Safety Investigations of Commercial Sodium-Ion Cylindrical Cells: Insights from Nail Penetration Tests and Gas Analysis

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Motivation

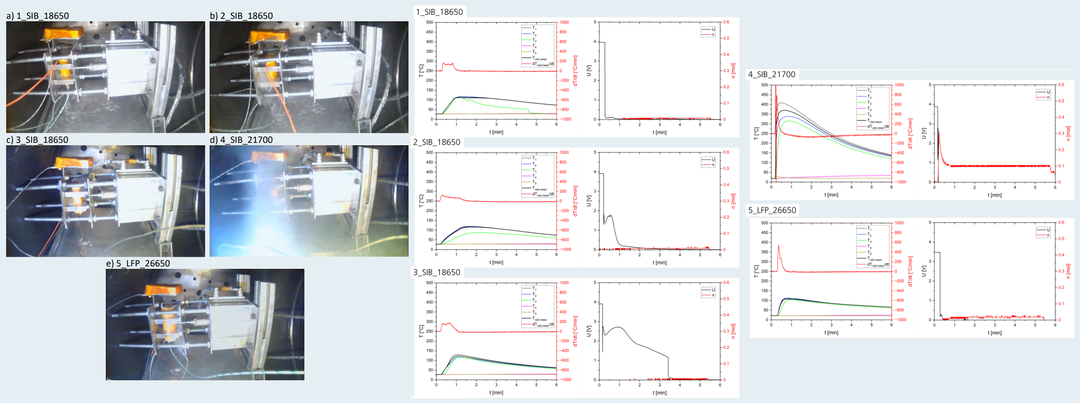
Sodium-ion batteries are emerging as a cost-effective and resource-abundant alternative to lithium-ion technology, yet safety data on commercial sodium-ion cells remain limited [1].
Recent studies emphasize the need to better understand the behavior of sodium-ion batteries under mechanical abuse conditions to enable safe large-scale deployment [2].This work investigates the thermal and chemical response of commercial sodium-ion cells during nail penetration to support safety assessment.

Investigated Cells

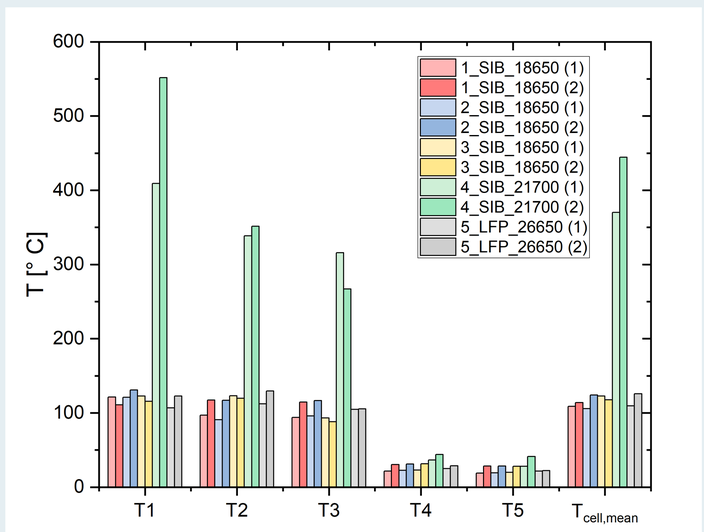
Cell Name	Cell Type/ Cell Format	Voltage Window (LCV – UCV) [V]	Nominal Capacity (specified) [mAh]	Measured Capacity (Charge) [mAh]	Internal Resistance @50%SOC Charge/Discharge [mΩ]	Spezific Capacity [Wh/kg]	Further referred as
Hakadi 18650E 1500	SIB 18650	1.50 – 4.10	1500	1313.41 ± 146.69	133.21 / 109.49	105.04	1_SIB_18650
Hakadi 18650 1300 20C	SIB 18650	1.80 – 3.95	1300	1320.48 ± 11.59	52.42 / 48.28	99.00	2_SIB_18650
Highstar NaCR 18650 1.3ER	SIB 18650	1.80 – 3.95	1300	1268.73 ± 26.89	77.12 / 68.44	105.96	3_SIB_18650
Highstar NTE21700 20E	SIB 21700	1.50 – 3.95	2000	1856.18 ± 59.87	39.63 / 33.39	109.07	4_SIB_21700
LithiumWerks ANR 26650 M1B	LFP 26650	2.00 – 3.60	2600	2465.35 ± 31.65	11.56 / 11.67	112.90	5_LFP_26650

Thermal & Mechanical Behavior

- Mechanical abuse reveals divergent thermal responses



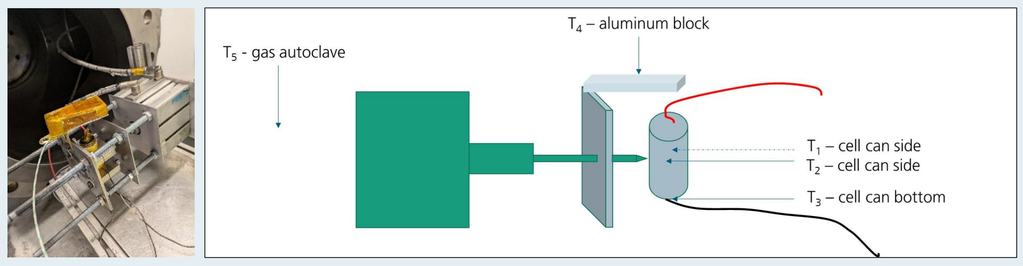
- Temperature profiles at five different positions (T_1–T_5) during nail penetration of fully charged cylindrical cells.

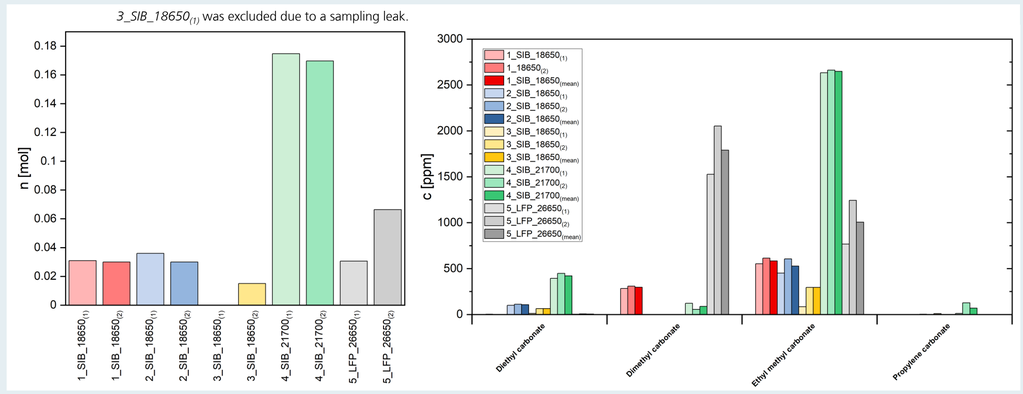


- The 18650 SIB cells and the *5_LFP_26650* only show light thermal runaway < 120° C
- Only the *4_SIB_21700* cell shows a significant thermal runaway with maximum temperature of ~ 450 °C

Experimental

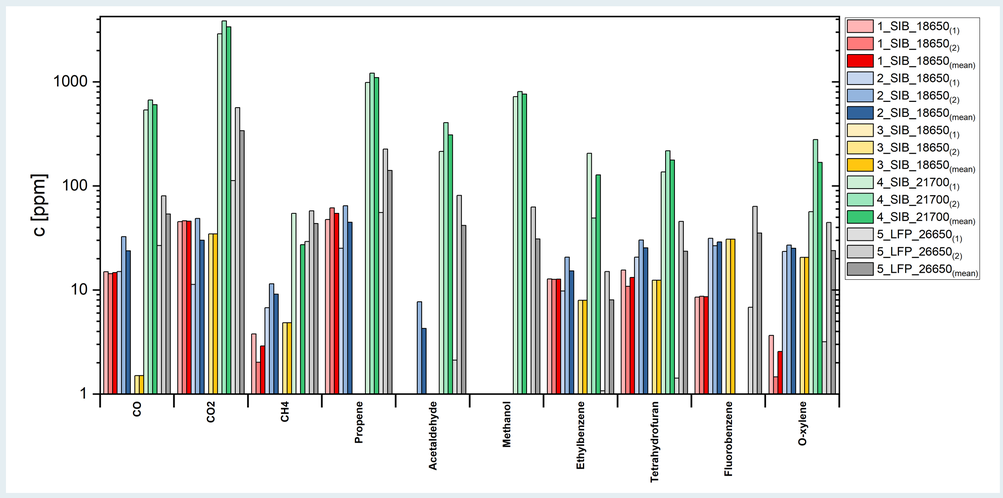
- Tests are performed in an 125 L autoclave under inert gas conditions.
- A pneumatic cylinder with a 3 mm nail and a speed > 8 cm/s is used.
- Cell voltage, pressure and temperatures at different positions were measured during test.





Gas Emission & Chemical Insights

- Highest gas amount was measured with *4_SIB_21700* → only cell with a significant thermal runway
- EMC was the dominant species, highest in *4_SIB_21700* (~2700 ppm) and *5_LFP_26650* (~1000 ppm).
- DMC was elevated in *5_LFP_26650* (>2000 ppm) and *1_SIB_18650* (~250 ppm).
- DEC and PC remained low (<500 ppm) across all cells.



- The *4_SIB_21700* cell showed by far the highest gas emissions, with CO_2 > 5000 ppm and strongly elevated hydrocarbons.
- Methanol, acetaldehyde, and CO were also highest in *4_SIB_21700*, indicating severe electrolyte decomposition.
- The *5_LFP_26650* produced similar species but at lower concentrations.

Conclusion

Nail penetration tests revealed strong cell-dependent safety behavior. Most 18650 cells showed limited temperature rise without thermal runaway, whereas the 21700 cell exhibited severe thermal runaway and the highest gas release. Gas analysis identified CO_2 as the dominant species, indicating electrolyte decomposition as the main reaction pathway. The combined thermal and gas analysis approach provides valuable insights for safety evaluation and cell design optimization. [3]

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Projektträger Jülich Forschungszentrum Jülich

References:
[1] Carter, R., Waller, G. H., Jacob, C., Hayman, D., West, P. J., & Love, C. T. (2025). First Look at Safety and Performance Evaluation of Commercial Sodium-Ion Batteries. Energies, 18(3), 661.
[2] Rui, B., Sun, S., Tan, X., Chak, C. M., Ma, L., & Xu, J. (2025). Mechanical abuse and safety in sodium-ion batteries. Journal of Materials Chemistry A, 13(17), 12203-12215.
[3] Schuhmann, S., et al. (2026). Safety Investigations of Commercial Sodium-Ion Cylindrical Cells: Insights from Nail Penetration Tests and Gas Analysis, (*Paper in preparation*)

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