



Overview of Lithium-Ion Battery Hazards and Protection Strategies

**Special Legislative Commission to Advance
Lithium-Ion Battery Safety in Maryland**

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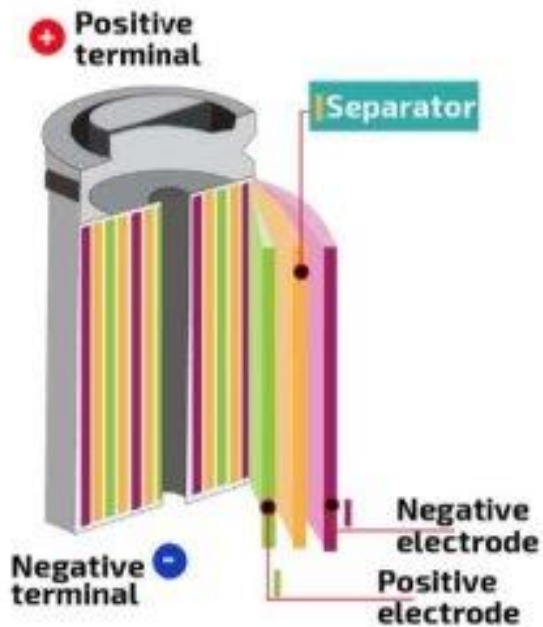
Outline

1. Overview of lithium-ion batteries (LIB): parts, types, sizes, and uses
2. Hazards of LIB and thermal runaway
3. Fire incidents involving LIB: causes, consequences
4. Fire detection and suppression options for LIB fires
5. Recycling and Damaged, Defective or Recalled Batteries



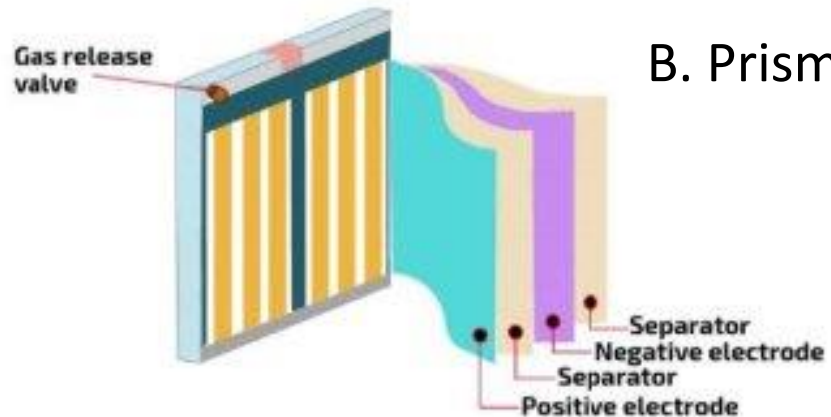
Battery Form Factor

A.



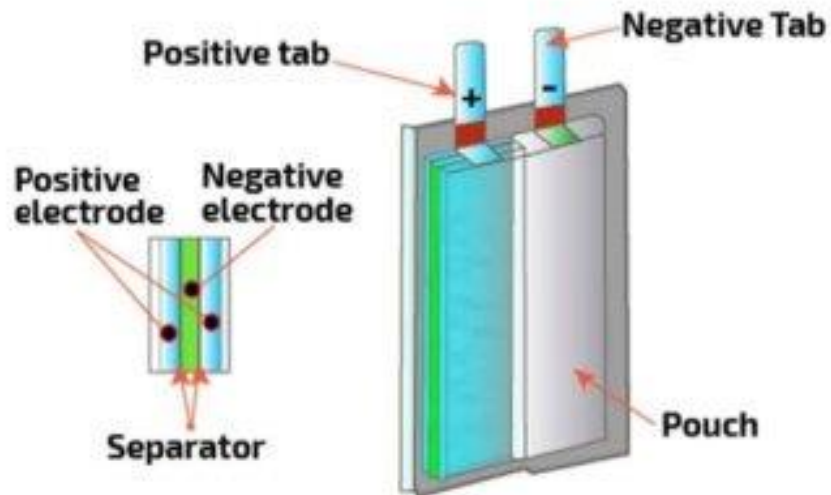
A. Cylindrical Cell

B.



B. Prismatic Cell

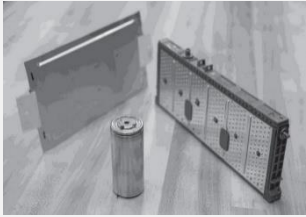
C.



C. Pouch Cell



LIBs from Cell to System



Cell

Smallest individual component



Module

*Cell integration
“Intelligence” added*



Unit

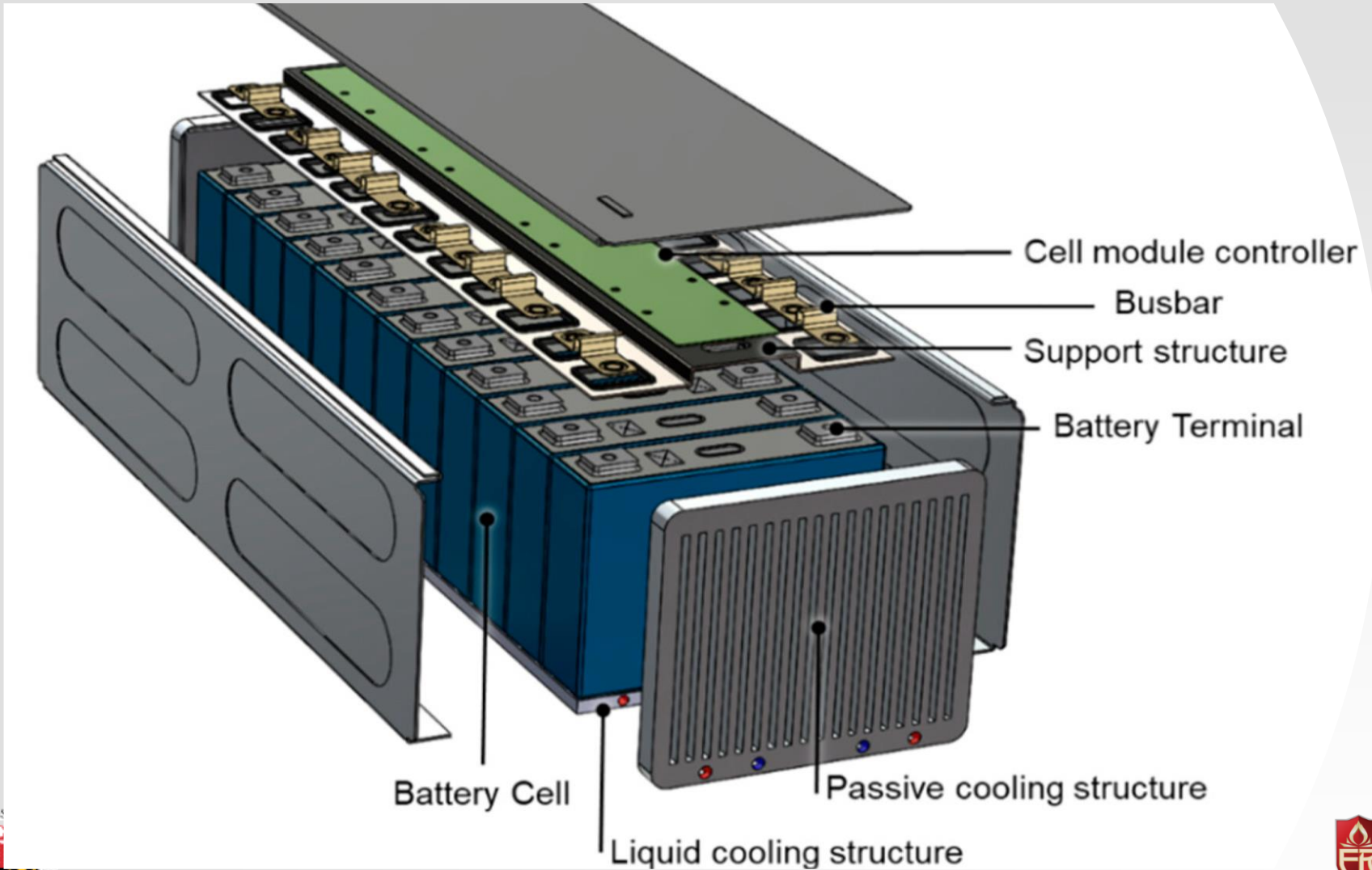
Module integration



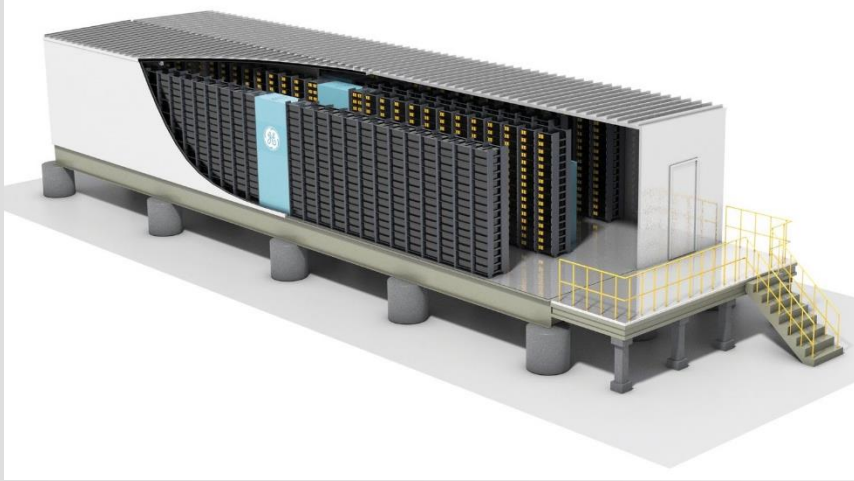
Container

*Includes FPE Features:
detection, suppression,
explosion control*

Module



Battery Energy Storage System (BESS)

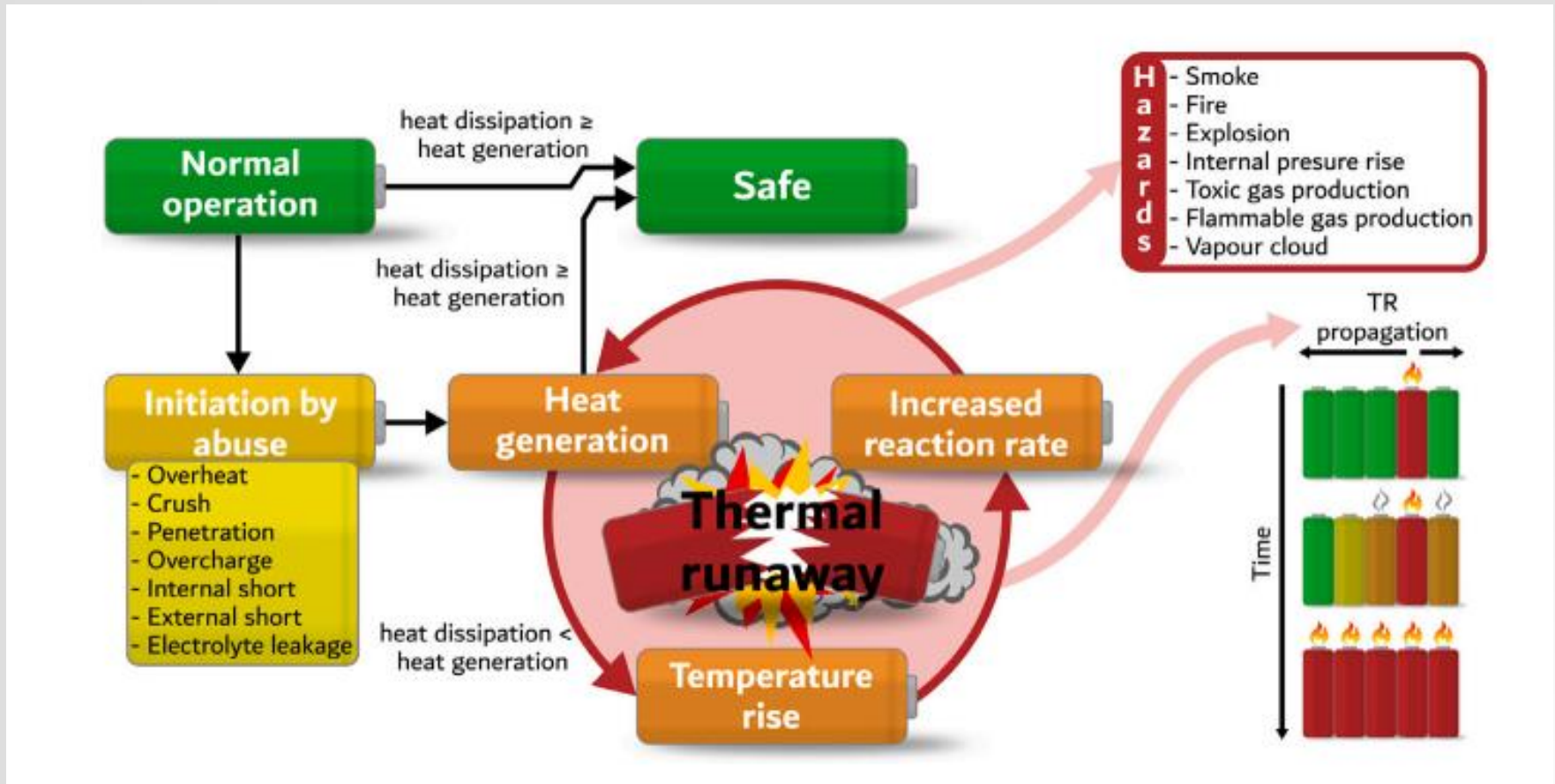


Cell Chemistry

Name	Chemistry	Typical Uses
LCO	Lithium Cobalt Oxide	Small portable electronics (phones, laptops, cameras)
LMO	Lithium Manganese Oxide	Portable power tools, medical instruments, some hybrid or electric vehicles
LTO	Lithium Titanate Oxide	EVs, charging stations, uninterrupted power supplies, wind and solar energy storage, solar street lights, telecommunication systems, aerospace and military equipment
LFP	Lithium Iron Phosphate	Replacement for lead-acid, deep-cycle batteries
NMC	Lithium Nickel Manganese Cobalt	Power tools and powertrains for electric bikes, scooters, some EVs
NCA	Lithium Nickel Cobalt Aluminum	EVs, other products that require high loads with long battery life

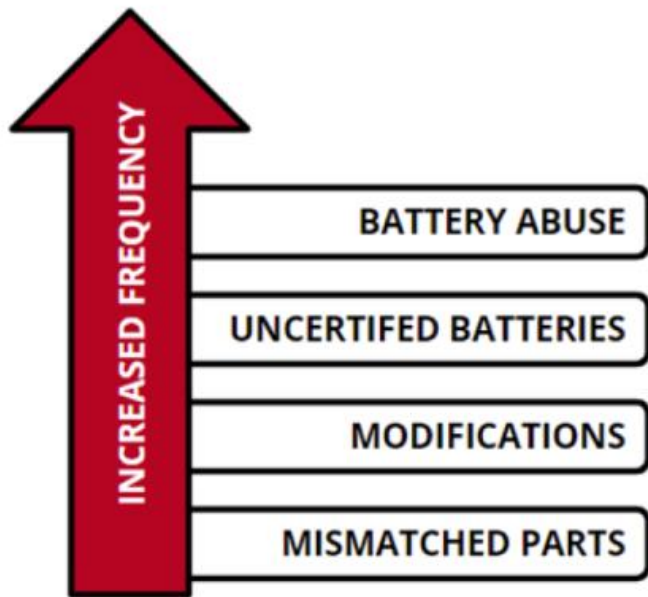


Thermal Runaway



Review of Gas Emissions from Lithium-Ion Battery Thermal Runaway Failure - Considering Toxic and Flammable Compounds, Bugryniec, Resendiz, Nwophoke, Khanna, James, Brown, J. of Energy Storage 87 (2024)

Causes of Thermal Runaway



		RARE	UNLIKELY	POSSIBLE	PROBABLE
FATAL	HIGH	VERY HIGH	VERY HIGH	VERY HIGH	
SEVERE	MEDIUM	HIGH	VERY HIGH	VERY HIGH	
MODERATE	LOW	MEDIUM	HIGH	VERY HIGH	
MINOR	LOW	LOW	MEDIUM	HIGH	

F

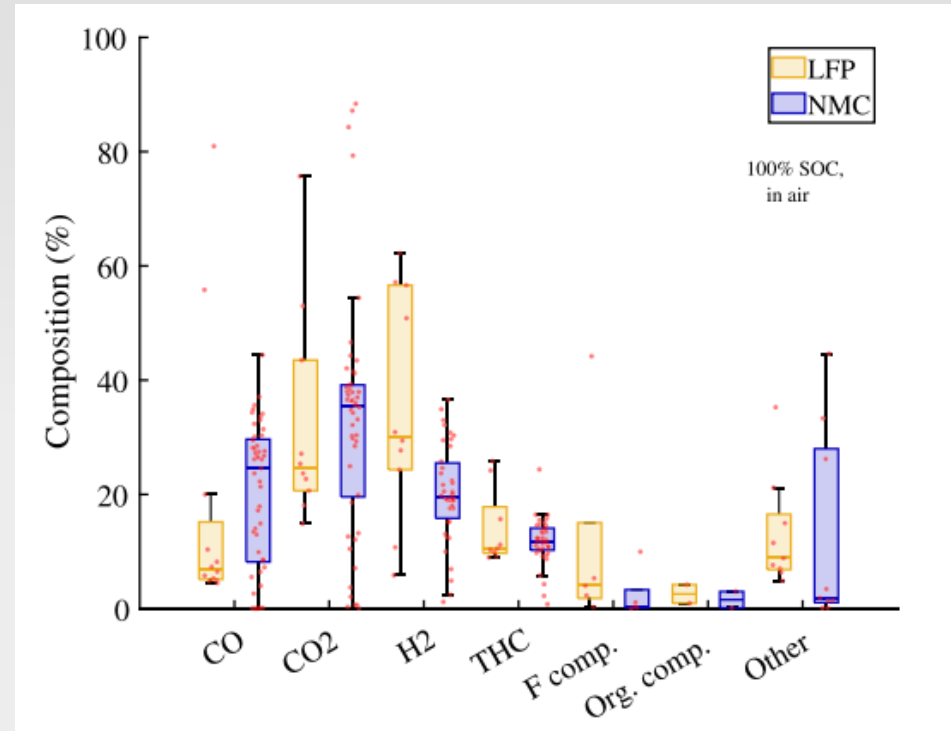
Thermal Runaway

- ❖ **Video of gas release from damaged module**
- ❖ **Video of burning module placed into bucket of water**
- ❖ **(videos removed because of file size)**



Gas Emissions During Thermal Runaway

- ❖ Carbon dioxide
- ❖ Carbon monoxide
- ❖ Hydrogen
- ❖ Hydrocarbons (methane, ethane, ethylene, acetylene, propene, propane, ...)
- ❖ Hydrogen fluoride
- ❖ Fluoroethane
- ❖ Hydrogen chloride
- ❖ Hydrogen cyanide
- ❖ Nitrous oxides
- ❖ Sulfur dioxide



Bugryniec, et al., *Review of Gas Emissions from Lithium-Ion Battery Thermal Runaway Failure - Considering Toxic and Flammable Compounds*, J. of Energy Storage, 2024

Soot Emissions

❖ Primarily, heavy metal-oxides

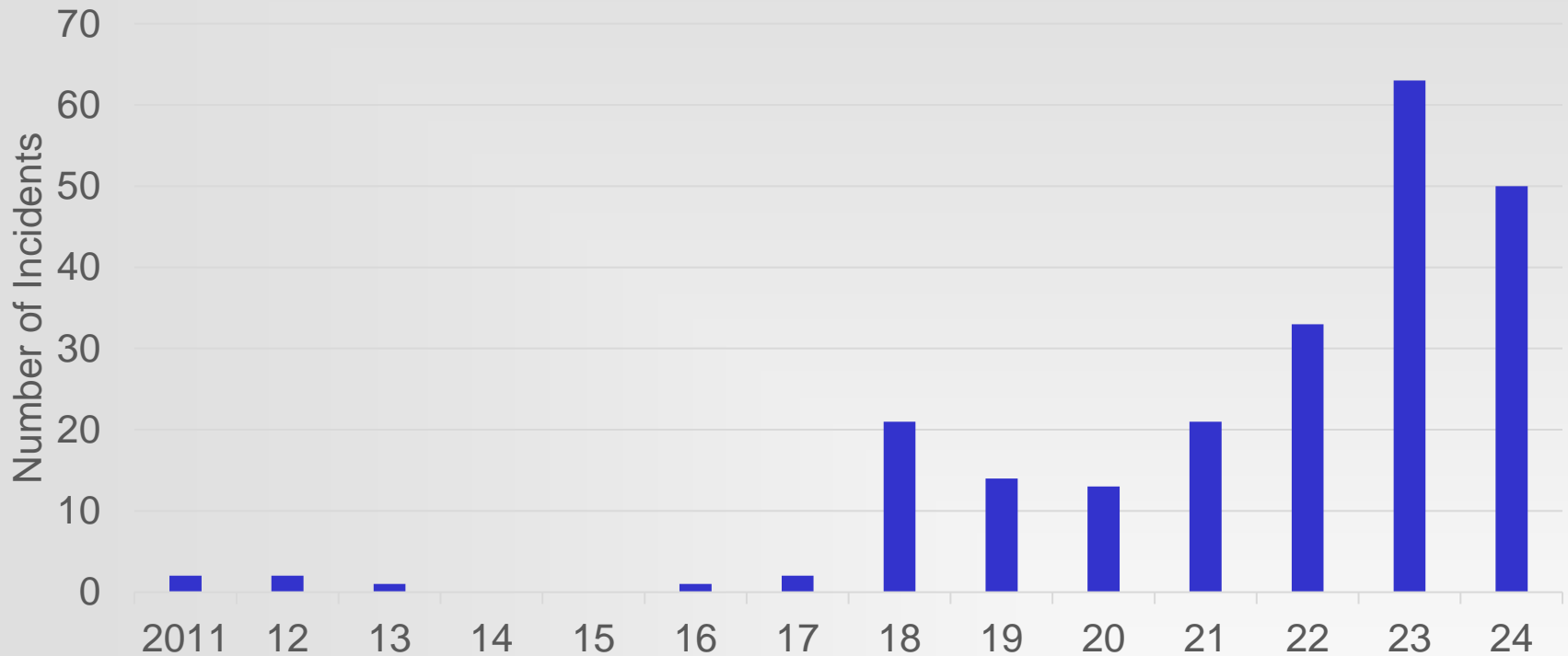
- Nickel
- Manganese
- Cobalt

❖ Others

- Lithium
- Fluorides
- Chlorides
- Polycyclic aromatic hydrocarbons (PAH)



ESS Incidents



❖ **2,262 fires in 2023 (increase of 303% since 2018)**

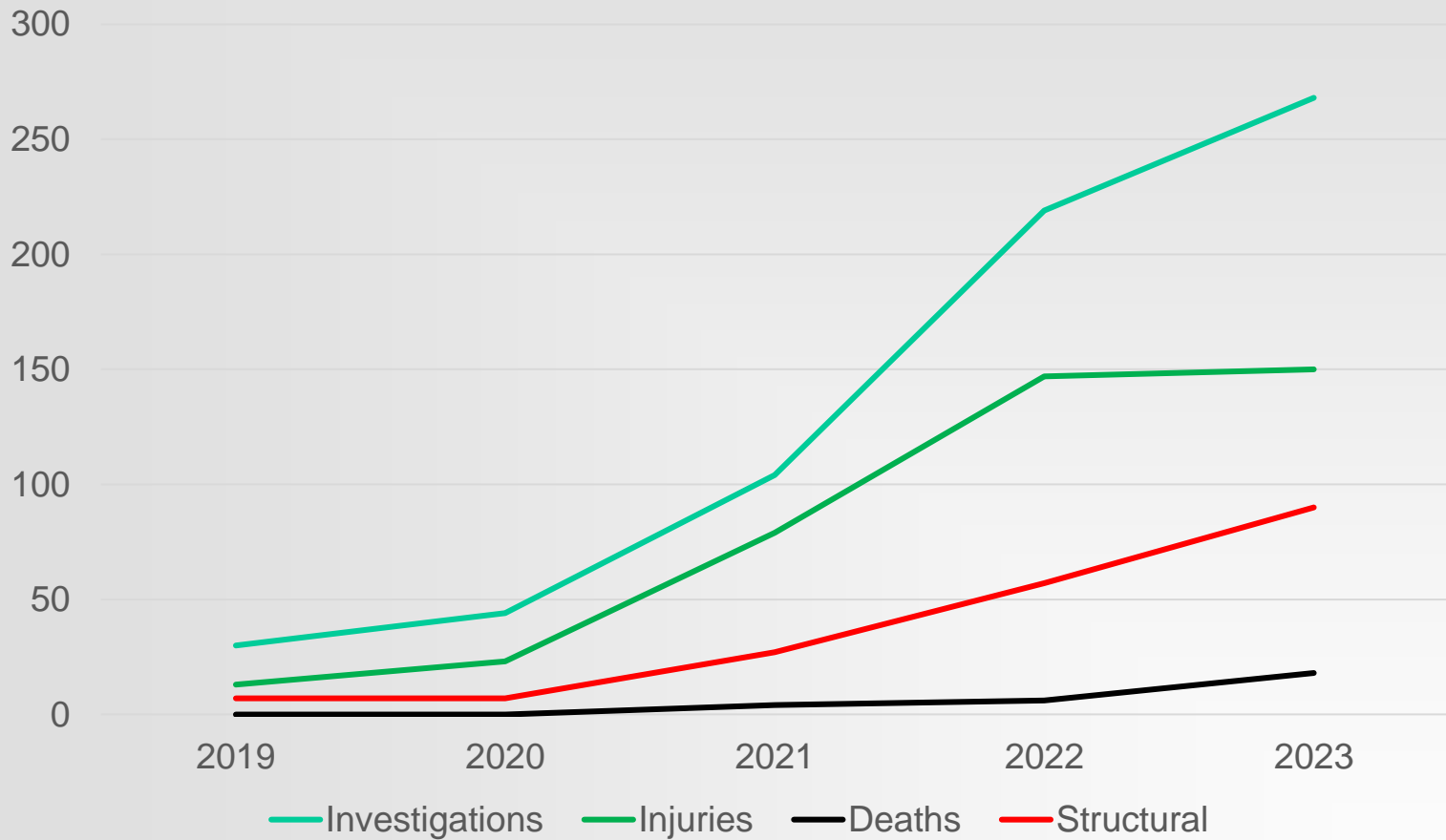
❖ **2018 - 2023: 773 injuries, 132 fatalities**



UL Solutions



Fire Incidents with Micro-Mobility Vehicles, New York City



Incidents at UMD, College Park

❖ **Scooter in high-rise residence hall.**

- **Scooter made noise in a 3rd floor resident room. As resident took it toward elevator, started smoking before she got on the elevator, activating SD/fire alarm. Burst into flame as she exited the elevator in lobby. Mostly extinguished by an ABC. Note: E-micro-mobility devices were already not permitted in residence halls.**

❖ **Scooter outdoors**

- **Thrown into outdoor fountain. In water 12 hours, removed by good Samaritan, sat unattended outside for 16 hours and ignited. UMD Police unsuccessfully attempted to extinguish with ABC. Extinguished by FD with hose line.**

❖ **Skateboard in classroom building.**

- **Started smoking in lobby. Owner took it outside where it ignited. Extinguished with ABC. FD soaked with hoseline before it was taken for disposal.**



Micromobility Devices

- ❖ **Experiment with e-scooter in living room, UL Fire Safety Research Institute**
- ❖ [https://vimeo.com/768559847/589a05cc67?&signup=true#_ =](https://vimeo.com/768559847/589a05cc67?&signup=true#_=)



Incident with EV

❖ **Mountain, CO. April, 11, 2023**

<https://www.youtube.com/watch?v=PNuSUsvnxEA>

❖ **From SFPE Foundation Report: “Grand Challenges in Energy and Infrastructure”**

- **Chevrolet Volt caught fire two weeks after a crash.**
- **EV FireSafe [84] reported several cases of re-ignition, namely one in which four separate re-ignitions occurred (after extinguishment, during vehicle loading, and 2 during storage), and another in which 2 ignitions occurred 68 days apart after a garage fire in a residence**

Detection

❖ Signatures used for detection:

➤ Gases

- Carbon dioxide
- Hydrogen
- Volatile organic compounds

➤ Particulates – Air sampling detector

Suppression

❖ **Ideal battery extinguishing agent:**

- **high thermal conductivity and capacity and low electrical conductivity.**

❖ **Application of Water**

- **Water has good heat remove capability but is electrically conductive**
- **potential for shorting neighboring cells → may initiate thermal runaway in another cell.**
- **potential of HF generation peaks over short periods of time → poses health risk to emergency responders**

Suppression Strategies

- ❖ **Stopping thermal runaway requires that suppression agent interacts directly with affected cell).**
- ❖ **Suppression system operation in vicinity of ignited battery can prevent fire spread to other combustibles in the area.**



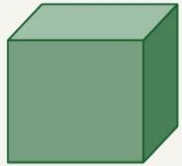
Suppression of EVs

Type of vehicle	Quantity of Water	Quenching Time	Re-ignition
Mock-up of PHEV/4.4kWh	275, 1060	72, 586	10 minutes after start
Mock-up of EREV, 16 kWh	1074, 1165, 2640	9:32, 14:02, 21:22	10 minutes after start



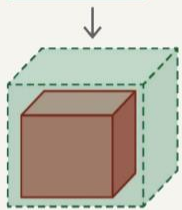
Grand Challenges in Energy and Infrastructure, SFPE Foundation, 2023.

BESS Information: Standards



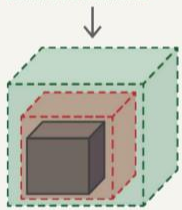
BUILT ENVIRONMENT

- ICC IFC, ICC IRC, ICC IBC
- NFPA 5000
- NFPA 1



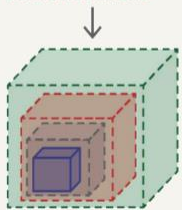
INSTALLATION / APPLICATION

- **NFPA 855**
- IEEE C2
- DNVGL GRIDSTOR
- NFPA 70
- IEEE 1635/ASHRAE 21
- FM GLOBAL 5-33
- UL 9540 A
- IEEE P1578
- NECA 416 & 416



ENERGY STORAGE SYSTEMS

- **UL 9540**
- ASME TES-1
- NFPA 791



SYSTEM COMPONENTS

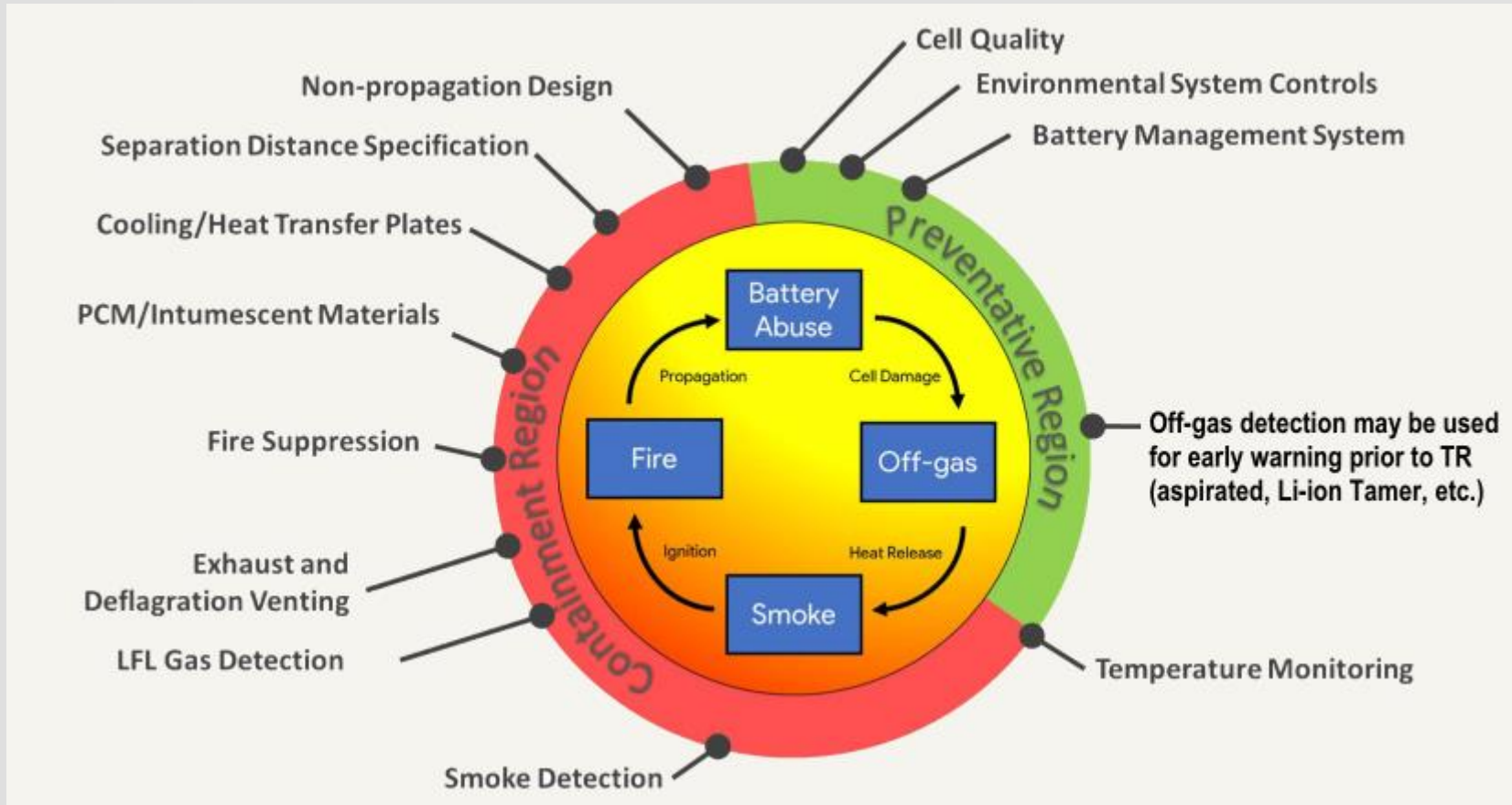
- **UL 1973**
- UL 1974
- CSA 22.2 No. 340-201
- UL 810A
- IEEE 1547
- UL1741
- IEEE 1679 Series



N. Ryder, Li-Ion BESS: Prevent the Opportunity from Becoming the Risk, Greater Atlanta Chapter SFPE Conference, 2022.



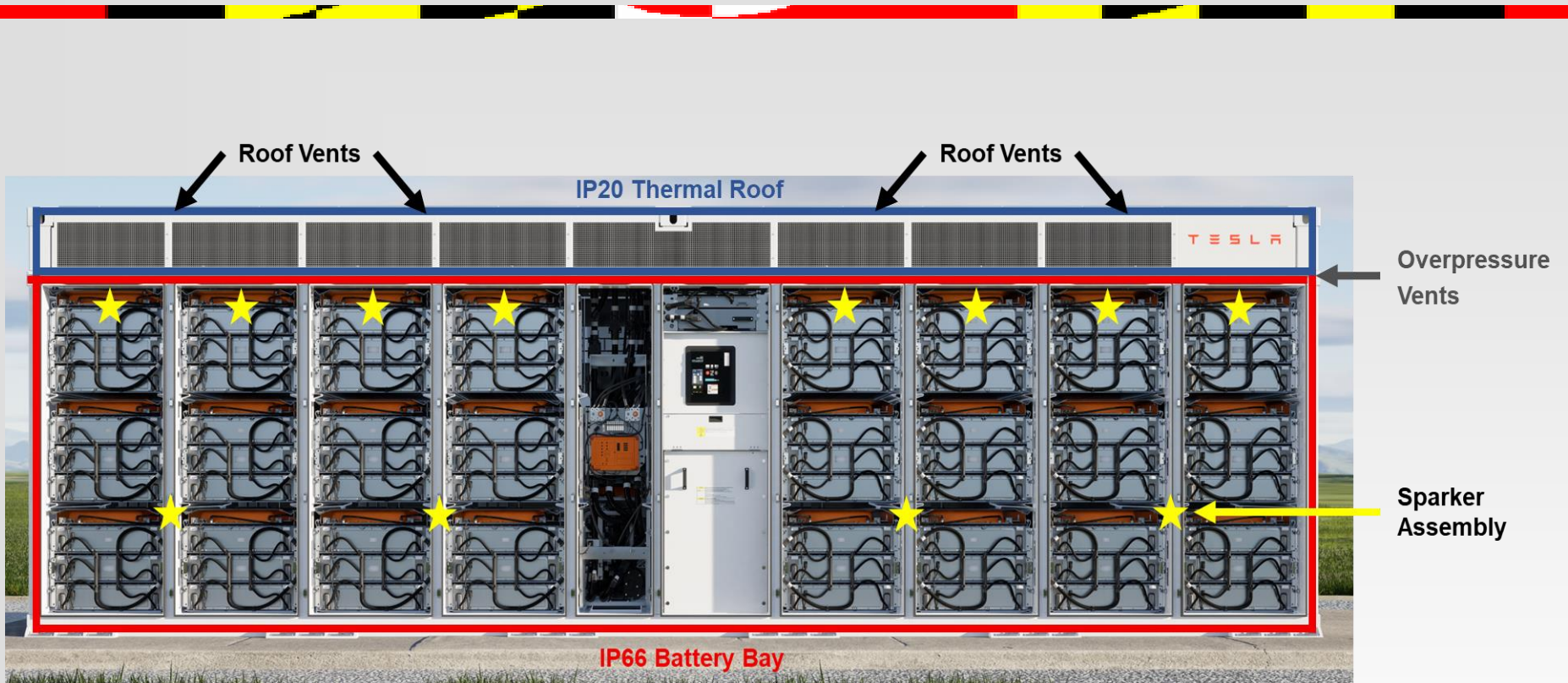
BESS Layers of Protection



N. Ryder, Li-Ion BESS: Prevent the Opportunity from Becoming the Risk, Greater Atlanta Chapter SFPE Conference, 2022.



Explosion control



NY State Activity

❖ Governor Hochul Inter-Agency Fire Safety Working Group on Emergency Response

- Division of Homeland Security and Emergency Services
- Office of Fire Prevention and Control
- New York State Energy Research and Development Authority
- New York State Department of Environmental Conservation
- Department of Public Service
- Department of State

❖ Developments

- Feb 2024: initial recommendations
- July 2024: draft fire code amendments for BESS installations (comment period ended in Sept.)

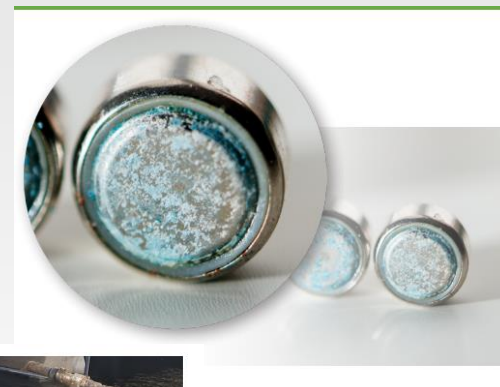
(<https://www.nyserda.ny.gov/About/Newsroom/2024-Announcements/2024-07-26-Governor-Hochul-Announces-Draft-Fire-Code-Language-That-Addresses-Recommendations>)



Procedures for DDR (Damaged, Defective or Recalled) Batteries (US DOT)

❖ Visual indications of DDR batteries

- Acute hazard, such as gas, fire, or noticeable leaking electrolyte.
- LIBs showing signs of physical or mechanical damage, such as:



Removal of DDR Batteries

- ❖ **Vehicles towed to location, separated from other vehicles by at least 50 ft**
- ❖ **Individual batteries: handle as hazardous waste**
- ❖ **FDNY Procedures**
 - The batteries or mobility device should be moved to the following location in order of preference until it can be appropriately over packed/mitigated by Haz Mat Company 1 or a Haz Mat Tech Unit:
 - Bathroom tub in fire apartment, with all cells fully submerged in water.
 - Sink large enough that all cells can be fully submerged in water.
 - Garbage pail or bucket large enough that all cells are capable of being fully submerged in water.



Public Education Messaging

C

Choose certified products

H

Handle with care

A

Always stay alert for warning signs

R

Recycle devices and batteries properly

G

Get out quickly if there's a fire

E

Educate others on safe practices

UL Standards and Engagement



Recommended Actions

- ❖ Adopt current standards – they are “catching up” to a rapidly changing hazard
- ❖ Regulations on e-mobility charging
 - Residential
 - Business – multiple scooters charged in small store overnight
- ❖ Support for emergency responders: exposure to heavy metals, acidic gases
- ❖ Public education needs to be a high priority – provide support to Fire Departments to do that?