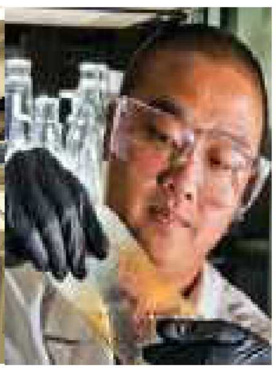
SAND2019-3926C

ES 202 - More Details of Electrical Energy Storage

CEATI-SOIG Meeting
April 10, 2019




Daniel Borneo

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2019

SAND2018-1911 C

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Introduction

Outline of presentation

- Overview – team and trends
- Technology / System Elements
  - Batteries: Characteristics and Market Readiness
  - Battery Management System or BMS D1
  - Power electronics
  - Energy management system or EMS D2
  - Site management system
  - Balance of plant – HVAC, Fire protection, site work
- Costs
- Projects / Experiences and Lessons Learned

Slide 2

D1 I added BMS
Dale, 3/1/2019

D2 I added EMS
Dale, 3/1/2019

Energy Storage Systems (ESS) / SNL Team

What We Do and Why

- Work with Utility, Industrial, Commercial, Private, State and International entities to:
  - Provide **third party independent analysis** for ESS D3
  - Support the development and implementation of **grid-tied ESS** projects
    - **Application/Economic analysis**
    - **RFI/RFPs**
    - **Design and Procurement Support**
    - **Commissioning Plan Development**
  - Monitor and analyze operational ESS D4ojects
    - Differing applications
    - Optimization tD5maximize return on investment by maximizing cost savings for revenues versus calls for battery energy storage systems
    - Operational performance
  - Develop public information programs
- Goal
  - Inform the Public and encourage investment.

Slide 3

D3 Do you really mean to say cells? Why not just say Energy Storage Systems (ESS) and particularly know that you don't just provide third-party independent analysis for battery energy storage systems (BESS), but for all energy storage systems including flywheels, thermal energy storage, etc.
Dale, 3/1/2019

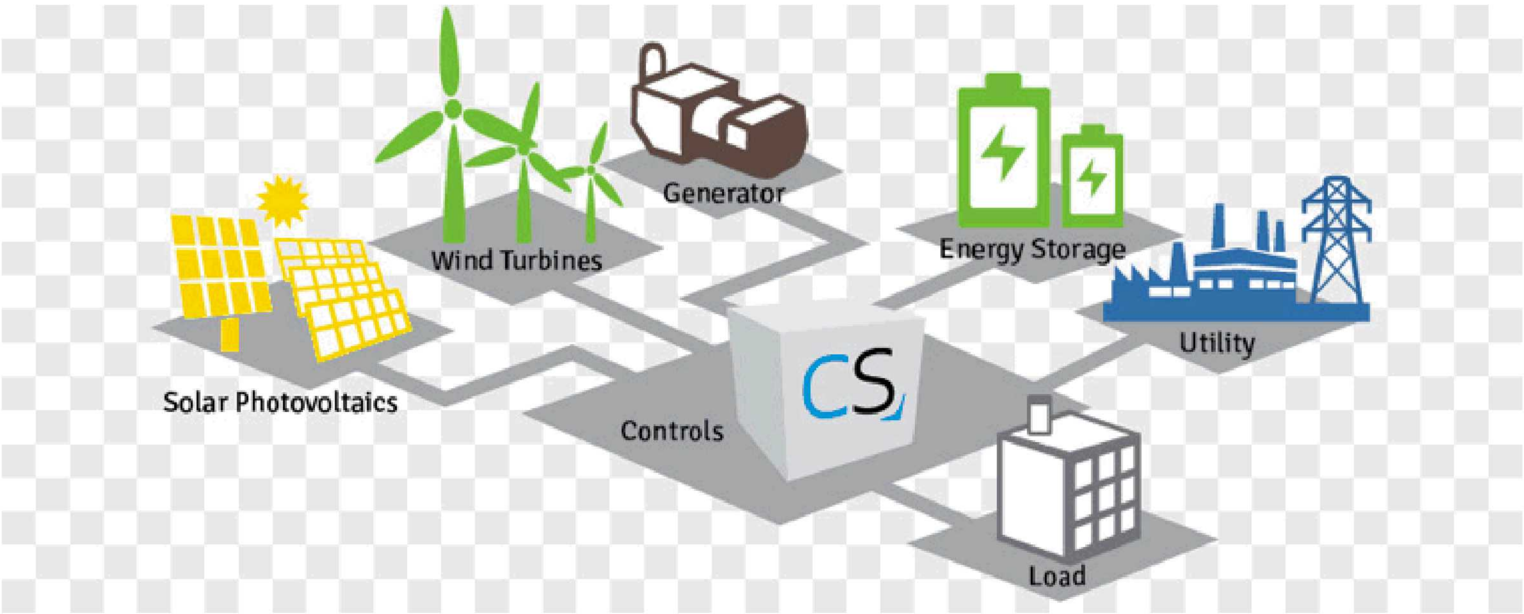
D4 I change this from ES to ESS
Dale, 3/1/2019

D5 Let's expand this from optimization to optimize nation to maximize return on investment by maximizing cost savings for revenues versus calls for battery energy storage systems
Dale, 3/1/2019

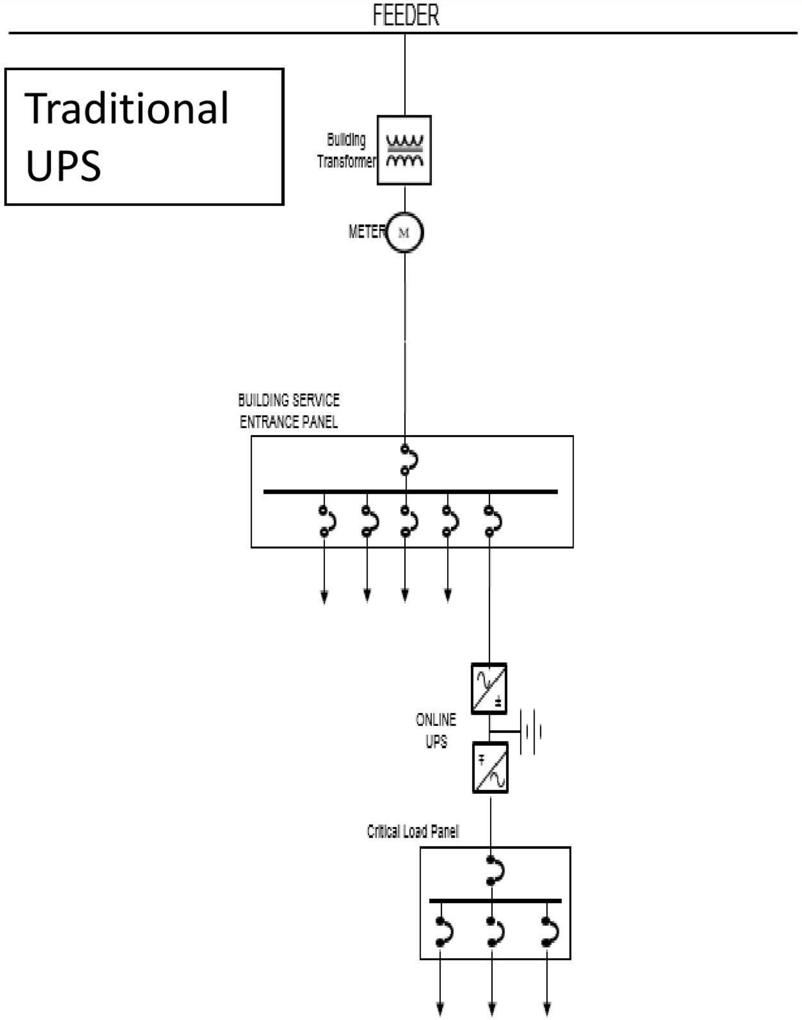
Grid Energy Storage

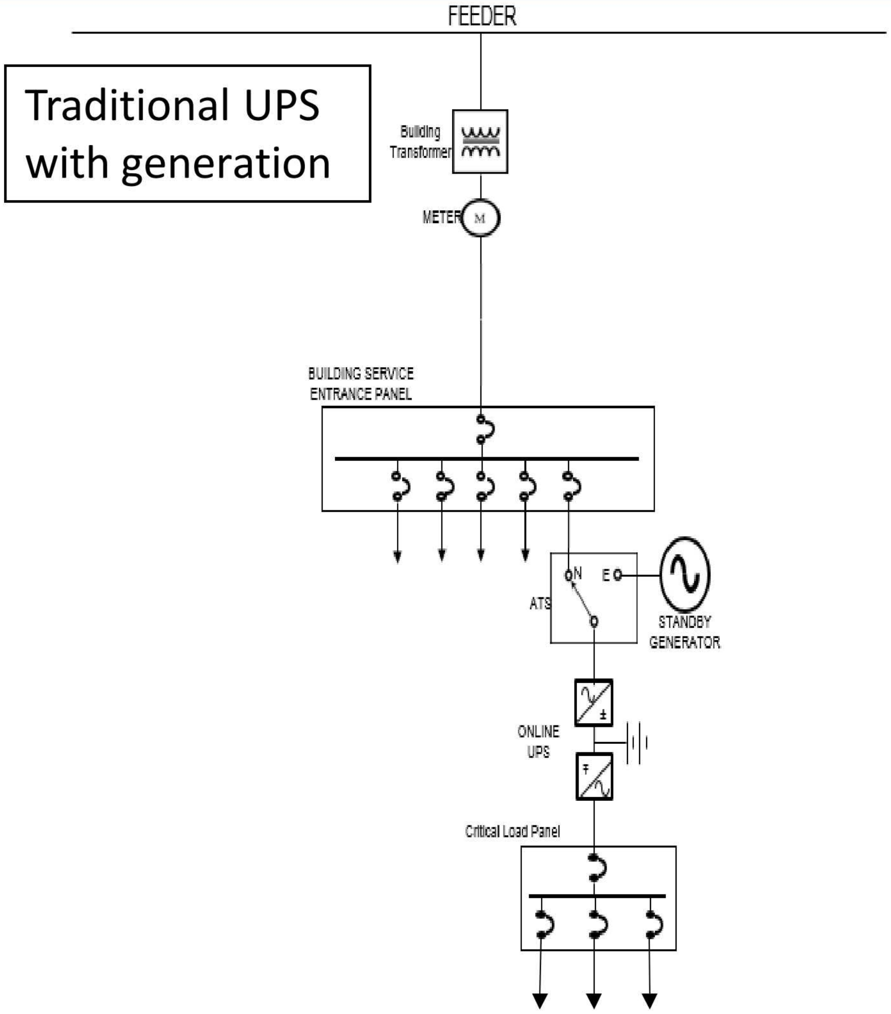
Integrated into grid systems

- Designed for Applications
- Sized for Applications
- Focus on Battery Energy Storage
- Other energy storage types:
  - Supercapacitors
  - Flywheels
  - Compressed air energy storage
  - Pumped hydro
  - Hydrogen Power-to-gas



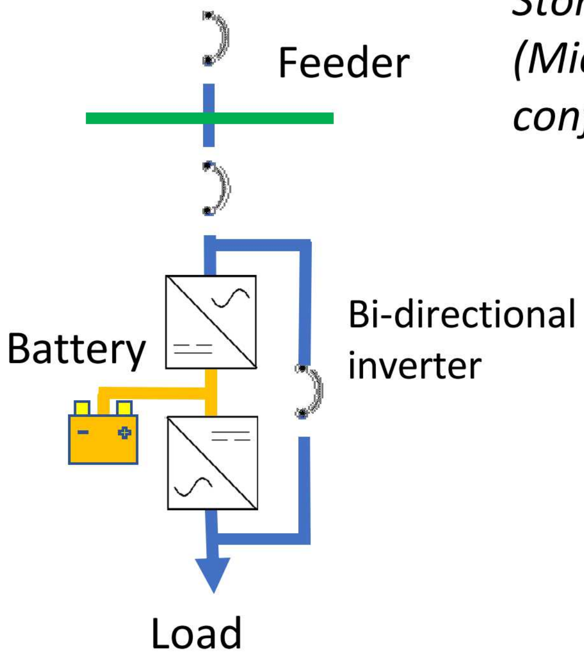
Energy Storage System (ESS) is NOT the same as an Uninterruptable Power Supply (UPS)



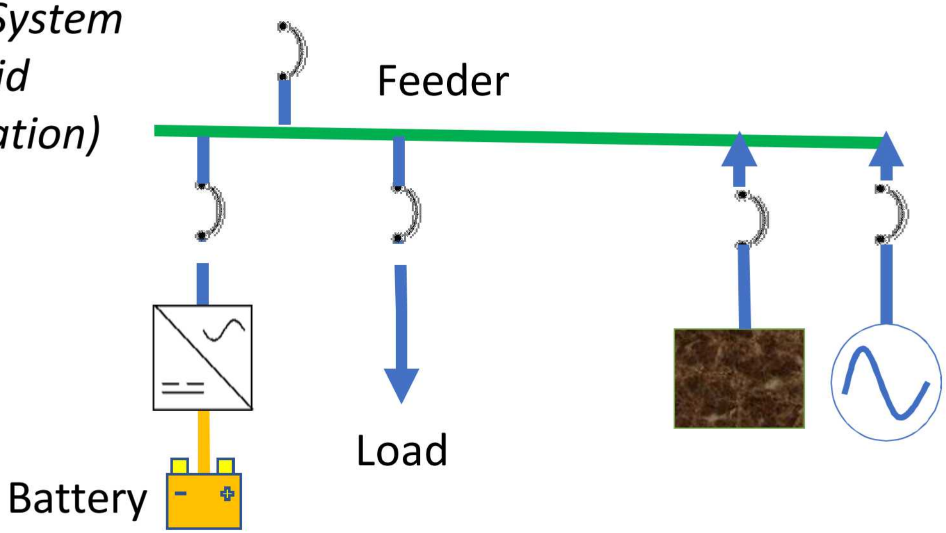


Energy Storage System (ESS) is NOT the same as an Uninterruptable Power Supply (UPS)

Traditional UPS



Grid-tied Energy Storage System (Microgrid configuration)



- Seamless Transition is Possible
- Does not require external signal to trigger Voltage source mode

- Less Equipment = Lower Capital Cost
- Easily Expandable
- Simple Controls
- To date seamless transition is difficult

Elements of Battery Energy Storage System (ESS)

Storage and Battery Management System (BMS)

- Storage device
- Battery Management & Protection (BMS)
- Racking
- $/KWh

Power Control System (PCS)

- Bi-directional Inverter
- Interconnection / Switchgear
- Transformer
- $/KW

Energy management System (EMS)

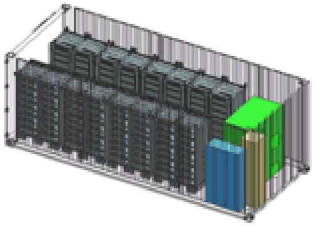
- Charge / Discharge
- Load Management
- Ramp rate control
- Grid Stability
- Monitoring
- $ / ESS

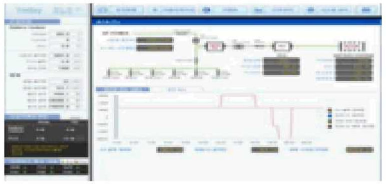
Site Management System (SMS)

- Distributed Energy Resources (DER) control
- Synchronization
- Islanding and Microgrid control
- $ / microgrid

Balance of Plant

- Housing
- Wiring
- Climate control
- Fire protection
- Construction and Permitting
- $ / project (function of scale)





Slide 7

D8 Dale, 3/12/2019

D9 What is the difference between the battery management system (which should be spelled out by the way somewhere) and the energy management system (EMS) I thought the BMS handled ramp rate control and charge and discharge as well as battery state of charge.
Dale, 3/12/2019

D10 I added storage and BMS.
Dale, 3/12/2019

D11 Spell out battery management system
Dale, 3/12/2019

Energy Storage Battery and System technology

- Over view of ES Technologies
  - Various ES types
  - Market size

D12

- Characteristics
  - KiloWatt/KiloWatthour
  - Efficiency
  - D13 “C rate” (discharge rate)
  - Energy density
  - Cycle life
  - System Components
  - Cost (usually in $/kWh)

Slide 8

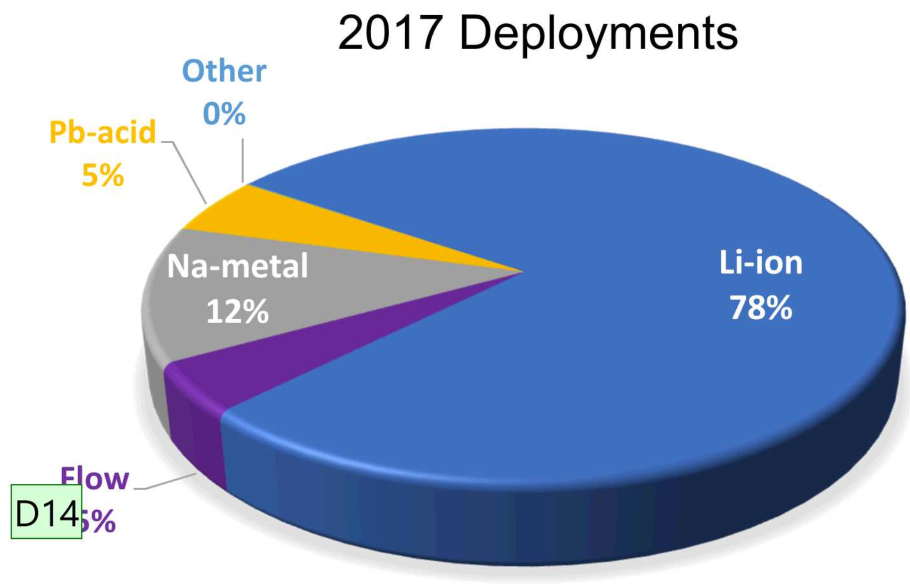
D12 Yes define the charge rate, and explain why it would vary.
Dale, 3/12/2019

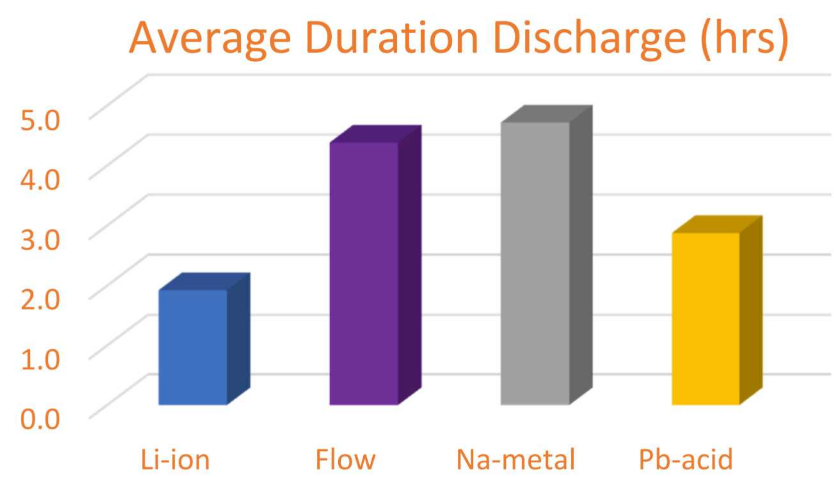
D13 This would be a good place to note that cost is usually defined in dollars/kW per hour of storage or simply as $/kWh for usually just the battery plus BMS and then also for total installed cost including the EMS, SMS, interconnection, power conditioning system and inverters, etc.
Dale, 3/12/2019

Grid Energy Storage Technologies / Market

Most Common Commercial Types

- Lead – Acid Technologies
  - 89 MW
- Lithium-ion
  - 1,300 MW
- Sodium Metal
  - 207 MW
- Redox Flow Batteries (RFB)
  - 75 MW
- Flywheels
  - Estimated 50MW
- Others
  - Other Flow Batteries
  - $NaNiCl_2$, (Zebra battery)
  - Ni-Fe
  - Zn-Ni
  - $Zn\text{-}MnO_2$
  - Supercapacitors





Slide 9

D14 I added RFB

Dale, 3/12/2019

Basic Battery Terminology

Electrochemical Cell: Cathode(+), Anode (-), and Electrolyte (ion conducting intermediate)

Energy (KWh) = Ability to do work.

Power (KW) = The rate at which the work is being done.

Dan's definition

ES- KW – The Capacity of the Energy Storage System i.e, 1KW

ES – KWh – The Capacity multiplied by the time (hour) rating of the system

A 1KW 2 hour system = 2KWh

Example - If 10 – 100 watt light bubs need to operate for an hour then:

10 x 100W = 1KW * 1 hr = 1KWh

Energy Density (Wh/kg or Wh/L): used to measure the energy density of battery.

Note: number often given for cell, pack, and system

Generally: pack = ½ cell energy density, and system is fraction of the pack.

$/KWh = Capital cost of the energy content of a storage device.

$/KW – Capital cost of power content of a storage device.

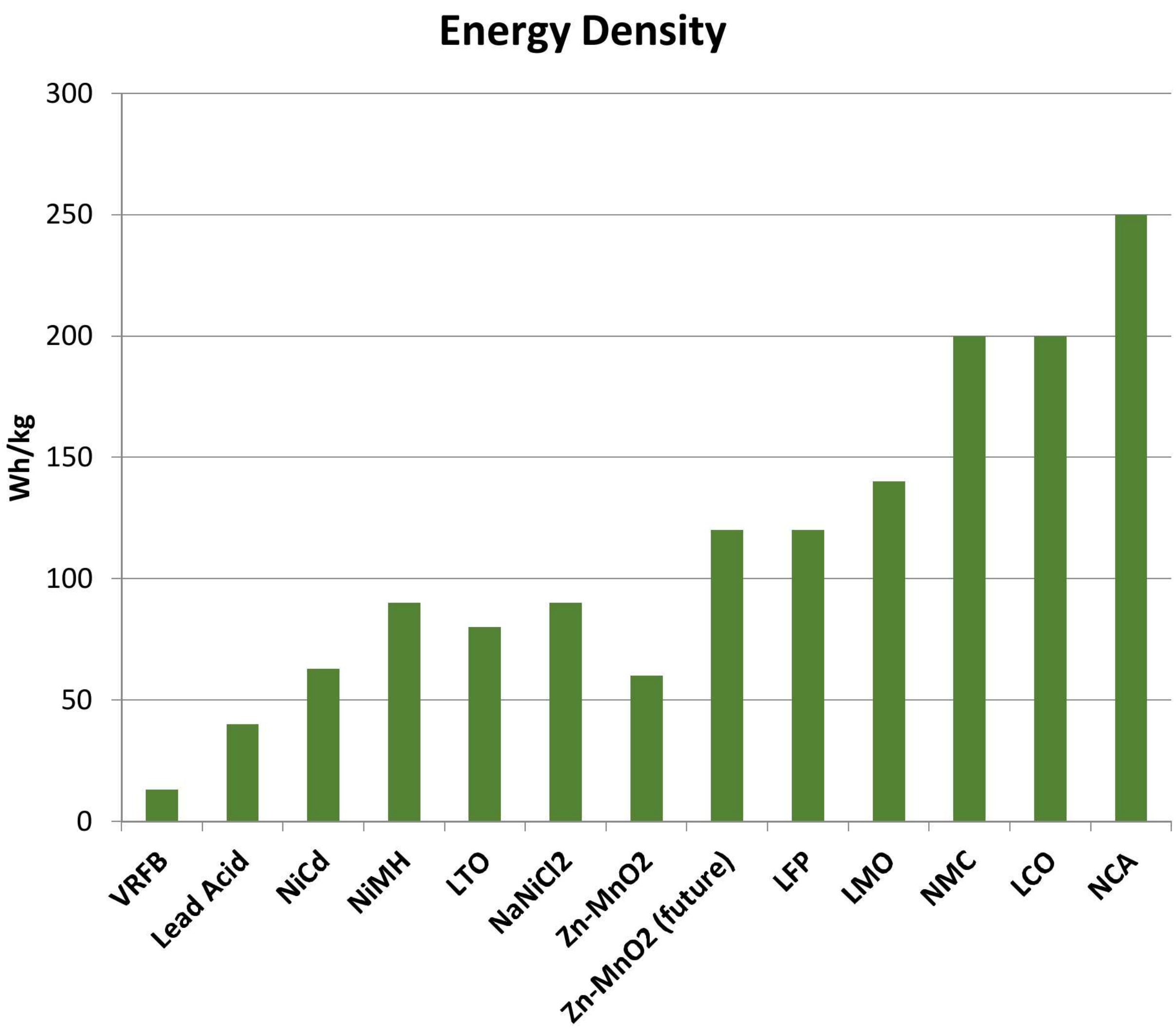
Round trip Efficiency – Output/input of all components. Measure of amount of energy output given an input to storage plus ancillary equipment

Battery Discharge “C” Rate Explained

Discharge “C” rate is the amount of energy a fully charged battery can discharge in one hour

- Example: a fully charged 1MW/1MWh battery operating at:
- 1C = discharge 1MWh in one hour
- 0.5C = discharge 500 KWh in two hours (two hour rate)
- 2C = discharge 2MWh in 30 minutes.
- Note: Power output will be limited by Power Electronics (Inverter)
- Note: The charging ability may be slower

Battery technologies and their energy densities D15



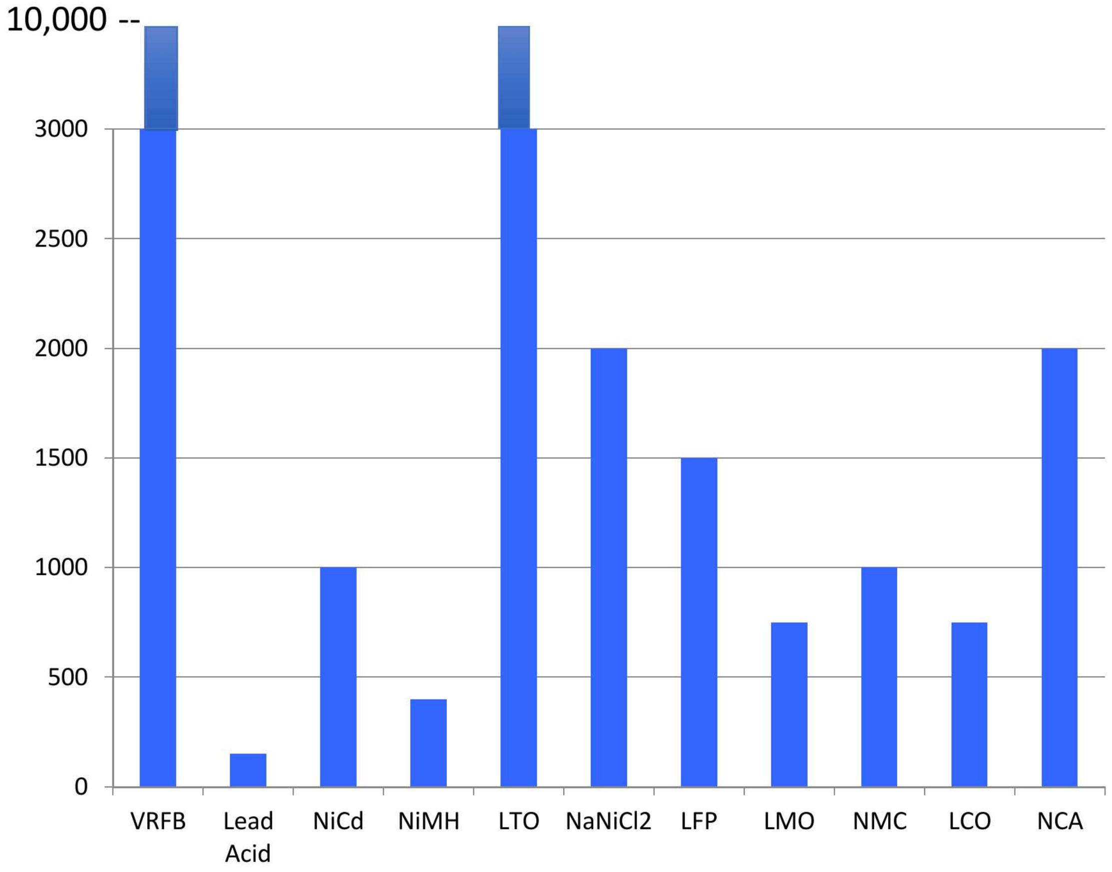
Abbreviation	Name
VRFB	Vanadium Redox Battery
Lead Acid	Lead Acid
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
LTO	Lithium Titanate
LFP	Lithium Iron Phosphate
LMO	Lithium Ion Manganese Oxide
NMC	Lithium Nickel Manganese Cobalt Oxide
LCO	Lithium Cobalt Oxide
NCA	Lithium Nickel Cobalt Aluminum Oxide
Zn-MgO2	Zinc Manganese Oxide
NaNiCl2	Sodium Nickel Chloride (Zebra)

Curtesy of: Battery University

Slide 12

D15 Note that energy density does not matter for stationary applications unless land is expensive or a constraint
Dale, 3/12/2019

Battery technologies and their cycle life (cycles at 80% DOD)



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Zn-MgO2	Zinc Manganese Oxide
NaNiCl2	Sodium Nickel Chloride (Zebra)

- Battery Lifetime depends on 4 main factors - %State-of-Charge (SOC), %Depth-of-Discharge (DOD), temperature, rate of re-charge.
- When cycling once per day or more, the lifetime depends mainly on %DOD and re-charge rate.

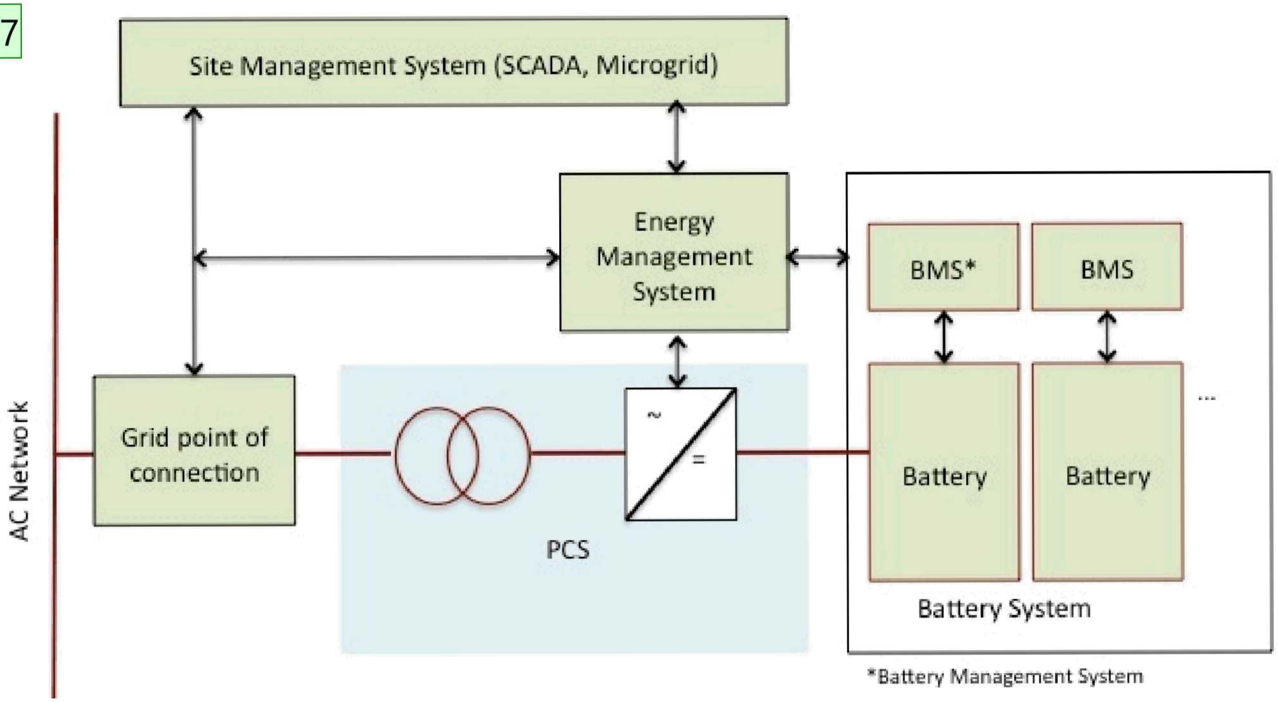
Curtesy of: Battery University

Power Electronics

- Converts DC to AC and reverse
- Controls and provides applications:
  - Controls real (P) and reactive (Q) power
  - Ability to look like generator to grid
  - Operate in anti-islanding or Island mode
  - Can provide four quadrant volt/VAr support D19
  - Grid stabilization (synthetic inertia, and active damping)
  - Black start (REQUIRES AUX Power) D18

PCS components: D17

- AC/DC circuit breakers
- AC/DC contactors D16
- Inverter modules
- Local Controller
- Master Controller
- Battery Management System (BMS) interface
- System monitoring



Slide 14

D16 What do you mean by contractors?
Dale, 3/12/2019

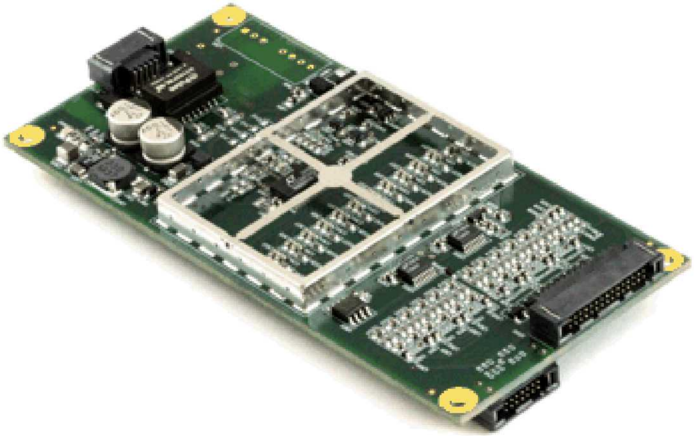
D17 Is the PCS managed by the EMS?
Dale, 3/12/2019

D18 How much Aux power would be required and for how long? Would this be a small Li ion or lead acid battery. Can't the battery itself provide the Aux power? I thought that all batteries provide black start.
Dale, 3/12/2019

D19 I added this comment
Dale, 3/12/2019

Battery Management System (BMS)

- The BMS controls (in conjunction with the energy management system) the charge and discharge of the battery.
- BMS adjusts charge voltage –
  - Charging to a lower Voltage limit allows extended operation at partial SOC
  - Prolongs life
- The BMS measures cell voltages, D20 currents, temperatures, and balances cells.
- The BMS monitors cell health and detects and annunciates cell and module failures.
- The BMS is part of the overall safety system.



Slide 15

D20 cell current?
Dale, 3/12/2019

Energy Management System

- Monitors grid voltage
- Manages energy flow to/from grid (ramp rate)
- Controls current or voltage source mode of operation of inverter
- Controls ESS
  - Communicates with inverter
  - Communicates with BMS
  - Communicates with customer interface
  - Controls balance of plant – HVAC, emergency stop, fire protection
- Insures inverters operate batteries within the battery parameters.

Site Management System (SMS) - 1

The SMS interfaces with the ES energy management system, distributed energy resources and the grid and acts as the Master Controller

- ➢Monitors and Controls Grid
  - Measure grid electrical conditions – voltage, current, frequency, Power
    - Event logging
    - Historical records
  - Sensors, Breakers, re-closer D22 ower Measurement Unit (PMI)
  - Distributed Energy Resources (DER)
  - State of Charge of ES
  - Determines Role of ES
    - Enable stability control
    - Demand reduction
    - Regulation/power quality
  - Data management

Slide 17

D22 What does this statement mean? Will the SMS manage the interactionof the BESS with other DER like RICE?
Dale, 3/12/2019

Site Management System (SMS) - 2

- Real time operational decision making – based on revenue opportunities
    - Financial / Rules and Markets (see Economics / value propositions)
        - Electric rates D24
        - Fuel tariffs
        - Time of day rates
        - Demand Charge reduction
        - Emission vs. energy cost optimization
- Safety
- Forecast
    - loads – electrical, thermal
    - Weather
- Optimize unit scheduling
- Cyber Security

- Creates and controls microgrid
    - Controls isolation breakers
    - Manages loads and load shedding
    - Enable Island mode
    - Synchronization and integration of various DER- renewable and traditional

Slide 18

D24 spinning reserve, frequency regulation, capacity credit, T&D asset deferral, etc.

Dale, 3/12/2019

Balance of Plant

- Balance of plant functions
  - HVAC: battery temperature operations (10-40 C fD25 itium-ion)
  - Fire protection: water sprinklers; oxygen-depleting chemicals; smoke alarms; fail-safe shut-down controls; emergency off
  - Electrical distribution: Over-current protection, i.e., coordinated breakers / fused disconnects
  - Communications
  - Site work: pad, fencing, conduit / wiring

On board cooling system for EPC 125kW bi-directional inverter.

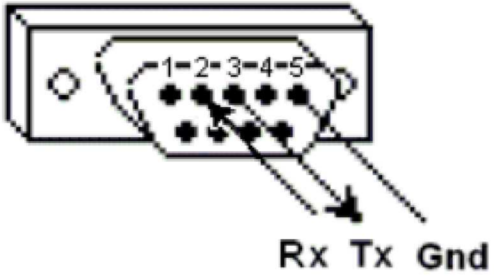
Slide 19

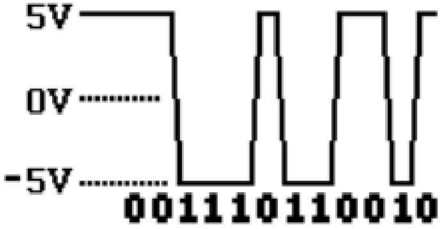
D25 Note that this is critical for Li ion but not RFB
Dale, 3/12/2019

Communication and Control

Communications / Control have become an essential piece of the Energy Storage System

- Several approaches to comm are currently popular: Modbus and DNP3
- Remote monitoring mandatory for utility interface
- Data storage useful for understanding performance and analyzing economic impact
- Data should be stored both onsite and at remote location.
  - Need to pick data points. We have lists of data to be collected and sampling rates.





Economics

COSTS

- Capital co D26 in $/kW, $/kWh (depends on hours of storage)
  - Costs for Battery Modules plus BMS are usually quoted $/kWh
  - Total installed cost can be quoted in either $/kW or $/kWh
  - Total cost can be 2X to 4X more than Battery Module plus BMS costs.
- O&M
- Levelized cost of electricity (depends on usage)

REVENUE or SAVINGS OPPORTUNITIES

- Peak capacity or transmission fee reduction
- Bid-in Markets: Spinning reserve, frequency regulation, capacity credit,
- T&D asset deferral
- Arbitrage

Slide 21

D26 Note that usually quoted for Battery Modules plus BMS in $/kWh and that total installed costs is quoted in $/kW and $/kWh and is 2X to 4X more than Battery Module plus BMS costs.

Dale, 3/12/2019

Hawaii Experience with Solar + Storage

D27

- Seven new projects in Hawaii will double the energy storage capacity in the state.
- NOTE: The incredibly low cost of energy compares favorably with fossil fuel.
- Includes 30% Investment Tax Credit

AES, Innergex, Clearway and 174 Power Global are developing the projects.

Project name	Island	Developer	Size	Storage	Cost per KWH
Waikoloa Solar	Hawai'i	AES	30 MW	120 MWh	$0.08
Hale Kuawehi	Hawai'i	Innergex	30 MW	120 MWh	$0.09
Kuihelani Solar	Maui	AES	60 MW	240 MWh	$0.08
Paeahu Solar	Maui	Innergex	15 MW	60 MWh	$0.12
Hoohana	O'ahu	174 Power Global	52 MW	208 MWh	$0.10
Mililani I Solar	O'ahu	Clearway	39 MW	156 MWh	$0.09
Waiawa Solar	O'ahu	Clearway	36 MW	144 MWh	$0.10

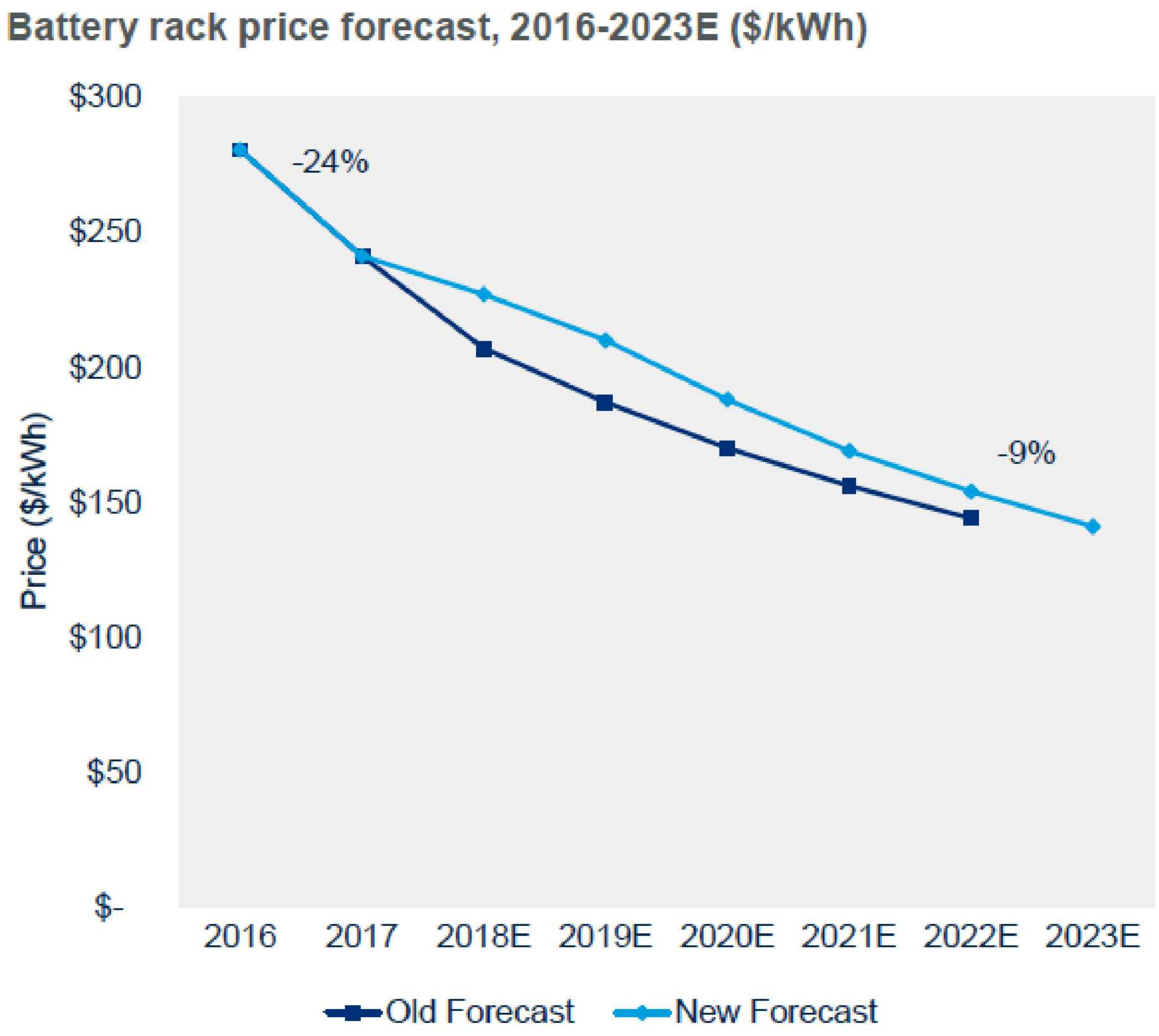
Source: Hawaiian Electric Industries

Slide 22

D27 Note that this includes a 30% ITC.

Dale, 3/12/2019

Lithium-ion Battery Prices



Source: Wood Mackenzie Power & Renewables

"Earlier in 2018, Wood Mackenzie P&R forecasted battery prices to decline by 14% over the course of the year. However, the pace of price declines slowed down dramatically once the market was hit by battery supply shortages in Q2 2018.

2018 saw demand for NMC batteries, from both the EVs and energy storage industries, outstripping the supply, as cell manufacturing capacity couldn't keep up with the rapidly growing demand. While there was shortage of nickel-manganese-cobalt-oxide (NMC) batteries in the market, there were plenty of lithium-iron-phosphate (LFP) batteries available..

D50

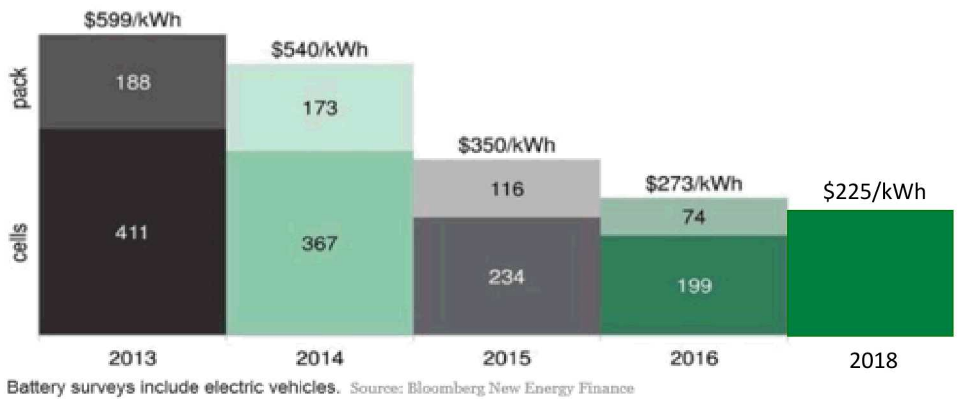
As greater production capacity comes online, battery supply constraints will be resolved, likely by the end of H1 2019."

Slide 23

D50 What is the cell cost and pack cost in the $200/kWh in 2018?

Dale, 3/12/2019

Battery Price is not the only cost driver



D28

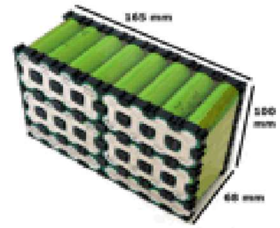
$225/kWh pack

↓

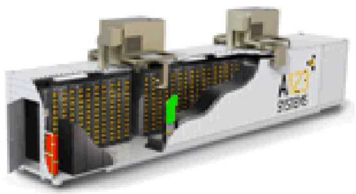
$585/kWh installed

Cell

Pack
X 1.4



System
X 2.0



Installed
X 1.3

Slide 24

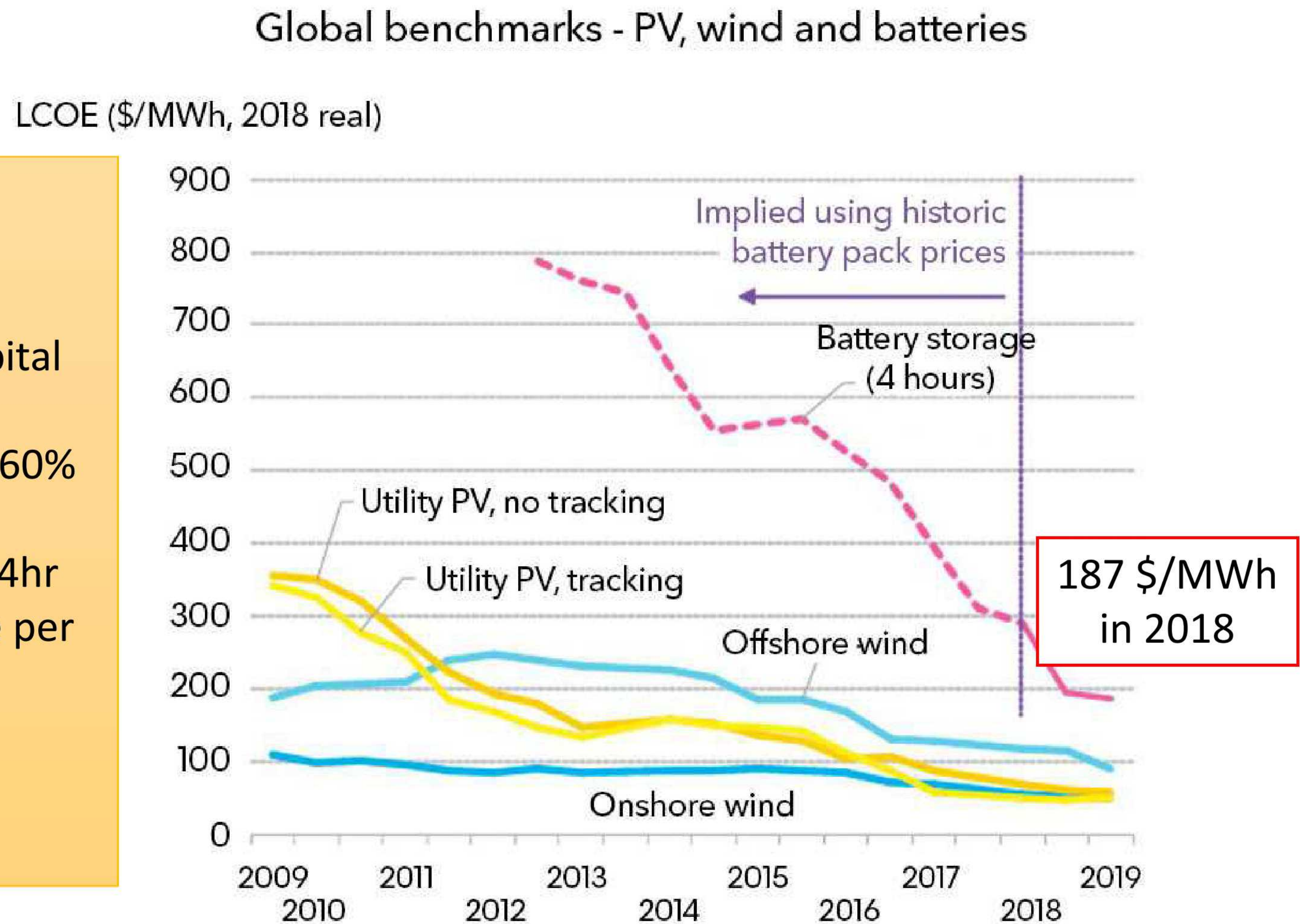
D28 Why use $80/kWj amd 2016 cost for a cell is $199/kWh for 2016?

Dale, 3/12/2019

Levelized cost of energy (LCOE)

LCOE for Li-ion batteries is based on numerous assumptions:

- power output rating; capital cost (2018 real projects)
- cost of charging energy (60% of wholesale base price)
- hours of operation/day (4hr charge/discharge, 1 time per day)
- assumptions about fixed charged rates, lifetimes, inflation etc.



Source: BloombergNEF. Note: The global benchmark is a country weighed-average using the latest annual capacity additions. The storage LCOE is reflective of a utility-scale Li-ion battery storage system running at a daily cycle and includes charging costs assumed to be 60% of whole sale base power price in each country.

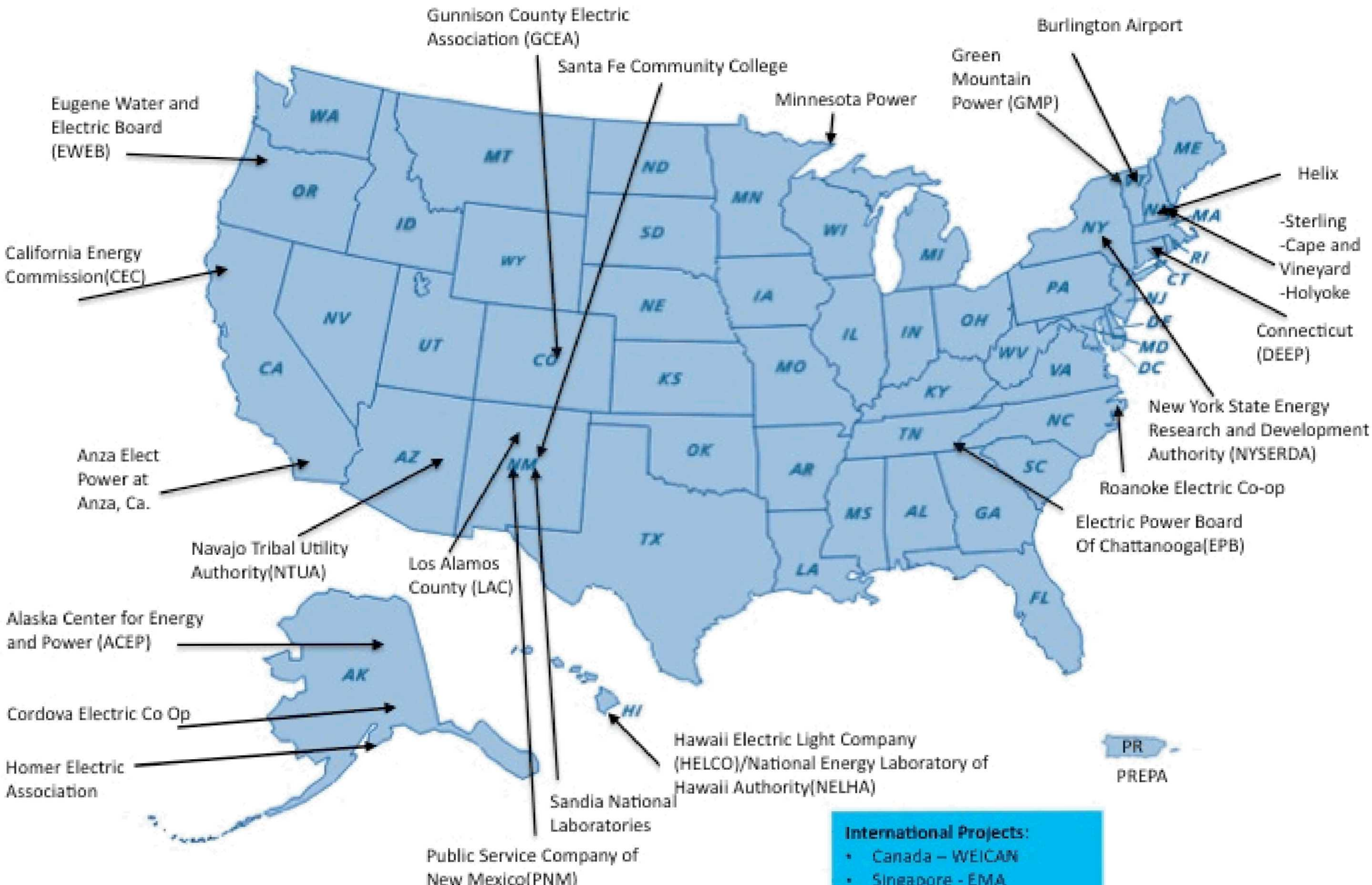
D51

Slide 25

D51 Why use $80/kWj amd 2016 cost for a cell is $199/kWh for 2016?

Dale, 3/12/2019

DOE/SNL Energy Storage Projects



International Projects:
- Canada – WEICAN
- Singapore - EMA

Use cases / applications: these dictate the design

- Energy storage application time scale
  - "Energy" applications – slower times scale, large amounts of energy D31
  - "Power" applications – faster time scale, real-time control of the electric grid

Application	**Power <15min**	**Energy >30 min**
Renewable Firming	x	x
T&D Upgrade Deferral		x
Demand Reduction		x
Energy Shifting		x
Power Quality/Reliability	x	x
Spinning Reserve		x
Frequency Regulation	x	
Capacity		x

Table 1 – Energy Storage Applications

Slide 27

D31 shouldn't energy be >15 minutes?

Dale, 3/12/2019

Experience during design, procurement, installation, and operation (part 1)

- Design analysis
  - Use case determines power output needed (kW) and hours of storage
  - ➔ kWh size of the battery
- RFP process
  - Items to do know and watch out for
    - Warranty
      - How long should it last
      - What applications is it going to be used for
      - How to define cycles and cycles life
- PPA vs own and operate
  - Pros and Cons
    - PPA – Pay for performance, but harder to adjust applications. Reduce risk but at what cost
    - Own and Operate – Take on the risk, but at what cost
- Construction strategies
  - Who should be the prime?
    - Who has the biggest slice of the budget?
  - Who will be the integrator?
  - Role of Owner's operations crew during construction and commissioning D32

Slide 28

D32 This is good comment...

Dale, 3/12/2019

Ownership Model Alternatives D33

Ownership	Pros	Cons
Power Purchase Agreement (PPA) Project Developer/operator builds and operates ESS. Owner pays for kWh delivered.	Performance risk is placed onto developer as owner only pays for kWh delivered. Maintenance by developer/operator. This is valuable in projects where the owner does not have support staff.	Lack of ownership. May be locked into operating load profiles and/or applications that become inconsistent with market needs.
Owner owned and operated Owner pays for developer to build system. Owner will own and operate system once commissioned.	Complete control of system installation and operation. Ability to adjust operating load profiles and applications as markets warrant.	Owner assumes risk. If system doesn't perform as specified, would only have contract requirements, warranty, or O&M agreements to solve operational issues. Will need access to maintenance support for minor inspections/ adjustments not covered by warranty or maintenance agreements.

Slide 29

D33 Excellent point on con on PPA
Dale, 3/12/2019

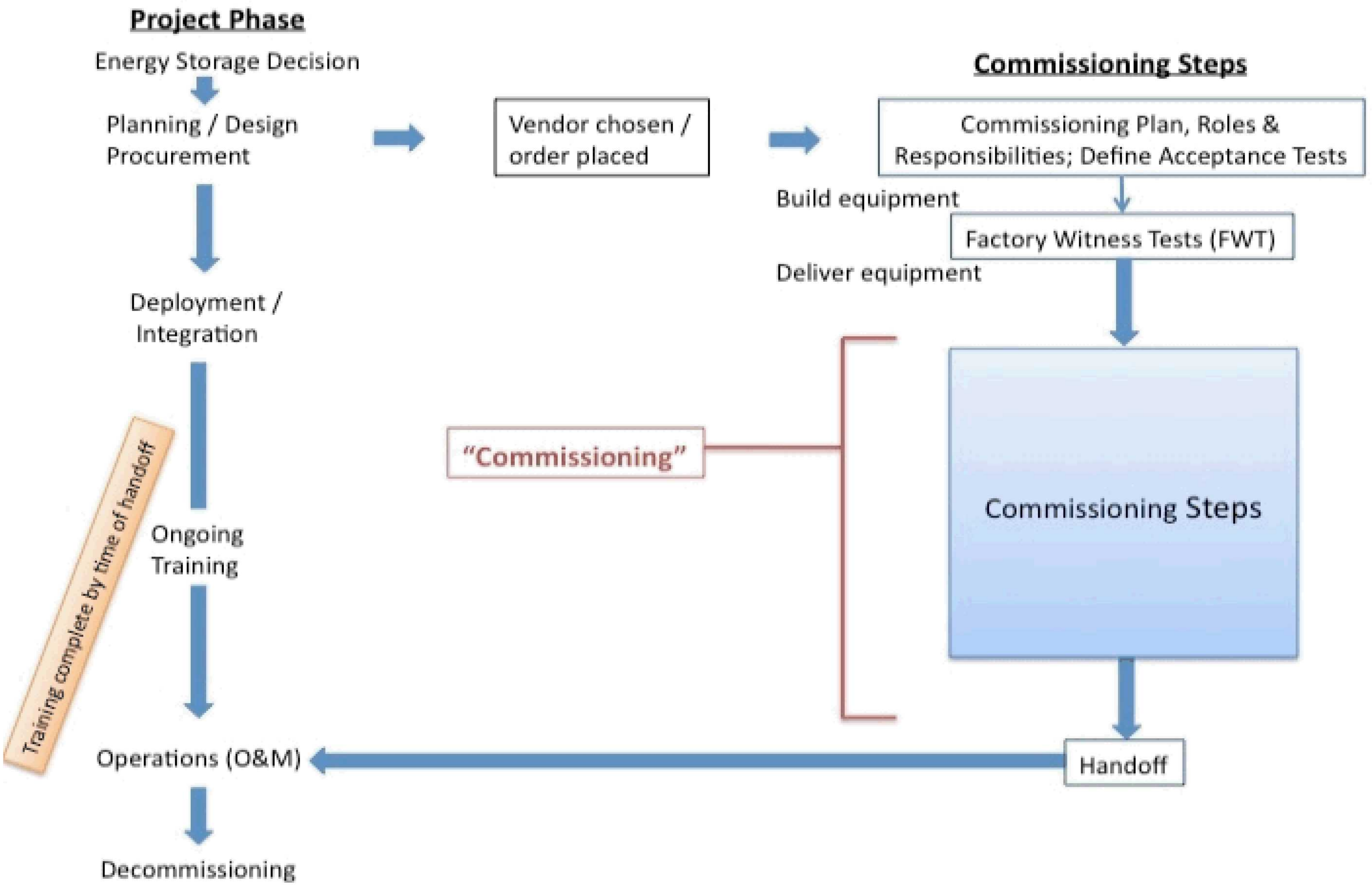
Contract Strategies

Contracting strategy	Description	Comments
Design/Build (D/B)	In this strategy a firm is hired by the owner to design and build the EES project. This is sometimes called a turnkey system.	This is convenient strategy when the owner has limited engineering and/or construction management resources. The D/B firm can be contracted to be all-inclusive and can also act as the owner representative.
Design/Bid/Build (DBB) or Engineer/Procure/Contract (EPC)	Using this strategy the owner will place a contract with a design firm, and then once the design is complete, the design is put out to bid to an installer.	When the owner has adequate staff, this strategy allows the owner more control, as they can act as the gate between design and construction.

Experience during procurement, installation, and operation (part 2)

- Commissioning
  - Get operators and maintenance involved
- Out year Maintenance contracts
- Warranty considerations
- Operational considerations
  - Monitoring external inputs
    - Weather
    - Load
    - Renewables
    - Rates and regulations
- Lessons learned

Commissioning Process starts at RFP



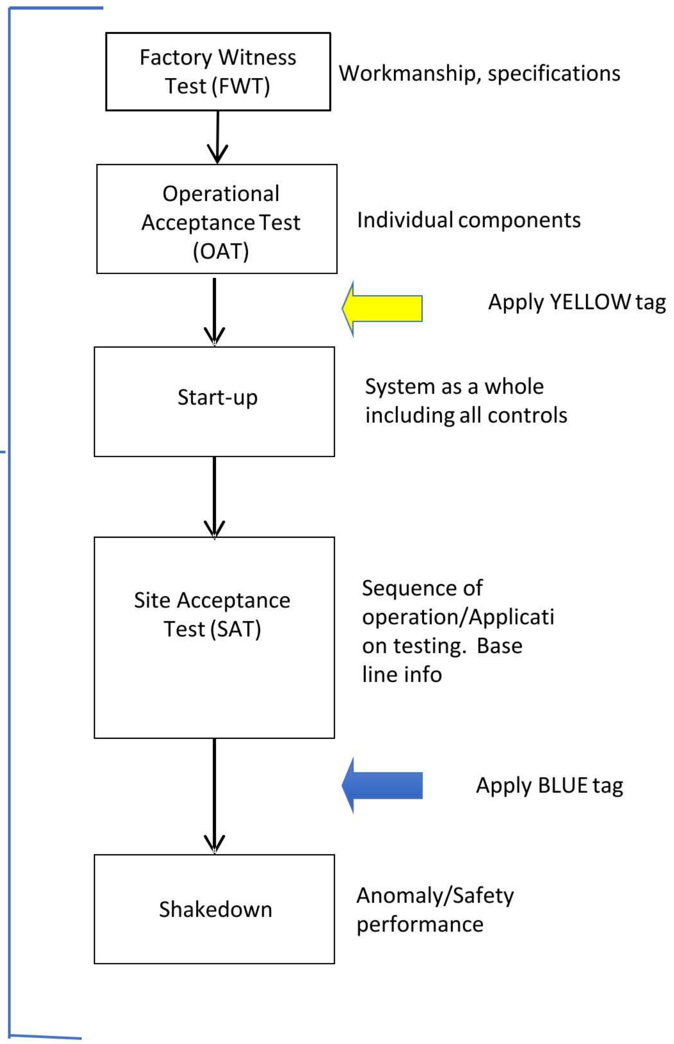
Commissioning / Testing Process details D34

COMMISSIONING

Safety and Reliability

Base line measurements

- Voltage
- Capacity
- Charge time
- Discharge time
- IR scan connections and batteries
- Fault current protection testing

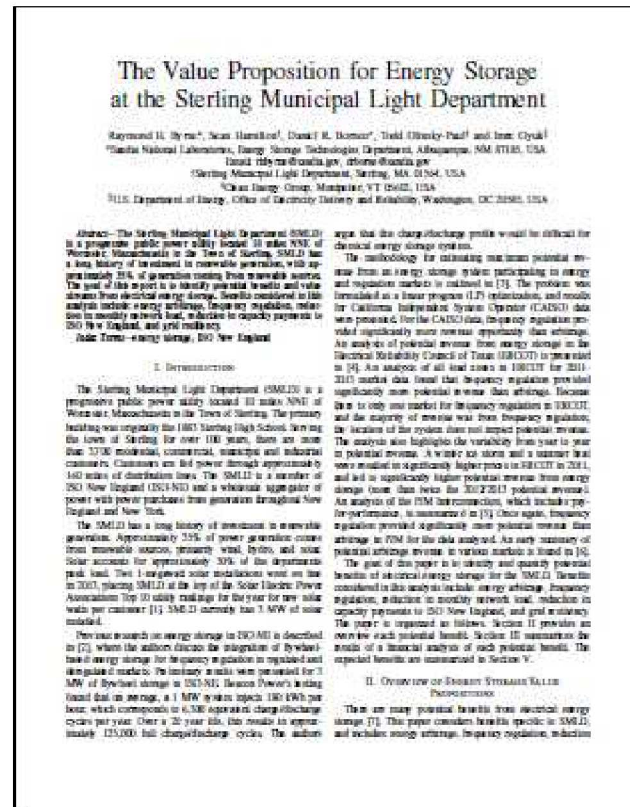


Slide 33

D34 what about determination and mitigation of fault currents?
Dale, 3/12/2019

Example Deployment Project: Sterling Municipal Light Department

- Conducted an economics analysis showing ~6 year payback for battery system (2.5 years with grants). Largest value comes from reducing the annual peak energy charge. D36
- Installed a 2 MW/ 3.9 MWh Li-ion battery storage system in Sterling Massachusetts
- Along with the existing PV array, ES can island from grid and provide 12 days of backup power to critical load at the Sterling police station D35
- Demand reduction application saves the ratepayers ~$400,00 per year by decreasing the costs associated with capacity and transmission charges


The Value Proposition for Energy Storage at the Sterling Municipal Light Department

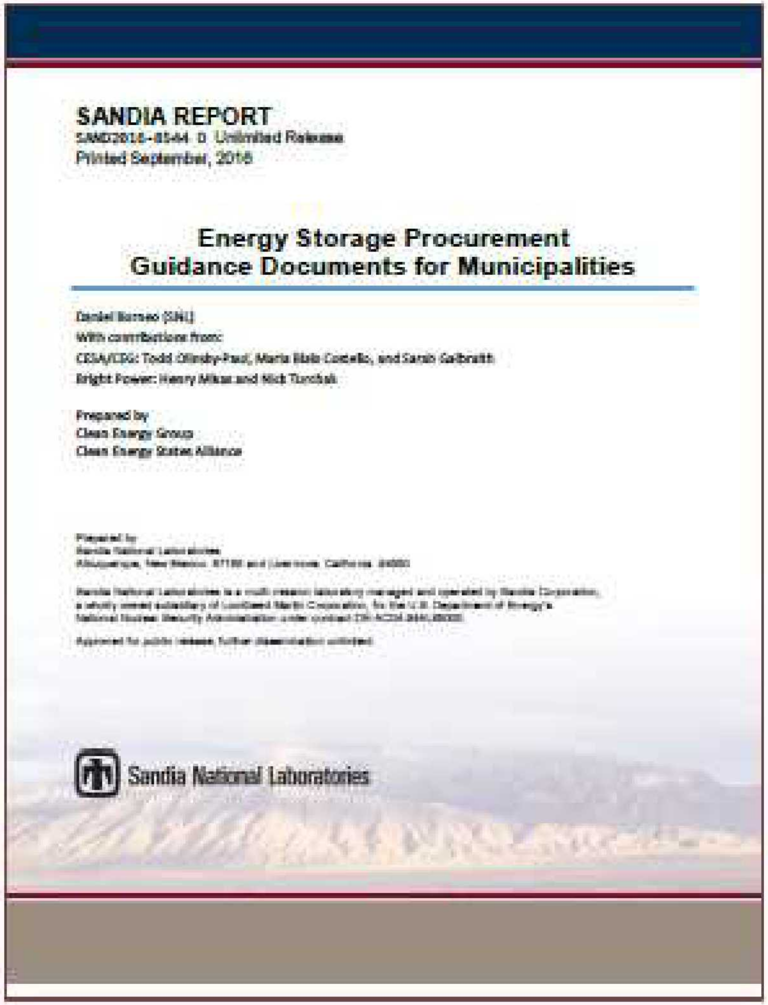
Slide 34

D35 Really 12 days?
Dale, 3/12/2019

D36 What is the value stream? arbitrage? demand charge reduction? frequency regulation in what energy market?
Dale, 3/12/2019

Example Deployment Project: Sterling Municipal Light Department

- Issue
  - Lack of knowledge and experience regarding procurement of a combined system lead to a difficult and arduous process for vendors
- Lessons Learned D39
  - For successful integration of storage, it can be helpful to have 1 project combining PV and Storage done by 1 company rather than 2 separate projects done by 2 companies
  - There is a growing need for companies who can do both


SANDIA REPORT
Unlimited Release
Printed September, 2016

Energy Storage Procurement
Guidance Documents for Municipalities

Daniel Borneo (SNL)
With contributions from:

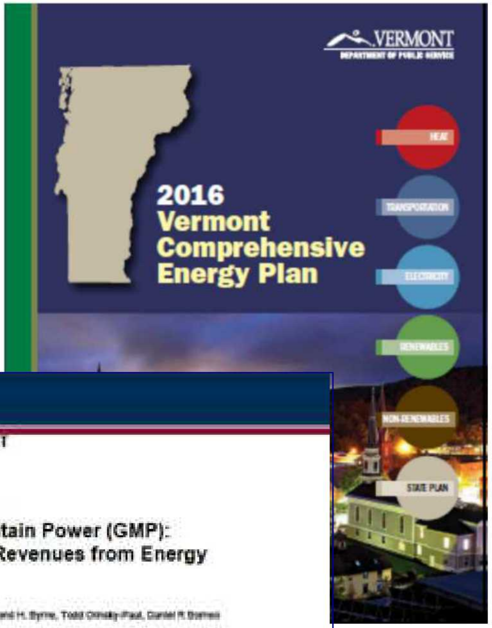
Prepared by
Clean Energy Group
Clean Energy States Alliance

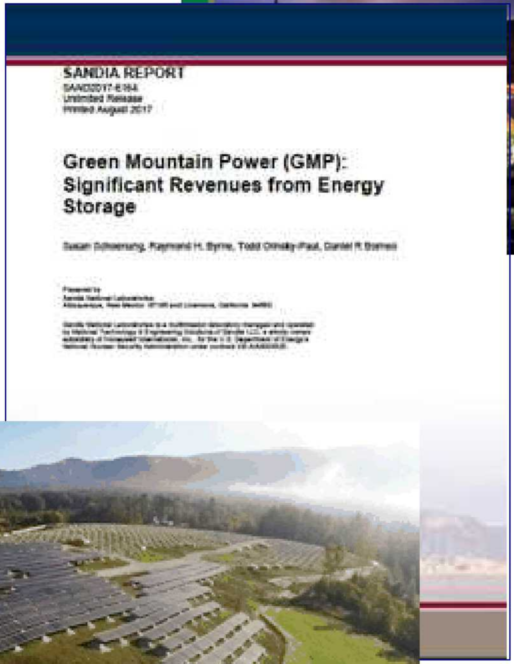
Slide 35

D39 excellent.
Dale, 3/12/2019

Example Deployment Project: Green Mountain Power

- 4Mw/3.4MWh of a combined lead-acid and li-ion system Installed in Rutland, Vermont D38
  - Integrated / coupled with 2.5 MW of PV
- Helps with ancillary services, backup power for an emergency shelter, and demand management
- Issues
  - Project built with 4 X 500KW multi input (DC) inverters D37
  - 500KW ea. of LA and Li-ion, plus ~500KW of PV per inverter
  - Inverters limit output
    - Reduced demand reduction capability
- Lessons Learned
  - Not designing for flexibility of applications limited DR value




SANDIA REPORT

Green Mountain Power (GMP): Significant Revenues from Energy Storage

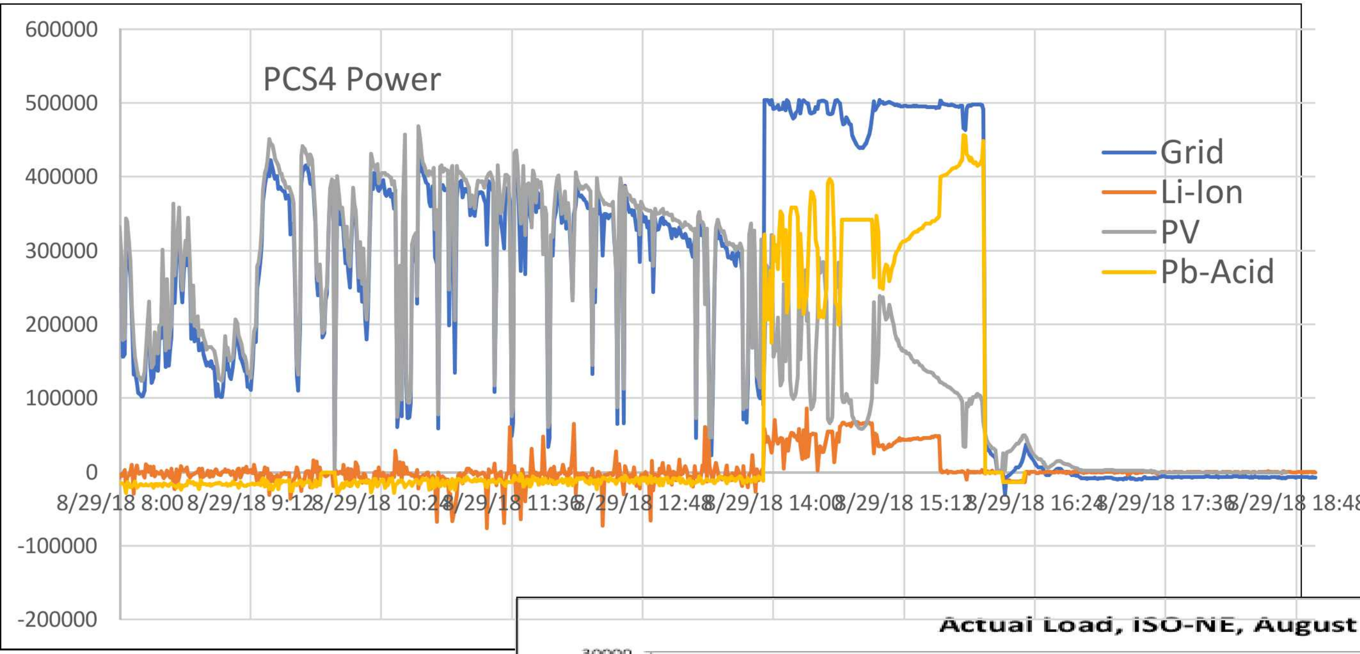
Slide 36

D37 I added the X
Dale, 3/12/2019

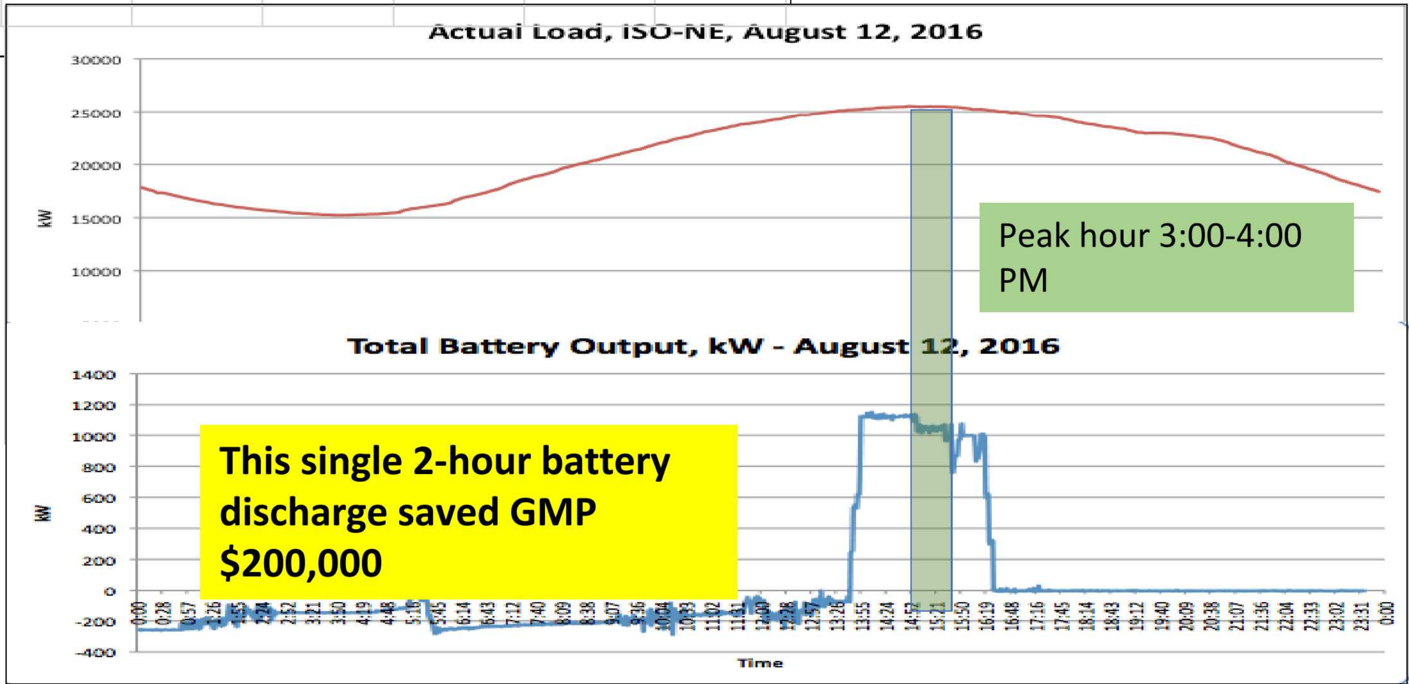
D38 Is the BESS DC coupled with the solar PV?
Dale, 3/12/2019

GMP Operational Data

D40



"Grid" is the power output FROM the GMP solar+storage system TO the grid. It is the sum of the PV and battery power. The batteries were intentionally turned on during that hour to reduce system load (and annual fee). Pb-acid batteries did most work.



Slide 37

D40 Any idea why the sharp rise in grid? is the main work horse the Pb acid? Why Pb acid and Li ion?

Dale, 3/12/2019

Eugene (Oregon) – Eugene Water and Energy Board (EWEB) Project

- System
  - A 0.5MW/1MWh NEC Li-on system
    - Installed by Worley Parsons
  - Support 50 kW of solar
- Location
  - The ESS is located at Howard Elementary School
- Completion Date
  - Operational October 2018
- Partners
  - DOE/OE, Sandia, EWEB, ODOE, Contractor: Worley Parsons
- Goals
  - Demonstrate battery storage and distributed generation as a part of EWEB's community resiliency plan
    - Eugene is located in an area vulnerable to earthquakes
    - In the event of a disaster the ESS can provide power to the emergency water distribution system located at Howard Elementary School
  - The system will also be utilized to test microgrid use cases
    - Increased site reliability
    - Energy Arbitrage
    - Voltage support
    - Peaking shifting

Lessons Learned at EWEB

- Microgrid Controller
  - For smaller distributed microgrids, it is cost ineffective to have a fully featured microgrid controller
  - Costs for a fully featured controller can be 50% of the cost of the battery system
- System Design
  - Current design is 2 smaller systems combined in a master-slave configuration
  - Preferred to have a single system
    - Fewer conduits
    - Fewer conductor runs
    - Smaller footprint
    - Simpler metering
    - Simpler configuration

Cordova (Alaska) Energy Storage Project

D42

Slide 40

D42 Alaska?

Dale, 3/12/2019

Cordova Electric Co-op (CEC) Project D43

- System: Saft, 1 MW, 1 hour NCA/NMC Li-ion; ABB Power Electronics
- Location: Cordova, AK
- Completion: Estimated Summer of 2019
- Partners: CEC, DOE-OE, Sandia, PNNL, SAFT

- Goals :
  - Reduce Diesel - In winter, the two CEC run-of-river projects, Humpback Creek and Power Creek, freeze up and diesel generation is required to supplement the hydro.
  - Maintain system frequency while eliminating need for Hydro spinning reserve requirement
  - Microgrid services. (Fuel savings are estimated at ~ 35,000 gallons/year.)
- Lessons Learned during Analysis
  - Batteries generally have calendar aging capacity loss of 1.5% per year, our chemistry is estimated at 0.5% D44
  - Energy loss is kWh; kW remains near constant, round trip DC efficiency drops slightly
  - Deep cycling causes rapid loss of life – this indicates frequency control as a high-value case
- Frequency controls (small charges/discharges) can occur while bulk charging or discharging is conducted D45
- Removal, recycling, replacing batteries can cost 60% of initial package cost. D46
- Factory warranties and required annual maintenance are expensive

Slide 41

D43 I added CEC
Dale, 3/12/2019

D44 I replaced Capacity with Energy
Dale, 3/12/2019

D45 Excellent point :)
Dale, 3/12/2019

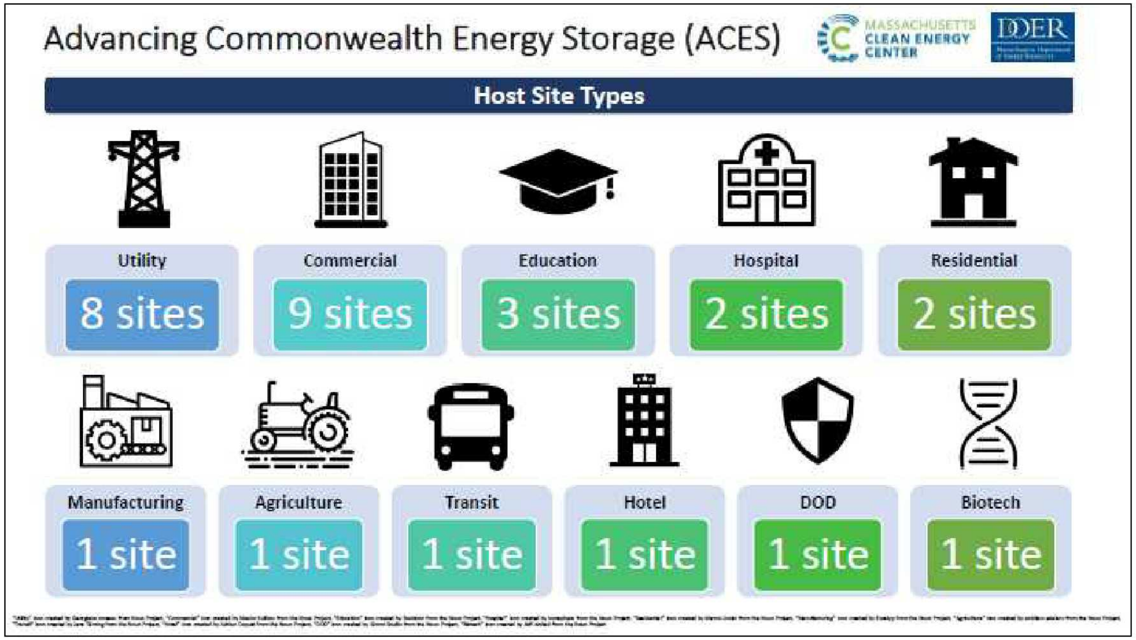
D46 Really? Wow, I had no idea. Any idea on the cycle life? Were most DODs 70%? Were many at 100%? Is SAFT NMC or NCA chemistry?
Dale, 3/12/2019

Example ES Benefit Analysis Projects

- **Boston Medical Center, Massachusetts:** Optimization analysis for major metropolitan hospital using battery storage for demand charge management and resilient power. Focus on optimizing the BESS with an existing CHP plant to improve power quality and reduce voltage fluctuations to the CHP.
- **Gunnison Rural Electric Co-op, Colorado:** One of several analyses for rural electric co-ops, to show the economic benefits of battery storage. Focus on using battery storage to reduce costs and improve power reliability.
- **Albuquerque Public Schools, New Mexico:** Analysis for Rio Grande High School, optimizing battery for demand charge management.
- **Burlington International Airport, Vermont:** Technical assistance to airport for installation of solar storage microgrid for resiliency and cost savings.
- **Peaker plant replacement:** Analysis of the technical capability of energy storage to replace gas peaker plants for capacity provision and grid stabilization.
- **EV fast chargers:** Analysis of economic opportunity for energy storage co-located with electric vehicle fast chargers, to reduce demand charges that present a barrier to EV adoption.

Example State Technical Support Projects

- **Connecticut:** Department of Energy and Environmental Protection microgrid grant program. Technical support for state agency to review proposals for microgrid grants.
- **Vermont:** VT Energy Storage Study. Technical support to Vermont Department of Public Service to write an energy storage study for the state legislature.
- **Massachusetts:** Mass Clean Energy Council ACES grant program. Technical support for state agency developing energy storage demonstration grant program. This program awarded $20 million to support 26 energy storage projects demonstrating new applications, business models and economics in the state of Massachusetts.



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Thank You

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Back-up slides

Power Electronics

Power electronics provide two critical services:

1. Efficient conversion between disparate forms of electricity
2. Unprecedented control over the flow of electrical energy

New **topologies**, **component materials**, and **control strategies** increase power processing capabilities and drive power electronics into new application domains