Detailed Characterization of Emissions from Battery Fires

SOUTHWEST RESEARCH INSTITUTE®

October 2022

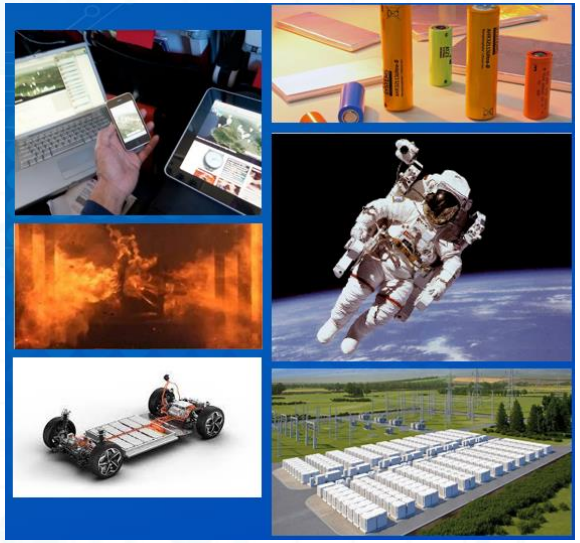
Vinay Premnath, Principal Engineer

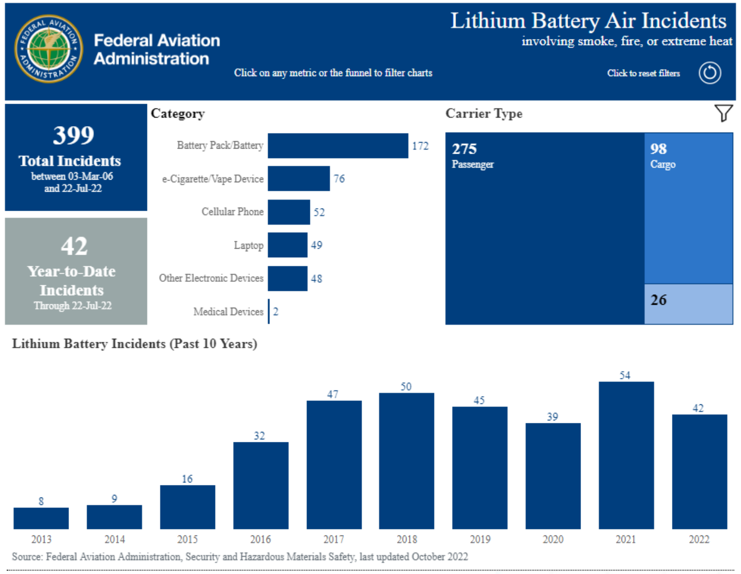
Outline

- Background – why is this topic important?
- Research overview
- Experimental methods
- Results – what we learned
  - Physical observations, gaseous and particle emissions
- Summary – important takeaways

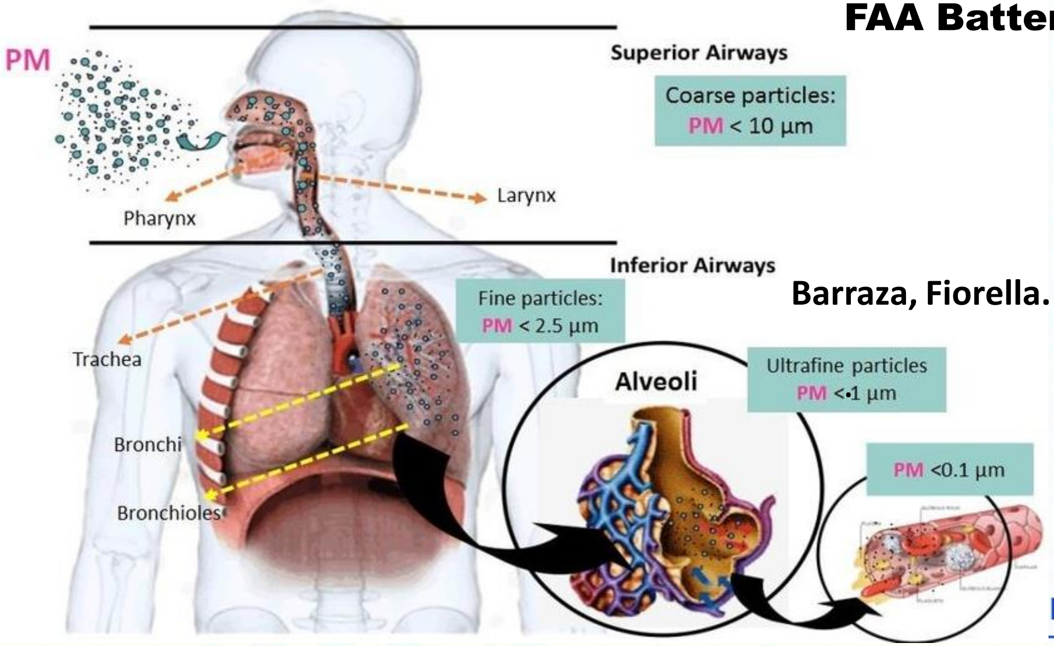
Background

- Several battery fire incidents over the last few months
- During failure events, particulates and gases are released
  - Emissions may be toxic, flammable, explosive and could impact visibility in an enclosed space
  - These emissions pose a serious risk to human health either via inhalation or skin absorption
- Critically important to understand composition of particulates and gases emitted from such fires
  - To equip first responders with appropriate PPE
  - To understand impact on people in the vicinity
  - Environmental impact – air and water quality
  - To develop mitigation and control strategies





FAA Battery incidents



Barraza, Fiorella. (2017)

Research Overview

- Objective was to investigate emissions from Li-ion battery fires triggered by thermal runaway
  - Cell level studies – focus was on gaseous emissions
    - Included LMO and NCA chemistries
  - Module-level studies – focus was on ‘fine’ particle (<2.5 μm) emissions and some gases
    - Included LFP and NMC chemistries
- Test programs were designed to gain information on variability, impact of battery chemistry and initiation mechanism on emissions
- For cell level tests, overcharge was used as the abuse mechanism
- For module level tests, the following tests were conducted
  - Test 1 – LFP via nail penetration
  - Test 2 – LFP via nail penetration
  - Test 3 – LFP via overcharging
  - Test 4 – LFP via overcharging
  - Test 5 – NMC via nail penetration

Tests 1–2: Variability/Repeatability

Tests 3–4: Variability/Repeatability

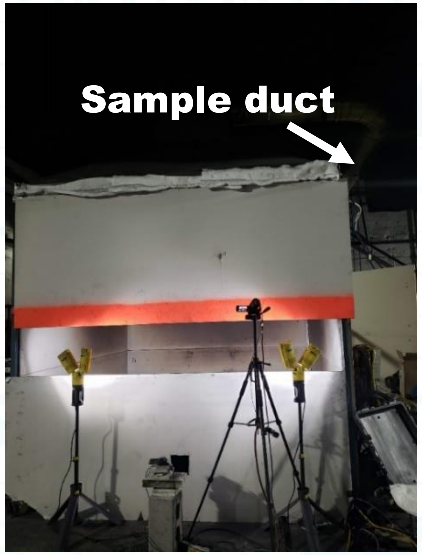
Tests 1–2 vs. Tests 3–4: Initiation mechanism

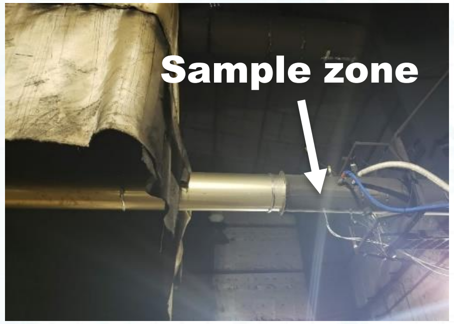
Tests 1–5: Battery chemistry

All test articles were charged to full SOC

Experimental Methods

Modules were instrumented with temperature and voltage sensors

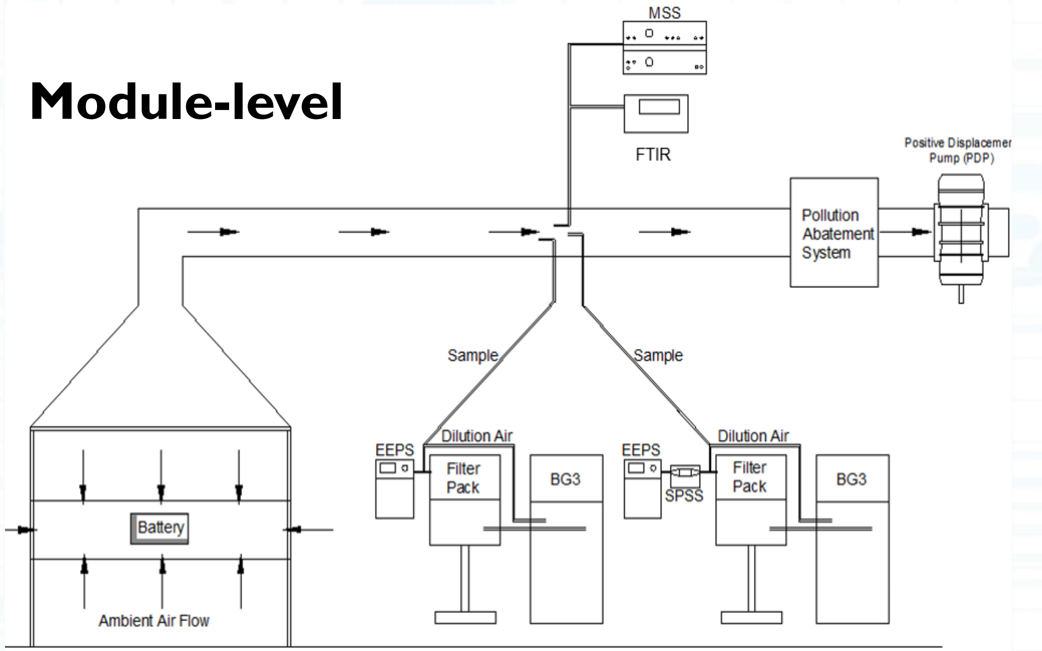




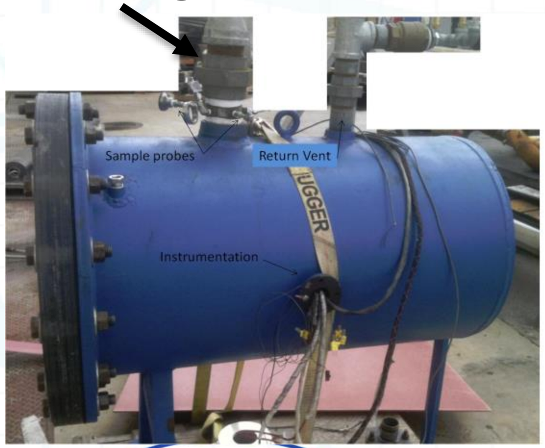
NMC

LFP

Module-level



Sampling location



Cell-level

LMO

NCA

- Test article placed inside the enclosure
- Particle/gaseous emissions sampled from inception to completion – no control systems were engaged
- Sufficient oxygen was always present to sustain combustion

Emissions Instrumentation

PM measurement – gravimetric filter method

+

Heat-Pak

PM filter

Soot – AVL micro-soot sensor

Total Particle Sizer – PN/size (volatile + solid)

Solid Particle Sampling System

+

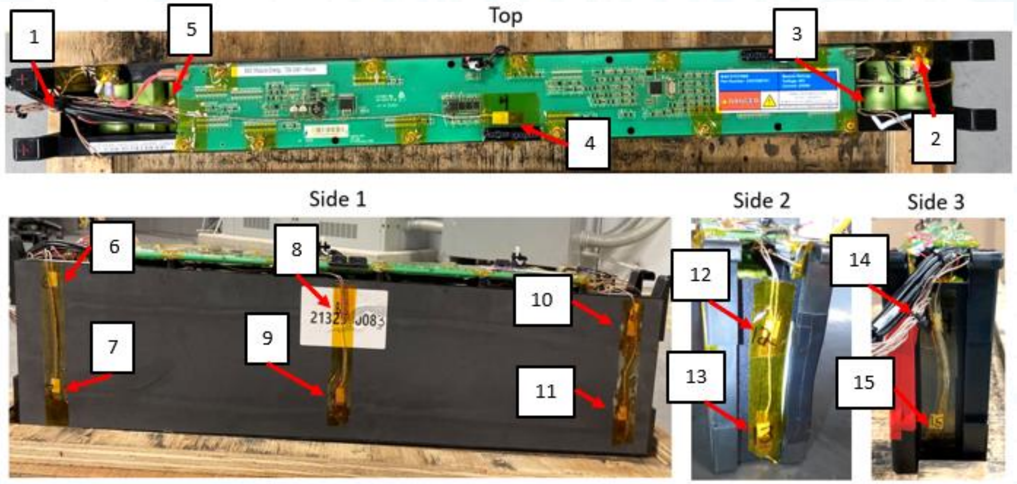
FTIR

Solid Particle Sizer – PN/size (metallic + soot, no volatiles)

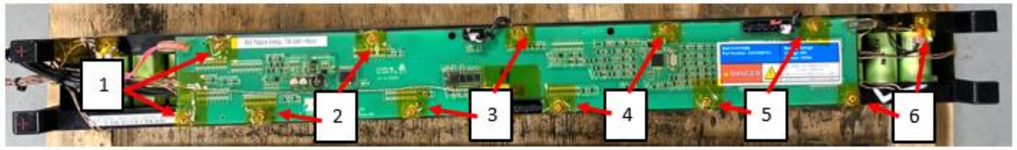
- Focus was on 'fine' particle emissions
  - Sub 2.5 µm particles
- Particle measurements included
  - Particulate Matter mass (PM2.5)
    - Regulated air quality metric
  - Real-time black carbon (or soot) concentration
  - Real-time total particle number/size
    - Includes volatile + solid particles
    - 5.6 nm to 560 nm
  - Real-time solid particle number/size
    - Includes metallic + soot particles (no volatiles)
    - 5.6 nm to 560 nm
- Gas measurements were conducted using an FTIR
  - CO, CO_2, NO, NO_2, HCN, HCl, HF, CH_2O, CH_4 and C_3H_8

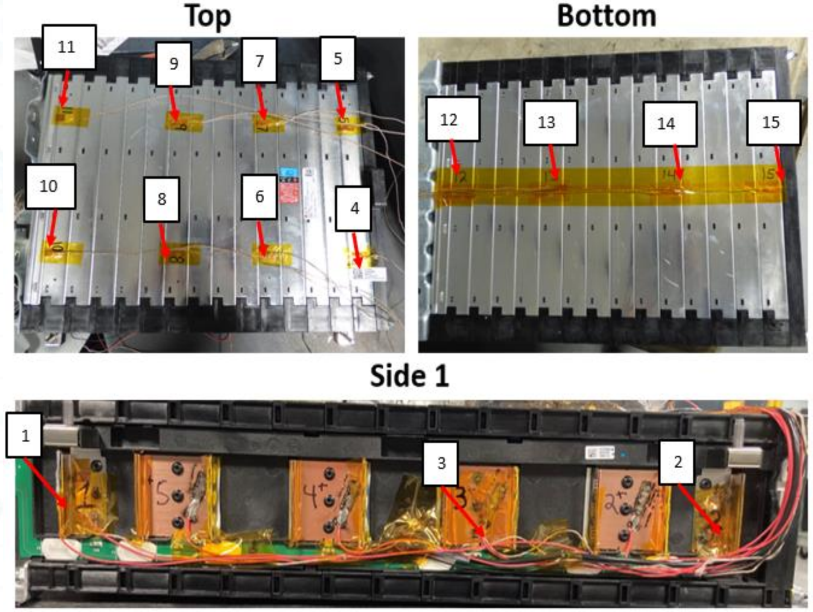
Battery Module Instrumentation

LFP module

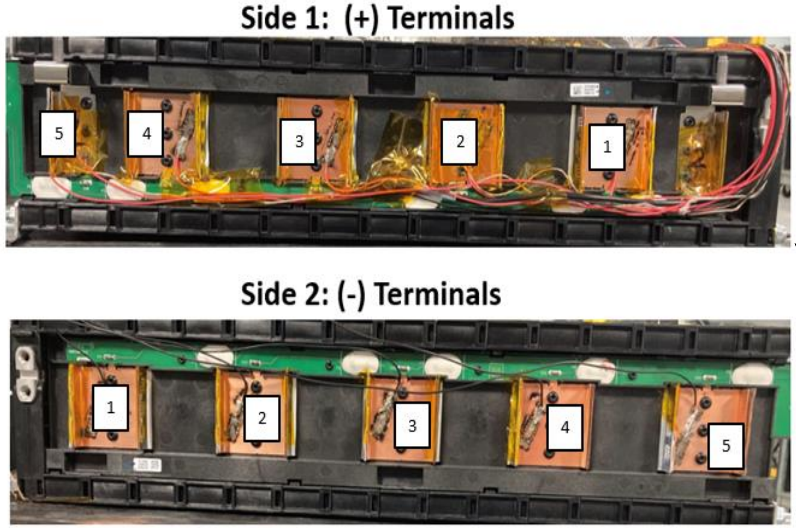


LFP module voltage sensors





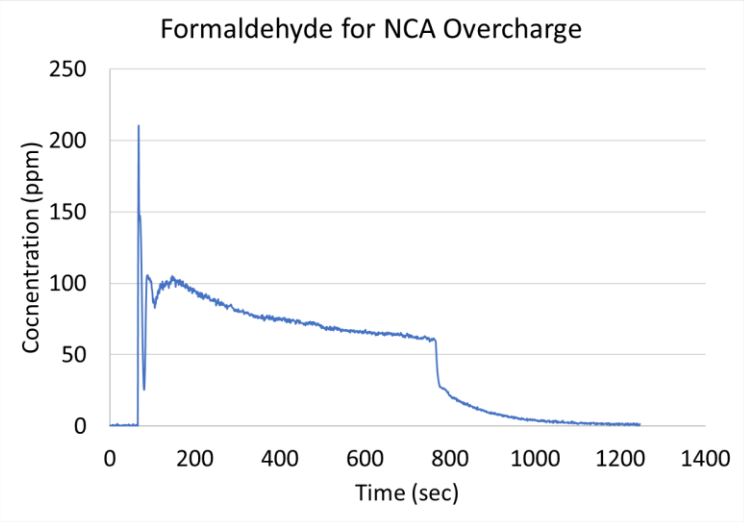
NMC module thermocouples

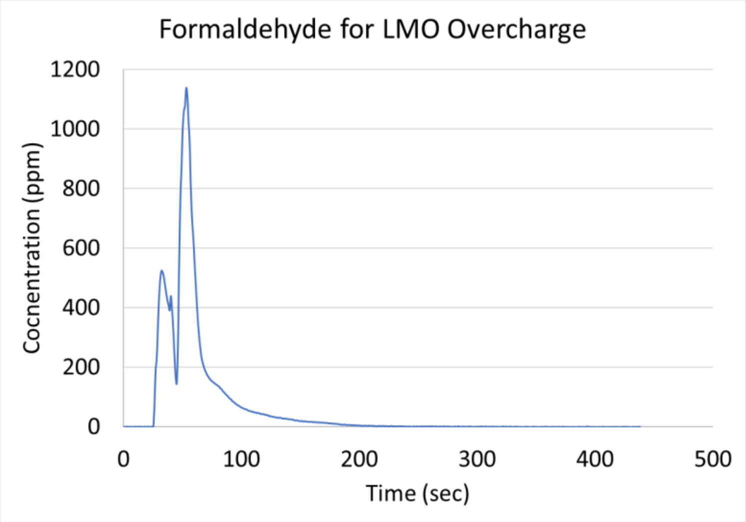


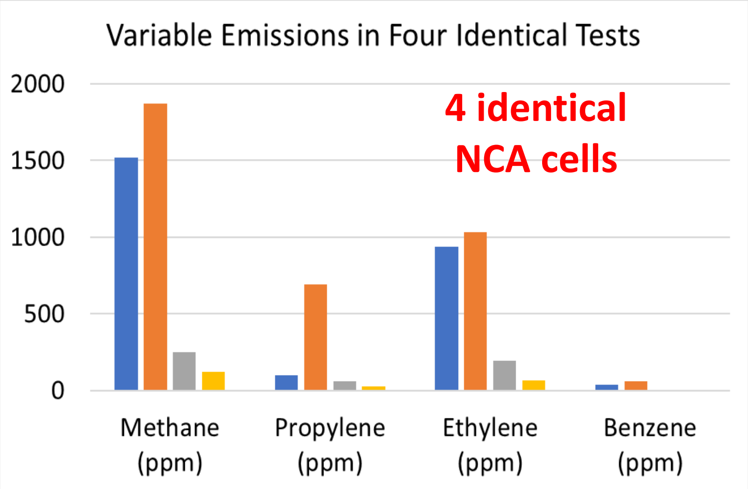
NMC module Voltage sensors

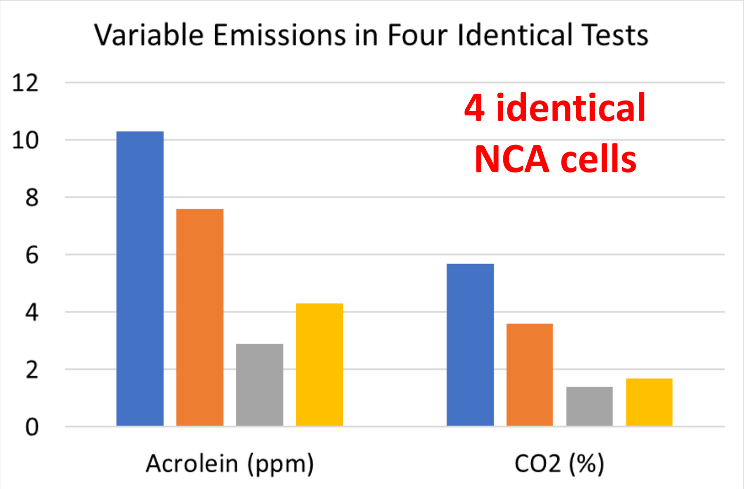
- LFP module was instrumented with 16 thermocouples and 6 voltage sensors
- NMC module was instrumented with 16 thermocouples and 5 voltage sensors

Results – Cell-Level Tests (Brief)





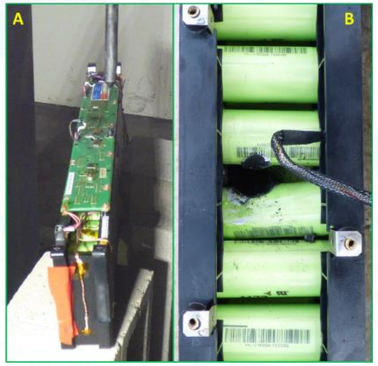


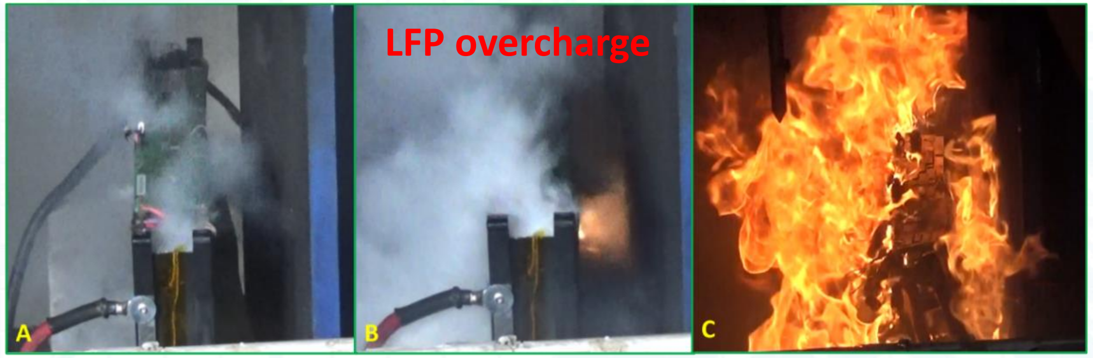


- Thermal runaway was induced via overcharging
- Test setup simulates an enclosed space with some level of ventilation
- Pretty high levels of formaldehyde were observed for both chemistries
  - Highly toxic compound
- High levels of variability were observed for four tests conducted using similar abuse factors and identical NCA cells

Module-Level Results-1 Physical Observations

LFP nail penetration



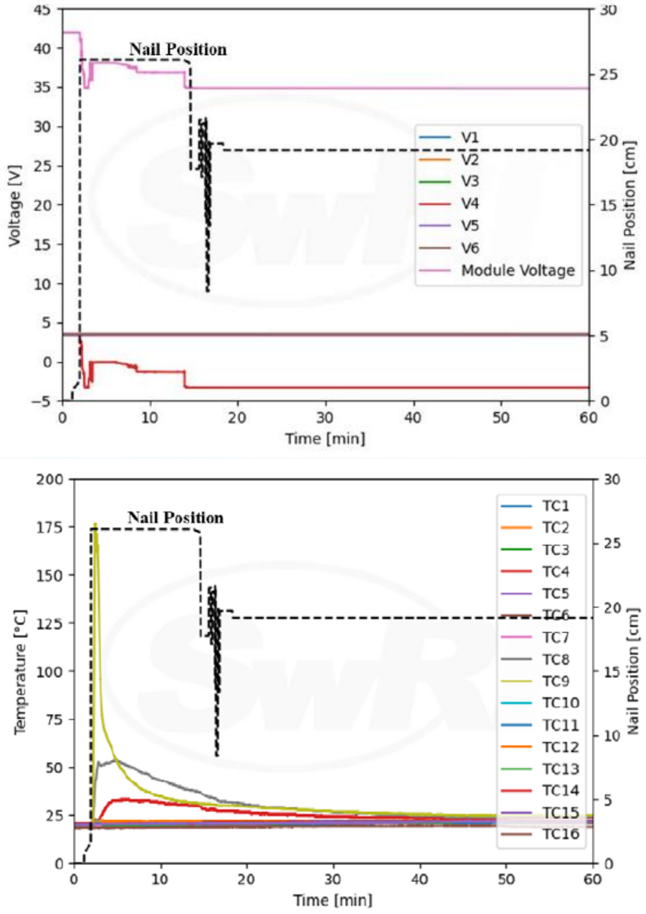


NMC nail penetration

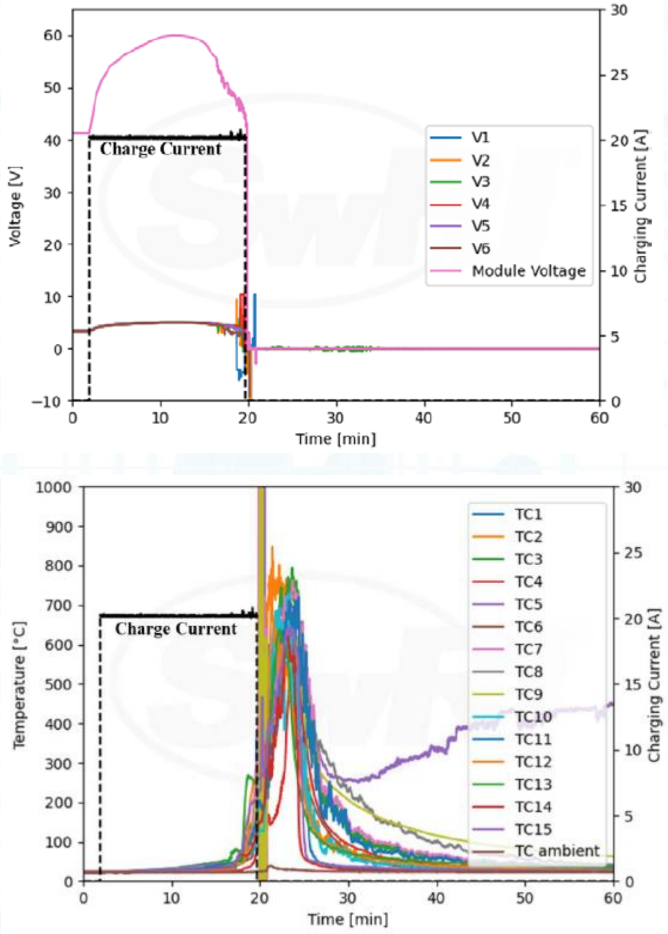
- LFP nail-penetration tests
  - Only cells in the path of the nail experienced thermal runaway
- LFP overcharge tests
  - All cells in the module experienced thermal runaway
  - Significant smoke and fire was observed
- NMC nail-penetration tests
  - All cells in the module experienced thermal runaway
  - Thermal runway propagation was observed cell-to-cell
  - Significant smoke and fire was observed

Module-Level Results-2 Battery Parameters

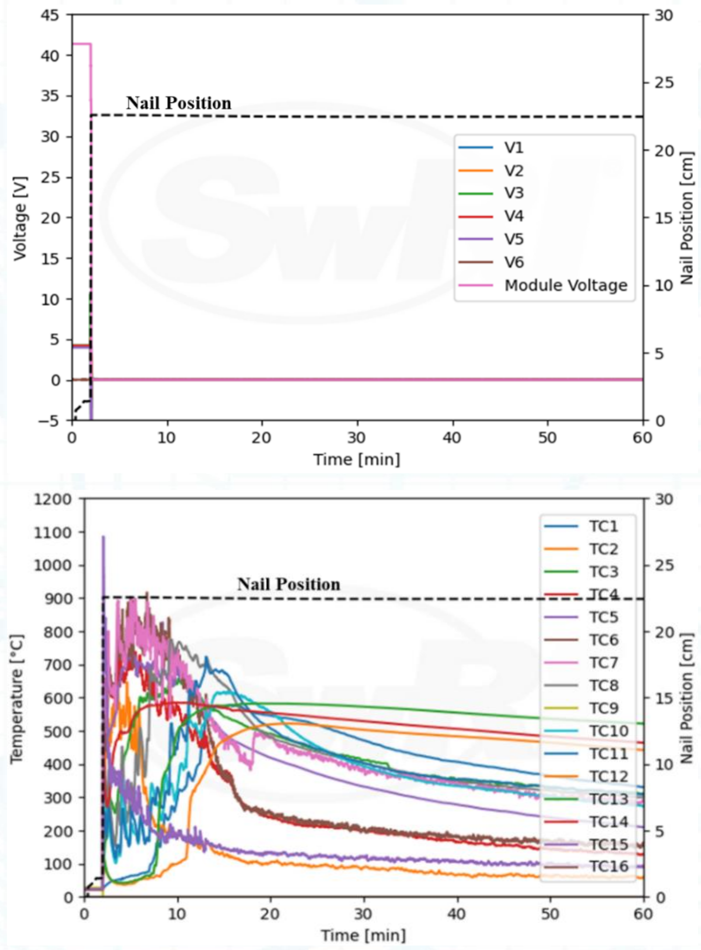
LFP via nail-penetration



LFP via overcharging



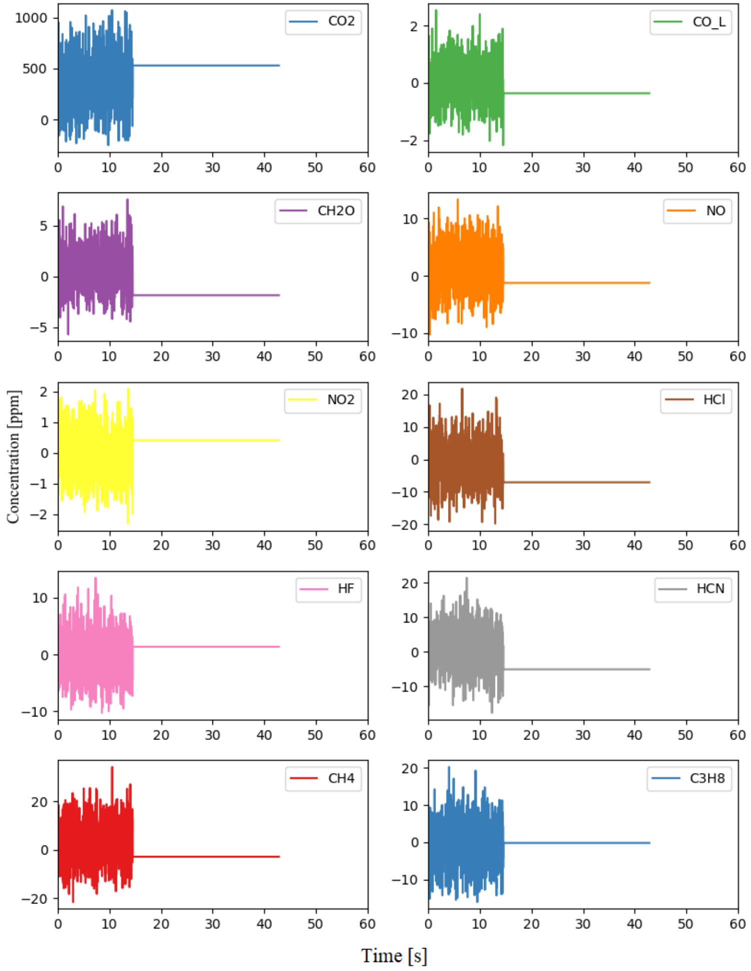
NMC via nail-penetration



- All modules were charged to full state-of-charge
- LFP modules entered thermal runaway after about 15 minutes of overcharging

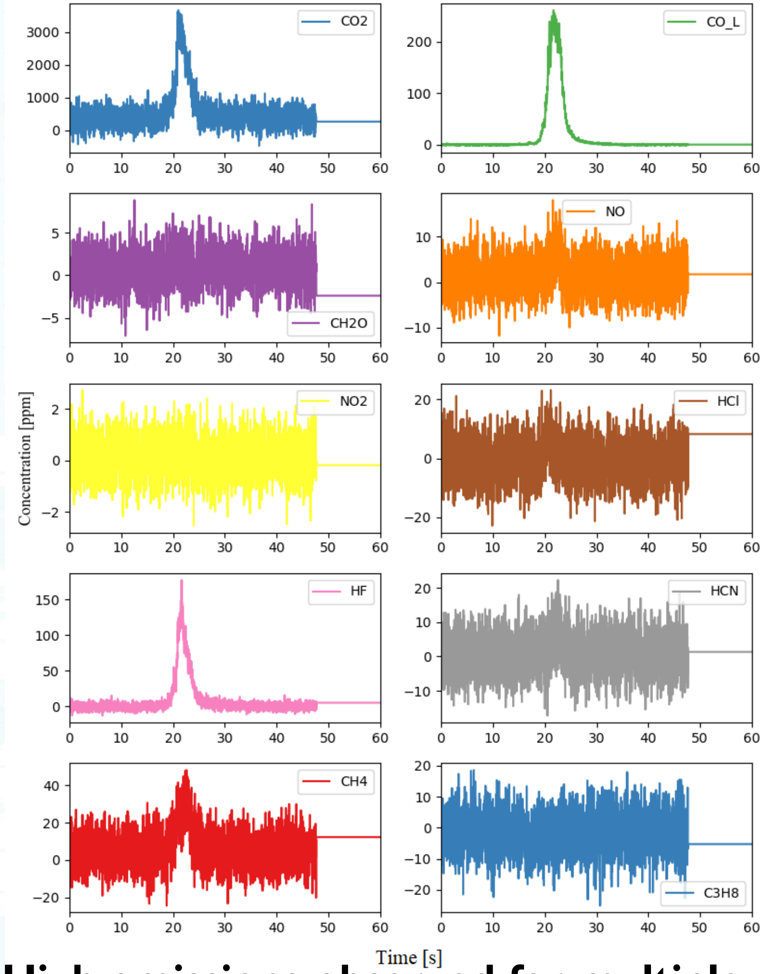
Module-Level Results-3 Gaseous Emissions

LFP via nail-penetration



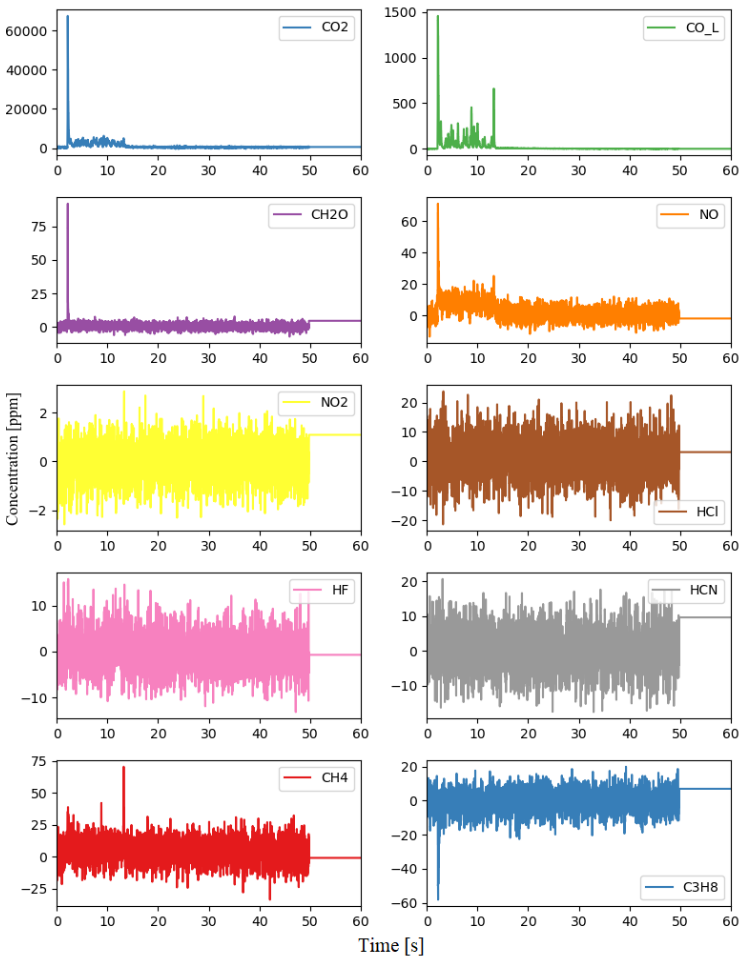
- LFP via nail-penetration (no significant emissions)

LFP via overcharging



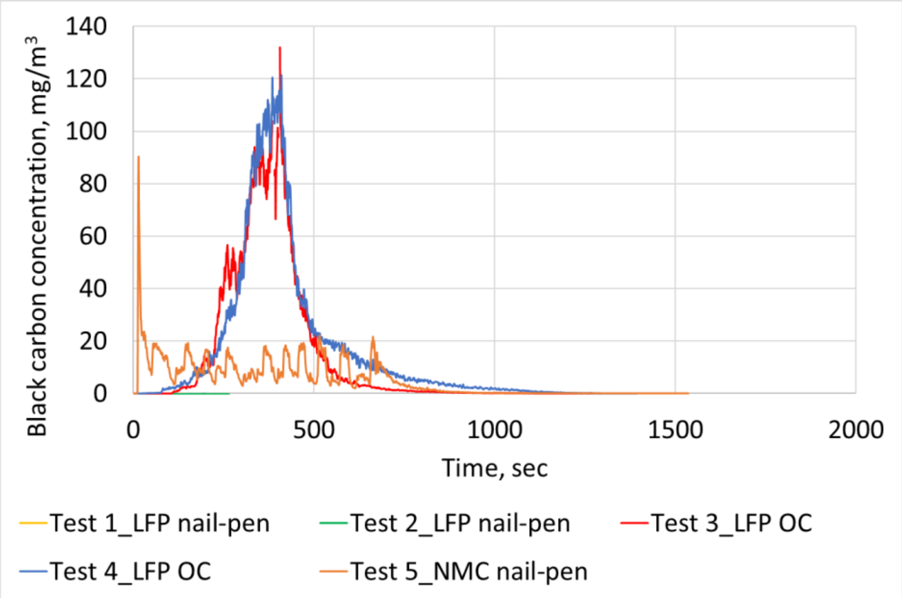
- High emissions observed for multiple gases
- HF exceeded immediately dangerous to life or health (IDLH) limit of 30 ppm

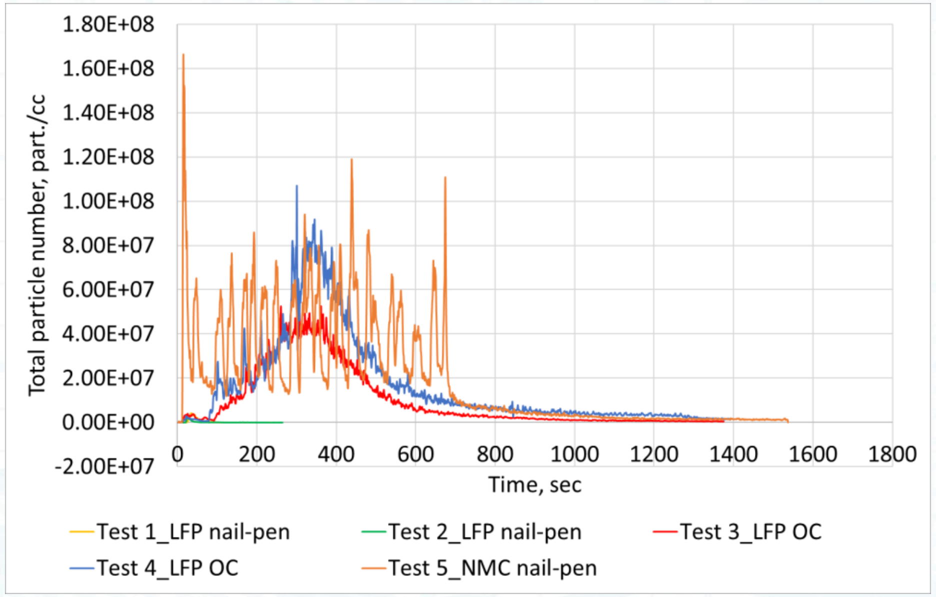
NMC via nail-penetration

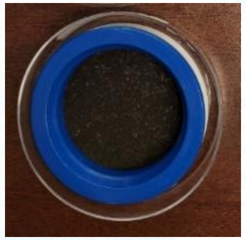


- CO_2 peak 20 times higher than LFP
- Formaldehyde above IDLH limit of 20 ppm

Module-Level Results-4 Particle Emissions





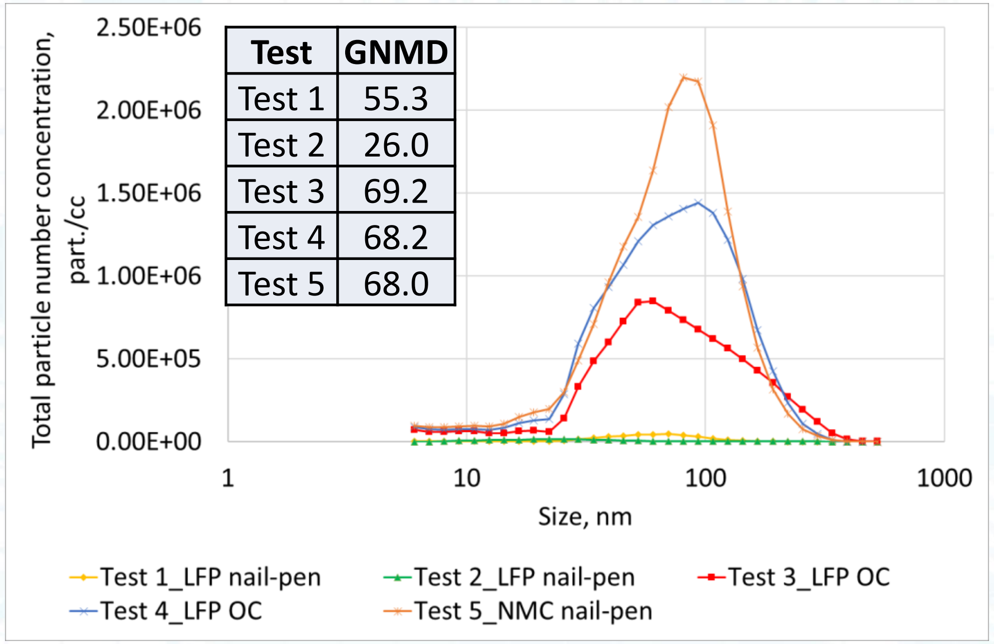


Test	Test duration, sec	PM2.5 emissions, g/hr	Black carbon emissions, g/hr	Solid PN emissions, part./hr	Total PN emissions, part./hr
Test 1_LFP nail-pen	260	1.81	0.00	1.56E+15	4.24E+15
Test 2_LFP nail-pen	266	0.00	0.00	1.12E+14	1.61E+15
Test 3_LFP OC	1376	386.09	149.90	8.89E+16	1.13E+17
Test 4_LFP OC	1392	375.97	185.78	6.11E+16	1.83E+17
Test 5_NMC nail-pen	1535	551.03	66.52	1.06E+17	2.08E+17

- Significant PM2.5, soot and particle number emissions were observed for the LFP overcharge and NMC nail penetration tests

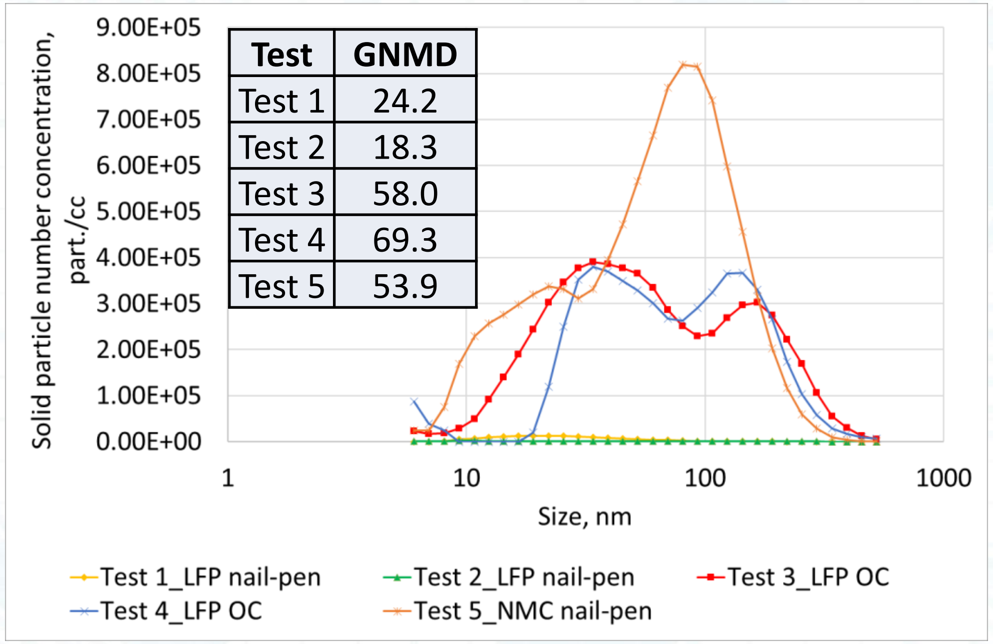
Module-Level Results-5 Particle Size Distributions

Total particle size distribution



Test	GNMD
Test 1	55.3
Test 2	26.0
Test 3	69.2
Test 4	68.2
Test 5	68.0

Solid particle size distribution



Test	GNMD
Test 1	24.2
Test 2	18.3
Test 3	58.0
Test 4	69.3
Test 5	53.9

- Particles were observed to be in the respirable size range
- Peak concentrations were observed to be in the ultrafine particle size range (sub 100 nm) – known to be more toxic to human health
- All five tests exhibited unique size signatures, both, for solid and total particles

Summary

- Emissions from battery thermal runaway events can result in significant particle and gaseous emissions
  - PM emissions includes ultrafine particles that are more harmful to human health (sub 100 nm) in addition to micron sized particles
- Battery chemistry coupled with initiation mechanism influences magnitude of emissions, along with release profile
- Physical dimensions/arrangement of cells within a module could influence the severity of the runaway event
- Emissions from thermal runaway events of identical modules induced into runaway via the same mechanism could be highly variable

- Additional research is required to examine impact of variables such as cell chemistries/formats, SOC, initiation method, packaging, etc.

Thank you for your attention!

Southwest Research Institute®

Vinay Premnath
vpremnath@swri.org
210-522-3783