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where energy meets environment

Off-Gas Monitoring for Lithium Ion Battery Health and Safety

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Power Sources Committee Meeting

Wright Patterson AFB

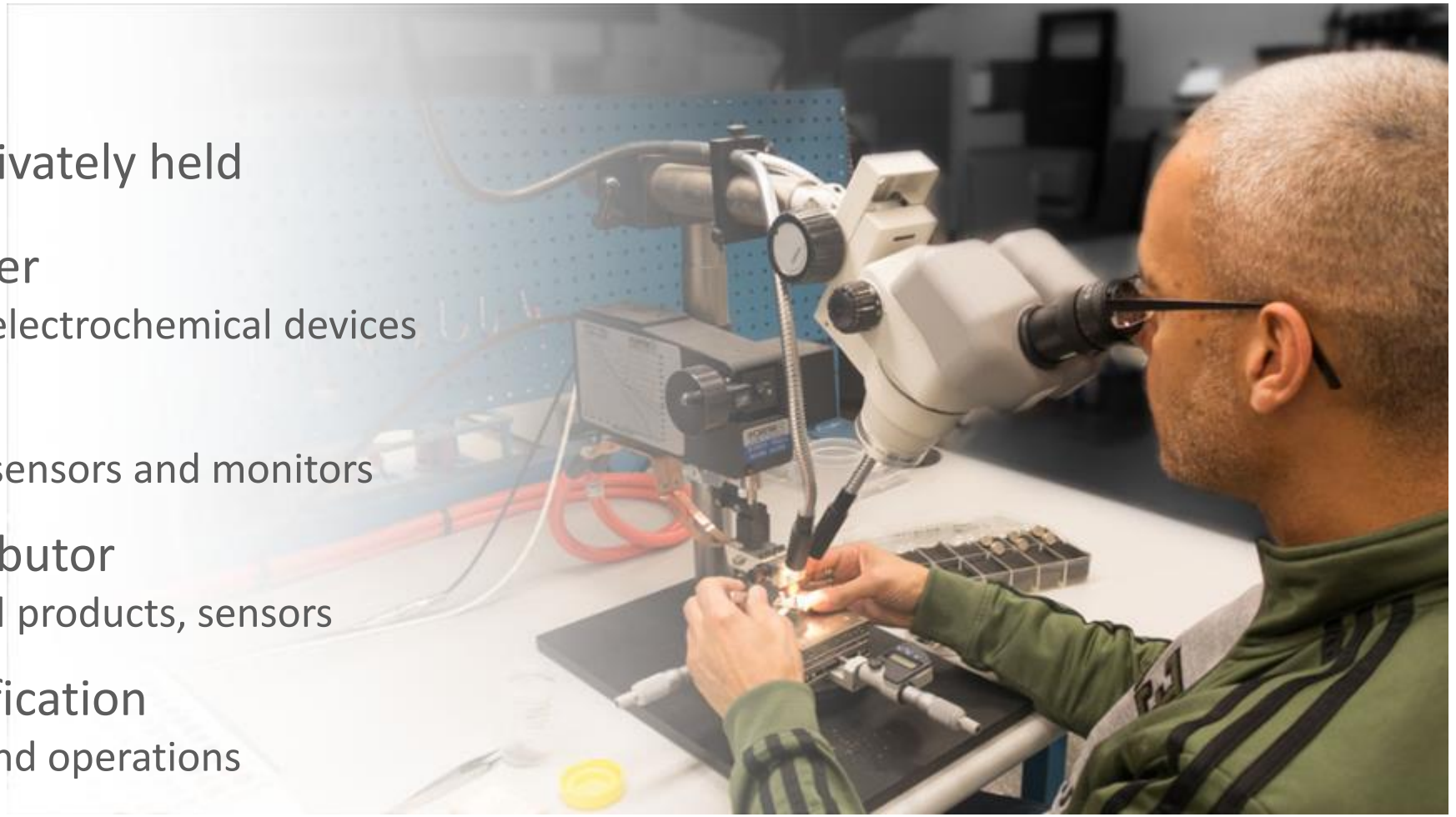
June 21, 2017

Overview

- Introduction to Nexceris
- Problem Statement
- Battery Off-Gas Detection Capability
- Recent Demonstration Test Results
- Product Development Status
- Acknowledgements

Nexceris, LLC

- Founded in 1994, privately held
- Technology Developer
  - advanced ceramics, electrochemical devices
- Product Developer
  - fuel cells, catalysts, sensors and monitors
- Manufacturer/Distributor
  - fuel cells and related products, sensors
- ISO 9001:2015 certification
  - covers all products and operations



www.nexceris.com

Our Brands

NTM Sensors
we sense a green future

NTM Sensors provides gas sensors and monitors for hydrogen gas safety

FCM
fuelcellmaterials.com
PERFORMANCE AND QUALITY DELIVERED

fuelcellmaterials.com is our sales division for supplying high quality fuel cell and battery materials, coatings, and related materials in R&D and OEM markets.

Problem Statement

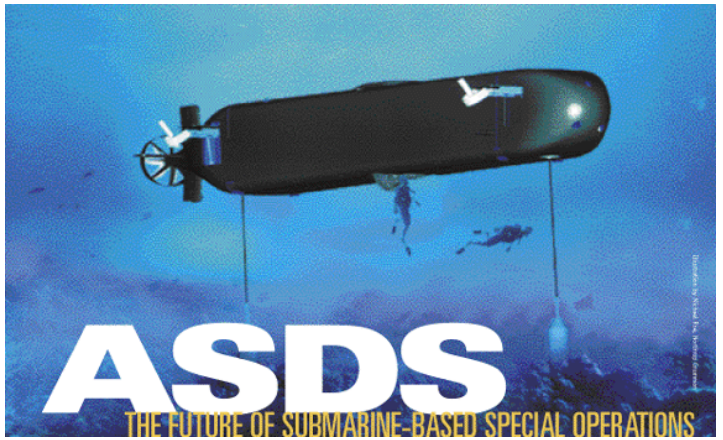
Lithium Ion Battery Safety

- Lithium-ion batteries are concentrated energy sources that can cause catastrophic events when abused
- In rare cases, batteries can cause catastrophic events even when not subjected to improper conditions
- The goal for safer battery systems is not only to isolate these events when they do occur, but also to predict and, ideally, to avoid them altogether

LI-ION BATTERY INCIDENTS

Incidents across multiple industries

- **Automotive:** NHTSA initiated $8.75M study after lithium ion battery related car fires (2012)
- **Marine:** Battery fire onboard Campbell Foss hybrid tug boat (2012)
- **Aviation:** FAA grounds Boeing 787 after issues with lithium ion batteries (2013)
- **Military:** Battery fire ended the Navy's Advanced SEAL Delivery System Program (2008)
- **Consumer Electronics:** Samsung recalls millions of Galaxy Note 7 phones (2016)



Battery Failure Sequence

Stressor

- Thermal, electrical, mechanical
- Latent manufacturing defect

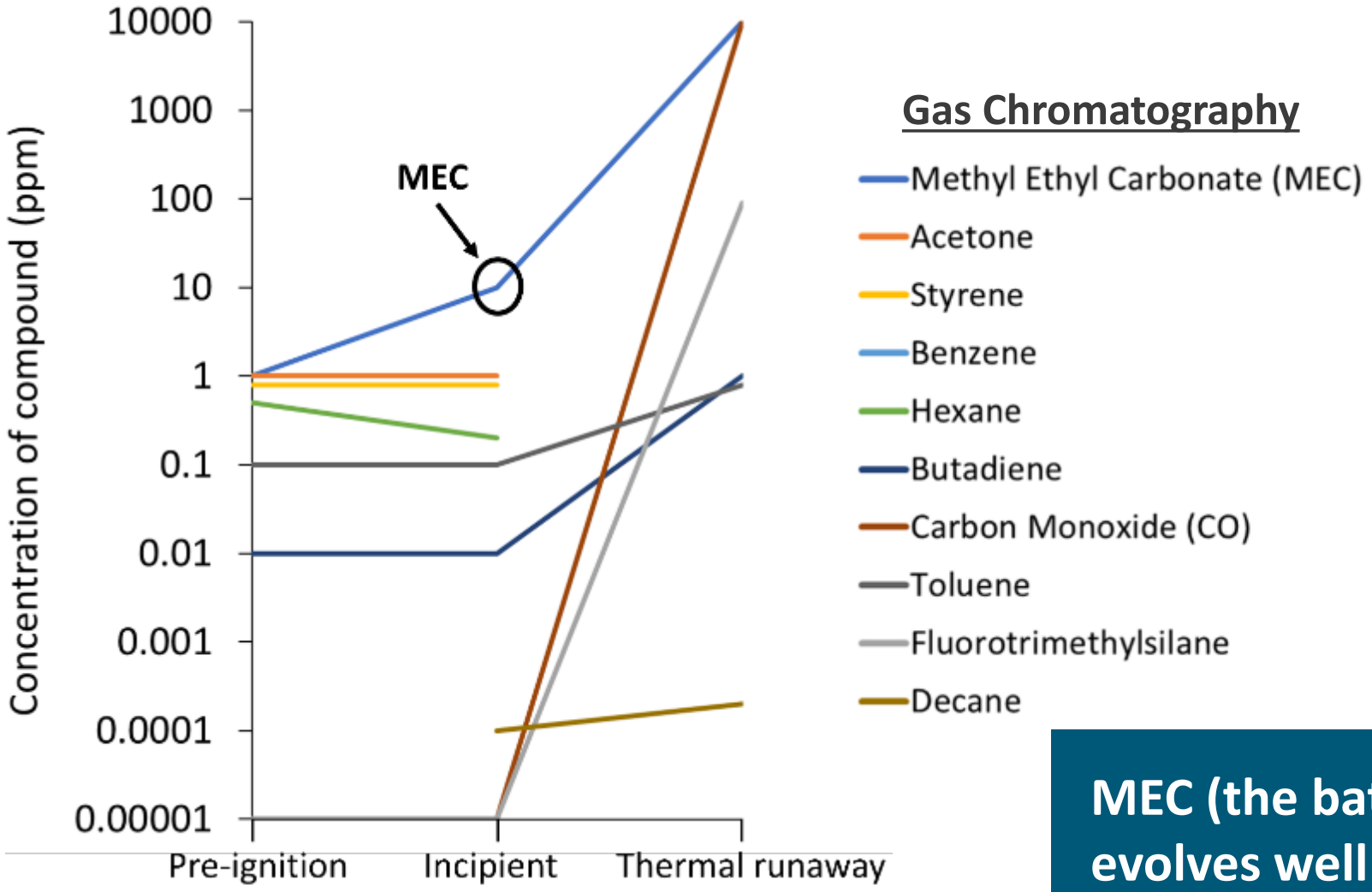
Failure

- Material degradation
- Exothermic reactions
- Off-gassing
- Thermal runaway

Propagation

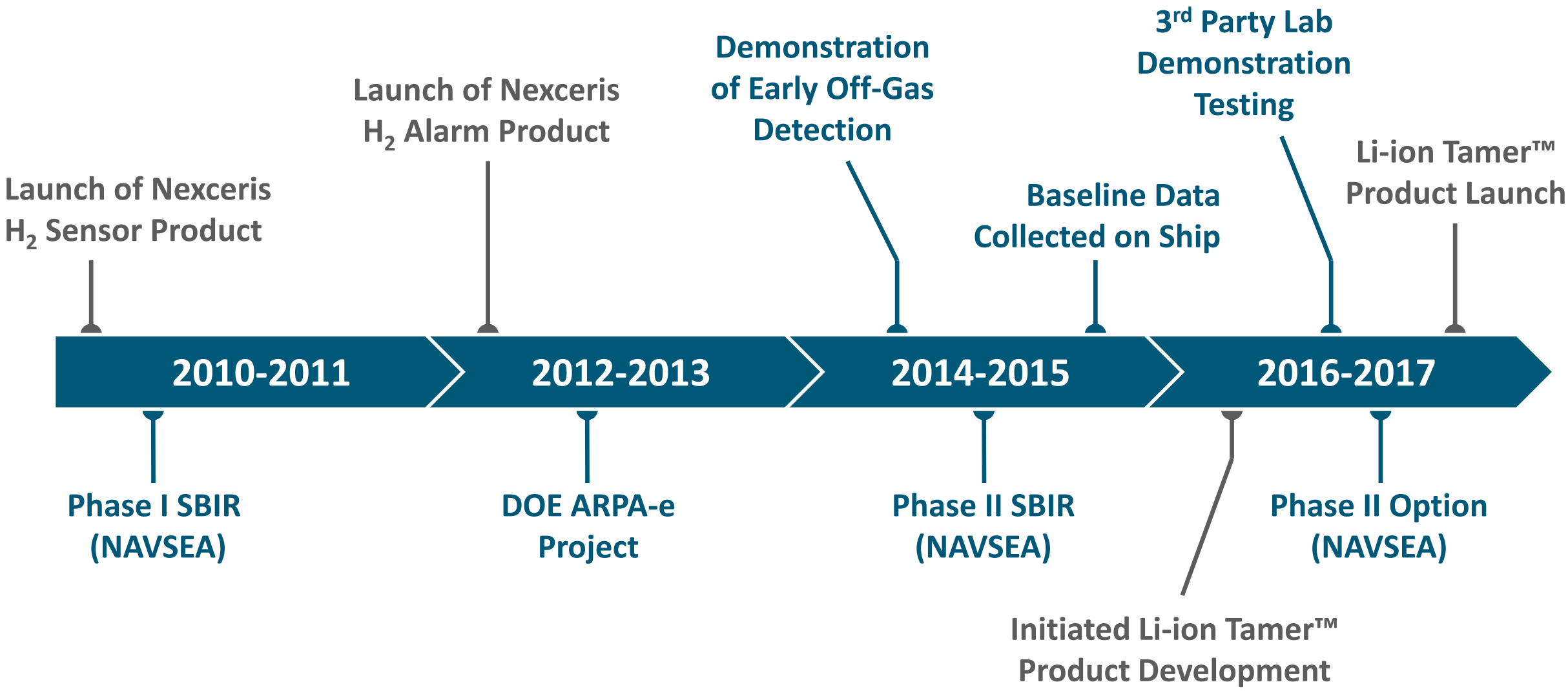
- Cell-to-cell
- Module-to-module

OFF-GASSING CHARACTERISTICS (ARPA-E)



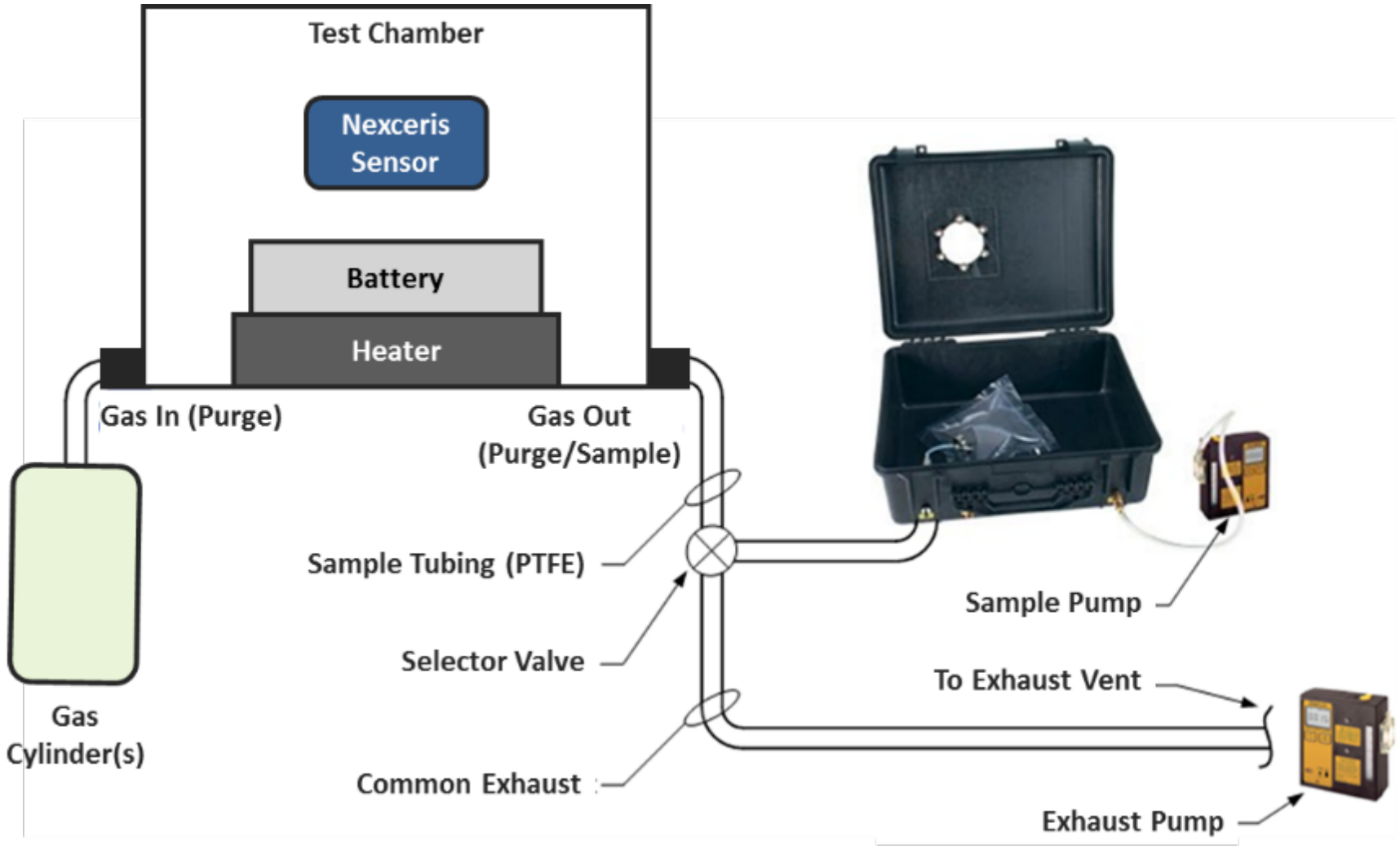
MEC (the battery electrolyte solvent) evolves well before thermal runaway

Product Development History



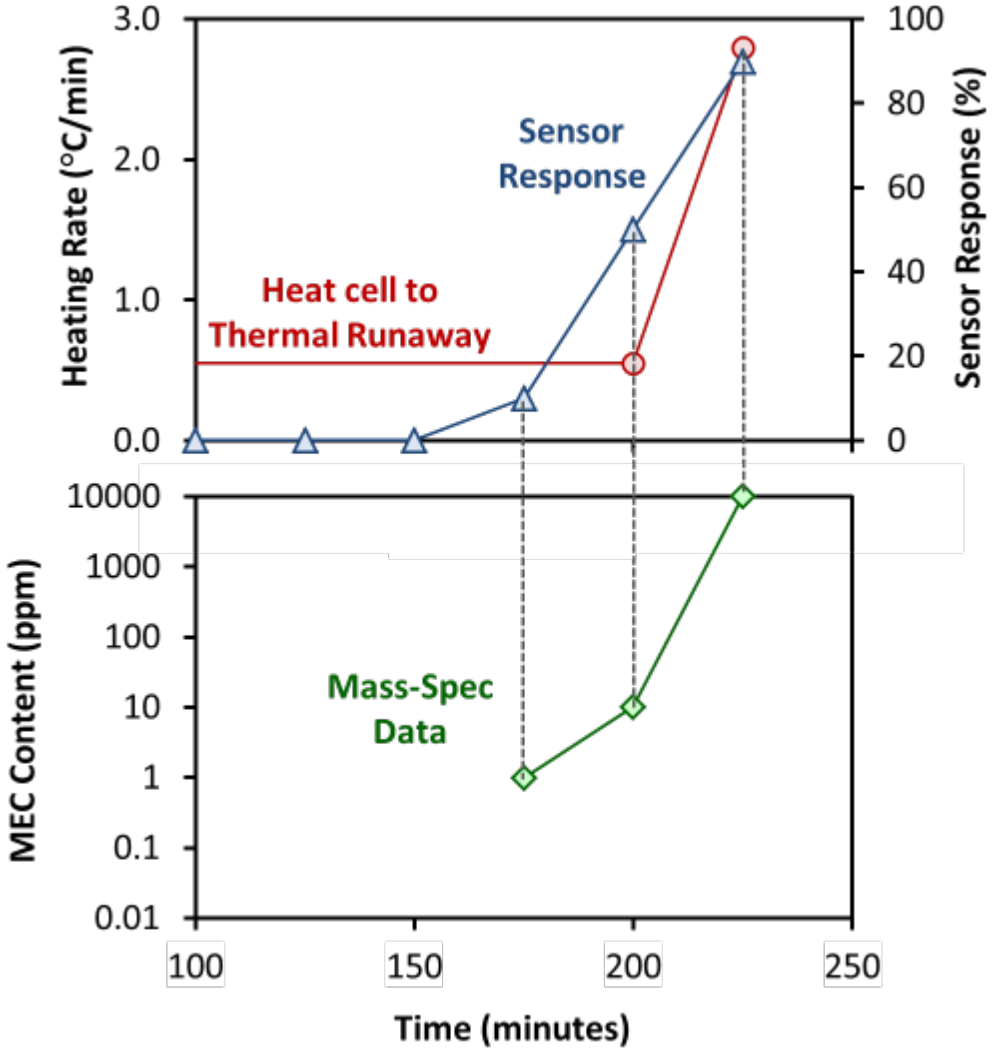
THERMAL ABUSE TESTING (ARPA-E)

- Chamber is designed to monitor battery off-gas during abuse testing.
- Bag samples collected for third party analysis.



THERMAL ABUSE TESTING (ARPA-E)

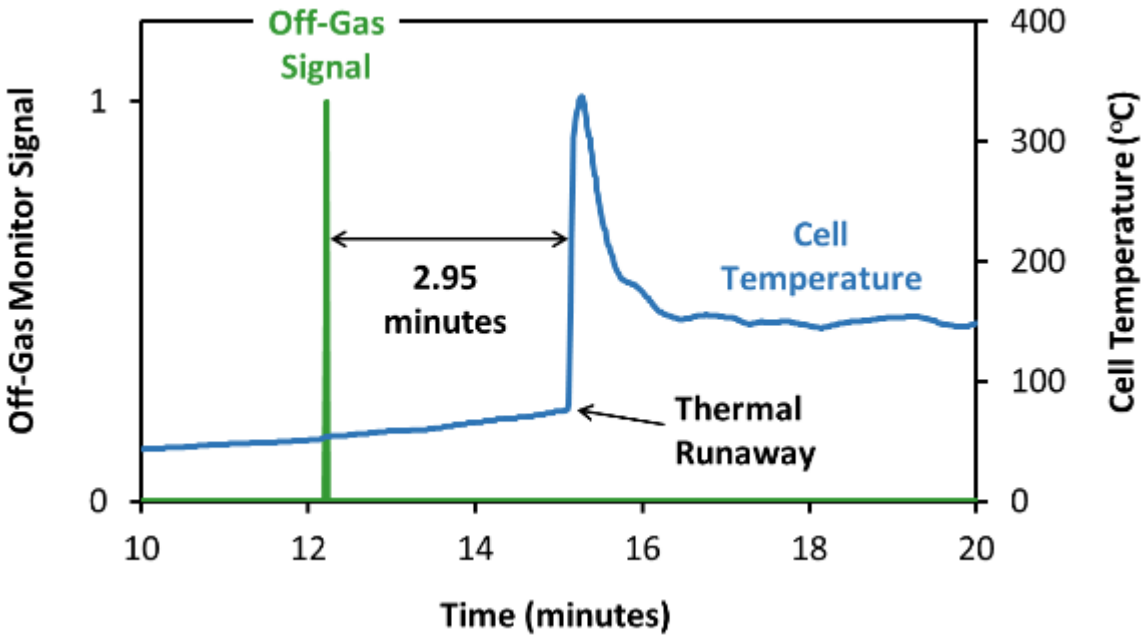
- Early detection demonstrated prior to thermal response of the cell.
- Detection of ppm levels of gas outside the cell before temperature rise.
- Confirmed gas species with bag sample analysis



Battery Failure Testing

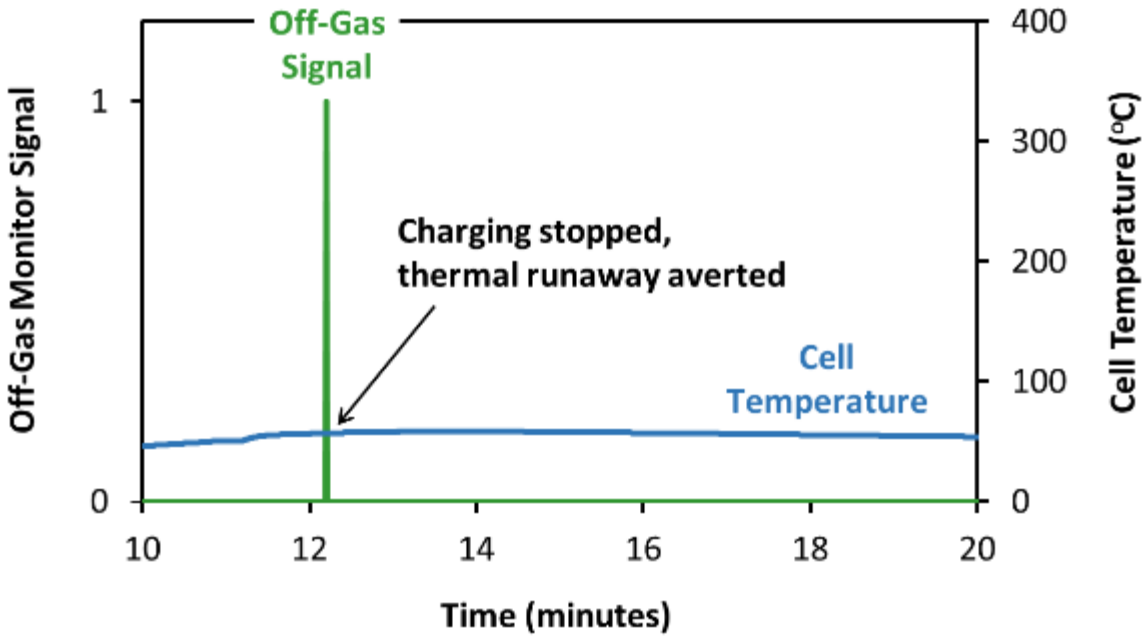
- Nexceris has established capabilities for characterizing failing batteries and designing systems around prevention of catastrophic events
- Testing ongoing to assess off-gassing characteristics of lithium ion cell form factors and chemistries
- Testing completed on wide range of battery chemistries (including NMC, LCO, LFP and LTO), and is continuing to assess off-gassing mechanisms for battery safety stakeholders

Mitigation of Thermal Runaway



Overcharge failure test (5C charge rate)

Off-gas detected 3 minutes before thermal runaway

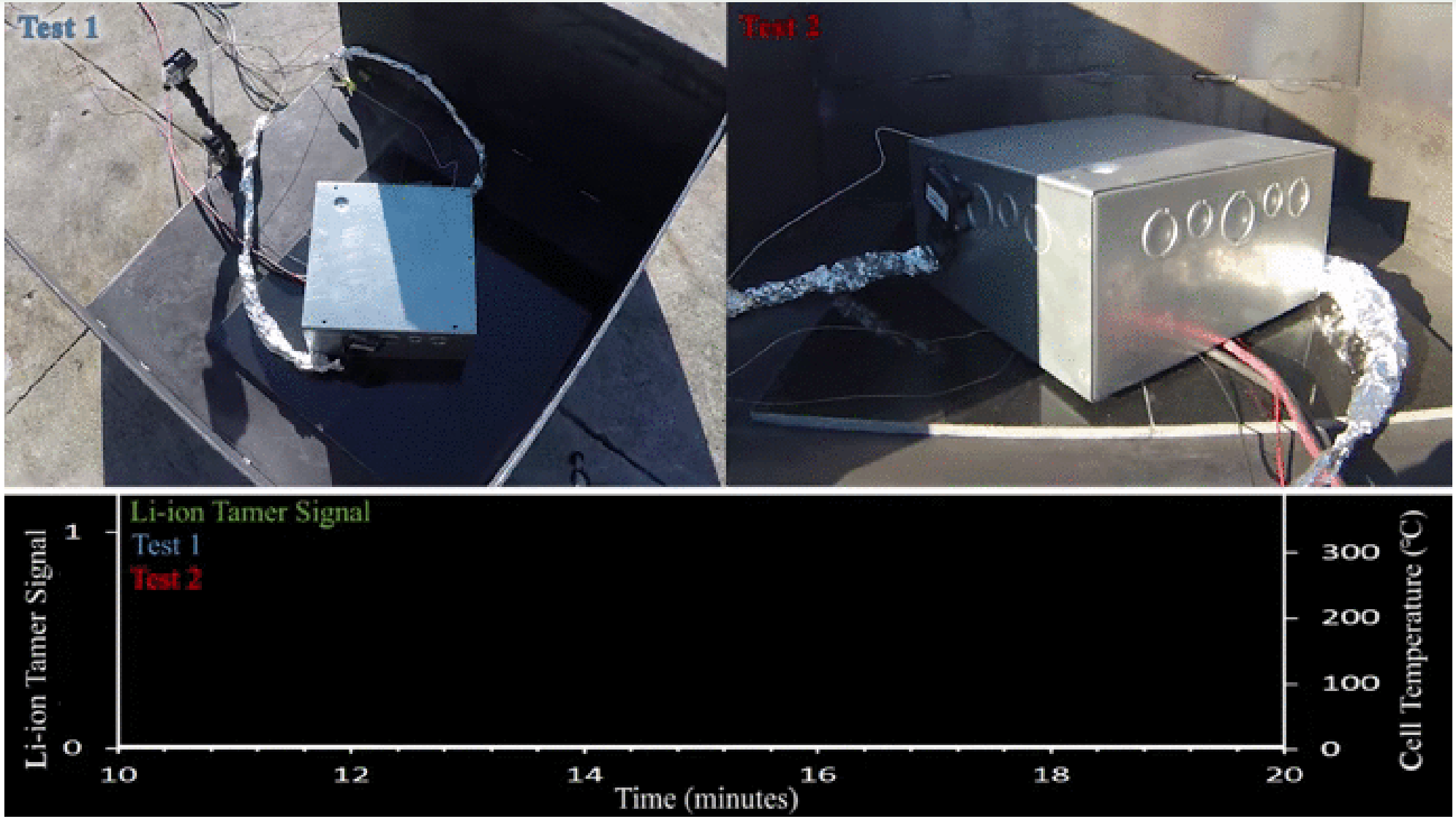


Overcharge failure test (5C charge rate)

Charging suspended when off-gas detected

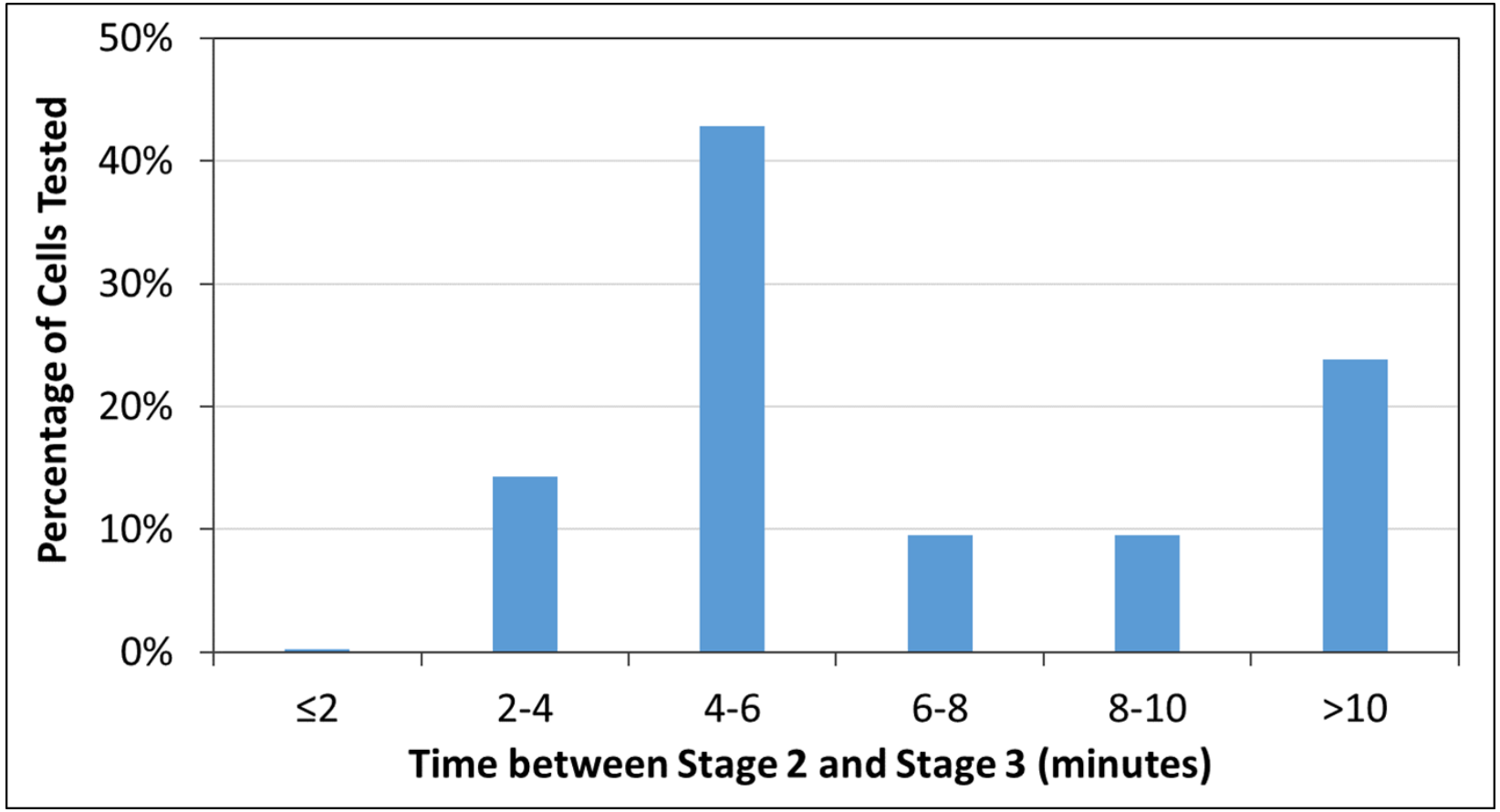
Thermal runaway avoided

MITIGATION OF THERMAL RUNAWAY



Summary of Battery Abuse Data

- Thermal abuse testing summary
- Cells off-gas a minimum of two minutes prior to thermal runaway
- Demonstrated ability to prevent thermal runaway when mitigating actions are taken



Off-gas monitoring can provide early warning of cell failure

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Off-Gas Monitoring Device

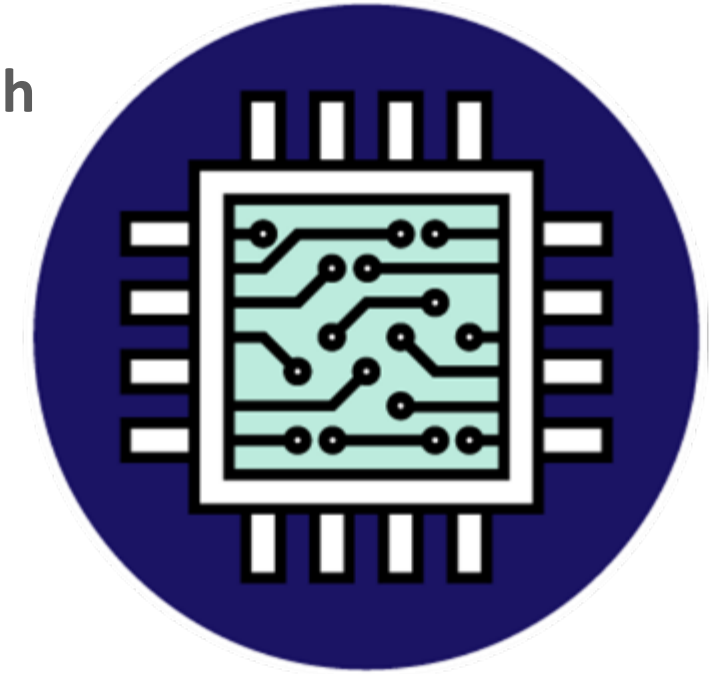
Li-ion Tamer® Battery Monitoring

- Small footprint
- Low Power
- Provides early warning of battery failure
- Multiple integration points:
  - Direct mounting on BMS (Monitor-on-a-Chip)
  - Module implementation
  - Rack or Pack implementation
  - Room level implementation

Implementation Example 1: BMS Integration

Monitor-on-a-Chip

- Surface mountable directly to BMS
- Provides signal when off-gas is detected
- Offers unique diagnostic tool for determining battery health
- Features:
  - Small size: ~15mm x 15mm
  - Low power draw: <30 mW
  - Indication of off-gas within battery module
  - Maintenance free

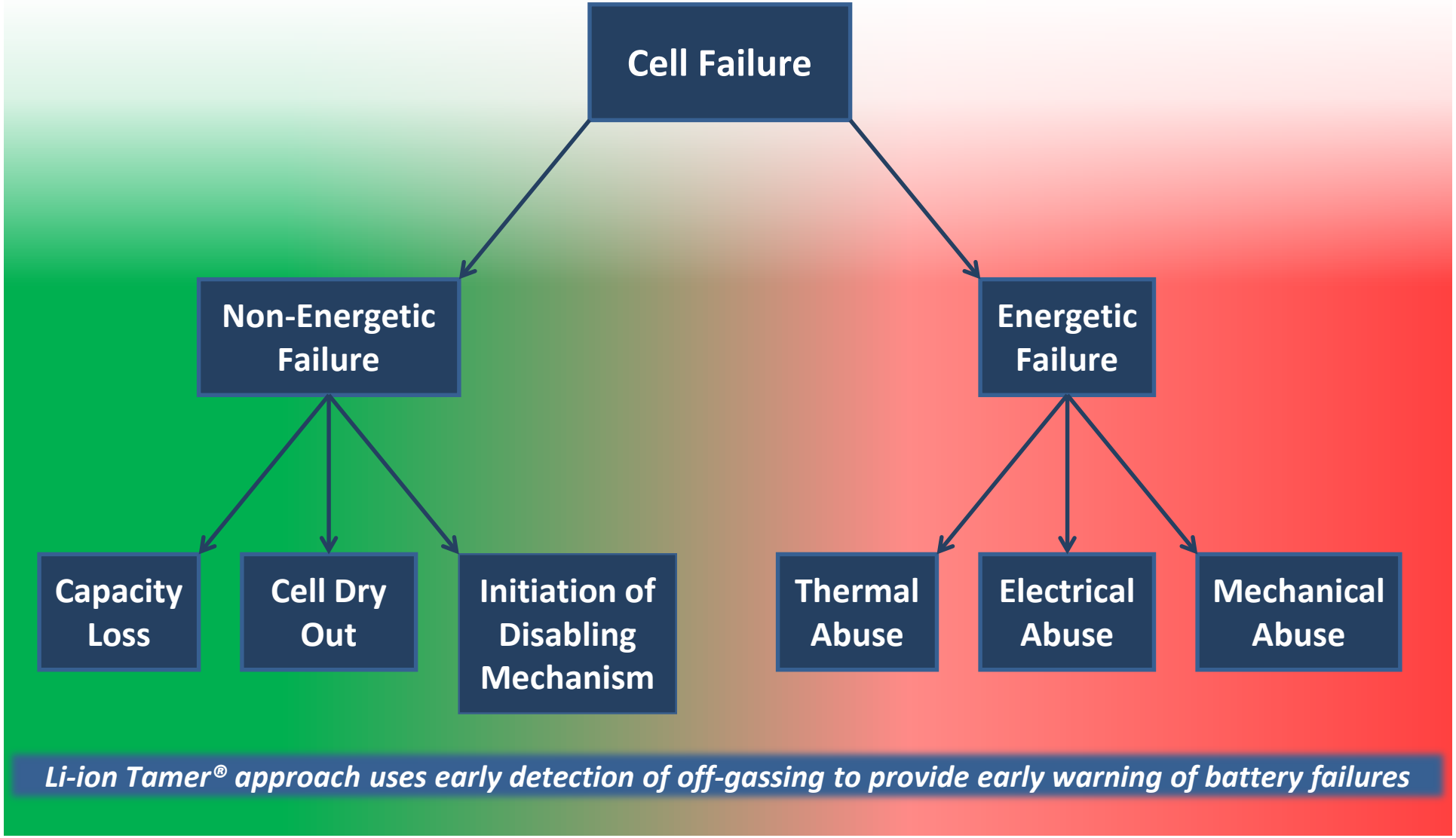


Implementation Example 2: Module Integration

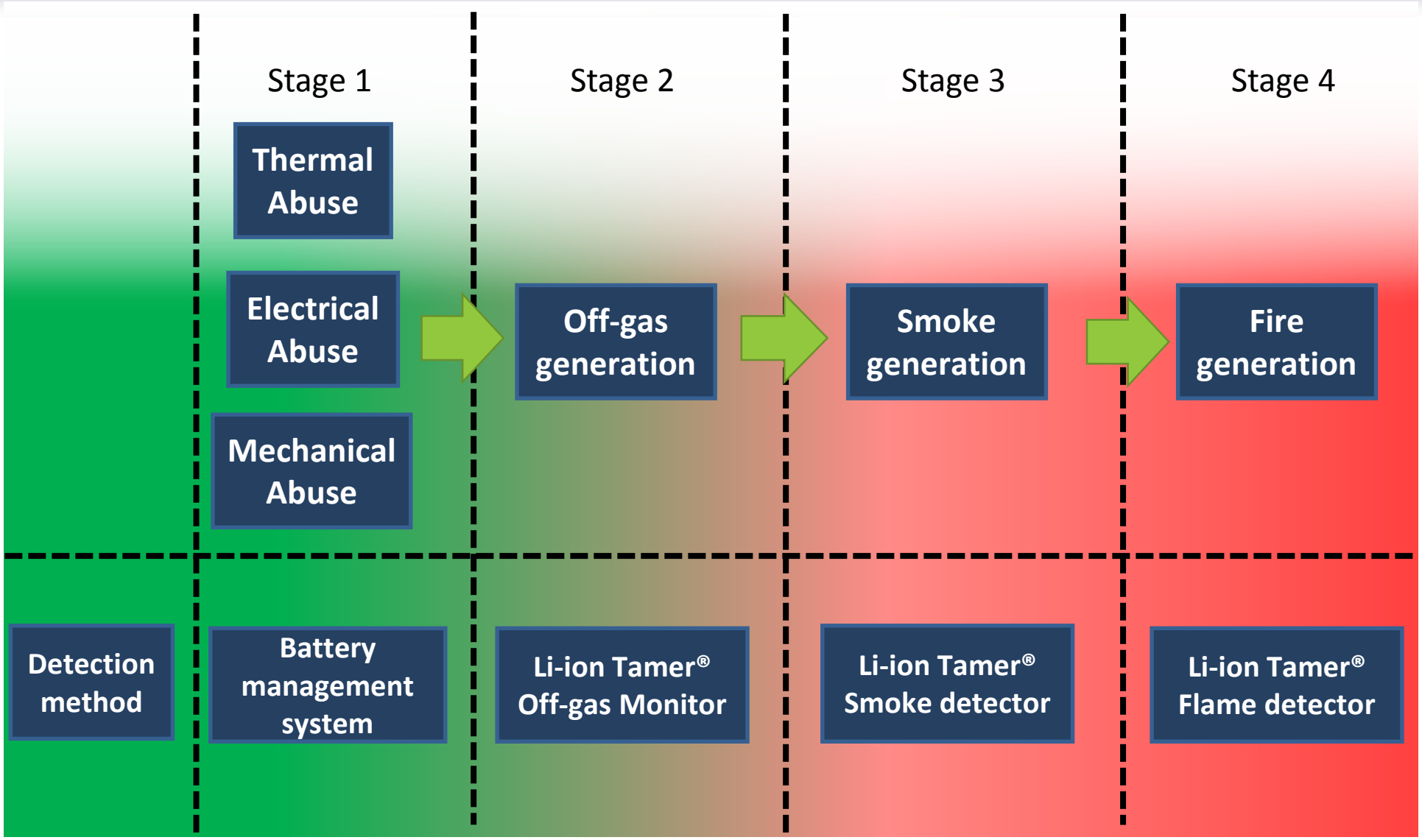
Off-gas monitoring inside modules

- Packaged device allows for monitoring inside a module
- Monitor for off-gas at the potential source
- Flexible signal integration
- Features:
  - Small size: 25mm x 35mm
  - Low power draw: <30 mW
  - Indication of off-gas within battery module
  - Maintenance free

Diagnosing Stages of Battery Failure



DIAGNOSING STAGES OF BATTERY FAILURE

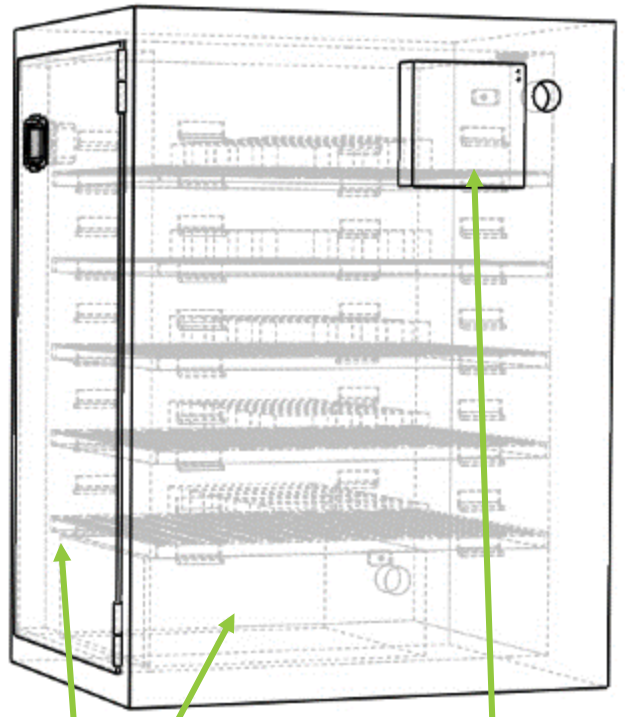


Integration Example 3: Battery Rack/Cabinet Monitoring

Off-gas monitoring
(Stage 2 Detection)

Smoke & heat monitoring
(Stage 3 Detection)

Exhaust capability

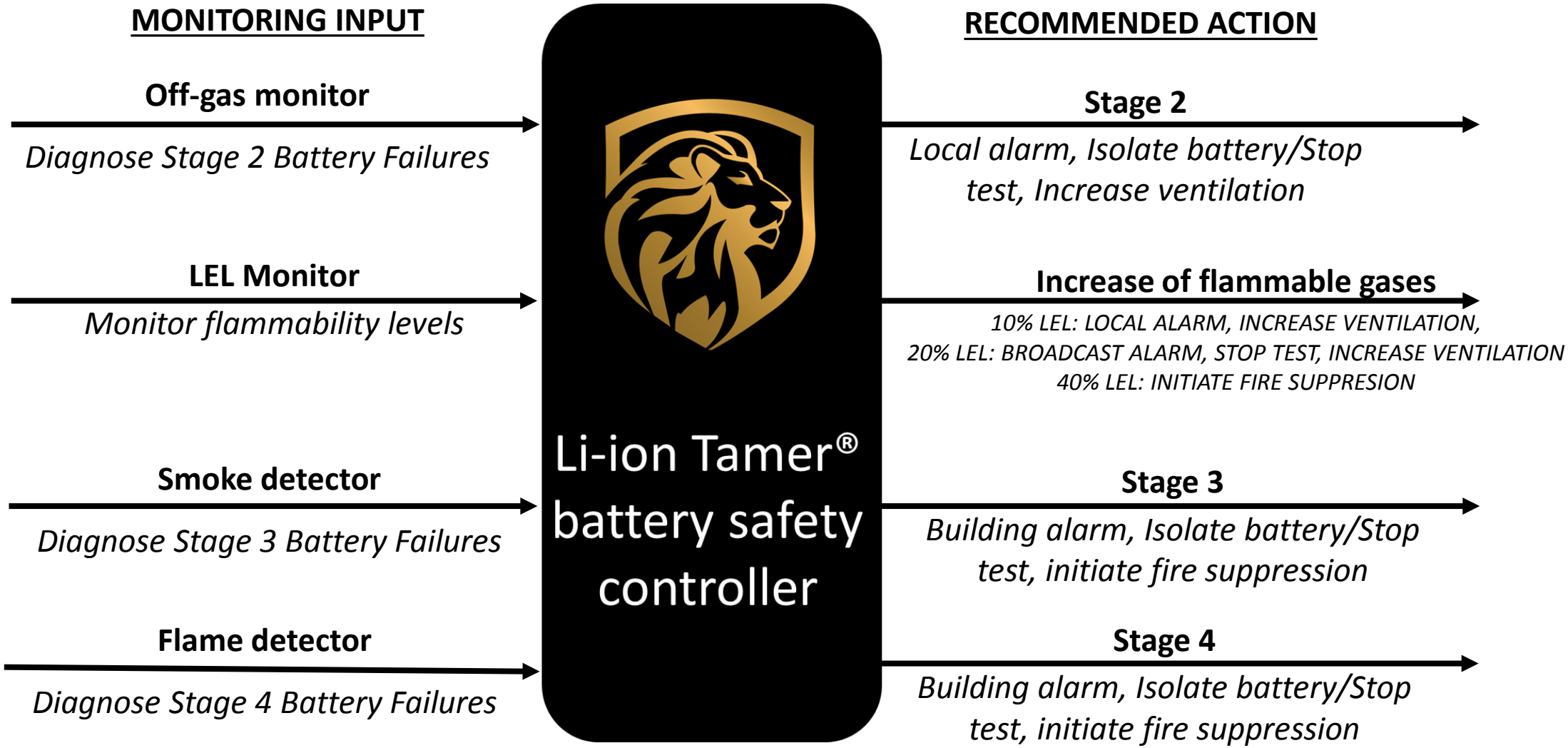


Shelves made of fire barrier materials
(Stage 4 Protection)

Fireproof enclosure
(Stage 4 Protection)

Li-ion Tamer®
Audible & visual alarms

Implementation Example 4: Battery Room Monitoring



Military Applications

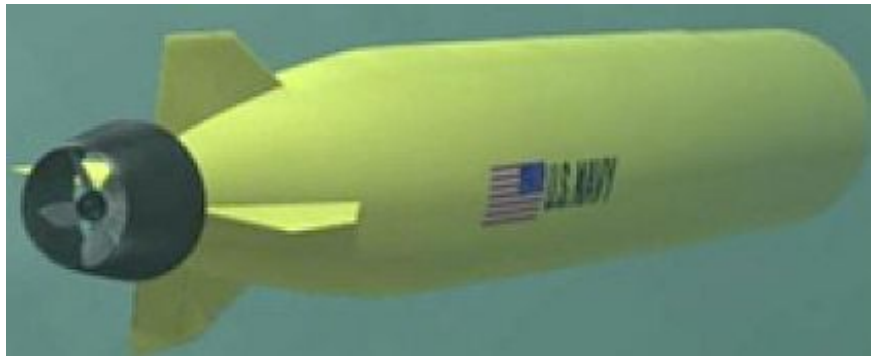
Directed Energy Weapons

- The Navy is planning on fielding directed energy weapons (rail guns) on DDG-class surface ships.
- Megawatt-hours of energy is required, and few ships have enough pulsed-power to draw from.
- Lithium ion batteries would enable rail guns to be fielded on a larger number of ships.
- Safety is critical and must be addressed.
- The Navy is evaluating off-gas monitoring for this application.

Military Applications

Unmanned Undersea Vehicles

- The Navy is developing advanced UUVs with increasing size and capability.
- Lithium ion batteries are being used for smaller UUVs and are being considered for larger UUVs.
- Launching UUVs from ships requires that batteries are stored (fully charged) or re-charged on the ship.
- Offgas monitoring would greatly enhance safety of storing and charging batteries on naval vessels.



Military Applications

Silent Watch

- Lithium ion batteries are being considered by the Army and Marines to increase durations of silent watch missions.
- Silent watch missions require as much as of 25-30 kW-hr of energy storage.
- Silent watch missions are executed in areas where ambient temperature can be at extremes of normal battery operation, increasing battery safety risks.
- Off-gas monitoring could improve safety during silent watch and during charging between missions.

MILITARY APPLICATIONS

Other Opportunities

- **Logistics:** With increasing use of lithium ion batteries by the military, safety aspects of transportation, storage and re-charging will need to be addressed.
- **Soldier Power:** As power needs for individual soldiers increase, higher energy density lithium ion batteries will be required and the safety aspects of in-field battery charging will need to be considered.
- **Unmanned Aerial Vehicles:** Lithium ion batteries are being used to increase UAV mission durations. Off-gas monitoring could increase safety during battery re-charging

COMMERCIAL APPLICATIONS

Electric Vehicle charging stations and operational battery sensing

Grid level energy storage

Battery powered marine vessels

Other applications include…

- Shipping, handling, and storage of lithium ion batteries
- Aviation
- Lithium ion battery manufacturing

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NEXT STEPS

Critical Protection for your Critical Components

- We are looking for partners
- If you use lithium ion batteries, we can help make them safer
- Battery system integrators, battery storage and shipping, battery end users
- Hardware is available for demonstration in your application

www.li-iontamer.com

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Li-ion Tamer® Product Team

- Steve Cummings
- Nick Frank
- Bill Dawson
- Scott Swartz
- Nate Cooley
- Sarah Palenik

Acknowledgements

NAVSEA
NAVAL SEA SYSTEMS COMMAND

DNV

arpa·e
CHANGING WHAT'S POSSIBLE

BIC