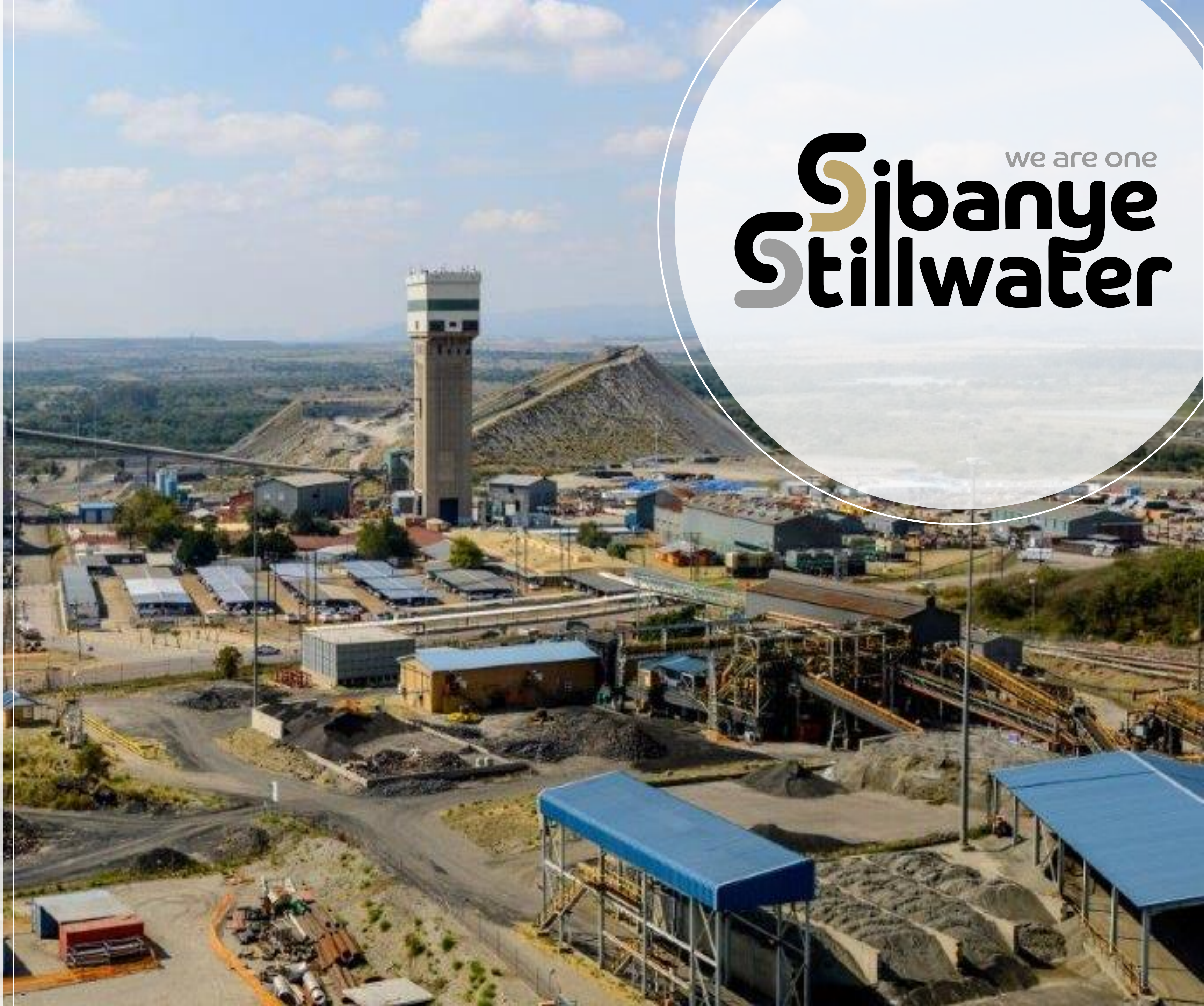
Understanding battery chemistries, safety considerations, and suppression challenges in the mining industry

SAIMM Mine Health and Safety Conference 2025

Ashleigh Townsend
SEECE Lecturer NWU; Project Superintendent, Sibanye-Stillwater, Group Technical



Introduction

- Migration towards battery electric technology
- Investigate the apparent risk vs. real risk (Thermal runaway)
- Safe adoption of lithium-ion battery technology in the mining industry
- Controlled large-scale testing conducted at the Kloppersbos explosion testing facility with CSIR

Bowtie Risk Analysis

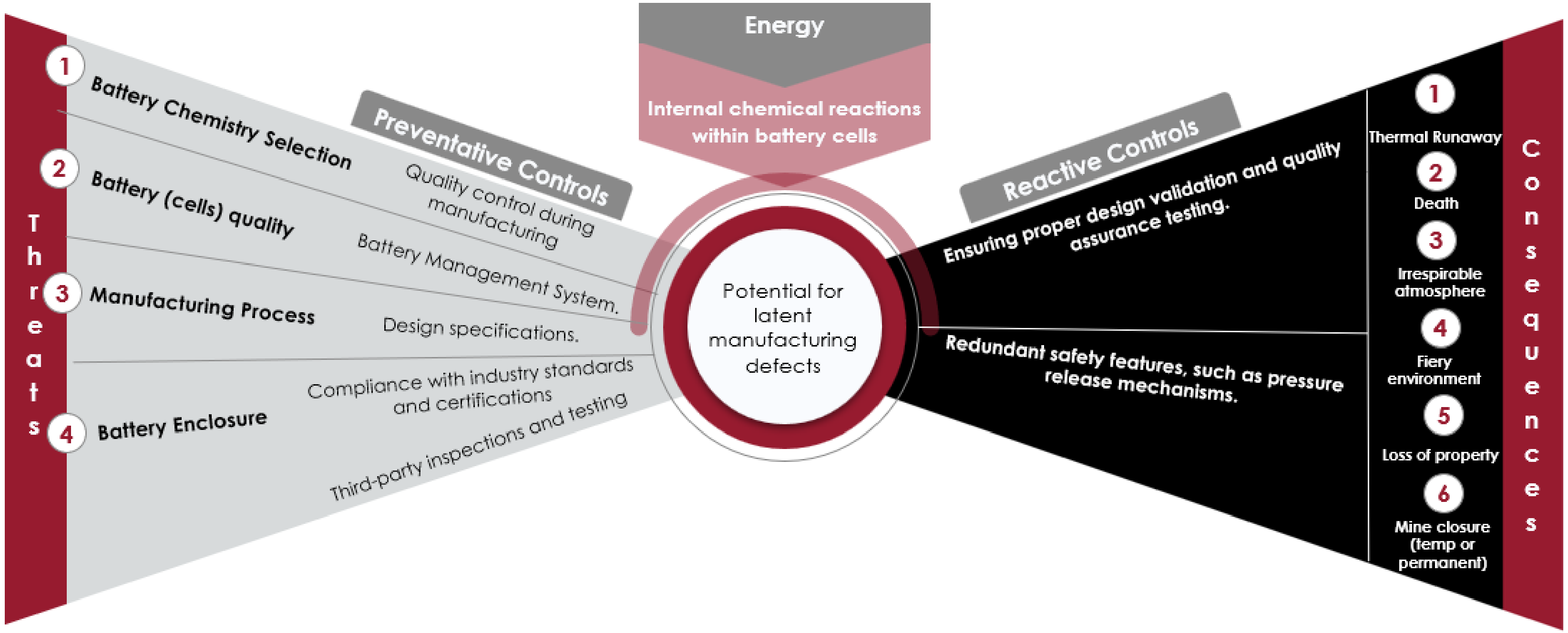
⚠ **Thermal Runaway** – Excess heat or internal failures cause uncontrolled reactions.

⚠ **Fire & Explosion** – Chemical instability, physical damage, or improper disposal.

⚠ **Toxic Gas Release** – Battery failure leading to irrespirable atmospheres.

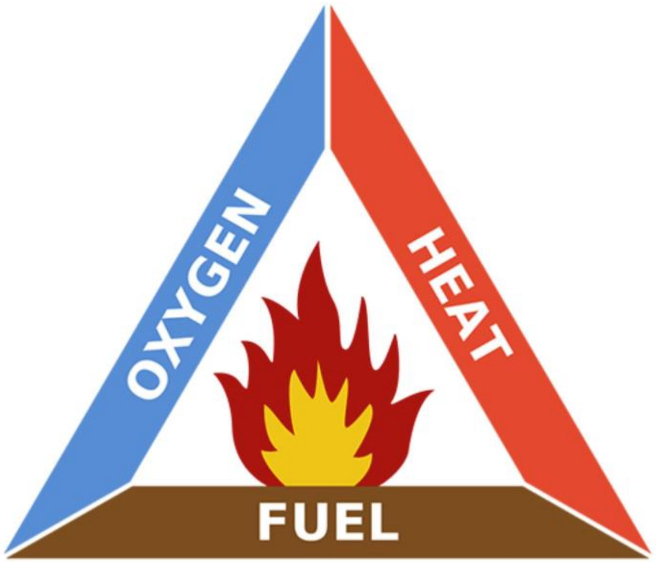
⚠ **Property & Operational Loss** – Equipment damage, mine shutdowns, and financial impacts.

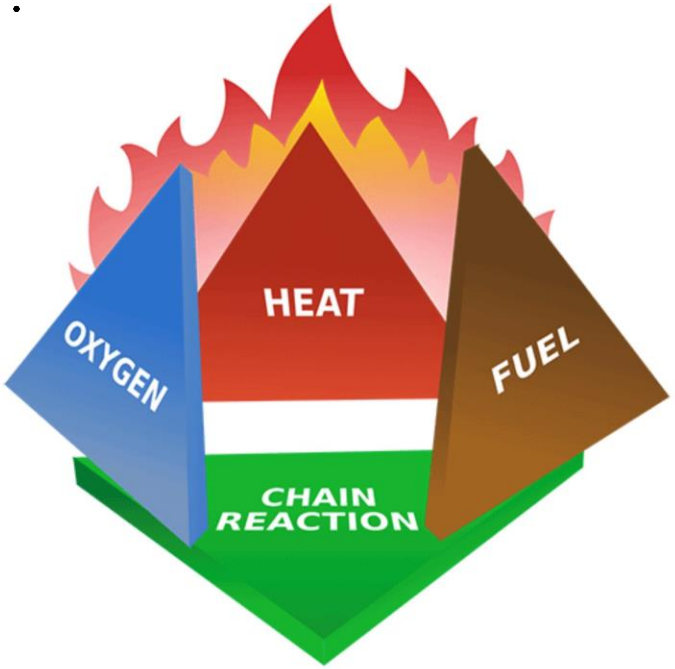
⚠ **Human Safety Hazards** – Risk of death or injury.



Lithium Battery Risks

- Thermal runaway – state of self-sustained heating.
- Fire triangle – remove one leg and fire cannot be sustained.
- Thermal runaway leads to **aggravation of all three legs** – known as chain reaction – develops a fire tetrahedron
- Oxygen from electrode breakdown; heat from TR; fuel from electrolyte breakdown
- LIBs generate all three legs *during* thermal runaway (chain reaction) – herein lies the danger.



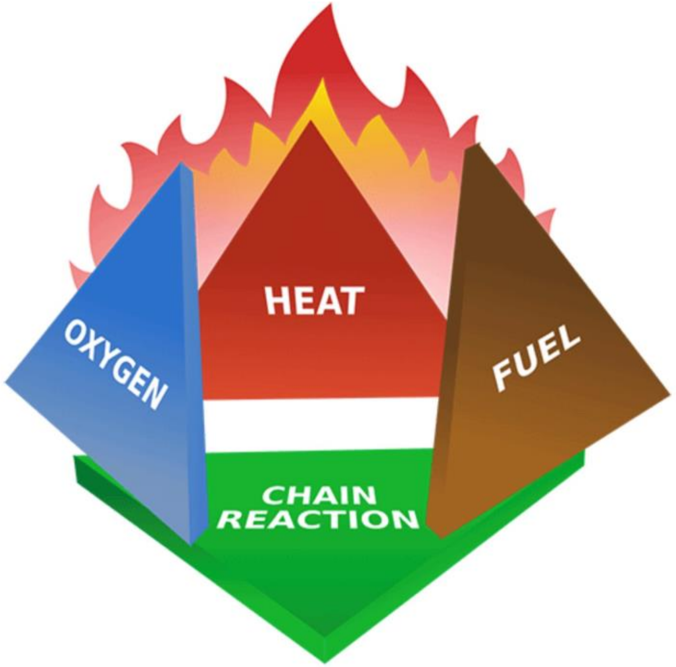


Types of Lithium-ion Batteries

	Name	Energy density (kWh/kg)	Thermal runaway (TR) temp (°C)	Rate of increase (TR) (°C/s)
LiPo	Lithium Polymer	0.15-0.25	120-180	10-100
NCA	Lithium-Nickel-cobalt-aluminium oxide	0.2-0.3	200-250	10-50
NMC	Lithium-nickel-manganese-cobalt-oxide	0.15-0.25	210-250	10-50
LFP	Lithium-iron-phosphate	0.09-0.16	270-300	5-20
LTO	Lithium-titanate	0.05-0.09	>300	<10

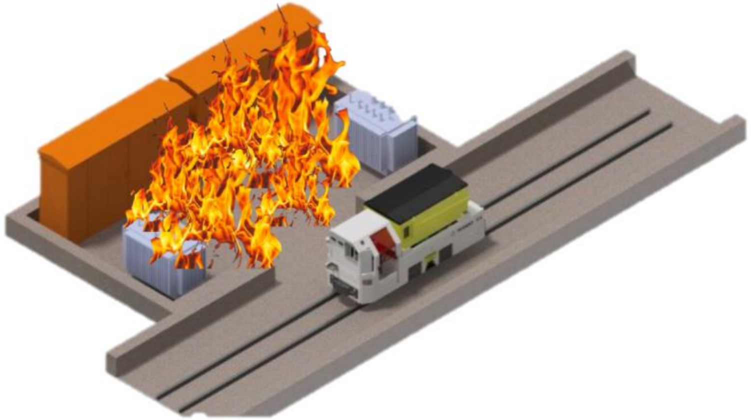
Grouping of lithium-ion batteries

- Metal-oxide cathode – NMC, NCA, LiPo
- Metal-phosphate cathode – LFP
- Titanate anode – LTO
- Metal oxide cathodes have weak oxygen bonds – release readily when heated
- Metal phosphate cathode and titanate anodes have solid oxide bonds – do not release when heated
- These batteries require external oxygen at sufficient concentrations to sustain a fire.
- This phenomenon is seen in the Kloppersbos tests.



CSIR Kloppersbos Testing Overview

- CSIR Kloppersbos explosive testing facility – equipped to safely conduct large-scale explosion and fire tests under controlled conditions.
- Emulates underground environment including1.5 m/s ventilation and enclosed spaces.
- Conducted at medium and large -scale for comparison on LFP and Lead acid Locos.
- Large scale represents worst case scenario underground – transformer burning at >900℃ temperatures with side of loco exposed.
- External flame/heat used as this is the foundation of thermal runaway initiation in LIBs.
- Mine rescue services involved – first responders, require understanding of severity of these incidents, how to respond.
- The first of their kind in South Africa and globally to be performed at this scale and under realistic mining conditions
- The findings used to guide industry standards, OEM design improvements, and mine safety protocols.



Key Test Findings – Lead Acid Full Scale Tests

- Loco plastic lid started to **melt within 20 minutes** after commencement of the test.
- **Within 40 minutes** the LA cells were on fire.
- **Audible popping** was heard from some cells as they entered thermal runaway.
- The **gasses released** by the burning cells **increased significantly** causing push-back against the ventilation.
- **No self-extinguishing** seen after removal of propane flame.

Videos of Tests – Full Scale Lead Acid

Key Test Findings – Lithium Full Scale Tests

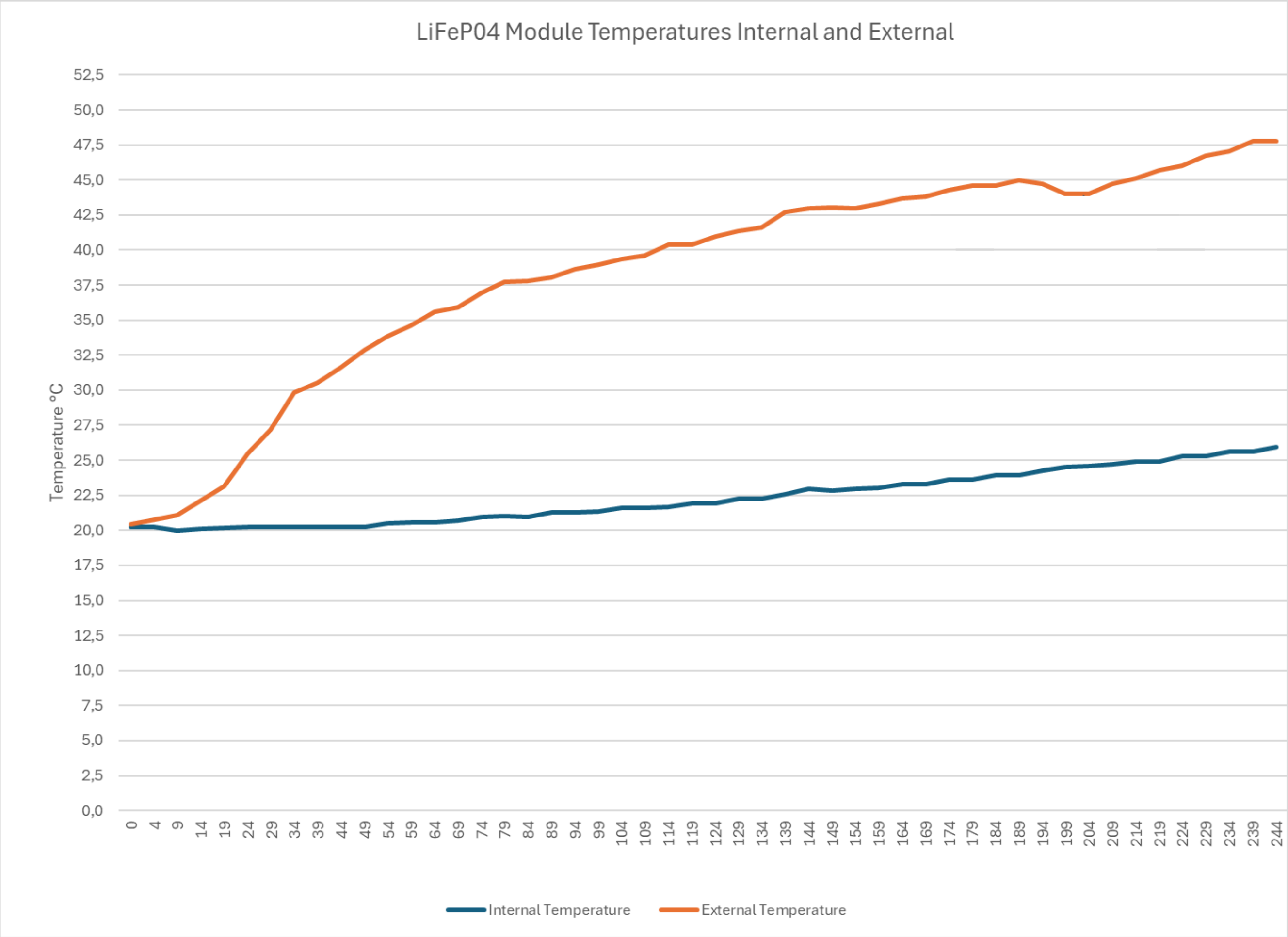
- The test was administered for 4 hours.
- **No significant event was seen.**
- The inner cannisters are set to release suppressant at 105°C – this was not reached.
- The BMS PCBs per module indicated an elevated temperature, however they did not reach a temperature that required a shut-off of the system.
- Compared to midscale test – significantly more design around enclosure, specifically to prevent thermal incidents from occurring.

Key Test Findings – Lithium Midscale Tests

- Thermal runaway occurs – but **controllable.**
- **No explosion occurred**.
- **Flame is observed external** to the module where the flammable gas is released.
- Cell vented vapor ignites due to exposure to flame source and sufficient oxygen.
- Cell venting is sequential and predictable.
- Temperature of battery flame is ¼ of that of propane flame.
- **Self-extinguishing occurs.**

Key Test Findings – Lithium Full Scale Tests

- Internal module total temperature increase of 5°C over 4 hours.
- From midscale tests – internal temperature of module needs to reach 230℃ for venting to occur.
- For full scale – requires additional ~200°C.
- Logistic curve provides various gradients, extrapolation results in best case of 22 hours of continuous flame application of 900℃ for venting to occur.



Key observations

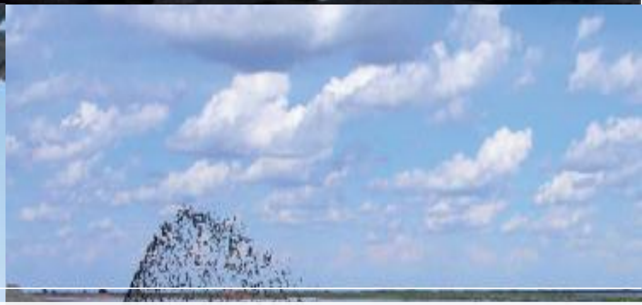
- Medium-scale LFP batteries demonstrated **stable, self-extinguishing behaviour;**
- Gases released during LFP TR **require an external ignition source** to start a fire;
- Fire occurs external to LFP cells;
- With correct enclosure design **heat and flammable gasses are dissipated sufficiently** and **oxygen concentrations limited** – preventing heat build-up and extreme thermal events;
- With **proper engineering controls, training, and monitoring**, LFP systems can be safely deployed underground.

Suggested Recommendations for Industry

- **Prioritise Lithium Iron Phosphate battery** chemistries for underground use due to enhanced stability and safety.
- Ensure control room has a **log of battery chemistry types** and locations underground.
- Mandate **OEM certification** of venting, fire barriers, and battery enclosures that meet underground safety criteria.
- Implement **real-time temperature monitoring**.
- **Review and revalidate all risk assessments** to ensure hazards are known and adequately controlled – applicable to more than just LIBs.

Acknowledgements

- We would like to take this opportunity to acknowledge and thank the following team members for their contribution and involvement:
  - Mike Calvert
  - Lodewyk le Grange
  - Tom van den Berg
  - Mannas Fourie (MRS)
  - Riaan Bergh (CSIR)
  - Heleen Olivier & Jacques van Rensburg



Questions

Bowtie Risk Analysis – Key Controls & Risk Mitigation

- ✅ **Manufacturing & Procurement** – Battery selection criteria; supplier quality control; compliance with ISO standards (Sibanye developed a Group Standard for Lithium Batteries).
- ✅ **Storage & Transport** – Safe handling procedures; dedicated and controlled storage; secure transport.
- ✅ **Usage & Maintenance** – Condition monitoring; Battery Management System (BMS); emergency shutdown systems; proper operating procedures.
- ✅ **Disposal & End-of-Life Management** – Safe decommissioning; recycling; controlled waste disposal.
- ✅ **Training & Awareness** – Employee education on battery risks; emergency response; regular safety and compliance audits.

- ✅ **Battery Type Awareness –** Different battery chemistries; various thermal runaway behaviours; different suppressant requirements.

Key Test Findings – Lead Acid Midscale Tests

- Conducted to determine possible hazard (gas, explosion, fire) at medium scale before commencing with full scale.
- Used to test MRS suppressants.
- The battery entered a burning state **within 4 minutes**, burned at same temperature as propane burner.
- Cell **leaked sulfuric acid** as seen in picture.
- Cell **continued to burn** after removal of external flame.

Key Test Findings – Lithium Midscale Tests

- When the external heat source is removed, the system **self-suppresses and self-extinguishes**.
- System cools down without any suppressant or coolant applied.
- **Water can suppress flame and cooldown system with no adverse effects**.**
- Burnout time for a full module based on 2 tests at CSIR and OEM factory test conclude estimated 4 hours 15 min.
- Module steel plate temperature sustained at 230°C is required for single cell venting event.
- Propane flame (900°C) at 100mm needs 40min of energy transfer to heat module steel plate for a single cell venting event.

Videos of Tests – Lithium Midscale First Venting Event

- First venting event occurred 42 minutes after external flame was applied.

Videos of Tests – Lithium Midscale Self Extinguishing

- External flame removed at 82 minutes.