Scalability of thermal runaway in battery systems

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The rapidly increasing implementation of lithium-ion and sodium-ion batteries in mobile and stationary energy storage systems poses new safety challenges. In this context, preventing thermal runaway (TR), the most safety-critical event in battery systems, is of utmost importance. While TR behaviour at the cell level is well understood, the mechanisms governing its scaling to modules, packs, and multi-megawatt storage systems remain insufficiently investigated. This limitation arises from complex thermal, mechanical, and electrochemical interactions, restricting reliable prediction of heat release, gas evolution, and propagation behaviour in large battery systems.

This work addresses the central question of how TR behaviour can be predicted and scaled using fundamental parameters such as chemistry, geometry, state of charge, and energy capacity. Building on recent literature, experimental results and simulation datasets are systematically evaluated to identify physically meaningful parameters required for scalable TR modelling. In particular, calorimetry data are used to characterize thermal-abuse behaviour and derive kinetic parameters for Arrhenius-type reaction models describing exothermic heat release during TR. These governing variables form the basis for parameterising a multi-physics simulation framework capable of resolving TR initiation and propagation.

Comprehensive simulation studies are conducted to identify, rank, and quantify the parameters that most strongly influence TR behaviour, including heat release, propagation, and failure severity. By integrating literature data, targeted simulations, and controlled upscaling analyses, this work provides a basis for developing and validating scaling laws, TR prediction envelopes, and uncertainty bounds from cell to battery energy storage system (BESS) level. The results support safer battery-system design, inform dangerous-goods regulations, and establish a scalable framework for systematic TR assessment across battery scales.