savE®

Thermal management of Li-ion Batteries

PLUSS®

TECHNOLOGY FOR
A BETTER WORLD

What we do

We enable temperature control solutions,
Innovatively and Sustainably

CORE STRENGTH

Deep Understanding of Material Science

Research and Development

Green technology

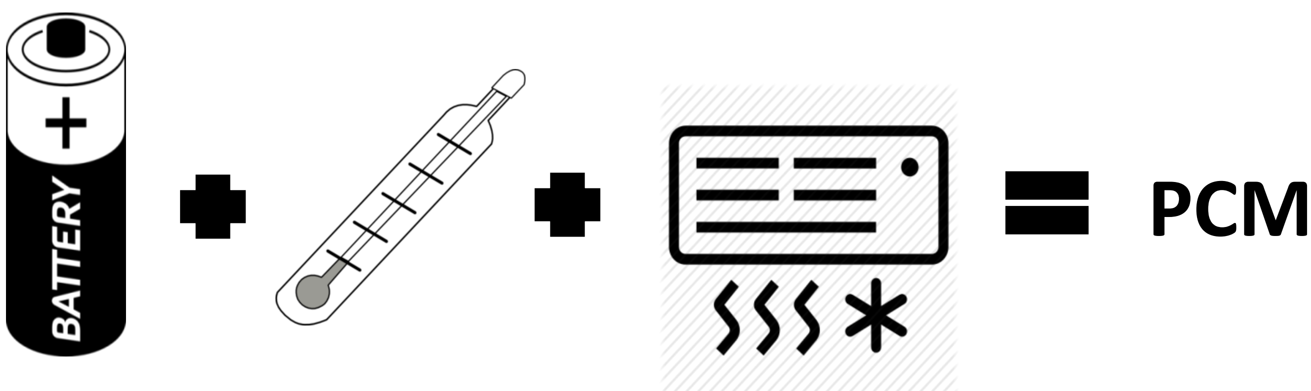
Product Company

Strong on Intellectual property rights

INTRODUCTION

What are Phase Change Materials

- Stores large energy in the form of latent heat
- Also called Passive Cooling Materials.
- Release/Absorption of heat at constant temperature
- Release/Absorption process repeatable over a substantial number of cycles

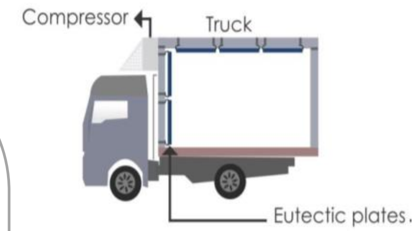


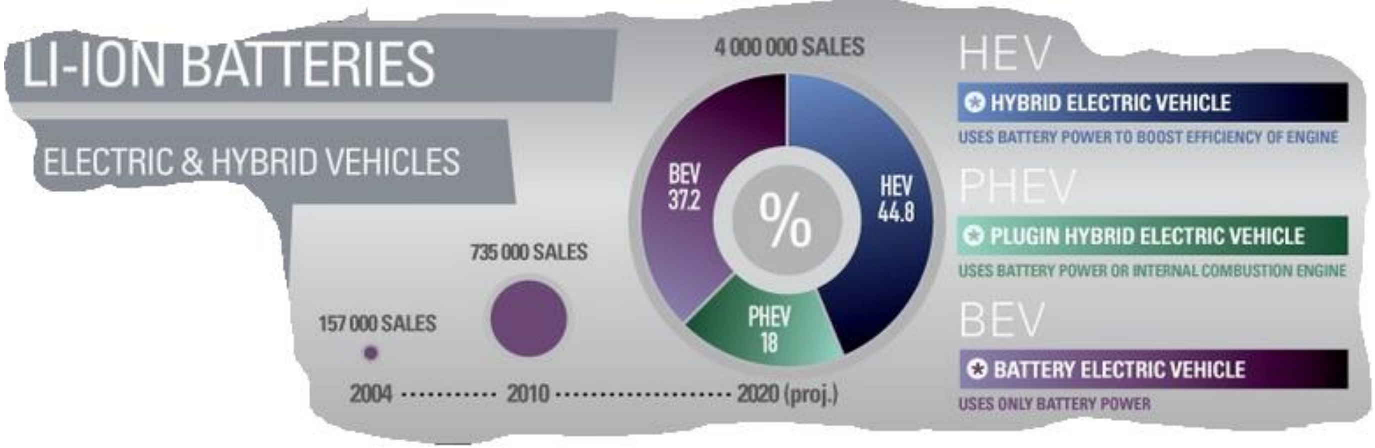
savE® Phase Change Materials (PCMs) - Applications

- Thermal energy storage materials sold in bulk for maintaining temperatures
- Proprietary offerings across wide temperature range from -33°C to +89°C

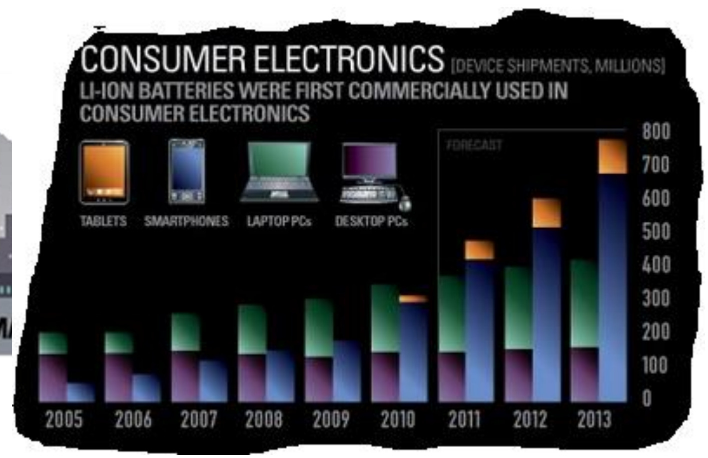
Applications:

✓ Cold Chain	Temperature sensitive pharmaceutical and food products.
✓ Refrigeration	Back up during power failures.
✓ Refrigerated Trucks	Passive temperature control trucks
✓ Cold Storage	Back up during power failures
✓ Building HVAC	Energy efficiency and demand side management
✓ Electric Vehicles	Li-ion Battery thermal management





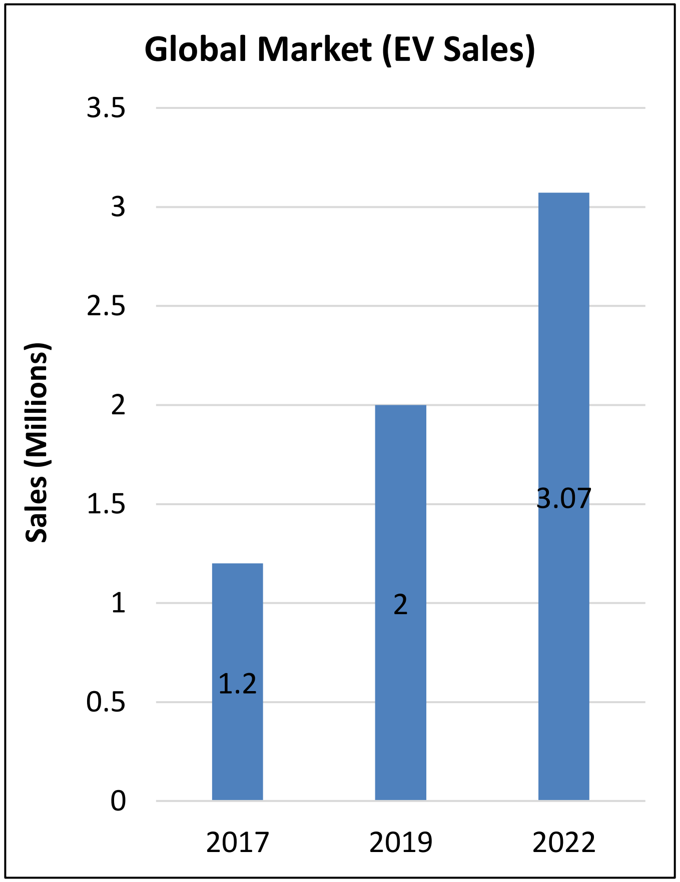
Li-Ion Batteries: Pursuit of a Greener World



Source: Visual Capitalist

Global Market (EV Sales)

- More than 10 OEM's with more than 165 commercial models sold more than 1.2 millions electric vehicle in 2017.
- China and Europe together capture 75% of global sales. China alone sold more than 600,000 Electrical vehicles in 2017.
- With a CAGR of 20.68%, it is expected to sell more than 3 million Electrical vehicle.
- Although the growth is less than what was expected, still it is believed that 25 million Electrical vehicles will be sold by 2025.
- BY 2025, 16 OEM's target to release more than 400 commercial models.

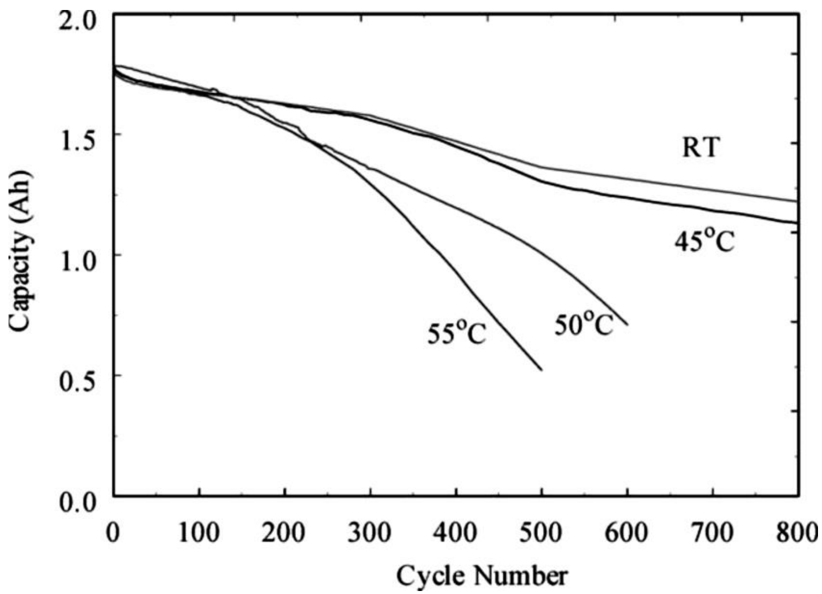


Source: Frost and Sullivan

Li-ion Batteries: Thermal Constraints

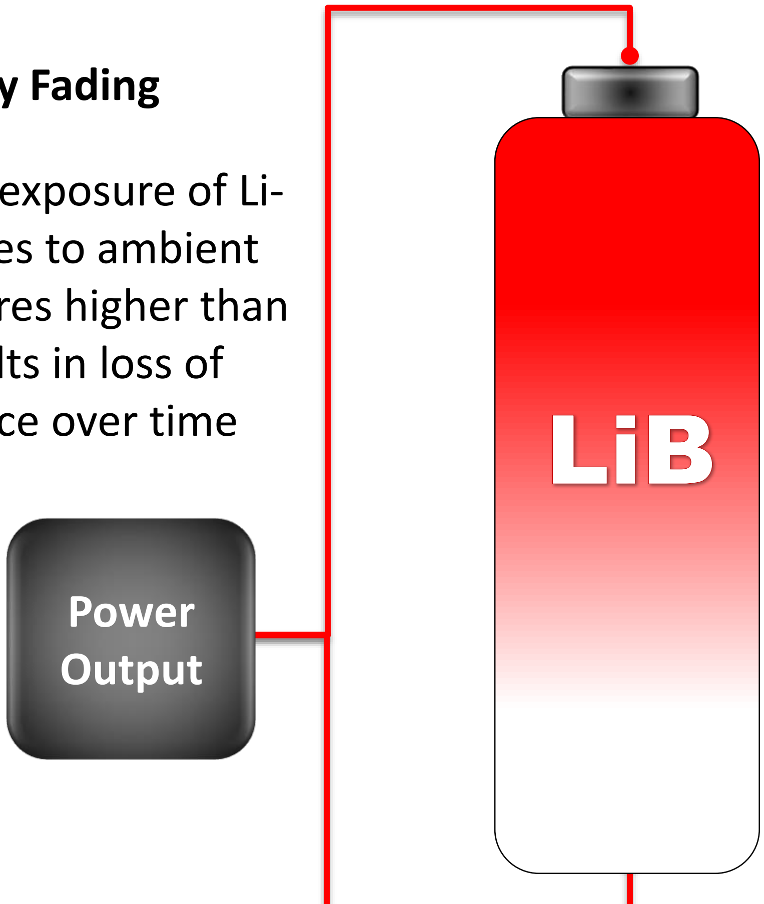
Since the electrochemistry of Li-Ion batteries is very temperature sensitive, an improper control of thermal conditions in battery application can result in a multitude of issues and concerns.

Depending on charge/discharge rates, ambient environment, and battery engineering, heat dissipation rates can typically range from 5 W to 100 W per commercial battery pack.



Capacity Fading

Prolonged exposure of Li-Ion batteries to ambient temperatures higher than 45 ° C results in loss of performance over time



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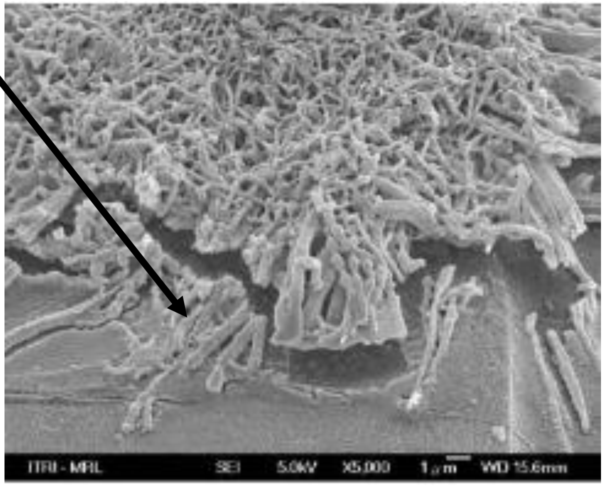
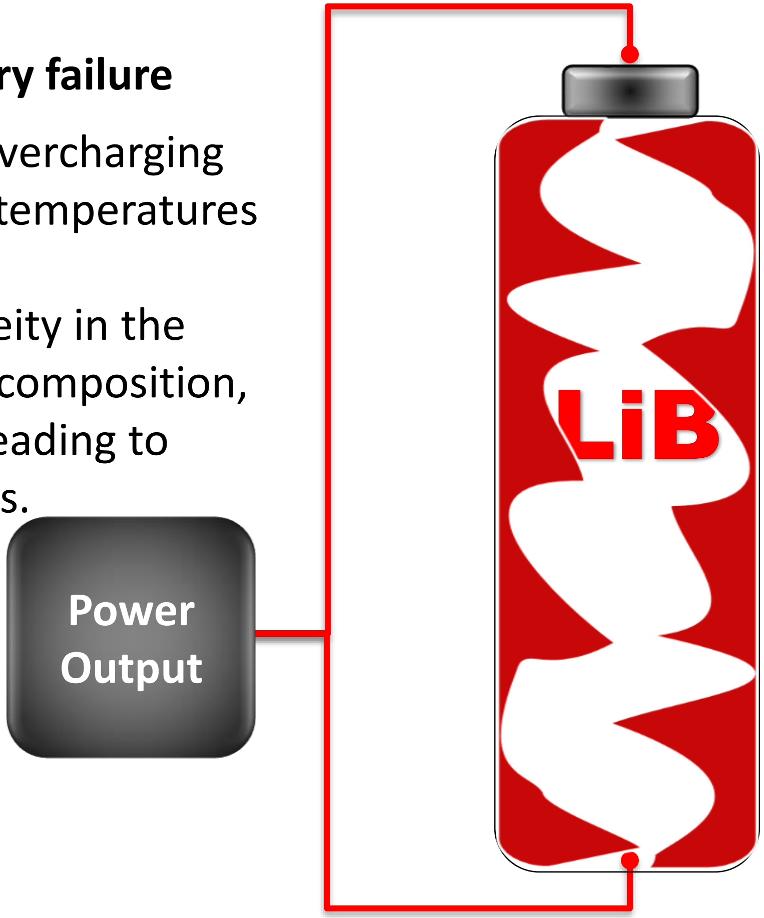
Formation of Lithium dendrites on the battery separator



Battery failure

Moderate overcharging can lead to temperatures that cause inhomogeneity in the electrolytic composition, ultimately leading to short circuits.



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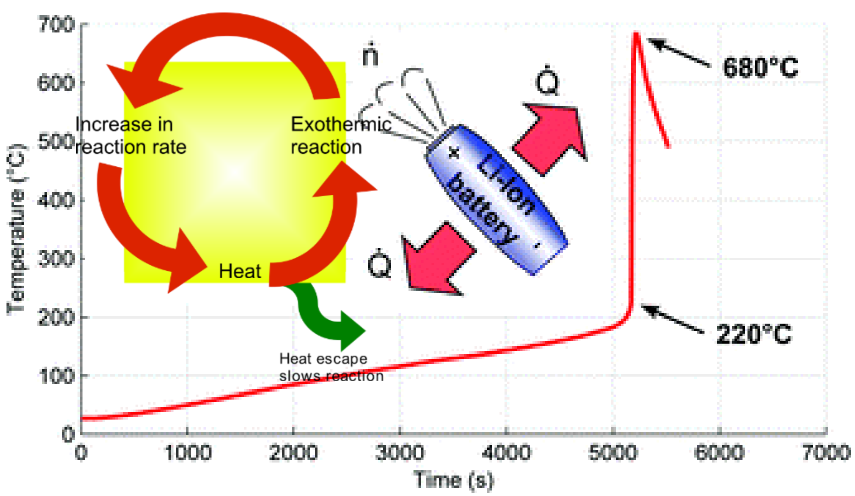
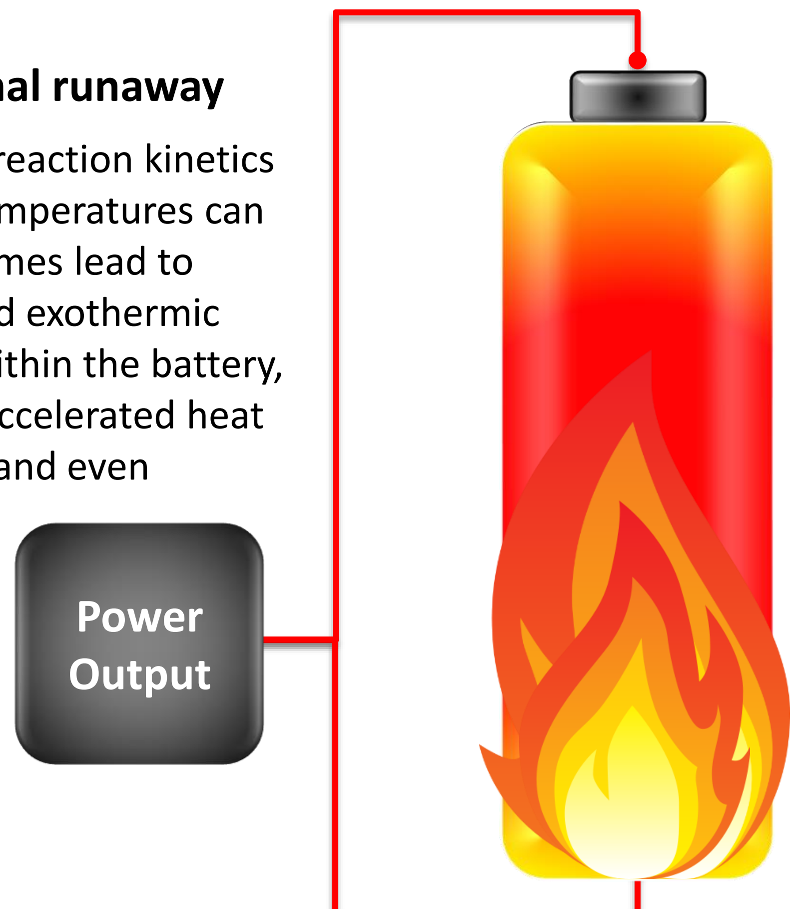


Thermal runaway

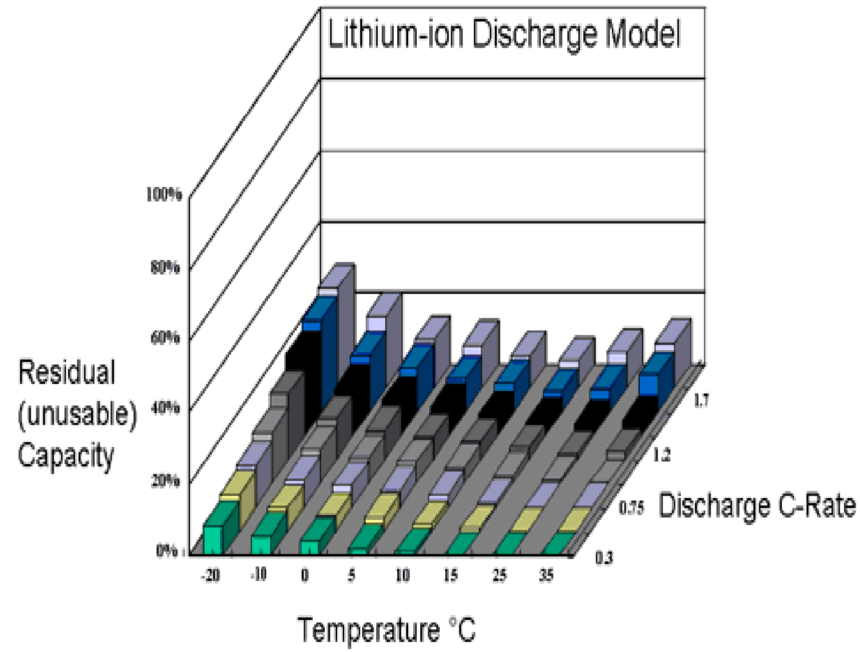
Increase in reaction kinetics at higher temperatures can also sometimes lead to uncontrolled exothermic reactions within the battery, leading to accelerated heat generation and even explosion.



Temperature Affects & Need For Thermal Management of Li-Cells

1. Operation of electrochemical system
2. Charge acceptance
3. Power output
4. Safety and reliability
5. Life and life-cycle costs

Capacity reduction at different temperatures and discharge rates

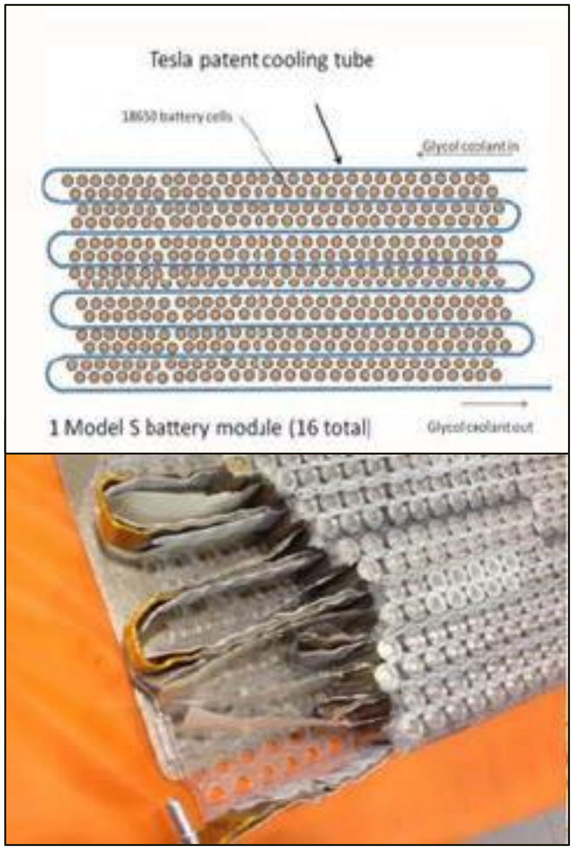


We need Thermal Management of Li-cells to balance the temperature variations due to :	
	(A) Changes in temperature
	(B) Unequal impedance distribution among cells
	(C) Difference in heat transfer efficiencies among cells

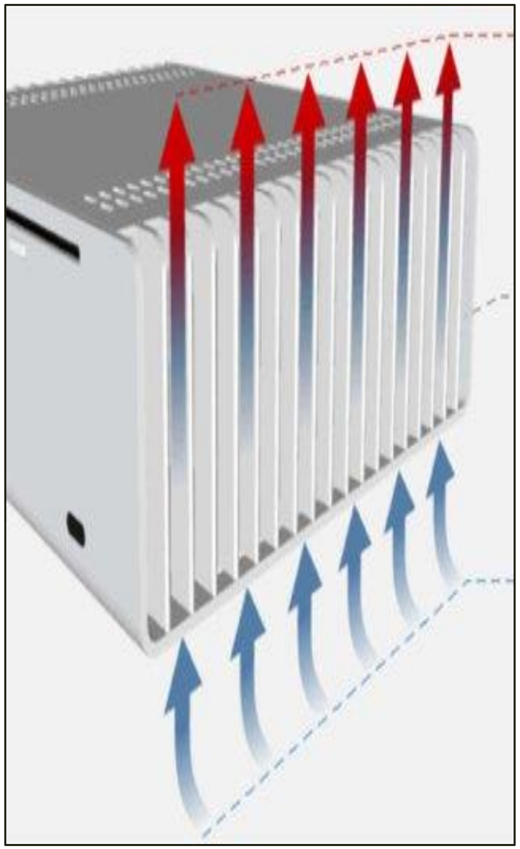
Source: http://www.mpoweruk.com/soc.htm

Methods To Control Cell Temperature

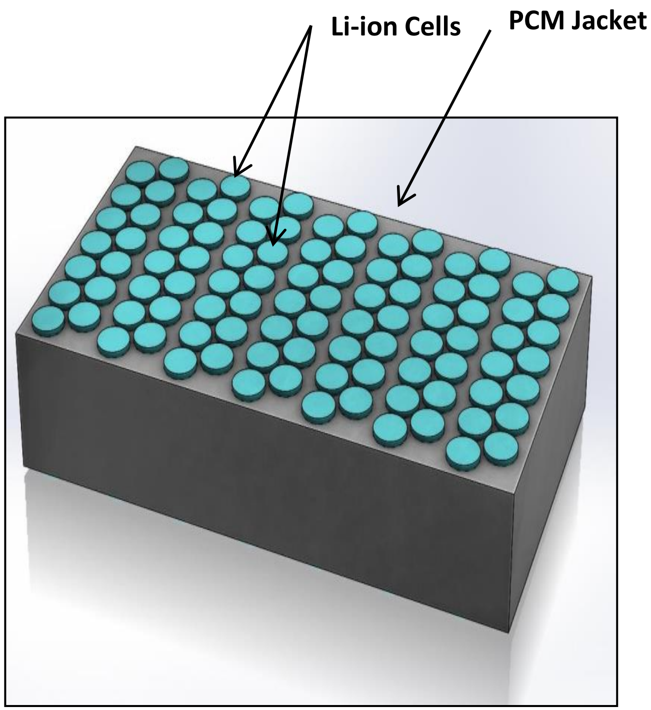
(1) Active cooling



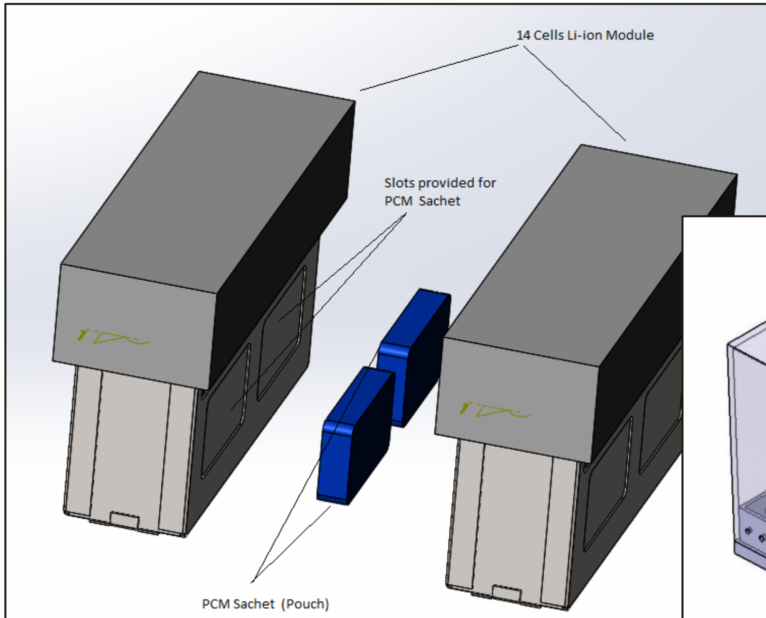
(2) Passive cooling by natural convection



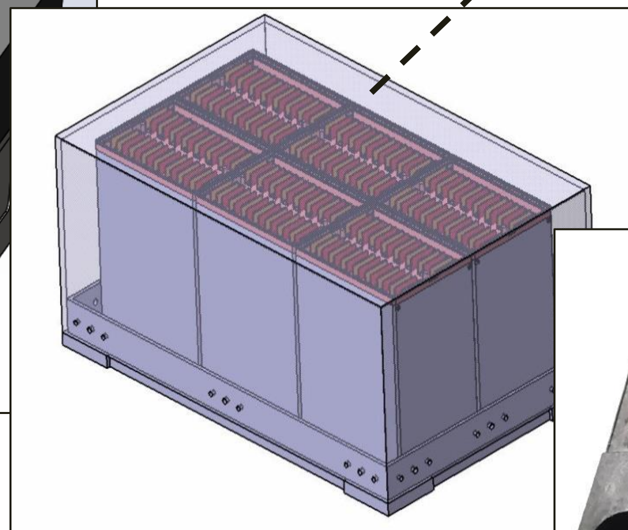
(3) Passive cooling using Phase Change Materials (PCM)



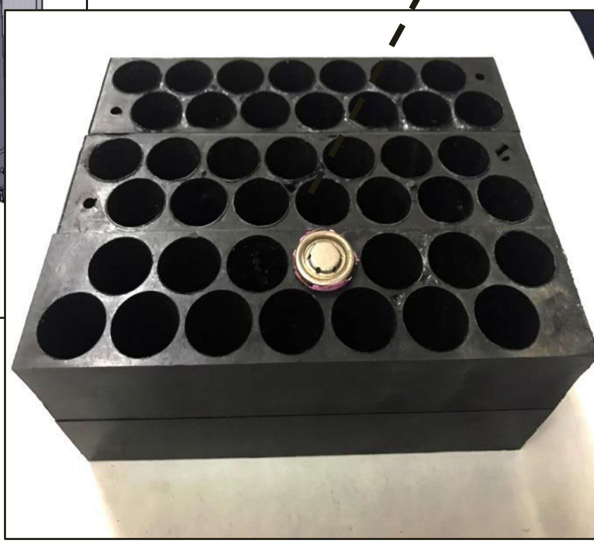
Passive Cooling Using Phase Change Materials (PCM)



1. Encapsulated PCM Modules

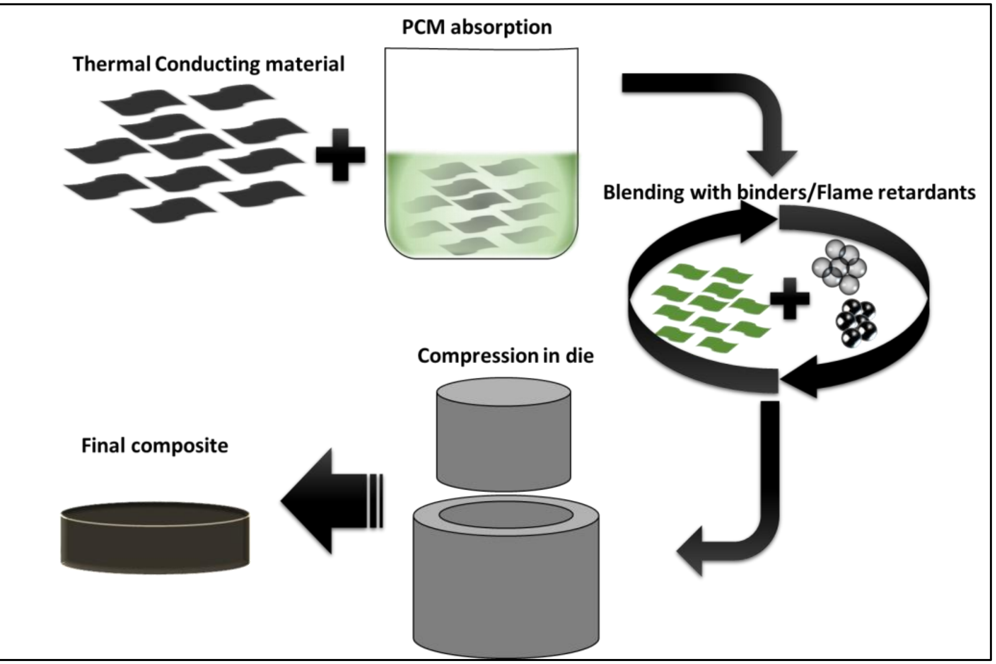


2. PCM Flooded System



3. PCM block-jackets

Passive Cooling Using Phase Change Materials (PCM)



The Pluss Edge: Form Stable PCM (encapsulated PCM)

One of the major challenges of leakage issues of molten PCM out of the battery cabinet is resolved.

Advantages of Passive Cooling Using PCM

- No moving parts such as pumps & fans.
- Lower product cost.
- Less weight and compact structure.
- No requirement for external energy.

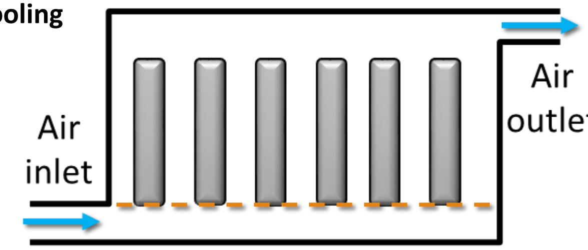
Thermal Management of Batteries Using Passive cooling : PCM

- Keeps cell in desired temperature range
- Minimize cell to cell temperature variation
- Maximize energy extraction from cell and battery
- Maintain battery performance
- Increase Lifetime by 50%
- Avoid need for oversizing battery packs
- Can be used in combination with active cooling system to reduce the capacity

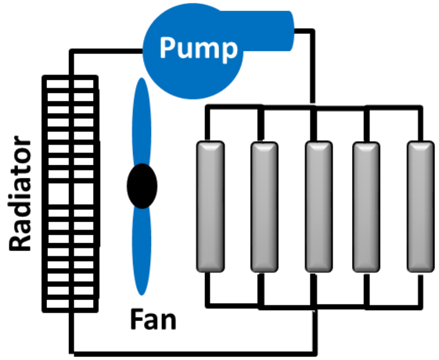
Comparison with Conventional Cooling Techniques

Parameters	Liquid cooling	Air cooling	PCM Module
Temperature spread control	Effective	Ineffective	Effective
Cooling performance	High	Low	High
System complexity	Complicated	Simple	Simple
Space occupation in electrical vehicle	High	Moderate	Low
Additional weight to electrical vehicle	Heavy	Light	Moderate
Additional energy Supply	Yes	No	No
Cost	High	Low	Moderate
Safety	Leakage issues, no FR	Safe, no FR	Safe, has FR

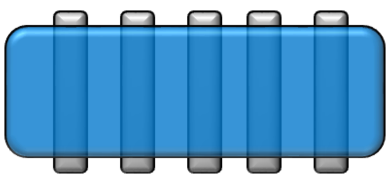
Air Cooling



Liquid cooling



PCM Module



The design of the PCM module allows the setup to be retrofit into existing air-cooled systems as well.

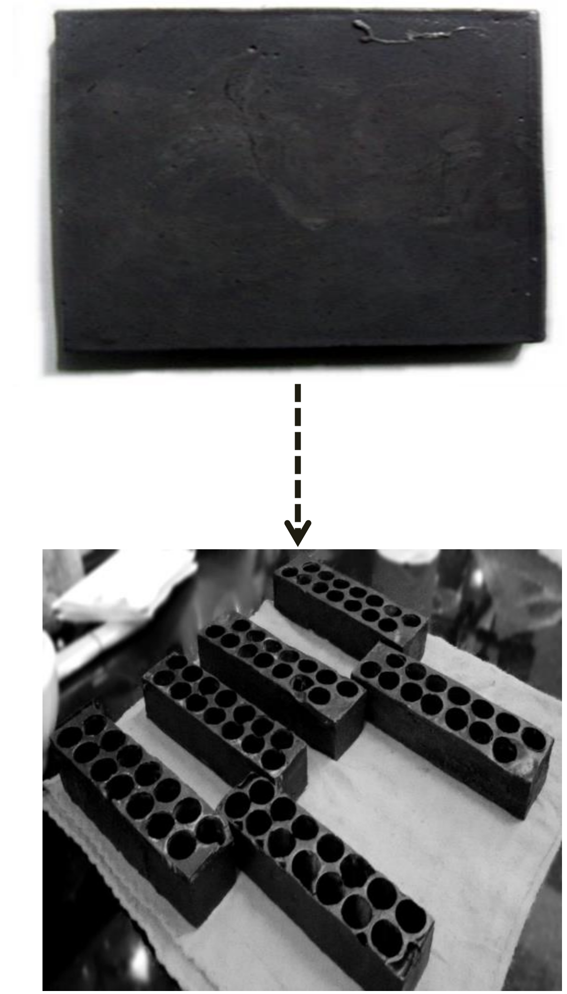
Li-ion Battery Thermal Management: PCM Alternatives

Organic Material PCM

- Artificially synthesize; plant based fatty acid
- Better Latent heat than FS material
- Low thermal conductivity
- Susceptible to leakage
- Has to be encapsulated as molding is not possible

Form Stable PCM

- Approximately 10-15% reduction in Latent heat
- Approximately 10-15% reduction in Latent heat
- Higher Thermal Conductivity
- Leak Proof due to form stability
- Moldable

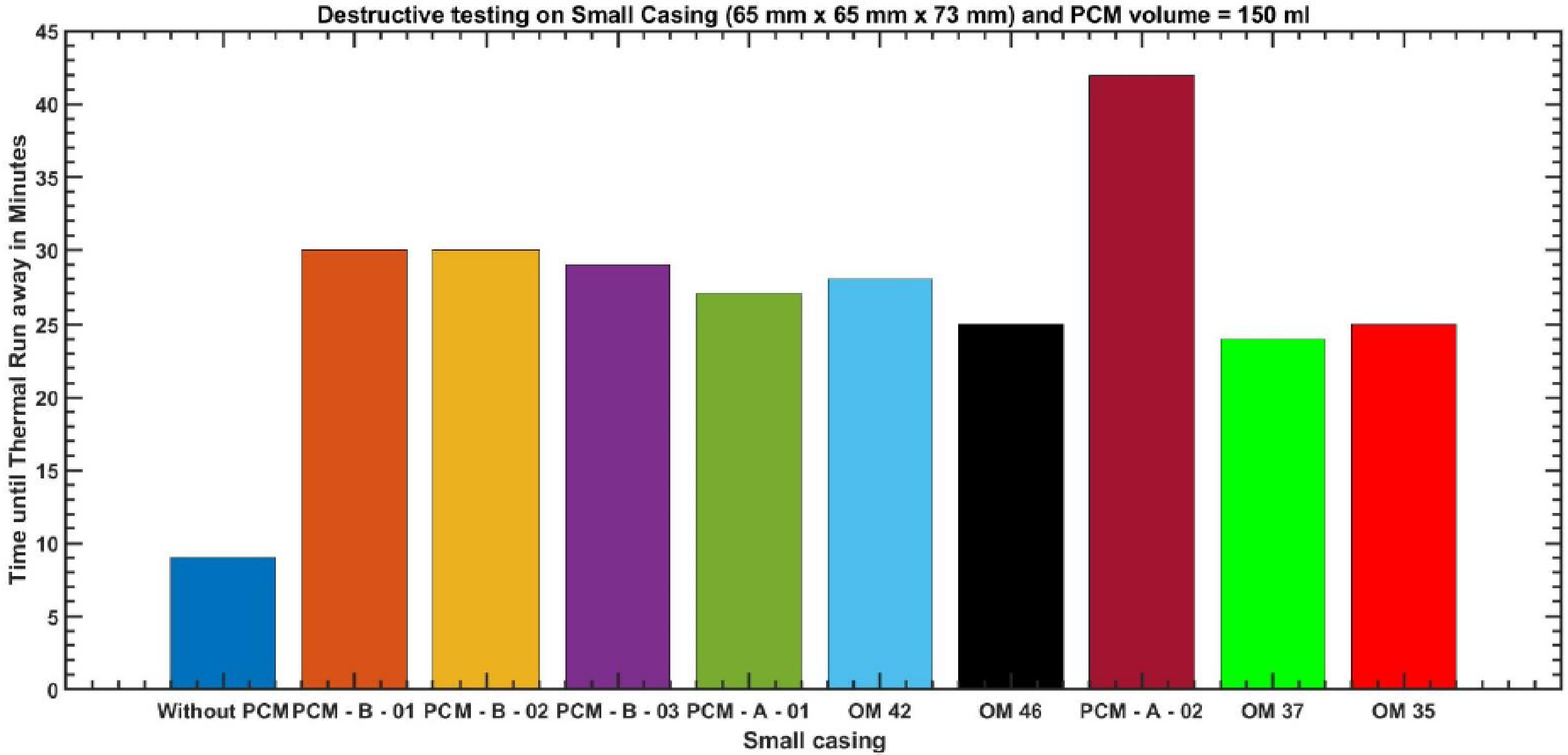


FS (Form Stable PCM)

PCM OM42 : Results and Observations

1. Test result for Destructive Testing

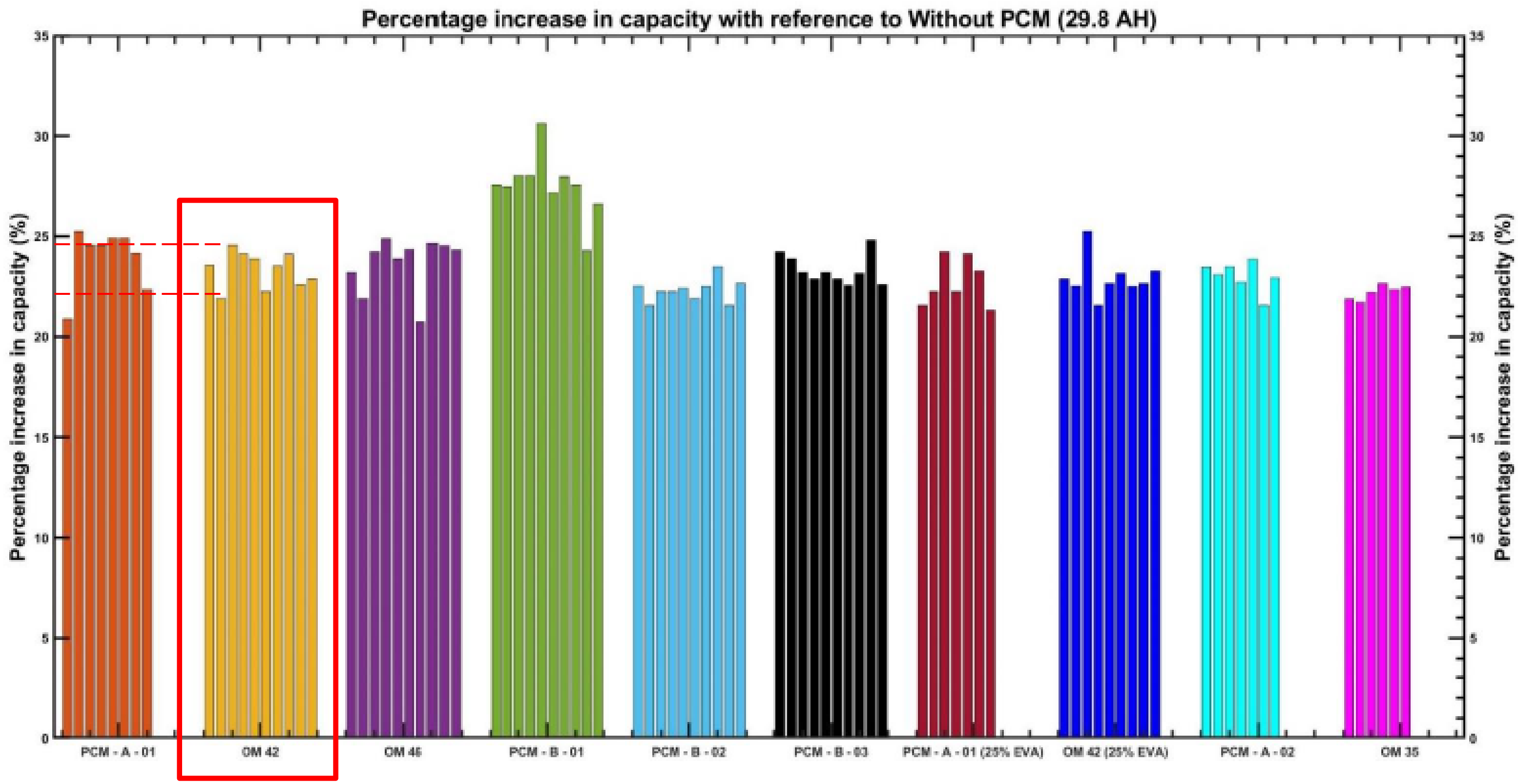
- Small casing size (65 mm x 65 mm x 73 mm).
- 9-cell arrangement.
- 100 W load to the center cell.



PCM OM42 : Results and Observations

2. Performance Testing at Ambient Temperature

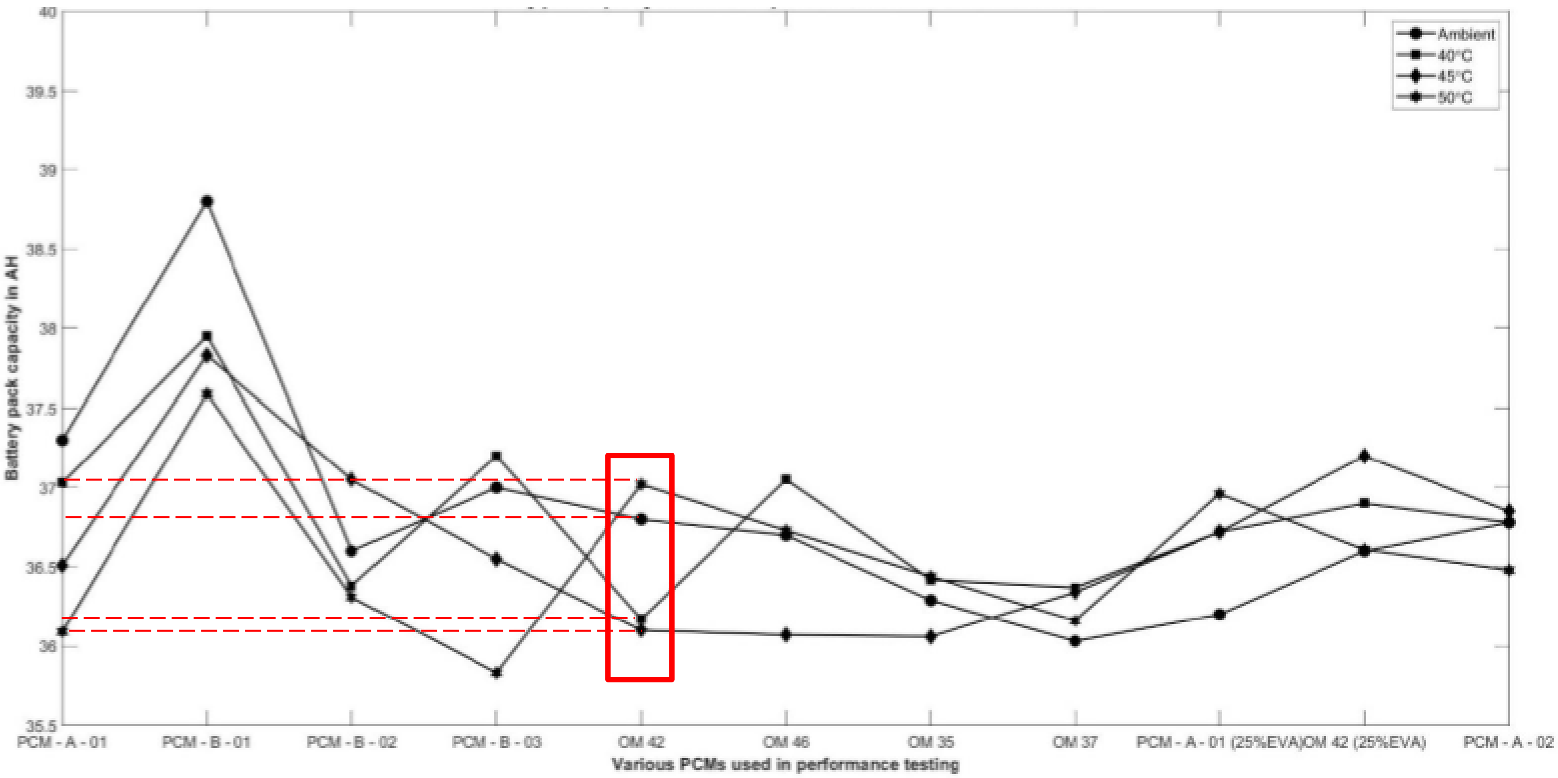
- Without PCM battery pack capacity: 29.8 Ah
- Battery discharge rate: 0.75C rate
- Battery pack is fully charged at upper cut-off limit.
- With PCM OM42, the capacity is increased by 22% - 24% for the battery pack to 36.8 Ah.



PCM OM42 : Results and Observations

3. Performance Test at Elevated Temperatures

- Without PCM battery pack capacity: 29.8 Ah
- Battery discharge rate: 0.75C rate
- Battery pack is fully charged at upper cut-off limit.
- With PCM OM42, the capacity is increased by 24% for the battery pack to 36.8 Ah. This is the highest capacity obtained among all the four PCMs (OM35, OM37, OM42 and OM46).



PCM cooling: Experimental Results and Observation

Time (h:mm)	w/o PCM (°C)	ΔT increase w/o PCM	w/ PCM (°C)	ΔT increase w/ PCM
0:00	30.5	0	32.5	0
0:15	34.7	4.2	36.6	4.1
0:30	38	3.3	39.5	2.9
0:45	40	2	41.5	2
1:00	42.25	2.25	42.8	1.3
1:15	44.25	2	43.5	0.7
1:30	46*	1.75	45	1.5
1:45	46*	0	46.25*	1.25

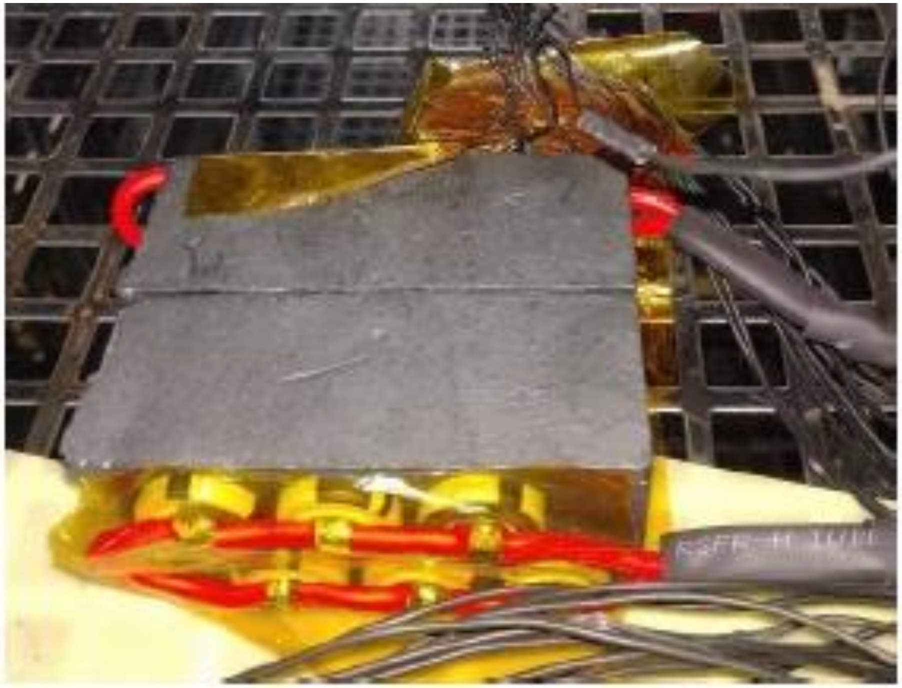
Phase Change Zone

- Experiment Parameters :-
  - 18650 type Li-ion battery
  - Peak current: 20 amp
  - Peak voltage: 5 V
  - PCM phase change temperature: 42 ^{0}C
  - Cutoff Temperature : 50 ^{0}C
  - Ambient Temperature : 43 ^{0}C

- At peak current drawing stage;
  - Time taken to reach from 40 to 45^{0}C w/o PCM = 27 min
  - Time taken to reach from 40 to 45^{0}C with PCM = 50 min

- At Phase change
  - The time taken to reach from 42 to 43^{0}C w/o PCM = 6 min
  - The time taken to reach from 42 to 43^{0}C with PCM = 20 min

PCM cooling: Experimental Results and Observation



Parameter Settings-

1.CC Discharge Current & Voltage-18A 2.5V

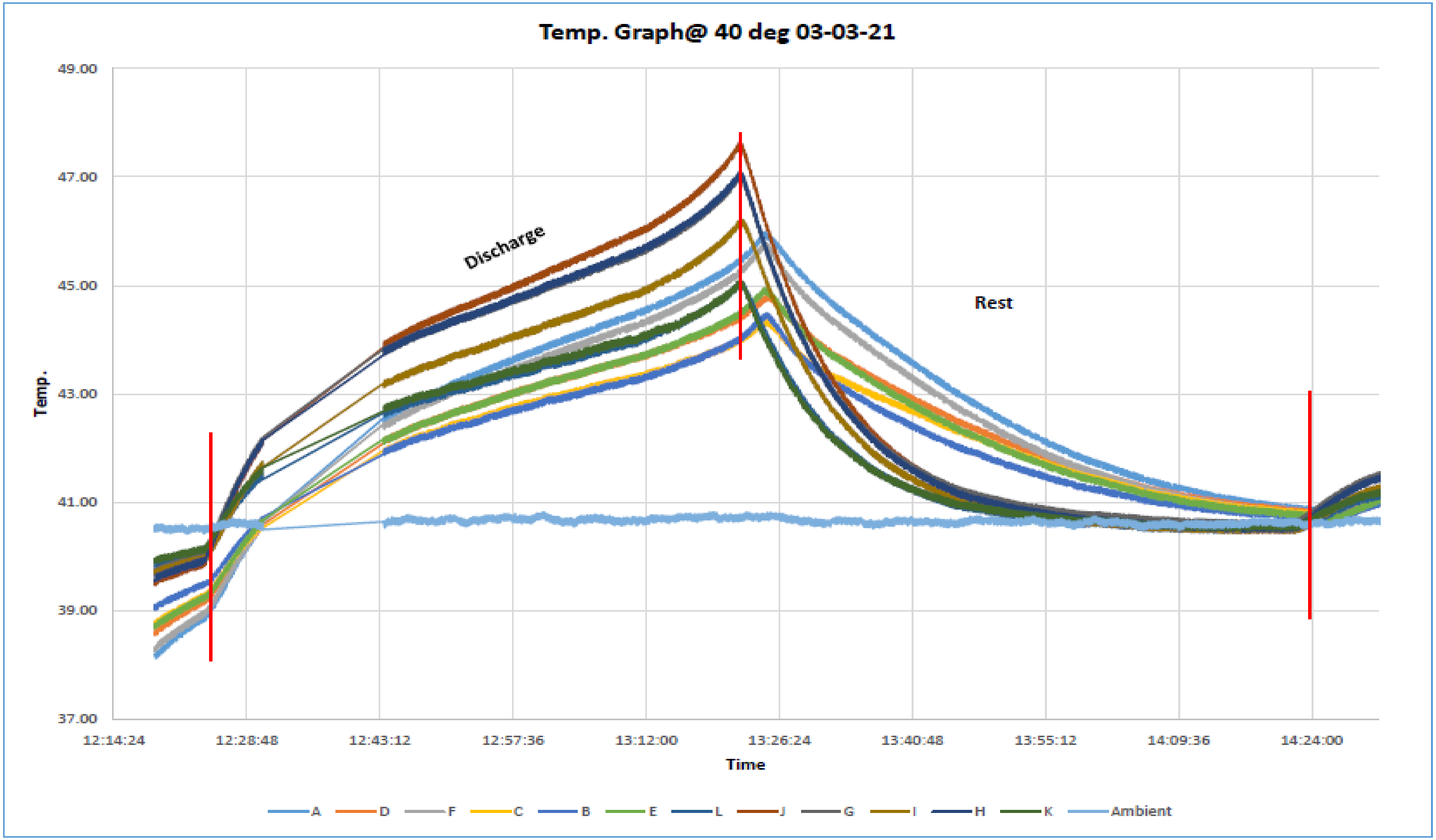
2.CC-CV Charge Current & Voltage-CC9A CV0.1A 4.2V

3.In Between Rest Time-1 Hr

4. Thermal Chamber Set Temp.-44 deg

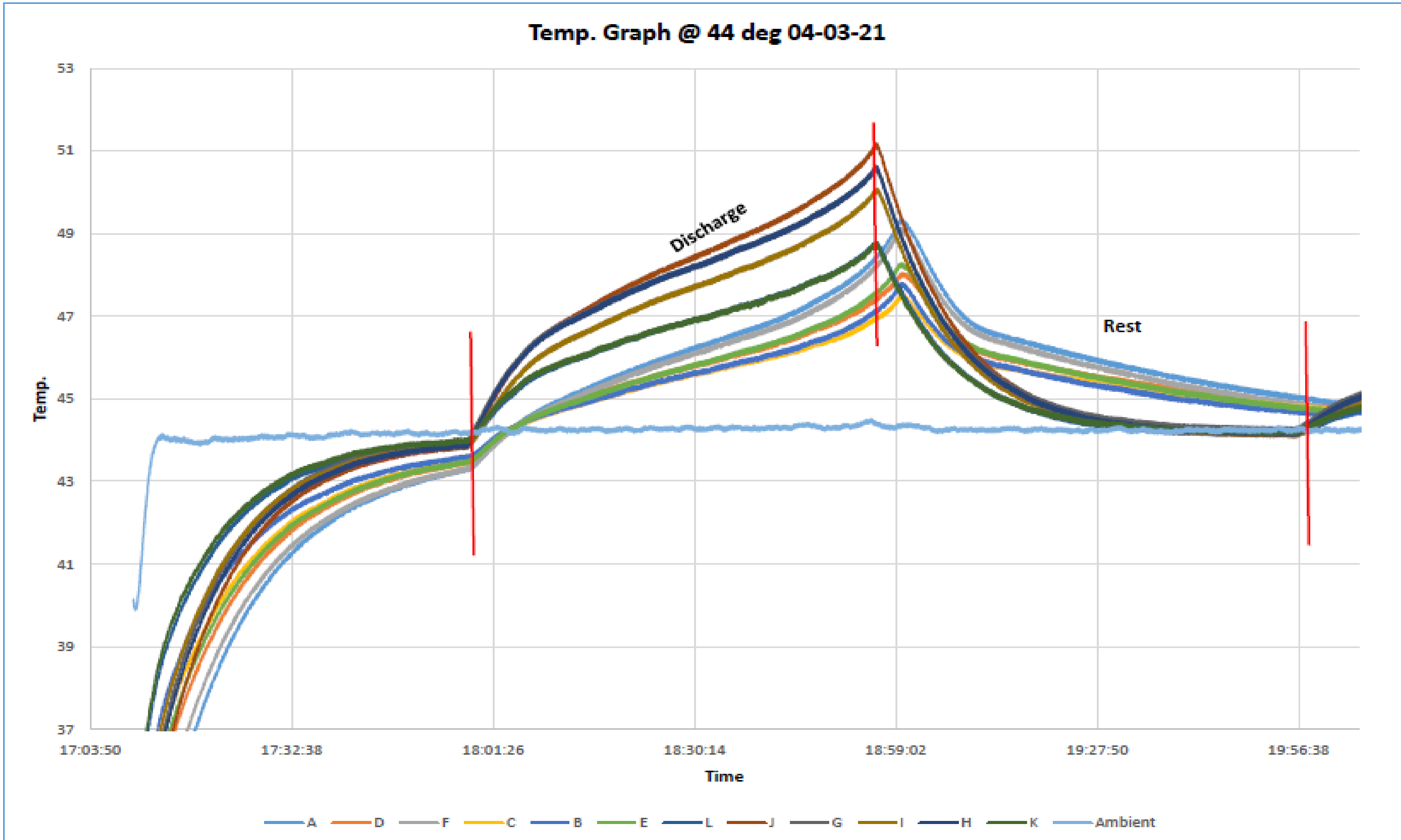
5. Battery Initial Temp.-44 deg

PCM cooling: Experimental Results and Observation



With PCM: A-F **Without PCM: G-L**

PCM cooling: Experimental Results and Observation



With PCM: A-F   **Without PCM: G-L**

PCM cooling: Experimental Results and Observation

Summary At 40°C 03-03-21

		PCM						Without PCM					
S.No.	Items	A	B	C	D	E	F	G	H	I	J	K	L
1	Discharge Initial Temp.	39	39	39	39	39	39	40	40	40	40	40	40
2	Discharge Final Temp.	45	44	45	44	44	44	45	48	47	46	47	45
3	Temp. Diff. Discharging	7	5	6	5	5	5	5	8	7	6	7	5
4	Rise in Temp./min DSG	0.107	0.087	0.104	0.076	0.074	0.087	0.080	0.126	0.115	0.100	0.116	0.081

$(\frac{dT}{dt})_{avg,PCM} = 0.089$

$(\frac{dT}{dt})_{avg,WPCM} = 0.103$

Ratio = 0.866

Summary At 44°C 04-03-21

		PCM						Without PCM					
S.No.	Items	A	B	C	D	E	F	G	H	I	J	K	L
1	Discharge Initial Temp.	43	44	43	43	44	43	44	44	44	44	44	44
2	Discharge Final Temp.	48	47	48	47	47	48	49	51	51	50	51	49
3	Temp. Diff. Discharging	5	4	5	3	4	4	5	7	7	6	7	5
4	Rise in Temp./min DSG	0.084	0.064	0.081	0.056	0.058	0.068	0.078	0.119	0.109	0.100	0.111	0.079

$(\frac{dT}{dt})_{avg,PCM} = 0.068$

$(\frac{dT}{dt})_{avg,WPCM} = 0.099$

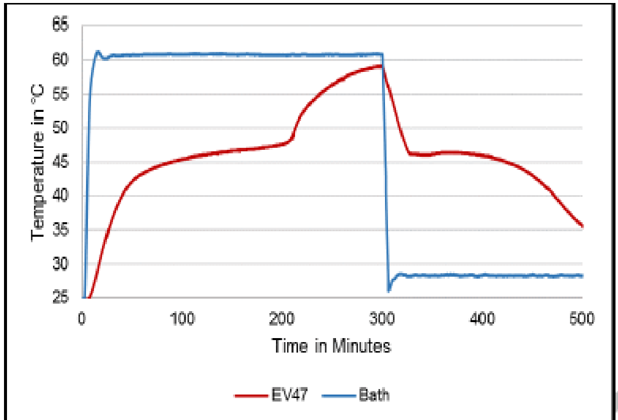
Ratio = 0.688

TECHNICAL DATA SHEET OF EV47

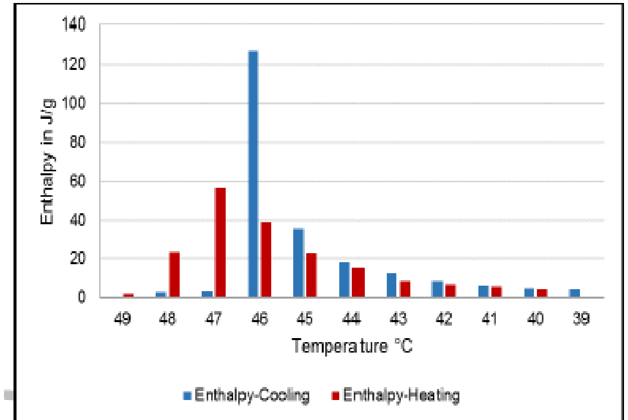
Technical Specification:

Product	:	EV Battery Composite Material EV47
Description	:	Form Stable Phase Change Material – PCM embedded in polymer matrix
Appearance	:	Black Solid @ 25^0C

Phase Transition Temperature Range and Stored Thermal Energy*



Temperature vs Time Curve



Enthalpy vs Temperature Curve

Property	Value**	Test Method	Test Conditions (if any)
Phase Transition Temperature			
Melting	47˚C	PLUSS® T-History	@ 60˚C Air Bath
Freezing	46˚C	PLUSS® T-History	@ 28˚C Air Bath
Latent Heat/Enthalpy			
Melting	185 kJ/kg	PLUSS® T-History	@ 39 to 49˚C
Freezing	225 kJ/kg	PLUSS® T-History	@ 39 to 49˚C
Density			
Solid	1068 kg/m^3	ASTM D891-95	@ 20˚C
Specific Heat			
Liquid	3.24 kJ/kgK	PLUSS® T-History	@ 55˚C
Solid	2.41 kJ/kgK	PLUSS® T-History	@ 30˚C
Thermal Conductivity			
Solid	0.93 W/mK	Hot Disc Method	@ 23˚C
Maximum Operating Temperature	90˚C		
Nail Penetration Test	Pass		
Flash Point	200ºC		

Innovation Benefits

Energy savings per annum

- **Usable battery capacity :** Eliminate capacity fade; **5% to 15% per cycle saved in new batteries**
- **Energy utilized by thermal management system** – Passive cooling technology eliminates energy for conventional thermal management; **20% of the battery energy saved per cycle**

GHG savings per annum

- Better Thermal management increases battery life by 5 to 7 years(~75%); **GHG emission towards replacement of batteries can be reduced by 50%**

Cost savings

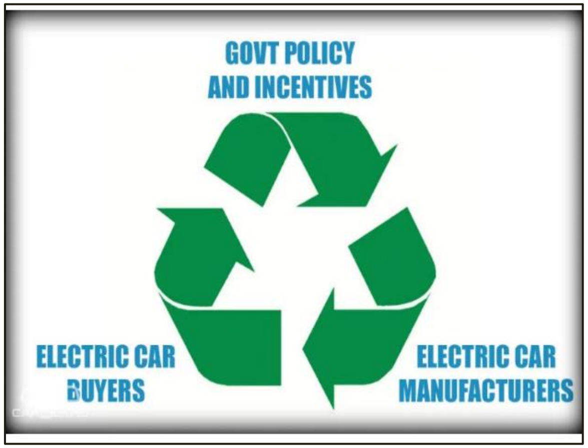
- **75% Capital cost saving** - Active cooling system is 20% of the cost of battery pack **while PCM based cooling system would be only 5% of the battery pack**
- **15% Operating cost savings –** In comparison of no thermal management system or conventional heat sink, **PCM based battery pack improves operating cost by 7 to 15%, while adding minimal fuel costs due to light weight designs**

Innovation Benefits

Technology benefits	The form stable PCM accommodates very little space, is customizable to battery and EV specs, and is retrofittable.
	The additional weight added to electrical vehicle is relatively very low compared to conventional cooling systems.
	The flexible process design also allows us to tailor the thermal management module to cater a large variety of applications, such as solar panels & co-generation.
Environmental benefits	Form stable PCM can be considered as utmost critical component as it is targeted to protect the batteries from explosions or thermal runaway situations in electrical vehicles.
	Energy and GHG savings
	Lower CAPEX and OPEX of module would facilitate growth of affordable commercial EV technologies
	Technology can be scaled to be implementable in a variety of other applications that employ Li-Ion batteries, such as microgrid applications, server farms and data centers.

Challenges in India

- Harsh ambient conditions (45^{o}C temperature).
- Demand of electricity is more than supply.
- Less Incentives by Govt. to make EV more lucrative.
- Domestic battery supply (make in India needs to be promoted).
- Infrastructure.
- Dealer Reluctance.



PARTNERSHIPS

- **National Centre of Cold Chain Development**
  NCCD is an autonomous body established by the Government of India with an agenda to positively impact and promote the development of the cold-chain sector in the country.

National Centre for Cold Chain Development

- **India Energy Storage Alliance**
  IESA was launched in 2012 to help technology and system integration companies involved in energy storage and microgrids to understand and capture the opportunities in the growing markets.

India Energy Storage Alliance

- **Reichs-Ausschuss für Lieferbedingungen (RAL)**
  Several active PCM enterprises formed the Quality Association PCM in 2004 to develop proper quality assurance procedures.

RAL
GÜTEZEICHEN
Phase Change Material

- **Clean Energy Access Network (CLEAN)**
  CLEAN is an all India representative organization launched in 2014 with a clear mandate to support, unify and grow the decentralized clean energy sector in India.

CLEAN
Clean Energy Access Network

AWARDS AND KEY RECOGNITIONS

Top 5 innovators under the India Innovation Growth Program

CII Innovation Award 2014 – Most Innovative MSME Company

MiraCradle™ included in the WHO Compendium of Innovative Health Technologies

MIT Innovators under 35, India

Cold Chain Innovation of the year 2016 for Celsure™

PLUSSTAINABLE

/plʌsˈsteɪnəb(ə)l/

able to maintain the optimal rate or level to meet the needs of the present without compromising the needs of future generations, **the PLUSS way.**