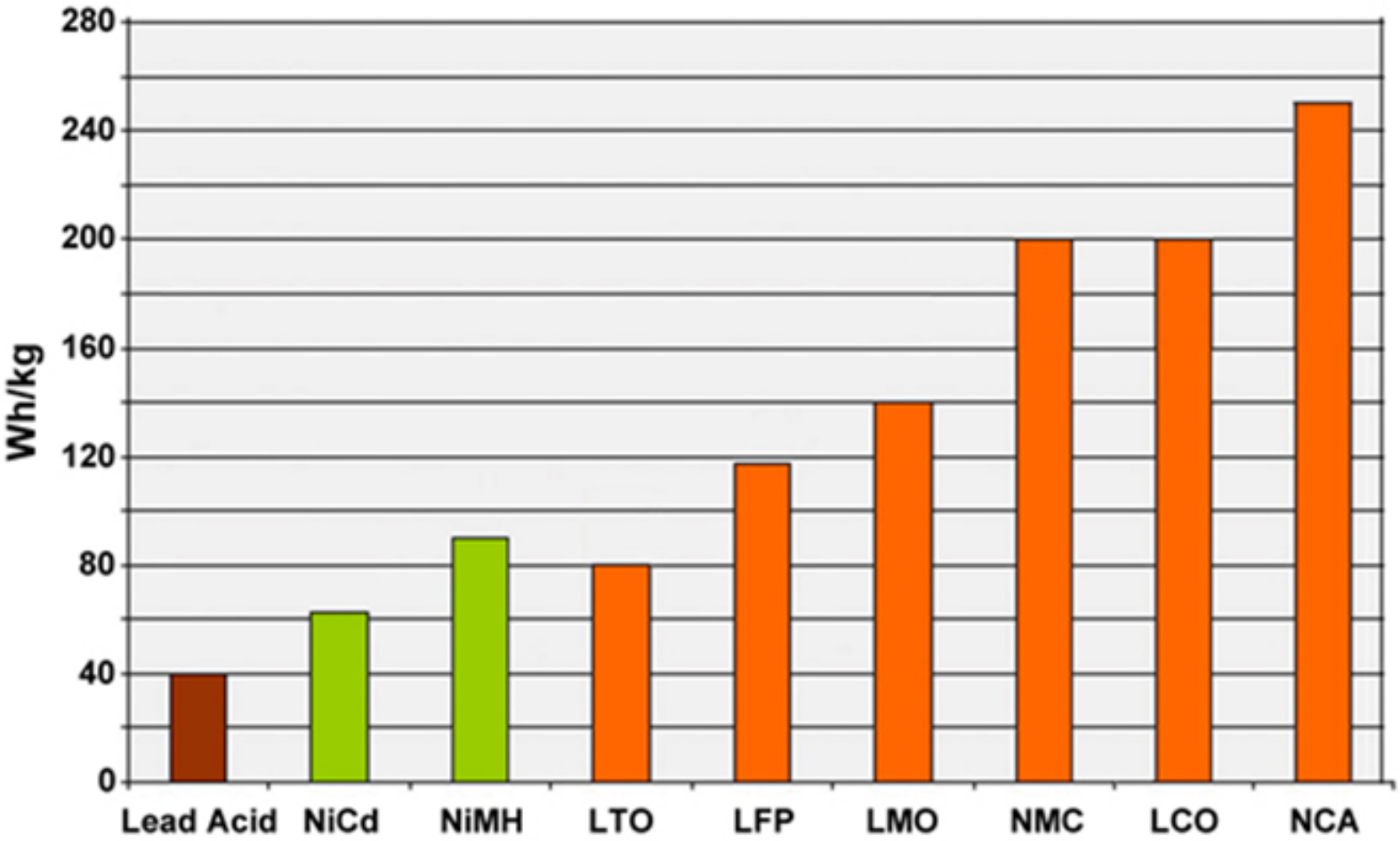
Temperature Adjustable Thermal Management System with Thermal Runaway Protection for Li-ion Packs

Mark Hartmann - CTO

Outlast®

Background

- Cell Chemistry and Energetics – High power/energy but poor stability. Lower power/energy but good stability.

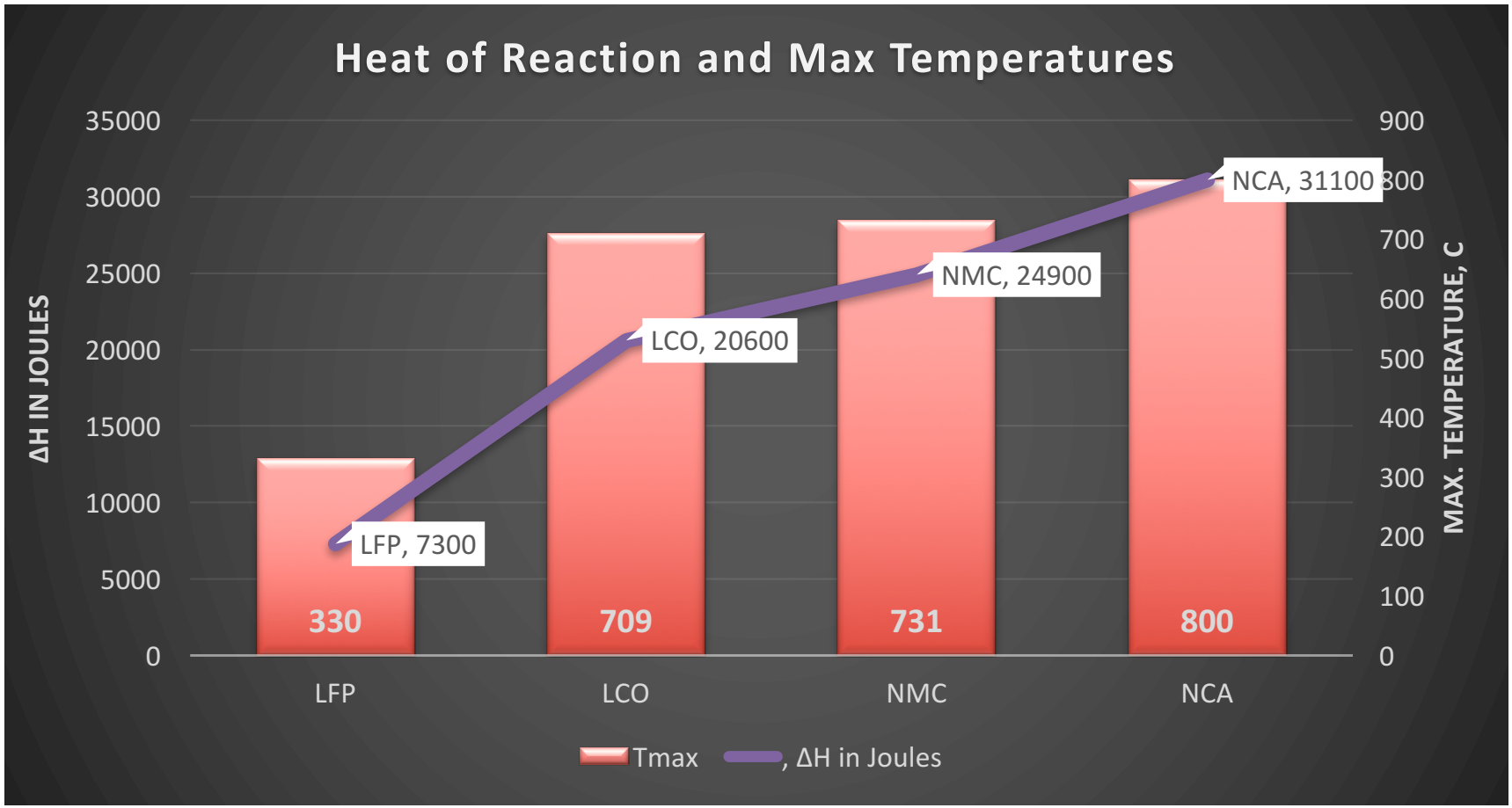


ref: BatteryUniversity.com

Thermal Event Energies

- Thermal Event Energy Data ranges for different Li-ion Chemistries
  - All data based on 18650 Cylindrical cells at 100% SOC

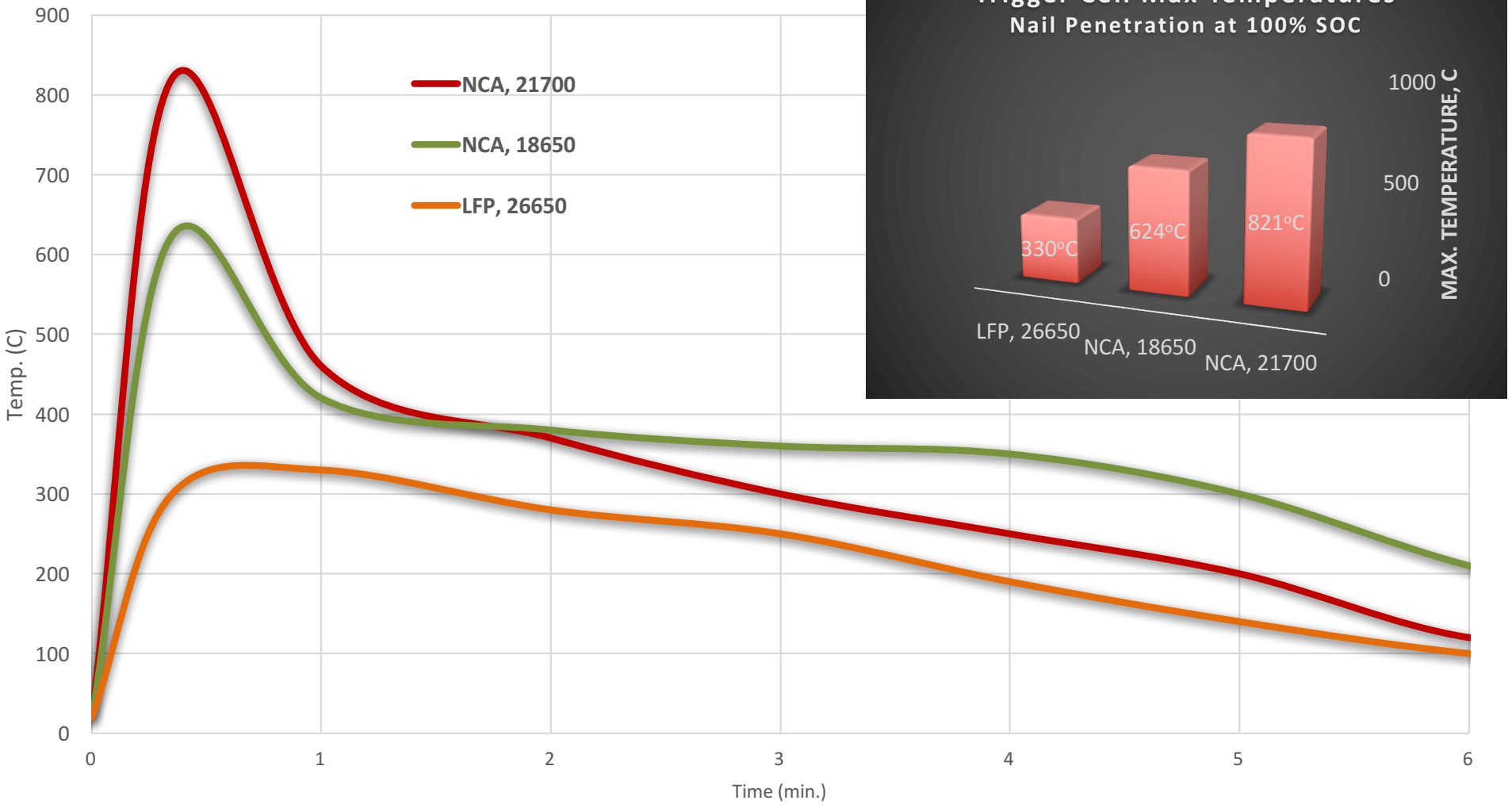
Chemistry	Tmax	Heat of Reaction, ΔH in Joules
LFP	243-330 °C	1000-7,300
NMC	665-731 °C	14,900 – 24,900
LCO	654-709 °C	17,900-20,600
NCA	-	31,100



Ref: Experimental Analysis of Thermal Runaway in 18650 Cylindrical Li-Ion Cells Using an Accelerating Rate Calorimeter, Lei, et. al, *Batteries* June 2017, vol. 3, issue 2, 14

Experimental Thermal Runaway Data

- Nail Penetration at 100% SOC



Various Products

- Various technologies and solutions that work in specific cases.

	Paraffin PCM	Graphite	Air	Combination 1	Optimized Combination 2
Thermal Mass	✓			✓	✓
Thermal Conductivity		✓		✓	✓
Hi Pack Energy Density & Connectivity (s/p)				✓	✓
Thermal Propagation	Fail	Fail	Fail	Fail	PASS
	High thermal mass/ latent heat but poor FR	High conductivity but no thermal mass	Poor conduct., no thermal mass, no FR	Poor thermal mass	Optimized thermal mass and other properties
References	-Outlast -Wilk, Wilke, et.al	-NREL -Wilk, Wilke, et.al	-Outlast -Wilk, Wilke, et.al -NASA	-Outlast -Wilk, Wilke, et.al	-Outlast -Customer Testing -Wilk, Wilke, et.al -NASA

Nail Penetration– Thermal Runaway Protections

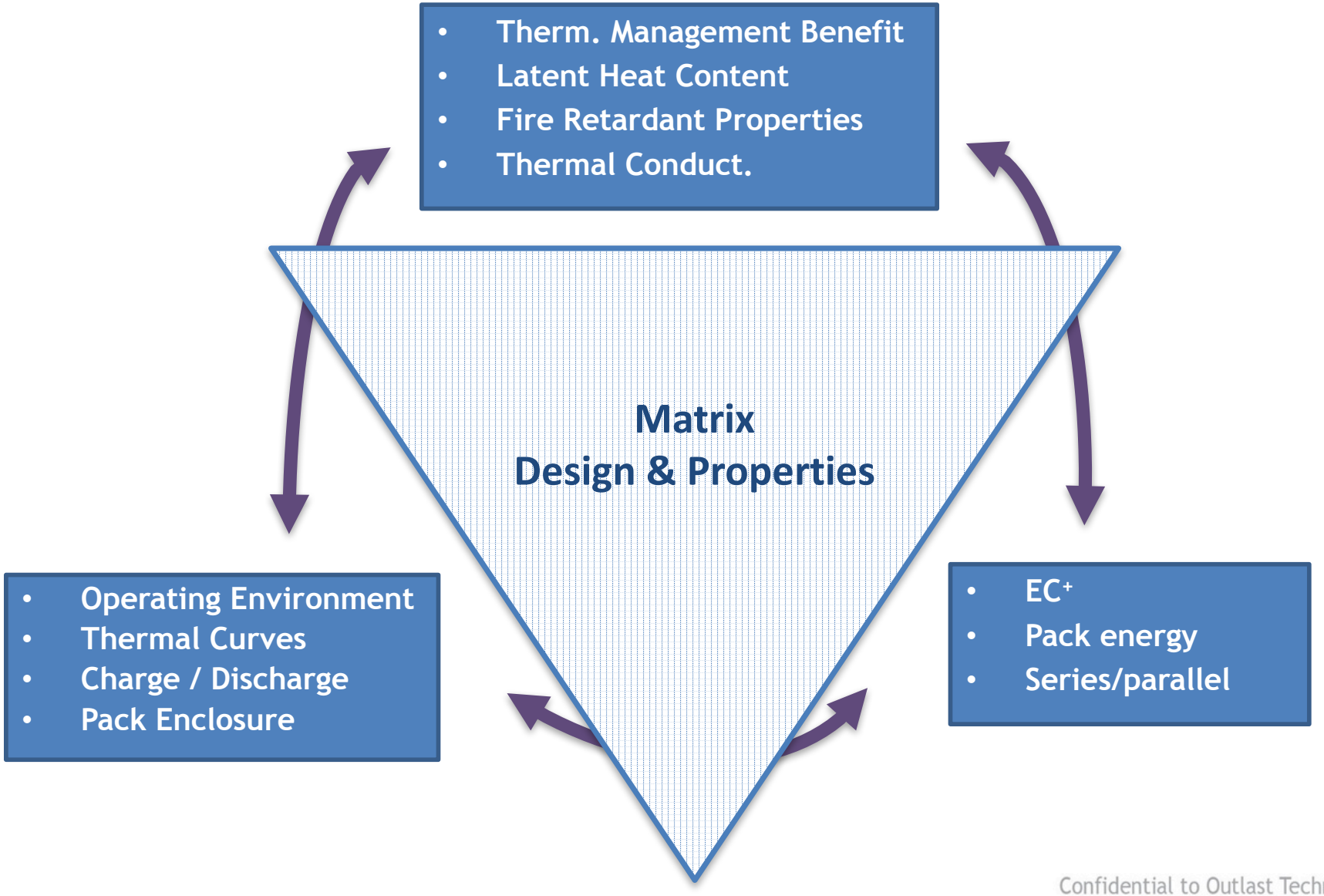
21700 NCA cells, 5S2P

Transition Temperature (degree C)	Dim. Between Cells (mm)	No.	Test Condition		Behavior of Trigger Cell (Burning Cell)	Behavior of Adjacent Cell			Judgement
			Environmental Temperature (degree C)	Cell Charging Condition	Peak Temperature (degree C)	Burned or not	Peak Temperature (degree C)	Time from testing start to burning (sec.)	Pass: No burning NG: Burning
40-45	1.5	1	55	Full	658	Burned	182.9	848.2	NG
		2	55	Full	592.8	Burned	177.8	282.4	NG
		1	20	Full	709.4	Not	116.2	-	Pass
		2	20	Full	596.2	Not	120.7	-	Pass
55	2	1	55	Full	821.5	Not	134.8	-	Pass
		1	45	Full	756.8	Not	143.1	-	Pass

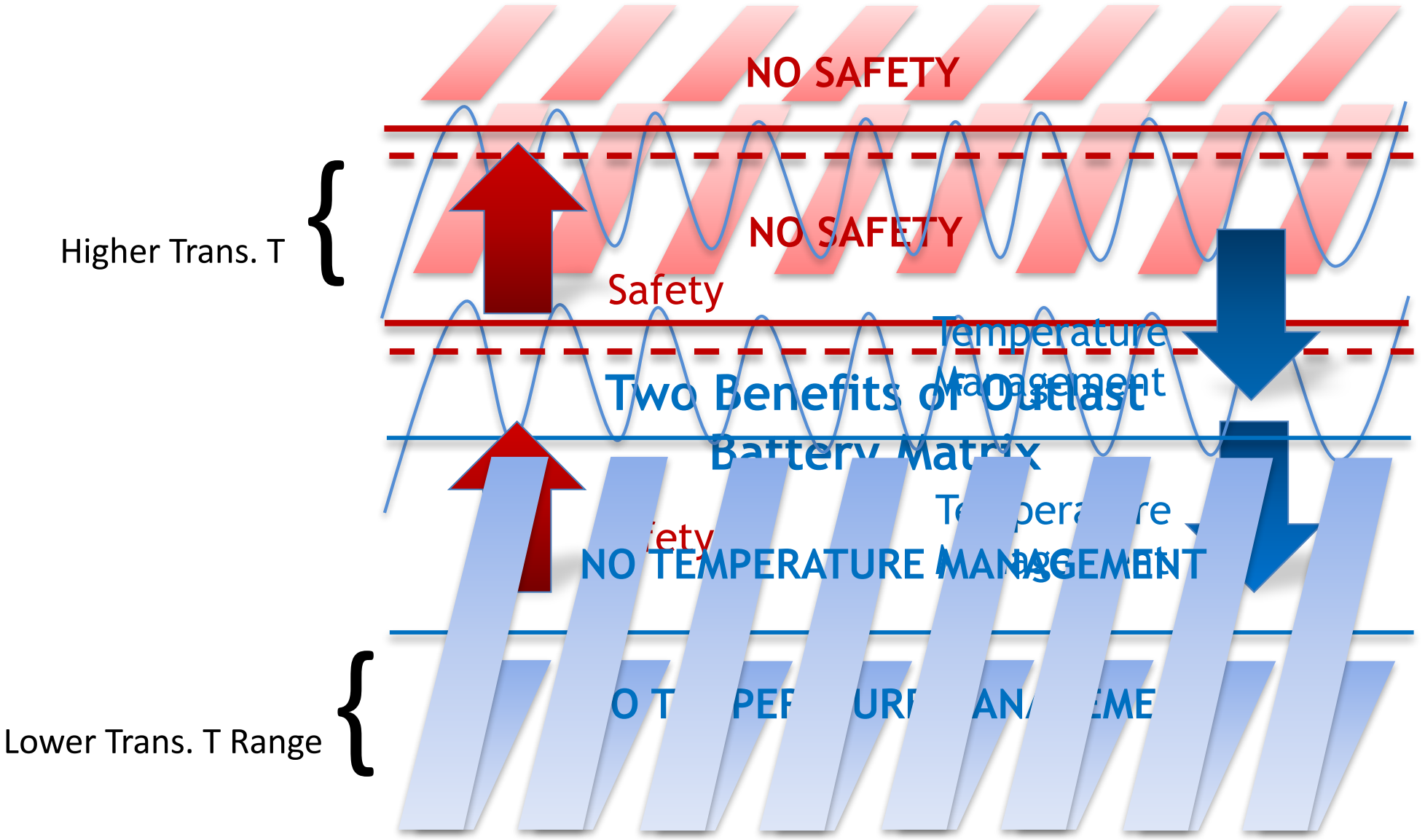
Test Sample: 5S2P Battery Pack

Pack Design Variables

NO one-size-fits-all



Temperature/Safety Relationship



LHS® Solutions

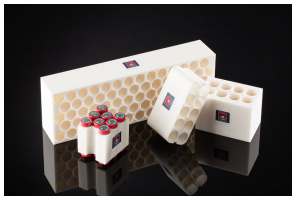
- Thermal Runaway Protection
- Cell Surface Thermal Control
- Homogenous Pack Temperatures
- Temp. Management leads to Increased Cell Life
- Improved Fast Charging Properties
- Passive Thermal Management
- Electrically Insulative
- Allows for Cell Expansion/Contraction
- Shape Stable
- Less Complexity, Economical and generally lower weight than metal or ceramic.

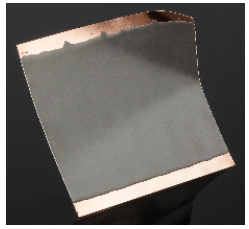
PROTECTED BY Outlast®

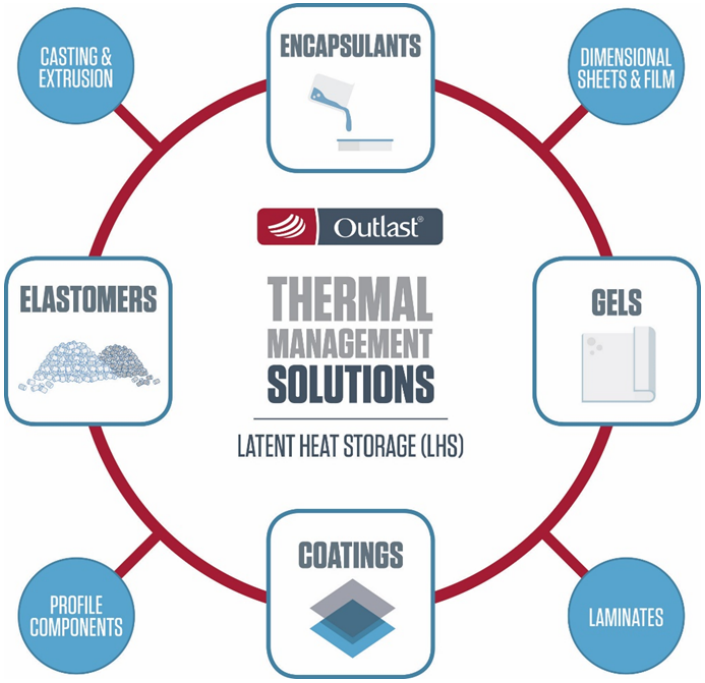
LHS™ TECHNOLOGY

LHS Products for Battery, Electronic and Industrial Applications

LHS materials are provided in a number of different formats from compounded product to finished components:

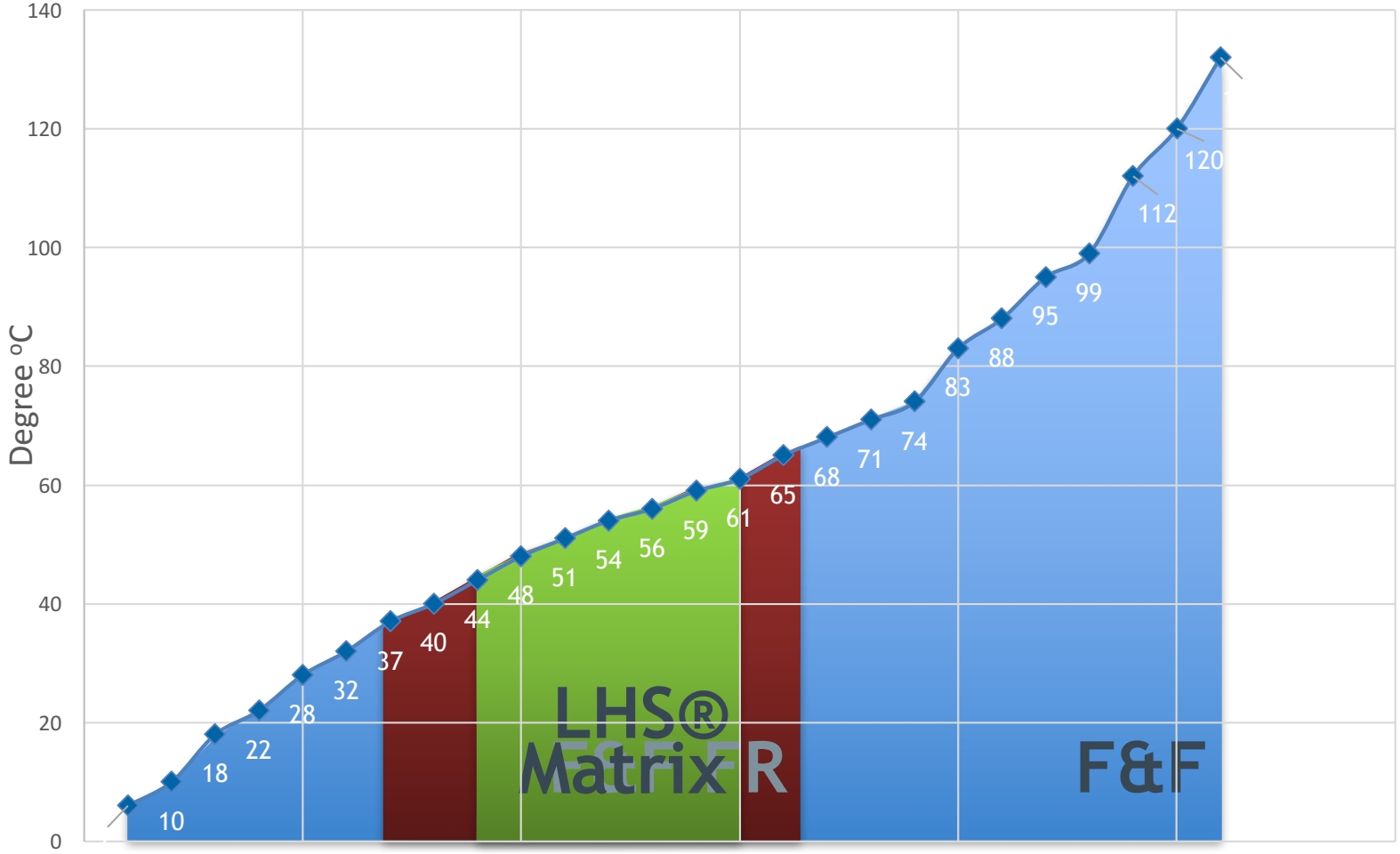






LHS™ Thermal Energy Storage

Various Product Transition Temps.

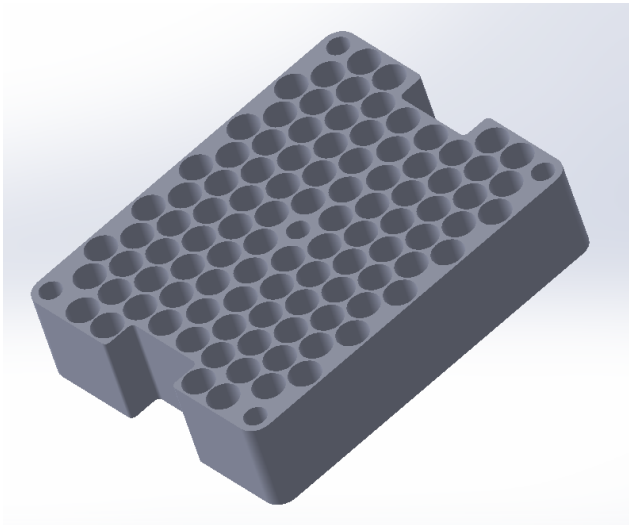


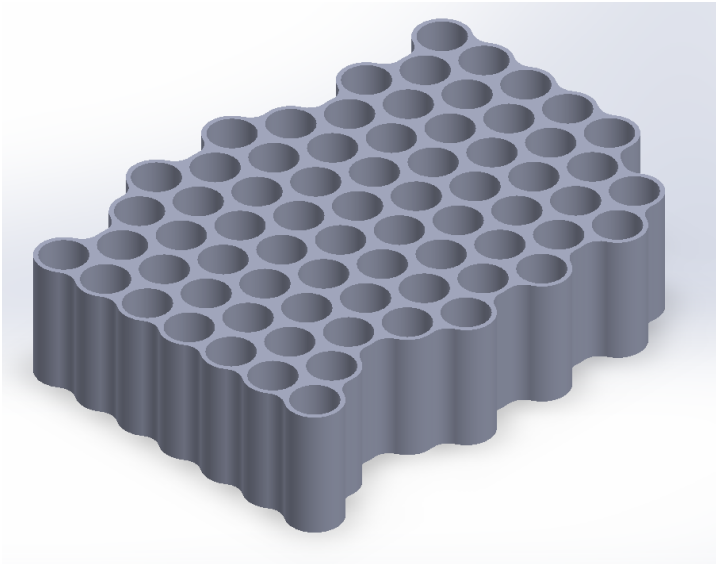
Products

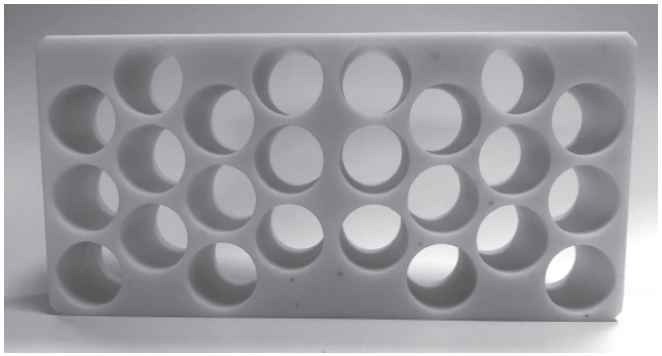
- Fill and Flow material (F&F, F&F FR)
- Matrix sheets
  - Same material as molded cylindrical cell matrix
  - Provide thermal management and inhibit propagation for pouch and prismatic cell systems

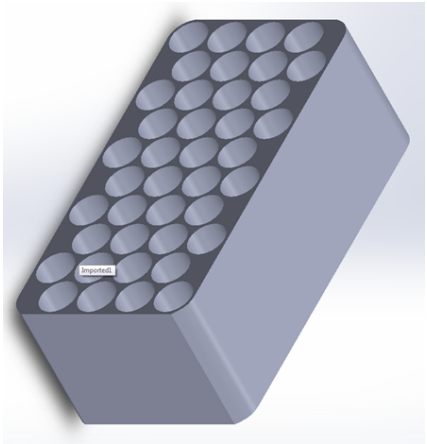
LHS Matrix for Battery Packs

- Various large scale customers and pack



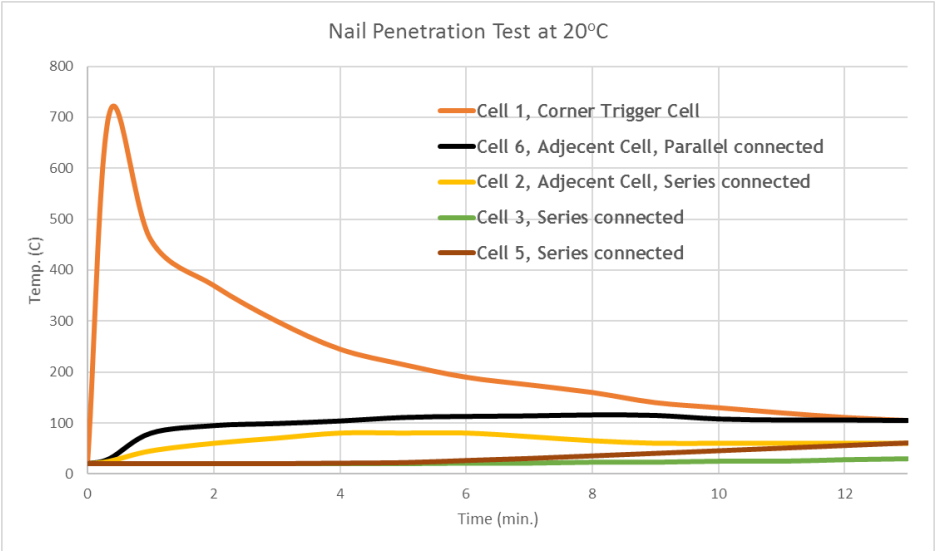


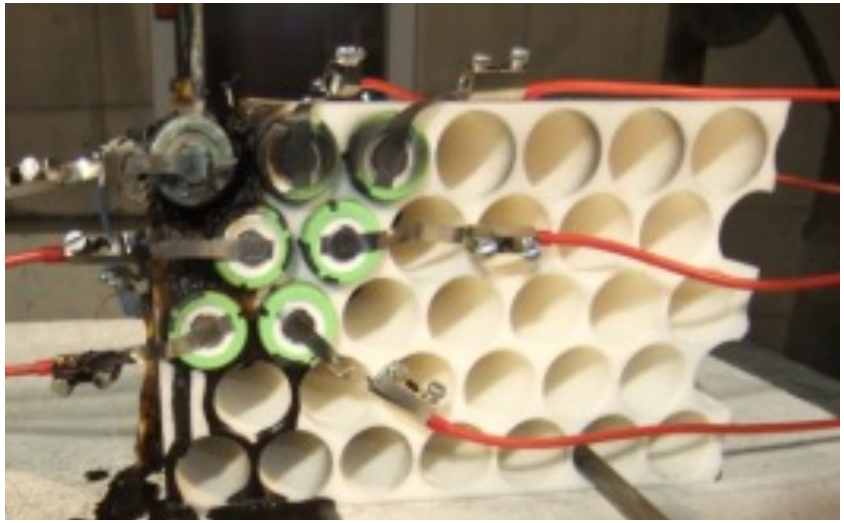


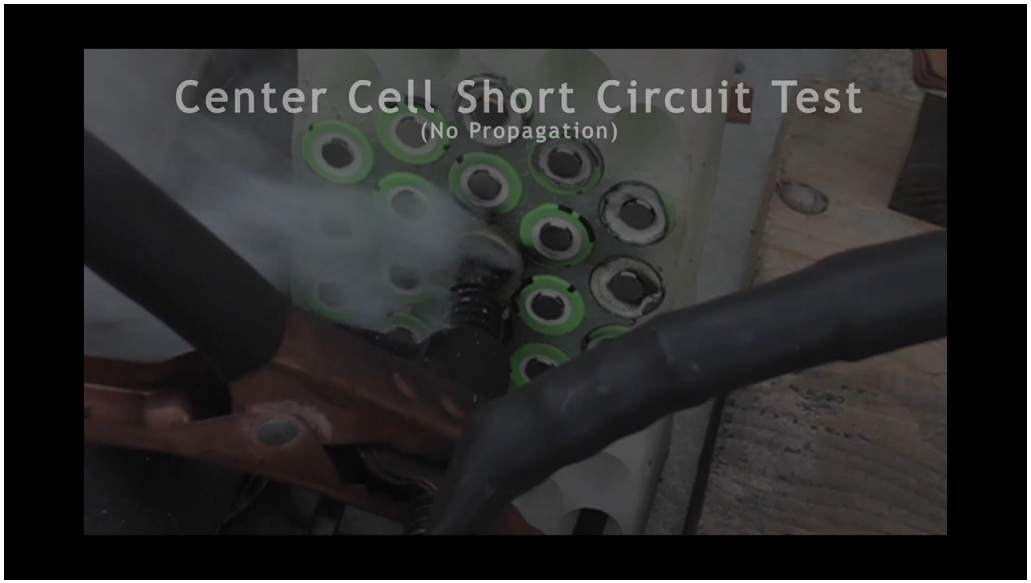


Thermal Propagation Testing

- 700 Wh series connected pack - PASS

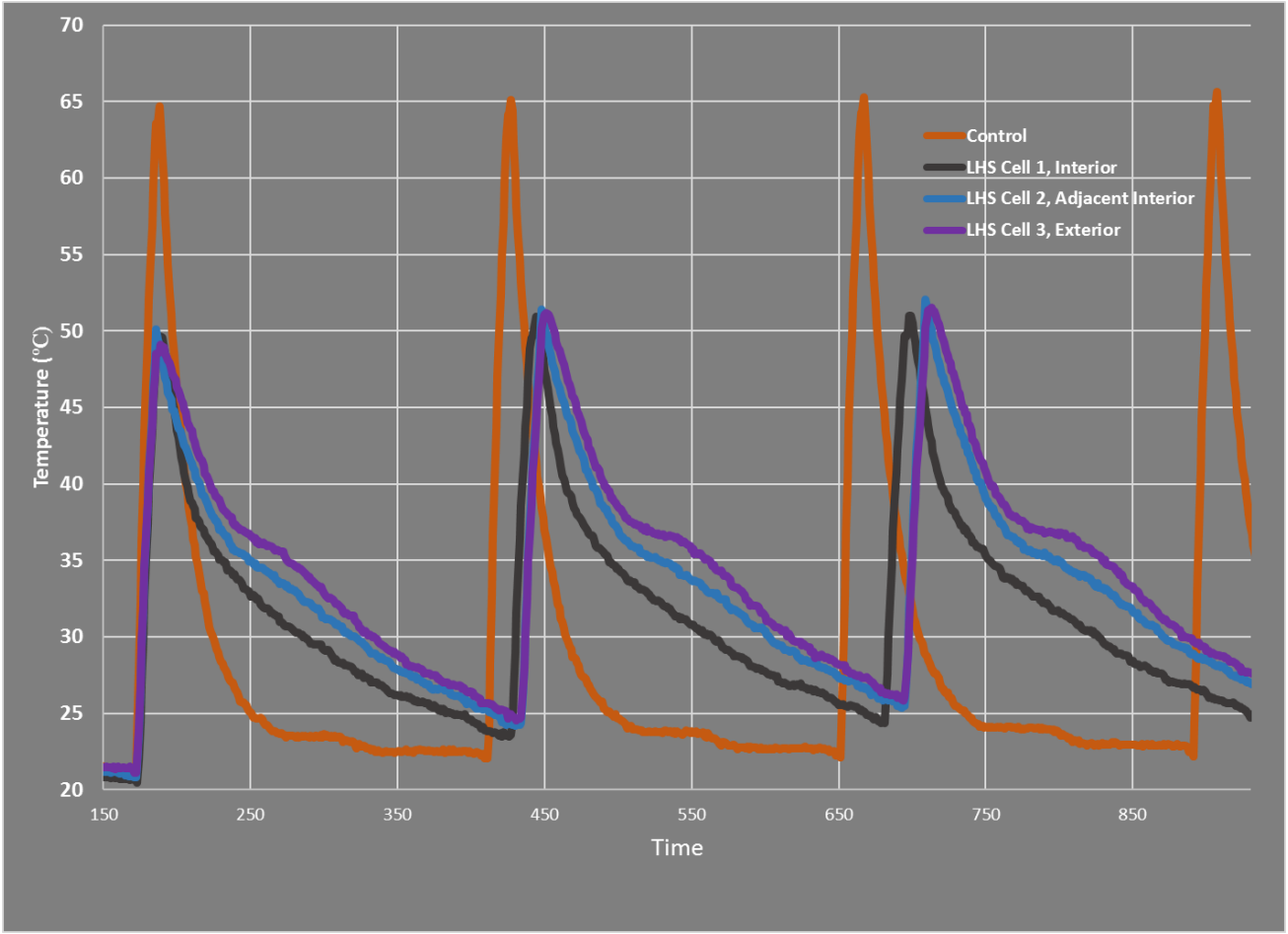


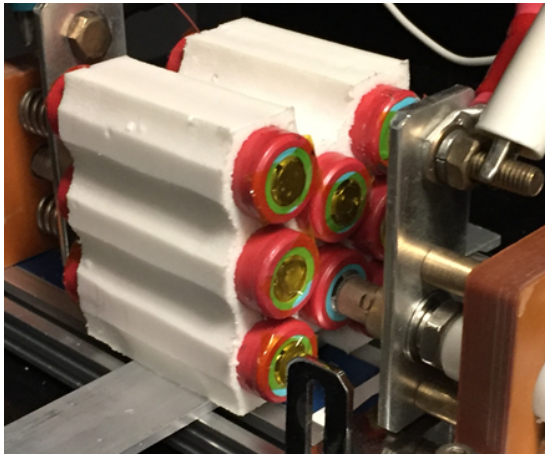




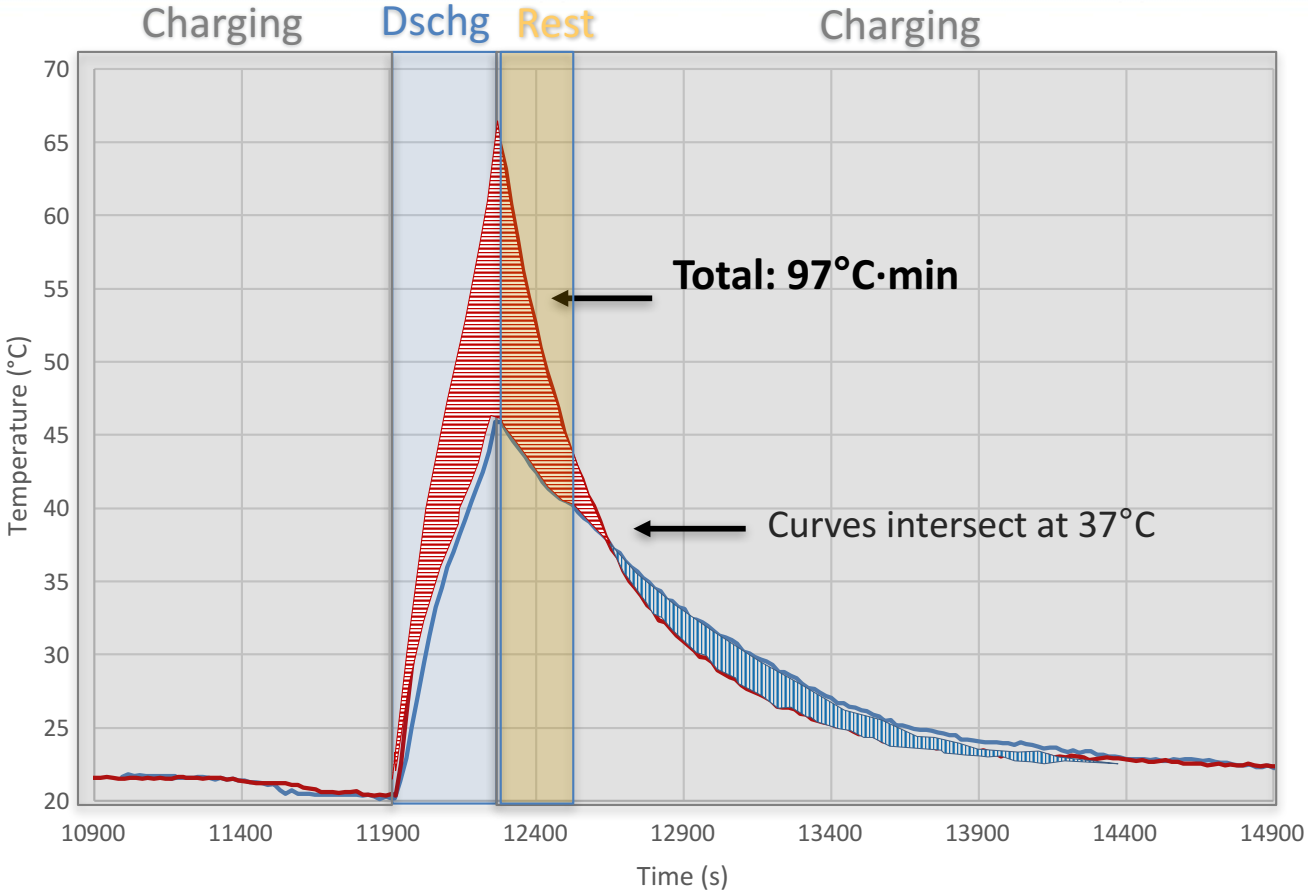
LHS Matrix – Pack Temperature Homogenous Temperatures

- A 10-15°C reduction in battery temp. Batteries stay below 55°C
- Better homogeneity for battery temperatures.
- Less complex C/D electronics required (BMS)





LHS® Battery Thermal History Comparison

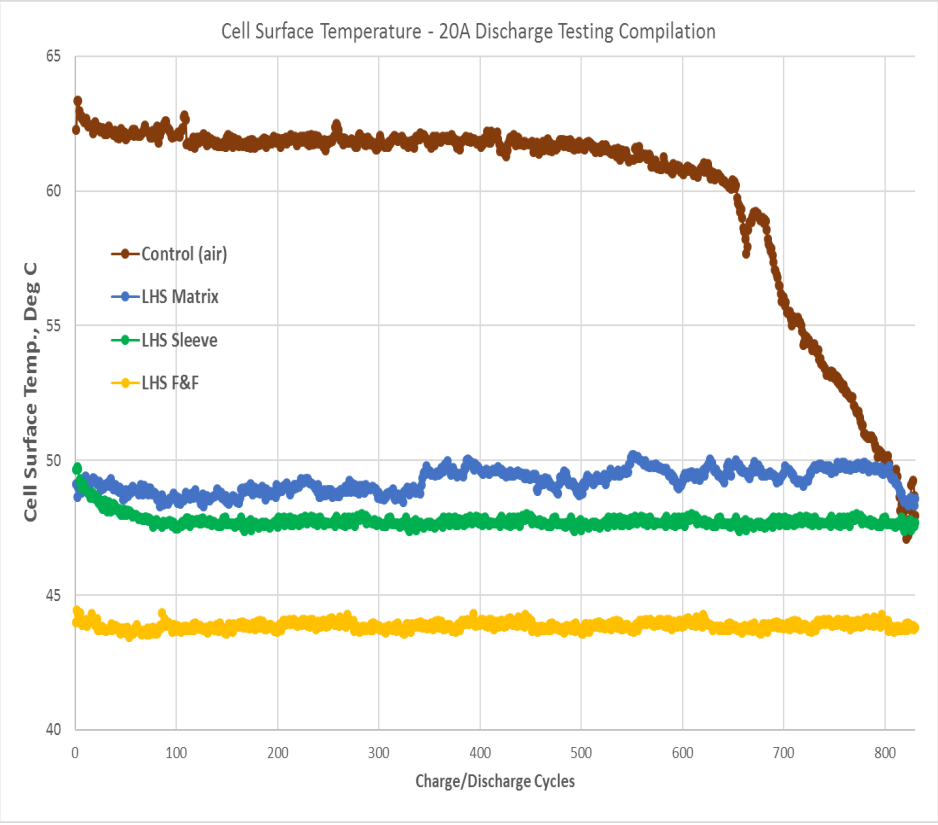


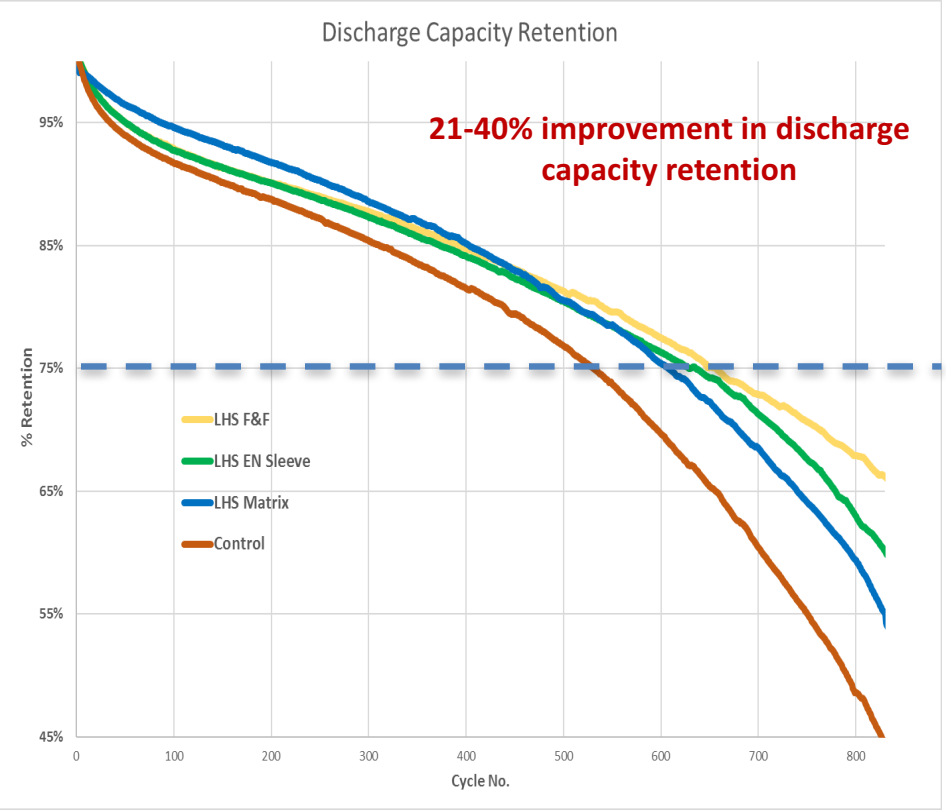
- Battery exposed to less thermal history, ~97°C·min/cycle in this experiment.

Thermal Cycling and Reliability

Testing Program:

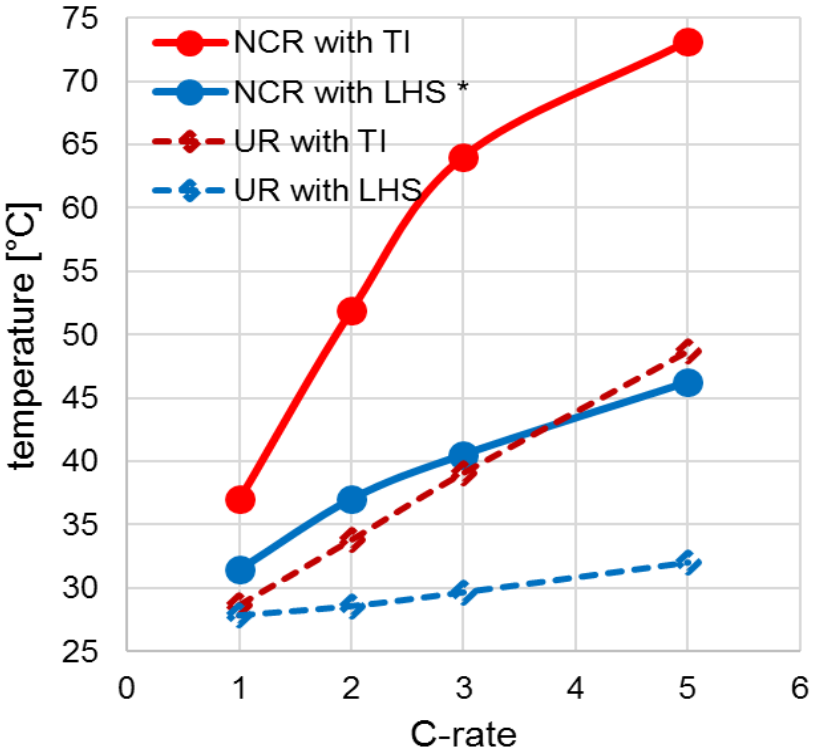
- A control cell and a LHS® covered cell were tested on Arbin BT Battery System (UR18650RX).
- The cells rest for 1 minute before charging at 1.95A till voltage reaches 4.2V, then trickle charges until current drops to 0.25A.
- Cells rest for 10 seconds before discharging at 20A until voltage of 2.5V is achieved.
- The cells rest for 5 minutes before looping back to the charge cycle. This repeats for 1000+ cycles
- ***Control cell degraded and died after 700-800 cycles. Similar batteries in LHS® products continued for >1000 cycles.***
  - ***No loss of LHS® properties, no damage or matrix change.***



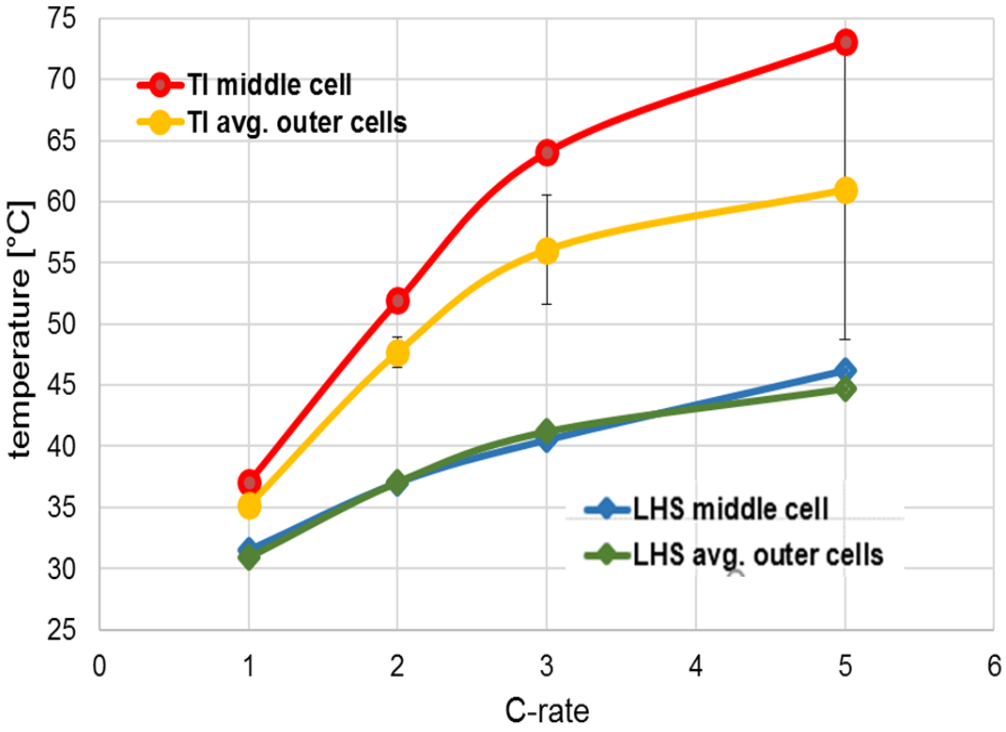


LHS® Benefits – Pack Temperatures during Fast Charging

NCR vs UR



NCR middle vs outer



25°C test chamber temperature; Abbreviations: NCR = NCR18650PF; UR = UR18650RX; LHS = LHS-matrix; TI = plastic

- Results of 6-cell en bloc
  - NCR cells (high energy) show generally higher temperatures than UR cells (highpower)

Hochschule Aalen

matworks

Concluding Remarks

- Understanding the pack variables, one can adjust the product transition temperatures and latent heat storage capacity to provide:
  - Prevent Li-ion cell thermal propagation and runaway.
  - Effectively reduce li-ion battery temperatures and improve battery life.
  - Provide homogenous temperatures across packs.

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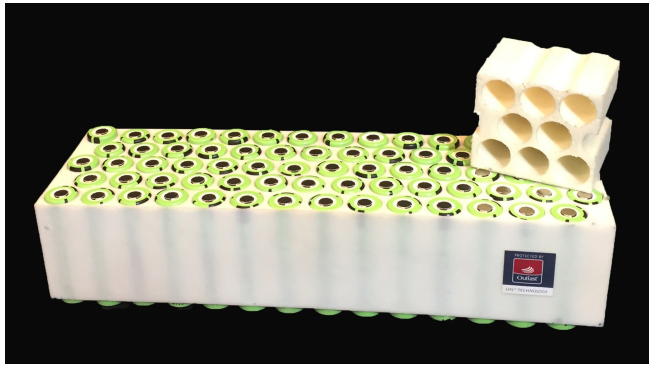

Competitive Technologies

Benefits & Comparison

	LHS® Battery Matrix	PCM/Graphite	Ceramic	Metal/Graphite Heat Sink	Air	Active Cooling System
Thermal Runaway Protection	✓	✓	✓	✓✗	✗	✓✗
Increased Battery Life	✓	✓	✗		✗	✓
Cell Surface Thermal Control	✓	✓	✗		✗	✓
Homogenous Pack Temperatures	✓	✓	✗	✗	✗	✓
Improved Fast Charging Properties	✓		✗		✗	
Passive Thermal Management	✓	✓			✗	
Electrically Insulative	✓	✗	✓	✗	✓	
Thermally Conductive		✓	✓	✓	✗	
Weight	✓	✓	✗	✗	✓	✗
Cell expansion/contraction	✓	✓	✗	✗	✓	
Shape Stable	✓	✓	✓	✓		
Complexity / $$	✓	✗	✗	✓✗	✓	✗

Benefits and Comparison

- Carbon or Metal Heat Sinks
  - Electrical cond., weight, thermal cond. (pro/con)., rigid, $, etc.
- Ceramics
  - Weight, thermal cond. (pro/con)., rigid, $-$$, etc.
- Active cooling systems
  - $$, complexity, homogenous cell touch, weight, propagation resistance?
- Intumescent FR systems
  - $, smother fire, no temp. management, lose pack, design to contain, etc.

LHS Products for Battery, Electronic and Industrial Applications

BENEFITS	Battery Matrix	Battery Sheet	LHS FR, Fill & Flow	LHS Fill & Flow	Battery Sleeve / Elastomer	Encapsulant & Potting Compound
Thermal Runaway Protection	+	+	+			+
Increased Battery Life	+	+	+	+	+	+
Cell Surface Thermal Control	+	+	+	+	+	+
Thermal History Reduction	+	+	+	+	+	+
Homogenous Pack Temperatures	+	+	+	+	+	+
Improved Fast Charging Properties	+	+	+	+	+	+
Passive Thermal Management	+	+	+	+	+	+
Electrically Insulative	+	+	+	+	+	+
RoHS Compliant	+	+	+	+	+	+
Shape Stable	+	+			+	+