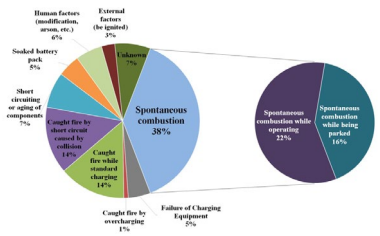
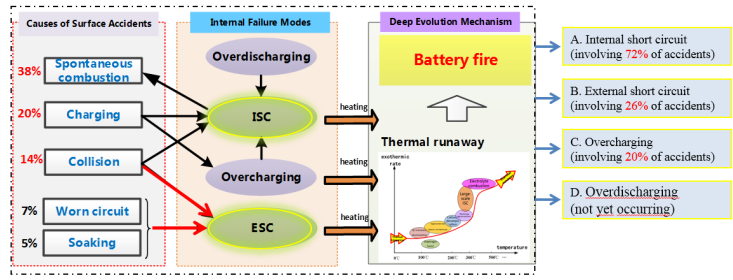
Early detection of Flammable and Hazardous gases in Li ion batteries

xEV Fire Analysis:

- It is difficult to ascertain the current rate of xEV fires that are battery based on current, inadequate vehicle fire records (Bob Swaim, NTSB lead investigator, ret)
- In a study of 101 xEV fires across four years, Nearly half are from spontaneous combustion, with 16% occurring while neither charging nor driving (Xiong, 2019)



Source: Xiong, Rui. International Battery Safety Workshop, 2019



Concerns with Venting and Latency:

- Venting gases in pack include ***flammable gas*** at concentrations above LEL (4% for H2, 4.4% for CH4, 12.5% for CO, 2.7% for Ethylene (C2H4), 3% for Ethane (C2H6…)
- Venting gases include ***hazardous gases*** including CO, Benzene, HF compounds, HCl, and Hydrogen Cyanide in concentrations above STEL for typical garage spaces (Lebedeva, 2020)
- Venting into enclosed air space introduces latency issues; once released, the mixture resides in the vented volume; external ignition source can trigger event

Flammable Gases

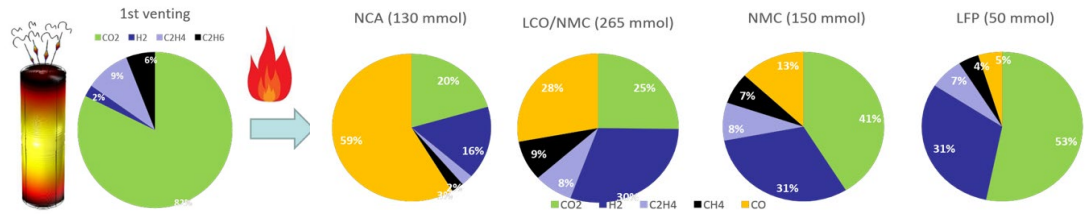
No.	Cell	SOC (%)	θ_{in} (°C)	θ_{m} (°C)	Δm (g)	n_{gas}^{total} (mmol)	H_2 (%)	CO_2 (%)	CO (%)	CH_4 (%)	C_2H_4 (%)	C_2H_6 (%)
1	NCA	0	—	302	—	65	1.7	94.6	1.6	1.6	0.3	—
2	NCA	0	160	316	4.4	52	1.8	94.7	1.5	1.2	0.4	—
3	NCA	0	160	315	4.5	55	1.2	96	1.5	1.1	0.2	—
4	NCA	0	161	214	4.4	39	0.9	96.2	1.1	1.4	0.3	—
5	NCA	0	150	243	4.4	59	0.8	96.6	1	1.3	0.3	—
6	NCA	25	150	739	5.9	67	15.5	62.7	5.5	8.7	7.5	—
7	NCA	50	140	970	8.5	157	17.5	33.8	39.9	5.2	3.2	0.4
8	NCA	75	140	955	—	217	24.2	20.8	43.7	7.5	3.3	0.5
9	NCA	100	144	904	—	273	22.6	19.7	48.9	6.6	2.4	—
10	NCA	100	138	896	20.5	314	26.1	17.5	44	8.9	2.7	0.9
11	NCA	100	136	933	20.9	244	28.5	22.7	41.5	5.9	1.3	0.3
12	NCA	112	144	—	19.2	252	25.1	18.8	48.1	5.9	2.1	—
13	NCA	120	80	929	—	281	23.5	20.8	48.7	5.4	1.6	—
14	NCA	127	80	983	—	317	28.8	16.2	46.6	6.4	1.3	0.3
15	NCA	132	80	943	17	262	25.8	18.9	49.2	4.7	1.4	—
16	NCA	143	65	1075	20.1	303	26.2	22	43.4	6.9	1.5	—
17	LFP	0	—	251	6.1	55	2.7	93.5	1.8	0.7	0.7	0.7
18	LFP	25	195	231	6.1	31	7.1	85.3	3.1	1.2	3.1	0.2
19	LFP	50	130	283	6.1	32	20.8	66.2	4.8	1.6	6.6	—
20	LFP	75	149	362	6.3	41	21.8	62.6	6.4	1.9	6.3	1
21	LFP	100	140	440	7.1	32	29.4	48.3	9.1	5.4	7.2	0.5
22	LFP	115	155	395	6.2	61	34	52.2	6.4	2.6	4.7	0.1
23	LFP	130	80	448	—	58	30.1	55.8	7.7	6.4	—	—

Hazardous Gases

Chemical Name	Chemical Formula	IDLH (Immediately Dangerous to Life and Health) [ppm]
Carbon Monoxide	CO	1,500
Benzene	C_6H_6	3,000
Hydrogen Fluoride	HF	30
Hydrogen Chloride	HCl	100
Hydrogen Cyanide	HCN	50

Source: Considerations for ESS Fire Safety, DNV-GL Report No. OAPUS301WIKO(PP151894), Rev. 4 February 9th, 2017

Total gas released during thermal runaway for 100% SOC cells



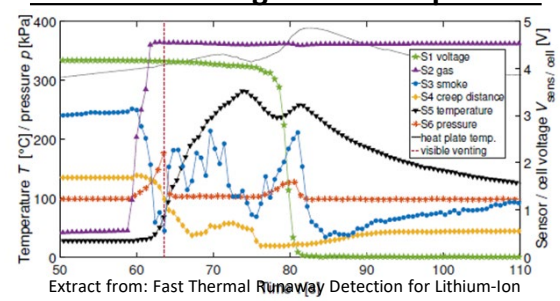
Data adapted from: RSC Advances 7.39 (2017): 24425-24429. Adapted from: Journal of Power Sources 307 (2016):56-62.

RSC Advances (2015) 5, 57171; Thermal runaway of commercial 18650 Li-ion batteries with LFP and NCA cathodes – impact of state of charge and overcharge.

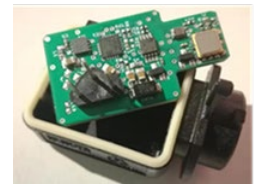
Needs Analysis for "on board" Flammable/Hazardous gas detection

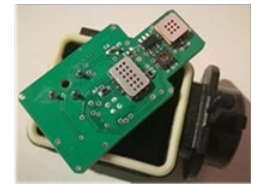
- Meet pending GB14 requirements requiring 5 minute "safe egress" capability for xEV's
- Electrolyte leakage detection for futureproofing against possible EU requirements for hazardous gas detection
- Agnostic to battery electrochemistry and cell size/configuration
- For xEV applications, device must be ASIL "B" or greater
  - Redundant detection capability
  - Must exhibit no Missed (Type 1) and false positive (Type 2) faults
- Must have internal diagnostics
- Gas sensors immune to cross sensitivity, contamination resistant
- Must meet operation life >20,000 hours
- Detection of initial venting or gas release within 3 to 5 seconds
- Operational envelope:
  - -40 to 125C
  - sea level to 5400m altitude for land vehicles, may need to include eAircraft performance requirements
- Price sensitive market

Hot Plate venting sensor comparison



Extract from: Fast Thermal Runaway Detection for Lithium-Ion Cells in Large Scale Traction Batteries ;Batteries 2018,4,16 By Sascha Koch





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