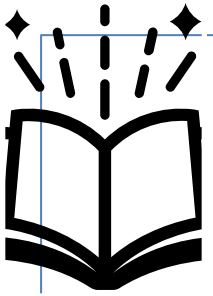
Repeatability of Gas Production from Closed Vessel Battery Abuse Tests

SOUTHWEST RESEARCH INSTITUTE®

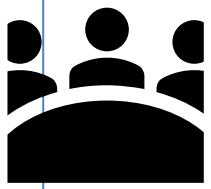
Andre Swarts

2025 NASA Aerospace Battery Workshop

Outline

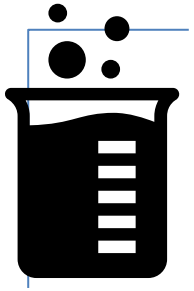


Introduction



Project

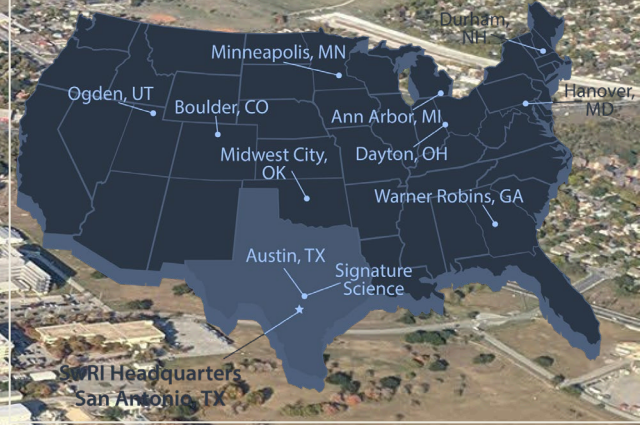
Approach



Results

Conclusion

Benefiting government, industry, and the public through innovative science and technology

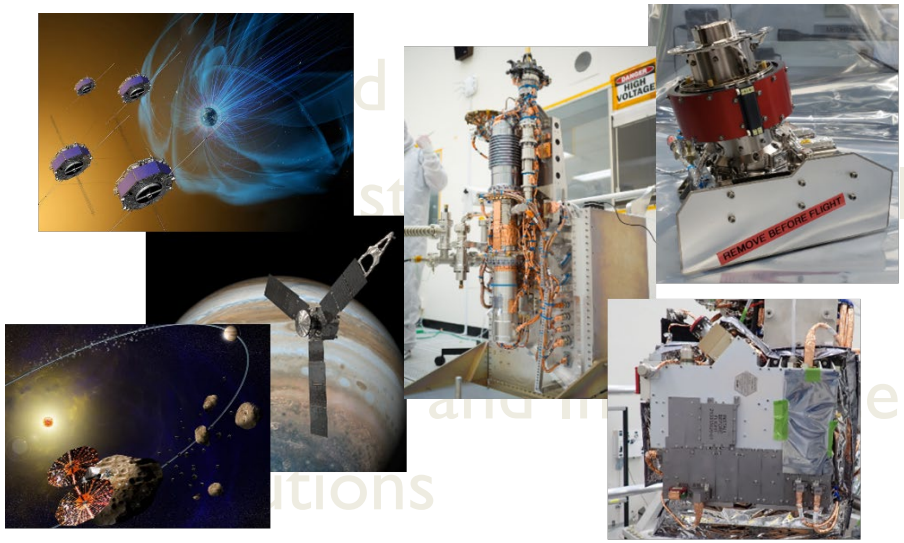


- More than 75 years of operation
- 501(c)(3) nonprofit corporation
- 3100+ employees (All R&D, no manufacturing)
- $844M in total revenue (FY23)
- 2,000+ acre facility in San Antonio, TX
- 2.5 M sq-ft of laboratories & offices
- Over 1500 patents
- 54 R&D 100 awards
- Internal Research program - $12 million in FY 2024 towards 242 projects

SwRI Technical Divisions

- Applied Power
- Chemistry and Chemical Engineering
- Defense and Intelligence Solutions
- Intelligent Systems
- Mechanical Engineering
- Office of Automotive Engineering
  - Powertrain Engineering
  - Fuels and Lubricants Research
- Space Sector
  - Space Systems
  - Space Science
  - Solar Systems Science & Exploration
- Center for Nuclear Waste Regulatory Analyses - FFRDC

SwRI Technical Divisions



- **Space Sector**
  - **Space Systems**
  - **Space Science**
  - **Solar Systems Science & Exploration**

Spacecraft

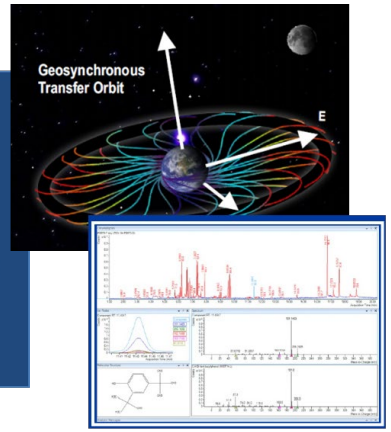
Avionics Boxes
Power Systems
Propulsion
Spacecraft Bus
Environmental Test

Space Mission Concepts, Design and Management

PI Institution IMAGE, New Horizons, IBEX, MMS, JUNO, Lucy, and PUNCH missions

Space Instrumentation

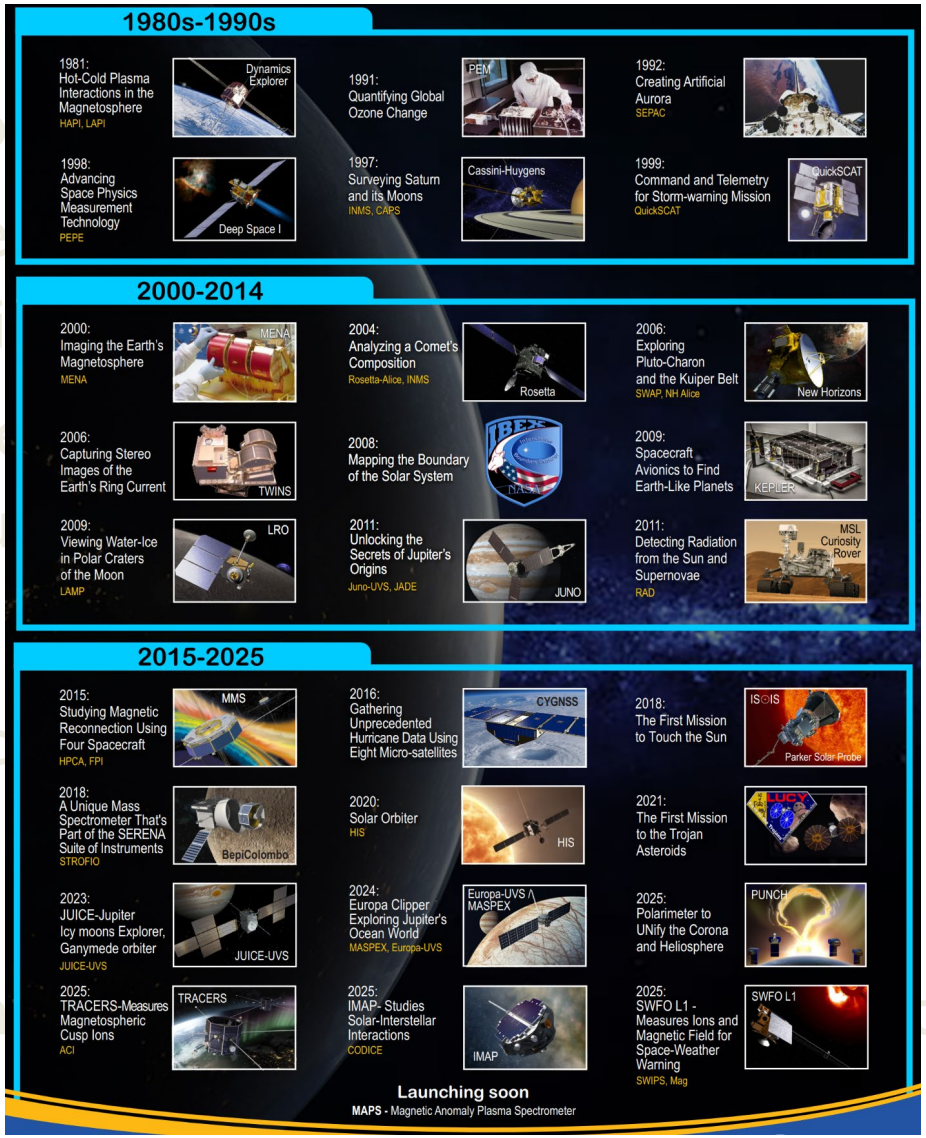
Plasma Instruments
Ultraviolet Spectrographs
Mass Spectrometers
Magnetometers



Mission Support

Quality Assurance
Radiation analyses
Contamination Control
Planetary Protection
Operations and Data Analysis

SwRI Technical Divisions



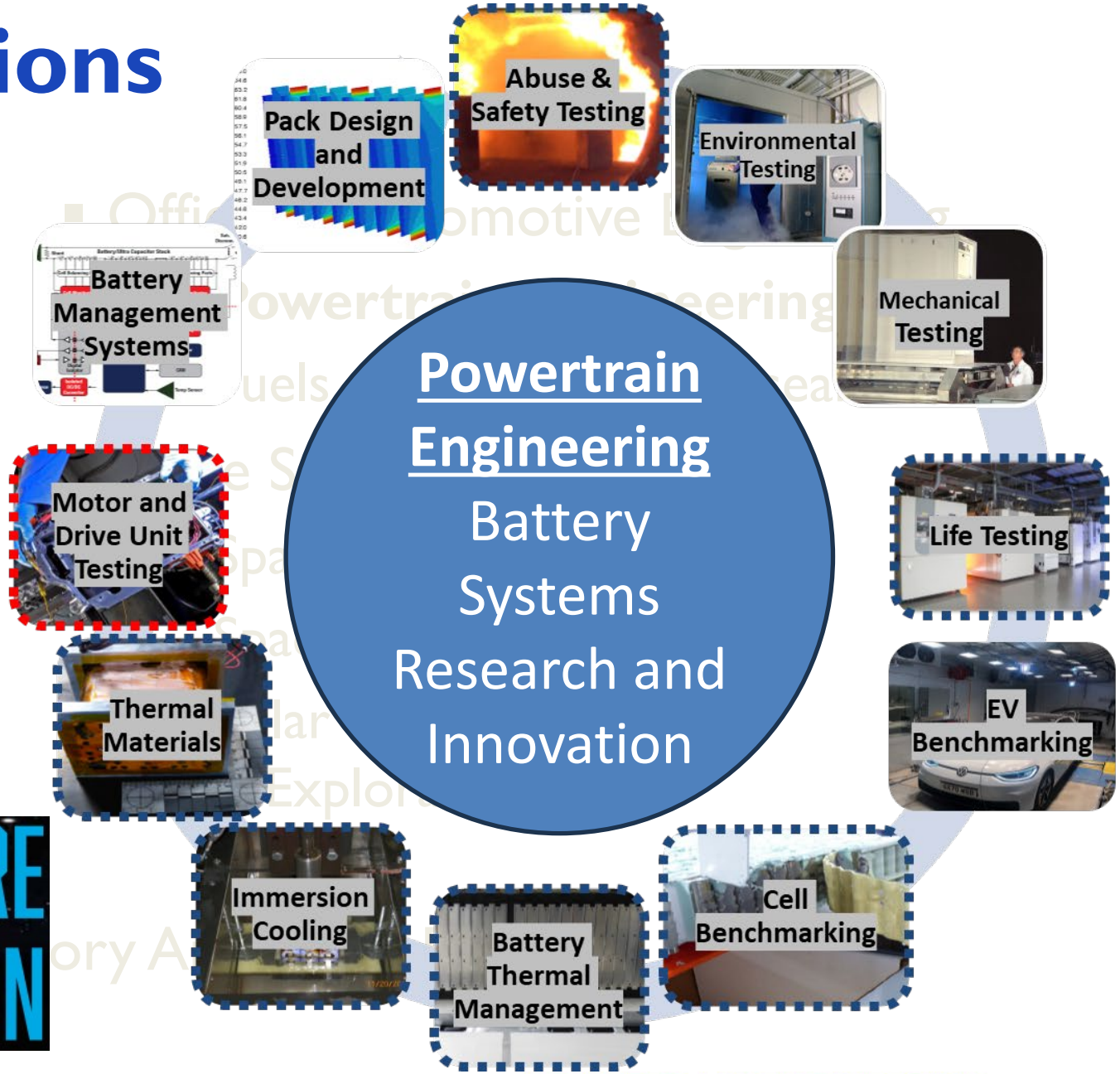
- Space Sector
  - Space Systems
  - Space Science
  - Solar Systems Science & Exploration

SwRI Technical Divisions

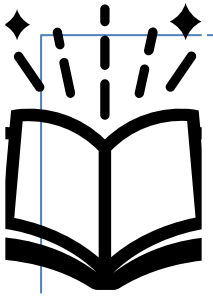
- **Chemistry and Chemical Engineering**

Supported by

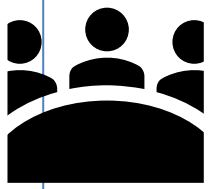
- **Mechanical Engineering**



Outline

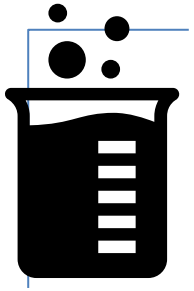


Introduction

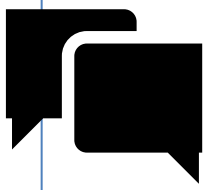


Project

Approach



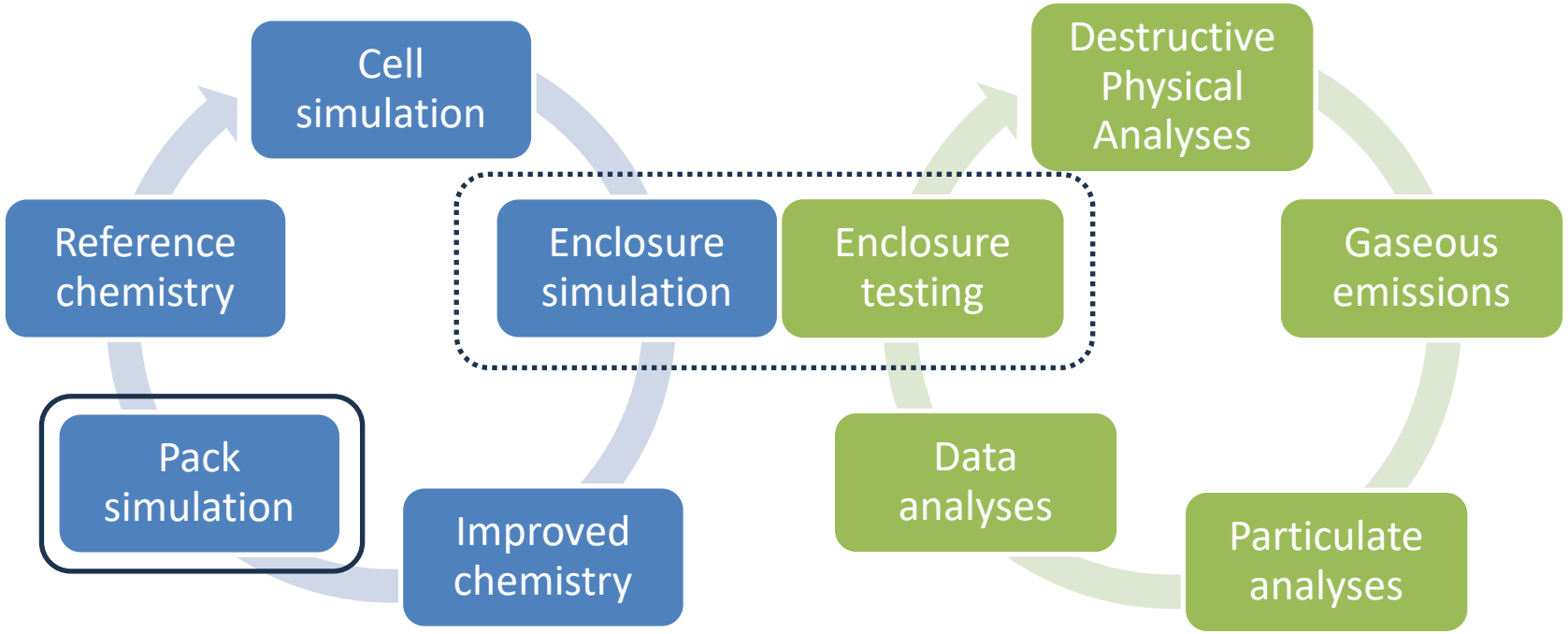
Results



Conclusion

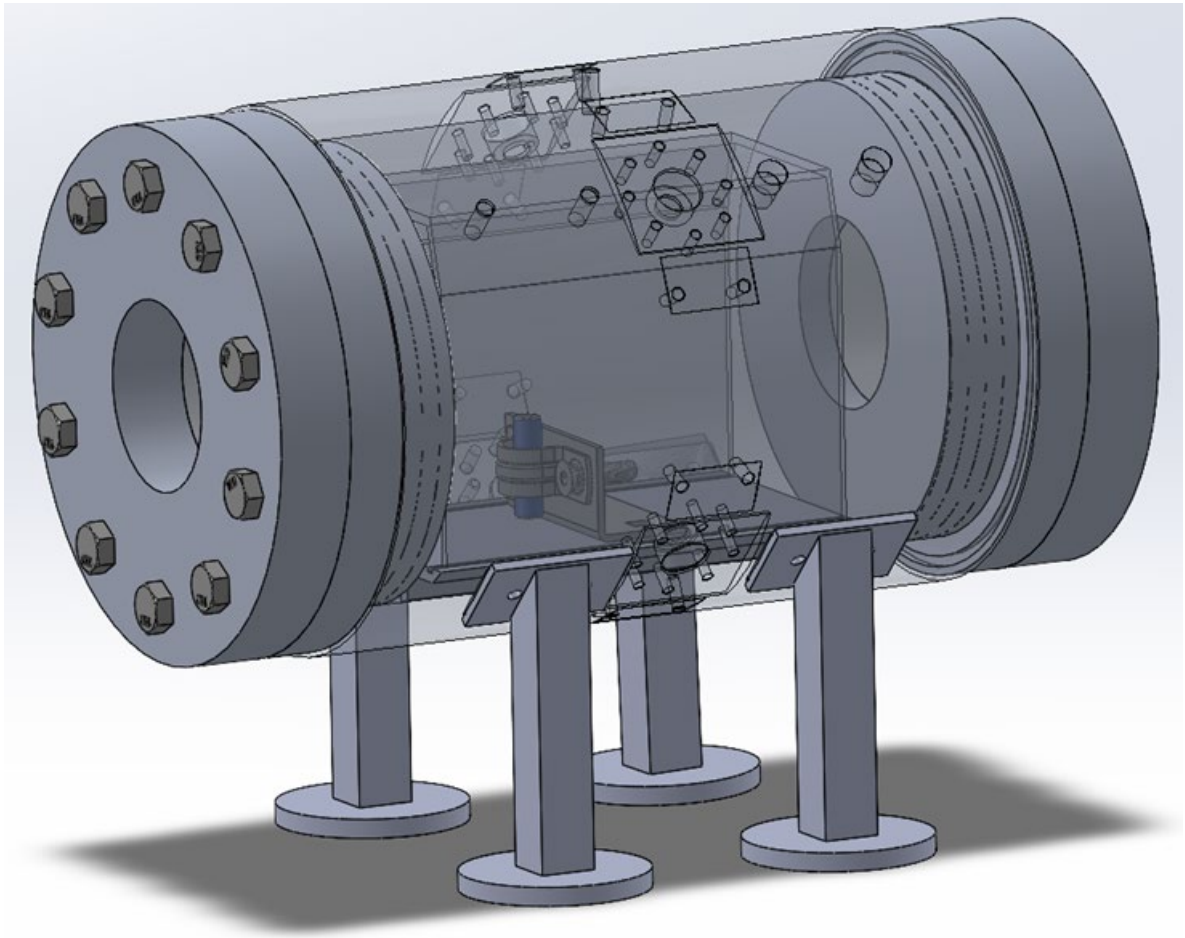
Project Overview

- Results herein are from an internal research project *Vent Gas and Solid Particle Model Development during Battery Thermal Runaway*
  - Develop a predictive physics-based model for vent gases and solid particles during battery thermal runaway.



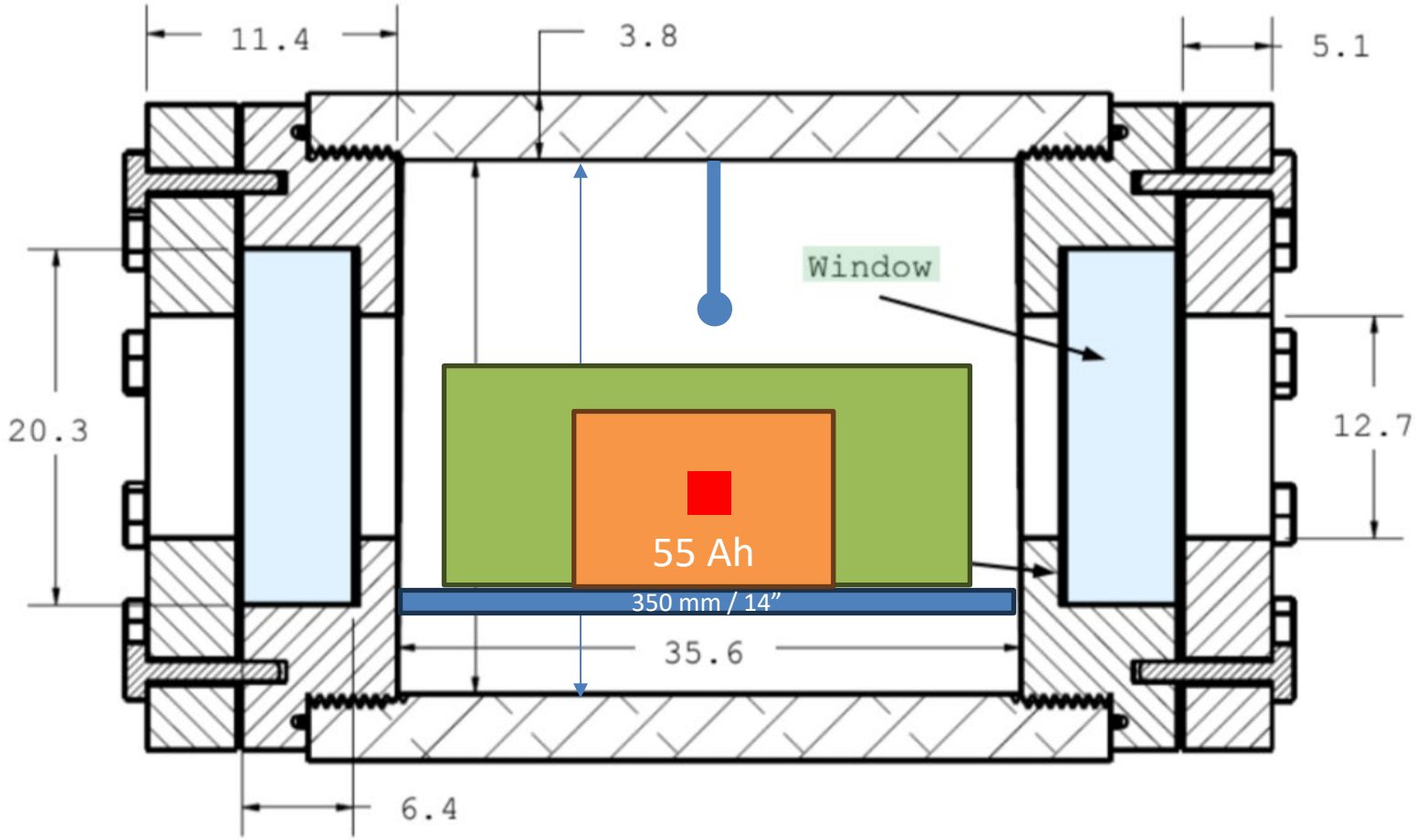
Methodology is application-agnostic, but the project had automotive / off-highway focus

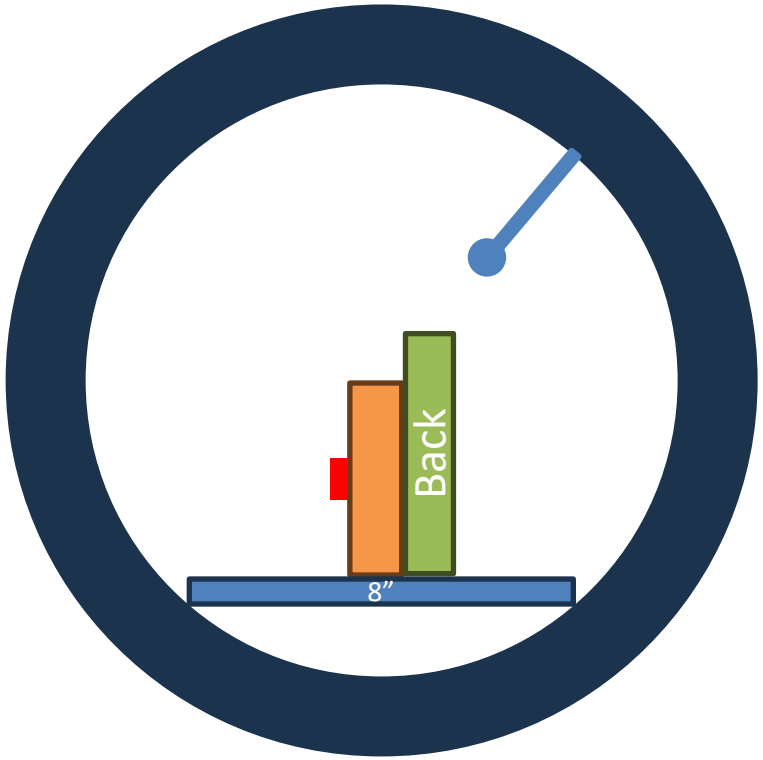
Test Platform



- Cylindrical enclosure of ~26 liters
- Separate oxygen, nitrogen, and air connections for filling
- Side fill and sampling locations
- Top and bottom purge locations
- Four configurable access panels
- Optional optical access at ends
- Tests were performed on Gotion 55 Ah NMC 811 prismatic cells

Enclosure and Cell Placement Details





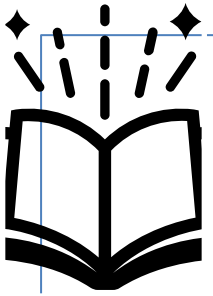
- Showing location of enclosure gas temperature thermocouple

Test Conditions

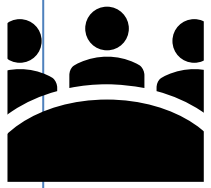
#	SOC	Heating Rate (°C/min)	Test Environment	Heater Maximum (°C)	Emissions Measurement
1	100	~15	Nitrogen at elevated pressure	550	No
2	100	30	Nitrogen	550	No
3	100	30	Nitrogen	550	Yes
4	100	30	Air	550	No
5	100	30	Nitrogen	550	Yes
6	100	30	Nitrogen	550	Yes
7	100	MAX	Nitrogen	550	Yes

This presentation will focus on the four tests under repeat conditions – 2,3,5,6

Outline

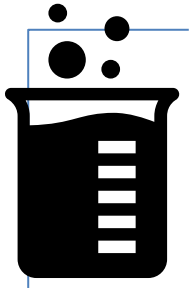


Introduction



Project

Approach

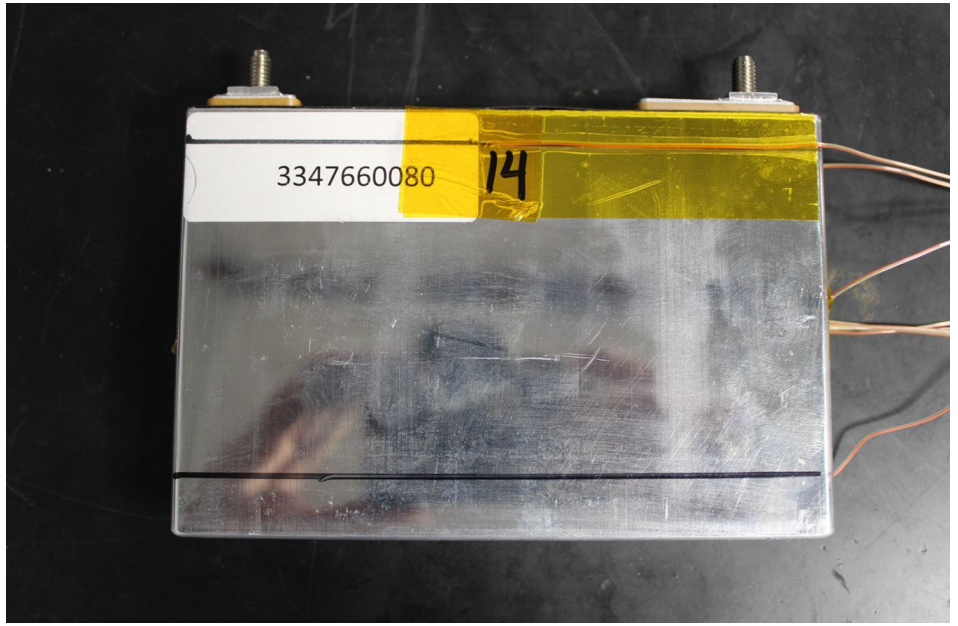


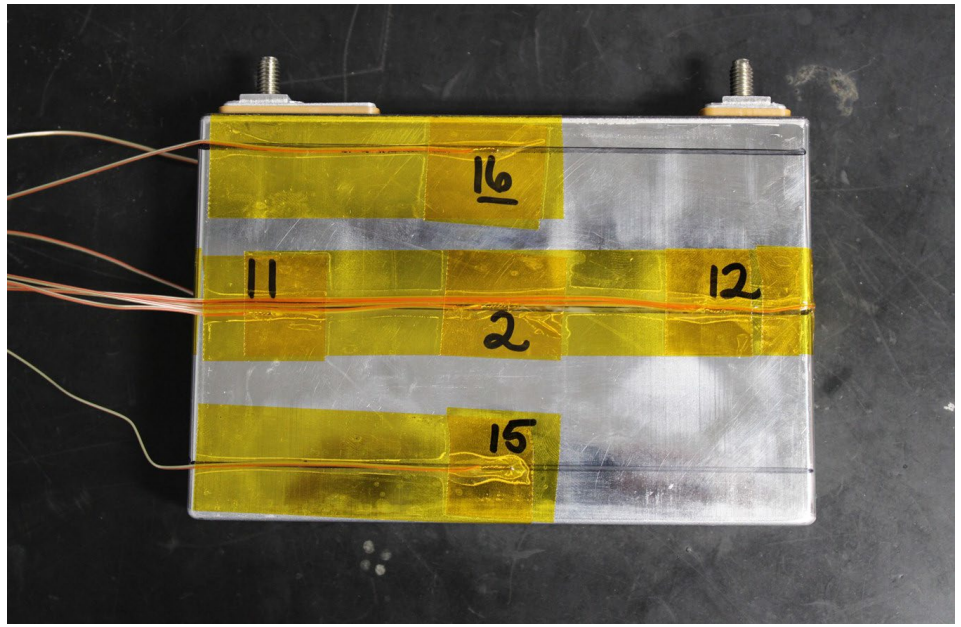
Results

Conclusion

Cell Preparation

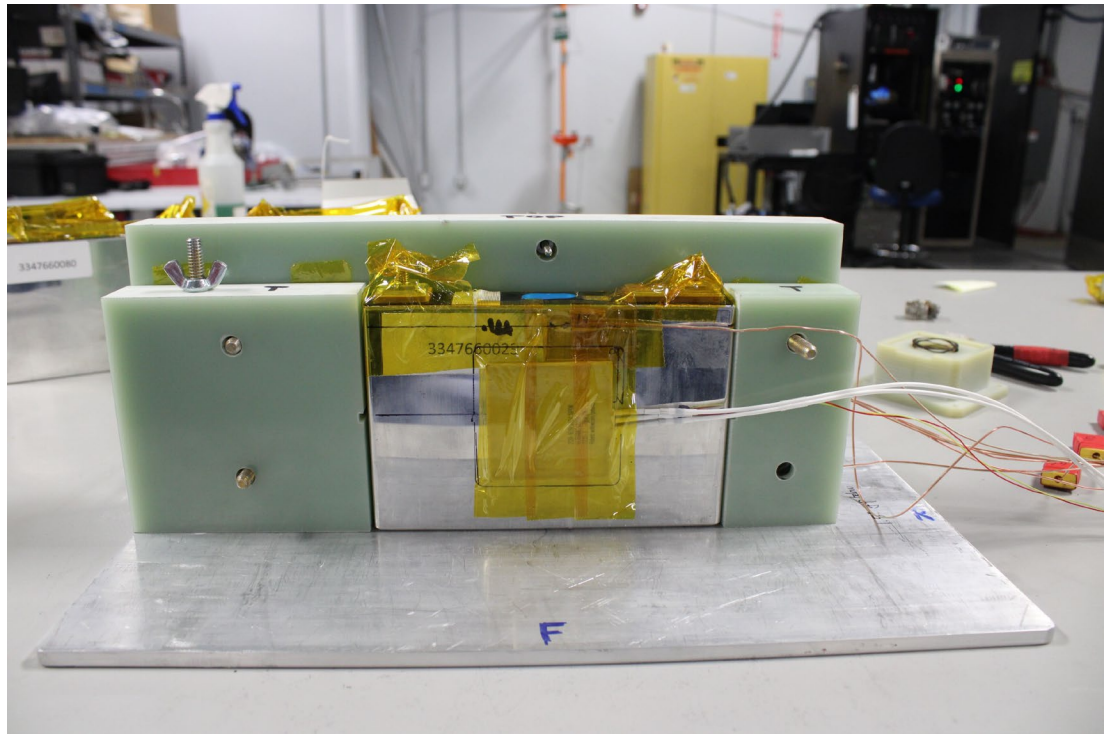
- Initial weight, visual inspection and bar coding
- Multiple surface thermocouples added

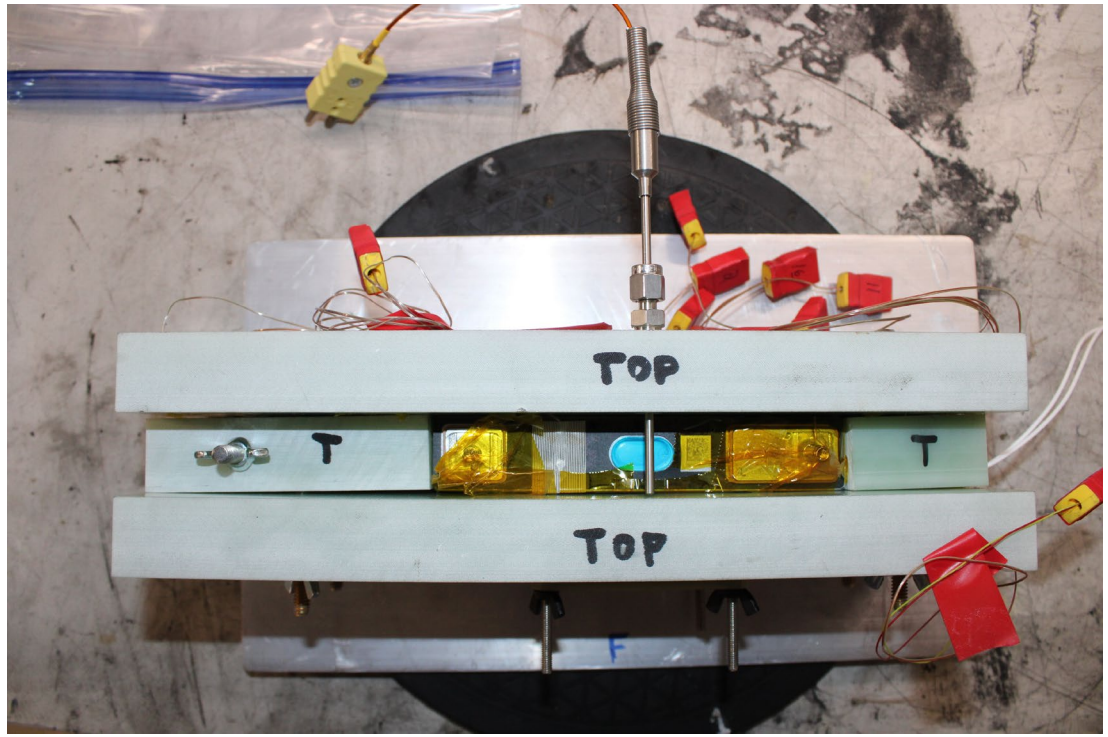




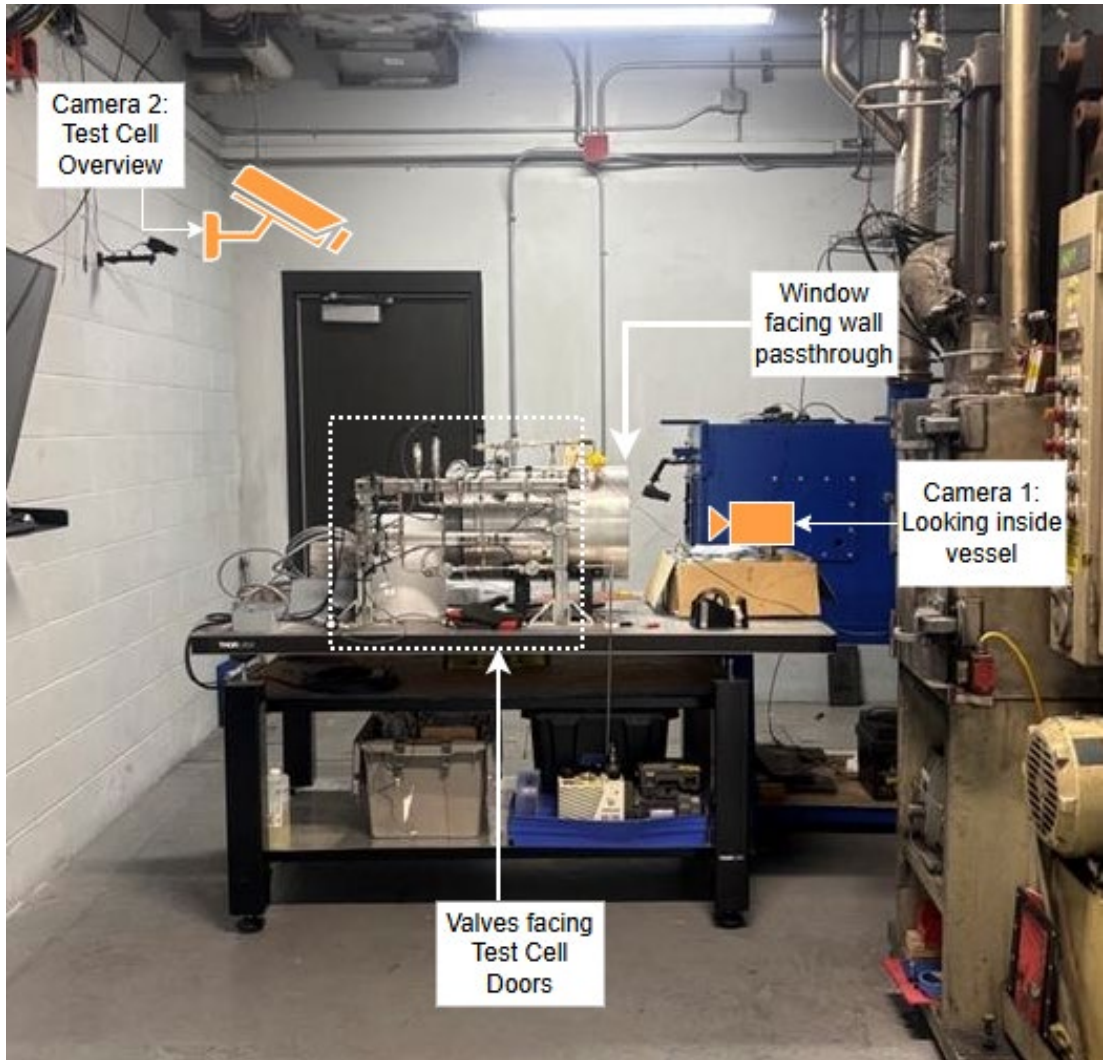
Heater and Fixture Details

- Failure was initiated by a 1000 W 2”x2” ceramic heater with controlled heating rate
- Cell was secured in a fixture with heater and thermocouple above cell vent

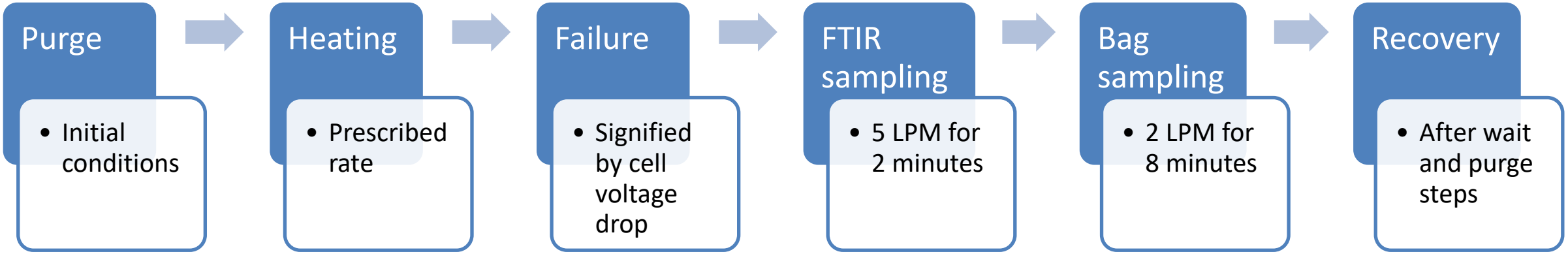




Fixture Installation



Test Sequence and Emissions Measurements



- FTIR was specifically calibrated to favor major gas species rather than toxics such as HF to support model development
- Bag sample was subjected to GC-TCD and GC-FID analyses to resolve hydrogen and hydrocarbon concentrations, unburned electrolytes

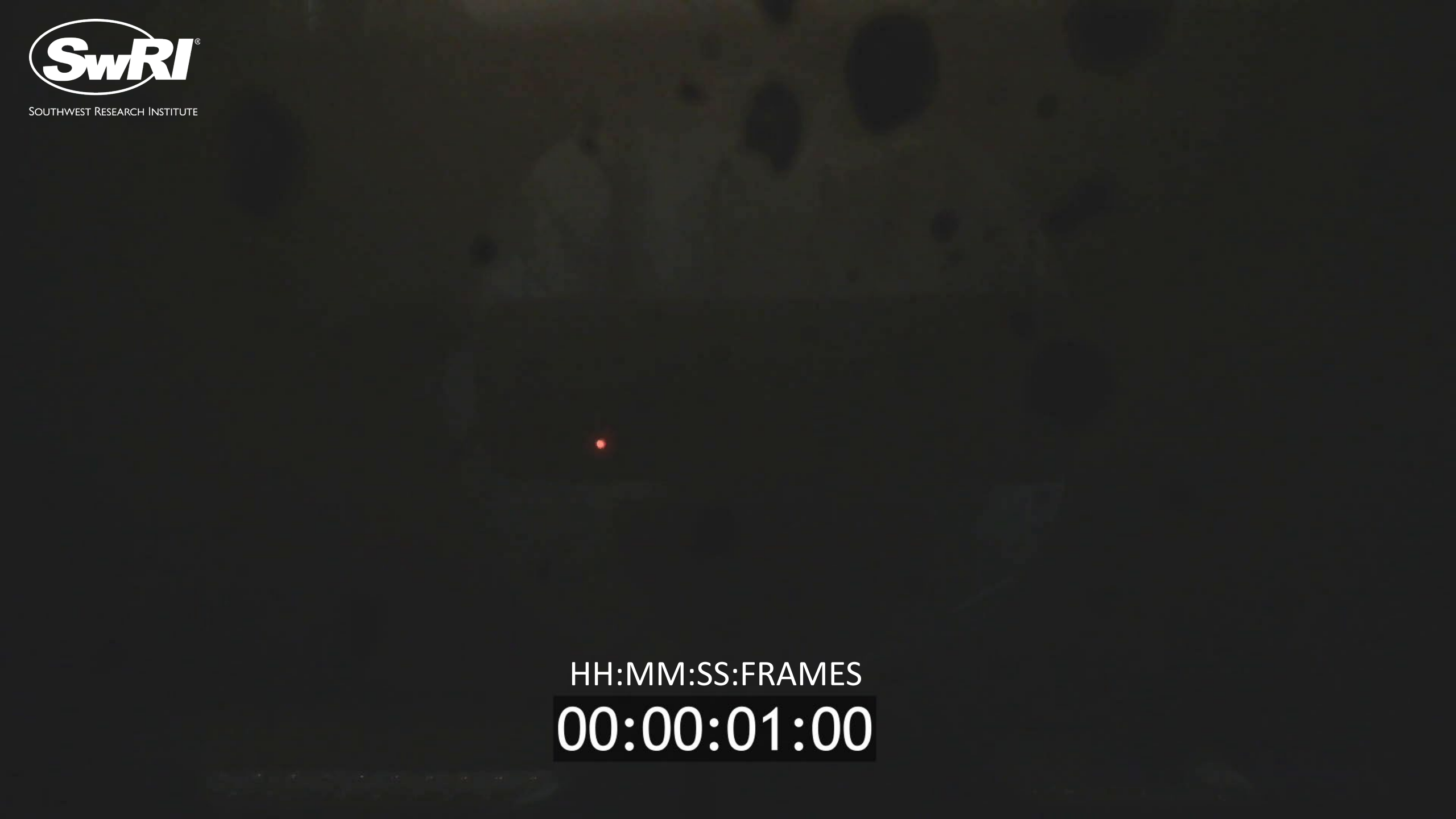

3347660023
HH:MM:SS:FRAMES
-00:00:01:00

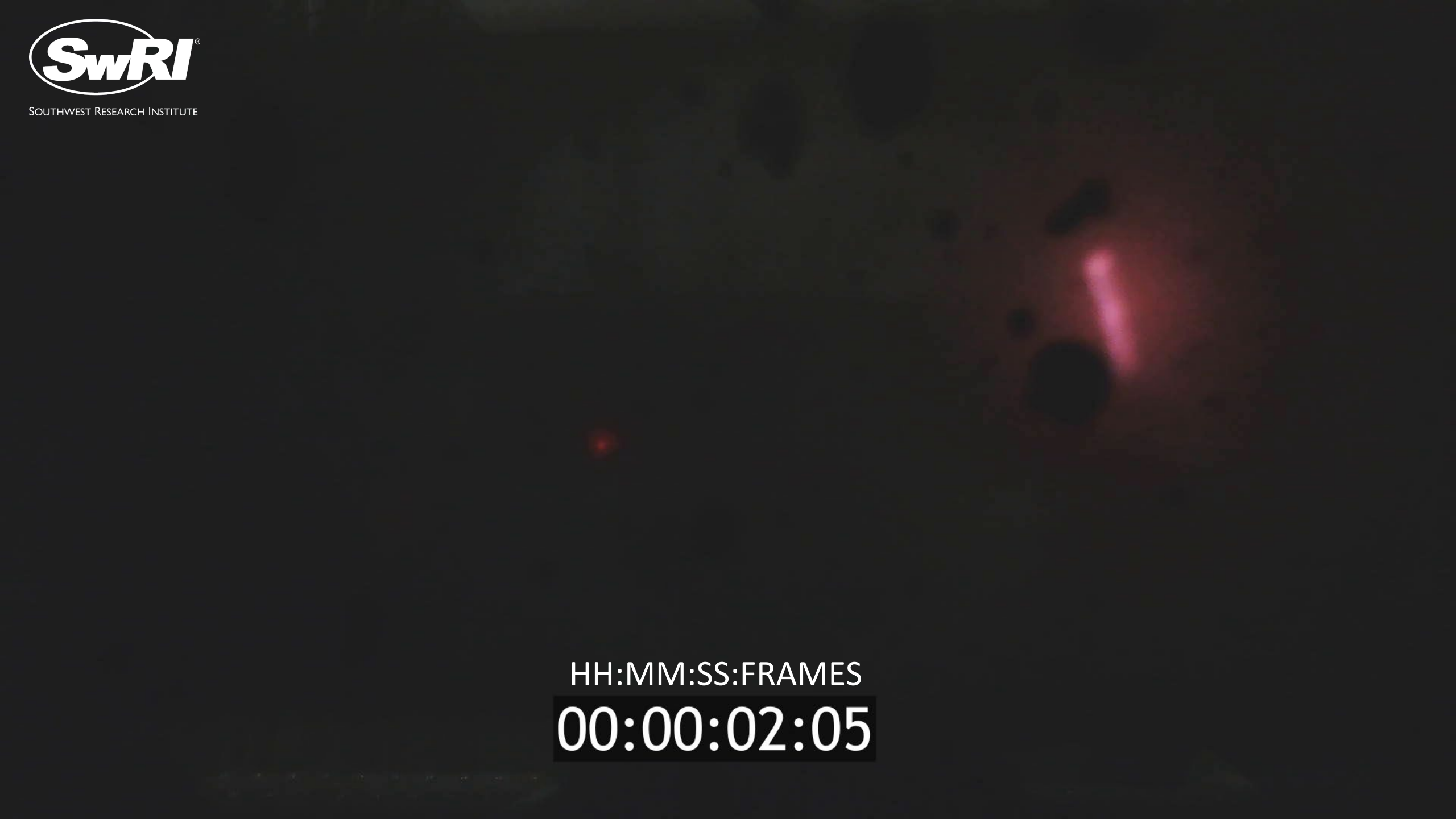

SwRI
SOUTHWEST RESEARCH INSTITUTE
3347660023
HH:MM:SS:FRAMES
00:00:00:00


SwRI
SOUTHWEST RESEARCH INSTITUTE
3347660023
HH:MM:SS:FRAMES
00:00:00:15


SwRI
SOUTHWEST RESEARCH INSTITUTE
HH:MM:SS:FRAMES
00:00:00:30

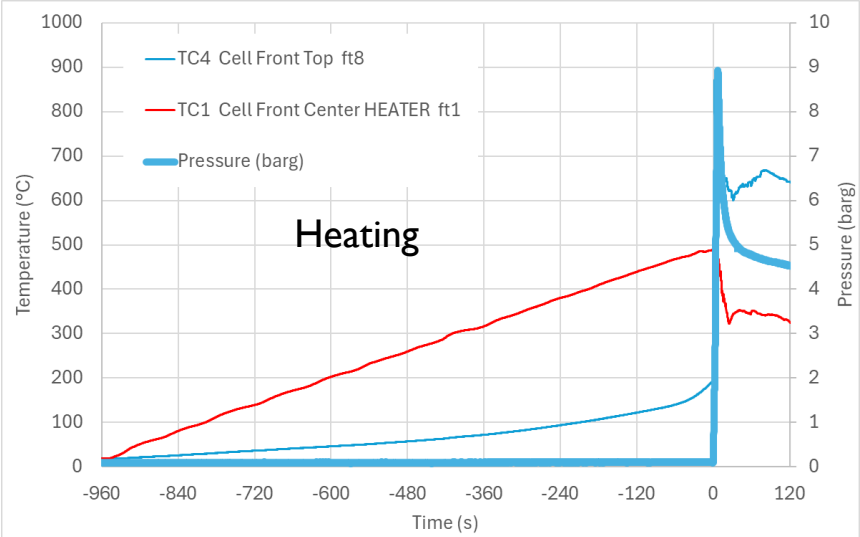

HH:MM:SS:FRAMES
00:00:00:45

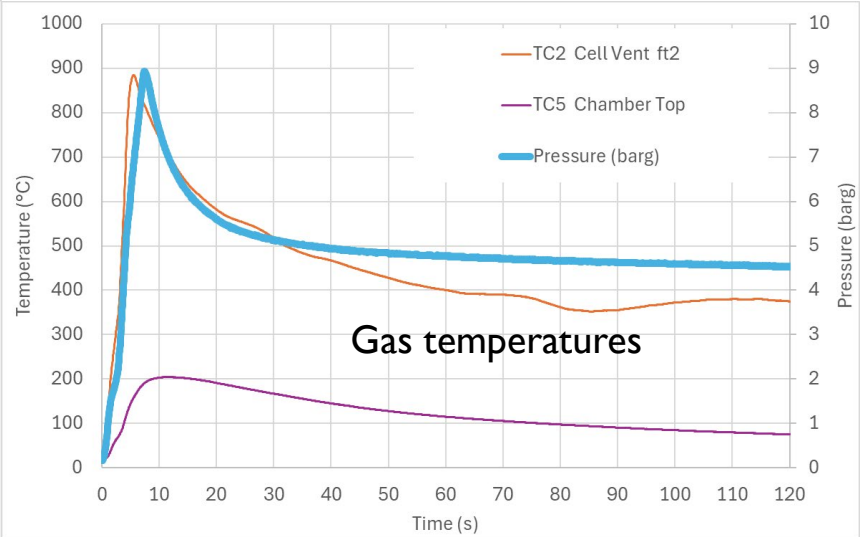

SwRI
SOUTHWEST RESEARCH INSTITUTE
HH:MM:SS:FRAMES
00:00:01:00

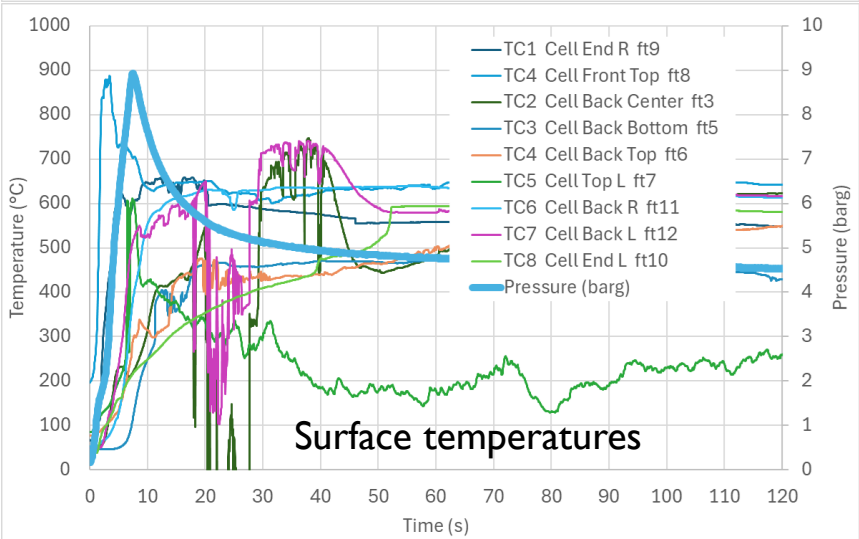

SwRI
SOUTHWEST RESEARCH INSTITUTE
HH:MM:SS:FRAMES
00:00:02:05

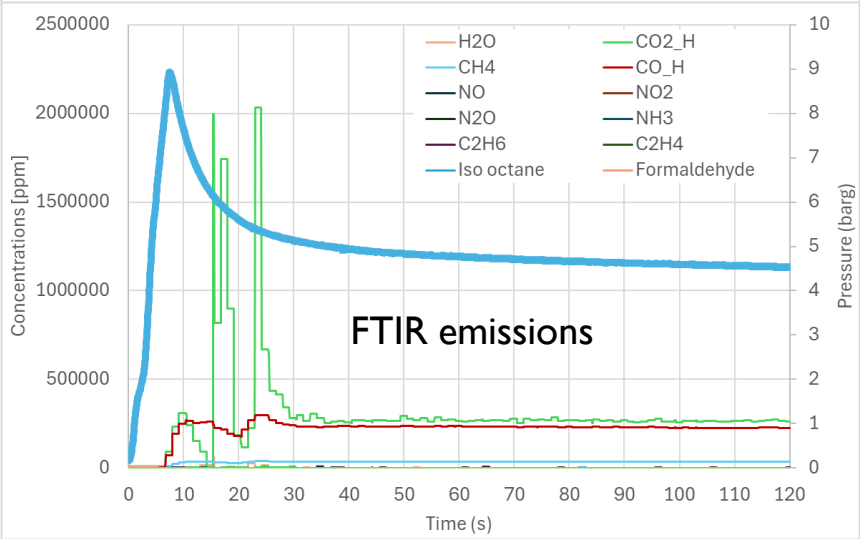

SwRI
SOUTHWEST RESEARCH INSTITUTE
HH:MM:SS:FRAMES
00:00:04:10

Typical Data









- TC2 vent temperature increased at cell failure
- TC5 represents the temperature
- Variability in surface temperatures
- Spikes observed in CO2, presumably due to sample inhomogeneity

Post-Test Extraction

- Enclosure

- Fixture

- Particulates recovered from the enclosure after article and cell extraction

Post-Test Inspections

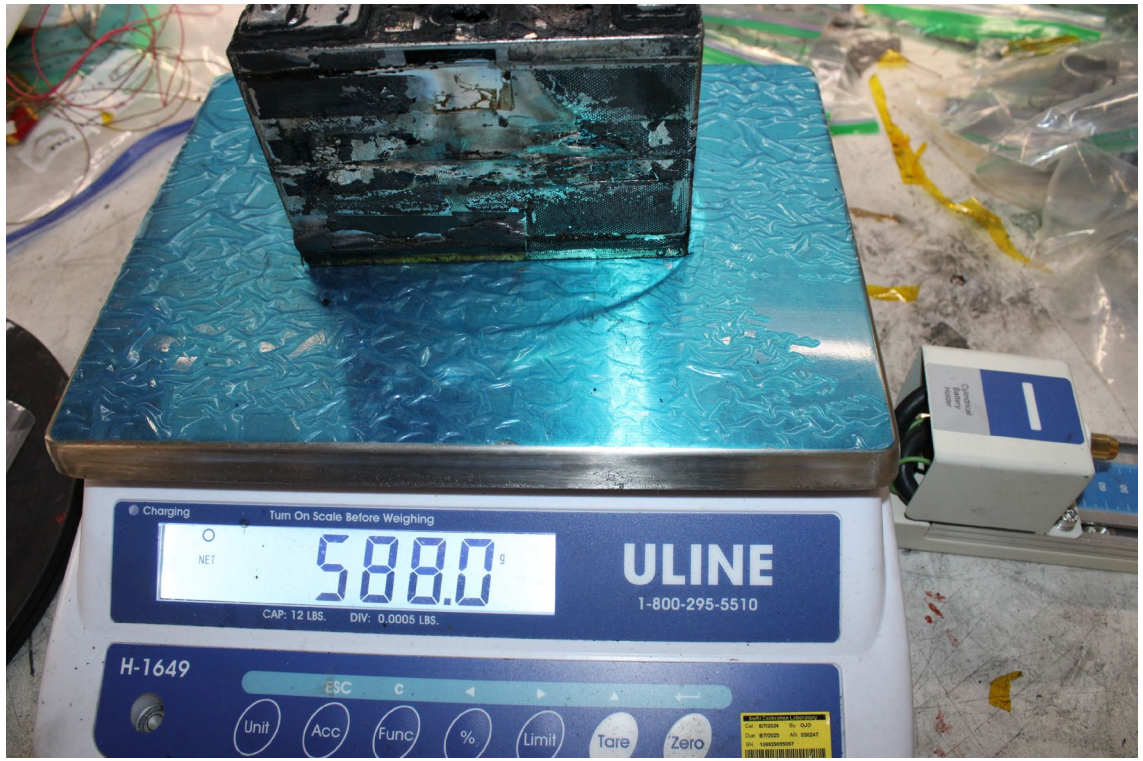
- Front

- Back

- Cell case remained mostly intact with only vent-patch compromised

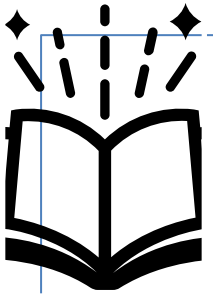
Post-Test Weights

- Cell carcass

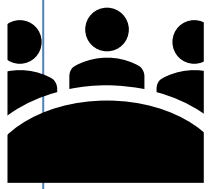


- Recovered particulates

Outline

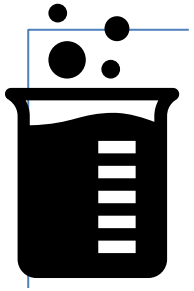


Introduction



Project

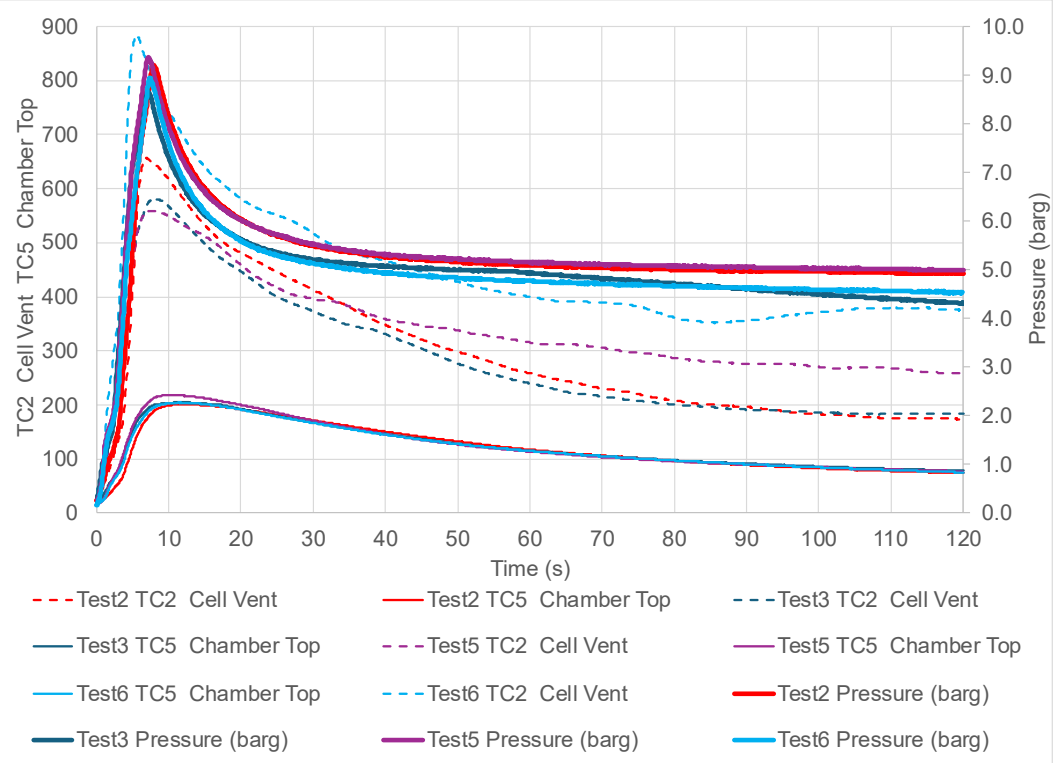
Approach

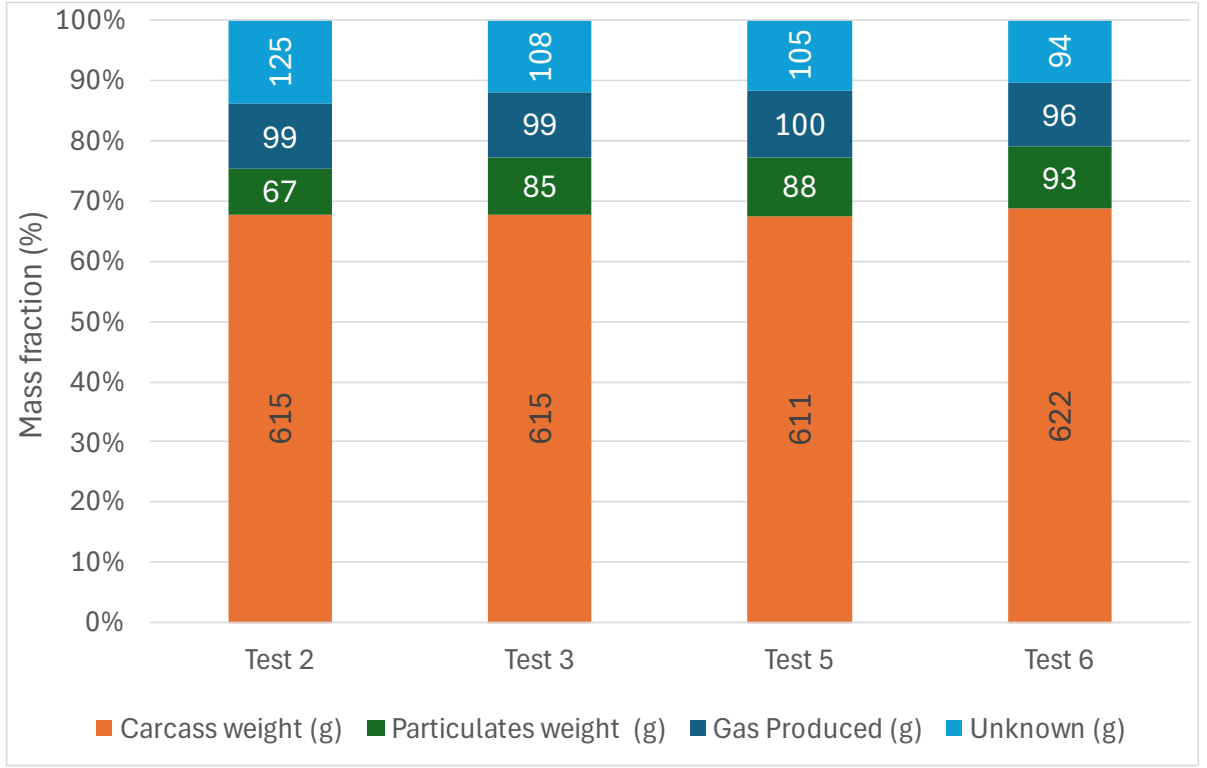


Results

Conclusion

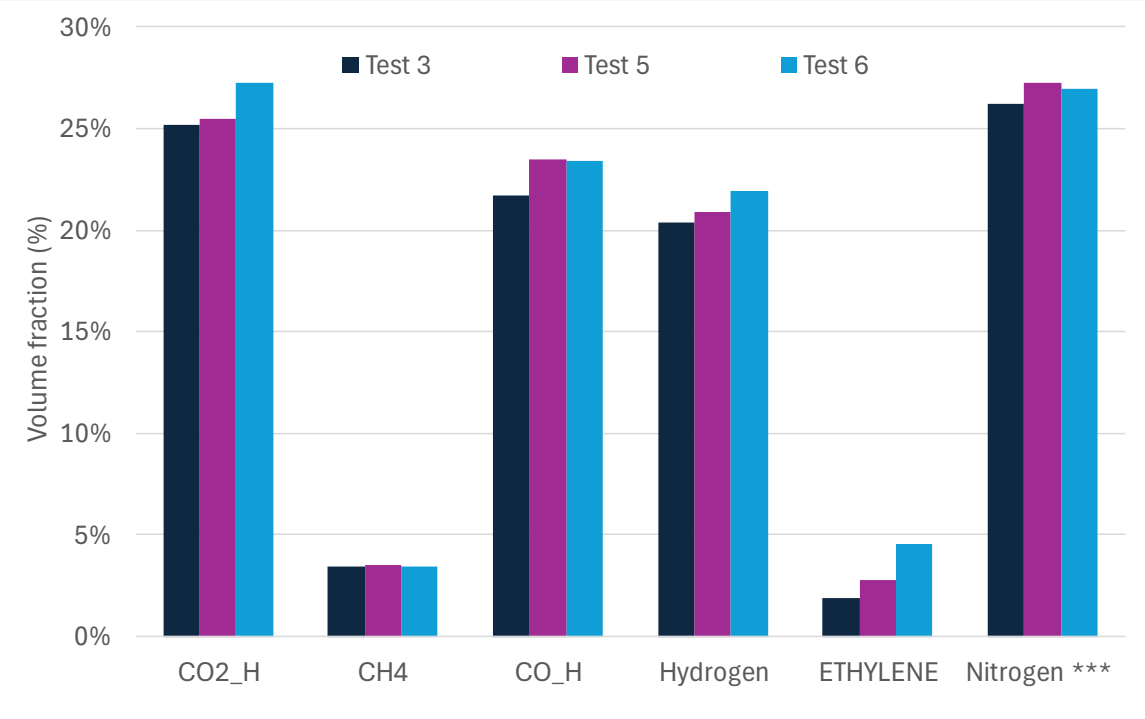
Comparative Operational Results

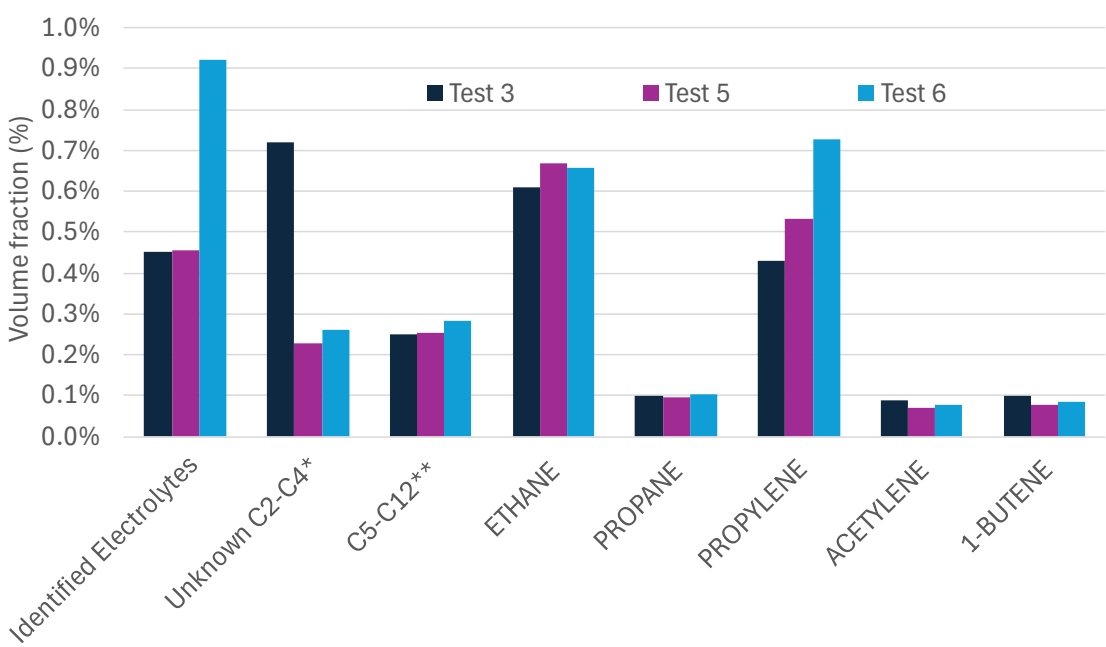




- Pressures and chamber gas temperatures were comparable
- Weight distribution was similar
  - Gas produced was calculated using ideal gas law with conditions at 60 seconds

Gaseous Emissions Comparison

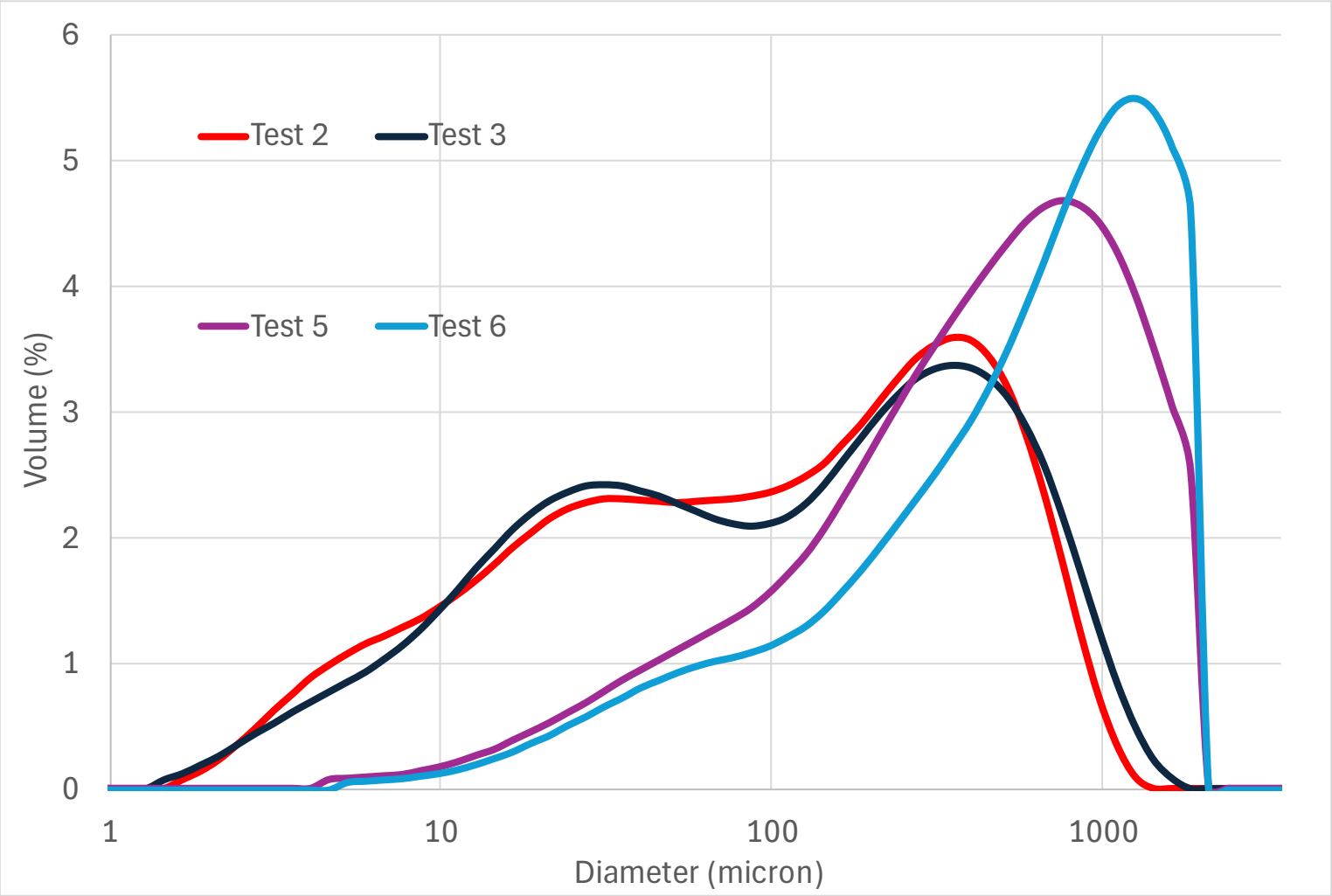




*Used Carbon number 3.5 for Conversion of PPMC to ppm
**Used Carbon Number 7.0 for Conversion of PPMC to ppm
*** Estimated from initial conditions

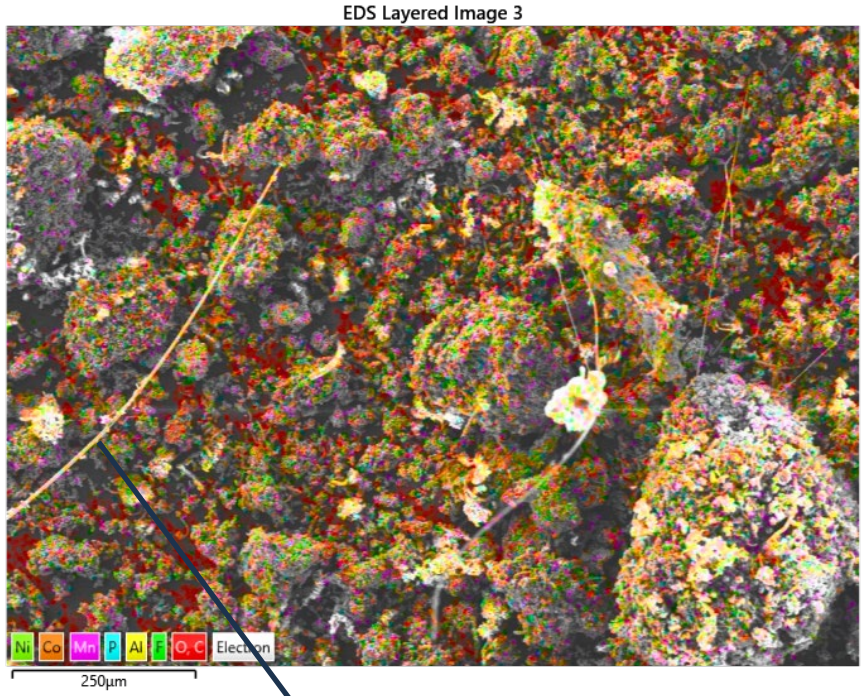
- Reasonable comparison between the three tests
  - Some variability in ethylene, propylene, electrolytes, and unknown C2-C4

Particle Size Distribution (PSD) Comparison

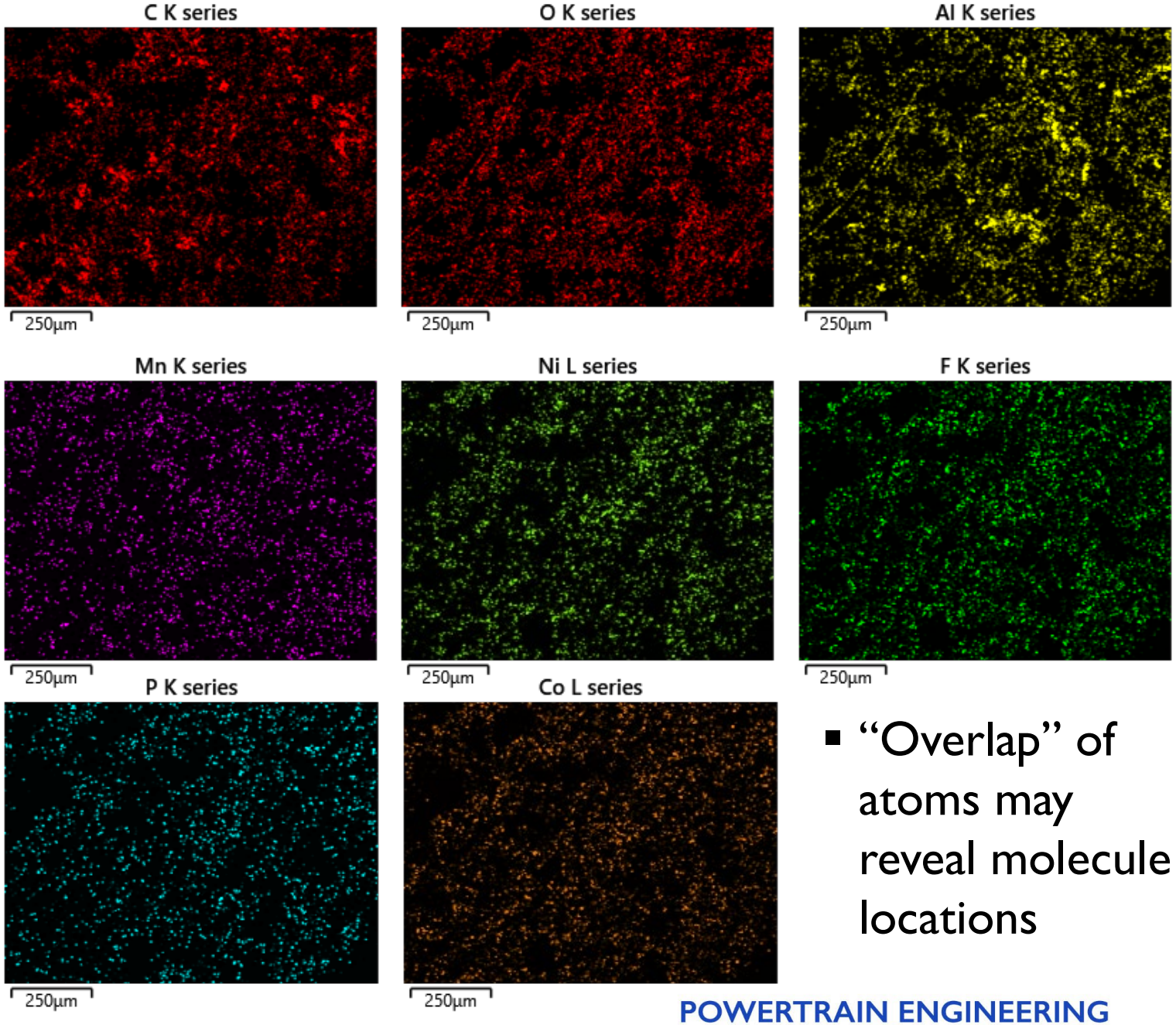


- Recovered particles were subject to Malvern particle size distribution (PSD) instrument
- Apparent shift in size from Tests 2, 3 to 5,6
- Samples were not sieved but hopper feeder limitation of 3.5 mm is visible

Particulates Typical EDS

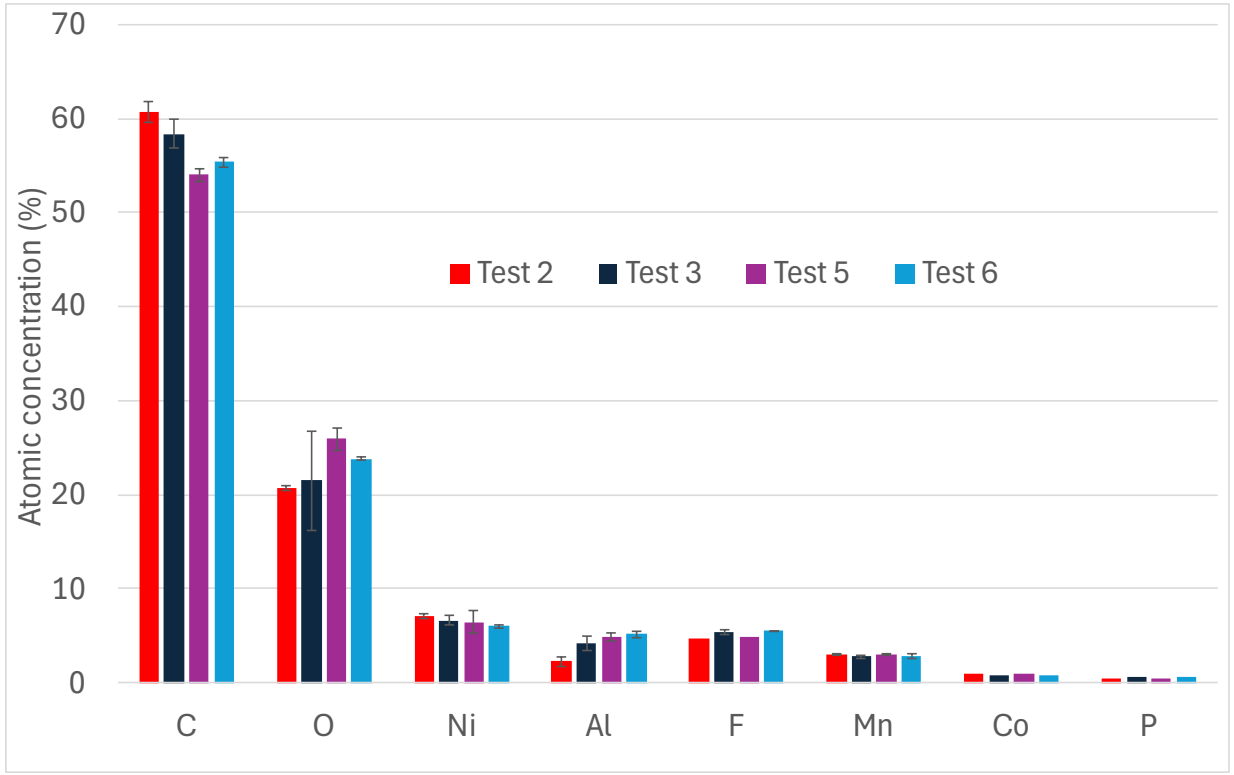


Likely strands from separator



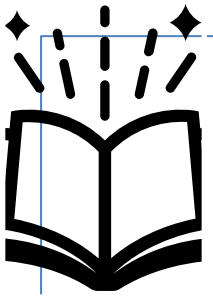
- "Overlap" of atoms may reveal molecule locations

Average EDS Composition

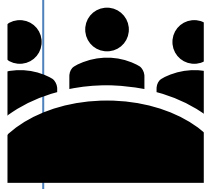


- Weighting applied based on magnification of the different samples
- Generally, 55 % C, 24 % O, 7 % Ni, 5 % F and Al, 3 % Mn, 1 % Co and P
- Not for quantitative comparison: only limited locations were investigated

Outline

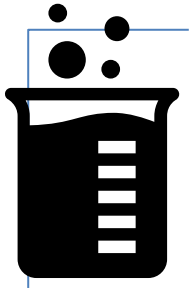


Introduction



Project

Approach



Results

Conclusion

Test Summary

- Consistent operational data and mass allocation
  - CoV = standard deviation / average
    - Not a comprehensive statistical treatment of the data

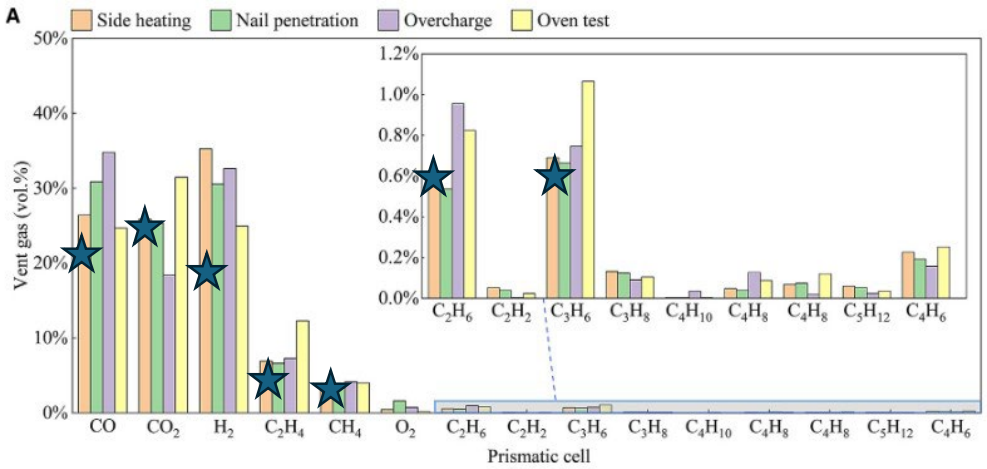
Operational	Average	CoV (%)
Temperature at 60 s (°C)	114.7	0.7%
Pressure at 60 s (barg)	5.0	3.8%
Tmax (°C)	209.1	3.8%
Pmax (barg)	9.0	3.8%
Carcass weight (g)	616.0	0.9%
Particulates weight (g)	88.7	4.5%
Gas Produced (g)	98.3	1.8%
Gas rate (L/kWh))	557.4	3.8%

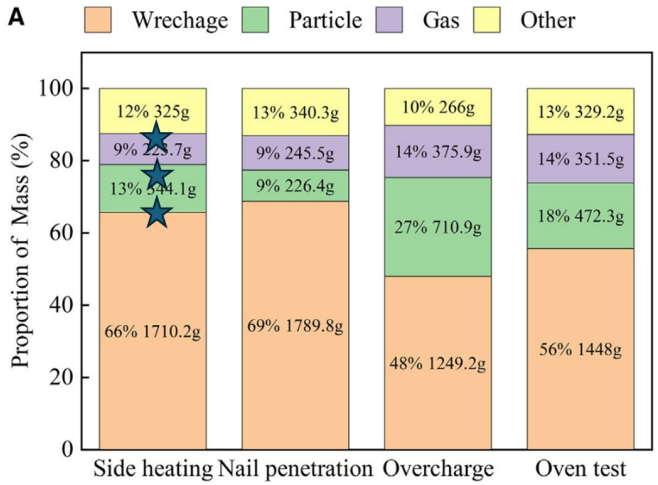
- Consistent gaseous emissions
- Consistent particulates composition
- Variability in particulate size distribution
  - Not a primary focus of this project
- Limited visual information due to window fouling

Gas composition	Average	CoV (%)
CO_2	24.4%	1.4%
CH_4	3.2%	4.0%
CO	21.5%	2.5%
Hydrogen	19.7%	0.7%
Identified Electrolytes	0.6%	32.7%
Unknown C2-C4	0.2%	9.2%
C5-C12	0.3%	8.2%
ETHANE	0.6%	4.1%
ETHYLENE	3.5%	22.7%
PROPANE	0.1%	3.8%
PROPYLENE	0.6%	13.6%
Nitrogen	25.0%	2.7%

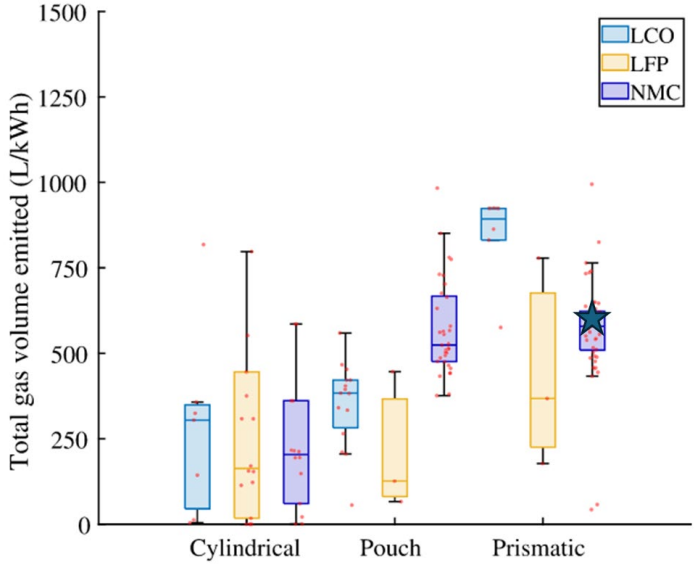
Particulates	Average	CoV (%)
C	57.1%	5%
O	23.0%	10%
Ni	6.6%	6%
Al	4.2%	32%
F	5.2%	7%
Mn	2.9%	4%
Co	0.9%	12%
P	0.6%	15%
Sauter mean diameter	124 micron	69%
50th percentile diameter	466 micron	72%

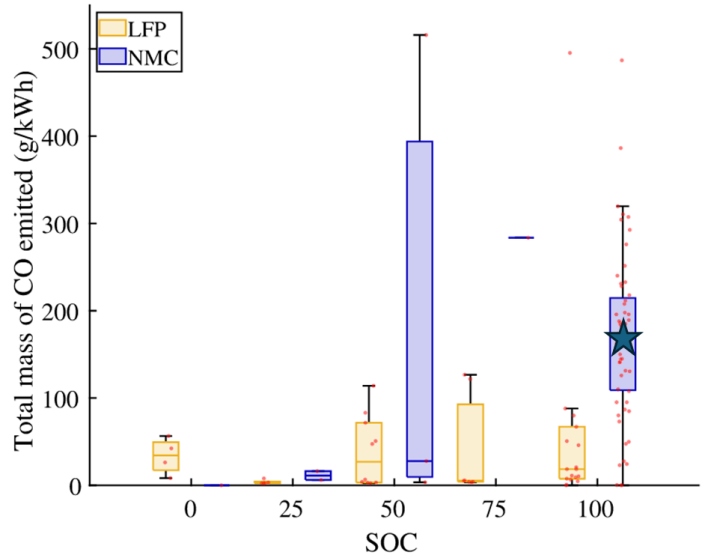
Literature Comparisons





https://doi.org/10.1016/j.xcrp.2023.101705

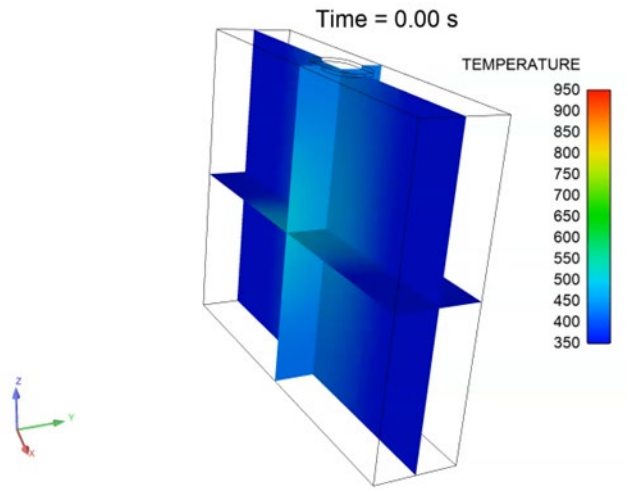


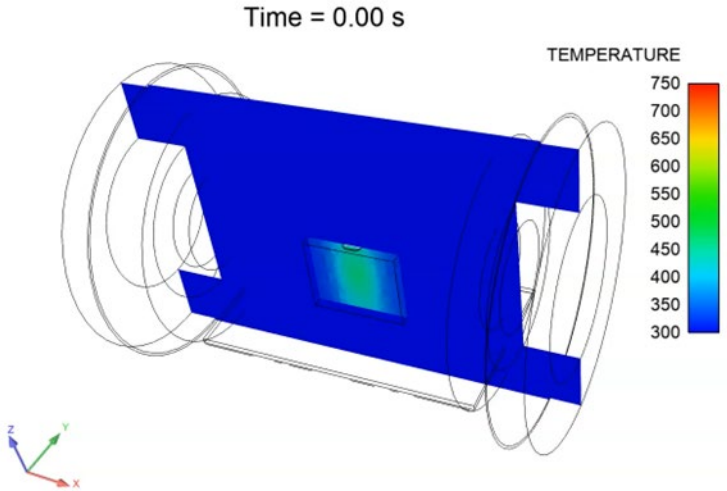


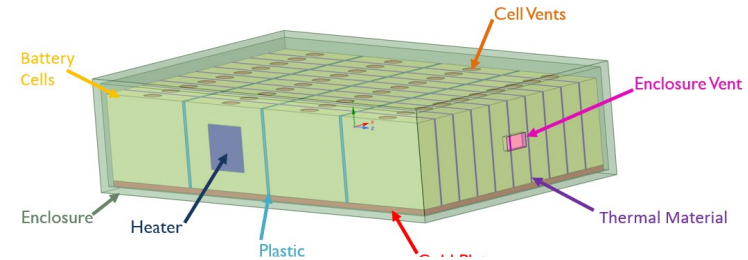
https://doi.org/10.1016/j.est.2024.111288.

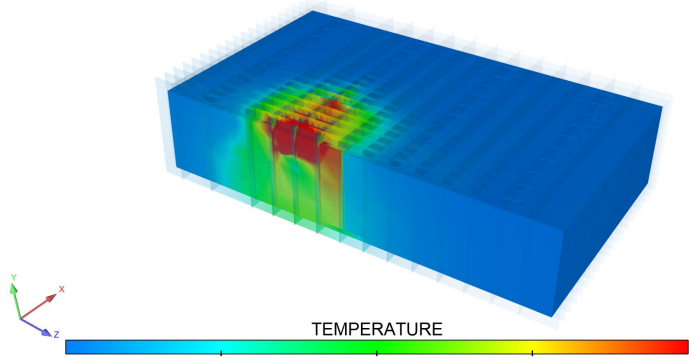
Simulation Example

- Thermal and chemical kinetics with solid geometry of the battery cell
- Heat release and venting of gas and particulates to gas domain
- Apply coupled solution to a battery module









Looking Ahead

- Ongoing work
  - Nail-penetration abuse testing using the same cells
    - Significantly larger variability with more sever outcomes
  - Impact of SOC and SOH
  - Enhanced bag analyses
  - Enhanced particulate recovery and sample preparation
  - Other cells chemistry, size, and form factors
  - Enhanced energy release measurements and calculations
- Did not talk about:
  - Destructive Physical Analyses (DPA)
  - Impact of variations in test conditions (Tests 1, 4, and 7)
  - Cell surface temperature measurements
  - Model development details and simulation results
- Future work
  - Other abuse initiation
  - Varying heating rates
  - Measuring suspended solids from enclosure
  - Reintroducing toxic gas analyses

Acknowledgements

- SwRI Advisory Committee for Research (ACR) for funding
- Simulation and project management
  - Shiyou Yang, Matt Hoffmeyer, Zainal Abidin
- Test execution
  - Annie Ramirez, Arcadio Maldonado, Chris Thomas, Adrian Valadez, Bobby Pool
- Emissions measurements
  - Svitlana Kroll, Nolan Wright
- Management and technical staff

battery.swri.org

Thank you!

SOUTHWEST RESEARCH INSTITUTE®

Questions?