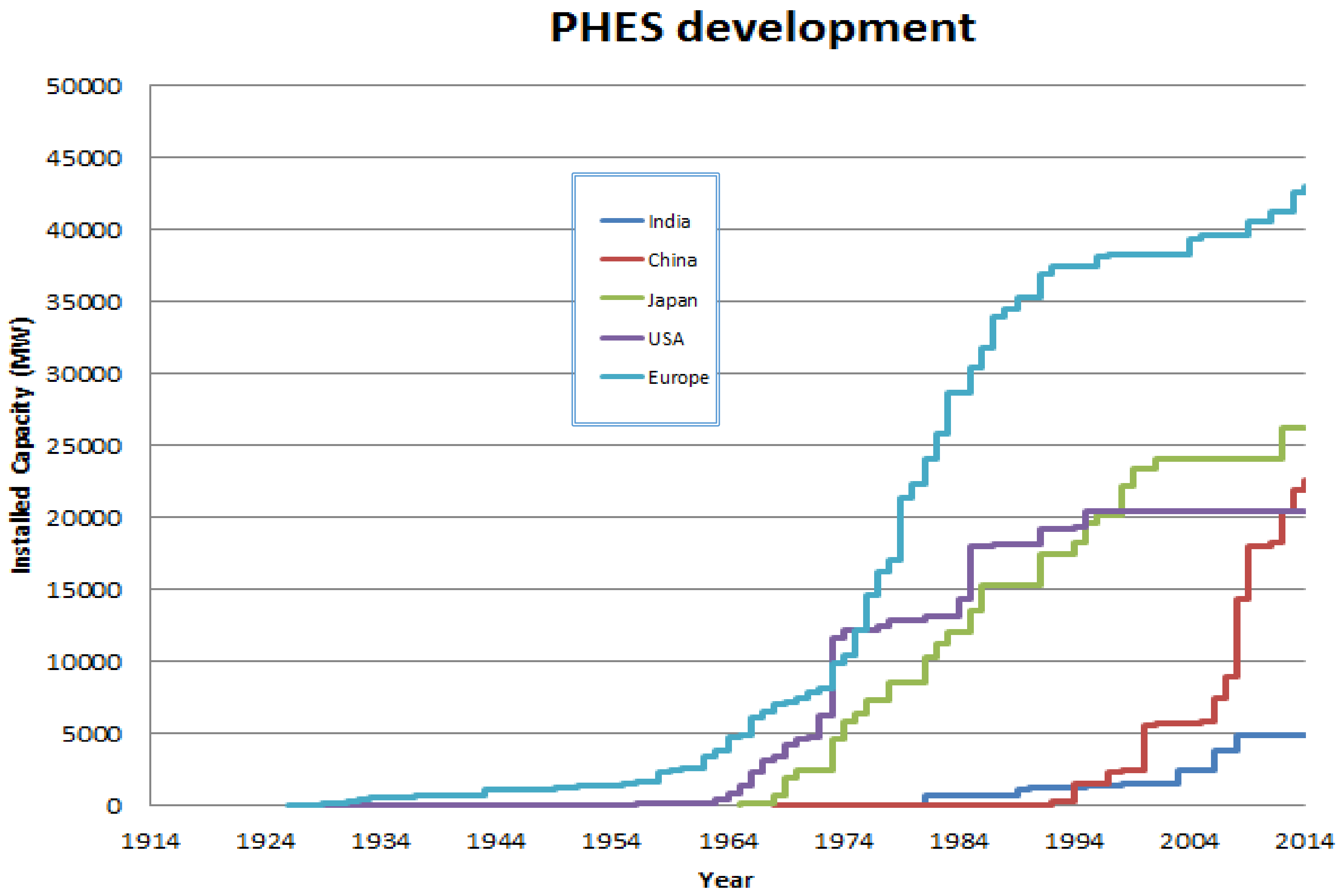


FIGURE 1 Map of Existing Pumped Storage Hydroelectric Projects in the U.S.

Source: Technical Analysis of Pumped Storage and Integration with Wind Power in the Pacific Northwest (Prepared by MWH for the USACE HDC, August 2009)

38 facilities can store about 2% of the MWhr generated in the USA.

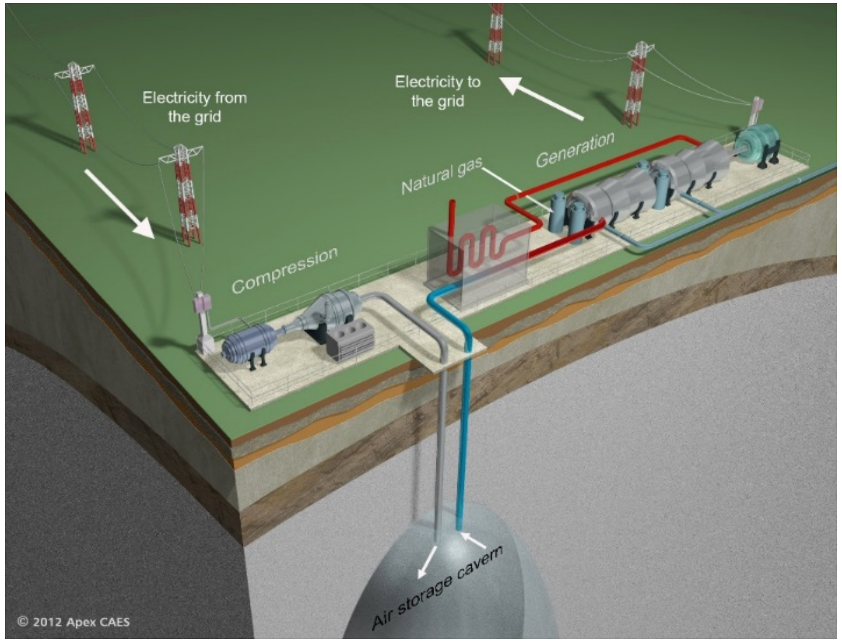
HISTORICAL GROWTH OF P.H.E.S.



PHES in United States and Europe has not grown much since 1994, while more PHES has been added in China and India.

COMPRESSED AIR ENERGY STORAGE (C.A.E.S.)

C.A.E.S. PRINCIPLE



1. *Energy is drawn from the electric system to compress air into an underground cavern, or an above-ground storage tank.*
2. *The compressed air is released and drives a turbine connected to a generator.*

- Compressing air heats it and expanding it cools it. Therefore, practical air engines require heat exchangers in order to avoid excessively high or low temperatures and even so don't reach ideal constant temperature conditions, or ideal thermal insulation.
- Achieving high efficiency is a technical challenge both due to heat loss to the ambient and to unrecoverable internal gas heat. Efficiency is about 42% if waste heat not recovered, 55% with recovery.
- Only 2 CAES constructed, one in Germany & one in Alabama.
- Theoretical efficiency of about 70% could be achieved if compression heat is recovered and used to re-heat compressed air during turbine operations.

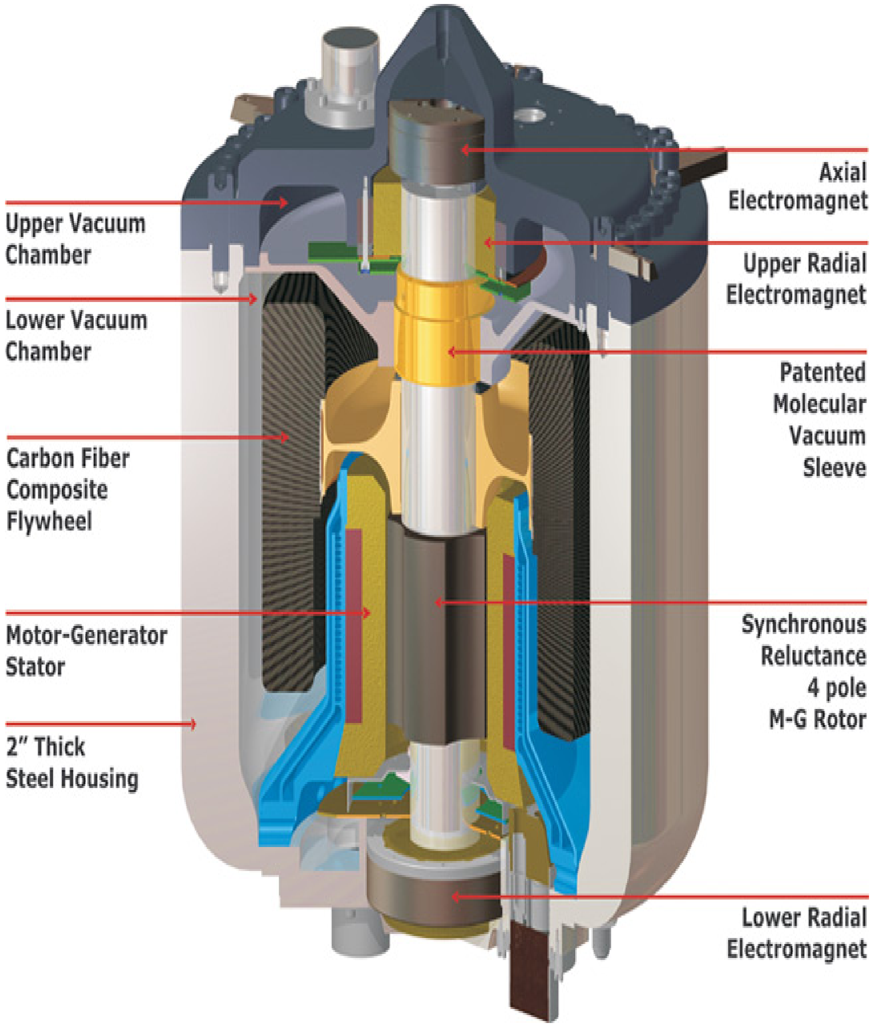
Liquified Air Energy Storage - Pilsworth

Above: LAES system at Pilsworth.

Left: Pilot system installed west of London.

- Under construction at Pilsworth landfill gas site near Manchester, UK.
- System rating is 5 MW, 15 MW-hr.
- Uses excess electricity to cool ambient air down to -196°C (-320°F), where the gases in the air become liquid.
- Liquid is stored in an insulated, low-pressure container.
- During peak periods, the liquid air is released back to high pressure, warmed up via a heat exchanger, and returns to gaseous state.
- The hot gas can then be used to drive a turbine and produce electricity.

FLYWHEEL ENERGY STORAGE



- Flywheel energy storage systems (FESS) use the energy stored in a rotating mass connected to a motor-generator set.
- The energy stored is proportional to square of the rotational velocity, so high RPM's are used.
- Low-speed flywheels are made of steel and rotate up to 10,000 RPM. Advanced FESS can operate as high as 100,000 RPM.
- FESS are best for high power, short duration applications that require many cycles.

OPERATING F.E.S.S. SYSTEMS

- Beacon Power opened a 20 MW, 15 minute (5 MWhr) flywheel energy storage plant in Stephentown, New York in 2011 using 200 flywheels. Beacon installed a similar 20 MW system at Hazle Township, Pennsylvania in 2014. The units operate at a peak speed at 15,000 rpm. The rotor flywheel consists of wound CFRP fibers which are filled with resin. The installation is intended primarily for frequency control.
- A 2 MW, 15 min (0.5 MWhr) flywheel storage facility in Minto, Ontario, Canada opened in 2014. The flywheel system developed by NRStor uses 10 spinning steel flywheels on magnetic bearings.
- Beacon Power began testing of their Smart Energy 25 flywheel energy storage system at a wind farm in Tehachapi, California.
- Stadtwerke München (SWM, Munich, Germany) uses a flywheel storage power system to stabilize the power grid, as well as control energy and to compensate for deviations from renewable energy sources. The plant originates from the Jülich Stornetic GmbH. The system consists of 28 flywheels and has a capacity of 0.1 MWh and a power output of 0.6 MW.
- In Ontario, Canada, Temporal Power Ltd. has operated a flywheel storage power plant since 2014. The maximum power is 2 MW. The system is used for frequency regulation.
- On the island of Aruba, a 5MW flywheel energy storage power plant was constructed by Temporal Power Ltd.
- The city of Fresno, California is running flywheel storage power plants built by Amber Kinetics to store solar energy.
- Chugach Electric (Alaska) plans to install two Beacon 100 kW flywheels, paired with a 1000 kW-hr battery system.

FLYWHEEL STORAGE DEVICE ACCIDENT, 2015

The flywheel at Quantum Energy Storage facility in Poway, California failed in 2015, causing major damage. Four people were injured, and the 14,000 sq ft building was declared “structurally unsound”. Quantum was fined $58,000 by Cal OSHA.

BATTERY ENERGY STORAGE

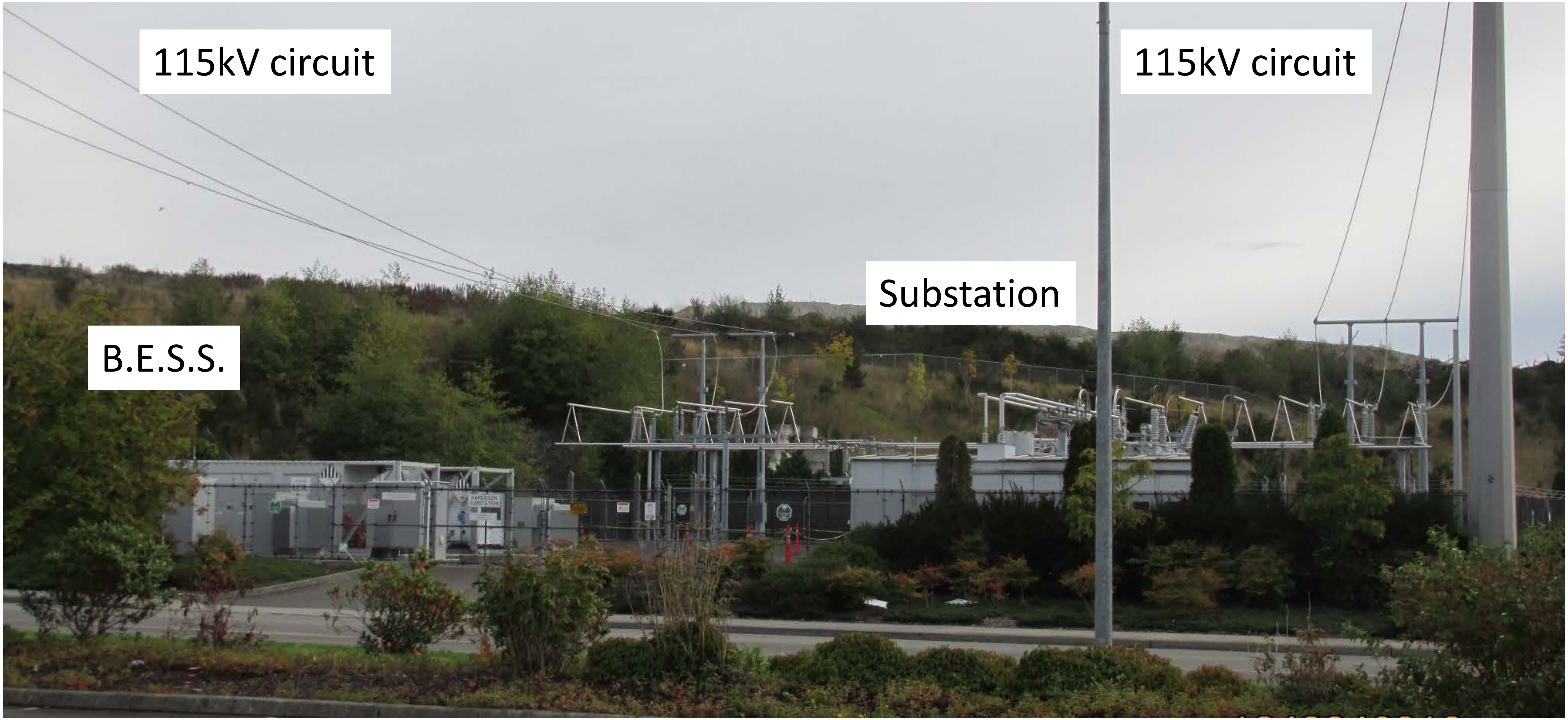
- Battery Energy Storage
  - ✓ Energy converted from electrical to chemical during charging, and from chemical to electrical during discharging
  - ✓ State of charge determined by the battery voltage
  - ✓ Batteries are fastest-growing type of energy storage because they are scalable, flexible, and easily deployed.
- Battery Types
  - ✓ Lead-acid – best for standby power only, lead-acid batteries degrade through multiple charge-discharge cycles.
  - ✓ Ni-Cad – better at charge-discharge than lead-acid, but batteries degrade.
  - ✓ Lithium-ion – more expensive, but good for many charge-discharge cycles and efficient. Best for short-duration applications.
  - ✓ Sodium-sulfur – Fair efficiency, about a 15-year life, best for high capacity installations.
  - ✓ Vanadium flow – new technology, great for long-duration applications with frequent charge-discharge, about 70% efficient.
  - ✓ Ultra-capacitor – most often used with batteries when a high discharge rate is needed.

SnoPUD BATTERY ENERGY STORAGE

- MESA-1 at Hardeson, Lithium-ion batteries
  - ✓AC Voltage 3Φ, 480 volt ungrounded
  - ✓DC Voltage 700 (discharged) to 1000 volts (fully charged)
  - ✓MESA 1A & 1B capacity, 1080 kW-hr (3.8 B Joules)
  - ✓Equivalent of 2,000 auto batteries or 380,000 AA
  - ✓Hardeson 1A (in-service, 2014)
  - ✓Hardeson 1B (in service 2015)
- MESA-2 at Everett, Vanadium-flow
  - ✓Power=2200 kW, Capacity=8000 kW-hr
  - ✓28.8 B Joules, equivalent to 3 million AA batteries or 15,000 auto batteries
  - ✓DC Voltage 480 (discharged) to 1,000 volts (fully charged)
  - ✓Construction complete April 2017, acceptance July 2017
  - ✓Housed in 20 standard-size shipping containers

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Hardeson Substation, 2015 Installation, Li-Ion

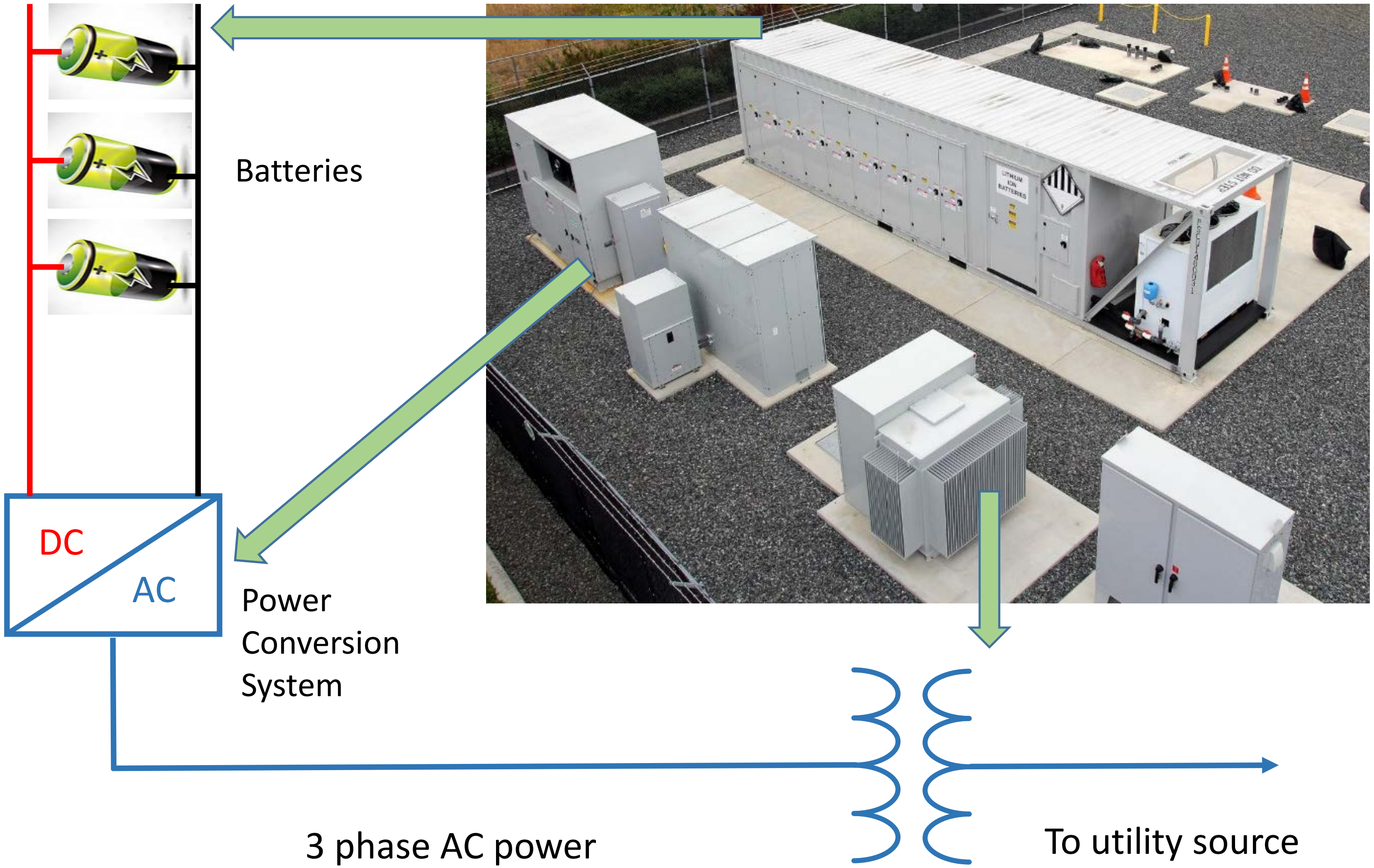


Everett MESA-2, Flow Battery, 2017 Installation

Total installation is 2.2 MW, 8 MWhr
Housed on 20 ISO shipping containers

Four strings in parallel
Each string rated 550 kVA
Energy storage 2000 kWhr each string

BATTERY STORAGE – BLOCK DIAGRAM



Batteries

Power
Conversion
System

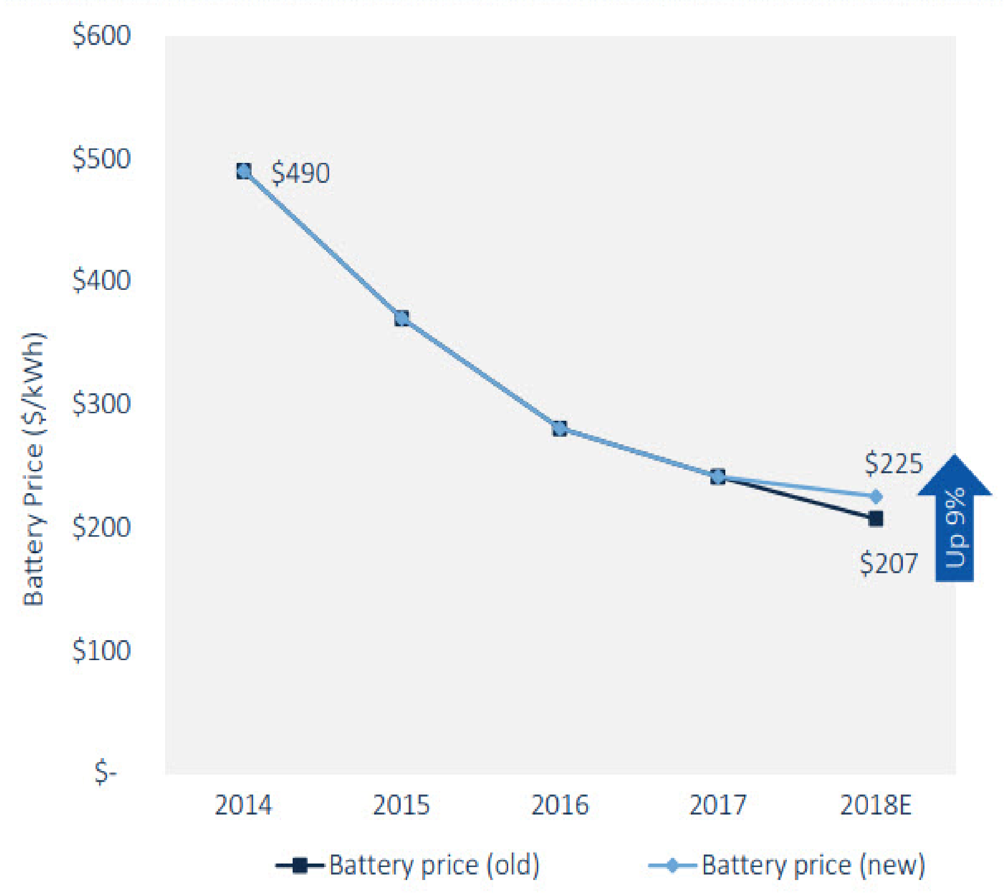
3 phase AC power

To utility source

LI-ION BATTERY ENERGY STORAGE

- Systems are scalable
  - Small systems are fractional MW-hr
  - Large systems up to 135 MW-hr
- Available from numerous vendors
  - GS-Yuasa, LG Chem, Tesla
- Li-ion is very good for multiple charge-discharge cycles
  - Modules with daily charge-discharge can last 10 years or more
- Very good efficiency and dynamic response

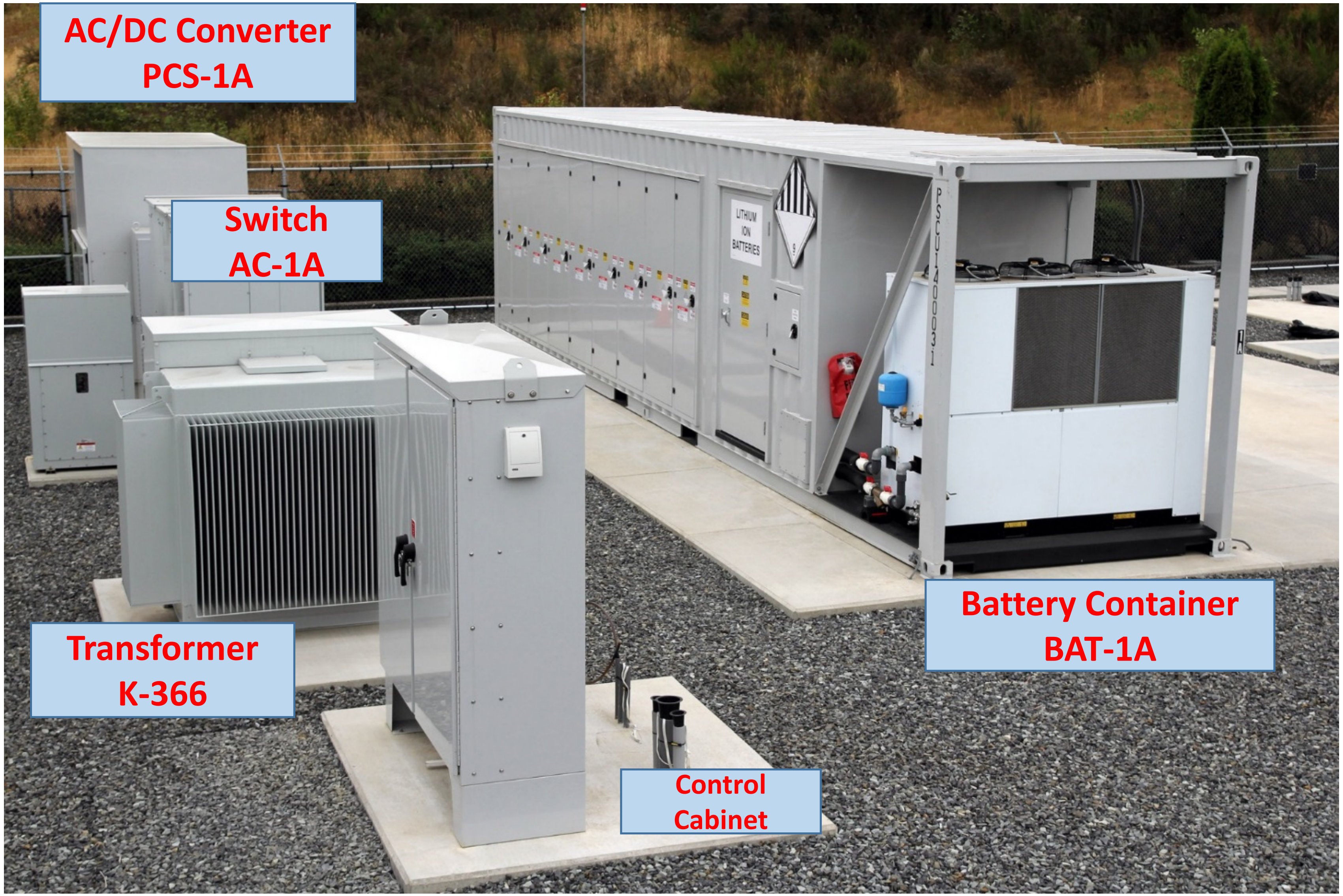
Lithium-Ion Battery Prices, 2014-2018E ($/kWh)



Source: GTM Research

MESA 1A EQUIPMENT

- Dedicated 12kV circuit from Hardeson switchgear goes to MESA-1.
- Stepped down to 480 volts through transformer K-366
- Disconnect switch AC-1A provides isolation
- PCS1A converts AC 480 volts to DC 1000 volts and controls power flow
- PCS1A output goes to the battery container



HARDESON - MESA 1B EQUIPMENT

- Second phase design similar to first
- Battery vendor LG-Chem
- Completed Dec 2015

Battery Container BAT-1B

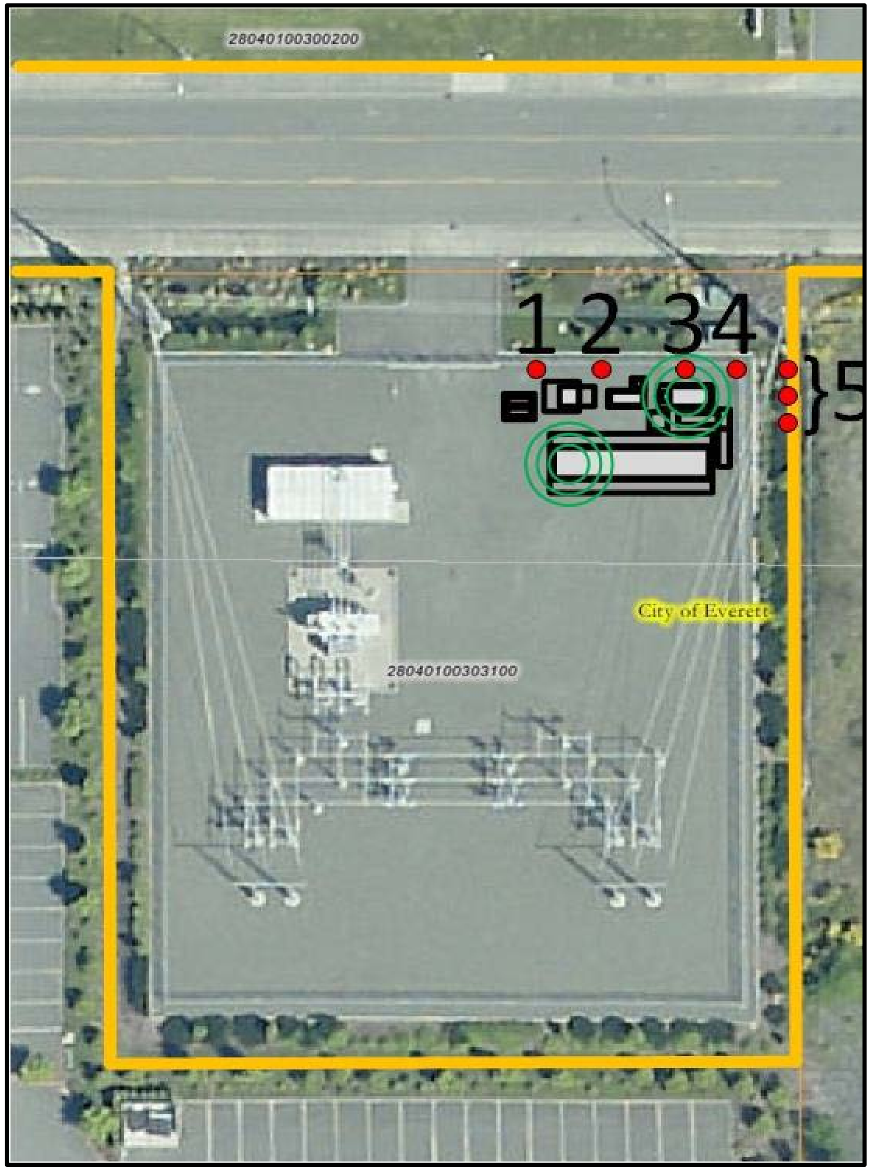
PCS-1B

Controller & relay cabinet

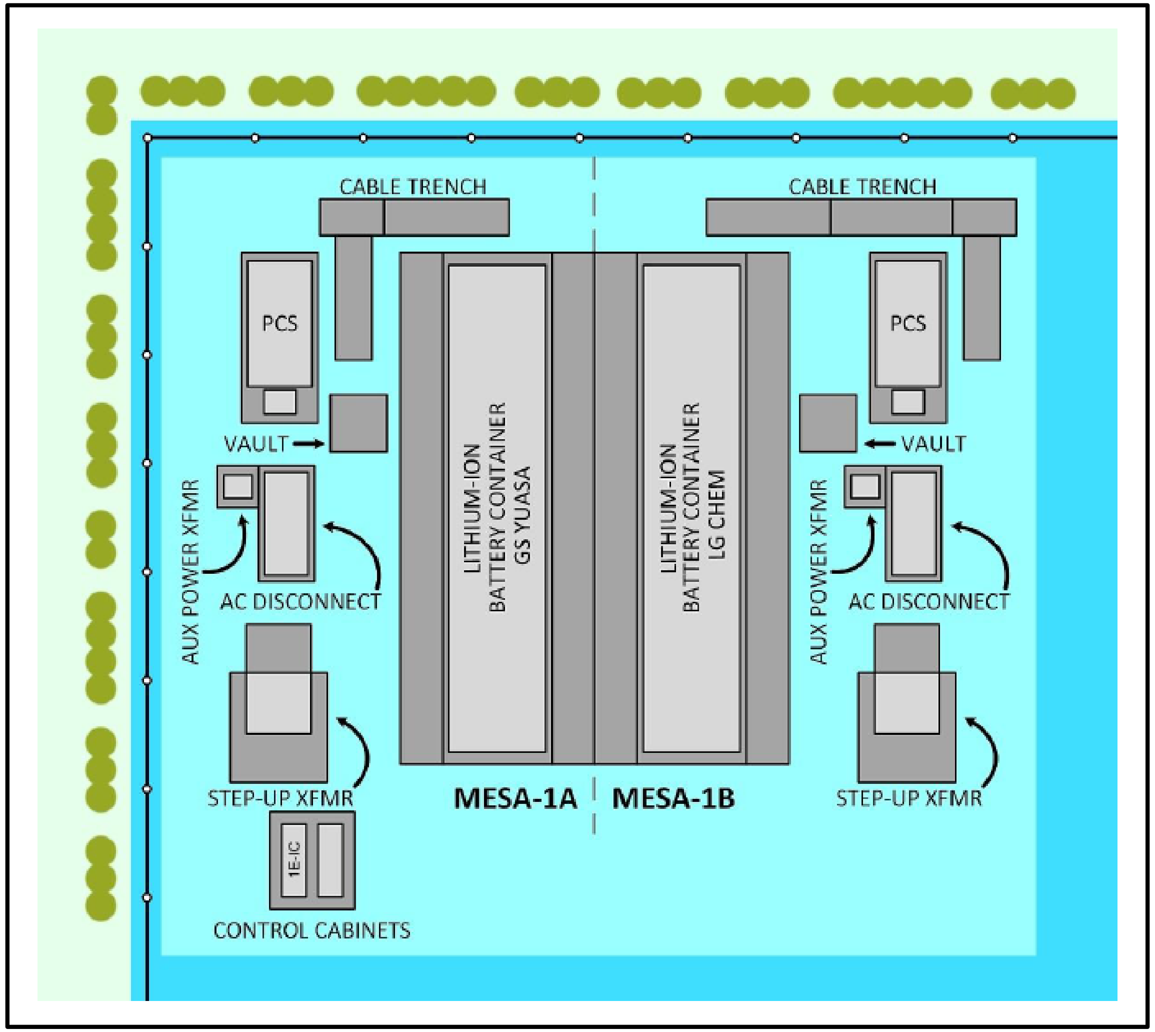
Transformer K-367

AC-1B

Site Layout



MESA 1A site physical arrangement.

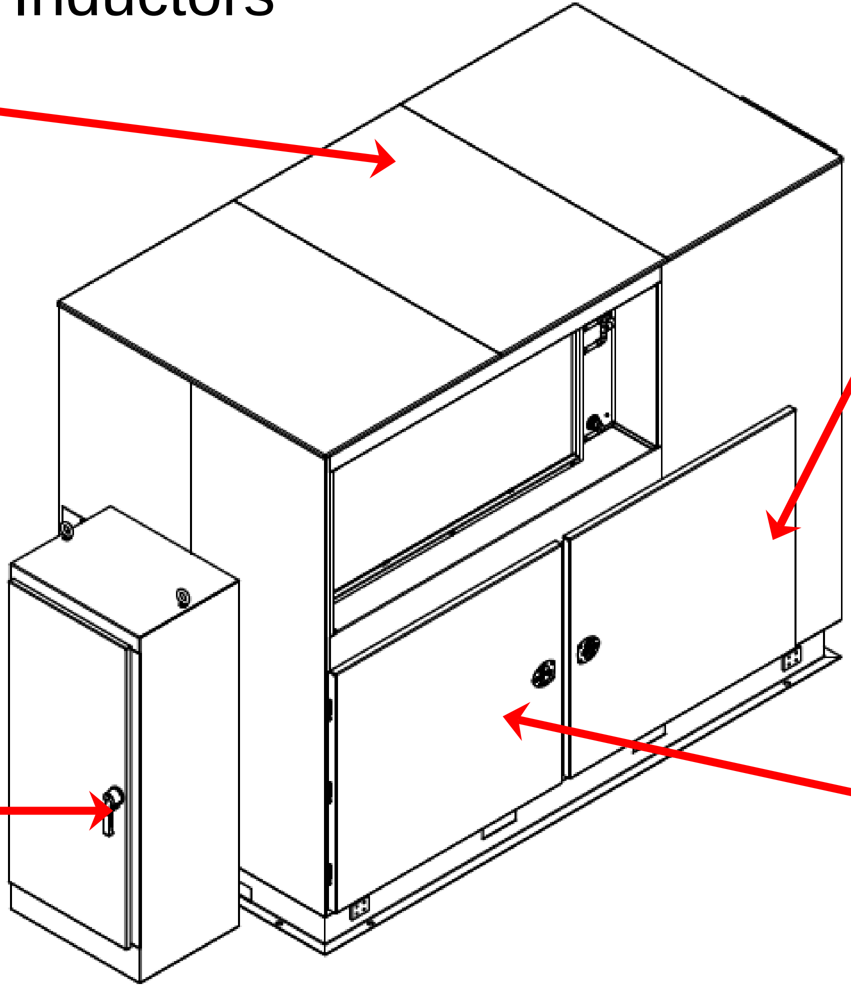


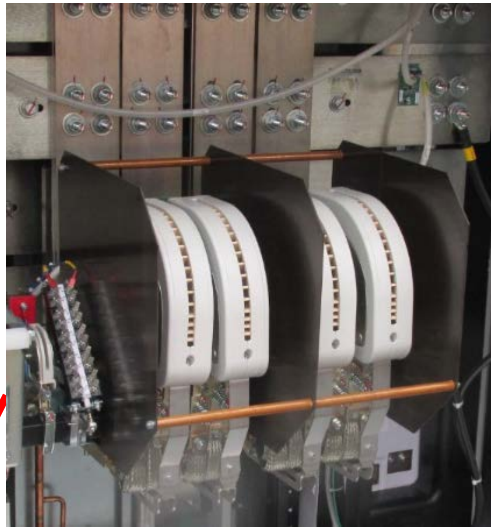
MESA 1A and 1B site physical configuration.

Power Conversion System (PCS)

- Incoming power source is 480 volts AC
- PCS converts to about 1000 volts DC, depends on battery charge
- Has inverters, capacitors, inductors & fans
- HMI panel and controls
- PCS controls amount and direction of power flow
- PCS efficiency is 97.5% to 98.5% if loaded between 20% and 100% of rated

Filter Capacitors & Inductors

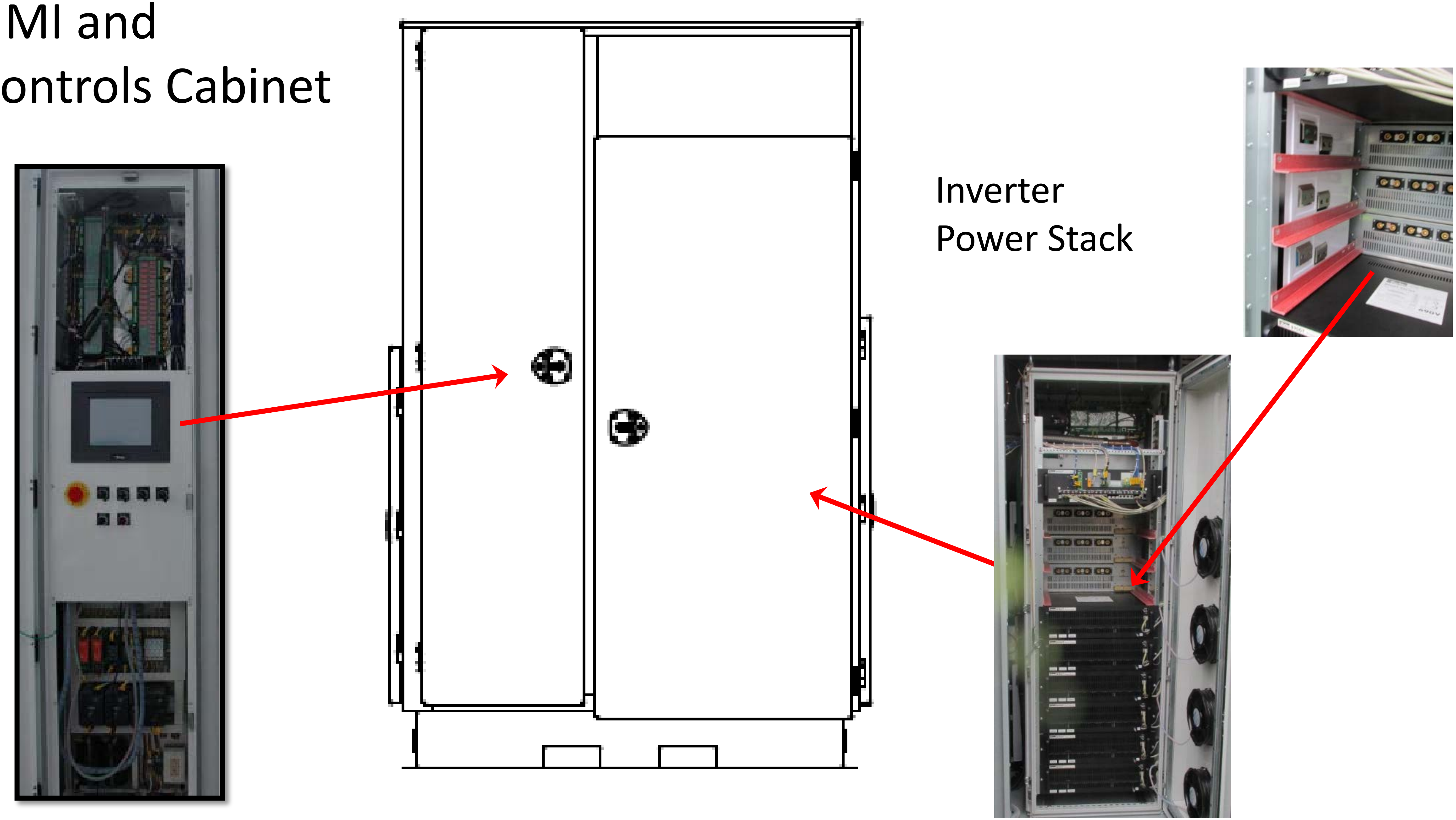




DC Contactors

AC Connections and Breaker

DC Battery Power Connections



HMI and
Controls Cabinet

Inverter
Power Stack

Battery Container

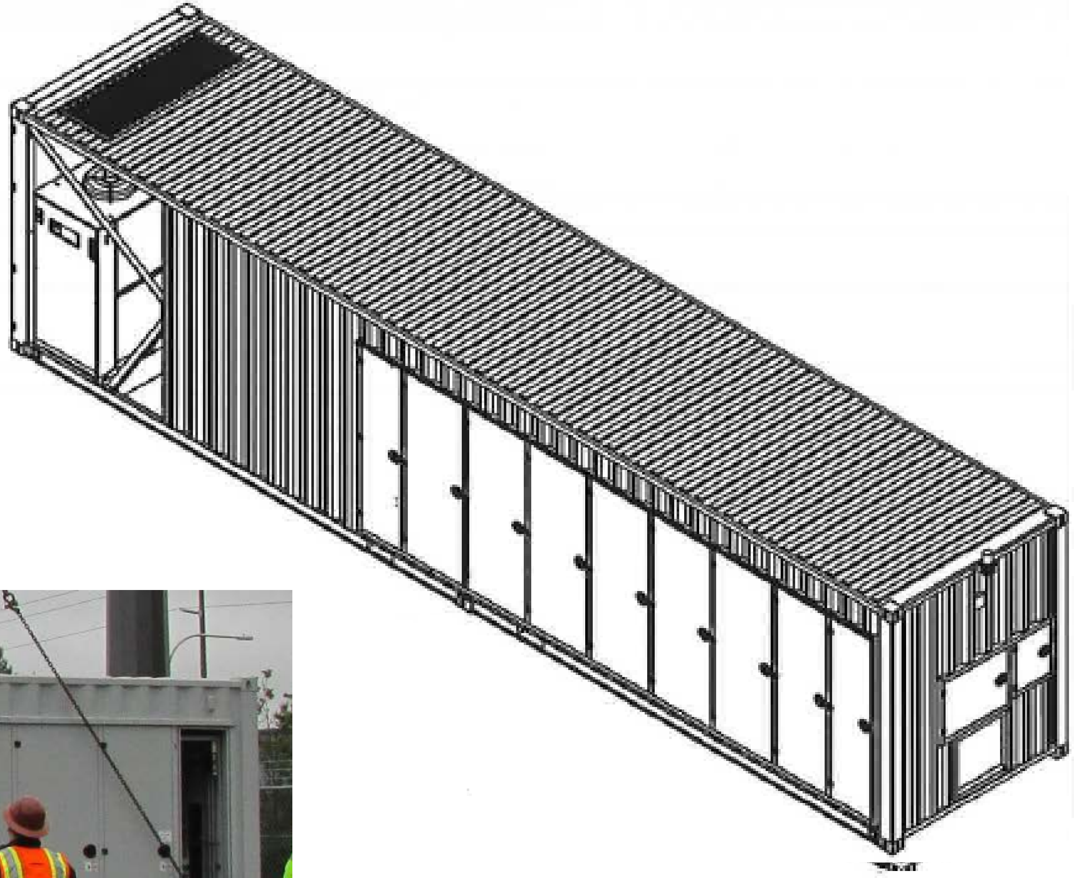
Left – interior of battery container

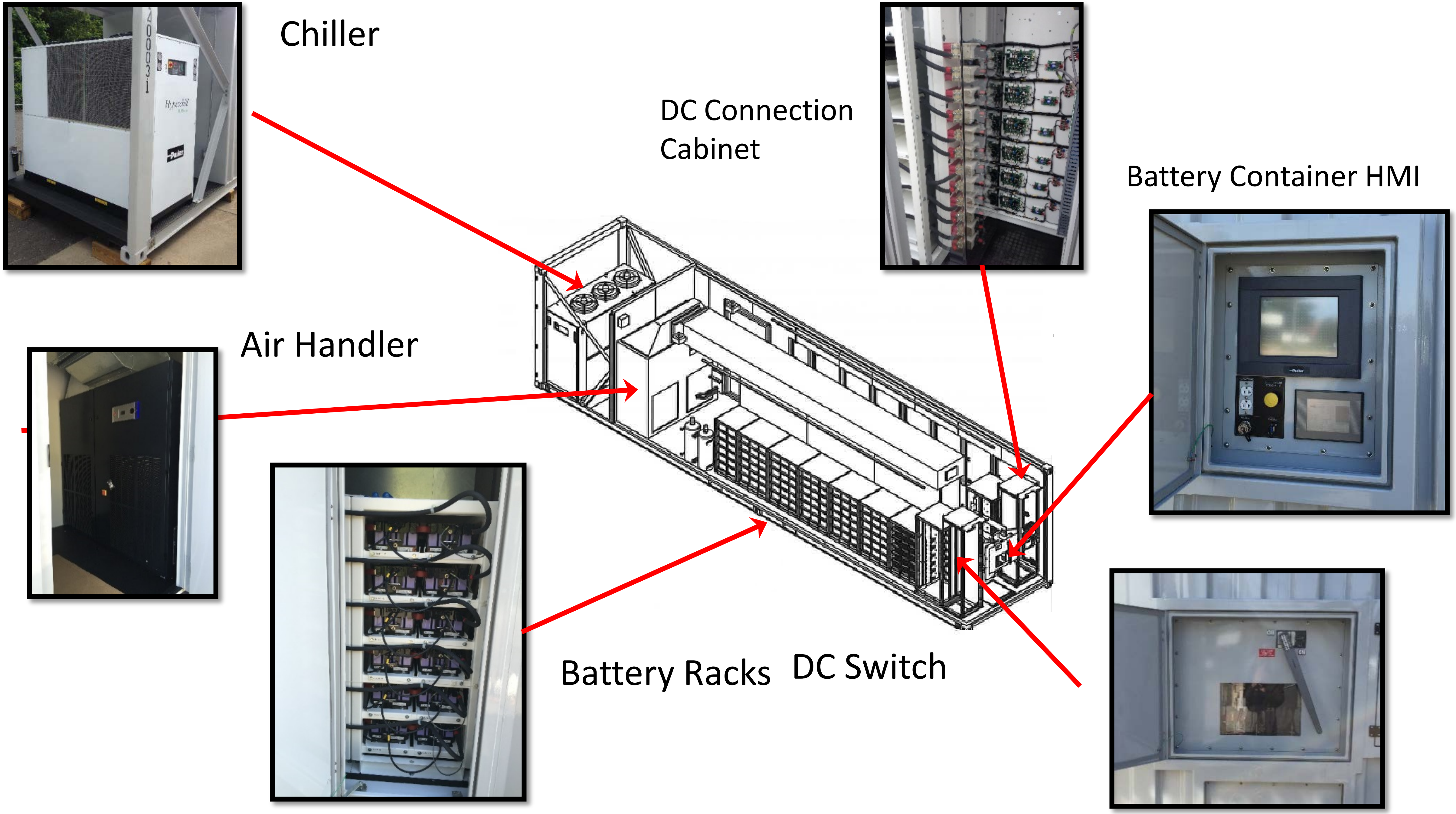
Below – exterior, north side

Battery Container Overview

Contents:

- Li-ion battery modules
- Chiller & air handler
- Fire suppression
- DC manual switch
- DC contactors and fuses
- HMI showing status and condition





Chiller

DC Connection Cabinet

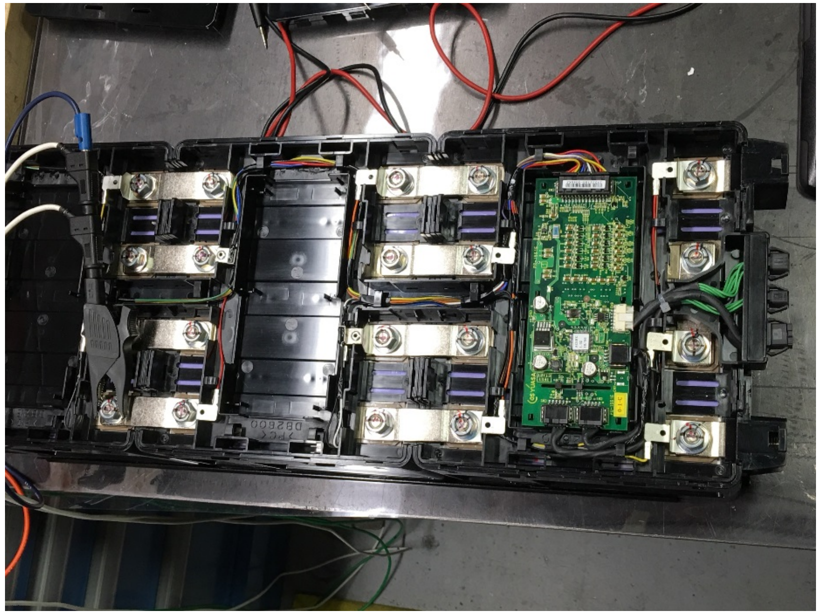
Battery Container HMI

Air Handler

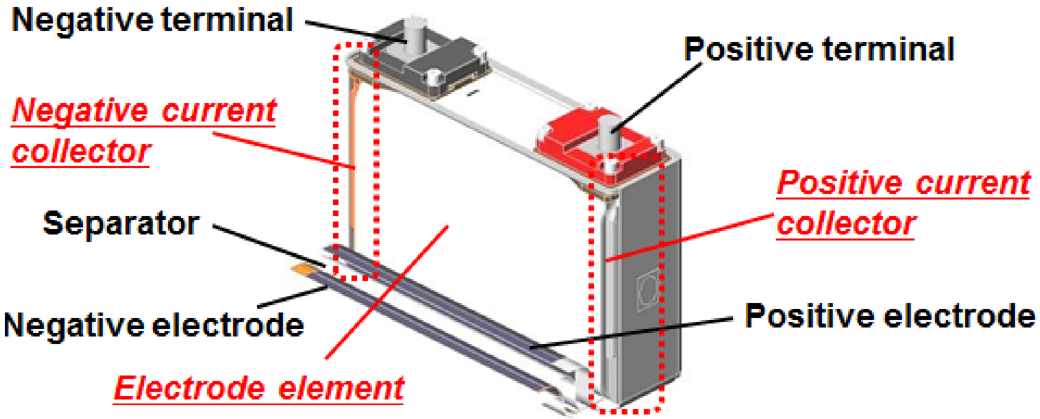
Battery Racks

DC Switch

Lithium-Ion Battery Modules



- A module is built from 12 or 28 individual cells
- Cell voltage ranges from 3 to 4V
- Built-in monitoring for individual cell voltage, current and temperature
- Approximately 80lbs
- Design lifetime is 10-13 years

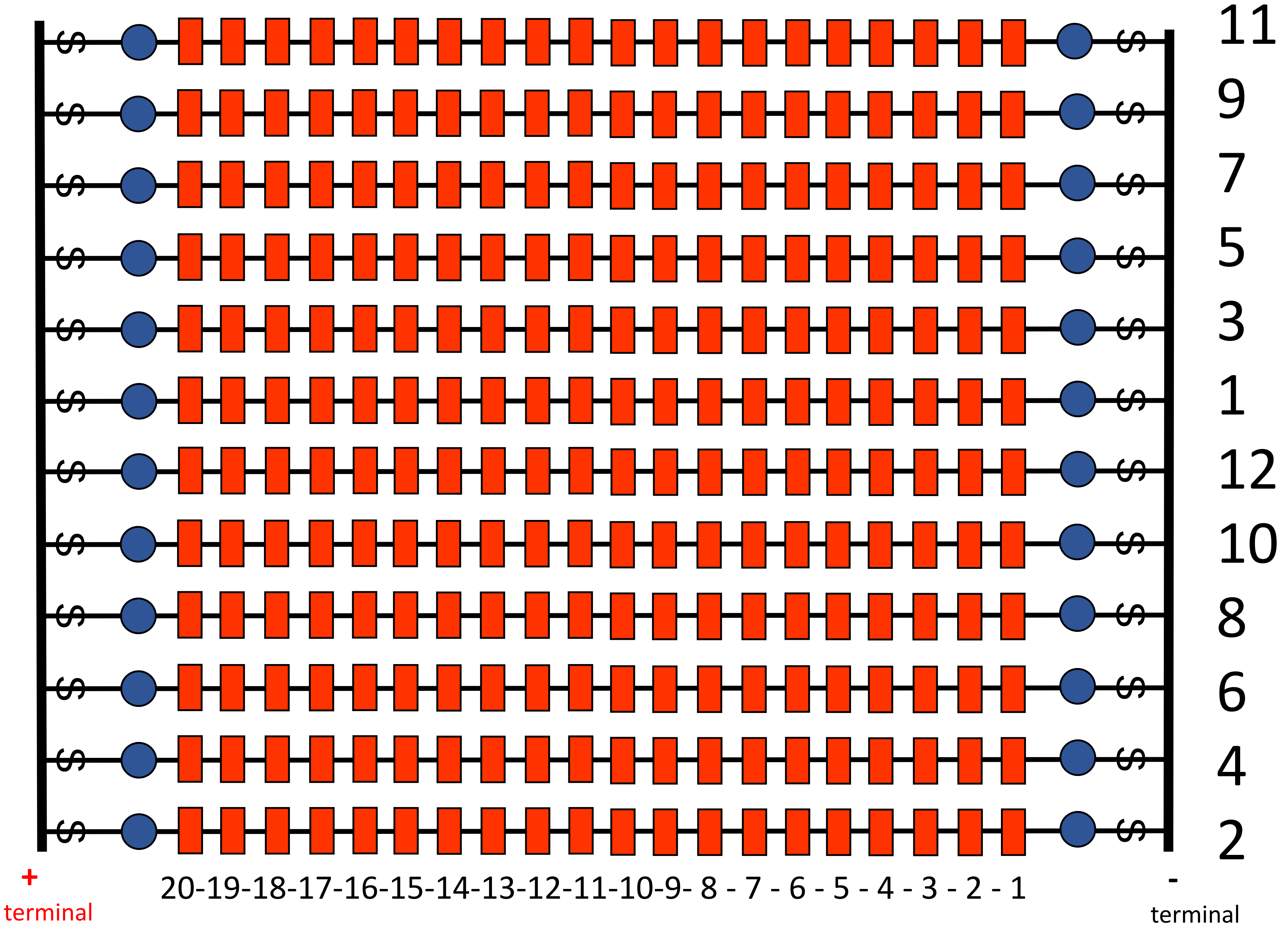


Battery Connections in Container


11/03/2014

- Battery container holds 240 lithium-ion modules in series/parallel combination
- Each module operates at around 50 volts, 20 modules in a series string
- Twelve parallel strings provide capacity
- Each string is fused and has a disconnect
- Round-trip efficiency is approximately 88%.
- Capable of many charge/discharge cycles

BATTERY SERIES/PARALLEL STRINGS



Control Cabinet Layout

Doosan HMI

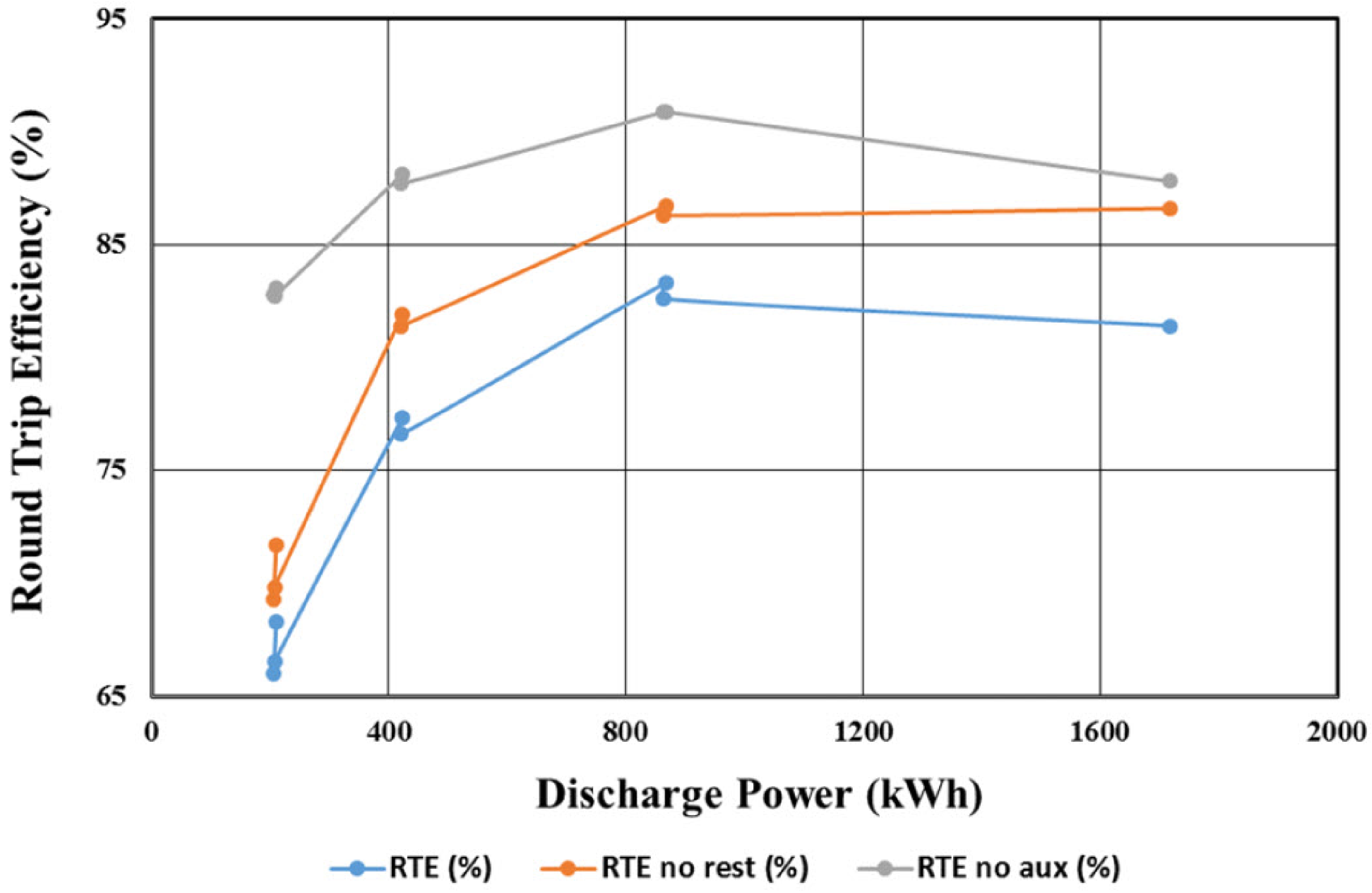
Comm gateway

Meters ION 8650

Relays SEL-751

Test Switches

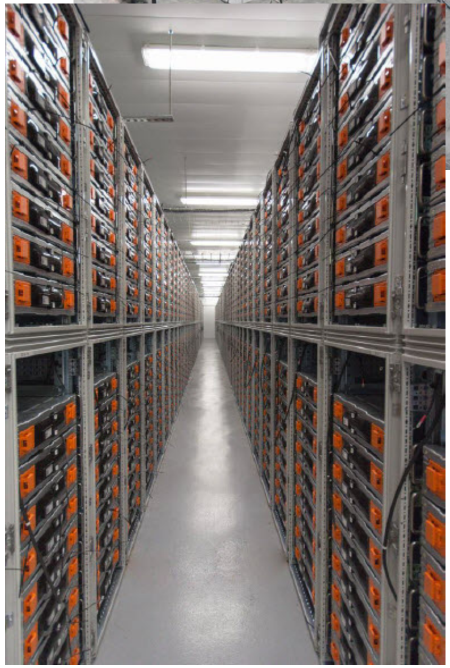
MESA-1 (Li-Ion) System, Round Trip Efficiency



Source:
PNNL Report 27237
MESA-1, An Assessment of
Battery Technical Performance
January 2018

Li-Ion SYSTEMS IN CALIFORNIA

Above Left: SDGE, Escondido 120 MW installation

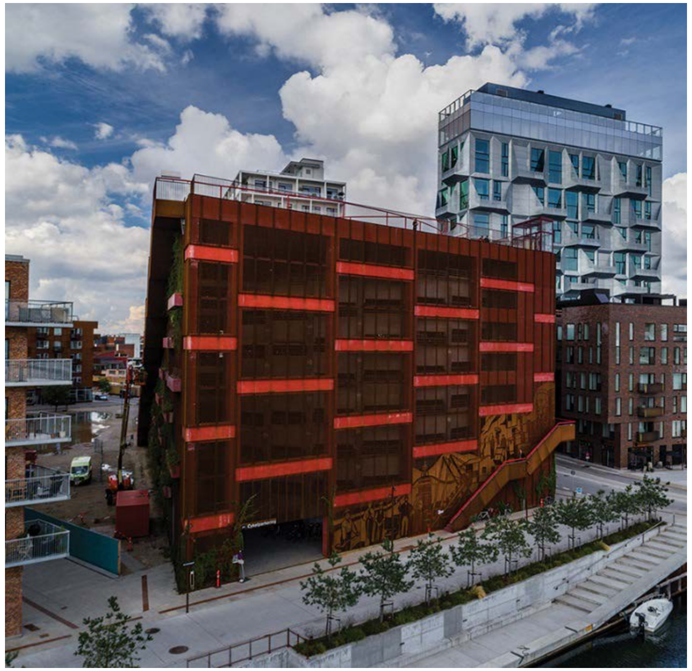


Right: Li-Ion modules in Tehachapi

Tehachapi Battery Energy Storage System
Energy Capacity: 32 MW-hr

Li-Ion SYSTEMS AT OTHER UTILITIES

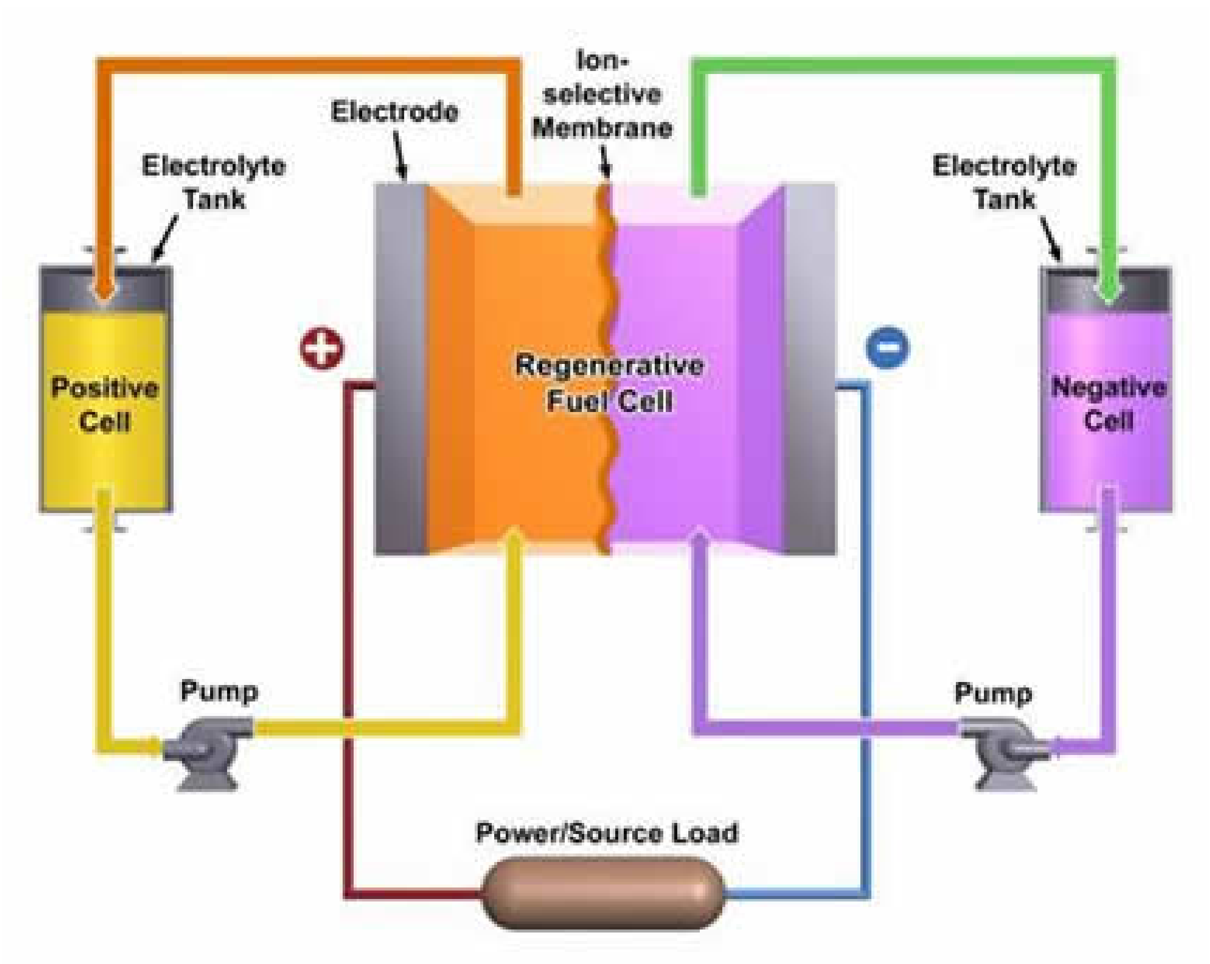
Below: EnergyLab Nordhavn
Copenhagen, Denmark



Above Left: Tesla Li-Ion batteries at Kauai solar farm

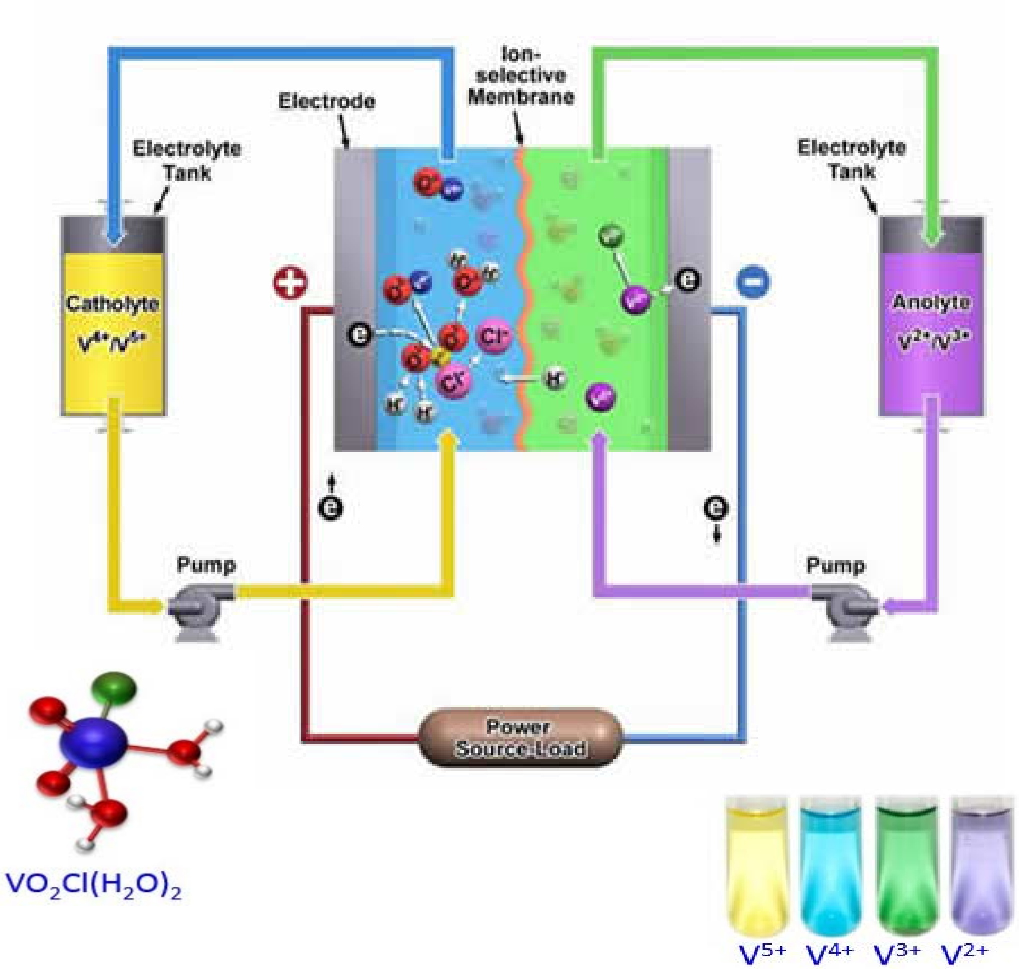
Right: BESS in Minster, OH

Flow Batteries – VRB, ICB, ZNBR



- ➢Types of flow batteries:
  - ✓Vanadium Redox flow, best for large utility-scale applications
  - ✓Iron-Chromium flow batteries, available for telecomm equipment backup at 5kW for 3 hours. There is research into larger-scale systems.
  - ✓Zinc-Bromine flow batteries, tested on trailers for portable 1 MW, 3 MW-hr storage systems. High energy density, but expensive.
- ➢Advantage: Systems can be optimized for their particular use case. Adding more electrolyte increases energy storage amount.

Vanadium Flow Battery Description



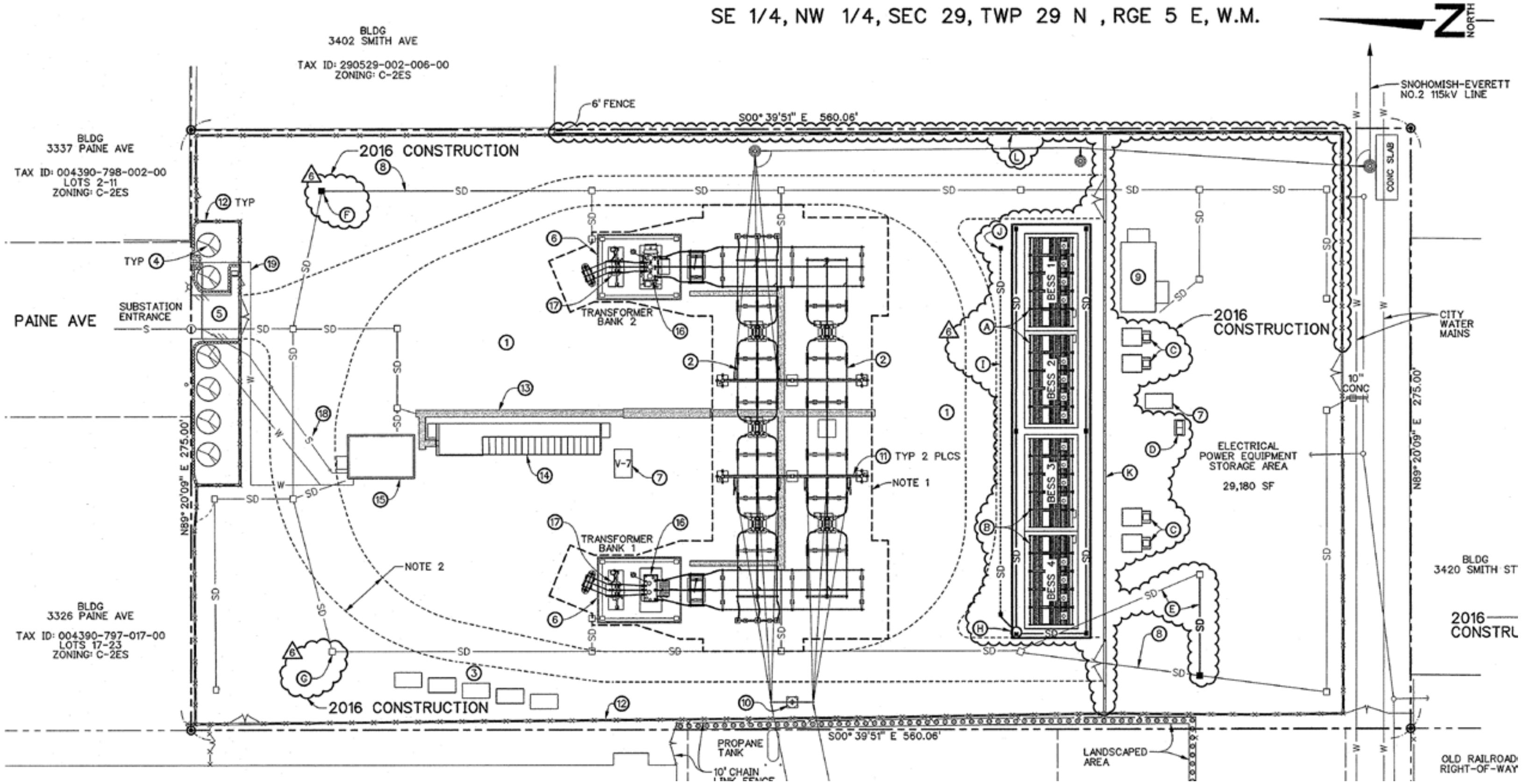
Cathode: $VO_2Cl + 2H^+ + e^- \leftrightarrow VO^{2+} + Cl^- + H_2O$

Anode: $V^{2+} - e^- \leftrightarrow V^{3+}$

Cell: $VO_2Cl + V^{2+} + 2H^+ \leftrightarrow VO^{2+} + V^{3+} + Cl^- + H_2O$

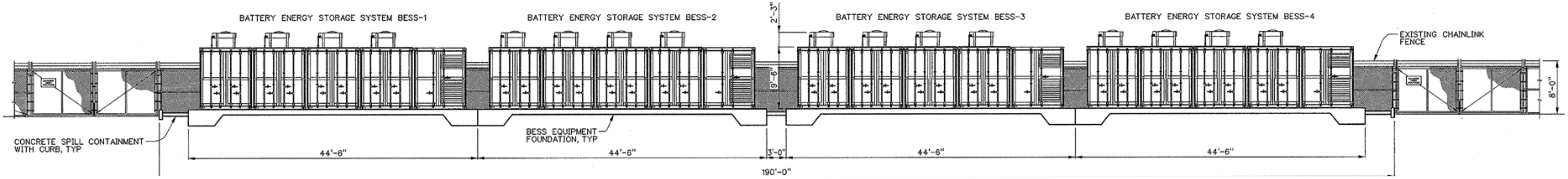
- The positively charged catholyte and a negatively charged anolyte are circulated through the flow battery by pumps.
- H+ ions flow through the ion exchange membrane which separates positive from negative side.
- Charging or discharging occurs only when the liquid electrolytes are flowing. Once the pumps stop, this battery is inactive.
- Power rating is determined by battery size, energy rating by the volume of electrolyte.

MESA-2 Installation at Everett Substation

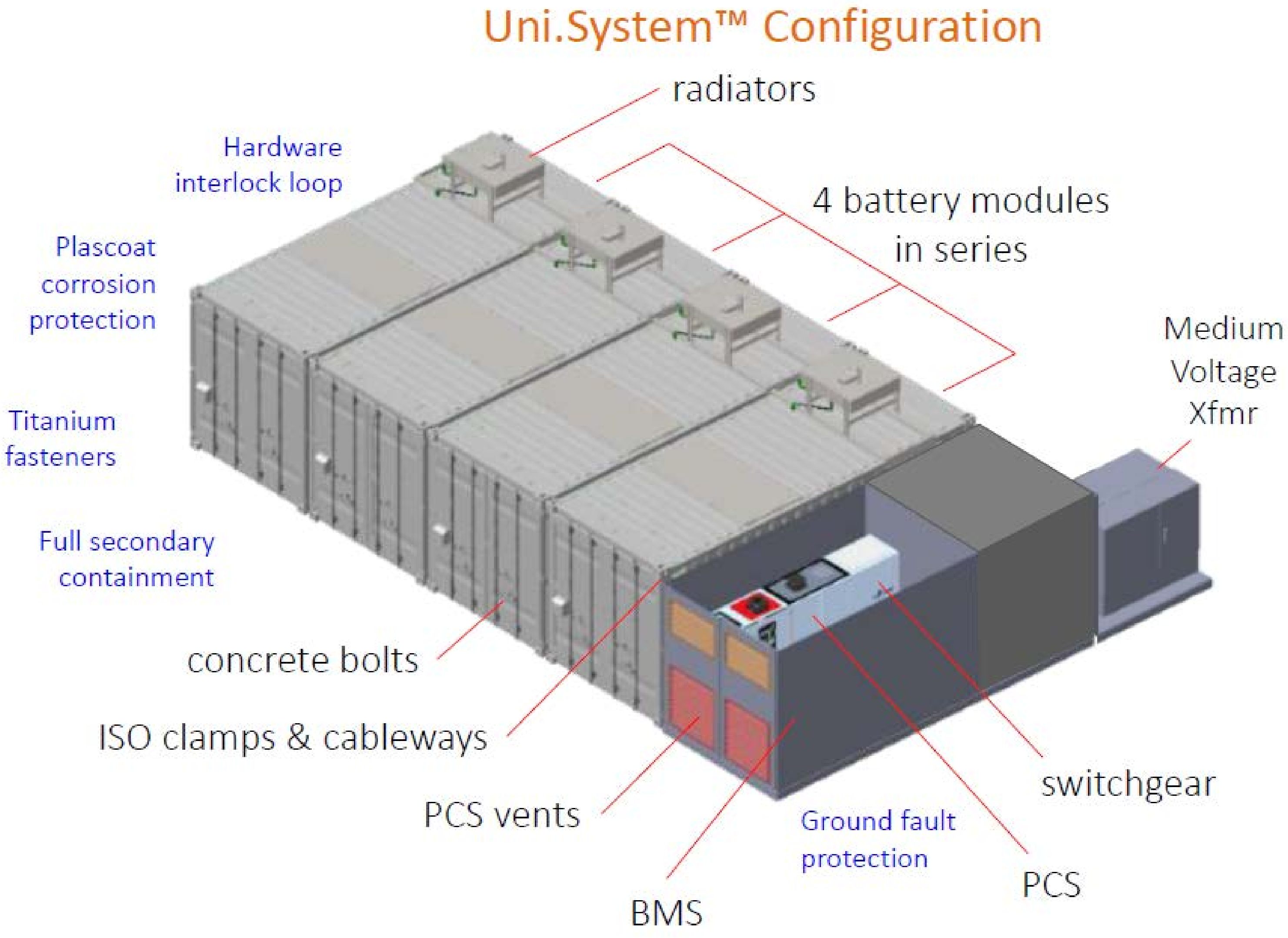


MESA-2 Installation, 2017

- ➢ Everett station, has 5 breaker ring bus and two 28 MVA transformers
- ➢ Energy storage cost estimate = $11.2M
- ➢ 20 ISO shipping containers
- ➢ 8,000 kWhr storage
- ➢ 2,200 kW power rating
- ➢ Operates at 283 volts, stepped up to 12,470 volts



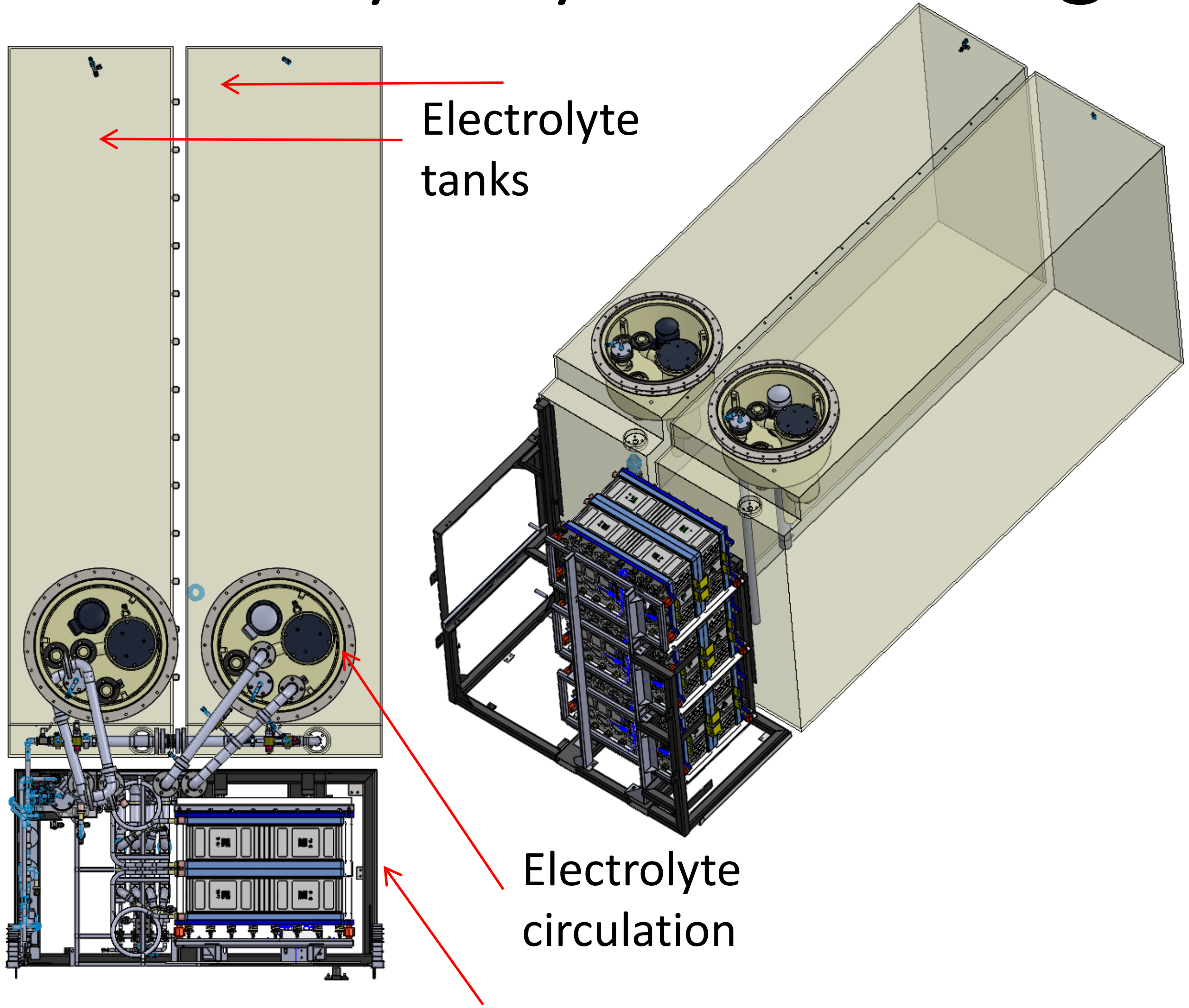
One Battery String



Manufactured by
Uni-Energy Technologies
in Mukilteo, Washington
(425) 290-8898

www.uetechnologies.com

Battery Physical Arrangement



Electrolyte tanks

Electrolyte circulation

3-Stack Skid

- A skid consists of three battery stacks in series. There is one skid per container.
- There are fifty cells in each stack, the stack voltage ranges from 40-80 volts while operating.
- Two circulating electrolyte solutions (positively charged catholyte and a negatively charged anolyte) are contained in large tanks at the back of each container.
- The charging and discharging occurs while the liquid electrolyte is flowing through the battery cells. Minimal charging or discharging occurs if the flow has stopped.
- The electrolyte tanks act as a large heat sink, preventing overheating of the battery stacks and the individual cells within them.
- Physical separation of cells/stacks and electrolytes also helps avoid thermal run-away.

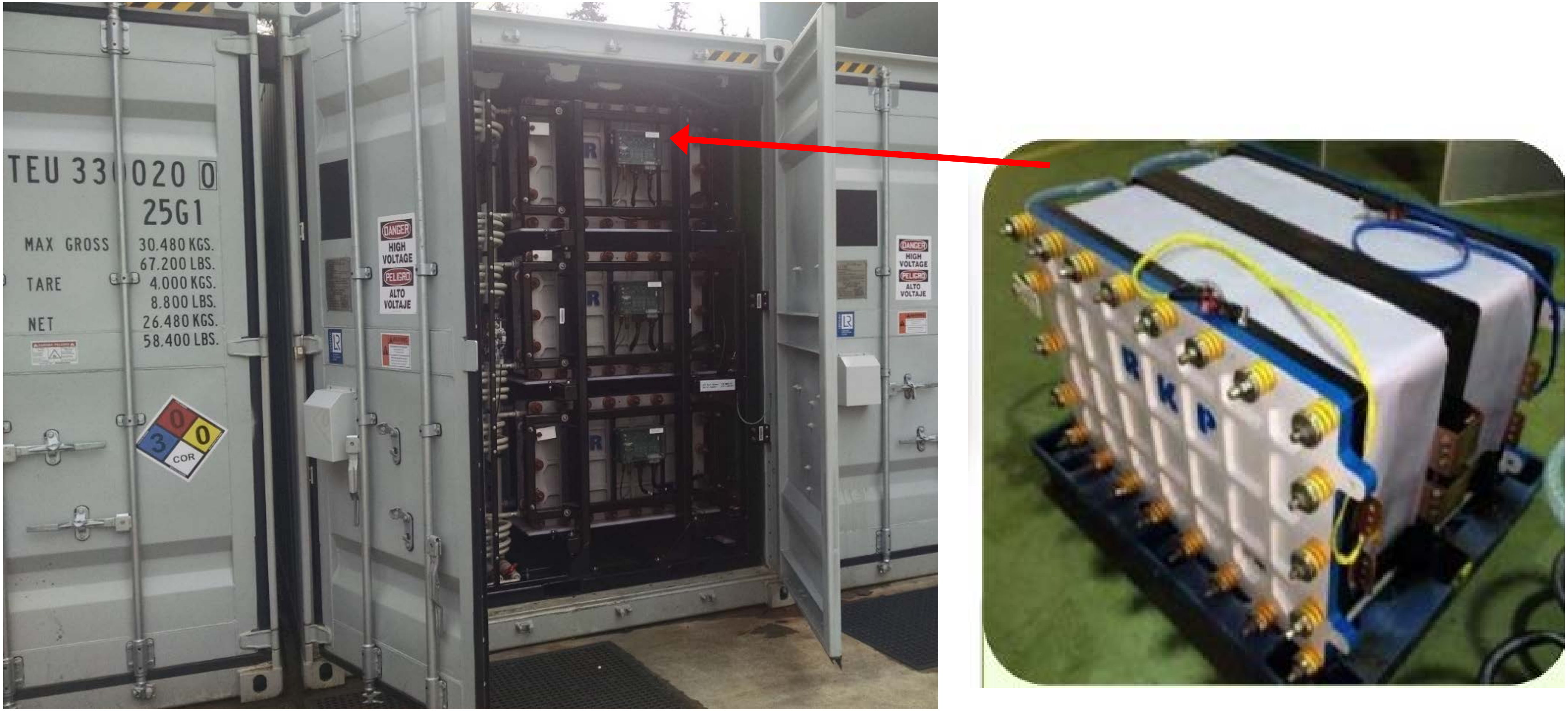
MESA-2 Container Delivery

MESA-2 Electrolyte Filling


11/10/2016

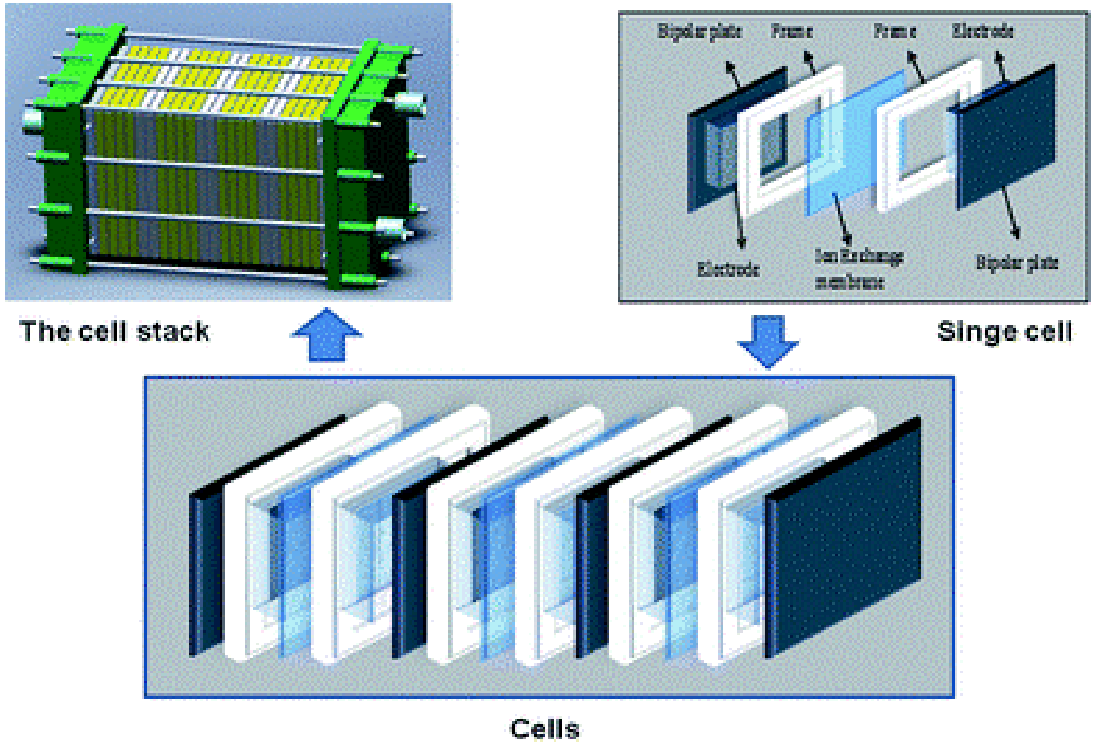

11/10/2016

MESA-2 Battery Containers



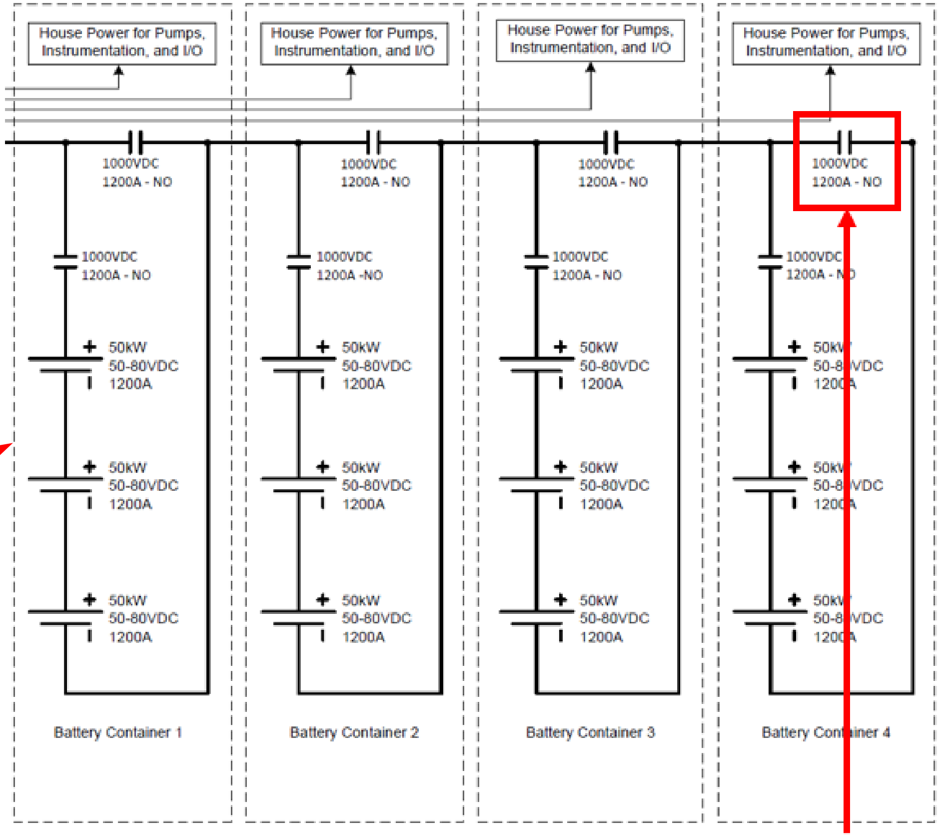
Battery Stacks

- Three stacks per container, 50 cells per stack
- 0.8-1.6 VDC per cell, 40-80 VDC on a stack
- Built-in monitoring for individual stack voltage, temperature, pressure



Containers Series Connected to get 1000 Volts DC

- Each container has from 120-240 VDC.
- Four containers in series to obtain from 480-1000 VDC in one string.
- Contactors isolate a container in event of trouble.
- Four strings paralleled to get 2.2 MW capacity.



Power Conversion and tie to the AC Power System

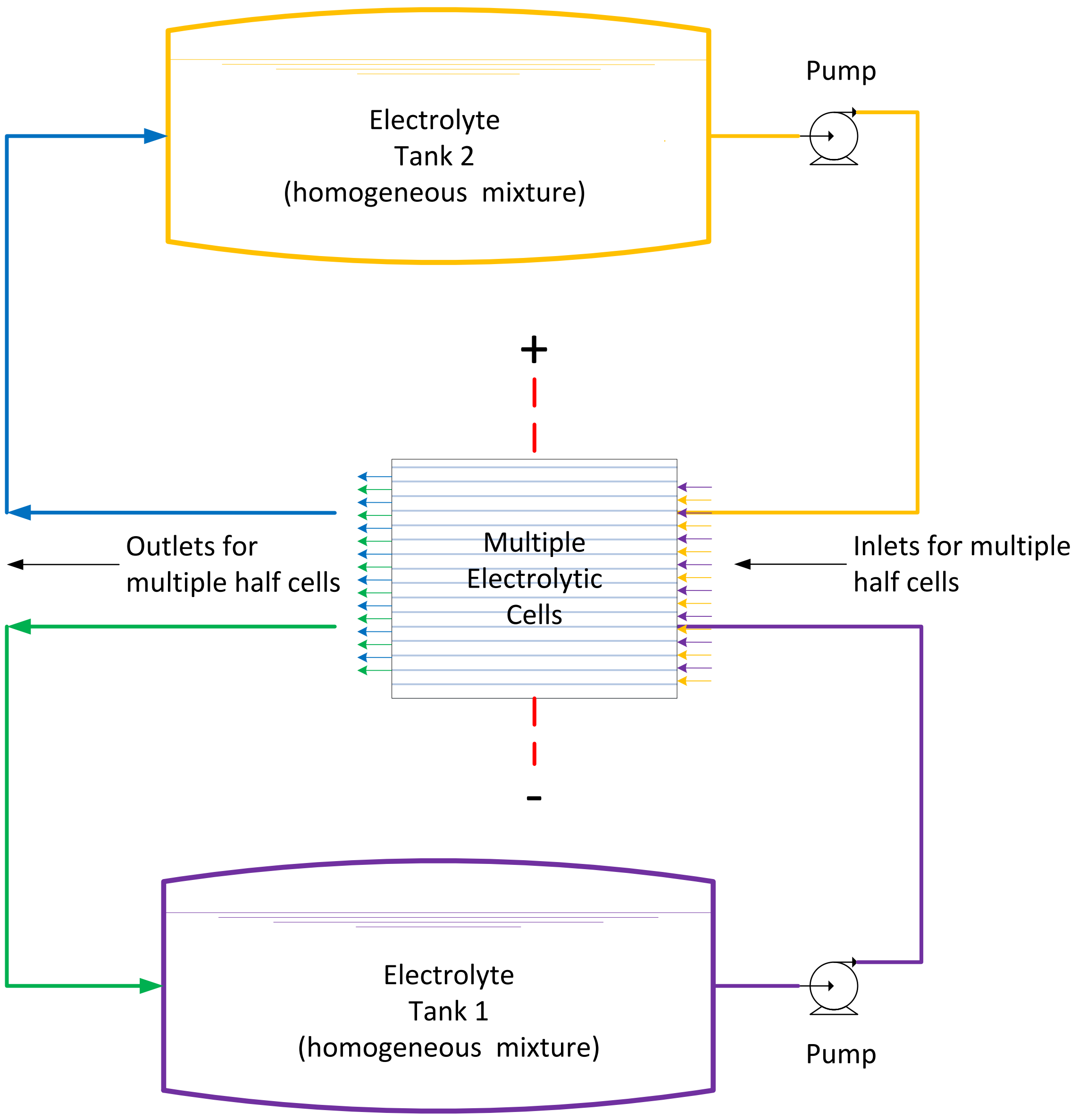
DC to AC conversion

PLC for
control

HMI readout

Safety Considerations

- Battery energy in separate anolyte and catholyte tanks
- No thermal runaway is possible - all cells share the same electrolyte
- Mixing both electrolyte tanks together produces a temperature increase of approximately 15 degrees C
- Only 2% of system energy is in the cell stacks at any time
- Shorted stack produces no lasting damage
- No thermal runaway in shorted cells is possible, unlike solid state cells



Vanadium Flow Batteries, Small Systems

Avalon batteries tied to solar array, 40kW-hr modules

UET Reflex system, made from 10 kW, 20kW-hr modules

Vanadium flow battery factory in Dalian China

NaS TYPICAL INSTALLATION

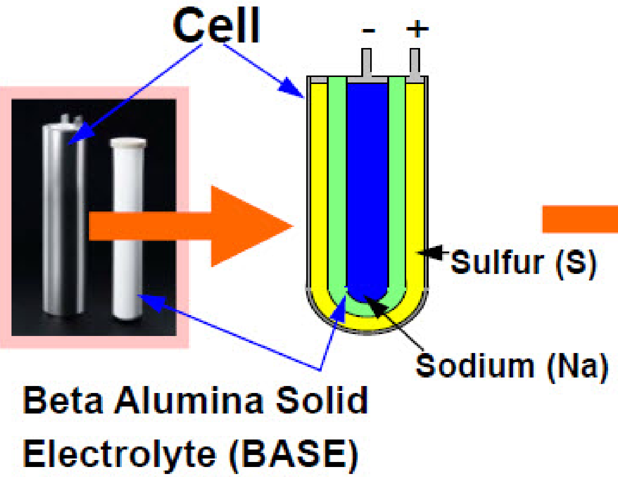
1 MW x 6 MWh standard battery system size

Each battery system has 20 modules, each module is 50 kW AC

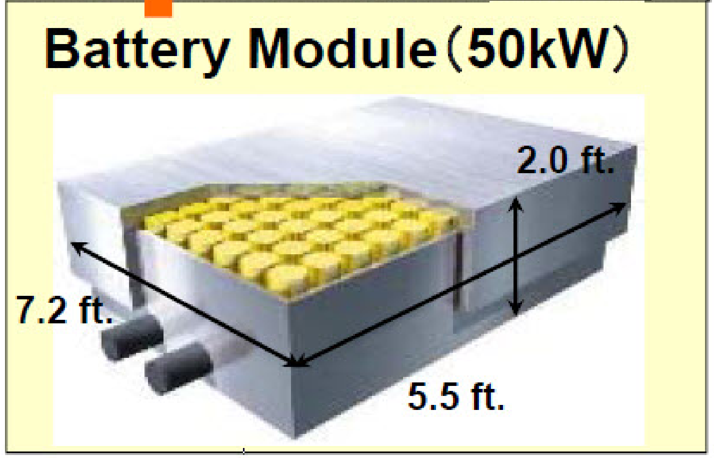
Each module is thermally insulated and has an operating temperature range of 300 to 350 degrees C.
Internal heaters and normal operation maintain temperature.

Each module consists of internal cells that are series-parallel connected and fused

Large projects consist of multiple 1 MW systems



NAS Battery System

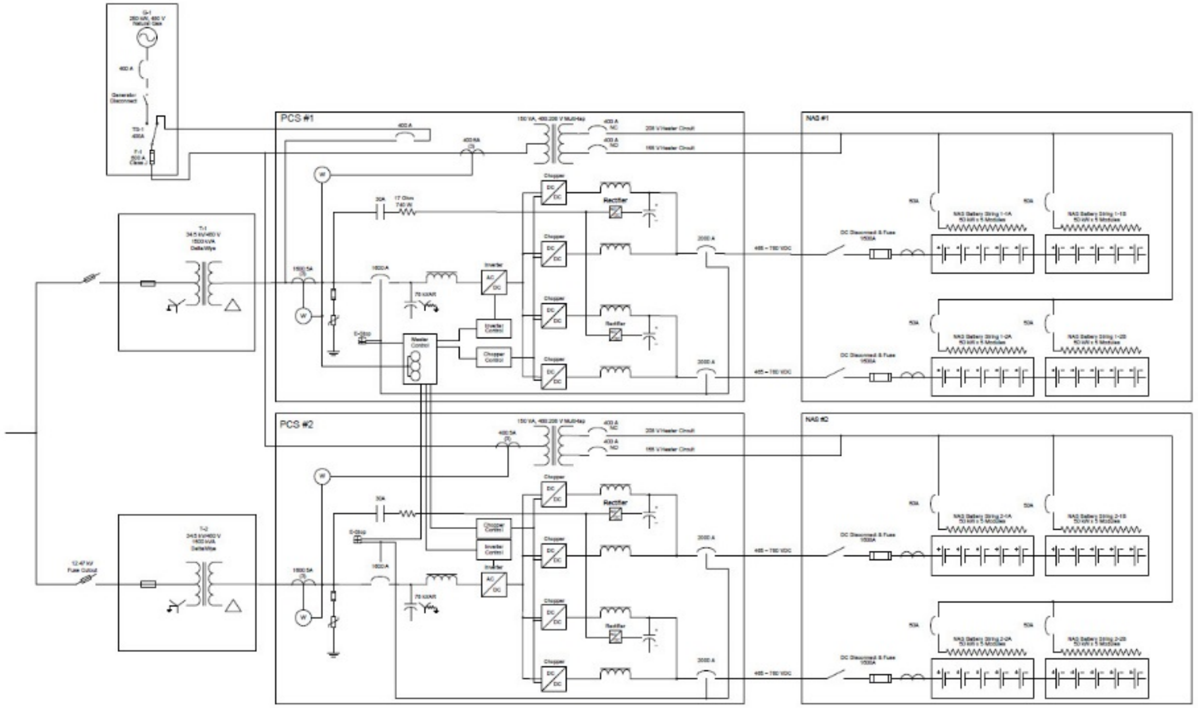


NaS BATTERY INSTALLATIONS

- In 2013, a 4 MW NaS battery system was installed by PG&E at Yerba Buena, located on the HGST property in the San Jose foothills. A similar 2MW NaS system was installed at Vaca Dixon. Batteries supplied by NGK, auxiliary equipment by S&C.
- In 2013, BC Hydro commissioned a 1 MW, 6 MWhr NaS battery system in Fields, BC. Primary purpose was to increase reliability to the remote area.
- In 2005, AEP installed a 1.2 MW NaS system in North Charleston WV. Success with that pilot project led them to install several 2 MW, 7.6 MWhr systems at Bluffton OH, Churubusco IN, and Balls Gap, WV.
- Original prototype NaS battery developed by NGK in Japan, and installed by Tokyo Electric (TEPCO) in 1992. TEPCO now has 65 MW power capacity with 460 MWhr energy storage installed on their system.

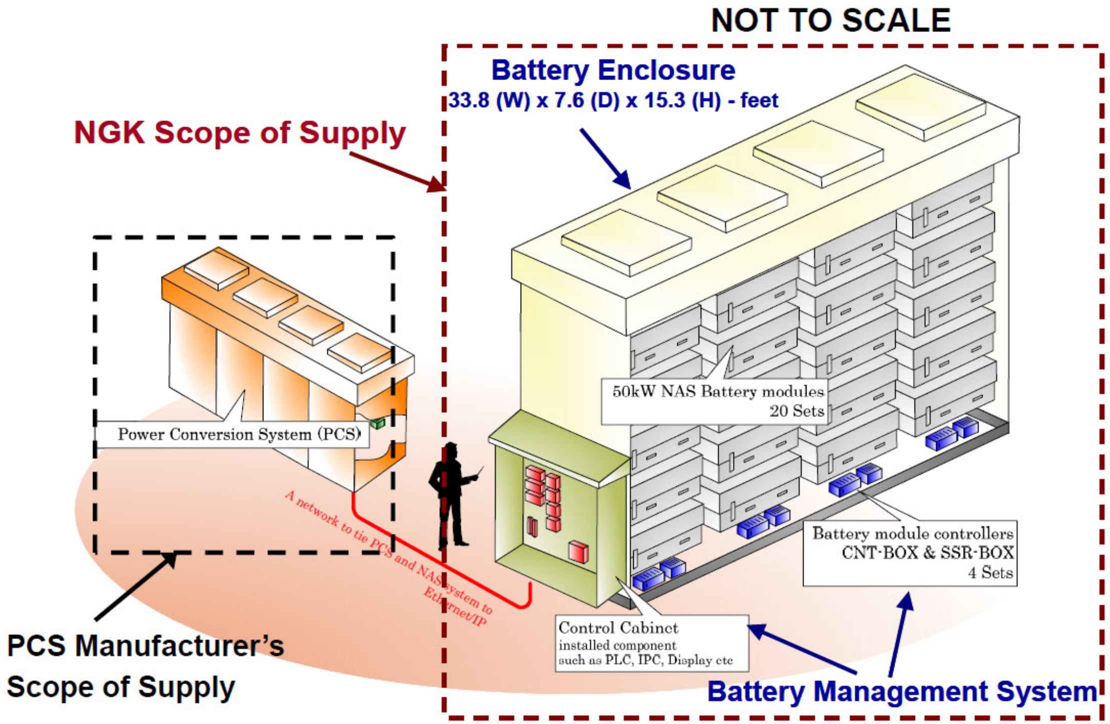
NaS ENERGY STORAGE AT A.E.P.

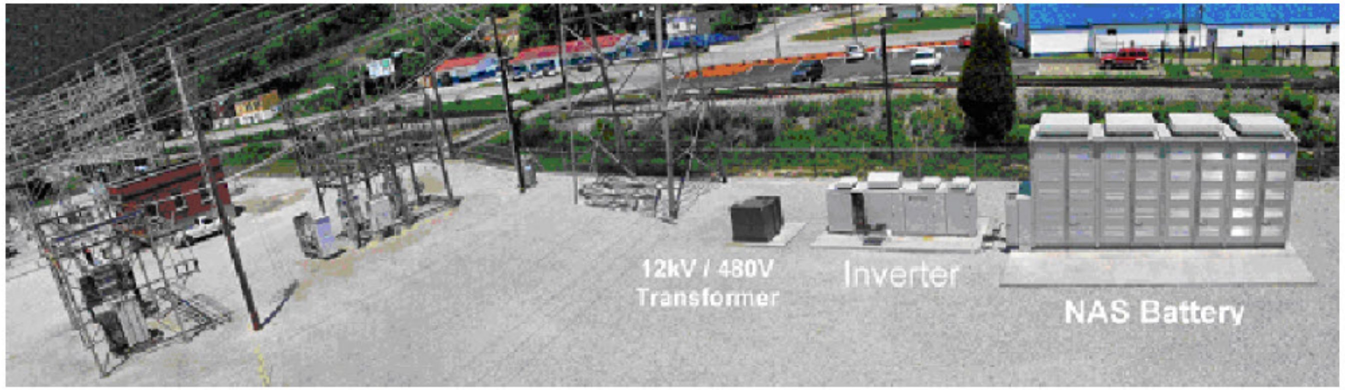
Forty modules, 50 kW ea
Total power 2 MW, Stored energy 7.6 MWhr
Charged voltage = 780V,
Discharged voltage = 465V
Reactive -2MVAR to +2MVAR
System rated from -30° to +40° C
Cell operating temp 300°-355° C
Cells must be maintained at 300° C or they will freeze
Cells can be frozen up to ten times with no capacity loss



NaS Battery Installations

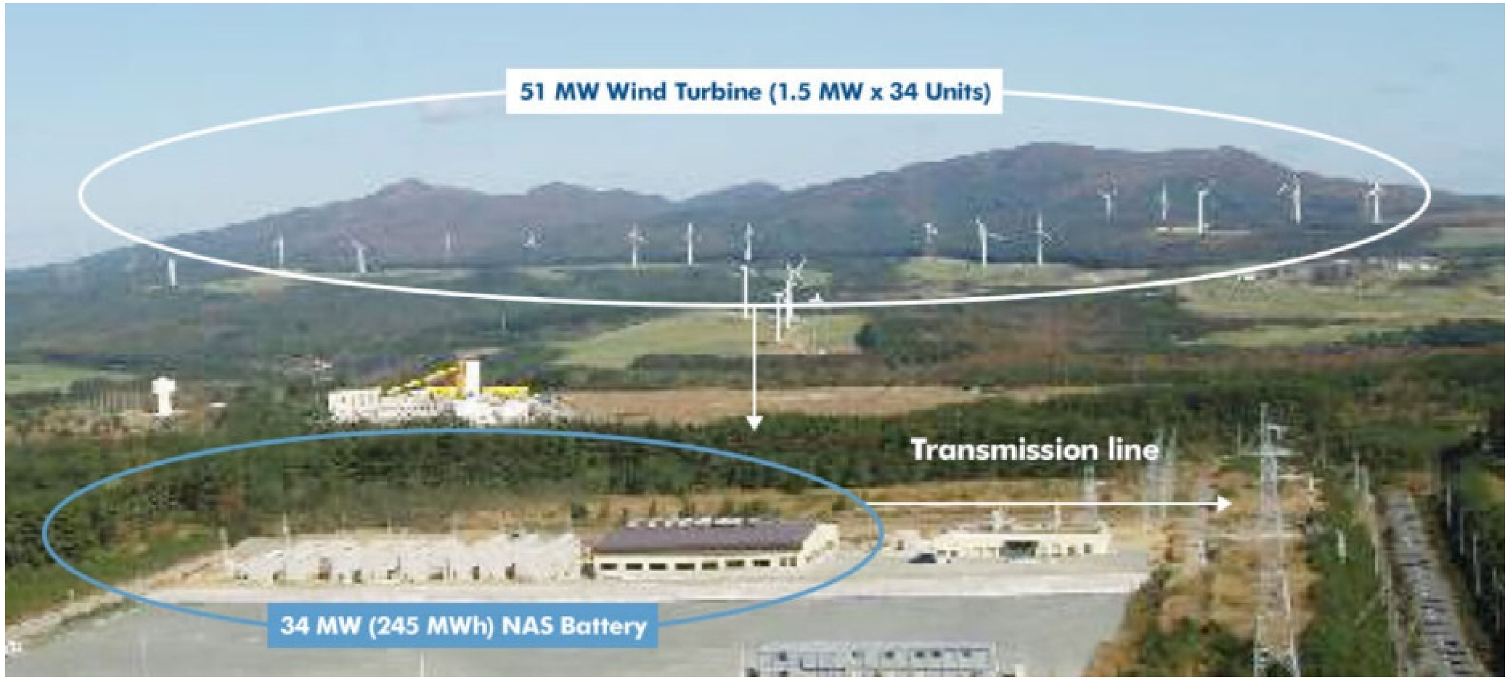
Left:
NaS system
In Santa
Catalina, CA





1.2 MW NaS Battery, Chemical Station - Charleston, WV

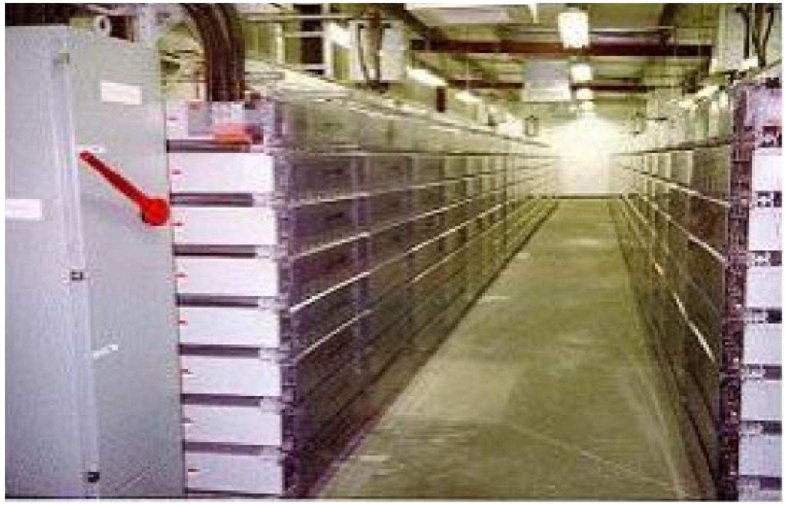
NaS WIND FARM INSTALLATION IN ROKKASHO, JAPAN, 2008



Ni-Cad Battery, Golden Valley Electric Association

- Nickel-Cadmium (NiCad) batteries were patented by Thomas Edison in 1906.
- GVEA installed a large BESS using NiCad batteries near Fairbanks, Alaska in 2003.
- The NiCad batteries were manufactured by Saft in Oskarschamn, Sweden.
- The BESS has 13,760 battery cells. Each battery weighs approx. 165 pounds.
- Batteries have an anticipated life of 20-30 years.
- ABB supplied the AC/DC power converter, and provided primary design and controls engineering.
- Can provide 25 MW for 15 minutes (6.25 MW-hr). During a test of its maximum limit, it discharged 46 MW for five minutes.
- This BESS project cost approximately $35M and won the Electric Power Research Institute Technology Award.
- NiCad batteries are falling out of favor due to toxicity of cadmium.

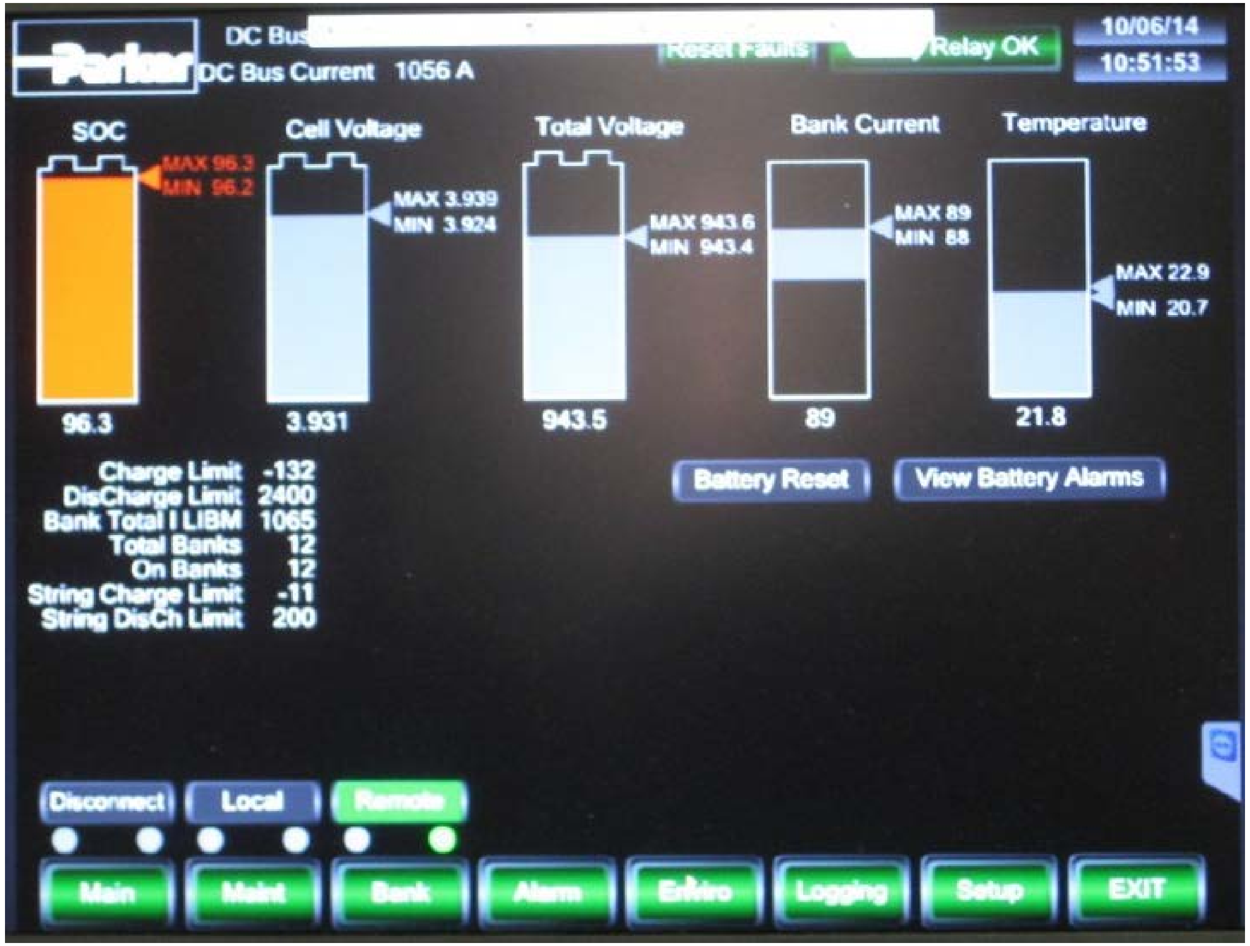
HISTORICAL LEAD-ACID B.E.S.S. INSTALLATIONS



- 10 MW, 40 MW-hr, 1988, SCE in Chino CA
- 10 MW, 15 MW-hr, 1993, Hawaii Electric Co.
- 20 MW, 14 MW-hr, 1994, Puerto Rico
- 3 MW, 4.5 MW-hr, 1995, Vernon CA
- 1.2 MW, 1.2 MW-hr, 1997, 25 mi from Ketchikan, AK

Control of Energy Storage Systems

- The battery bank is monitored for State of Charge (SoC), which is related to the voltage.
- The PCS will adjust the DC voltage to either push energy into the battery, or withdraw energy from the battery.
- Rate of charging and discharging must be monitored to avoid reduction in battery life.



DC Bus Current 1056 A

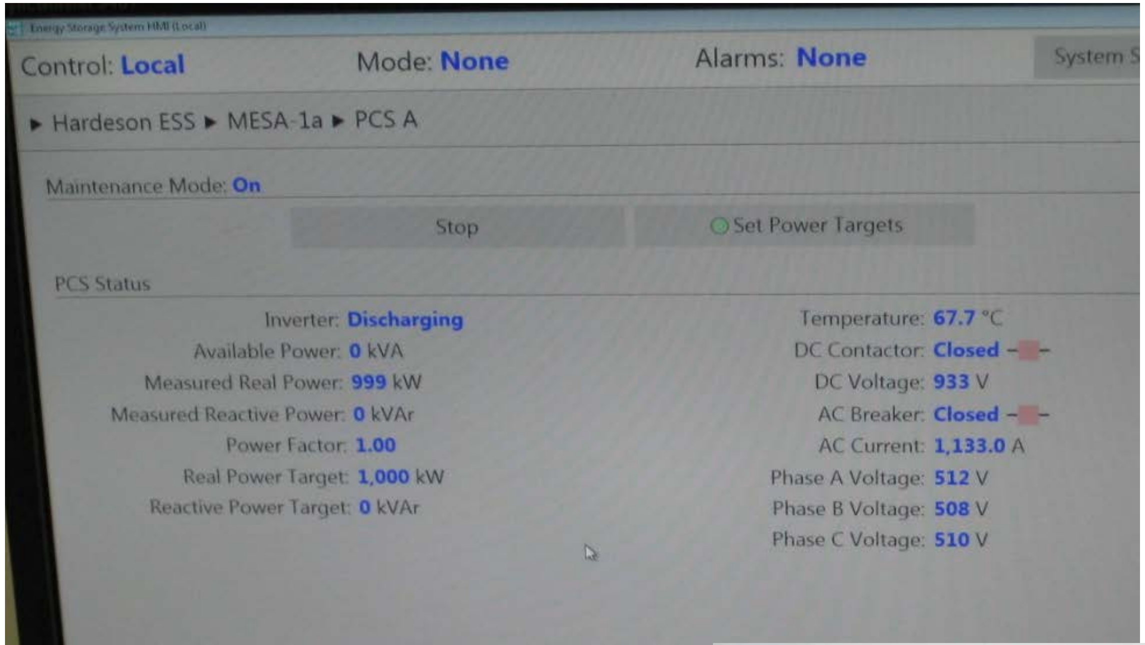
10/06/14
10:51:53

SOC	Cell Voltage	Total Voltage	Bank Current	Temperature
MAX 96.3 MIN 96.2	MAX 3.939 MIN 3.924	MAX 943.6 MIN 943.4	MAX 89 MIN 88	MAX 22.9 MIN 20.7
96.3	3.931	943.5	89	21.8

Charge Limit	-132
DisCharge Limit	2400
Bank Total I LIBM	1065
Total Banks	12
On Banks	12
String Charge Limit	-11
String DisCh Limit	200

1Energy Controller

- System control and charging / discharging cycles operated by 1Energy control platform.
- Pre-programmed cycles for charge and discharge, also can discharge on-demand.
- 1Energy control communicates to PCS and battery, ties to our SCADA system.


Energy Storage System HMI (Local)

Control: **Local** Mode: **None** Alarms: **None**

▸ Hardeson ESS ▸ MESA-1a ▸ PCS A

Maintenance Mode: **On**

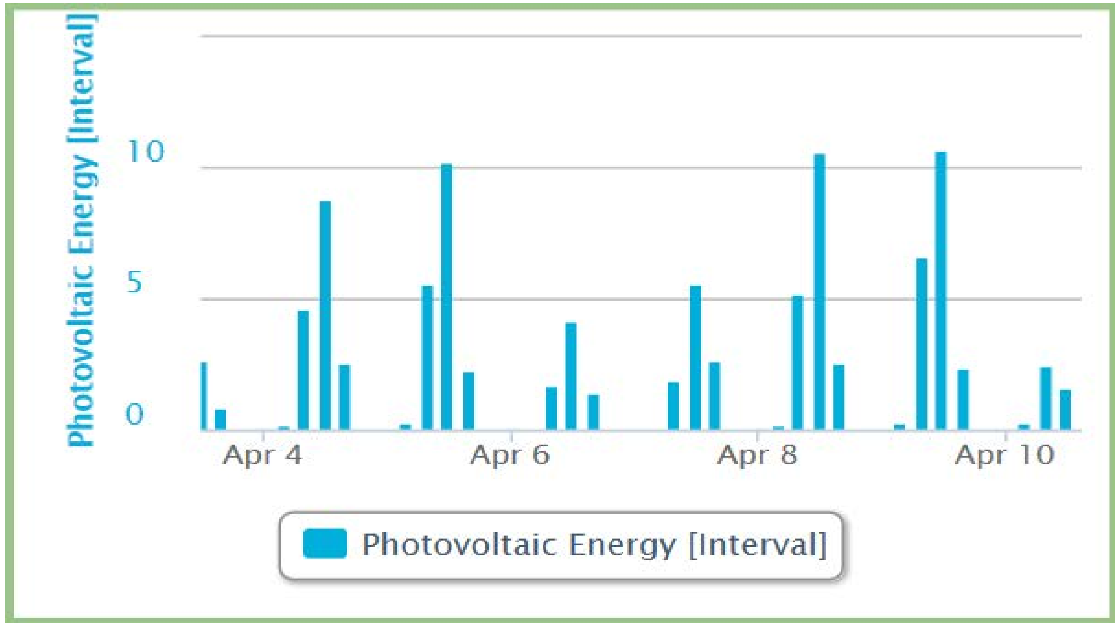
PCS Status

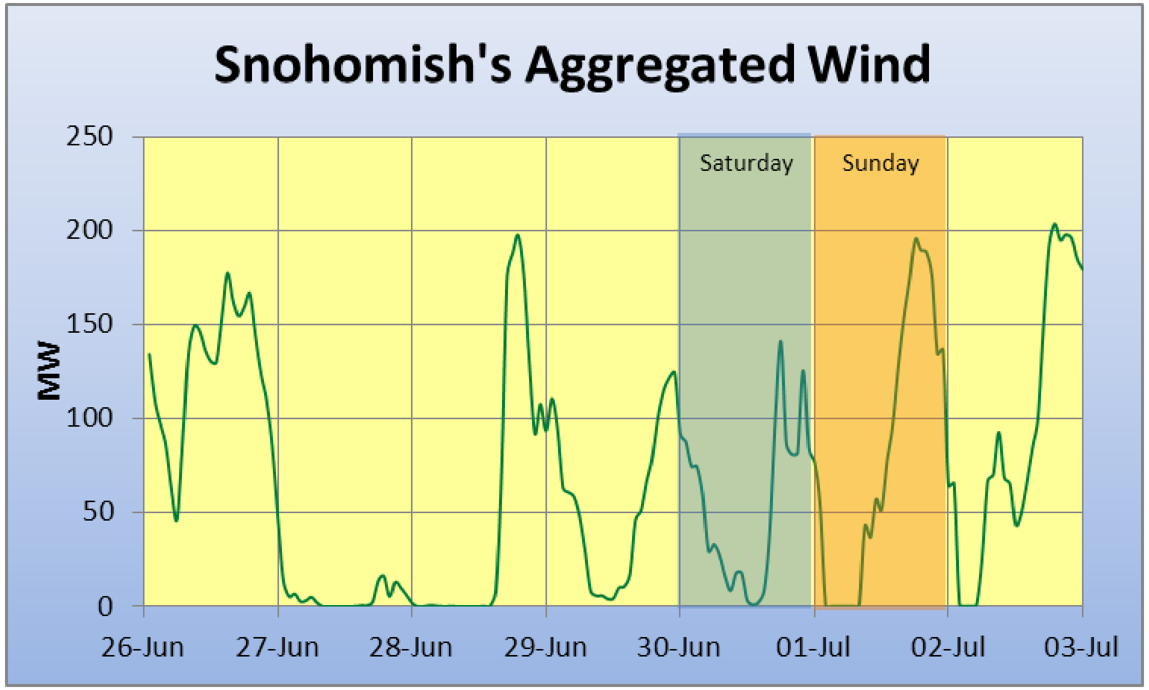
Inverter: **Discharging**
Available Power: **0** kVA
Measured Real Power: **999** kW
Measured Reactive Power: **0** kVAr
Power Factor: **1.00**
Real Power Target: **1,000** kW
Reactive Power Target: **0** kVAr

Temperature: **67.7** °C
DC Contactor: **Closed**
DC Voltage: **933** V
AC Breaker: **Closed**
AC Current: **1,133.0** A
Phase A Voltage: **512** V
Phase B Voltage: **508** V
Phase C Voltage: **510** V

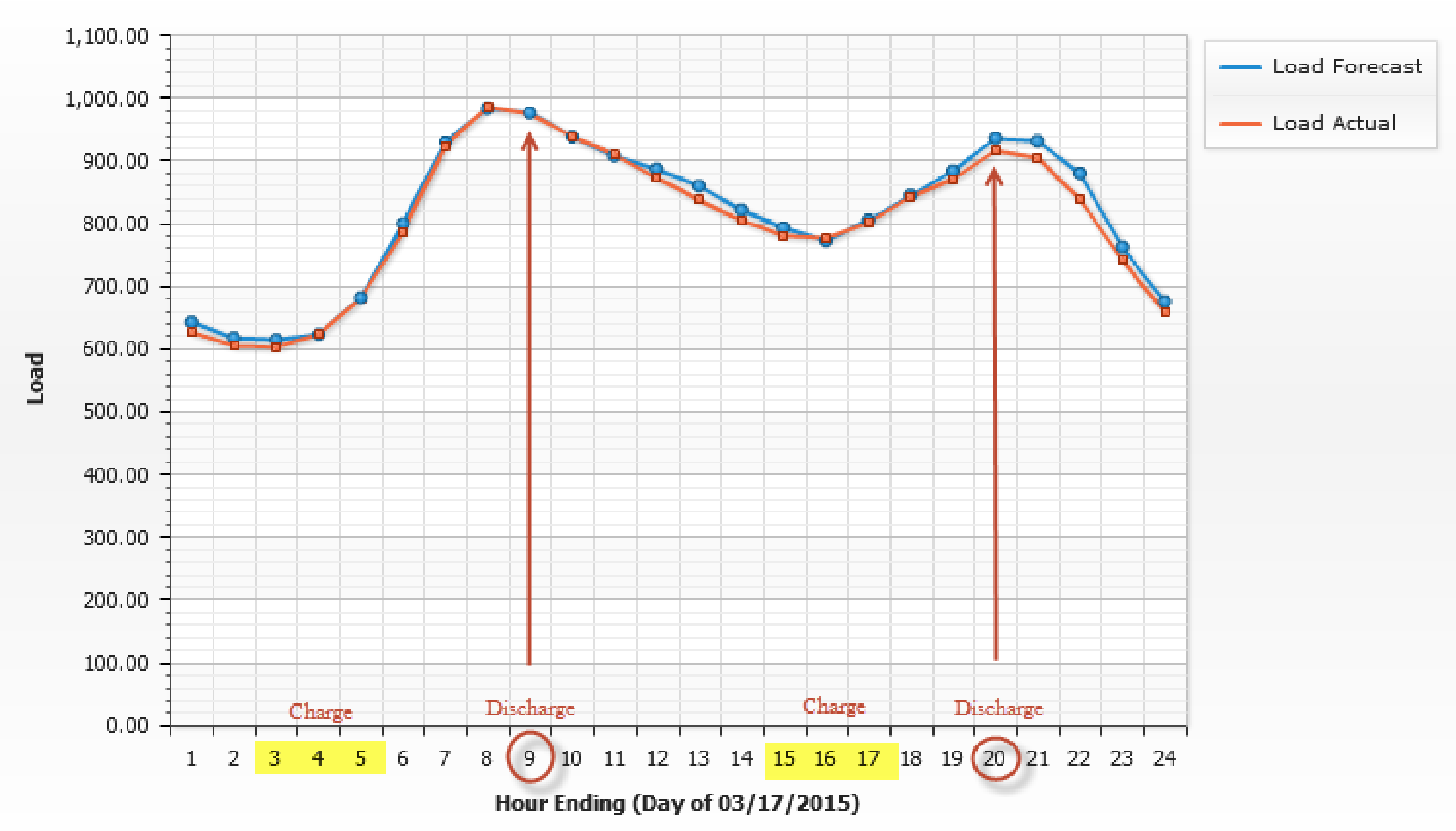
Energy Storage Aids Generation Mix

- SnoPUD generation is 85% hydro, 9% nuclear, 6% wind, and < 1% coal & natural gas. Although hydro has storage, it must be operated to maintain river flows.
- Most renewable energy sources such as solar and wind don't have reliable production patterns.





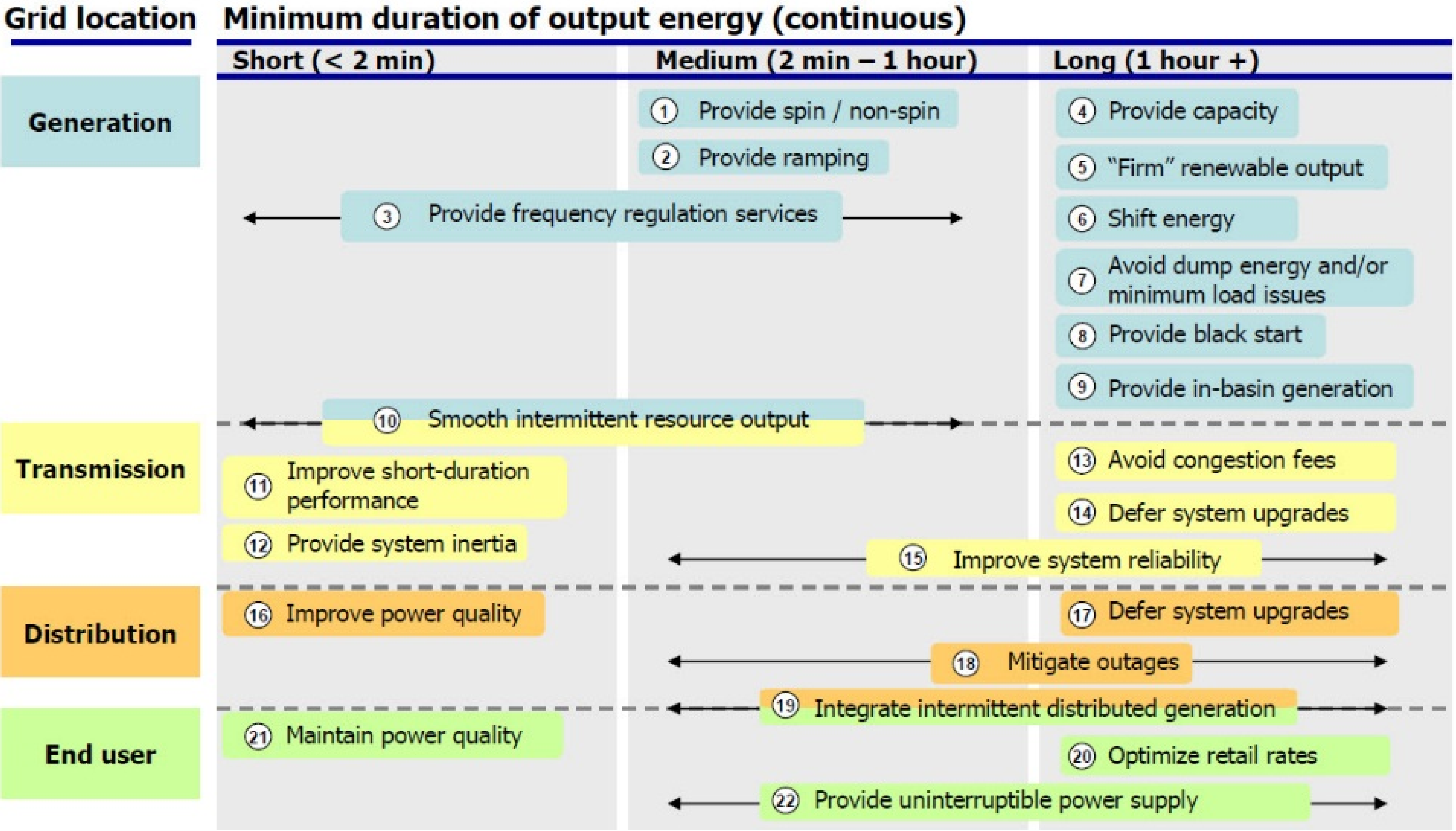
Energy Storage Helps Manage Imbalance Between Forecast & Actual



COMPARING ENERGY STORAGE OPTIONS

	Capital Cost	Maint. Cost	Efficiency	Energy Density	Recharge Time	Dynamic Response
Pumped Hydro	Medium	High	70-85%	Good	Fair	3 min
Compressed Air	Low	Low	42-55%	Very good	Fair	10 min
Flywheel	Low	Medium	85-90%	Fair	Excellent	millisec
Battery, Lead-Acid	Medium	High	60-80%	Very good	Good	millisec
Battery, Lithium-Ion	High	Low	65-85%	Very good	Excellent	millisec
Battery, Na-S	High	Medium	75-80%	Very good	Very good	millisec
Flow battery, Vanadium	Medium	High	65-70%	Excellent	Good	millisec
Ultra-capacitor	High	Low	Used with batteries	Fair	Excellent	millisec

Storage System Operational Uses



Grid location | **Minimum duration of output energy (continuous)**

Short (< 2 min) | **Medium (2 min – 1 hour)** | **Long (1 hour +)**

Generation
- ① Provide spin / non-spin
- ② Provide ramping
- ③ Provide frequency regulation services
- ④ Provide capacity
- ⑤ "Firm" renewable output
- ⑥ Shift energy
- ⑦ Avoid dump energy and/or minimum load issues
- ⑧ Provide black start
- ⑨ Provide in-basin generation
- ⑩ Smooth intermittent resource output

Transmission
- ⑪ Improve short-duration performance
- ⑫ Provide system inertia
- ⑬ Avoid congestion fees
- ⑭ Defer system upgrades
- ⑮ Improve system reliability

Distribution
- ⑯ Improve power quality
- ⑰ Defer system upgrades
- ⑱ Mitigate outages
- ⑲ Integrate intermittent distributed generation

End user
- ⑳ Optimize retail rates
- ㉑ Maintain power quality
- ㉒ Provide uninterruptible power supply

Source –
SCE White Paper, "Moving Energy Storage from Concept to Reality"

Picture at left:
Jackson Hydro Plant
Sultan, WA

Snohomish County PUD

Steve Larson
SLLARSON@SNOPUD.COM
(425) 783-5576