Early detection & suppression of lithium-ion battery fires

Mark Kadoshnikov

SIEMENS

Course outline

- **Overview** of Lithium-ion Batteries
- **Fire Hazards** of Lithium-ion Batteries
- **Early Warning** Fire Detection **Solution** for Lithium-ion Batteries
- **Suppression** for Lithium-ion Batteries
- Siemens Total Solution for **Lithium-ion Battery Fires**
- **Key Takeaways**

TODAY, THE BEST ENERGY STORAGE SOLUTION IS THE LITHIUM-ION BATTERY…

BUT IT IS ALSO THE **RISKIEST**

Electrical fire risk

Constant ignition source (electricity) and combustible materials such as plastics in printed circuit boards.

Electro chemical fire risk

Li-Ion batteries combine high amount of chemical energy with typically flammable electrolytes.

- Renewable energy
- Grid stabilization
- Peak load management
- Charging infrastructure
- Backup power supplies

… AND THE NUMBER OF INSTALLATIONS GROWS EXPONENTIALLY!

SIEMENS

Examples – Korea, Belgium, UK, Arizona, Illinois, Australia …

Dangers to manage

1 to >US$10 m losses per event

2018 → **Today**

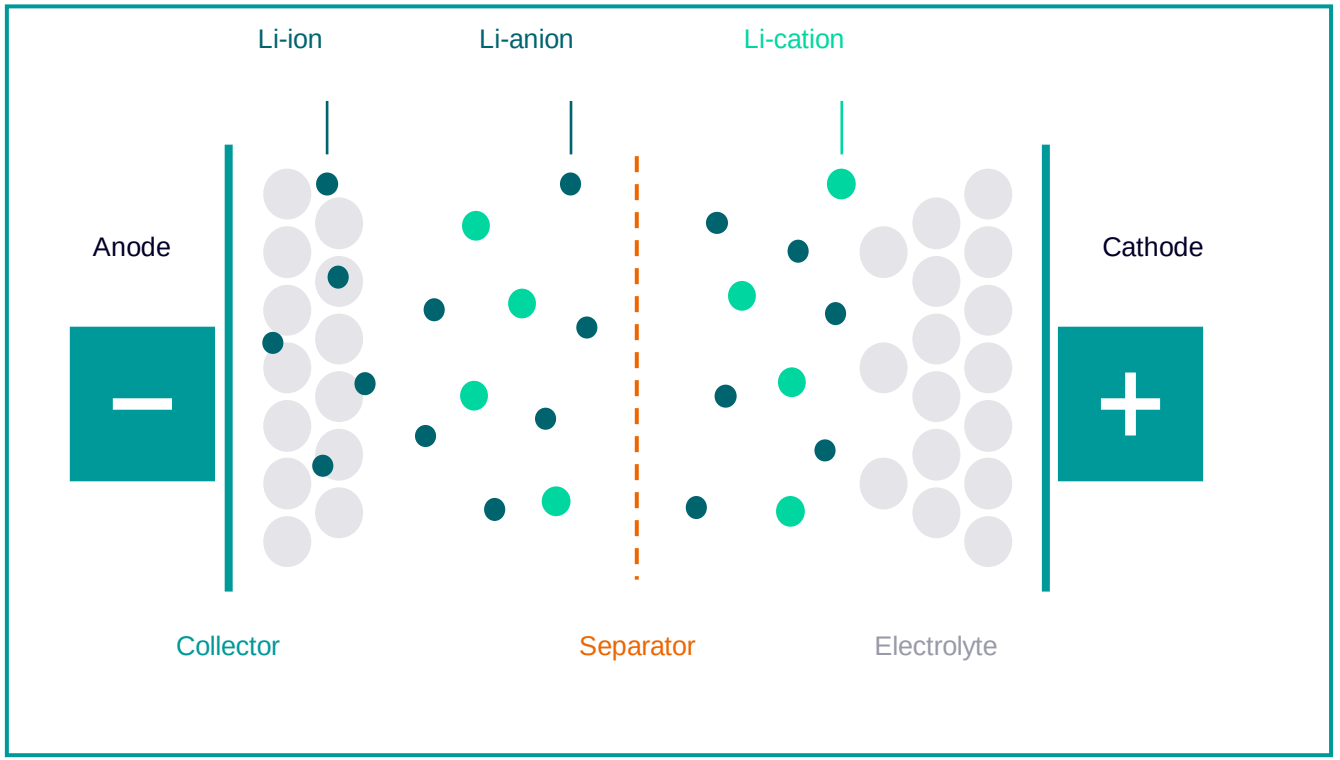
SIEMENS

Lithium-ion Fires – A Significant Risk
Why?

Ion-conducting, flammable electrolyte

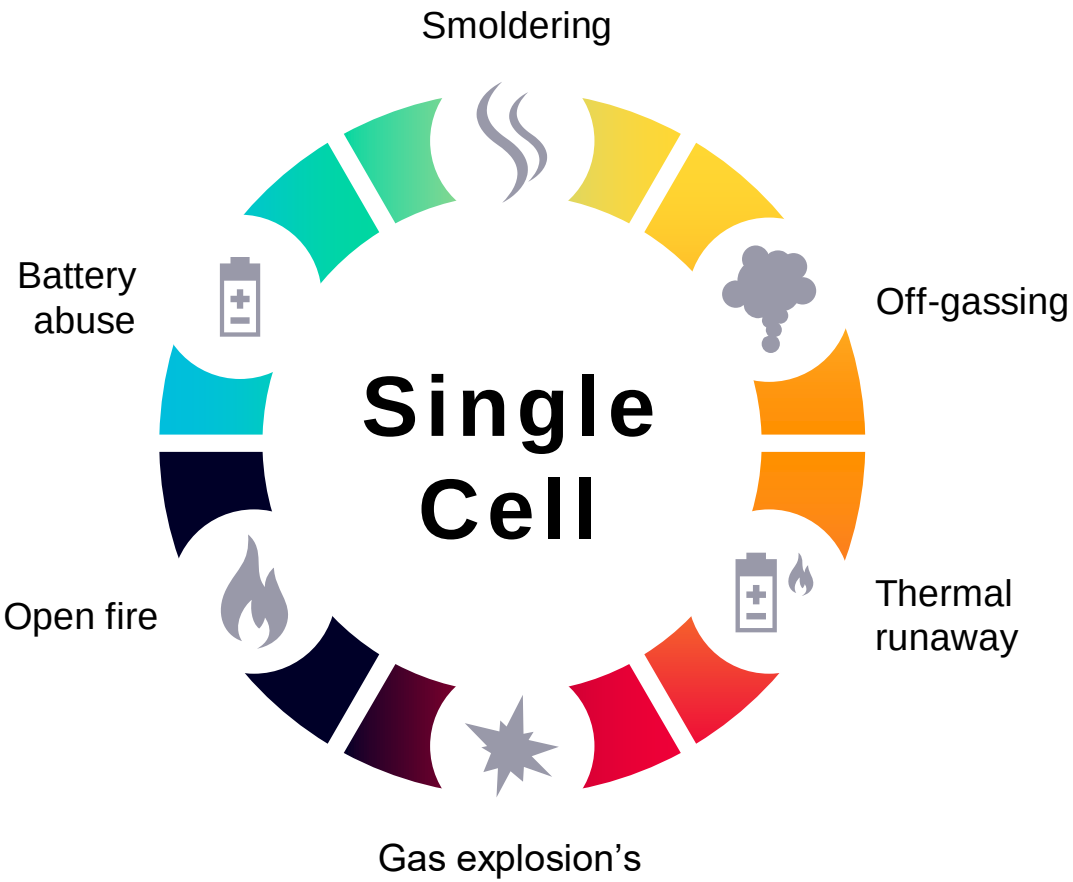
Separator ensures the electrical separation of the electrodes

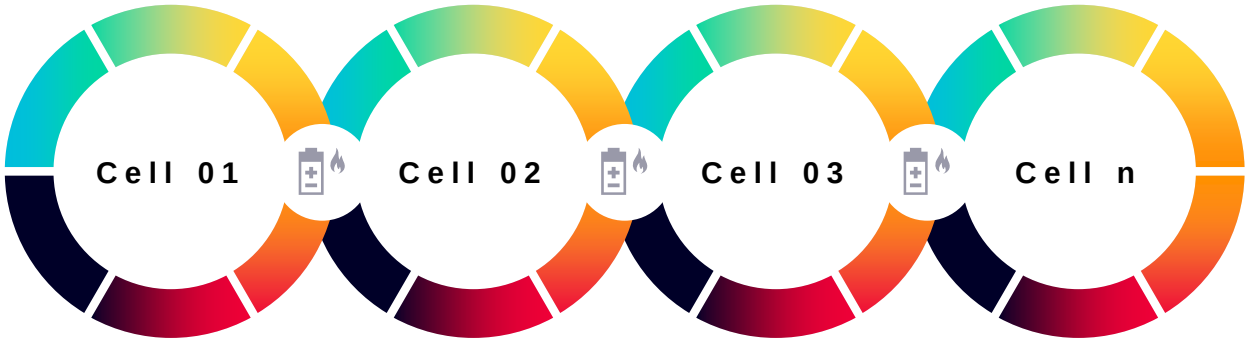
At the heart of the battery system are the electrochemical battery cells



SIEMENS

Thermal Runaway Development and Propagation





SIEMENS

How Do We Mitigate the Risk of Lithium-ion Battery Fires?

Runaway Detection

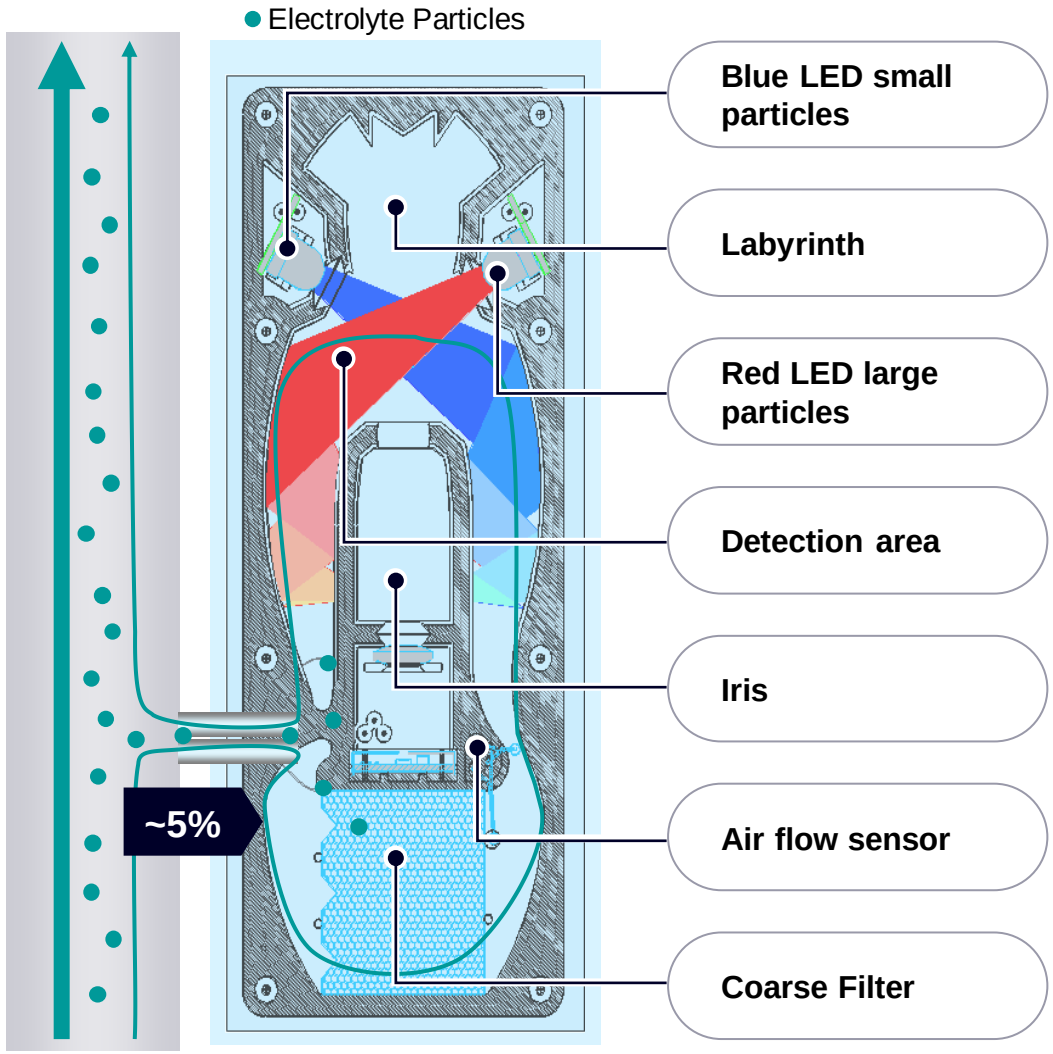
Propagation Prevention

SIEMENS

Electrolyte Particle Detection (Off-Gas)
The FDA241 - An aspirating smoke detector (ASD)

SIEMENS

FDA
Off-Gas Particle Detection Technology



Flow Management

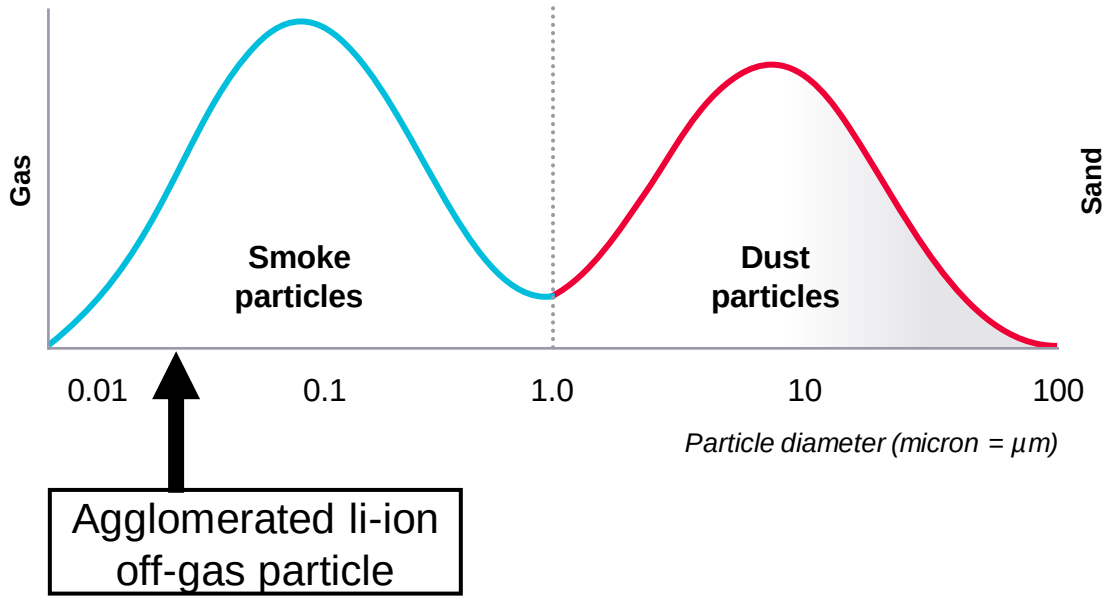
Increases effective nuisance resistance of chamber

Coarse filtering → Protection from Insects and large particles (Reduction of nuisance alarm conditions)

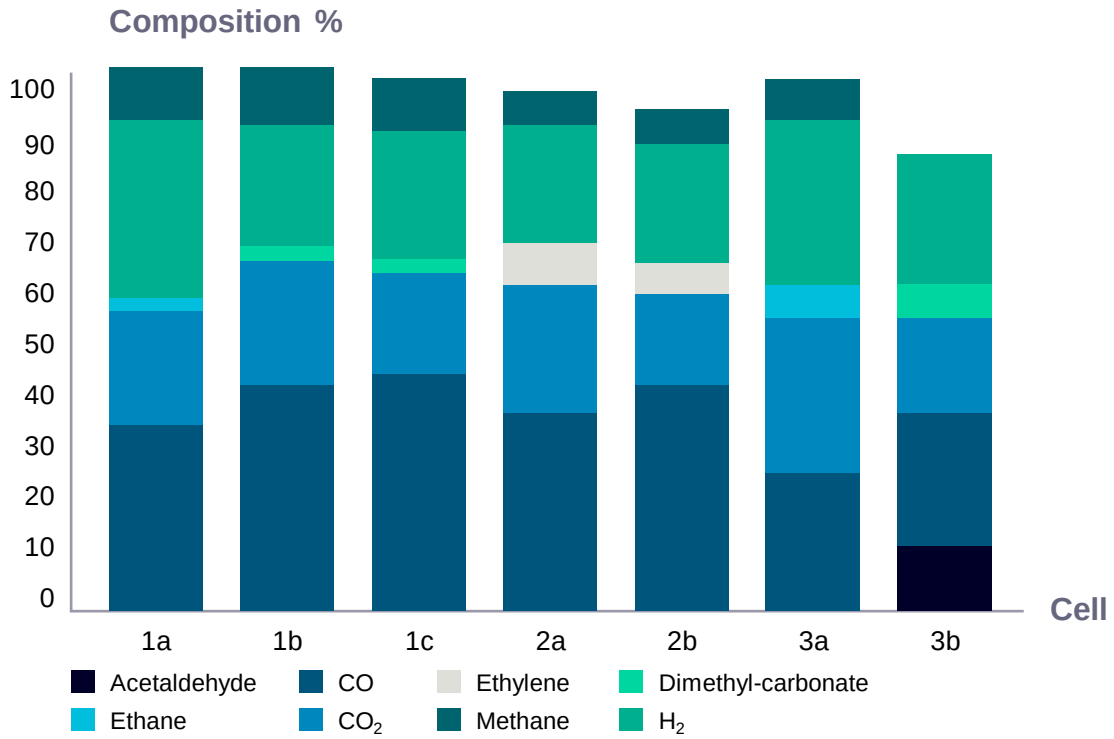
Contamination avoidance while only ~5% of air is going through the detection chamber

SIEMENS

Average distribution of combustion particles

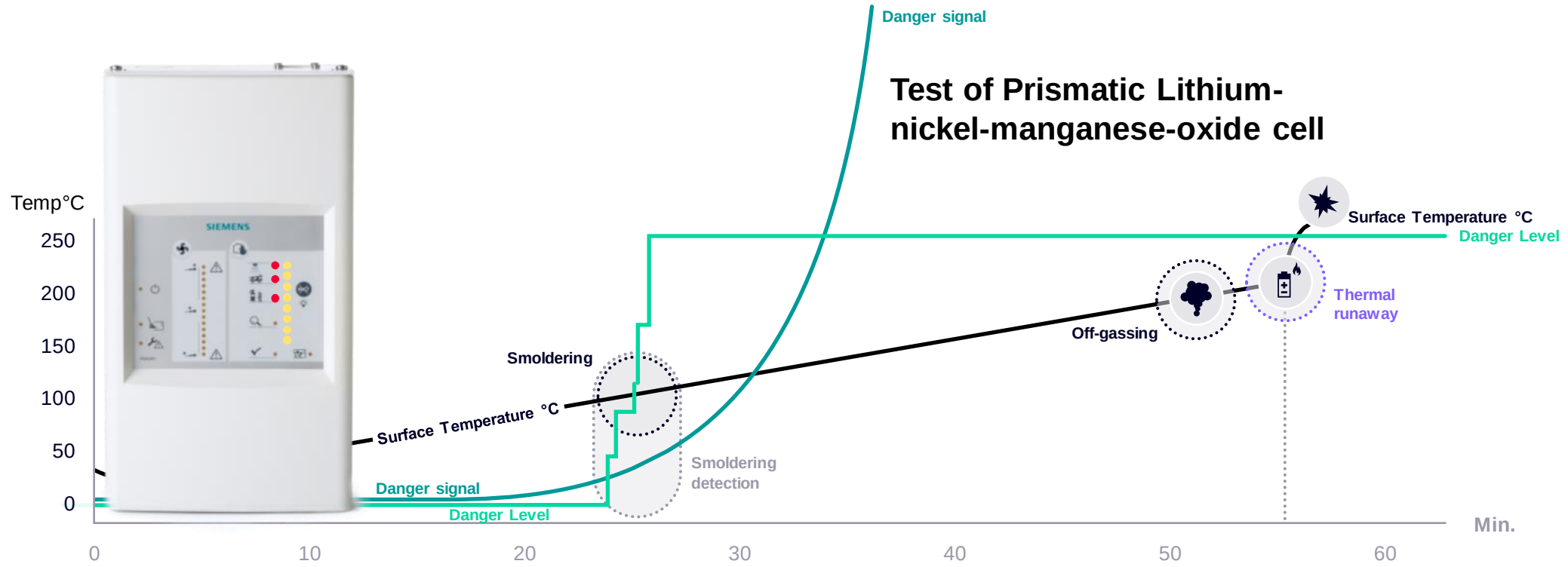


Runaway gas major species



SIEMENS

Detection Tests



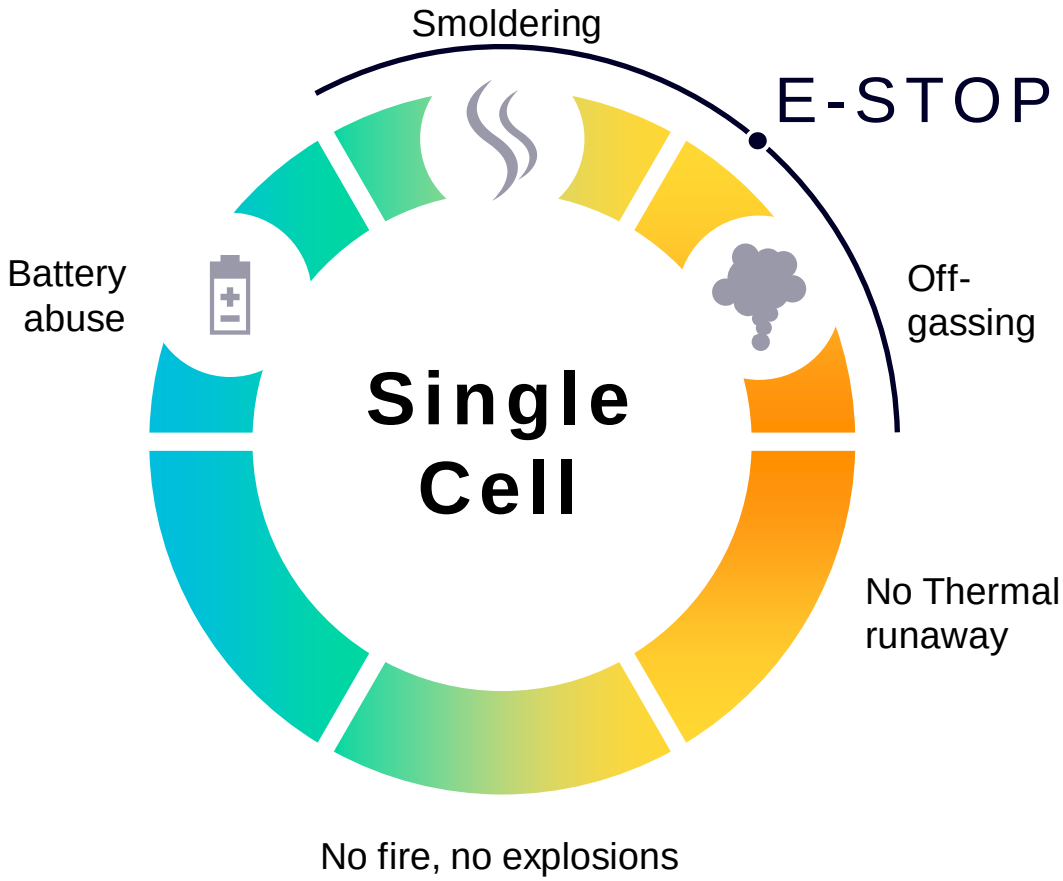
Forcing thermal runaway by heating

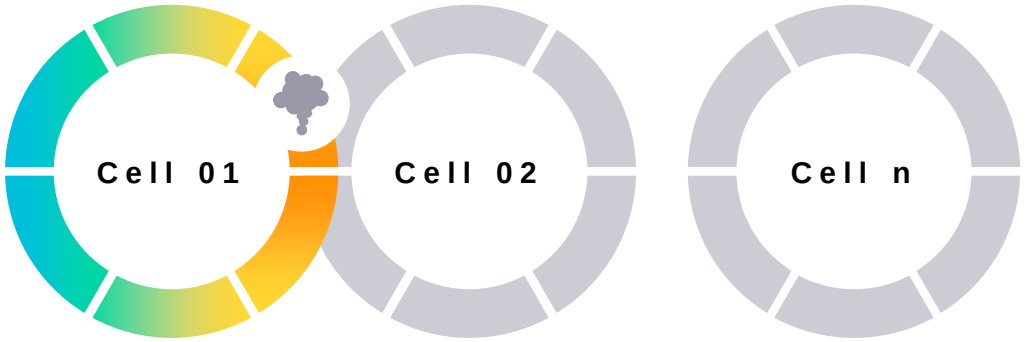
FDA241 detects smoldering @**T = 145 °C**
28 minutes before off-gas venting and
32 minutes before thermal runaway

Fire alarm due to earliest smoldering detection.
Ideal precondition for triggering of e-stop and
Explosion prevention and fire suppression

SIEMENS

Stop Electrical Abuse



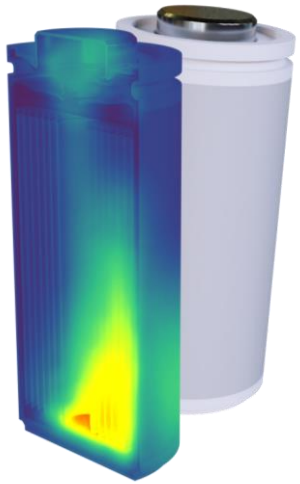


SIEMENS

Earliest detection of possible thermal runaway by ...

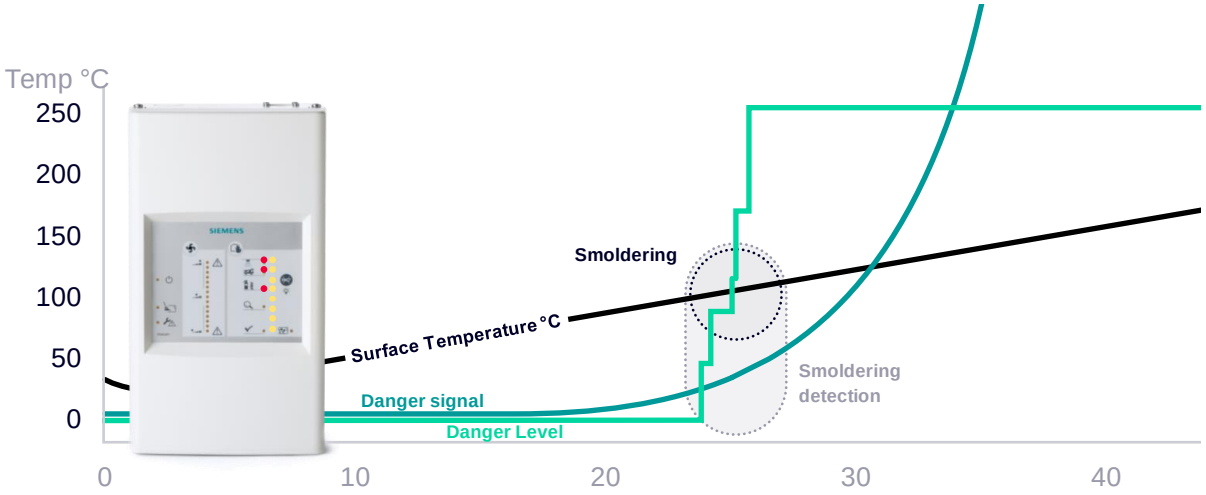
1 Electrolyte gas particle detection

2 Detection of smoldering fires



Depending on the Battery type, the FDA241 detects emerging thermal runaway more than 5 times faster than special electrolyte gas sensors.

Test of Prismatic Lithium-nickel-manganese-oxide cell



SIEMENS

How Do We Mitigate the Risk of Lithium-ion Battery Fires?

Runaway detection

Propagation prevention

SIEMENS

What happened in Surprise Arizona in 2019?

An explosion event occurred at **a BESS building** after a **thermal runaway situation** spread through the **Lithium-ion battery rack**

Four firefighters were seriously injured

- One of the men was propelled 75 feet away from the door of the structure as a result of the explosion
- Four others were exposed to toxic gasses

This event has **shed light on the need** for proper **Lithium-ion battery protection**

What do we know?

This facility was equipped with:

- A Vesda aspirating smoke detector
- A Novec 1230 suppression system
- Had an e-stop procedure in place

All operated as designed

Other concerning factors:

- Fire department was not notified by the ESS of the fire, but instead, they were notified 45 minutes later by a passerby
- Lack of deflagration venting panels
- Lack of proper battery backup for communication system (communications stopped from within the container prior to the explosion)
- No gas monitoring sensors that were viewable remotely (didn't have any)
- No signage was visible telling firefighters that the hazard was lithium-ion

Source: UL 9540A Installation Level Research Tests – Safety | Considerations for Outdoor Containerized Li-Ion ESS – April 2021

SIEMENS

What Went Wrong With the Detection/Suppression System?

- The **Vesda aspirating smoke detection** system only detected the risk **18 seconds** before the temperature peaked at 121.6°F
- The **Novec 1230 clean agent** was discharged 12 seconds **after** the temperature had already peaked
- The thermal runaway condition continued to pass from battery to battery, (cascading effect) even after the suppression system had dumped all of its' **agent, causing flammable gasses** to accumulate

Conclusion

- The Vesda detector did **not** detect the risk **early enough**
- The Novec 1230 suppression solution did **not stop the cascading effect** of thermal runaway.

Source: UL 9540A Installation Level Research Tests - Safety Considerations for Outdoor Containerized Li-Ion ESS – April 2021

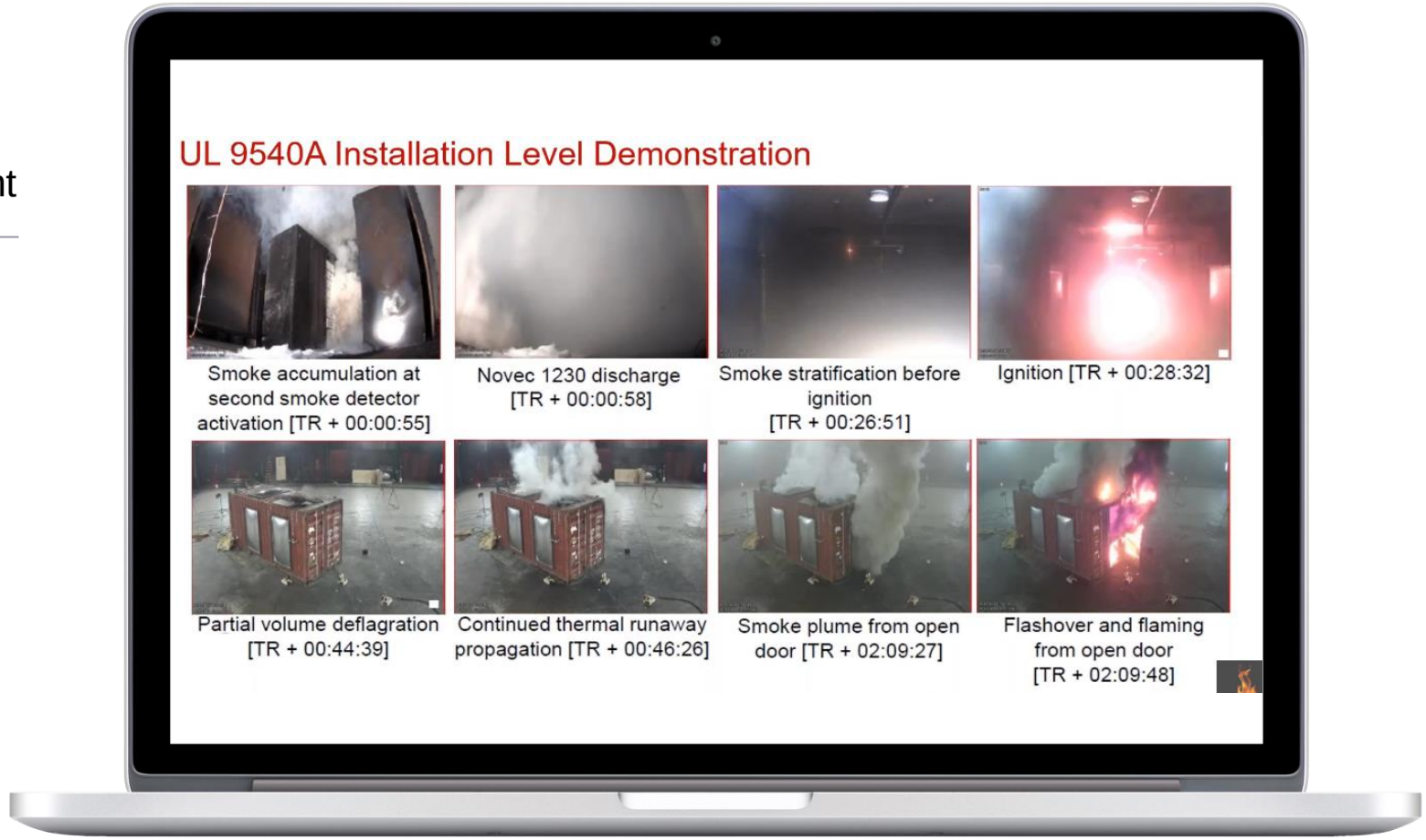
SIEMENS

Arizona Event Aftermath

UL did a follow-up test with Novec 1230 – the results were similar to the Arizona event

Key Findings

"When simulating a **total flooding system** approach, **Novec 1230** did not deliver sufficient cooling to prevent **propagation of thermal runaway** or to **prevent thermal exposure** to combustible construction materials."



Source: UL 9540A Installation Level Research Tests - Safety Considerations for Outdoor Containerized Li-Ion ESS – April 2021

SIEMENS

Why didn’t Novec 1230 provide adequate protection for Lithium-ion Batteries?

Novec 1230 cools fires via fluorocarbons. These molecules decompose when exposed to heat. This process decreases the necessary energy of the fire.

With Lithium-ion battery fires, you have less open flame and more hot smoldering surfaces.

- Novec 1230 is great at extinguishing open flames with fluorocarbons.

- **It is not good at cooling very hot surfaces effectively. Very hot surfaces remain hot for a very long time, on which the extinguishing agent continues to decompose.**

Highly toxic substances, like Hydrofluorocarbons, are continuously generated and as a result the extinguishing agent is continuously decomposed.

Thus, the extinguishing agent concentration drops steadily even without air exchange. Furthermore, 1230 is heavier than air so it migrates downwards.

As time goes on, and the gas is decomposed and seeps out of the bottom of the enclosure, tops of racks will no longer be cooled effectively.

- **When oxygen is re-introduced, the smoldering batteries are likely to likely to re-ignite and cause the toxic gasses generated by the destruction of the batteries to explode**

SIEMENS

Manufacturer's Data Sheet for Novec 1230

Use of Novec 1230 Fluid – Lithium-Ion Batteries

Novec 1230 fluid in a gaseous overhead fire suppression system, designed and installed per the ISO 14520 Standard or NFPA 2001 Standard, can extinguish Class A, B and C hazard fires.

In spaces where lithium-ion batteries are stored or utilized, owners may elect to install a fire suppression system using Novec 1230 fluid to suppress ancillary fires that are external to the battery. Extinguishing the ancillary Class A, B and C fuel fires in areas near the lithium-ion batteries may help prevent a battery from overheating due to an external fire.

Additionally, lithium-ion batteries may leak the electrolytes that are present within the battery, which may be combustible. Owners may elect to install fire extinguishing systems using Novec 1230 fluid to suppress fires external to the battery that are caused by electrolyte leakage, which are Class B hazards.

To be clear, Novec 1230 fluid, utilized in total flooding fire suppression systems designed for Class A, B and C hazard fires, cannot stop thermal runaway once initiated. Any additional benefit of a fire suppression mechanism, device or delivery system using Novec 1230 fluid to prevent a cascading lithium-ion battery thermal runaway event is highly dependent on the battery properties and the system itself which include factors outside of 3M's knowledge or control, including battery design, state of battery charge, and Novec 1230 fluid concentration levels, as a few illustrative examples. Accordingly, the fire suppression system manufacturer is solely responsible for ensuring that any claim regarding the ability of the system to prevent a cascading lithium-ion battery thermal runaway event is true and accurate.

SIEMENS

Technical Risk When
Using Novec 1230

Novec1230 decomposes on the hot surface of the battery –
Creating a toxic byproduct

The Battery continues off-gassing –
Releasing explosive gas into the air

Oxygen is re-introduced

The built-up **flammable gasses explode**
(ignited by the smoldering battery), and
toxic gasses escape into the environment

SIEMENS

Technical Timeline Explanation
Using Siemens Lithium-ion Protection Solution

FDA241 detects the incipient li-ion particles very early

Sinorix NXN N2 releases its inert gas

The combustion process of the battery is slowed and confined to the cell/module

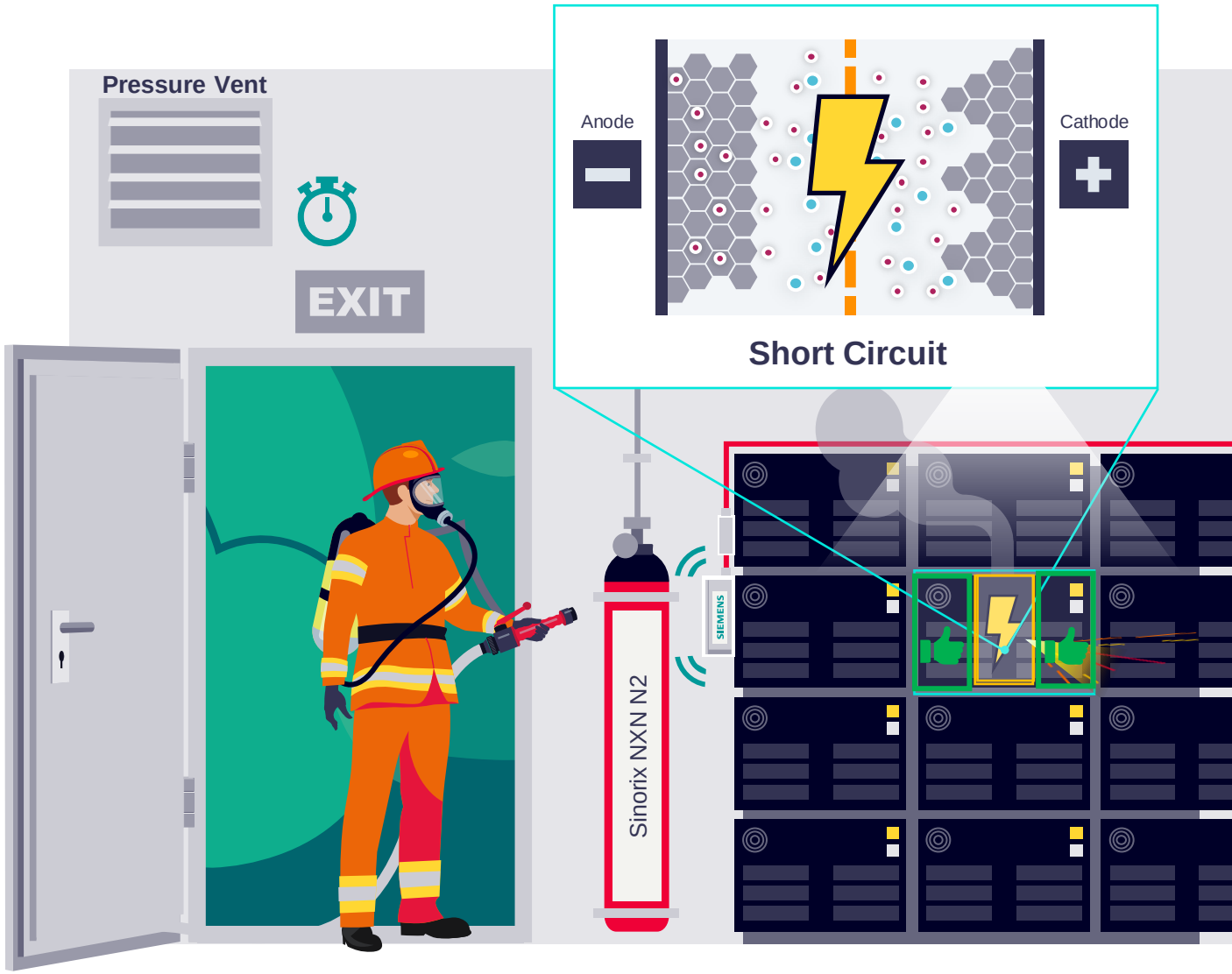
Battery briefly undergoes a “torch effect” event

After the torch effect short circuit concludes, the nitrogen keeps the surrounding battery cells/modules from catching fire

After the overpressure flaps stop moving, wait min. 30 minutes before venting and exhausting - No need to rush. We recommend you wait a few hours and monitor* the situation before turning on HVAC system.

The room can then be purged of nitrogen and entered by firefighters

**Monitor the FDA241 smoke levels, gas levels (if sensors are present), ambient temperature, cell temperature, pressure flap status*



Different types of batteries in a rack in different types of oxygen environments

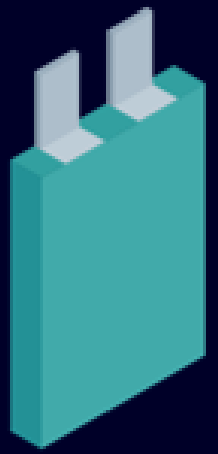
Prismatic and Cylindric Batteries

Cylindric
Cell

Prismatic
Cell

Pouch Cell Batteries

Pouch
Cell



SIEMENS

Why is Nitrogen the Ideal Solution for Lithium-ion Batteries?

To permeate hidden or covered spaces, like a **battery rack, gaseous solutions**, such as **nitrogen**, are most suitable. **Liquids** and **powders** must be **avoided**.

Only **natural extinguishing gases** should be considered so that the production of dangerous and/or harmful decomposition agents is avoided.

Unlike gases that are extremely dangerous to persons, like **CO_2**, nitrogen provides a **higher degree of safety** since it is abundantly present in Earth's atmosphere (comprising 78% of the air we breath).

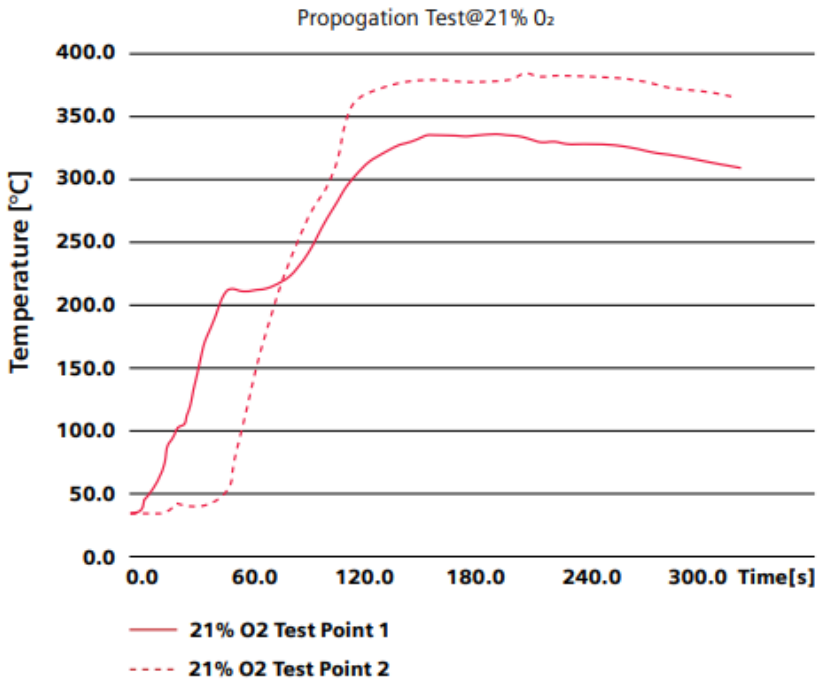
Sinorix NXN is targeted to **modern Lithium-ion batteries** which do not contain metallic-lithium therefore argon (and other rare/expensive gasses) aren't needed. Nitrogen suppression is the **best solution** to effectively protect Lithium-ion battery fire hazards.

SIEMENS

Propagation Test Results

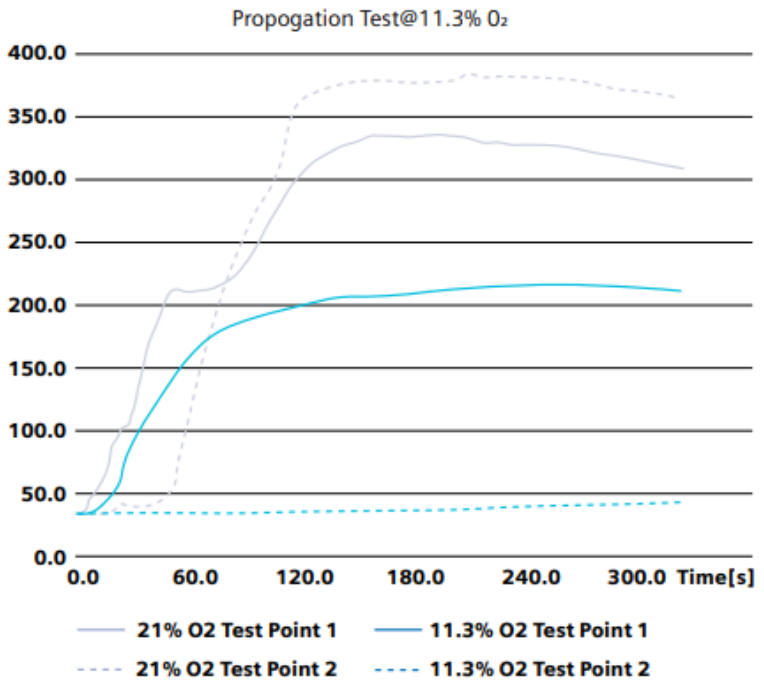
20.9% Oxygen

Graph A - Normal Oxygen Environment



≤11.3% Oxygen

Graph B - High Nitrogen Environment



SIEMENS

Overall Test Results

Cylindric cells | We've done hundreds of tests with cylindric batteries. We've tested 8 major manufacturers, and more are on the way. Our tests show that cylindric battery cells are the safest of the three because they have the least amount of shared surface area.

Sinorix NXN stopped cell to cell thermal runaway propagation every time

Prismatic cells | We've done dozens of tests with prismatic batteries from at least three battery manufacturers. When inserted by nitrogen, we have found that thermal runaway has not resulted in open flame or explosion.

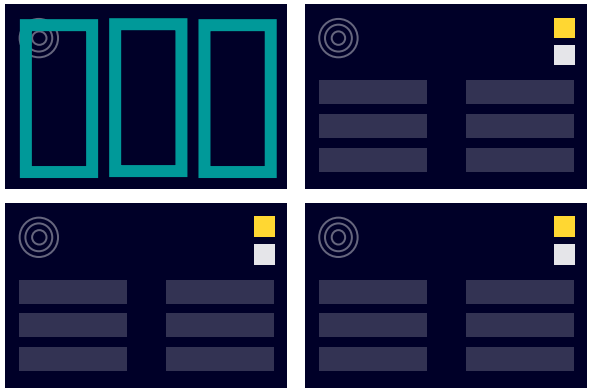
Sinorix NXN stopped cell to cell thermal runaway propagation every time

Pouch Cells | This type poses the highest fire safety risk because of the high density of batteries without separation between battery cells. We've tested pouch cells from various manufacturers dozens of times and results are very similar between all of them. Cell to cell propagation cannot be stopped when dealing with pouch cells. Module to module propagation, however, has been stopped every time.

Sinorix NXN stopped module to module thermal runaway propagation every time

Standard

Normal li-ion Fire Risk

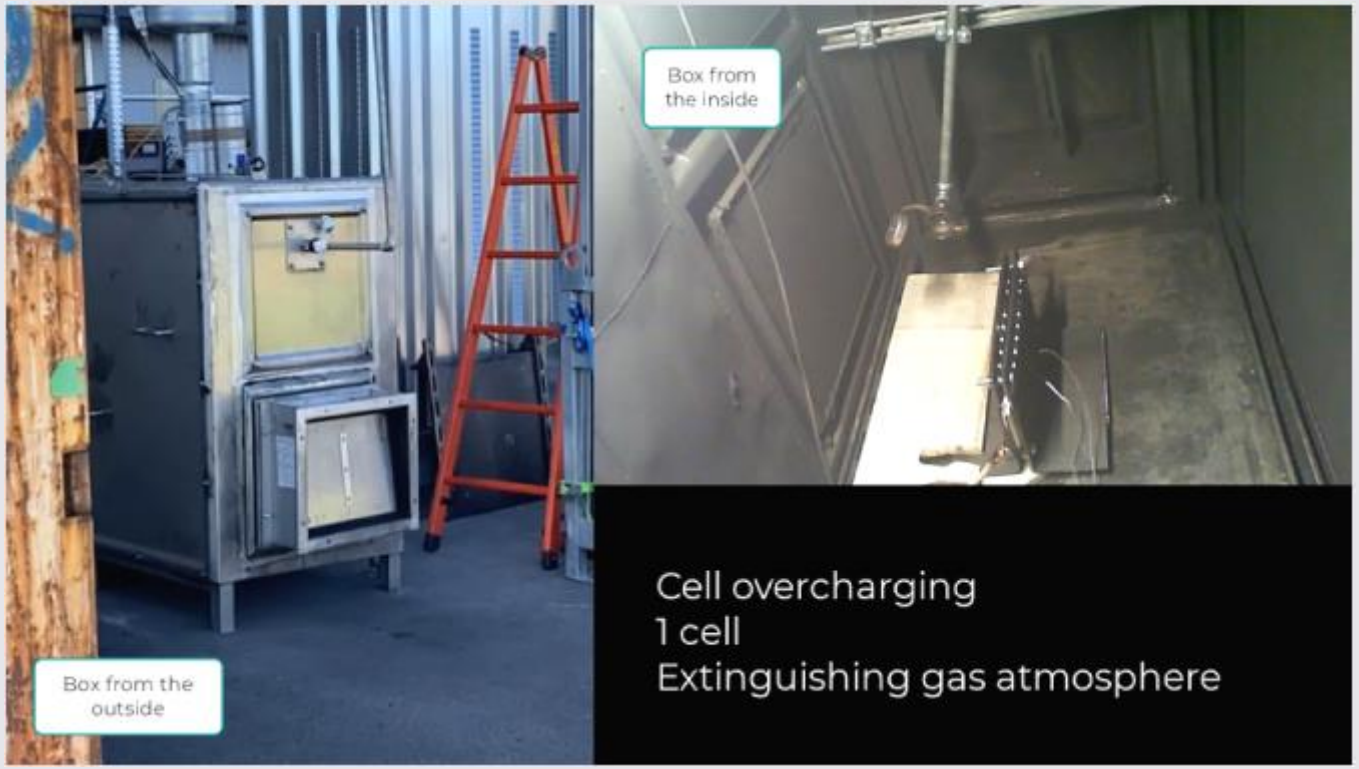


High Density

Very High Li-ion Fire Risk

SIEMENS

Video of Torch Effect



SIEMENS

Sinorix NXN
Pre-Engineered
Suppression System

SIEMENS

Sinorix NXN Pre-Engineered Solution

A 100% Nitrogen Gas Fire Suppression System – Not a mixture

- Intended to be used as total flooding systems, with remaining oxygen concentration below 11.3%

High pressure cylinders – 4,351 psi

- Allows the release of more gas with fewer cylinders

Pre-engineered system

- No hydraulic calculations needed. Easy to understand and install.

UL and ULC Listed

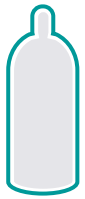
- For Class A, B and C fires

SIEMENS

Pre-Engineered System

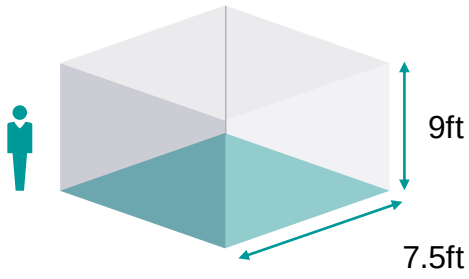
33 Liter

The maximum net volume (enclosure volume minus building parts) that can be protected by the system unit is **550 ft³**



EXAMPLE FOOTPRINT: (FT)

7.5 x 7.5 room (9ft ceiling)

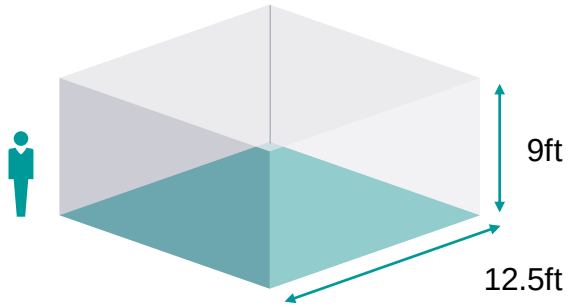


80 Liter

The maximum net volume (enclosure volume minus building parts) that can be protected by the system unit is **1,403 ft³**

EXAMPLE FOOTPRINT: (FT)

12.5 x 12.5 room (9ft ceiling)

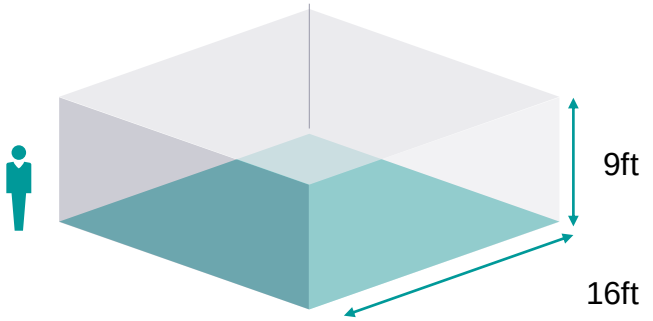


140 Liter

The maximum net volume (enclosure volume minus building parts) that can be protected by the system unit is **2,334 ft³**

EXAMPLE FOOTPRINT: (FT)

16 x 16 room (9ft ceiling)



*33 and 140 liter available in the spring of 2023

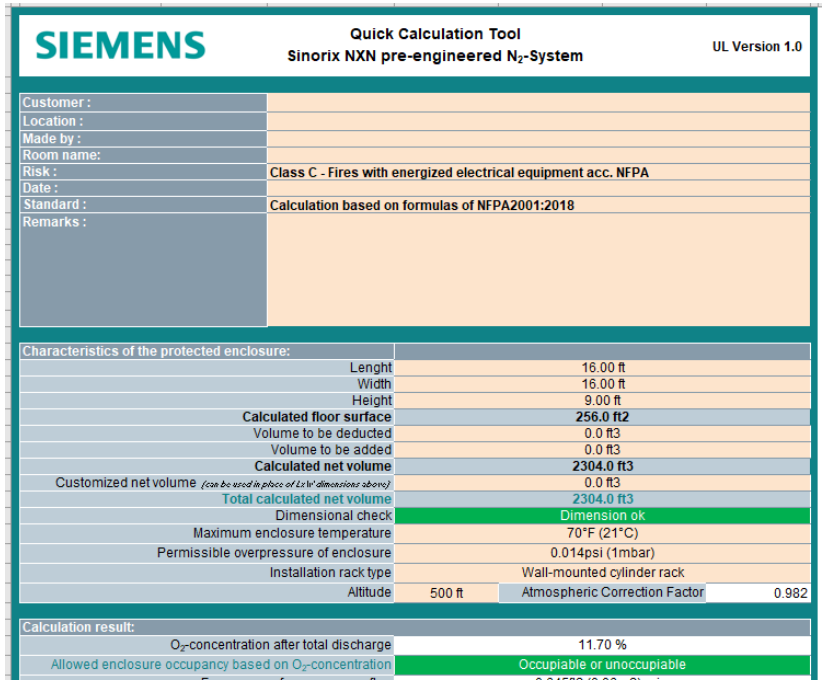
SIEMENS

How do Calculations work for this Pre-Engineered System?

Two Options:

1) Do the math yourself using formulas from the manual, section 5.2.4:

2) Use the Sinorix QuickCalc Tool:



SIEMENS	Quick Calculation Tool Sinorix NXN pre-engineered N_2-System	UL Version 1.0
Customer :		
Location :		
Made by :		
Room name:		
Risk :	Class C - Fires with energized electrical equipment acc. NFPA	
Date :		
Standard :	Calculation based on formulas of NFPA2001:2018	
Remarks :		

Characteristics of the protected enclosure:			
Lenght	16.00 ft		
Width	16.00 ft		
Height	9.00 ft		
Calculated floor surface	**256.0 ft2**		
Volume to be deducted	0.0 ft3		
Volume to be added	0.0 ft3		
Calculated net volume	**2304.0 ft3**		
Customized net volume *(can be used in place of L x b' dimensions above)*	0.0 ft3		
Total calculated net volume	2304.0 ft3		
Dimensional check	Dimension ok		
Maximum enclosure temperature	70°F (21°C)		
Permissible overpressure of enclosure	0.014psi (1mbar)		
Installation rack type	Wall-mounted cylinder rack		
Altitude	500 ft	Atmospheric Correction Factor	0.982

Calculation result:	
O_2-concentration after total discharge	11.70 %
Allowed enclosure occupancy based on O_2-concentration	Occupiable or unoccupiable

5.2.4 Calculating the oxygen concentration in the enclosure after discharge

The nitrogen concentration C [%] of the pre-engineered system that will be developed in the protected enclosure after a discharge has to be calculated by using the following formula according NFPA standard 2001 section 5.5.2:

$$C = 100 * \frac{10^{\frac{W*s}{2.303*V}} - 1}{10^{\frac{W*s}{2.303*V}}}$$

W = installed quantity of agent [lb (kg)]

Water capacity (+5/-0 %)	Part Number	Filling weight	
		lb	kg
33 l	S54476-C690-A1	22.5	10.2
80 l	S54476-C690-A2	54.5	24.7
140 l	S54476-C690-A3	95.5	43.3

s = specific volume of nitrogen at the min/max design temperature of the hazard area [ft^3/lb (m^3/kg)] = e.g. 13,800 ft^3/lb (0.861 m^3/kg) at 70 °F (21 °C)

For further values of the specific vapor volume of IG-100, refer to tables below (from A.5.5.2(c) and A.5.5.2(d) in NFPA standard 2001):

The QuickCalc Tool

Reviewing the Results →

Calculation result:	
O_2-concentration after total discharge	11.70 %
Allowed enclosure occupancy based on O_2-concentration	Occupiable or unoccupiable
Free space of overpressure flap	0.645ft2 (0.06m2) min.
Required System	140l-System

Bill of Material				
Pos.	Description	SAP#	Quantity	
1	CYFD-140-300-N2 Cylinder filled DOT	S54476-C690-A3	1	
2	MANOF243-B270 Pressure Gauge	S54476-F543-A1	1	
3	FLEX16-600 Hose DN16 PN360	S54476-B565-A5	1	
4	CAR12-360 Check Valve	S54476-B533-A1	1	
5	REG-F212 Pressure Regulator	S54476-B505-A1	1	
6	FIT-970 Fitting G3/4f-NPT1f	S54476-B790-A10	1	
7	FIT-971 Fitting R1m-NPT1f	S54476-B790-A11	1	
8	2002-G1-140 Nozzle	S54476-B34-A12	1	
9	RACW-140L-1 Wall Mounting Rail	S54476-B615-A1	2	
10	RAC-M10-373 Threaded Rod	S54476-B618-A1	2	
11	RAC-FIX-140 Cylinder Clamp	S54476-B617-A1	1	
12	RAC-CL34 Clamp - 1 inch	S54476-B609-A5*	1	
13	RAC-CL55 Clamp - Pressure Regulator	S54476-B609-A7*	1	
		* can also be purchased locally		

Additional components	SAP#	Quantity
1" Piping acc.	to be sourced locally	max. 50ft (15m)
1" Elbows acc.	to be sourced locally	max. 15pcs
Piping fixation acc.	to be sourced locally	
Overpressure flap	to be sourced locally	1

Step by step instructions can be viewed on the 'Instructions' tab

SIEMENS

Applications

Do

Isolated/contained spaces with Class A, B and C fire risks

- Hospital Battery Backup Rooms
- EV Car Dealership Battery Storage Rooms
- BESS containers
- UPS Battery storage rooms

Don’t

- Large Open Spaces (warehouses, outdoors, etc)
- Anywhere you cannot get containment →Factory floor with high ceilings

SIEMENS

Battery Storage Container with Siemens Lithium-ion Solution

SIEMENS

Traditional Battery Storage Room with Siemens Solution

SIEMENS

Only Product with VdS Approval

Sinorix NXN, when used in conjunction with the FDA early warning detector, has been shown to be able to stop the cascading effect of thermal runaway.

Very early detection

Nitrogen suppression

Combined detection & extinguishing in one panel

SIEMENS

Key Takeaways

Lithium-ion battery energy storage systems market expected to maintain increasing growth rate.

Lithium-ion batteries present fire hazards that can be mitigated by early runaway detection and propagation prevention.

Siemens FDA241 Off-Gas Detector for Lithium-ion Batteries provides the earliest possible off-gas detection (with dual-wavelength particle detection) in the industry.

Sinorix NXN, when used in conjunction with the FDA early warning detector, has been shown to be able to stop the cascading effect of thermal runaway.

For more resources on Siemens fire protection for Lithium-ion Visit www.usa.siemens.com/lithium-ion

Visit www.usa.siemens.com/hot-topics to learn more about upcoming Hot Topics for Engineers Webinars. Next up is Siemens UL Fire Portfolio on March 15th

Learn more about Siemens fire portfolio at www.usa.siemens.com/fire

SIEMENS

Questions

SIEMENS

⚠ WARNING ⚠

Only a trained and qualified person, who is aware of the risks associated with automatic extinguishing installations, is authorized to sell, install or perform inspections or checks on Sinorix automatic extinguishing systems.

Local regulations may require certifications and/or licenses before allowing you to work on extinguishing equipment.

SIEMENS

Disclaimer

Subject to changes and errors. The information given in this document only contains general descriptions and/or performance features which may not always specifically reflect those described, or which may undergo modification in the course of further development of the products. The requested performance features are binding only when they are expressly agreed upon in the concluded contract.