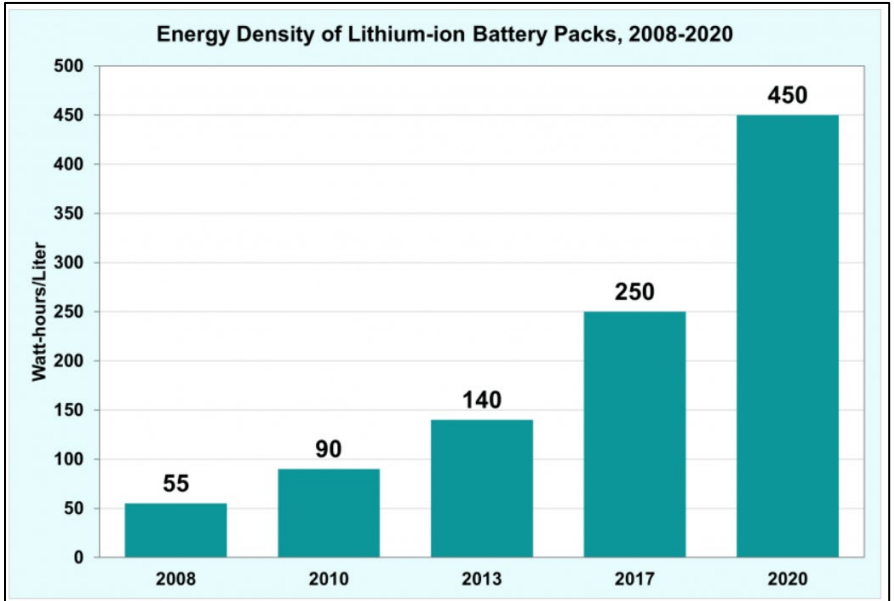
LITHIUM ION BATTERY EMERGENCY RESPONSE CHALLENGES

Bryan Vasser, EPA R4 OSC

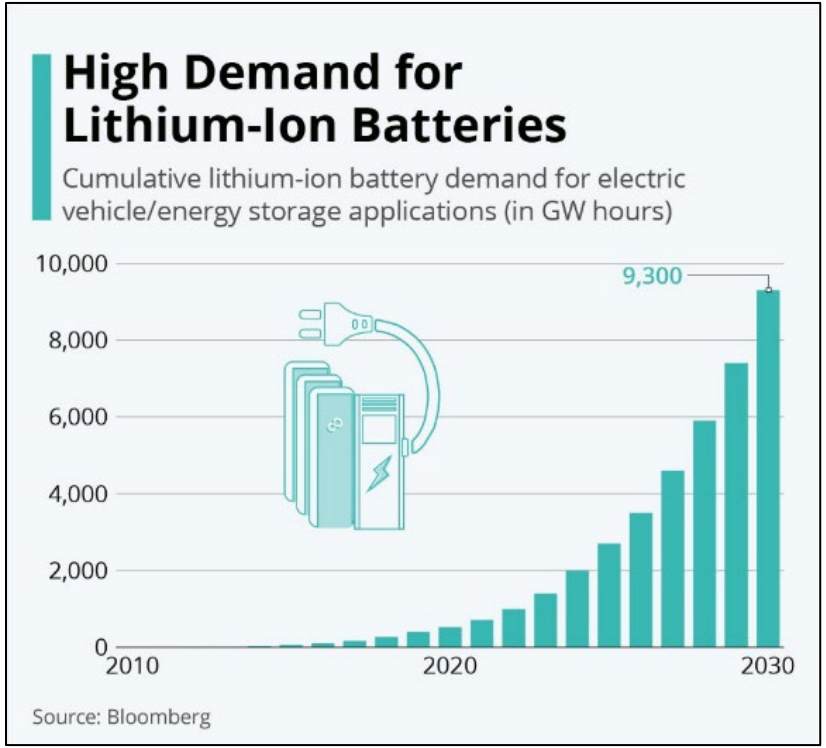
Objectives

- Background
- Current Response Tactics
- EPA Case Studies
- Air Monitoring Considerations
- Shipping
- Disposal Challenges

Battery Fires are on the Rise



Source: Nitin Muralidharan, Ethan C. Self, Marm Dixit, Zhijia Du, Rachid Essehli, Ruhul Amin, Jagjit Nanda, Ilias Belharouak, Advanced Energy Materials, *Next-Generation Cobalt-Free Cathodes – A Prospective Solution to the Battery Industry's Cobalt Problem*, January 2022.



Lithium-Ion Battery Types

18650
18x65mm

2170
21x70mm

Prismatic
Cell

Pouch
Cell

Cylindrical Cells (18650) are the most common cell in mobility (bikes, scooters, etc.) and are used by electric vehicles with 3000 to 7000 cells

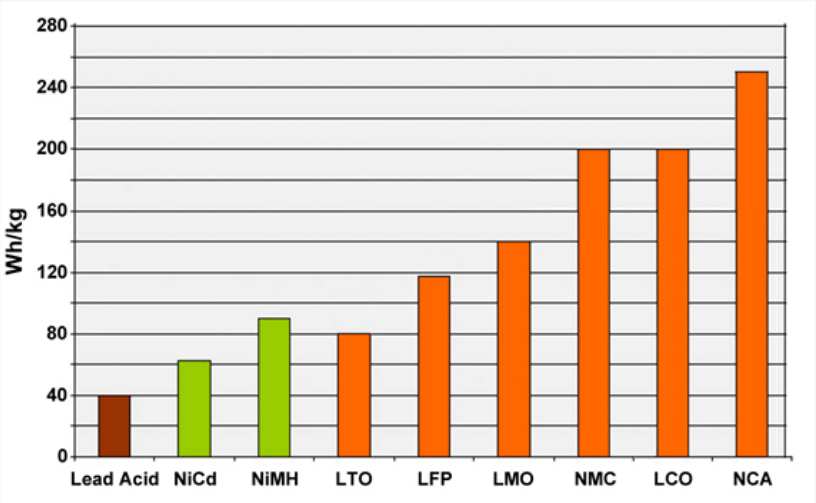
Prismatic and Pouch Cells are found in industrial and consumer electronics, respectively; both are used in electric and hybrid vehicles

LIB Chemistries

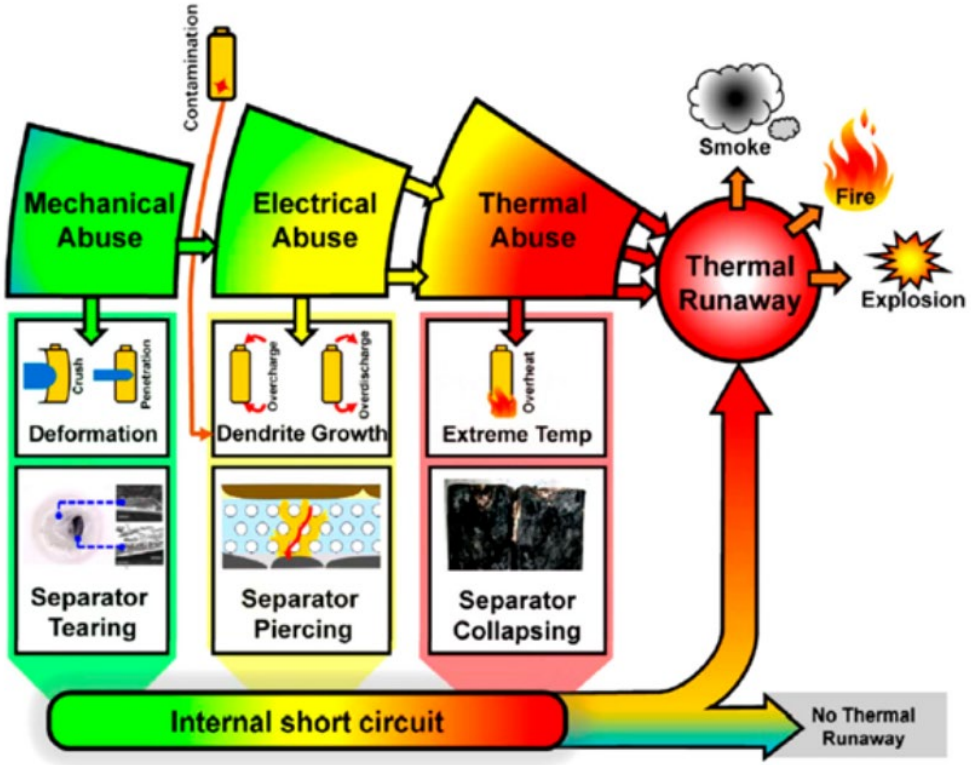
Chemistries cannot always be mixed in recycling

Acronym	Name	Formula
LCO	Lithium Cobalt Oxide	$LiCoO_2$
NCA	Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$
NMC	Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$
LMO	Lithium Manganese Oxide	$LiMn_2O_4$
LFP	Lithium Iron Phosphate	$LiFePO_4$
LTO	Lithium Titanate	Li_2TiO_3

Energy Density



Li-Ion Battery Hazards and Failure



Additive Mechanism

Thermal Runaway and Propagation

Macro Propagation

Not a Normal Fire!

- Very toxic atmospheres
- High burn temperatures
- Can burn without Oxygen **(can't smother!)**
- Explosive potential **(hydrogen gas)**
- Thermal Runaway reaction
  - Chemical reaction – rapid degradation
  - Nearly impossible to stop once it starts
  - Could happen in seconds or days
- Re-ignition is common

  minutes to months later!

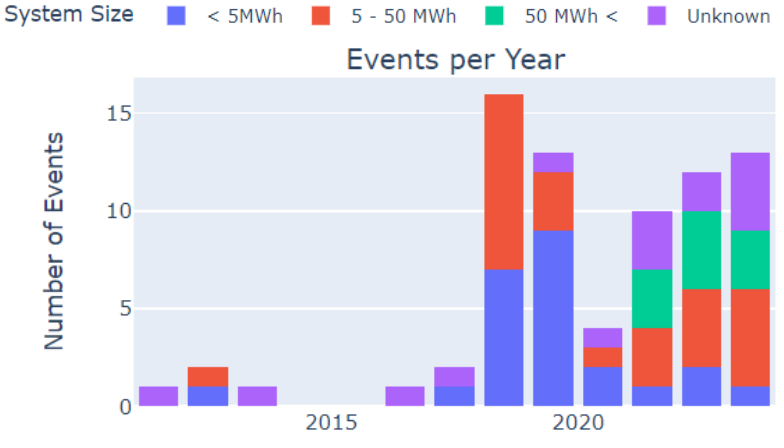
Three Primary Presentations of LIB

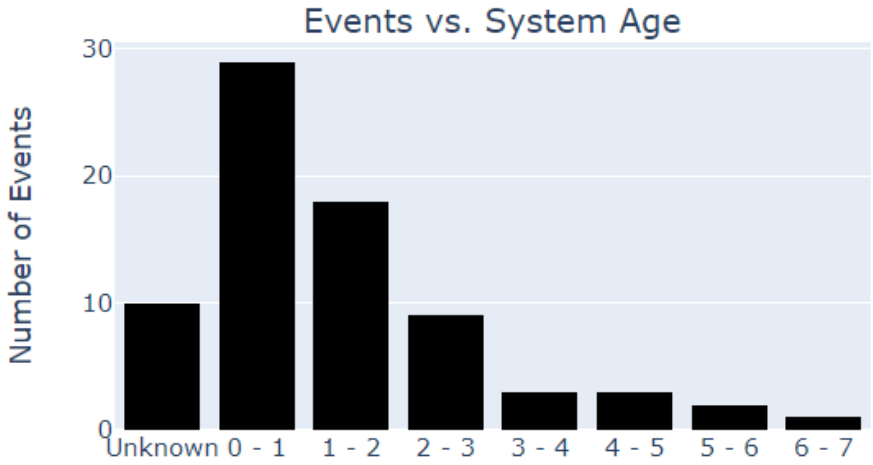
Energy Storage Systems

Electric Vehicles

Micro-mobility

BESS – Failure Events





Source: storagewiki.epri.com/index.php/BESS_Failure_Event_Database

BESS Fires - Tactical Considerations

Response

- Determine if batteries involved
- Shutoff/isolate
- Do not approach or access

Life safety

- Structural Fire Gear and SCBA
- Evacuate/Shelter-in-Place
  - Distances presume HF:
    - initial 100m
    - then protect 0.3-1.8km based on wind

Incident Management

- Let it burn (hour or days)
- Prevent propagation, protect exposures
- Use low GPM
- Runoff: minimize, contain or redirect

BEV Damage

LIB Location: Usually under the vehicle

Battery-involved fire?

- White smoke
- Hissing/popping sounds

Offensive firefighting:

- Water for cooling – thousands of gallons!
- Apply up into battery

Defensive firefighting:

- Let it burn & protect exposures
- Store 15m from exposures
- **Rekindle can occur days or weeks later!**

Tesla – Cylindrical Cell Batteries

18650 cell generation

LOTS of water required to extinguish

BEV Fires - Tactical Considerations

Response

- Determine if batteries involved
  - Most EV fires **do not** involve LIBs
- Refer to vehicle-specific ERG

Life safety

- Structural Fire Gear and SCBA
- Rescue, check for victims
- Chock wheels
- Evacuate/Shelter-in-Place
  - Distances presume HF: initial 100m

Incident Management

- Non-LIB – normal vehicle fire
- LIB – let it burn
- **No foam**
- Stay away from high voltage battery

Lists of ERGs are at

NFPA.org

EnergySecurityAgency.com

BEV – Emergency Response Guide

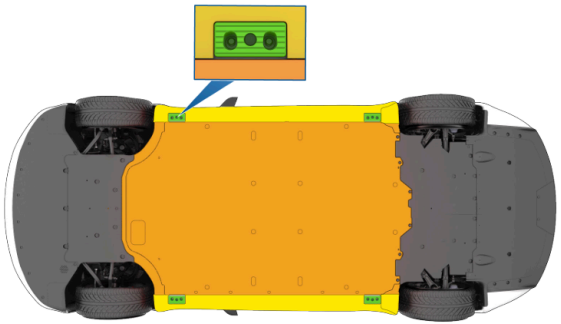
STABILIZATION / LIFTING POINTS

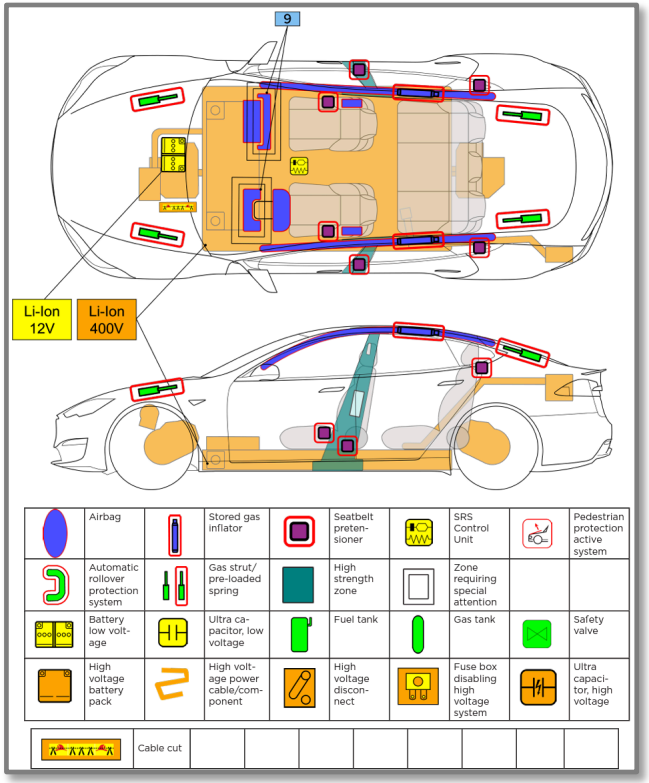
The high voltage battery is located under the floor pan. A large section of the undercarriage houses the high voltage battery. When lifting or stabilizing Model S, only use the designated lift areas, as shown in green.

WARNING Be careful to not damage the battery pack while stabilizing / lifting the vehicle.

WARNING The vehicle should be lifted or manipulated only if first responders are trained and equipped at the technician level per the applicable country's national fire training requirements and are familiar with the vehicle's lifting points. Use caution to ensure you never come into contact with the high voltage battery or other high voltage components while lifting or manipulating the vehicle.

WARNING DO NOT USE THE HIGH VOLTAGE BATTERY TO LIFT OR STABILIZE MODEL S.





BEV Fire - Tactical Considerations
Inside or Underground

FSRI and UL Fire R&D, 2022

Hazards from Lithium-ion Battery Thermal Runaways in Residential Garages

Simulated gas mixture from a 18kWh residential ESS in thermal runaway, consisting of CO, CO2, H2, and CH4

Micro-Mobility Devices

- Largest number of LIB incidents
- FDNY LIB micro-mobility fires
  - 44 in 2020
  - 220 in 2022
- Public exposure concerns
  - Stored and charged inside occupied residences and businesses
  - Stored near entry and exit ways
  - Can ignite with little-to-no warning
  - **<u>Rekindle is likely</u>**

Micro-Mobility - Tactical Considerations

Response

- Treat uninvolved LIB as UXO
- Outdoors – allow device to burn
- Indoors – attack residential fire

Life safety

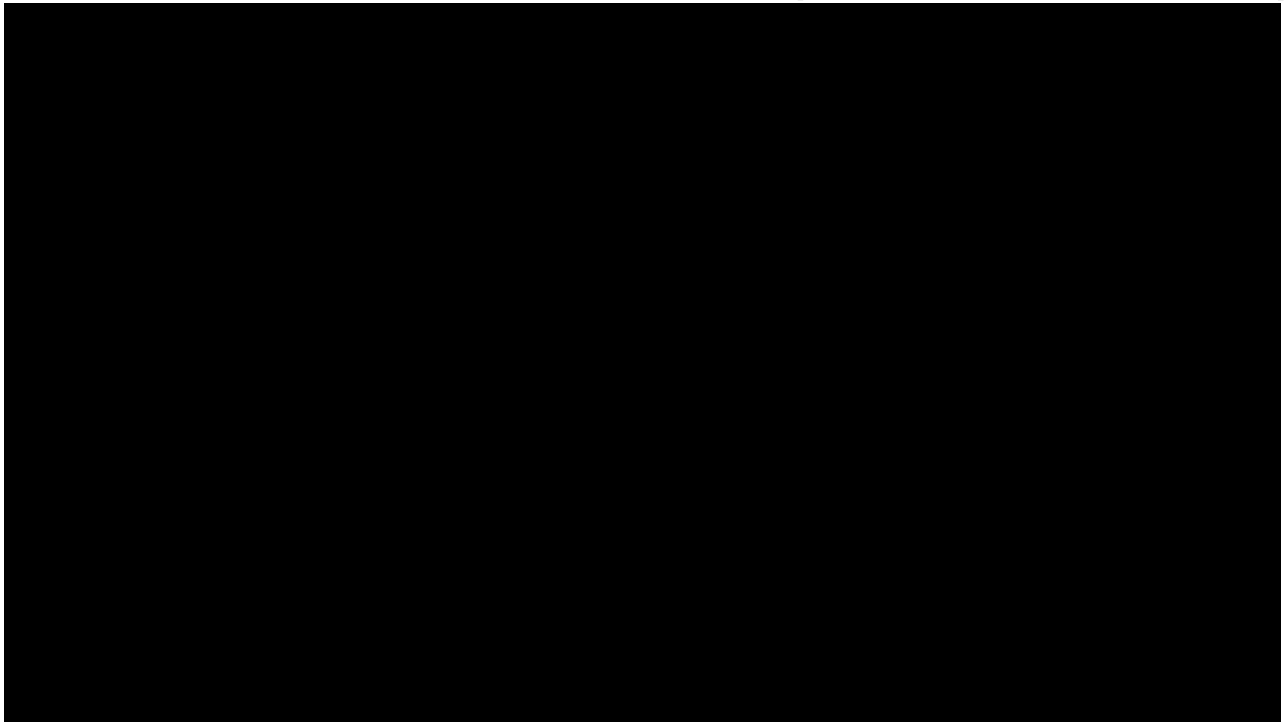
- Structural Fire Gear and SCBA
- Rescue, check for victims
- Evacuate
  - Distances presume HF: initial 100m

Overhaul

- Wear SCBA
- Move LIB to safe location
- De-energize LIB

LIB Considerations in Firefighting

- Rapid Failure, Overhaul, Toxic Atmosphere, Rekindle, Explosive



EPA Site Types

- Warehouses
  - Large numbers of a variety of batteries
- In Transit
  - Typically difficult due to location
- BESS
  - Large single battery type, difficulty in fighting fire and later disposal
- Natural Disasters
  - Large number, spread out, difficult to assess

Typical Problems Encountered During Response

- Assessing the public exposure/responder exposure
- PPE contamination
- Assessment of battery integrity
- Shipment of damaged batteries
  - Discharging
  - Packaging
  - Destruction
- Disposal/Recycling Capacity

Lakes Parkway Fire Response

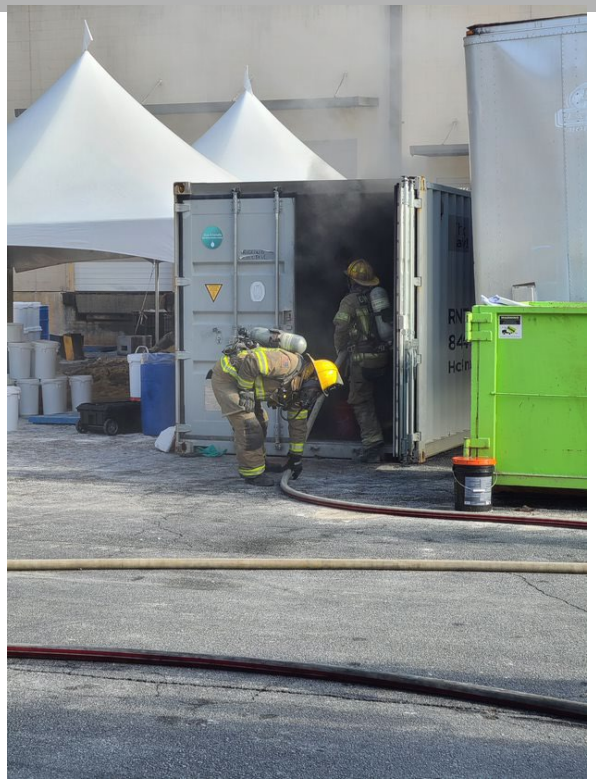
- Fire Department responded to facility, twice, three days apart and requested EPA assistance

Damaged Batteries are Unpredictable

First Fire of the Day – recently packaged bucket

Technically not a Fire

Second Fire of the Day – bucket packaged 5 days ago




20
GWINNETT
JACKSON

Aftermath

- Approximately 20 buckets were damaged during the second fire
- The bucket that caught fire had been packaged approximately 5 days ago and not been touched/moved for 4 days

Stop Work

Primary Goal:

- Stop calling the Fire Department

Secondary Goals:

- Stop having fires
- Find a way to safely package/ship/dispose of the DDR batteries

Deenergized batteries and Shipped under Special Permit

- Salt water solution – Approximately 0.5% NaCl
- 1 lb NaCl per 25 gallons water
- Soak from 3 days to 3 months
- Potentially HF, Cl2, HCl, other gases similar to plastic fires released during combustion
- 24 hour results indicated full discharge of test batteries

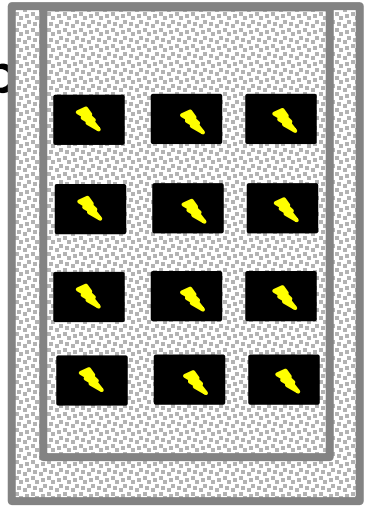
DOT SP-21329 – held by R4, site specific

- Special Permit to package multiple “large” lithium-ion batteries (>300Wh, 14 lbs)







In Transportation

- I-15 Freeway Closure
- BESS in transit

I-75 Explosion – June 29, 2024

CAMINO INCIDENT
SAN DIEGO COUNTY
BATTERY ENERGY STORAGE SYSTEM FIRE

INCIDENT

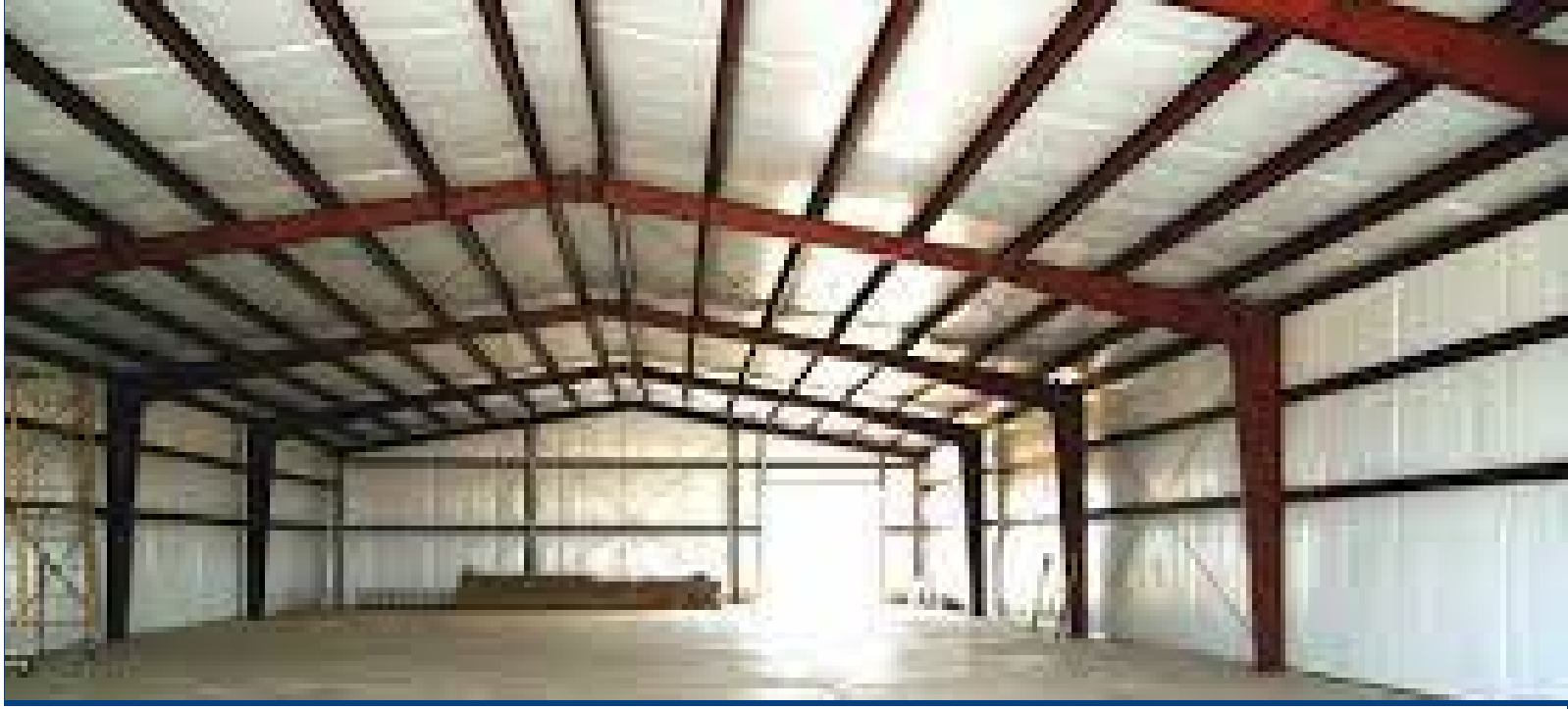
- May 15th, 2024 - CAL FIRE / San Diego County Fire Protection District
- Gateway Energy Storage Facility in Otay Mesa, San Diego County.
- The building's integrated inert gas fire suppression system activated but was unable to extinguish or contain the fire which led to a thermal runaway event inside one of the battery modules and a cascading propagation within the battery racks resulting in a large-scale commercial fire that took 5 days to stabilize.
- The last thermal event inside the building was noted 9 days after the onset of the incident.
- The fire remained contained to the building of origin and is now in the remediation phase that will take building owners months to complete.

AGENCIES

- CAL FIRE / San Diego County Fire Protection District - IC
  - TYPE 3 IMT
- San Diego Fire-Rescue
  - SDFD Hazmat
  - SDFD Bomb Squad
  - US&R CATF8
- Chula Vista Fire Department
- San Diego Police Department
- SD Department of Environmental Health and Quality

GATEWAY BATTERY ENERGY STORAGE SYSTEM

OTAY MESA, CA



BESS Frame

CAMINO INCIDENT SITE

Points of Interest

- Fire Department Connection
- Hydrant

Transformers

- Transformers

Buildings

- 1
- 2
- 3
- 4
- 5

Division Labels

- Div. A
- Div. B
- Div. C
- Div. D

N W E S

0 0 0.01 0.01 0.02 Miles

Summary of Events

Disposal Challenge

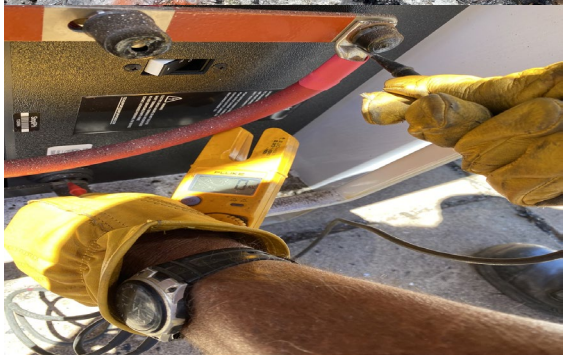
- Assessing the 15,000 battery modules
- Disposal/Recycling capacity for 10-12 million pounds of batteries (5000-6000 tons)
- In 2023, US recycling capacity estimated at 35,000 tons.

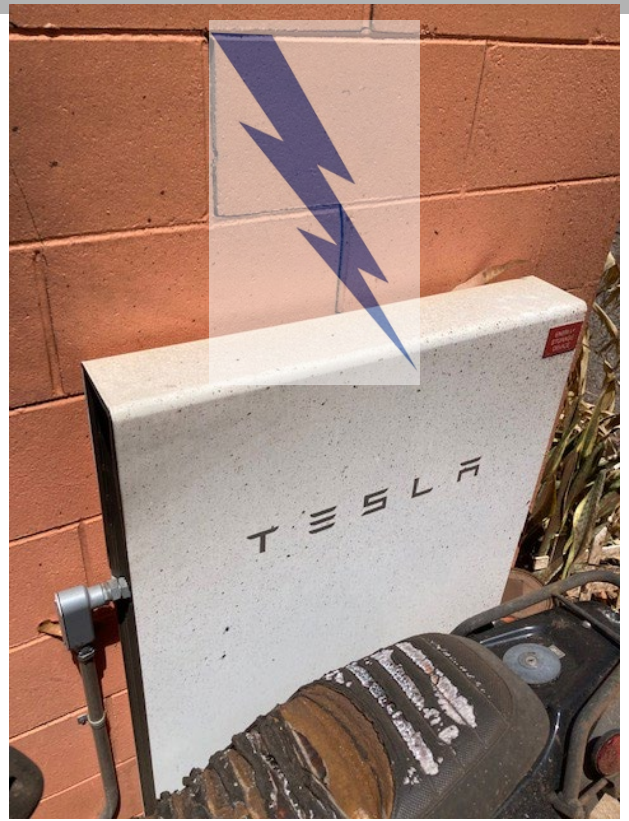
Natural Disaster Response

- Primary Sources:
  - Battery Energy Storge Systems
  - Electric Vehicles (Cars, go-carts, golf carts)

- Secondary Sources:
  - Limited mobility devices (bikes, scooters)
  - Power tools
  - Computers
  - Speculative/Creative Accumulation Sites

Reconnaissance of “Powerwalls” (Residential BESS)





EV Assessment

Staging

Battery Processing - Brining

Battery Processing - Crushing

Battery Processing - Shredding

Battery Processing - Shredding

Final Product

Disposal

Air Sampling Setup- EPA

SAN DIEGO LITHIUM-ION BATTERY FIELD STUDY DATA SUMMARY:

AIR MONITORING

Run	Test Media	Air Monitoring Data							
1	4 LiFePO4 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	-2.7	-1	0	0	0	0.001
		Max	20.9	0	5	0	0.8	0.58	0.707
2	4 LiFePO4 18500 SOC Unknown		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	-2.7	0	0	0	0	0
		Max	20.9	9.8	36	0	1.1	20	10.082
3	8 LiFePO4 18500 "Low SOC"		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	-2.1	0	0	0	0	0
		Max	20.9	66.5	171	2	3.9	0.95	7.567
4	8 LiFePO4 18500 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	-0.6	3	0	0	0	0
		Max	20.9	36.4	52	0	1.4	20	35.439
5	12 NMC (Nuon) 18650 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	-1.8	-2	0	-0.8	0	0
		Max	20.9	1.1	3	0	0	1.62	23.533
6	44 NMC 21700 Zheijang Skateboard 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	19.4	0	0	0	-0.6	0	0
		Max	20.9	135	2460	6	18.2	1.08	100
7	8 NMC Mollicel ISS 21700 <100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.2	0	14	0	1.6	0	0
		Max	20.9	50.5	1190	3	5.8	0	1.439
8	65 NMC KULR Ebike & Amazon 18650 SOC "as shipped"		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	0.3	5	0	0.6	0	0
		Max	20.9	26.4	206	0	1.4	0	0.188
9	18 NMC Mollicel ISS 21700 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	0	0	0	0	0	0.004
		Max	20.9	0.6	3	0	0.6	0	100
10	2 LiFePO4 ESS (Prismatic) 1 charged, 1 uncharged		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	20.9	2.1	3	0	0	0	NA
		Max	20.9	165	350	4	4.2	0	NA
11	48 NMC Zheijang Skateboard 21700 <40V SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	18.9	2.8	12	0	0	0	0.005
		Max	20.9	94.5	910	3	3	0.49	100
12	48 NMC Zheijang Skateboard 21700 100% SOC (49.6V)		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	18.9	2.1	10	0	-2.6	0	0.003
		Max	20.9	87.5	1560	4	13.1	20	100
13	3 x NMC Zheijang Skateboard in Akkugrain Box (144 cells total) 100% SOC		O2 %	VOC	CO	LEL %	HCN	HF	Particulate
		Min	19.1	0.4	0	0	0	0	0.005
		Max	20.9	780	11400	37	80.5	0	100

Yellow = over OSHA PEL, Green = H2 over MIE 4% LEL

Contaminant/Sensor	Action Level
Hydrofluoric Acid (HF)	Cal/OSHA PEL = 0.4 ppm, STEL 1 ppm
Hydrogen Cyanide (HCN)	Cal/OSHA PEL = 10 ppm, Ceiling = 4.7 ppm
Hydrogen (H2) LEL%	Minimum Ignition Energy (MIE) is 4,000 ppm or 4% by volume
Carbon Monoxide (CO)	Cal/OSHA PEL = 25 ppm, Ceiling = 200 ppm Also a 40% cross-sensitivity with H2

SAN DIEGO LITHIUM-ION BATTERY FIELD STUDY DATA SUMMARY:

AIR SAMPLING

Sampling Method	Media	Target Analytes
ASTM-D-1945	Tedlar Bag, vacuum box, pump	H2, CO, O2 ppm (v/v) and (m/m)
NIOSH 6010	Colorimetric tubes, pump	HCN
NIOSH 7902	Filter cassette, pump	HF (vapor and soluble particulate)
NIOSH 7303	Filter cassette, pump	Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, Tl, V, Zn Expanded list: Al, Fe, Mn, Sr, Sn, Ti

Run #	Test Media	Air Sampling Data									
3	8 LiFePO4 18500 "Low SOC"		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	260	<100	277k	ND	25	0.23			
			Cu	Ni	Sb	Zn					
		µg/m3	350	7	130	60					
7	8 NMC Mollicel ISS 21700 <100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	230	740	265K	ND	0.58	43			
			Ag	Ba	Co	Cu	Ni	Pb	Sb	Tl	Zn
		µg/m3	6	19	18000	29000	190k	30	570	130	9500
			Al	Fe	Mn	Sr	Ti				
		mg/m3	2500	140	21	1.1	64				
9	18 NMC Mollicel ISS 21700 100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	400	790	255k	2.5	0.94	1.3			
			Ba	Co	Cu	Ni	Sb	Tl	Zn		
		µg/m3	3	2800	650	26000	210	20	350		
			Al	Mn	Sr	Ti					
		mg/m3	2400	6.6	0.76	2.9					
11	48 NMC Zheijang Skateboard 21700 <40V SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	230	740	265k	ND	0.58	43			
			Co	Cu	Ni	Sb	Zn				
		µg/m3	220	43	1900	120	70				
			Al	Mn							
		mg/m3	70	0.24							
12	48 NMC Zheijang Skateboard 21700 100% SOC (49.6V)		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	240	1480	247k	0.87	0.77	24			
			Ba	Co	Cu	Ni	Pb	Sb	Tl	Zn	
		µg/m3	21	7600	7500	70000	430	1400	60	1100	
			Al	Fe	Mn	Sr	Sn	Ti			
		mg/m3	1000	12	6.9	0.83	21	4.2			
13	3 x NMC Zheijang Skateboard in Akkugrain Box (144 cells total) 100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	14400	16720	264k	ND	0.56	17			
			Ba	Co	Cu	Ni	Pb	Sb	Zn		
		µg/m3	46	3600	2300	33000	220	240	470		
			Al	Fe	Mn	Sr	Sn	Ti			
		mg/m3	650	13	0.54	0.15	21	1.8			

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NIOSH 7303	Filter cassette, pump	Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, Tl, V, Zn Expanded list: Al, Fe, Mn, Sr, Sn, Ti

Run #	Test Media	Air Sampling Data									
3	8 LiFePO4 18500 "Low SOC"		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	260	<100	277k	ND	25	0.23			
			Cu	Ni	Sb	Zn					
		µg/m3	350	7	130	60					
7	8 NMC Mollicel ISS 21700 <100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	230	740	265K	ND	0.58	43			
			Ag	Ba	Co	Cu	Ni	Pb	Sb	Tl	Zn
		µg/m3	6	19	18000	29000	190k	30	570	130	9500
			Al	Fe	Mn	Sr	Ti				
		mg/m3	2500	140	21	1.1	64				
9	18 NMC Mollicel ISS 21700 100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	400	790	255k	2.5	0.94	1.3			
			Ba	Co	Cu	Ni	Sb	Tl	Zn		
		µg/m3	3	2800	650	26000	210	20	350		
			Al	Mn	Sr	Ti					
		mg/m3	2400	6.6	0.76	2.9					
11	48 NMC Zheiang Skateboard 21700 <40V SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	230	740	265k	ND	0.58	43			
			Co	Cu	Ni	Sb	Zn				
		µg/m3	220	43	1900	120	70				
			Al	Mn							
		mg/m3	70	0.24							
12	48 NMC Zheiang Skateboard 21700 100% SOC (49.6V)		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	240	1480	247k	0.87	0.77	24			
			Ba	Co	Cu	Ni	Pb	Sb	Tl	Zn	
		µg/m3	21	7600	7500	70000	430	1400	60	1100	
			Al	Fe	Mn	Sr	Sn	Ti			
		mg/m3	1000	12	6.9	0.83	21	4.2			
13	3 x NMC Zheiang Skateboard in Akkurgain Box (144 cells total) 100% SOC		H2	CO	O2	HCN	HF (vapor)	HF (particulate, mg/m3)			
		ppm	14400	16720	264k	ND	0.56	17			
			Ba	Co	Cu	Ni	Pb	Sb	Zn		
		µg/m3	46	3600	2300	33000	220	240	470		
			Al	Fe	Mn	Sr	Sn	Ti			
		mg/m3	650	13	0.54	0.15	21	1.8			

Yellow = over OSHA PEL, Green = H2 over MIE 4% LEL

Occupational/Industrial Limits for Metals of Concern (µg/m³)

Metal	Carcinogen?	IDLH	NIOSH REL (10-hr TWA)	OSHA PEL (8-hr TWA)
Aluminum	No	-	10,000	15,000
Antimony [a]	No	50,000	500	500
Arsenic [a,b]	Yes	500	2b	10
Barium	No	50,000	500	500
Beryllium [a,c]	Yes	400	0.5	2
Cadmium [a]	Yes	900	N.E.	0.005
Chromium [a]	No	250,000	0.5	1
Cobalt [a]	No	20,000	0.05	0.1
Copper [d]	No	100,000	1	1
Iron	Yes	2,500,000	5,000	10,000
Lead [a,e]	No	100,000	50	50
Manganese [a,f]	No	500,000	1,000	5,000
Mercury [a,g]	No	10,000	0.1	100
Molybdenum	No	1,000,000	5,000	5,000
Nickel [a,h]	Yes	10,000	15	1000
Selenium [a,i]	No	100	200	200
Silver	No	10,000	10	10
Strontium	No	-	-	-
Thallium	No	15,000	100	100
Titanium	No	-	-	15,000
Tin	No	25,000	2,000	2,000
Vanadium [j]	No	35,000	50	50
Zinc	No	500,000	5,000	15,000

IDLH = Immediately Detrimental to Life and Health

NIOSH = National Institute of Occupational Safety and Health REL= Recommended Exposure Limit

OSHA = Occupational Safety and Health Administration PEL= Permissible Exposure Limit

a Metals designated as Hazardous Air Pollutants by the EPA.

b NIOSH REL for arsenic is a 15-minute ceiling

c OSHA PEL for beryllium has a 30-minute ceiling of 5 µg/m3

d Additional REL of 0.1 and PEL of 0.1 for copper fume

e NIOSH REL for lead is an 8-hour TWA standard

f NIOSH short term exposure limit (STEL) for manganese is 3,000 µg/m3 and the PEL is a

g NIOSH REL for mercury for skin is 50 µg/m3 and the REL is a ceiling

h Nickel as Ni(CO)4 has an IDLH of 14,000 µg/m3 and an REL and PEL of 7 µg/m3

i Selenium as SeF6 has an IDLH of 2000 µg/m3 and an REL and PEL of 400 µg/m3

j NIOSH REL for vanadium is a 15-minute limit

Helpful Links

- response.epa.gov/R4LithiumIonBatteryOutreach
- https://www.phmsa.dot.gov/lithiumbatteries
- https://www.epa.gov/recycle/used-lithium-ion-batteries