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WHITE PAPER | THERMAL

First-Pass Fire Tests for Battery Storage Developers

How much inter-cell barrier a module of large prismatic LFP cells needs to stop thermal runaway at the first neighbor, sized before the cell, module and unit fire tests.

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Method
Transient 1D finite-volume conduction with a measured runaway energy and onset

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Abstract

Large-scale fire testing is now required for stationary battery systems in the United States, and a failed test costs a unit, a redesign and months of schedule. The first design question is whether one cell's thermal runaway reaches its neighbor. We model a face-to-face stack of 280 Ah lithium iron phosphate (LFP) prismatic cells with a transient finite-volume conduction model. The failed cell releases the heat implied by its measured rise from runaway to peak temperature, 1.46 MJ over 300 s [1]; a neighbor goes into runaway when any point reaches 180 °C, the lower end of the measured runaway temperature for this cell [1]. The model matches an exact adiabatic energy balance and the error-function solution for two contacting bodies, and is converged in grid and time step to 0.1 K.

With cells separated only by a 0.1 mm film, the neighbor reaches runaway 3.4 minutes after the failed cell. A barrier resistance of 0.020 $m^2 \cdot K/W$ (about 0.6 mm of aerogel) stops runaway at the neighbor with convective edge losses, 0.052 $m^2 \cdot K/W$ (1.6 mm) keeps it below the 145 °C vent-opening temperature, and 0.096 $m^2 \cdot K/W$ (2.9 mm) keeps it below 120 °C. Edge heat loss is the dominant uncertainty: with adiabatic edges, a bound that no real module reaches, 2.5 mm is needed to stop runaway and 7.3 mm to stay below venting.

Keywords: thermal runaway propagation, LFP, prismatic cell, aerogel barrier, UL 9540A, NFPA 855, energy storage.

1. Introduction

Failure rates of grid batteries have fallen sharply, by 98 % per gigawatt-hour between 2018 and 2025 in one industry analysis [7], yet a single propagating event can stop a project pipeline. The 2026 edition of NFPA 855 makes large-scale fire testing mandatory, and the current edition of UL 9540A adds system-level tests with pass/fail criteria for fire spread [4], [5], [6]. Any later change to a tested design may require a new test [6].

Propagation in a module starts with one step: heat from a cell in runaway raising its neighbor to its own runaway temperature. The mechanisms of runaway and of propagation in large-format modules are well documented [2], [3]. For 280 Ah LFP prismatic cells, Jia et al. measured safety-vent opening at about 144 to 158 °C, runaway at about 180 to 205 °C and peak temperatures of 426 to 465 °C, with runaway lasting 175 to 301 s [1]. This paper turns those measurements into a sizing rule for the barrier between cells, stated in thermal resistance so that it applies to any barrier material.

2. Model and Method

The stack (Figure 1) is three cells in face-to-face contact, the failed cell at one end. Heat flows through the 205 × 174 mm faces; each cell is 72 mm thick and has 5.42 kg mass [1], giving a mean density of 2,110 kg/m³. Each cell is divided into 12 layers. Adjacent cells are joined through either a 0.1 mm insulating film (5×10^{-4} m²·K/W) or a barrier pad of resistance R_b. Conduction obeys $\rho c_p \partial T/\partial t = \partial/\partial x(k \partial T/\partial x) + q'''$, solved with an implicit finite-volume scheme [9] and a 2 s time step. The hottest point of each cell is its face temperature, reconstructed from the flux through the adjacent link.

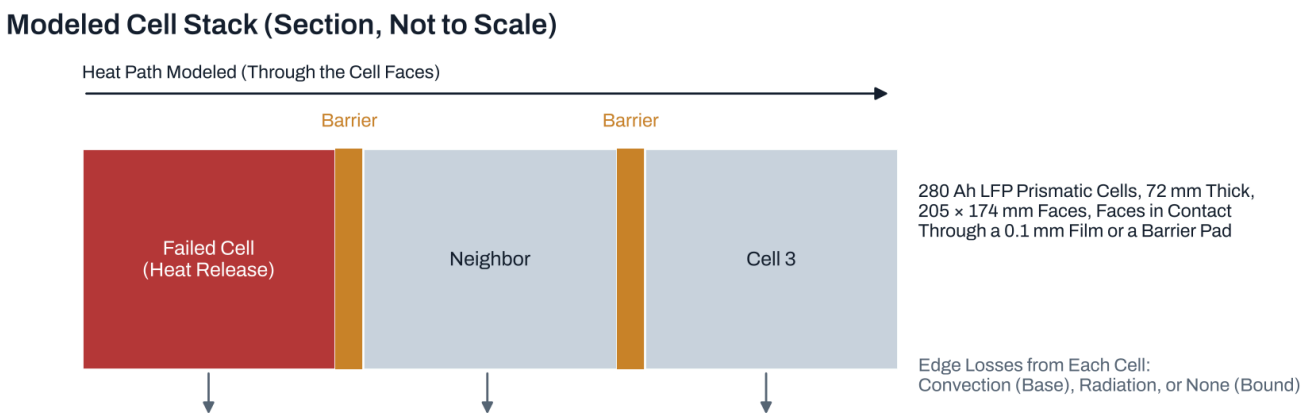


Figure 1. Modeled stack in section: the failed cell, its neighbor and a third cell, joined through barrier pads (or a 0.1 mm film when no barrier is fitted). Heat is tracked through the faces; each cell also loses heat from its four edges.

The failed cell starts uniformly at the runaway temperature and releases $E = m\, c_p(T_{max} - T_{tr})$ uniformly over t_d = 300 s, using the mean measured values at zero preload (T_{tr} = 202.6 °C, T_{max} = 447.5 °C, t_d = 301 s) [1]. This is the heat the cell retains; heat carried off in vent gas is excluded here and treated separately in the companion module study [11]. A neighbor starts its own release when any point reaches T_{tr} = 180 °C. Each cell loses heat from its edges (2(H + W) × thickness) to 25 °C surroundings by convection with h = 5 W/(m²·K) (base case); a second case adds radiation with emissivity 0.5, and a bound case has adiabatic edges [10].

Input	Value	Basis
Cell	280 Ah LFP prismatic, 205 × 174 × 72 mm, 5.42 kg	[1]
Runaway, vent and peak temperatures	180 °C trigger; 145 °C vent; 202.6 to 447.5 °C rise	[1]
Release duration	300 s (175 s tested)	[1]
Specific heat c_p	1,100 J/(kg·K) (900 to 1,300 tested)	Representative
Cross-plane conductivity k	0.8 W/(m·K) (0.5 to 1.5 tested)	Representative
Retained runaway heat E	1.46 MJ per cell	$m\, c_p(T_{max} - T_{tr})$
Barrier	R_b = 0 to 0.25 m²·K/W; aerogel k = 0.03 W/(m·K) for thickness	Representative
Edge losses	h = 5 W/(m²·K); radiation ε = 0.5; or adiabatic	[10]

Table 1. Model inputs. R_b is barrier thermal resistance per unit face area; ε is emissivity. E scales with c_p, so c_p has almost no net effect on the result (Section 4.3).

3. Verification

Check	Reference	Result
Energy balance over the transient	Release = storage + losses	Relative error 1e-14
Isolated failed cell, no losses	$T_{tr} + E/(m\, c_p)$ = 424.9 °C	424.90 °C
Two contacting cells, 180 and 25 °C, no release, 600 s	Error-function solution [8]	Largest difference 0.032 K on a 77.5 K rise
Grid and time step (6/4 s, 12/2 s, 24/1 s, 48/0.5 s)	Neighbor peak, 2 mm aerogel	135.07, 135.15, 135.17, 135.17 °C
Neighbor runaway time, no barrier	Finest grid	202 s against 200.5 s

Table 2. Verification. The base grid is 12 layers per cell with a 2 s step.

4. Results

4.1 Without a Barrier

With only the 0.1 mm film, the neighbor's contact face reaches 180 °C 202 s after the failed cell enters runaway, and its own runaway follows (Figure 2). In this one-dimensional model the third cell does not reach runaway, because each step starts with a cold far face; real modules add heating through vent gas, flames and the cell cans that the model omits, so the model is used only for the first step.

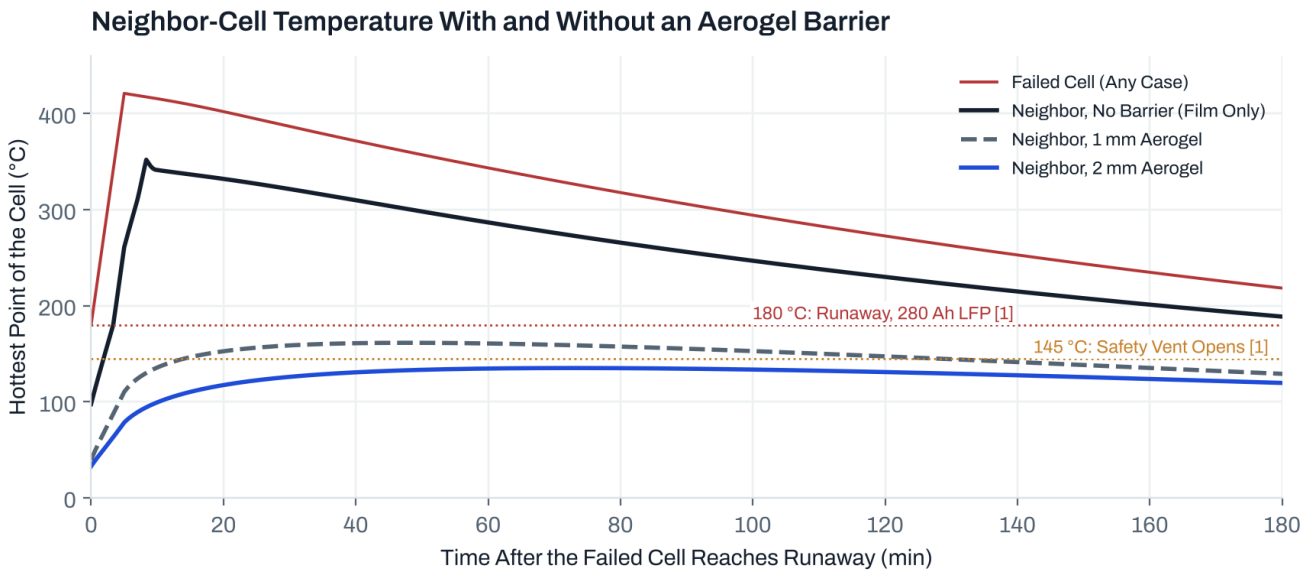


Figure 2. Hottest point of the failed cell and its neighbor over three hours, convective edges (h = 5 W/(m²·K)). The dotted lines mark the measured runaway temperature (180 °C, lower end of [1]) and safety-vent opening (145 °C, [1]).

4.2 Barrier Sizing

Figure 3 gives the neighbor's peak temperature against barrier resistance for the three edge cases. With convective edges, runaway stops at R_b = 0.020 m²·K/W, but the neighbor still reaches 177 °C, which leaves no margin. A margin to the 145 °C vent-opening temperature needs 0.052 m²·K/W (1.6 mm of aerogel); a 25 K margin below that, 120 °C, needs 0.096 m²·K/W (2.9 mm). With 2 mm the neighbor peaks at 135 °C about 73 minutes after the event; with 1 mm it peaks at 162 °C, above venting. Adding edge radiation lowers these requirements to 0.9 and 1.7 mm. With adiabatic edges the requirement grows to 2.5 mm to stop runaway and 7.3 mm to stay below venting.

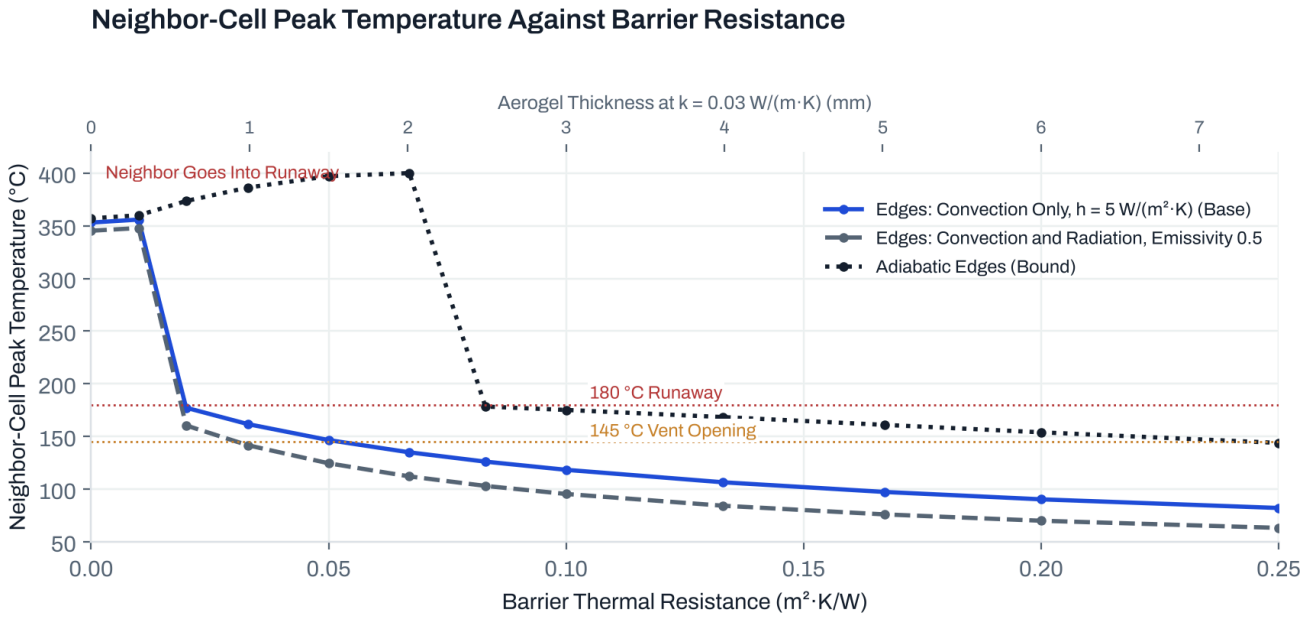


Figure 3. Peak temperature of the neighbor cell against the thermal resistance of the barrier between it and the failed cell, for three edge-loss assumptions. The upper axis converts resistance to aerogel thickness at k = 0.03 W/(m·K). Points above 180 °C are cases in which the neighbor went into runaway.

4.3 Sensitivity

At 2 mm of aerogel (Figure 4), the barrier conductivity is the most important input: 0.02 and 0.05 W/(m·K) give 118 and 155 °C. A cell with lower cross-plane conductivity runs its neighbor hotter (144 °C at 0.5 W/(m·K)), because the heat stays near the shared face. The runaway temperature of the failed cell changes the result by under 10 K, and specific heat has almost no effect because the released heat scales with it.

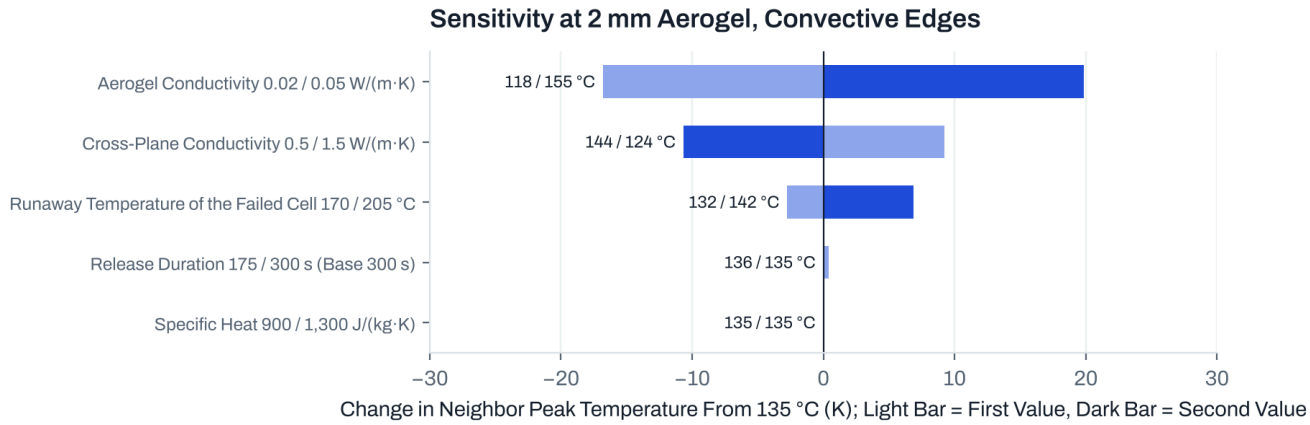


Figure 4. Change in the neighbor's peak temperature at 2 mm of aerogel (base 135 °C, convective edges) when one input moves to each end of its range. The labels give the two resulting peaks.

5. Discussion

For a developer the result gives a target before hardware is built: a barrier specified by its thermal resistance at temperature, not by its thickness. With realistic edge losses, about 0.05 m²·K/W keeps the neighbor below venting and 0.1 m²·K/W adds a 25 K margin. Aerogel conductivity rises with temperature, so the value at 150 to 300 °C, not the room-temperature datasheet value, should be used. The gap between the convective and adiabatic results shows what the module design controls: heat that leaves through the edges, the can and the module frame lowers the barrier needed, while a tightly insulated module needs a thicker barrier.

The model does not replace the certification test. It identifies designs that should pass the cell-to-cell step, ranks proposed changes such as a thinner barrier or a new cell, and gives the window for detection and suppression: with 2 mm of aerogel the neighbor's peak comes more than an hour after the first event.

Limitations. One-dimensional heat path through the faces; no heat transfer around the barrier through cans, busbars or the frame; no self-heating of the neighbor below 180 °C; no vent-gas or flame heating, which the companion study found can dominate when vent gas reaches the module lid [11]; constant properties; a single cell format. The rule should be confirmed in a cell-to-cell test before the module and unit tests.

6. Conclusions

1. Without a barrier, a 280 Ah LFP cell in runaway brings its face-to-face neighbor to runaway in about 3.4 minutes.
2. With convective edge losses, a barrier of 0.052 m²·K/W (1.6 mm of aerogel) keeps the neighbor below its 145 °C venting temperature, and 0.096 m²·K/W (2.9 mm) keeps it below 120 °C.
3. Edge heat loss sets the requirement: with no edge loss, 7.3 mm would be needed for the same venting margin.
4. Barrier conductivity at temperature is the most important material input; specify barriers by thermal resistance.

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