Safety of alternative and renewable energy technologies

David Lange (speaker)
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Hons Wyn
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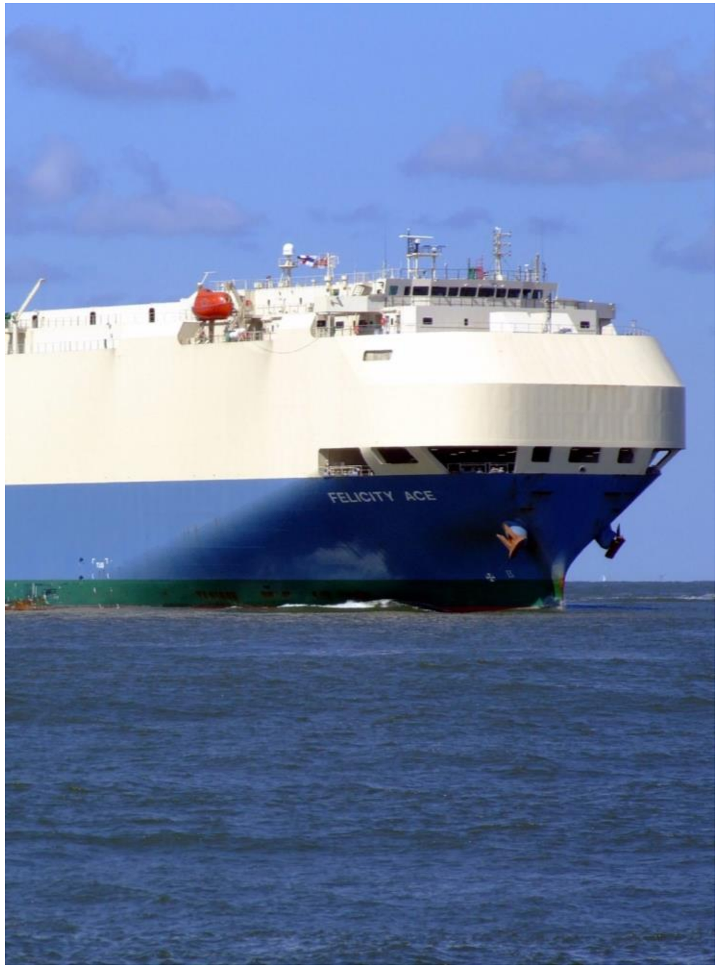
UQ Fire
The University of Queensland

Use cases



Shipping / transportation

- RO-RO
- Car transporters

Car parks

- u/g, a/g, stackers

Open road

Closed road (tunnels)

Offices

- End of Trip Facilities

Homes

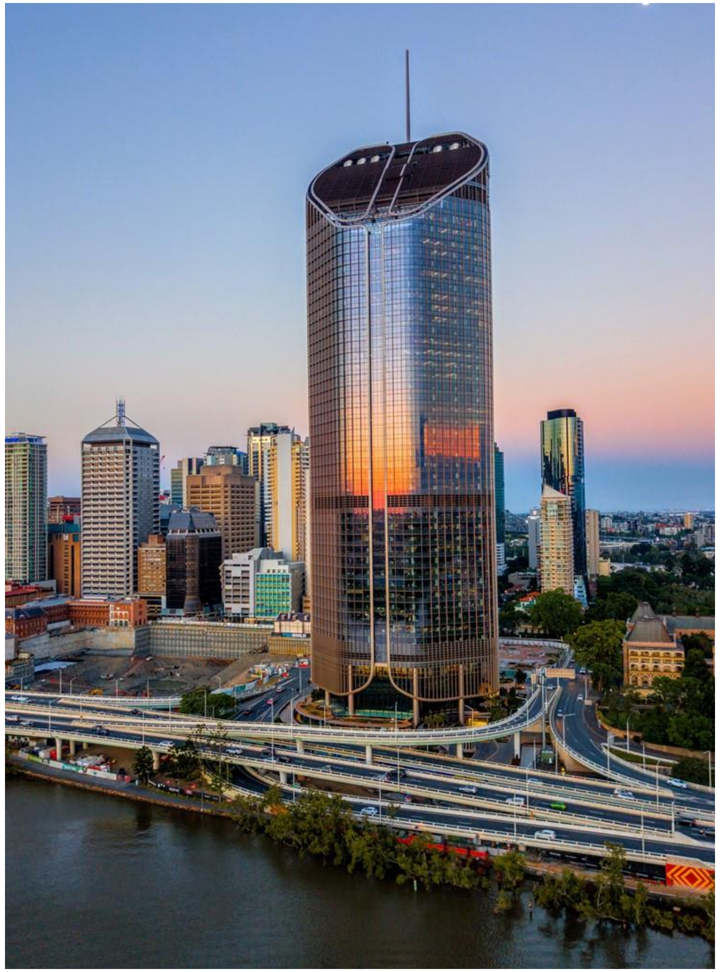
- Battery walls (second use)
- Single dwellings
- Apartment buildings
- Terraced units

Warehouses

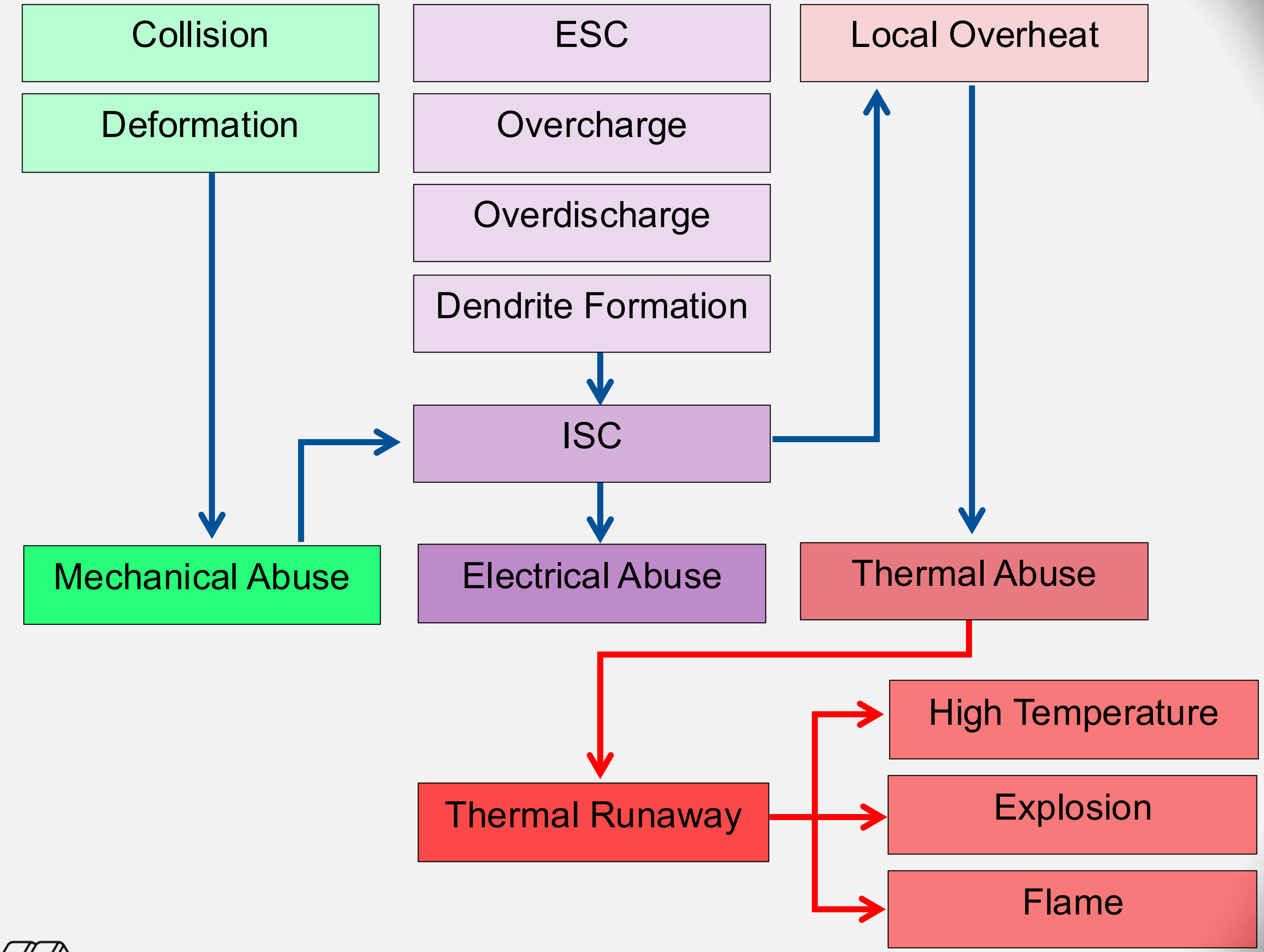
- Automated storage and retrieval systems

Recycle / re-use

Disposal



Abuse leads to thermal runaway



Consequences

https://www.abc.net.au/news/2022-03-02/felicity-ace-ship-with-luxury-cars-sinks-mid-atlantic/100876322

https://www.bbc.com/news/uk-england-hampshire-49071456

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https://www.brisbanetimes.com.au/national/queensland/firefighter-injured-in-overnight-blaze-at-griffith-university-campus-20200316-p54aet.html

https://www.nytimes.com/2023/06/21/nyregion/e-bike-lithium-battery-fires-nyc.html?login=email&auth=login-email

https://www.bbc.com/news/science-environment-63809620

NHRA T4-A8

Work Package 4 of the FRNSW SARET project

- Characterise the:
  - Physical
  - Environmental
  - Toxicological
- Consequences in Battery Energy Storage Systems

THE UNIVERSITY OF QUEENSLAND AUSTRALIA | UQ Fire

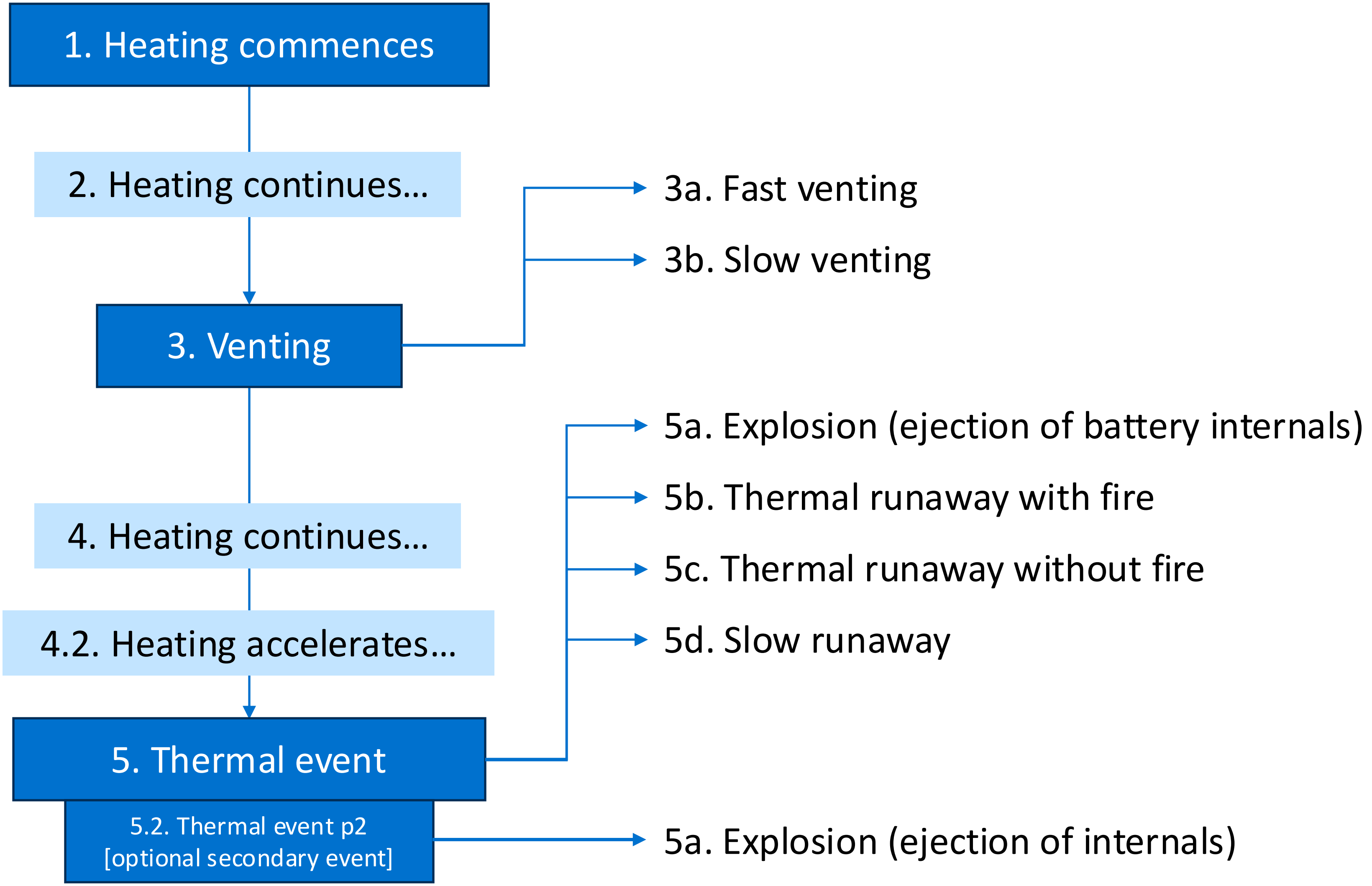
FIRE + RESCUE

LUNDS UNIVERSITET

HALLIWELL FIRE RESEARCH


1391.00
1345.94
1384.38
1348.22
1329.96
1343.98
1448.14
1376.14
1468.00
1412.48
1361.04
1384.02
1471.44
1437.10
1498.74
1583.00
1413.86
1476.76
1558.28
1557.80
1498.24
1607.30
1633.00
1562.00
0.00

Interpreting the differences



Interpreting the differences

1. Heating commences

2. Heating continues…

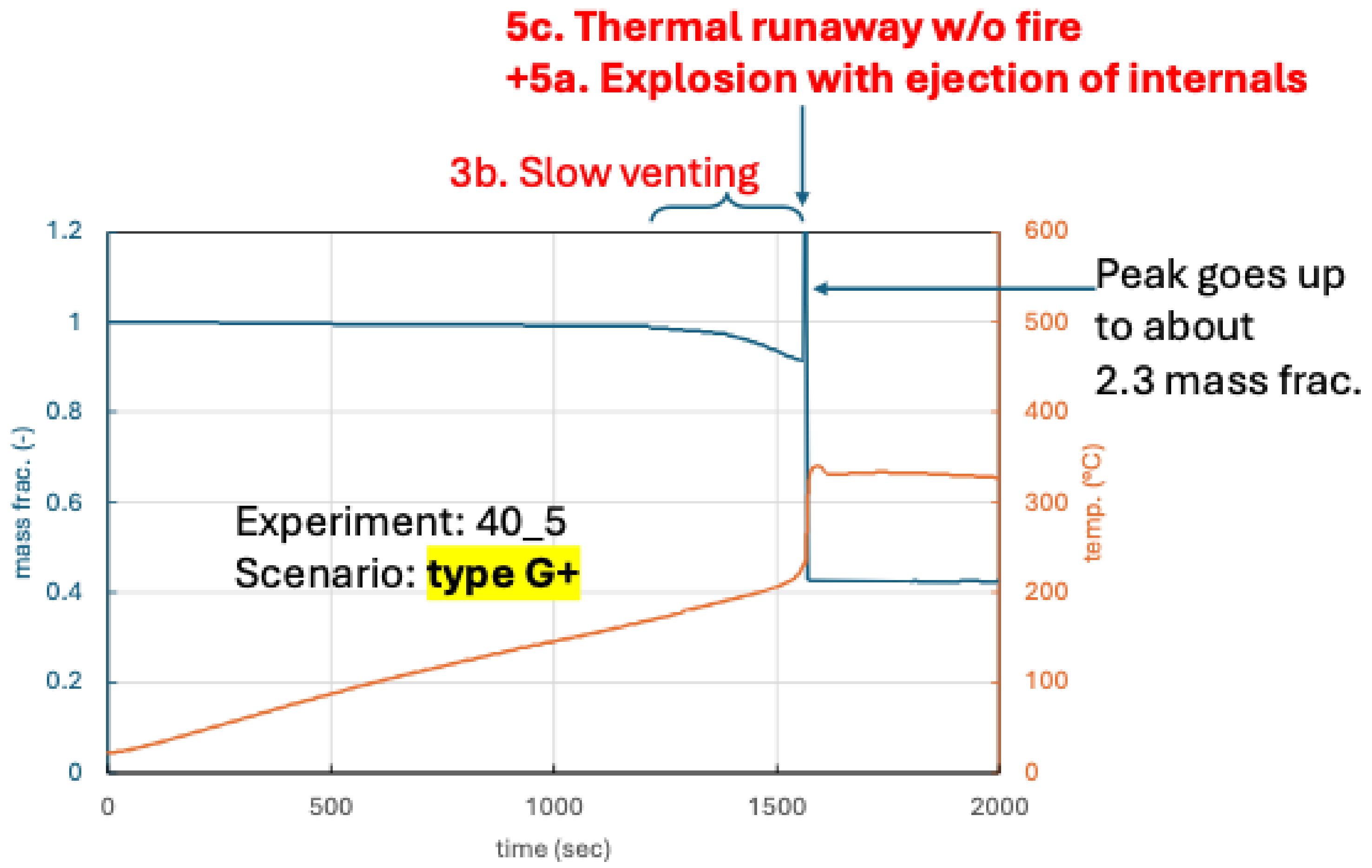
3. Venting

4. Heating continues…

4.2. Heating accelerates…

5. Thermal event

5.2. Thermal event p2
[optional secondary event]



Interpreting the differences

1. Heating commences
2. Heating continues…
3. Venting
4. Heating continues…
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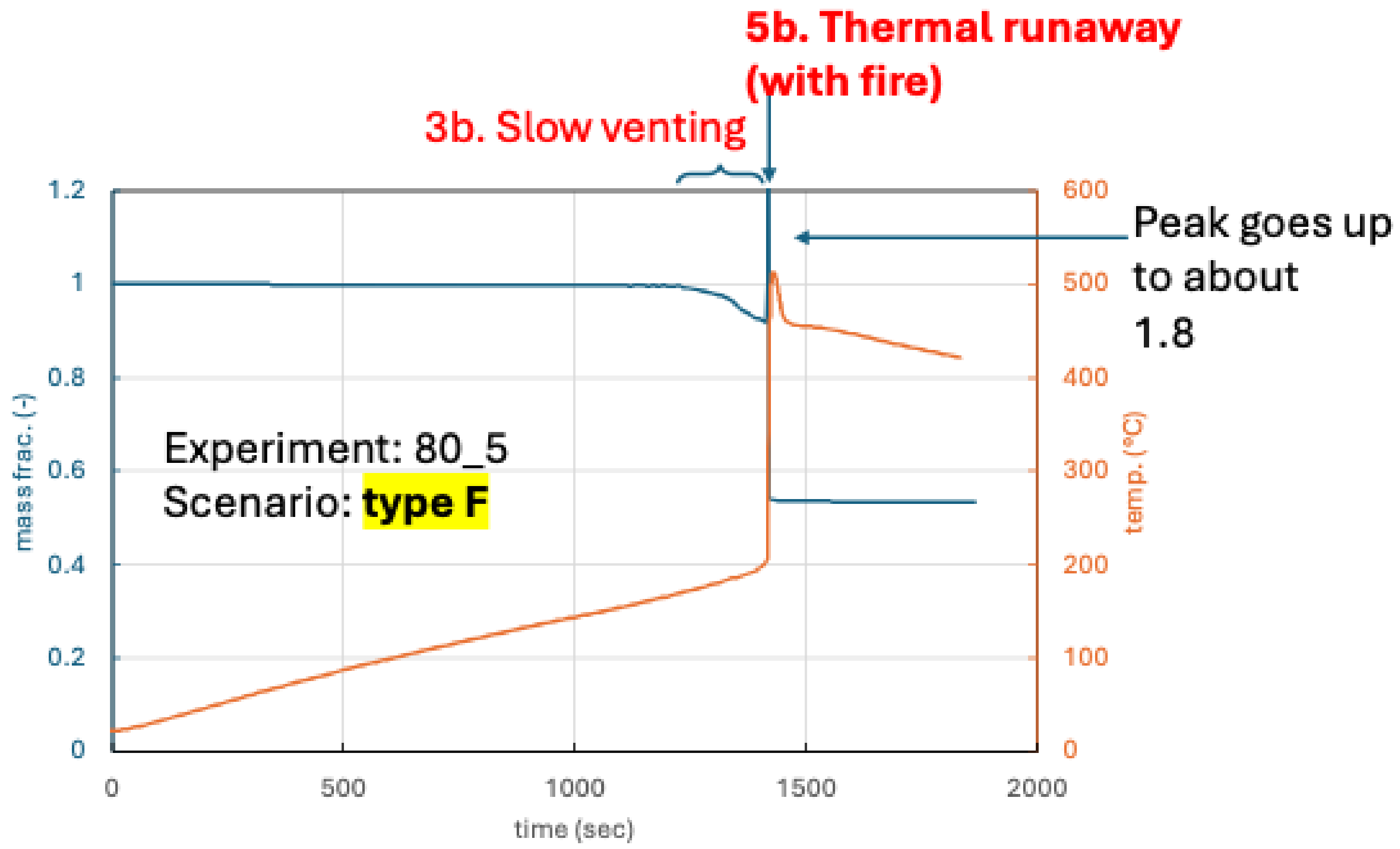
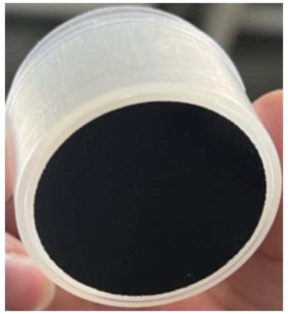


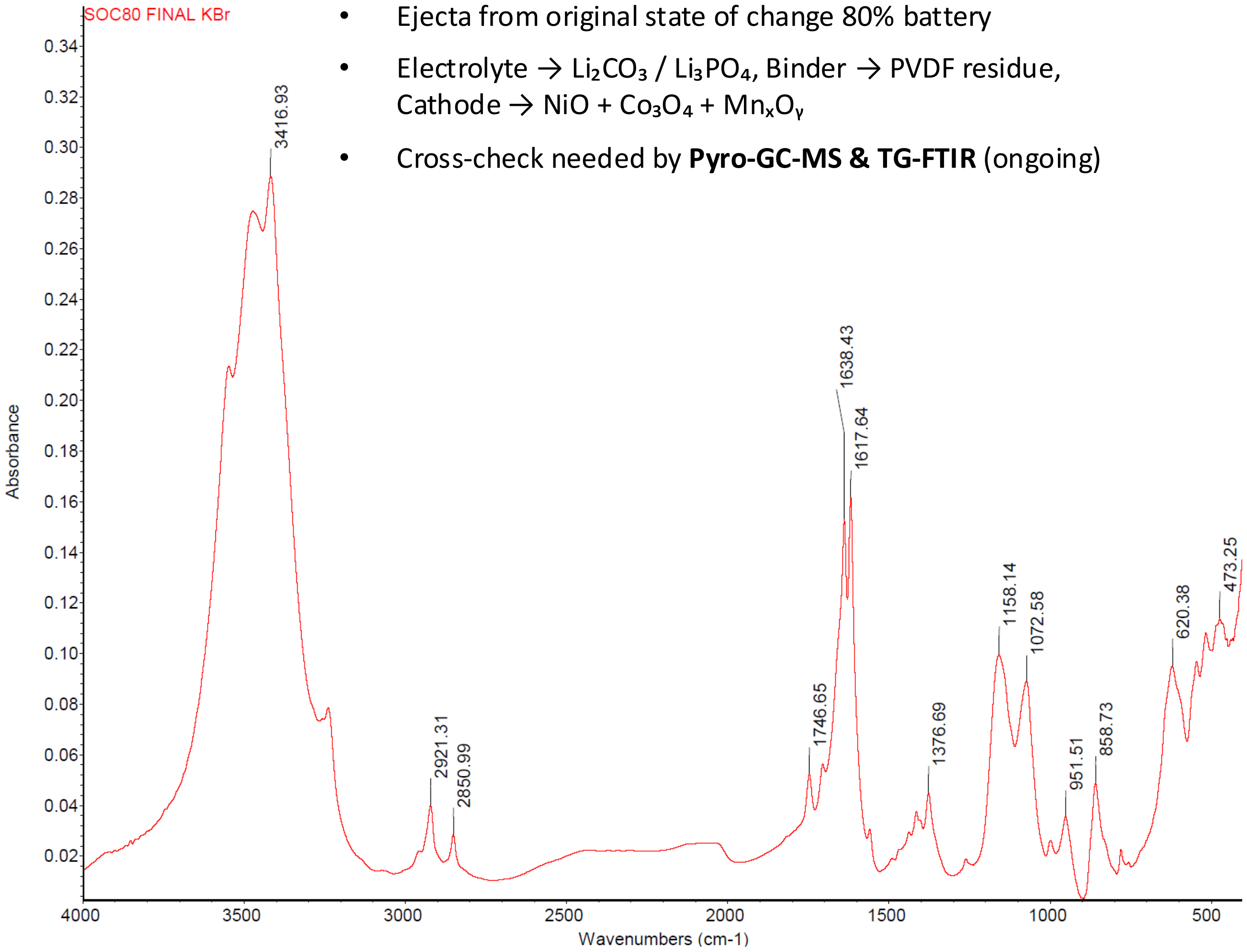
X-ray Fluorescence on Battery Solid Ejecta



Z	Formula	Concentration		Line Name	Compound
28	Ni	34.3	%	Ni KA1	Nickel
25	Mn	12.2	%	Mn KA1	Manganese
13	Al	11.9	%	Al KA1	Aluminum
29	Cu	9.2	%	Cu KA1	Copper
27	Co	8.6	%	Co KA1	Cobalt
15	P	0.9	%	P KA1	Phosphorus
20	Ca	0.4	%	Ca KA1	Calcium
17	C2H3Cl	0.2	%	Cl KA1	PVC
16	S	0.2	%	S KA1	Sulfur
14	Si	0.1	%	Si KA1	Silicon
40	Zr	0.1	%	Zr KA1	Zirconium
19	K	0.1	%	K KA1	Potassium
24	Cr	0.0	%	Cr KA1	Chromium
37	Rb	0.0	%	Rb KA1	Rubidium
38	Sr	0.0	%	Sr KA1	Strontium
35	Br	0.0	%	Br KA1	Bromine

Element(s)	Possible Origin	Relevant citation(s)*
Ni, Mn, Co	Active material of an (Nickel Manganese Cobalt) NMC ($LiNi\_xMn\_yCo\_zO_2$) cathode → converts to NiO, Mn_3O_4, CoO after fire/thermal runaway	Rigaku WDXRF application note quantifies Ni/Co/Mn ratios in NMC cathodes Review of Ni-rich NMC chemistry XRF study of spent Li-ion batteries lists Ni, Mn, Co as top metals
Al	Al foil cathode current collector → forms Al_2O_3/$Al(OH)_3$ residues	Corrosion & role of Al current collectors in Li-ion cells
Cu	Cu foil anode current collector → oxidises to CuO/Cu_2O	Description of Cu foil as the standard anode current-collector
P (F not visible)	Electrolyte salt $LiPF_6$ → hydrolyses/oxidises to $Li_xPO\_yF\_z$, Li_3PO_4, transition-metal phosphates	Thermal-decomposition pathway of $LiPF_6$ & formation of phosphorus species
Cl	Electrolyte / cathode chlorination during high-T processing – several thermal-recycling and chlorination flowsheets deliberately convert Li_2O → LiCl to separate Li from transition metals	Thermal decomposition-based gas-solid reaction
S, Ca, Si, K, Zr (≤0.5 %)	Separator ash, electrolyte additives (e.g., Li_2SO_4, $CaCO_3$ filler, SiO_2 anti-shrink), Zr-based coatings	These low-level hetero-elements are commonly reported in battery-residue XRF scans alongside major metals
Li, F, etc. & C, H, O, N (Missing)	Light-element- limitation of XRF or EDX	Inductively Coupled Plasma Mass Spectrometry for Li, Al, B, Na, Mg, K, Fe, Cr, Zn, Mo, W, Sn, Sb, V, Ti, Cd, Pb, Tl, As, Se, P, and S Combustion Analysis for C, H, O, N

Fourier Transform Infrared Spectroscopy



- Ejecta from original state of change 80% battery
- Electrolyte → Li_2CO_3 / Li_3PO_4, Binder → PVDF residue, Cathode → NiO + Co_3O_4 + Mn_xO_y
- Cross-check needed by **Pyro-GC-MS & TG-FTIR** (ongoing)

Compound Inferred	Assignment Proposed
Li_2CO_3 (lithium carbonate)	Li_2CO_3 always shows the strong doublet at 1490/1438 cm^{-1} and the 868–872 cm^{-1} bend; All three appear in exactly the correct ratio, so the match cannot be PVDF alone.
Li_3PO_4 / TM-phosphates	Stoichiometric phosphates give the two-lobe 1150/1050 cm^{-1} envelope plus a 590 cm^{-1} bend; the same trio is reported for Li_3PO_4 formed from $LiPF_6$ hydrolysis.
PVDF binder remnants	All three hallmark PVDF bands are visible, proving a trace of undecomposed binder. The 1180 cm^{-1} CF_2 peak also explains the PO_4 crest is slightly broadened.
NiO	Rock-salt NiO formed when Ni-rich NMC decomposes. Both IR-active NiO (620 cm^{-1}) modes match literature positions.
Co_3O_4	Spinel Co_3O_4 shows a dominant band at 660 cm^{-1} with a weaker shoulder at 570 cm^{-1}; both appear, confirming cobalt oxide in the ash.
Mn_3O_4 / MnO_2	Hausmannite Mn_3O_4 (and MnO_2) give Mn–O stretches at 610–630 cm^{-1} and a second band near 500 cm^{-1}; these fit the observed shoulders.

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Work Package 4 of the FRNSW SARET project

- Development of representative energy storage systems
- Instrumentation design to characterise the risks to nearby or adjacent infrastructure, persons or environments
- Demonstration of different methods of initiating failure, in-line measurements of gas species, and residue analysis
- Desktop studies of extinguishing systems, fire effluent and contamination to run-off water, and risks associated with stranded energy
- Free burn tests as well as extinguishing tests

Natural Hazards Research Australia

Thank you

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