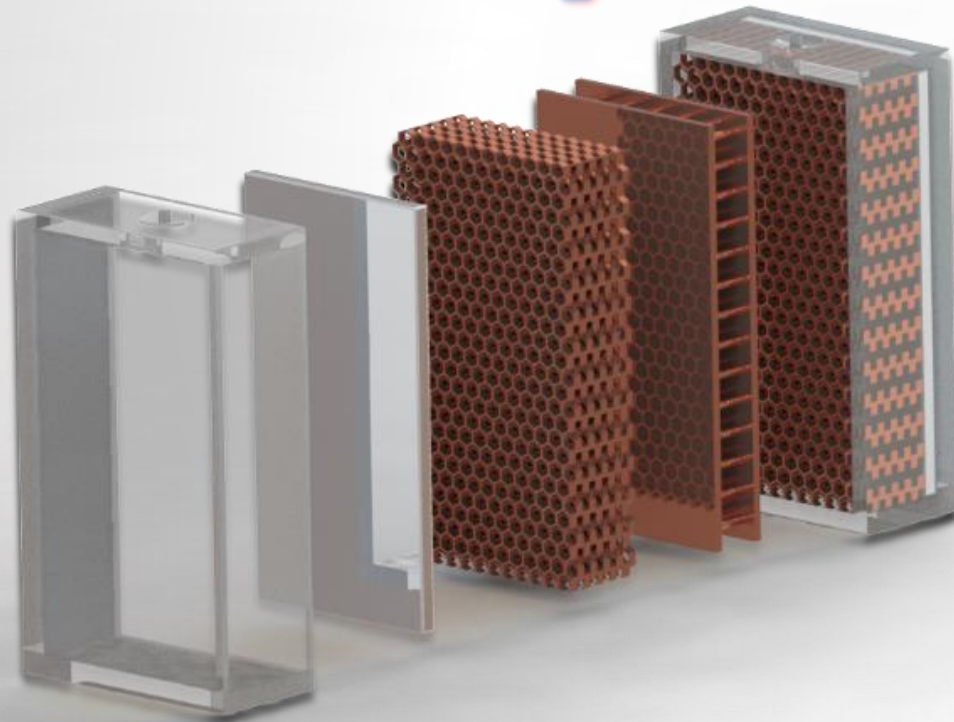


An Innovative thermal management system for Li-ion battery under a real driving condition



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Why are **BTMS**s essential for high power Li-ion batteries?

The powerful energy storage devices, like lithium-ion batteries used in electric vehicles, generate heat. Heating occurs during the rapid charge and discharge due to resistances in and outside the cells.

Northvolt has said it will build Europe's biggest electric car battery factory in its home country, Sweden.



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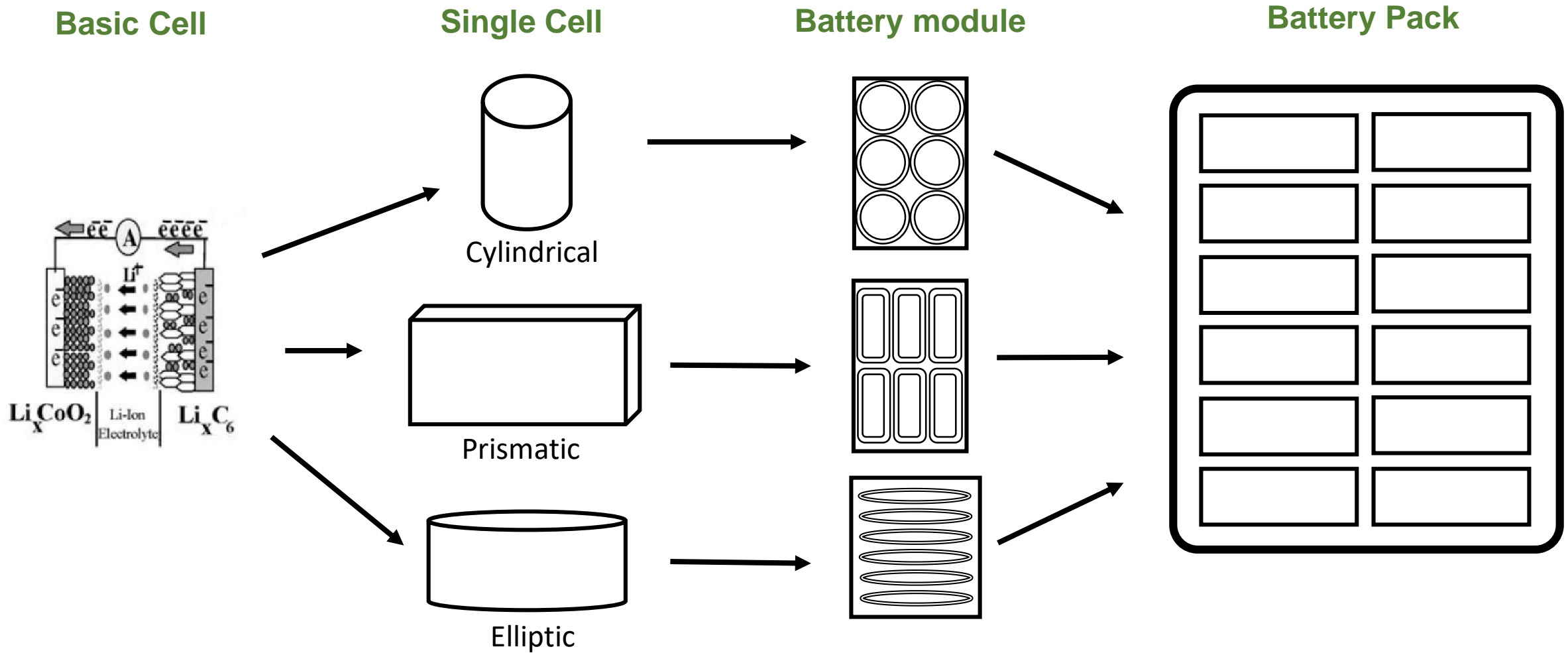
Why are BTMSs essential for high power Li-ion batteries?



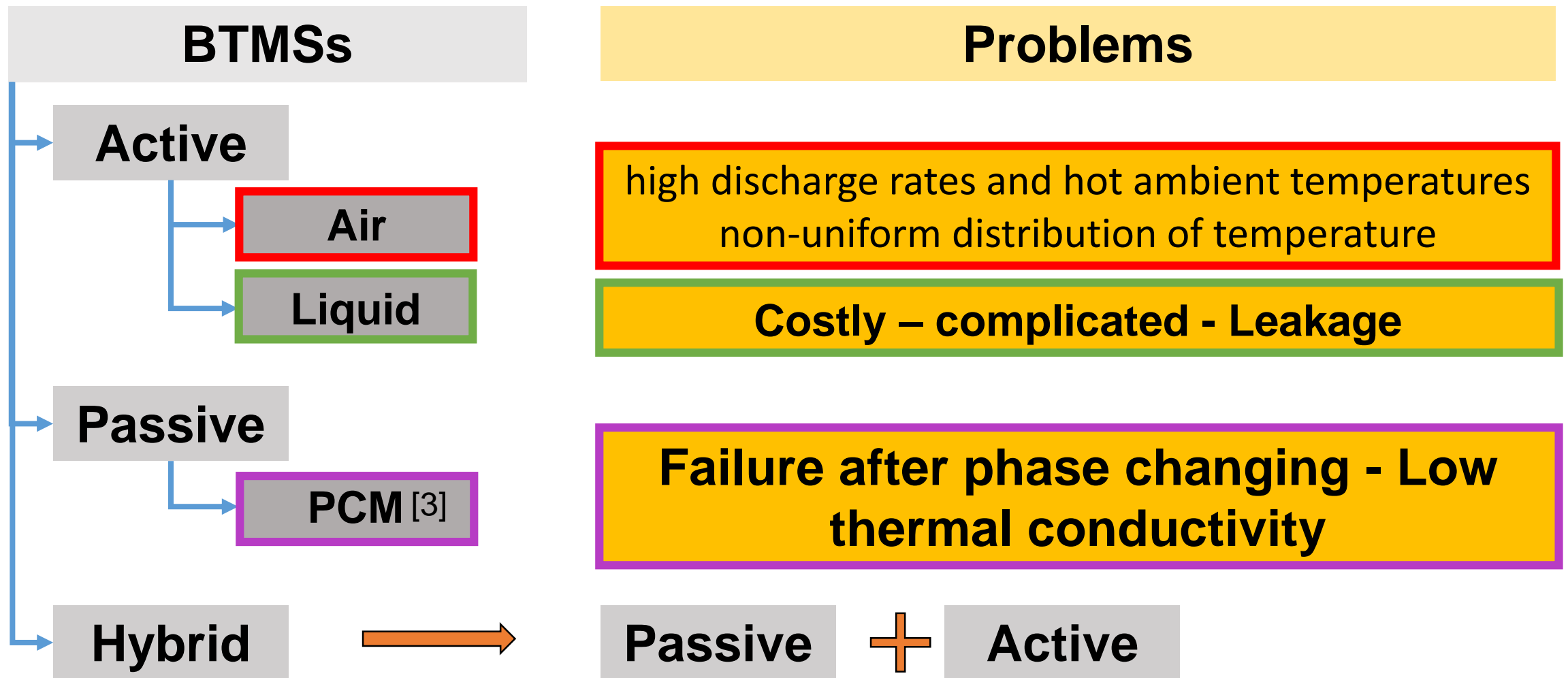
60 °C

Temperatures higher than 60 °C permanently damage the battery, and it can be very unsafe. Battery thermal management systems are designed to keep the battery temperature in a desired range. In this presentation, I will introduce a novel hybrid thermal management system and discuss the result of an experimental investigation under a simulated driving situation and hot weather condition.

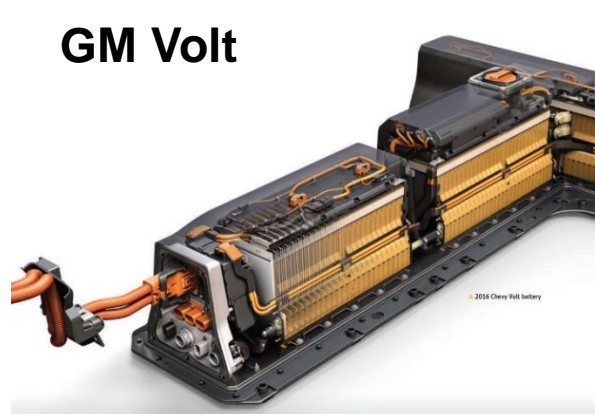
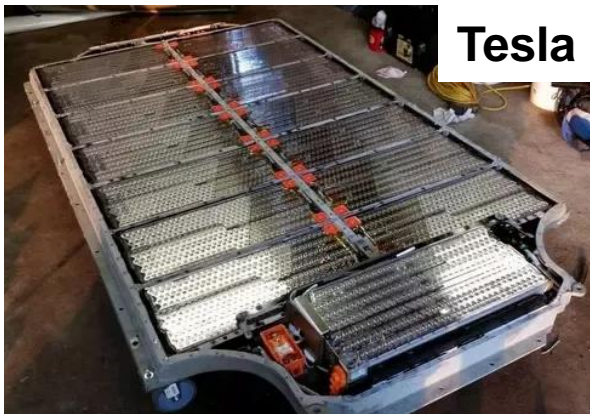
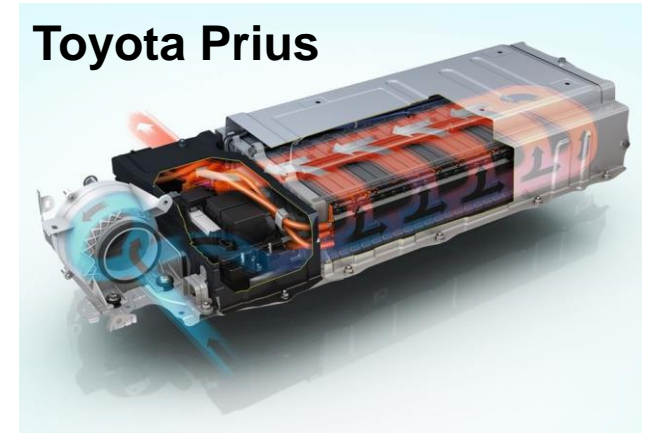
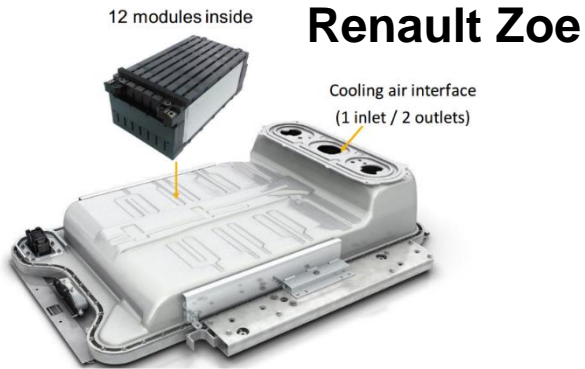
Schematics of the battery pack design with different cell types [1]



BTMSs: Types, Differences and Problems [2]



Prominent samples of battery packs for EVs



Electric vehicles present in the market today employ both air-cooling and liquid cooling. Some examples of air-cooled electric vehicles are Renault Zoe, Nissan Leaf, and Toyota Prius. The liquid-cooled electric vehicles include Tesla, GM Volt, and BMW i3.

BTMSs: Problems and Aims

Problems

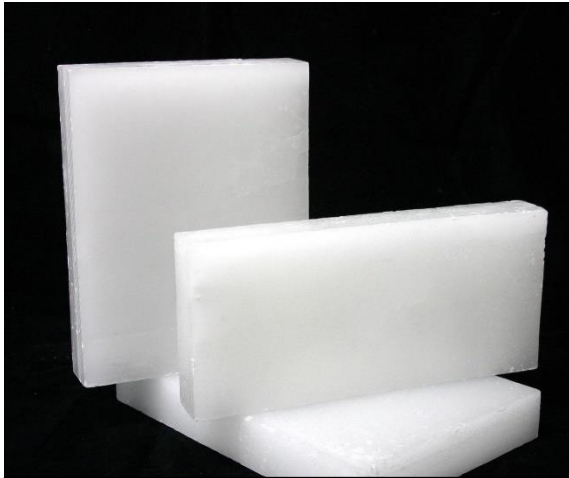
1. high discharge rates and hot ambient temperatures
2. non-uniform distribution of temperature
3. Costly
4. Complicated
5. Leakage
6. Failure after phase changing
7. Low thermal conductivity

Aims

1. Significant heat dissipation at high discharge rate and hot weather condition
2. uniformity distribution
3. low cost
4. simplicity
5. no leakage problem
6. Not only depend on PCM

Hybrid Thermal Management System

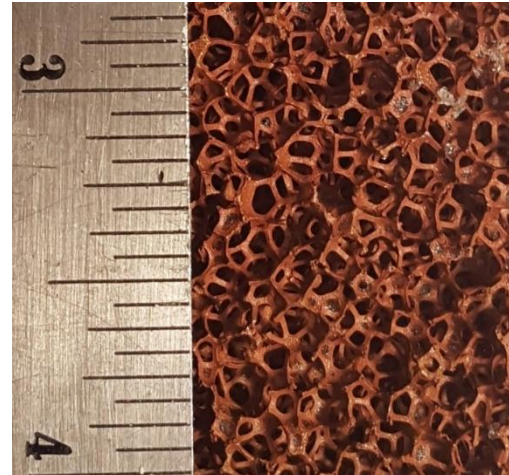
PCM



Paraffin with Melting point
between 42 – 44 degree C



Copper Foam



Porosity of 90 % - PPI of 20



Heat Sink



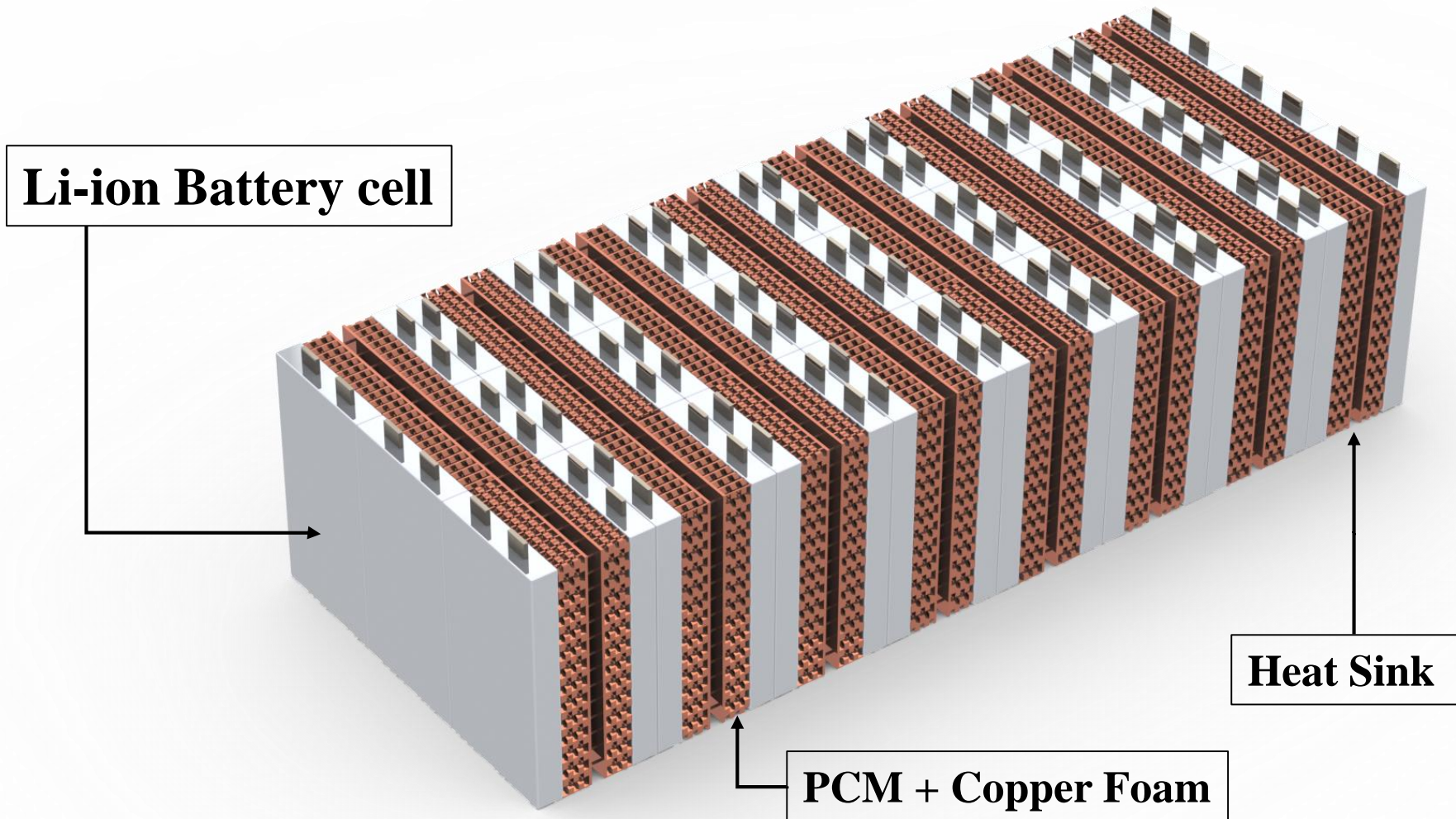
PASSIVE

ACTIVE

HYBRID

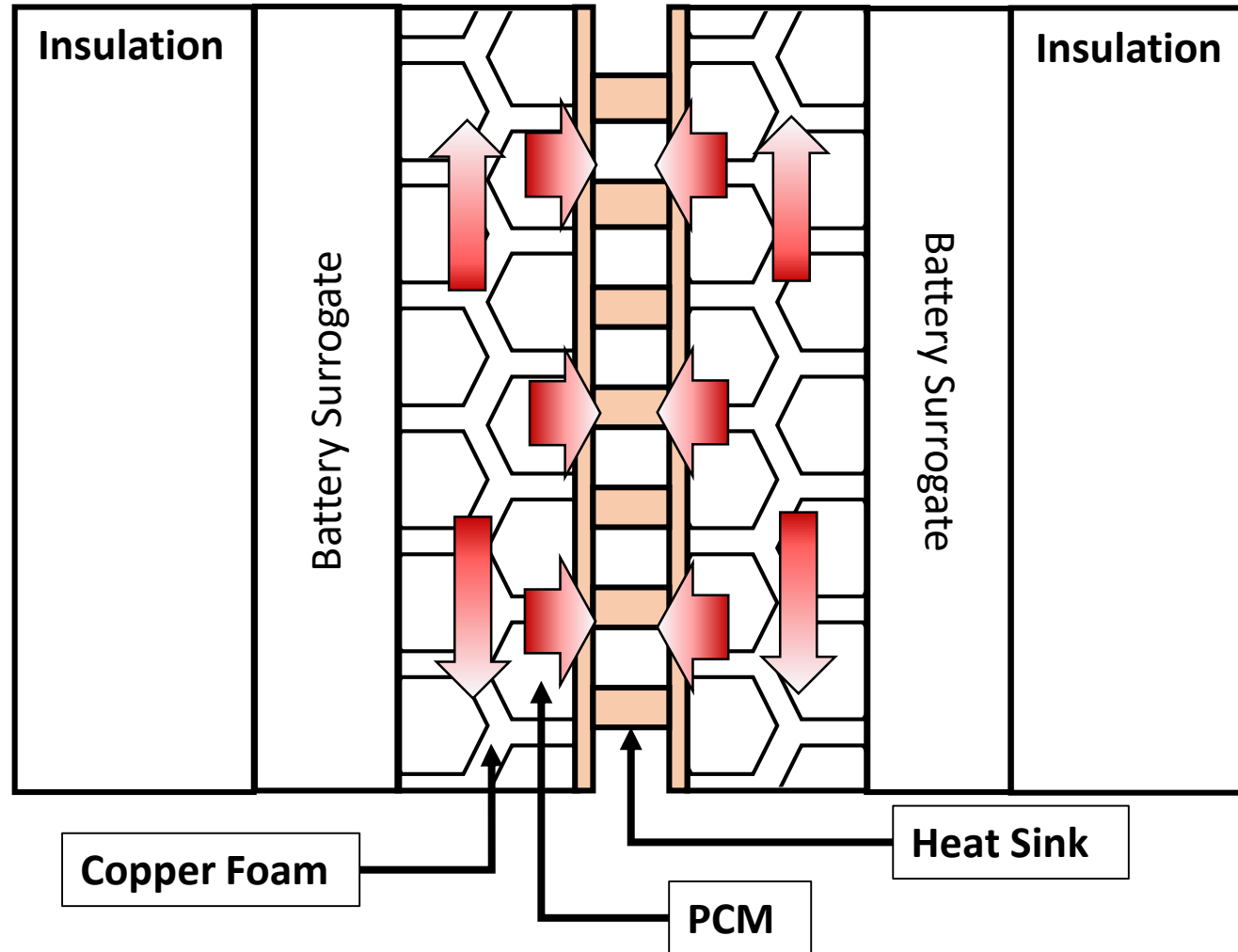
A novel hybrid thermal management system based on a unique combination of passive and active systems is designed. In the passive part, the copper foam is selected as the thermal conductivity enhancer for the paraffin. For active cooling, the air is chosen as the medium, and a pinned heat sink was designed and fabricated. The heat sink is directly connected to the battery cell surface using copper foam. So the copper foam is the common part between the two systems.

Hybrid Thermal Management System – Battery Module



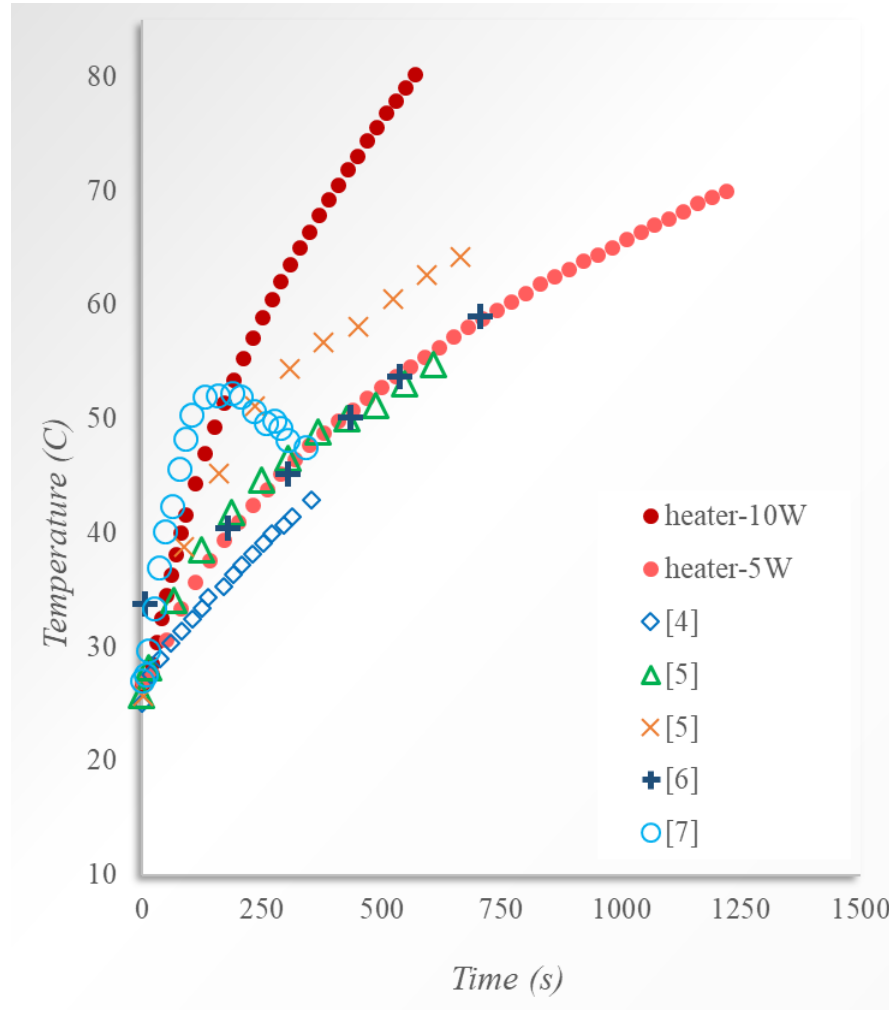
The slide shows a concept of the battery module with 16 large-scale lithium-ion cells. The focus of design is on the method the active and passive parts are integrated into. It makes that the heat simultaneously dissipates by active part and store in passive part.

Experimental test setup - Battery Simulation



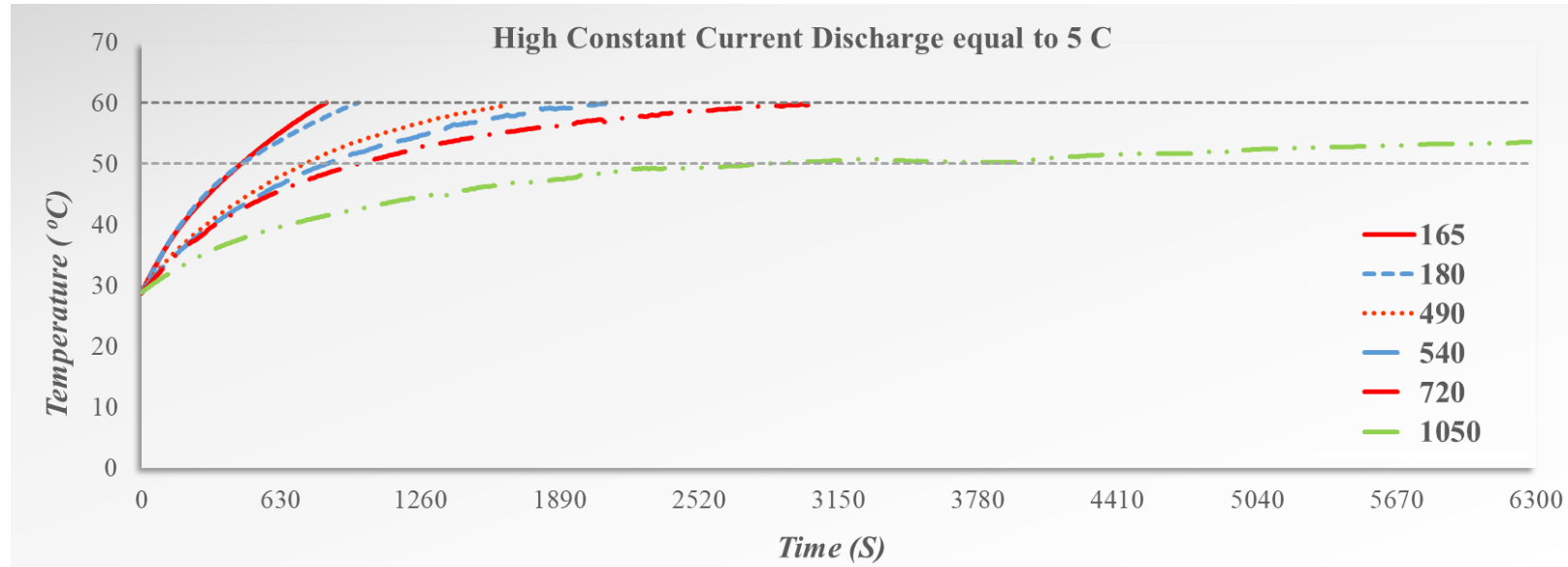
The method of combination of our design enables us to take advantages of PCM as heat storage to keep surface temperature uniform in the desired temperature range while active air-cooling system directly cools the cell surface and enhance the performance of the PCM. We use insulation to make the adiabatic conditions for tests and use film heaters instead of a battery for the safety issues at the thermal runaway.

Experimental test setup - Battery Simulation



A detailed literature survey was conducted for an ample series of experiments and evaluating abuse conditions of lithium-ion batteries to obtain data under natural convection. The approach to the simulation was to find the essential power for the heater in the way to cover all the data. Part of the survey is here. Finally, 5 and 10 watts was found to emulate the high constant current discharge and onset of thermal runaway.

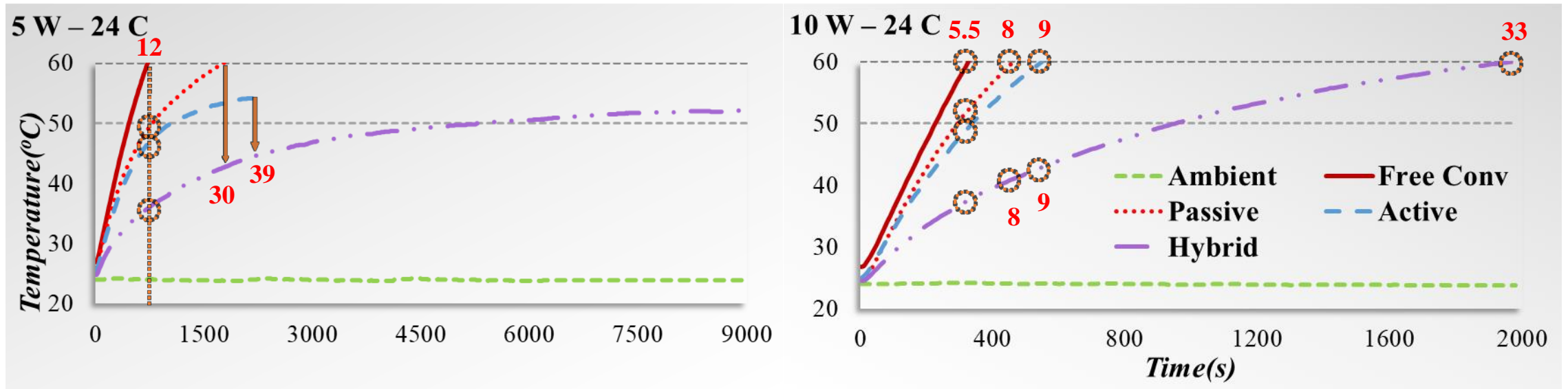
Results and Discussion



Air speed is only 3.2 km/h (2 mph)

At first, we follow the minimum use of external energy. The Reynolds increased from the 165 to 1050 while the input air temperature was kept constant at 20 °C. The result suggests that at Reynolds of 1050, which is equivalent to an airspeed of 3.2 km/h, it is possible to maintain the surface temperature of the battery below the 60 °C, at high constant current discharge. It is impressive that by the heat sink's structure, the pressure drop through the heat sink was only 4 kPa.

Results and Discussion



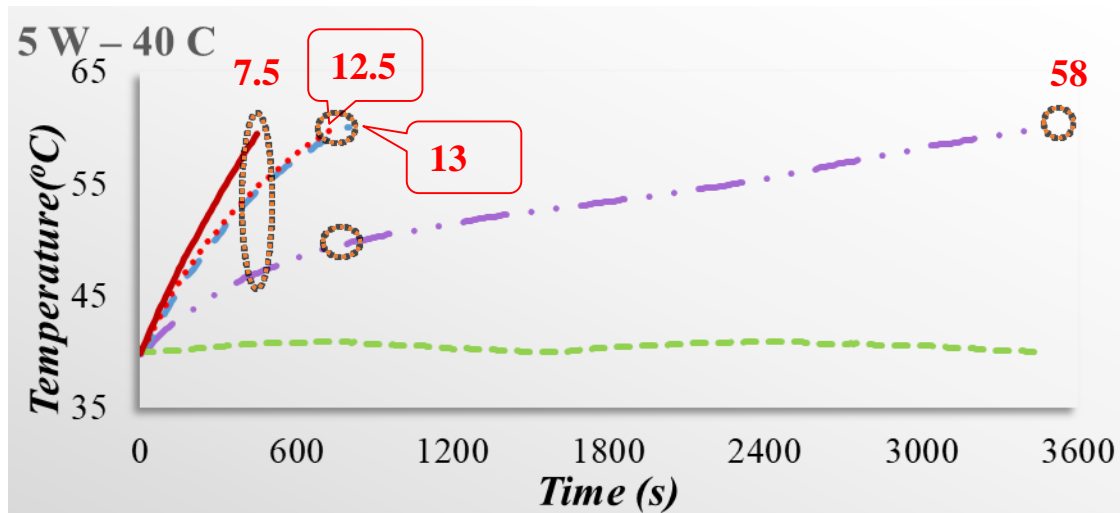
The results were compared to active and passive thermal management systems to assess the effect of active-passive integration.

At 5 Watts of heater power, at 24 °C, in the natural convection mode, the temperature of the heater surface exceeded 60 °C after 12 minutes. The corresponding temperatures for passive, active and hybrid show an improvement of 18.5, 22.5 and 40.4 percent compared to the natural convection.

	5W-24 (%)		10W-24 (%)	
<i>P/FC</i>	18.5	13.1	29.8	
<i>A/FC</i>	22.5	17.7	40.0	
<i>H/FC</i>	40.4	37.5	83.4	
<i>H/P</i>	28.8	31.7	76.4	
<i>H/A</i>	16.9	28.5	72.4	

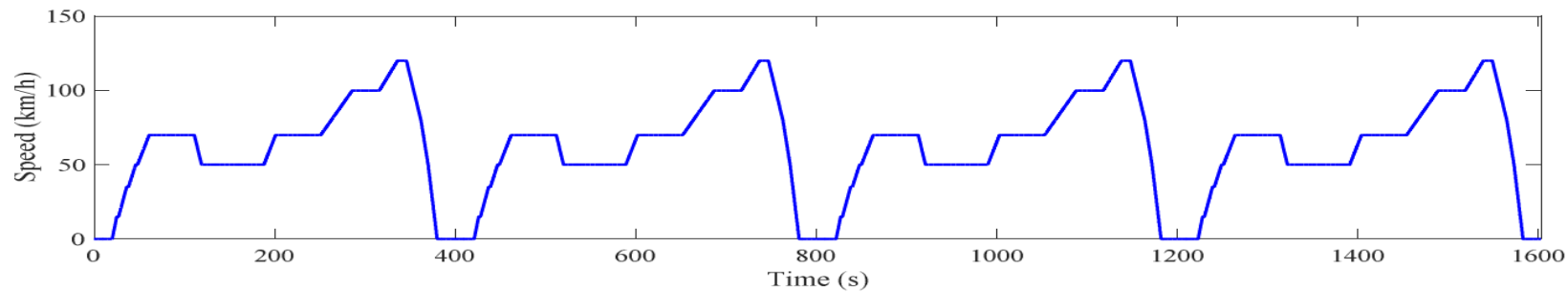
Results and Discussion

In the case of hot weather condition, 40 °C of room temperature, the difference between hybrid and the other systems is considerable. While active and passive system shows unacceptable behavior, the hybrid could manage the temperature in a reasonable range.



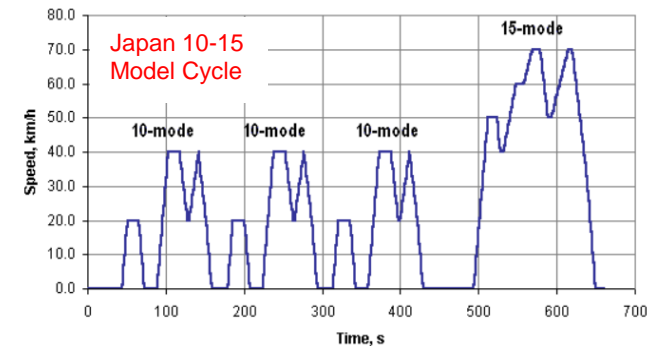
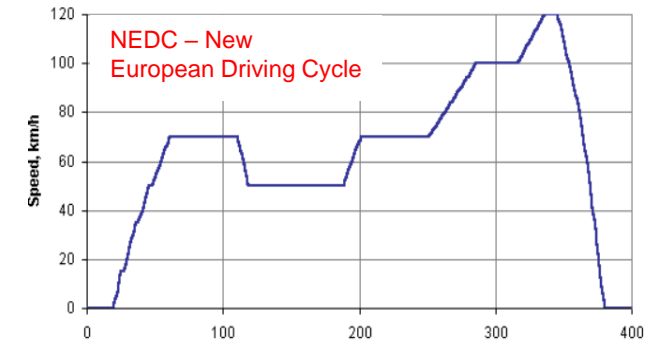
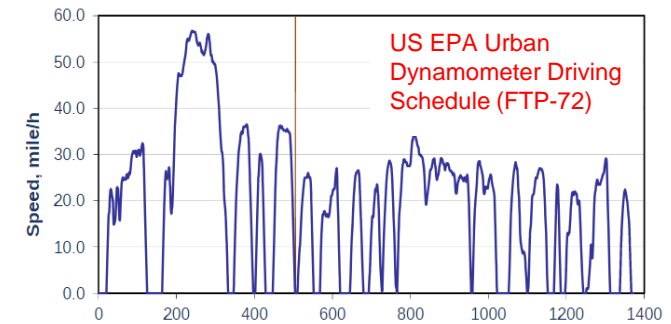
	5W-24 (%)	5W-40 (%)		10W-24 (%)	
<i>P/FC</i>	18.5	8.8	40.0	13.1	29.8
<i>A/FC</i>	22.5	9.3	43.8	17.7	40.0
<i>H/FC</i>	40.4	20.7	87.0	37.5	83.4
<i>H/P</i>	28.8	17.7	78.4	31.7	76.4
<i>H/A</i>	16.9	17.3	76.9	28.5	72.4

Results and Discussion - Dynamic mode

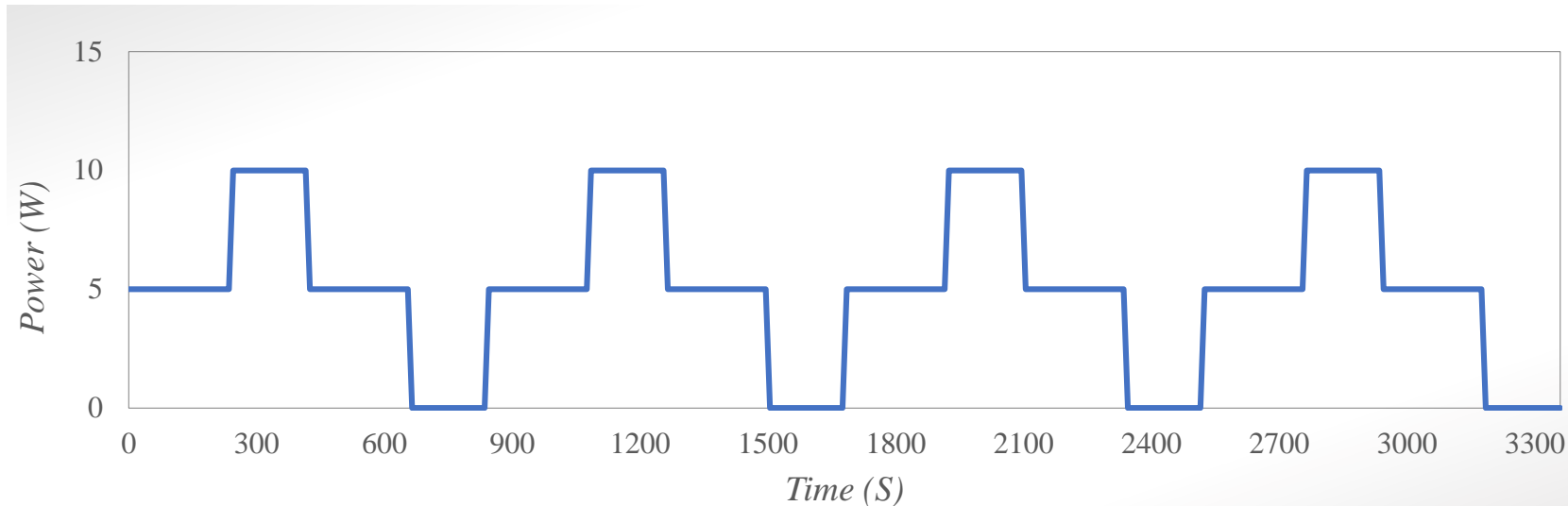


Speed profile of UN/ECE reg. 83 extra-urban driving cycle route [8]

Yuan, in 2017 had a study that focuses on the comparison of energy consumption of the electric vehicles in three different energy storage systems including lithium-ion battery. The mathematical approach was used to simulate three routes of vehicle movement. The results are then compared against existing urban driving cycles, such as the US federal test procedure, *New European driving cycle* and Japan 10-15.



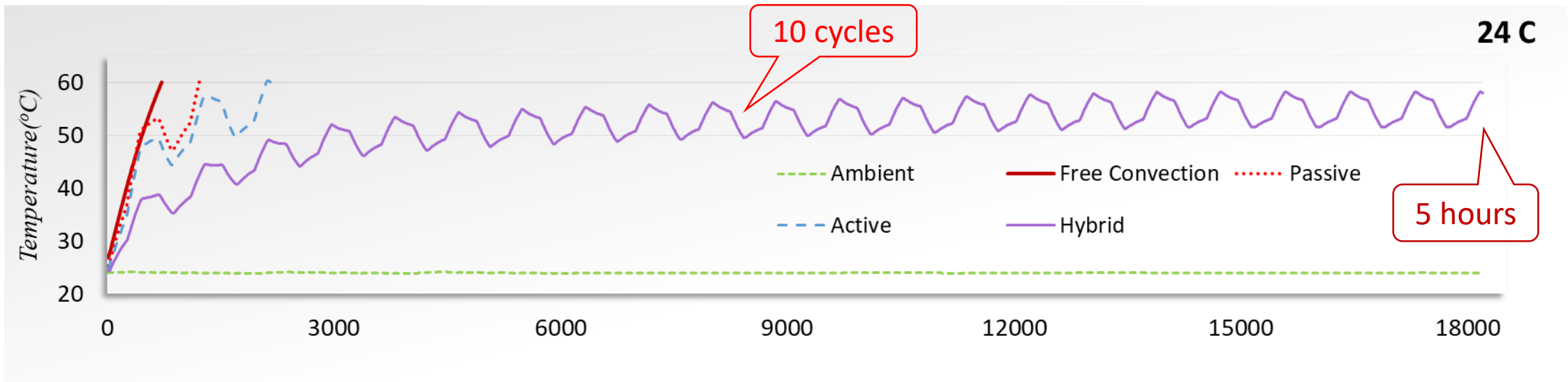
Results and Discussion - Dynamic mode



Heater power profile for dynamic mode in Tehran for driving state

The same mathematical approaches were used to simulate a real driving for high traffic using the city of Tehran and be tried to use the maximum charge to perform a dynamic mode to challenge our hybrid thermal management system in a real driving state including high and standard discharge rate and a stop mode in which there was no air convection. Each cycle was 14 minutes.

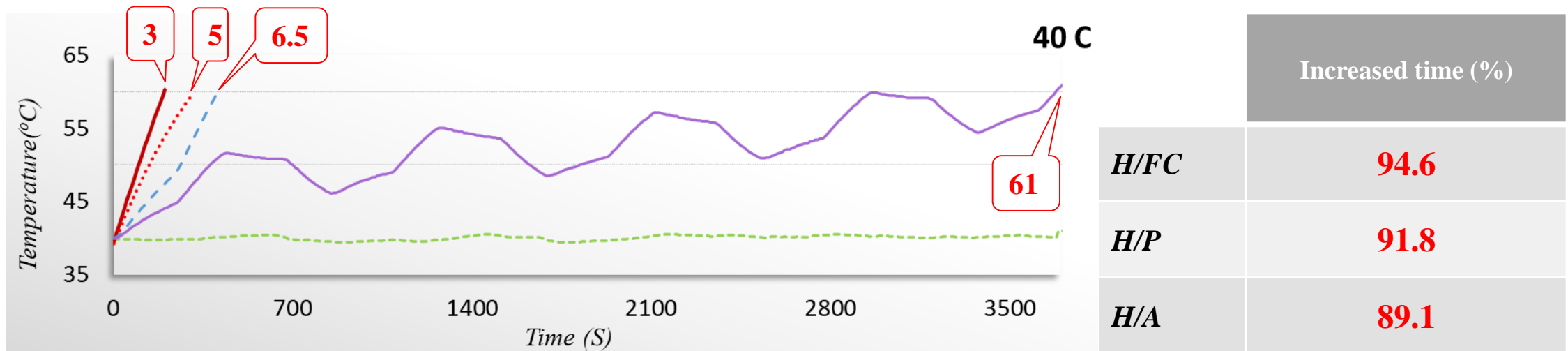
Results and Discussion - Dynamic mode for a real driving state



The results of the test were impressive. The passive and active systems could only keep the temperature under 60 °C just for 1 and 2 cycles while the hybrid system reached a steady state after around 10 cycles and never reached the 60 °C. It shows the power of design of hybrid system compared to active and passive.

Results and Discussion - Dynamic mode for a real driving state

In the case of hot weather, only hybrid could keep the temperature for 4 cycles and the other systems ended in total failure at the first cycle. The difference between the times is considerable and shows 90 percent of improvement.



Conclusion

- 1. Heat dissipates significantly in comparison with air cooling**
- 2. Can work in hot weather condition**
- 3. Uniform distribution of**
- 4. simple design**
- 5. Low energy consumption**
- 6. No electrically conduction of PCM**
- 7. Properties of the PCM play a key role**

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