Coffman Engineers

Battery Energy Storage Systems (BESS)

ACAT May 2020 Battery Presentation

COFFMAN ENGINEERS

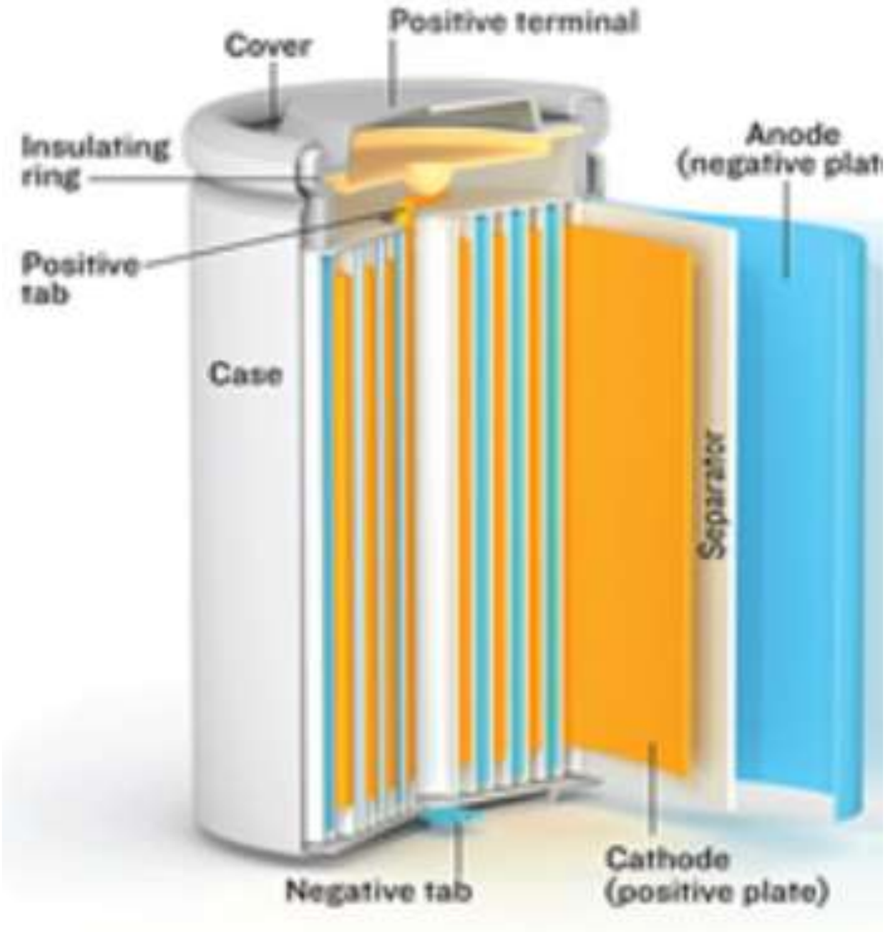
Battery Storage project locations

Services

- Civil Engineering
- Commissioning
- Corrosion Control
- Electrical Engineering
- Energy & Life-Cycle Cost Analysis
- Fire Protection Engineering
- Instrumentation & Controls
- Land Surveying
- Lighting Design
- Mechanical Engineering
- Pipeline Integrity Management & In-Line Inspection
- Process Piping
- Project Management
- Structural/Seismic Engineering
- Sustainable Design

Battery Services

- Feasibility studies
- Building size estimating
- Site layouts
- Commissioning
- AC and DC Electrical Engineering
- Energy & Life-Cycle Cost Analysis
- Fire Protection Engineering
- Instrumentation & Controls
- Thermal Management design (cooling and CFD modeling)
- Structural/Seismic Engineering for building, containers and battery racks
- HVT (over 34.5kV) Subconsultant



Battery Markets

- Private, selling electricity to grid operators
- Commercial (peak shaving)
- Healthcare (microgrids reliability)
- Industrial (peak shaving backup power)
- K-12 Education (Load shifting of solar)
- Military (resiliency-backup power-off grid)
- Residential (back up and off grid operation)
- Remote (microgrids) Wind/Solar/Diesel
- Residential/Hospitality (GHG reductions, reliability cost savings)

I. Energy Storage Systems (ESS)

Energy Storage can greatly reduce the need for Peaker (Standby) power plants, spinning reserve, transmission upgrades, and can allow renewable energy to be used when the source (solar / wind) is not available.

- Battery Energy Storage Systems (BESS) is a rapidly growing and evolving market.
- Pumped hydro energy storage systems are older, larger, and more established.
- Molten salt and compressed air are proven technology.
- Molten metal, flow batteries, liquified air are an innovative, relatively unproven technologies that may become mainstream.
- Flywheels no longer cost effective with low battery costs.

I. Energy Storage – largest globally

Title	Type	Size (MW / MWH)	Year completed
Racoon Mountain (USA, TN)	Pumped Hydro Storage	1,652 / 36,344 (22 hrs)	1978
Ludington (USA, MI)	Pumped Hydro Storage	312 / 1,872 (6 hrs)	1973
Huntorf (Germany)	Compressed Air	290 / 870 (3 hrs)	1978
Solana (USA, AZ)	Thermal, molten salt	280 / 1680 (6 hrs)	2013
Dalian VFB-UET (China)	**Battery, vanadium flow**	200 / 800 (4 hrs)	2018
Andasol (Spain)	Thermal, molten salt	135 / 1,031 (7.5 hrs)	2009
McIntosh (USA, AL)	Compressed Air	110 / 2,860 (26 hrs)	1991
KaXu Solar One (S. Africa)	Thermal, molten salt	100 / 300 (3 hrs)	2015
Hornsdale Power (Australia)	**Battery, lithium-ion**	100 / 129 (1.3 hrs)	2017
Fairbanks BESS (USA, AK)	**Battery, NiCad**	27 / 6.7 (0.25 hrs)	2003
Kauai ElectricBESS (HI USA)	**Battery, lithium-ion, solar**	13 / 52 (1.0 hrs)	2017

Largest U.S. BESS plants – in construction / design

1. **FPL Manatee Energy Storage Center: 409 MW/900 MWh.**
   Online date: late 2021. Taking place of 2 aging gas plants. Florida
2. **Vistra Moss Landing: 300 MW/1,200 MWh**
   Online date: December 2020. S. Bay Area California
3. **NextEra Skeleton Creek: 200 MW/800 MWh** Online date: 2023, wind / solar storage. Oklahoma.
4. **Tesla Moss Landing: 182.5 MW/730 MWh** Online date: December 2020
5. **AES Arizona: 100 MW/400 MWh**
   Online date: 2021
6. **Homer Electric: 50 MW/100 MWh**
   Online date: 2021. Tesla Batteries
7. **Gateway 250 MW / 250 MWH,** San Diego, CA, online end 2020/2021
   (Coffman Fire Protection Design)
8. **Chisholm 100 MW / 100 MWh,** Texas, online early 2021
9. **Bay Area 200 MW / 800 MWh**, online end 2021
   (Coffman Preliminary Design all disciplines)

Other Energy Storage Types

Stored Hydro, Ludington Michigan
(1,785 MW)

Molten Salt,
100 MW example
In Dunhuang, China

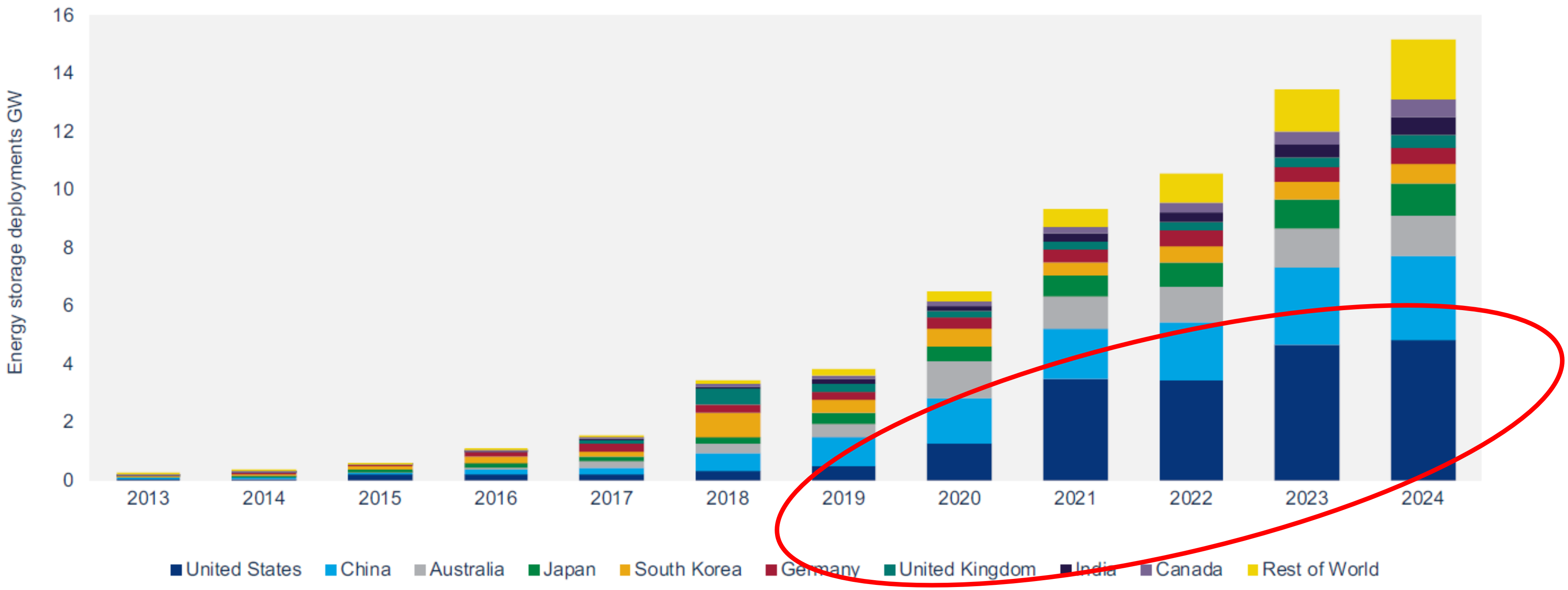
Battery storage system example

PRE COVID 19 ESTIMATES

II. Global deployments, > 15 GW/year by 2024

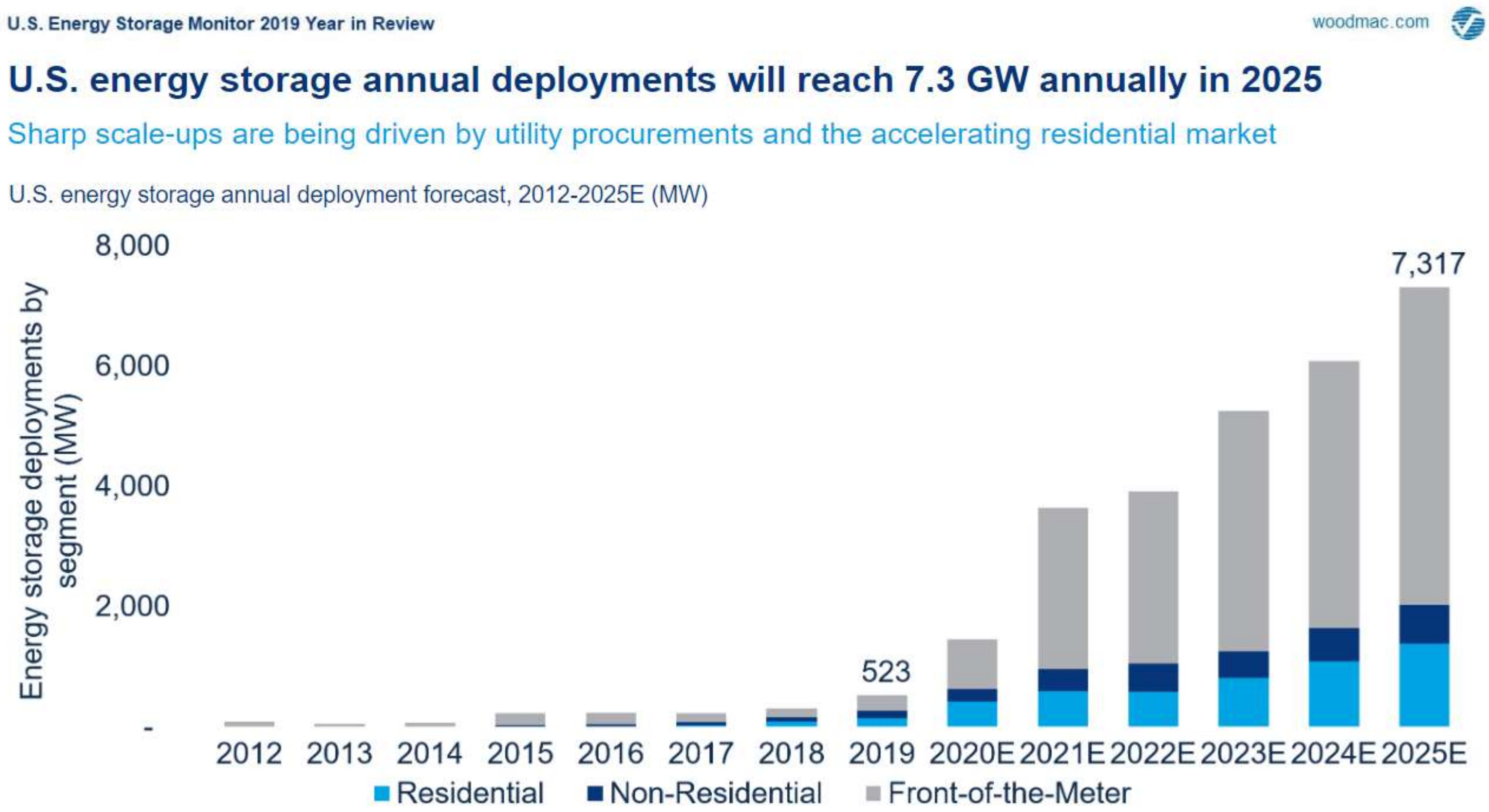
Global storage market will hit 15 GW annual deployments by 2024

Global annual energy storage deployments, historical and forecasted, 2013 – 2024(GW)

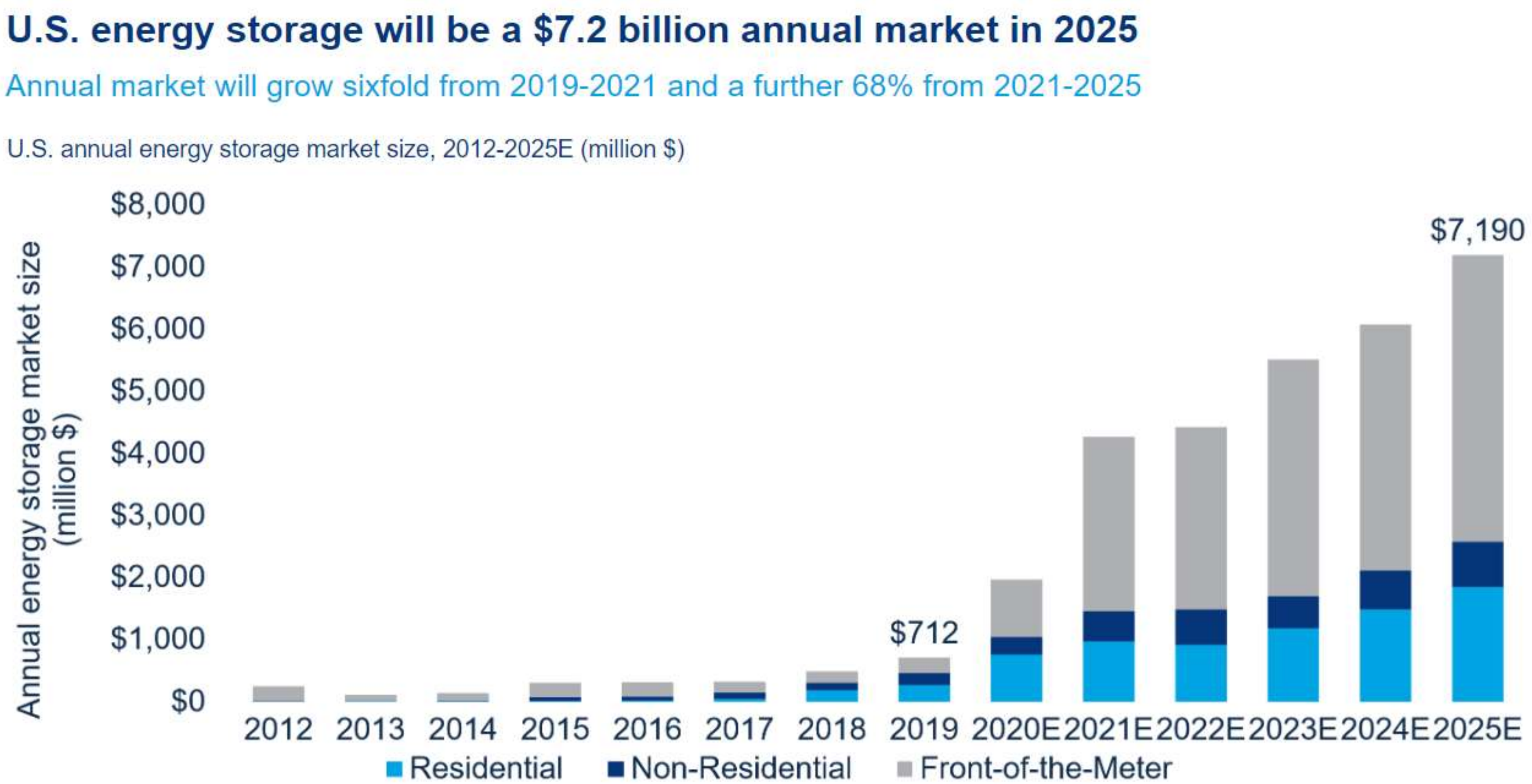


Source: Wood Mackenzie Power & Renewables

II. US deployments, > 7.3 GW/year by 2025



II. US deployments, > $7.2 BILLION by 2025



II. BESS – why batteries?

- Technology improvements and lowering cost
- Frequency control, voltage control,
- 100 millisecond responses (ERCOT 5 minute market)
- Easily scalable 1 to 1000 MWhrs
- Spinning reserve no fuel cost
- Reduce transmission upgrades
- Load shifting (peak solar to early evening)
- Eliminate needing a natural gas peaker plant
- Avoid brown outs and black outs (fast response)
- Balance system at end of transmission branches
- Can have power (MW) version vs energy (MWh) versions

II. BESS Challenges

- Fragile
- High charge and discharge rates create lots of heat
- C-Rate is a measure of the rate at which a battery is charged or discharged. 1.0 = 1 hour. 0.5 = 2 hours.
- Lithium may be limited resource
- Overheating can create thermal runaway (fire)
- Very heavy
- High temps void warranty and battery performance drops drastically
- DC results in efficiency losses converting to AC
- End-of-life disposal is unknown
- No long-term performance data available

II. BESS – Battery types

Currently battery types used are:

A. Lithium ion Battery (LIB), Positive Electrode material
   A. Lithium Nickel Manganese Cobalt (NMC) – vehicles, power tools, utility energy storage - 2008
   B. Lithium Nickel Cobalt Aluminium Oxide (NCA) electric vehicles – 1999
   C. Lithium Manganese Oxide (LMO), Hybrid electric vehicle, cell phone, laptop, 1996
   D. Lithium ferrous phosphate (LFP) Cheaper, slower response, large systems, buses
   E. Coming - CO2, graphene, other?

Technology is rapidly evolving. Plants are being planned, designed and built for batteries still in development.

II. Comparison of Battery costs (DOE)

Parameter	Li-Ion	Sodium -Sulfur	Lead Acid	Sodium Metal Halide	Zinc-Hybrid Cathode	Redox Flow
Cost ($/kW) 2018 / 2025	1,876 / 1,446	3,626 / 2,674	2,194 / 1,854	3,710 / 2,674	2,202 / 1,730	3,430 / 2,598
Cost ($/kWh) 2018 / 2025	469 / 362	907 / 669	549 / 464	928 / 669	551 / 433	858 / 650
Life (Years)	10	13.5	2.6	12.5	10	15
RTE Effic.	0.5%	0.34%	5.4%	0.35%	1.5%	0.4%
Response Time	1 Sec	1 Sec	1 Sec	1 Sec	1 Sec	1 Sec
Durability (Cycles)	7000	4000	800	4500	10000	++++

II. Benefits of Li-Ion Batteries

- Long life (15 years) vs. Lead-acid (3-7 years)
- Last Longer (Cycle Count)
- Density (x2 Lead-acid) (holds charge longer)
- Fast Charge / Discharge (0.9C charge, 6C discharge)
- Higher power
- Density Lightest of all metals

II. BESS – Manufacturers

Top Li-Ion Battery Manufacturers, by volume:

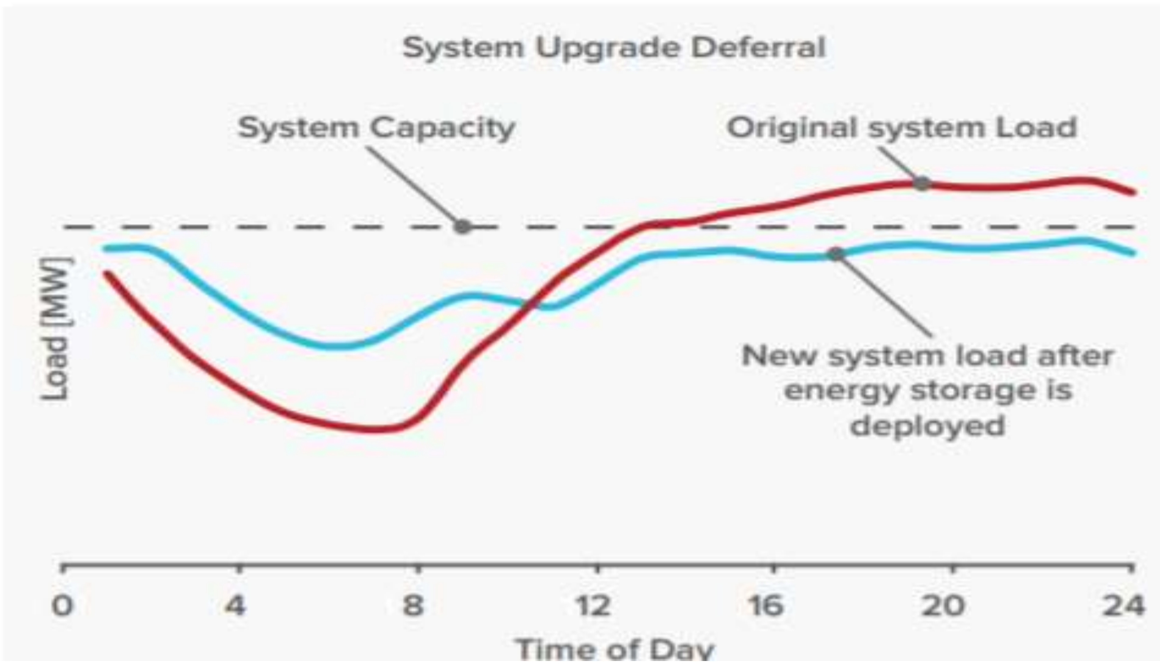
1. LG Chem (S. Korea) plans to triple production by end of 2020
2. CATL (China), planning a $2B factory in Germany; partnered with Powin Energy (Oregon) launching a solution with 4+ hour duration with 20-year warranty; partnered with Shenzhen KSTAR Science & Technology (China) to increase ESS manufacturing capacity
3. BYD Co. (China)
4. Panasonic (Japan)
5. Tesla (USA), Gigafactory is a JV with Panasonic
6. Samsung (S. Korea)
7. Korepower (Coeur d'Alene Idaho) Upcoming

II. BESS – Rewards – California prices

Reduced generation requirements

FIGURE 1

GENERIC SYSTEM LOAD PROFILE BEFORE AND AFTER ENERGY STORAGE IS USED TO DEFER A TRADITIONAL DISTRIBUTION SYSTEM UPGRADE.



II. BESS – Risks

- April 19, 2019, BESS system in Arizona caught fire and exploded, injuring 4 firefighters (burnt lungs/broken bones)
- APS is still planning to install 850 MW of battery storage by 2025
- Other infamous battery fires include:
    - Tesla Model S and Model X in Hong Kong and Shanghai in April 2019
    - Boeing's 787 Dreamliner airplane, 2013
    - Samsung Galaxy Note 7 phone and hoverboards
    - 35+ storage battery fires in South Korea in 2018/19
    - Kahuku HI, burned for 6 hours, fire fighters did not fight for hours as did not know if water ok. 2016

Note: In 2016 in Texas alone, there were 45 O&G fatalities

II. BESS – Risk Reduction

- UL 9540 qualifies safety of battery storage systems
- UL 9540A quantifies the thermal runaway and explosion hazard potential during a battery fire event
- Testing determines if battery fire will spread to adjacent batteries or not
- Testing determines off gassing volume and constituents for explosion prevention system design
- Storage systems must include explosion prevention per NFPA if an explosion hazard is identified
- Gas detection can be used as an early warning of a bad battery prior to thermal runaway
- Water can contain fire from spreading to adjacent racks or container
- Wider rack spacing, fire rated walls, and smaller rooms can minimize fire spread

II. BESS – Codes/Standards

Standards, not all adopted by all Authorities Having Jurisdiction (AHJs):

- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems
- UL 9540A "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems"
- FM Global "Development of Sprinkler Protection Guidance for Lithium Ion Based Energy Storage Systems"
- 2018 International Fire/Building Code (IFC/IBC)
- ASME (In the works?)
- ASHRAE Coming soon?

III. Coffman Experience and Expertise

- Feasibility studies
- Cost estimating
- Site layouts
- Thermal management building and containers
- Fire protection / site access and hydrants
- Fire protection inside buildings and containers
- Code studies analysis
- Electric DC design support (inverters and transformers)
- Seismic anchoring designs (racks / containers)
- AC aux loads to buildings and containers
- Civil site design for drainage and onsite storage of runoff

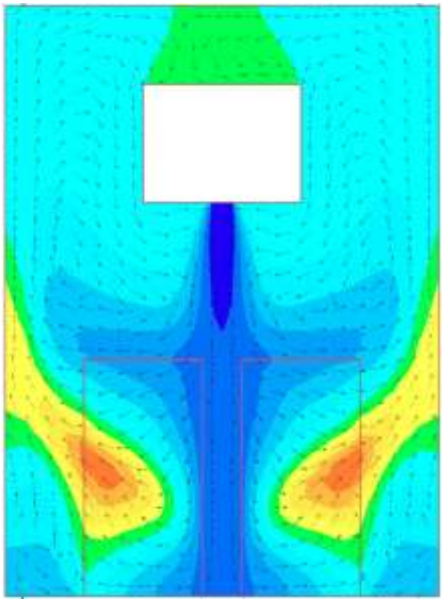
III. Battery Storage Facilities

Critical

Modeling to ensure HVAC system will not result in hot spots which could void battery warranties and/or increase risk for fire

Less - Critical

- Feasibility Studies
- Site layouts (drainage/collection)
- Solar Battery Life Cycle Costs
- Thermal Management
- CFD Computational fluid dynamic
- Heat/smoke dissipation modeling
- Fire Protection (site and facility)
- AC and DC Design support
- Seismic Anchorage



Battery Storage Li-ion,
4 MW, retrofit existing building

Client
DUDEK

UTILITY ENERGY STORAGE SOLUTIONS
Irvine, California

III. Battery Storage Facilities

Example Alaska Project

Battery/Flywheel Wind Energy Control

1 MW battery, 200kW flywheel

Client/ Owner
Chugach Electric Association, Inc.

MULTI-STAGE FLYWHEEL/BATTERY ENERGY STORAGE SYSTEM
Anchorage, Alaska

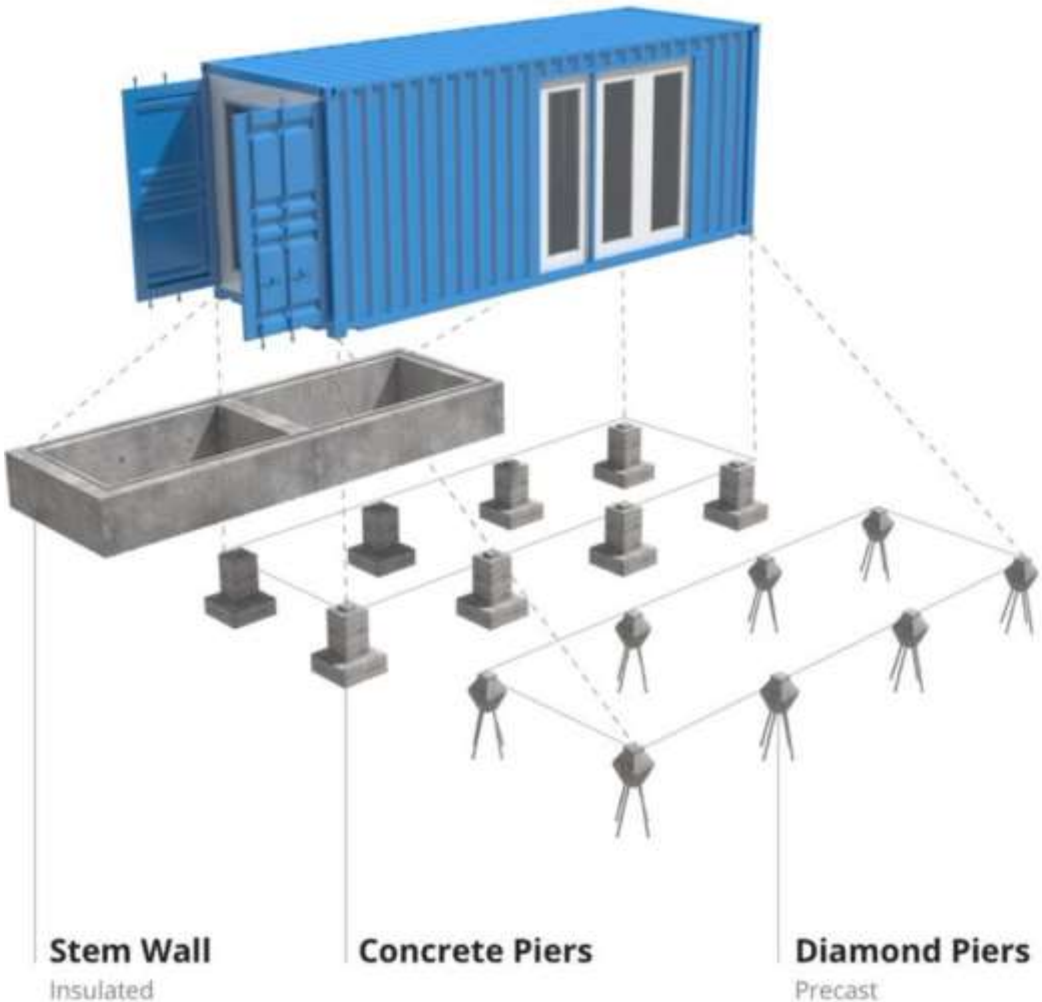
III. Battery Structural Loads

Battery racks are very heavy, building must support up to **<u>700+ PSF</u>**

- Battery racks are placed back to back with 6-12 inch spacing in back and $\geq$ 5' aisles between double rows
- Racks require strong foundation / seismic anchoring, thick slabs (12" – **<u>24" thick</u>**) and steel braced racking/frames
- Containers on slabs or piers
- Rack typically designed by battery manufacturer – large deep anchor bolts

III. Battery Foundation Types

- Slab on grade not shown
- Elevated helps provide electrical connection bends
- Piers allow field adjustment of cabling
- Rack typically designed by battery manufacturer; large deep anchor bolts (24 inches in some cases)
- Some racks installed individually or in blocks of prefab frames of many racks



III. BESS – System Services

FM Global excerpts

C.3.3 Transmission and Distribution Services

Strategically placed electrical energy storage used within a transmission or distribution infrastructure service may act as an energy buffer and thereby defer grid upgrades.

Applications include:

- Upgrade deferral
- Congestion relief
- Voltage support

III. BESS – System Services

FM Global excerpts

C.3.4 Customer Energy Services

EES used within customer energy management is used to provide a customer related service. This can be enhancing the power quality, improving reliability and/or realizing additional profits for a customer.

Applications include:

- Power quality
- Power reliability
- Retail energy time-shift
- Spinning reserve
- Load shifting (solar/wind)
- Offset Peaker Plant
- Demand charge management

Thermal Management

- Large HVAC systems, similar with large data centers…
- Except heat loads vary widely depending on charge rate and discharge frequency and rate
- Heat loads vary also on an hourly basis vs. data centers which have a more constant heat load
- C-rate means 1.0 full charge in 1 hour
    - 2.0 = full charge/discharge in 30 minutes
    - 0.5 = full charge/discharge in 2 hours

- Faster the charge or discharge, the more heat produced
- 0.5C rate can produce half heat of 1C rate
- C rate limited by manufacturer (time and Max rate)

Fire Protection UL 9540 / 9540A

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

- Full Scale Fire testing
- Provides design criteria required for system design compliance
- Typically required for Fire Marshall approvals

Answers the questions:

- Does a thermal runaway condition propagate from one battery component to another?
- Cell to Cell, Module to Module, Rack to Rack
- Initiated in one component using an artificial thermal stimulus
- Effects on neighboring components are observed
- Effects of system mitigations are observed
- Gas and heat production measured

Fire Protection

23 fires in S. Korea over past 2 years (+4 GWh installed in 2018)

Top 4 reasons for South Korea energy storage fires:

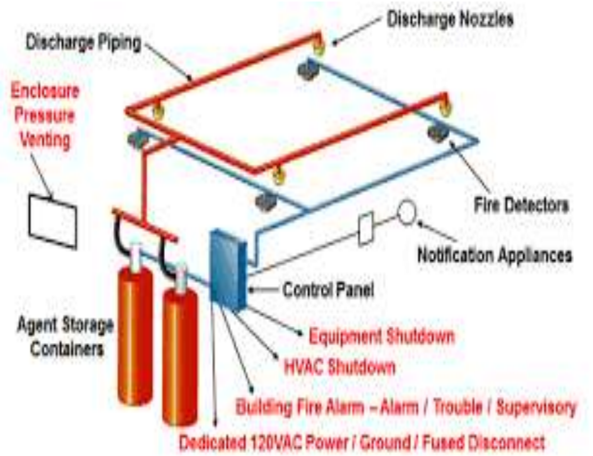
1. Insufficient battery protection systems against electric shock
2. Inadequate management of operating environment
3. Faulty installations (faulty wiring, mechanical damage)
4. ESS System Integration (inadequate information sharing between systems)

Fire Suppression - Water

- Water suppression is preferred to contain a fire resulting from thermal runaway
- Will not extinguish battery fire, meant to prevent spread of thermal runaway
- Not required for un-occupied containers, typically being provided for secondary fire protection, in addition to clean agent
- Water density varies depending on UL9540A Test Results (min. of 0.3 gpm / ft^2 over 2,500 ft^2)
- Significant water flowrates required (since 90 minutes of water required)
- Water supply meets current code requirements - Some areas do not have utility water at remote sites
- Fire pump and tank may be required

Fire Suppression – Clean Agent

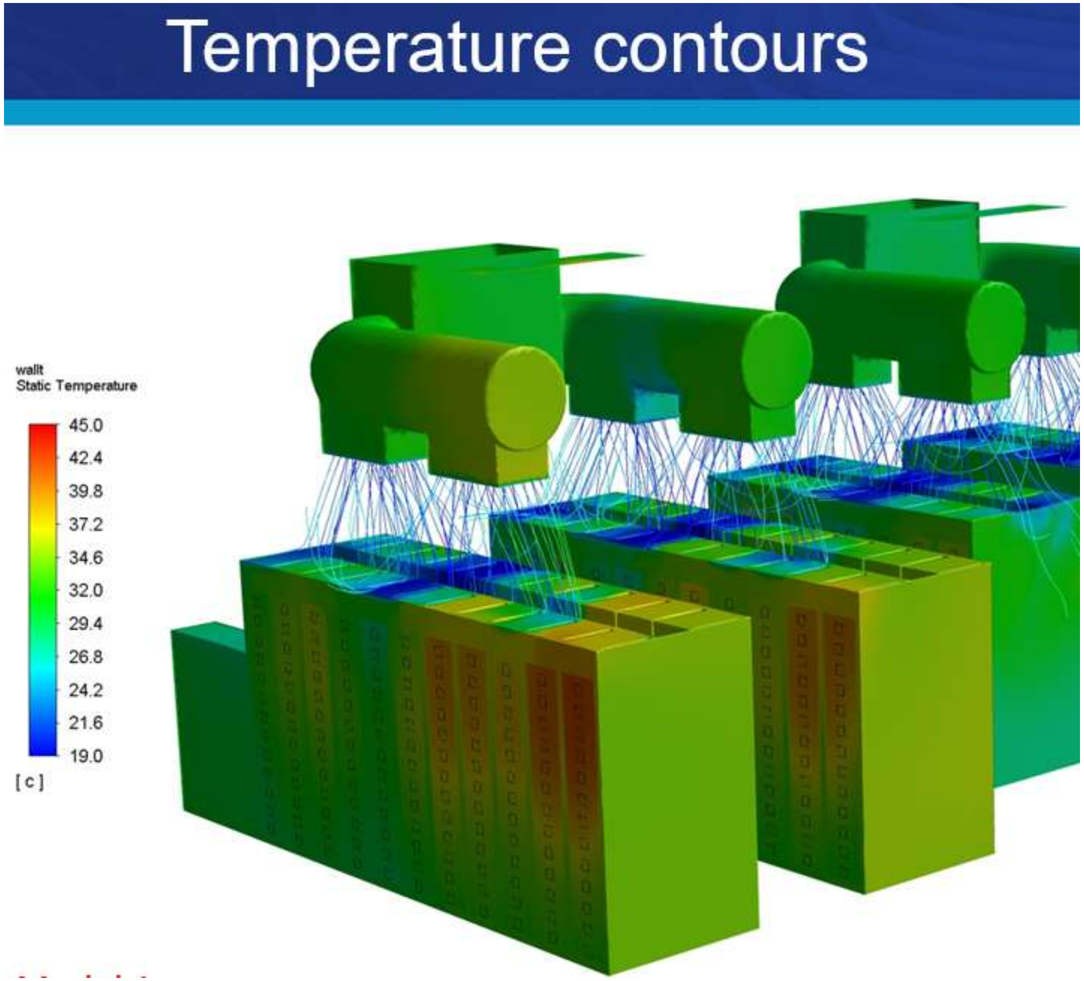
- Doesn't require water lines
- No Fire water pumps or storage
- Higher cost for building solutions
- Generally deemed ineffective for full extinguishment due to length of time battery fires burn once ignited (up to ~2 hours)
- Doesn't limit heat from thermal runaway – interrupts chemical reaction of fire
- Additional space needed for clean agent storage
- Reduces damage to batteries not involved in fire event
- No hazardous water runoff



CFD (Computational Fluid Dynamics)

- Some Owners require CFD Analysis (Manufacturers are doing on module and rack level)
- Costly ($10 - 30,000+ dollars) Building vs. Container varies drastically
- Very complex programs (ANSYS, SIMFLO, Flow3D, other)
- Not good data from battery manufactures
- Can use containment walls to lower battery temps
- Thermal air flows not always intuitive
- Can provide duct socks (multiple delivery points)
- Can use limited or extensive diffusers
- Can model battery modules separately or as a rack
- Used to find dead spots and placing Temperature, Humidity, Smoke, and Gas sensors

CFD (Building)

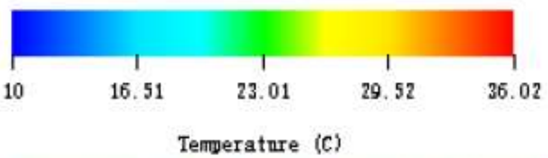


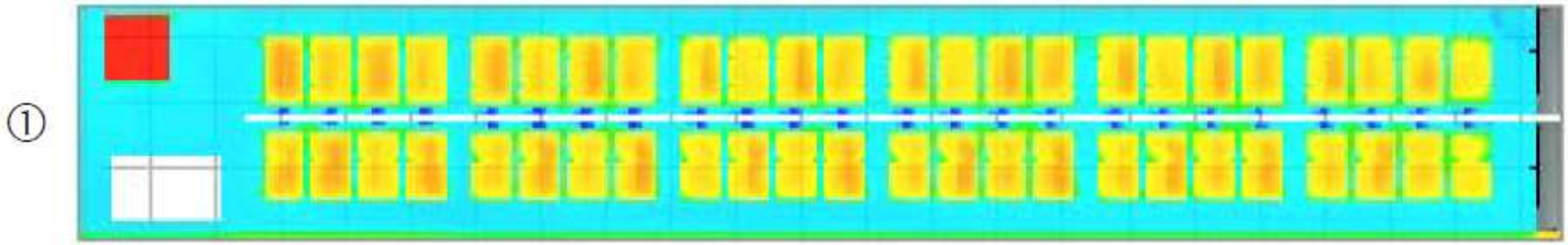
CFD (Container)

Simulation results Temperature field distribution

Scenario 3: EoL capacity 24 racks

0.25C Discharge





NFPA 855

National Fire Protection Association 855 = Standard for the Installation of Stationary Energy Storage Systems

- May not be adopted at the project location
- To be used as code or guidance
- 2020 is the first edition of this standard

- Purpose: “This standard provides the minimum requirements for mitigating the hazards associated with ESS.”
- **Not retroactive**
- Min density of 0.3 gpm/ft2 over area of room or 2500 ft2, whichever is smaller (750 gpm x 1 hour = 45,000 gal)
- If no reliable water supply, NFPA 1142 shall apply onsite storage, tanker trucks, etc.

Explosion Prevention

Recent 2019 battery fire in Arizona:

- A single rack caught fire and burned (thermal runaway)
- Enclosure exploded when first responders opened the door, injuring fire fighter
- Thermal runaway cells release explosive gases

- ➢ Code requirements include provision of explosion prevention if an explosion hazard is present.
- ➢ NFPA 855 requires explosion prevention to be provided using either NFPA 68, *Standard for Explosion Prevention by Deflagration Panels* **OR** NFPA 69, *Standard on Explosion Prevention* to reduce the risk of explosion during a fire
- ➢ Explosion prevention system design requires criteria from full-scale fire tests to complete sizing calculations

Explosion Prevention

- Off-gas detection can prevent thermal runaway (early power shut off to battery)

A firefighter unfurls a hose in front of the burnt-out ruins of a factory for lithium-ion batteries in Oelbronn-Duerrn, Germany on March 9, 2018. *Photographer: Uwe Anspach/Picture Alliance via Getty Images*

Gas Detection

- Individual cell off-gassing is the first indication Thermal Runaway is imminent unless isolation is initiated
- Gas detection can allow batteries to be taken off line prior to major thermal runaway event evolves to smoke development or fire
- Gas detection can be used to activate exhaust system for NFPA 69 compliance
- Gas detection can give fire fighters information on environment inside a container/building
- Gas production data from battery event not well known

<u>Gas detection can be:</u>

- ➢ Integrated with smoke detection
- ➢ Stand alone system
- ➢ UL certified is basic requirement (new types do not meet)
- ➢ Some owner's do not require gas detection
- ➢ Testing can show gas detection is not required if minimal gas production or by providing explosion prevention

Containers Vs. Buildings

Containers – Pros

- Fabricated off site so can be cheaper
- Can make piece of EQUIPMENT so building codes do not apply and limited fire protection requirements
- Possibly shorter site construction schedule

Containers – Cons

- Need more land per MW
- More cabling for site
- More aux loads for cooling
- More expensive HVAC per ton
- Shipping schedule longer
- Place to store batteries before start up
- Harder to control humidity and other issues with just wall mount HVAC units
- Foundations more complicated

Containers Vs. Buildings

Buildings – Pros

- More cost effective for larger systems (> ~50MW)
- Less land per MW
- Can have fewer/larger HVAC units serving more batteries
- Prefab buildings mature industry
- Tilt up can be very cost effective and fast schedule
- Simpler electrical routing and consolidation

Buildings - Con's

- More time required to create custom building design
- AHJ will get more involved for permitting
- Additional maintenance components
- Complex permitting
- More local labor
- Water supply to site most likely required
- Crane support limited

Thank You For Your Time

Feel free to ask us any questions you might have.

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COFFMAN ENGINEERS