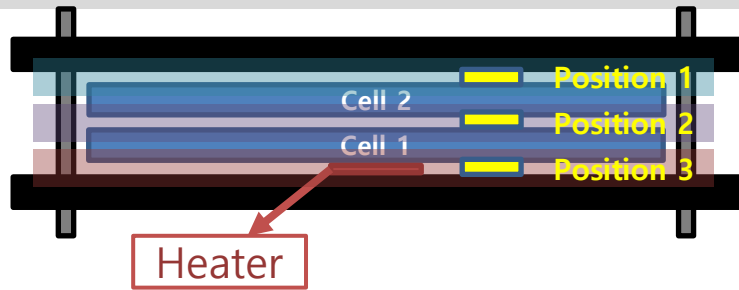


Thermal Propagation Test Verification at unit levels

Korea

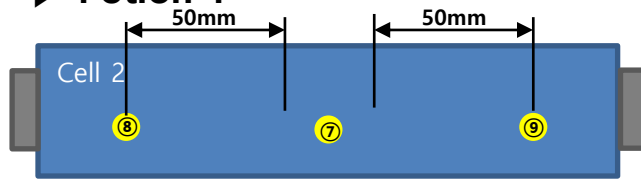


1. Condition of TP test : Cell Level

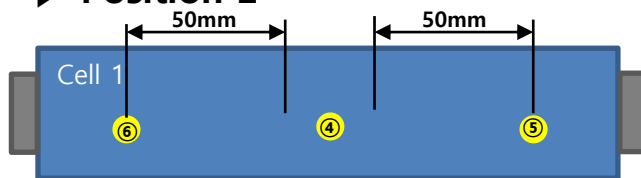


Using Heater controller
 : controlling the temp at a rate of 20°C/sec
 : AC type Heating controller

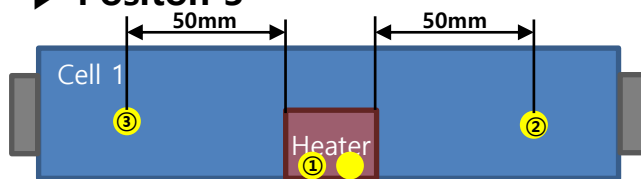
▶ Position 1



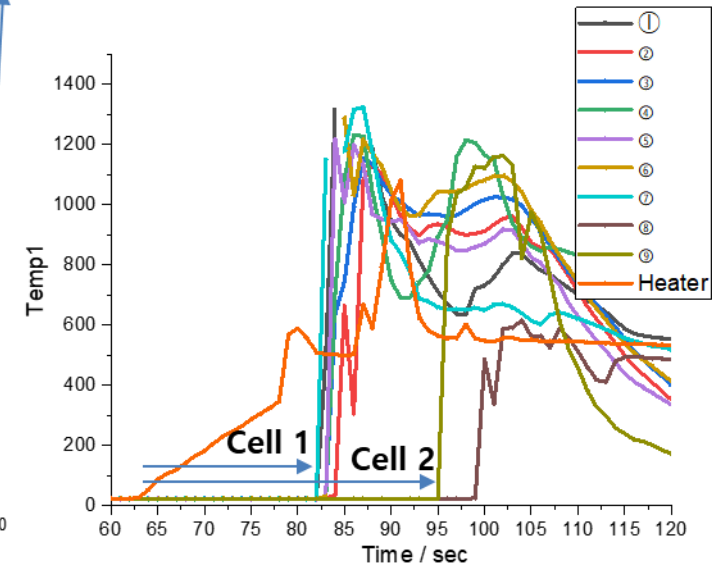
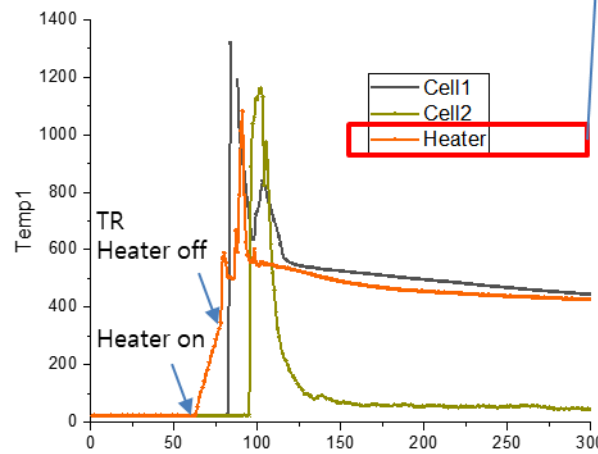
▶ Position 2



▶ Position 3



▶ TR analysis



Cell	시점	시간(s)
1	TR time	18sec
2	TR time	34sec

② Temperature sensor

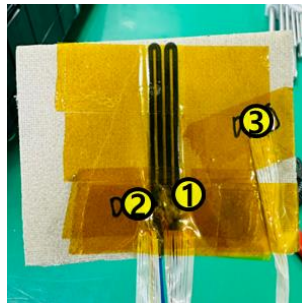
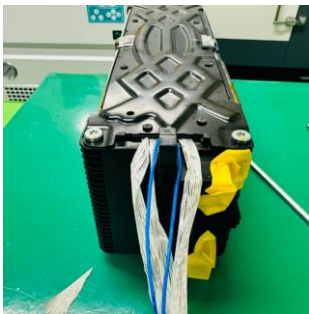
1. Condition of TP test : Module Level



Heater

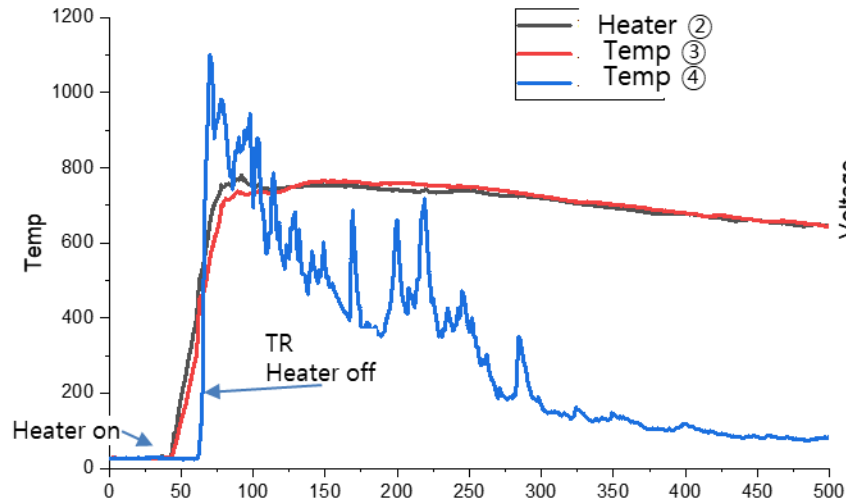


- Heater Temp : ①, ②
- Cell Temp : ③, ④



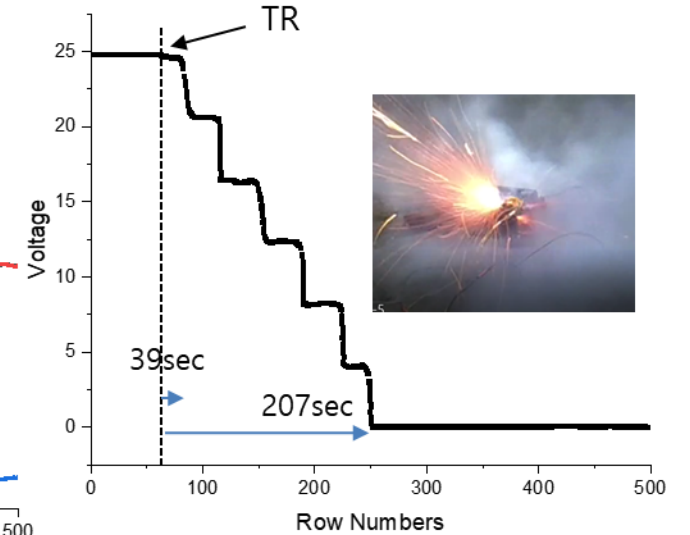
Test result

► Temperature



Cell	TR time	Time(s)
1	After heater on	18s

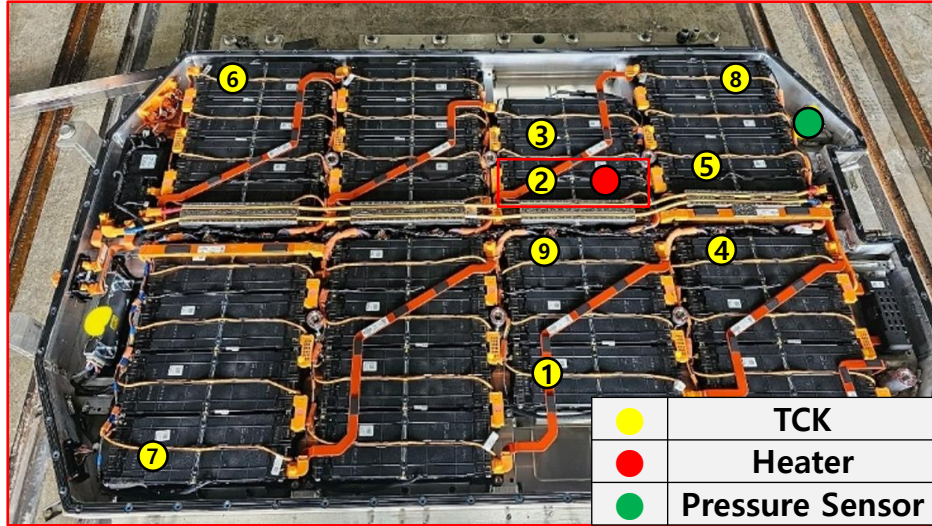
► Voltage



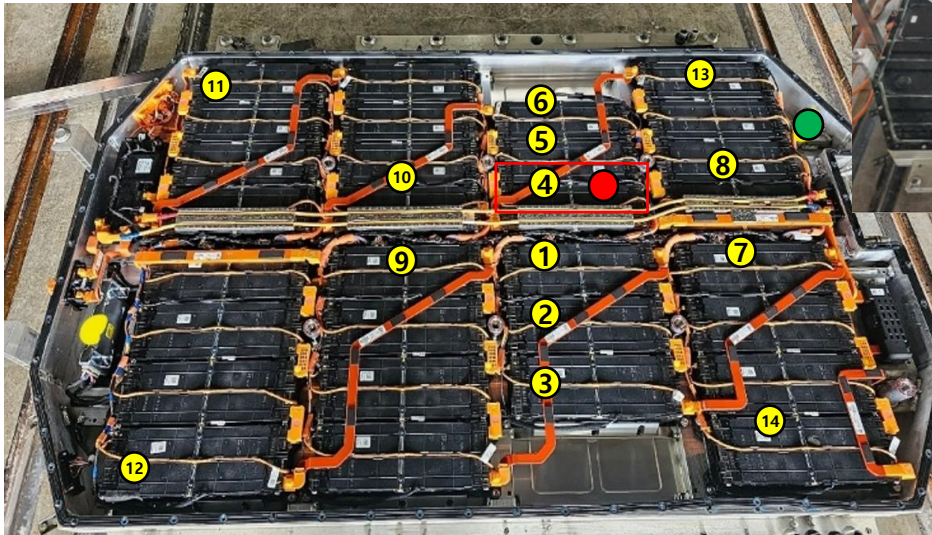
	Voltage(V)	Time(s)
Voltage drop	24.75V	39s
0V	-	207s

1. Condition of TP test : Pack Level

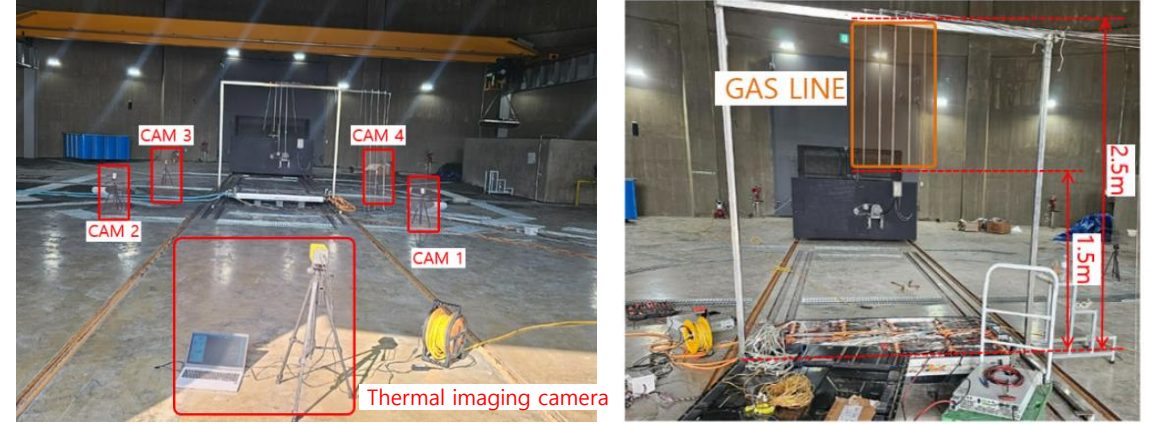
Position of Sensor



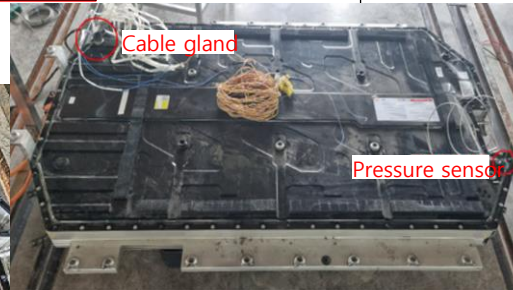
<Position of sensor>



Test

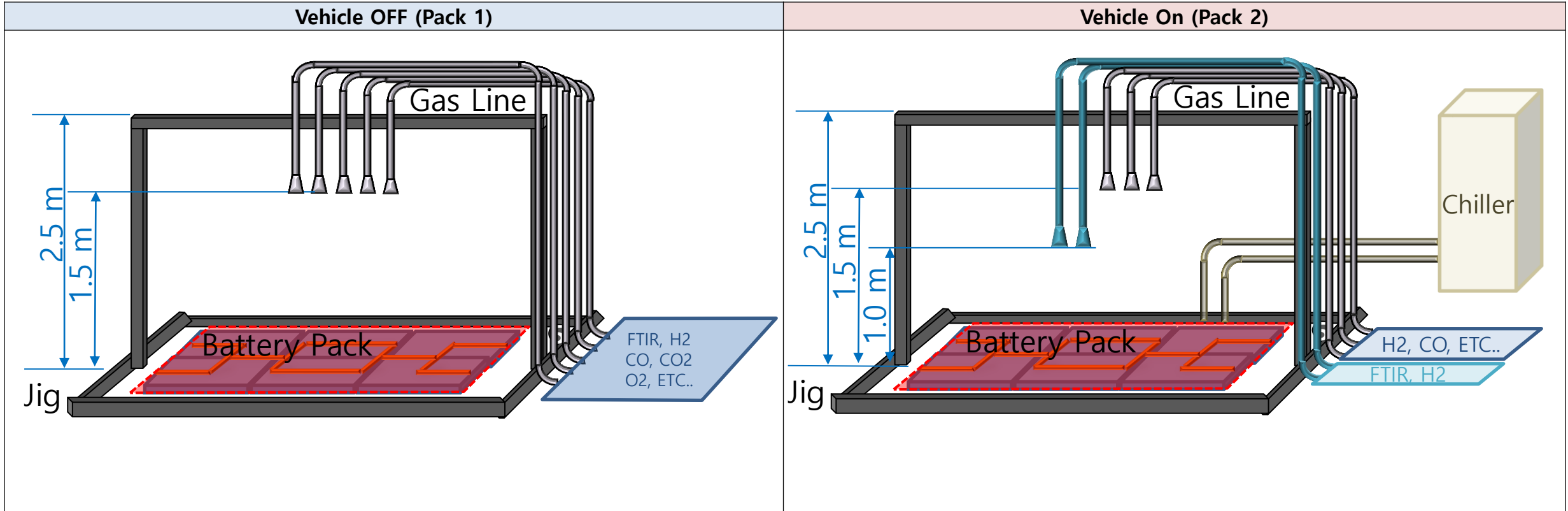


<Test setup>

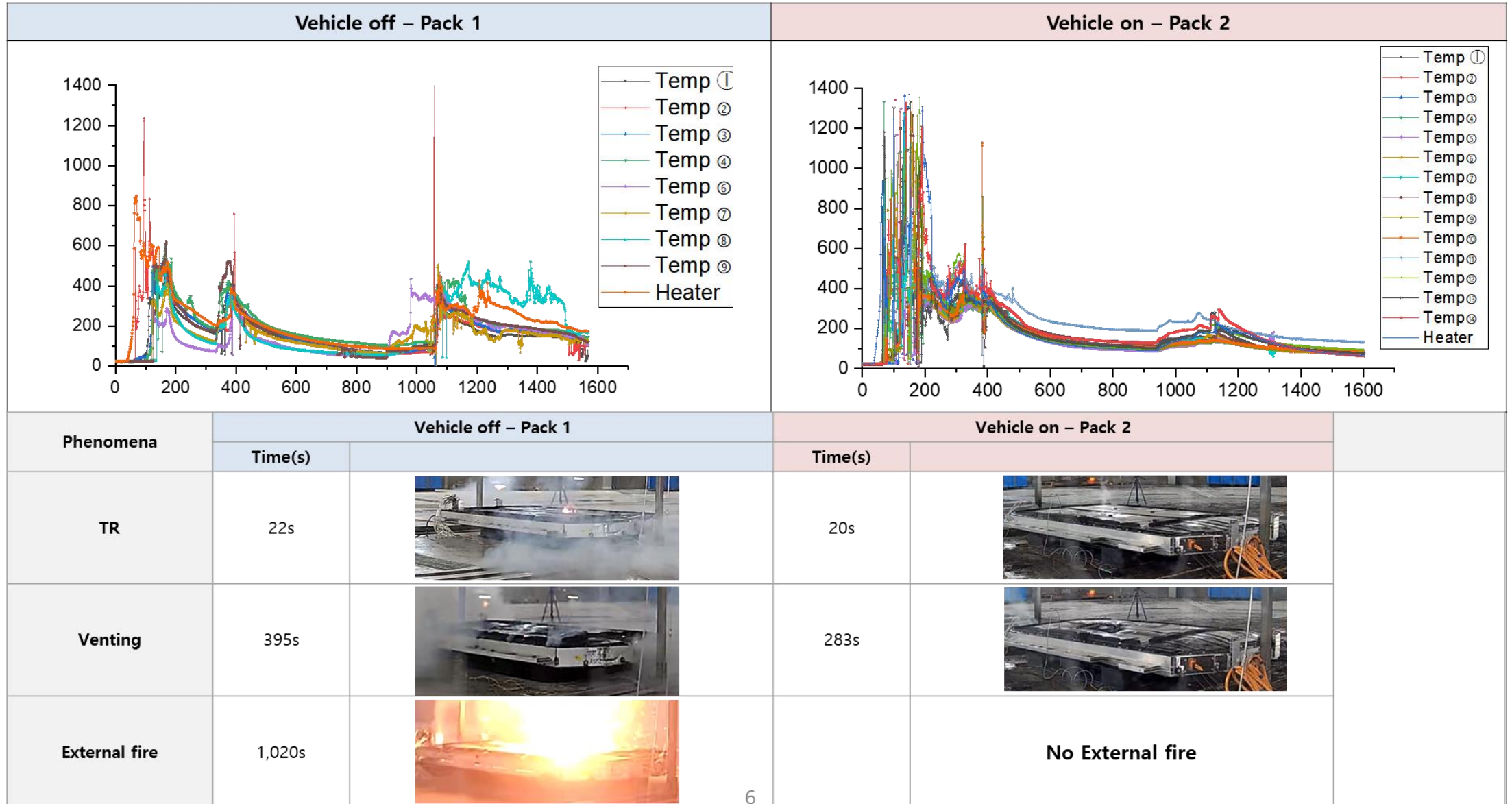


<Test setup>

1. Condition of TP test : Pack Level

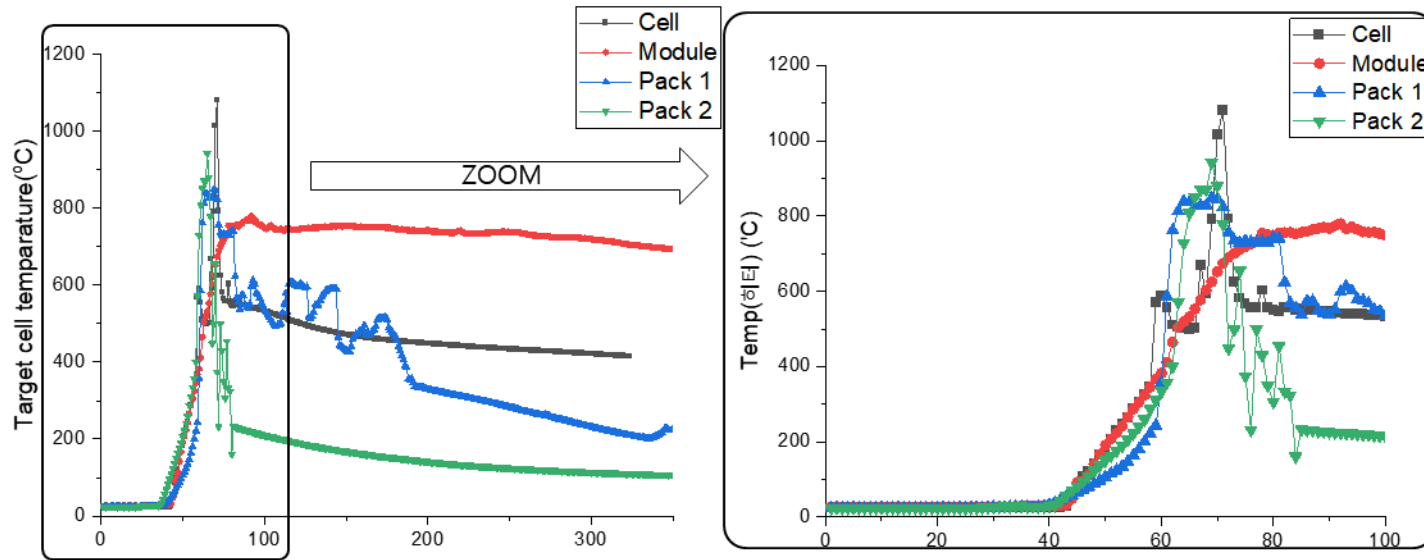


1. Condition of TP test : Pack Level



Condition of TP test : Cell, Module, Pack

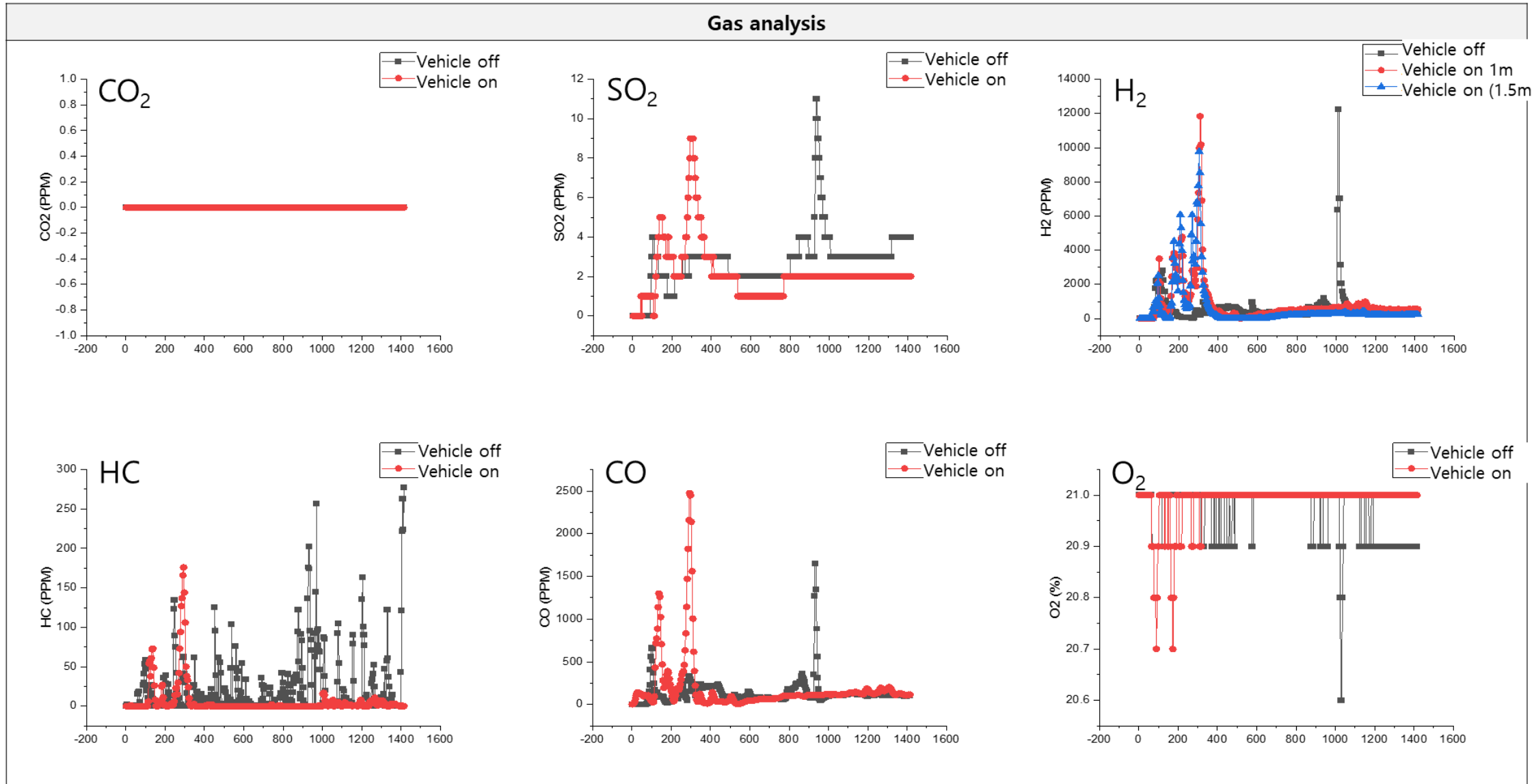
▶ TR time comparison (Heater Temp)



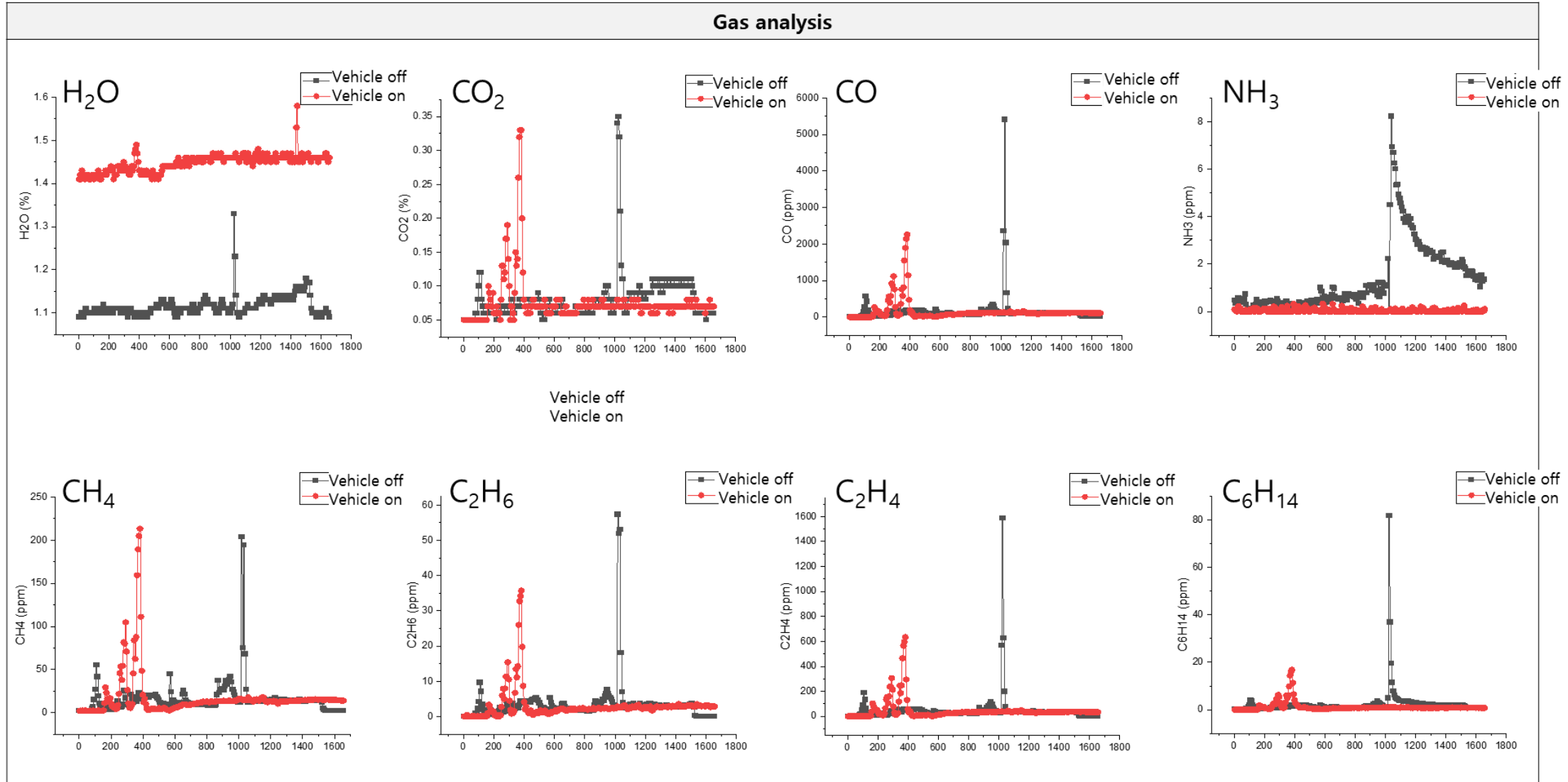
Heating rate	20°C/s
TR time	18~ 21s

▶ The TR time(after heater on) is almost same regardless of the test level

Gas analysis

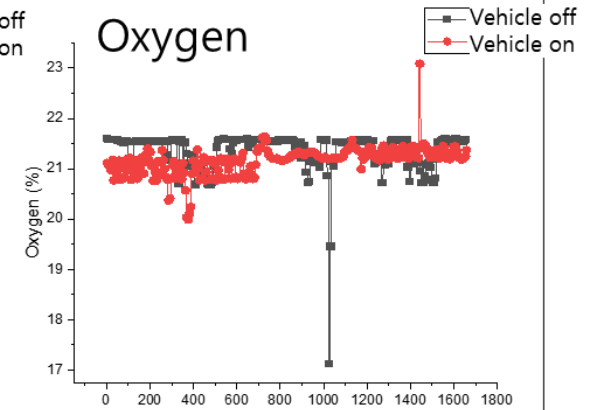
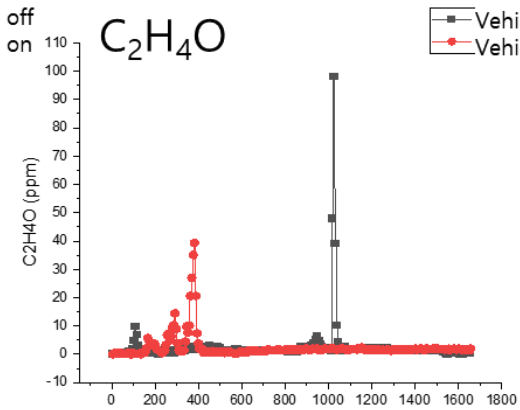
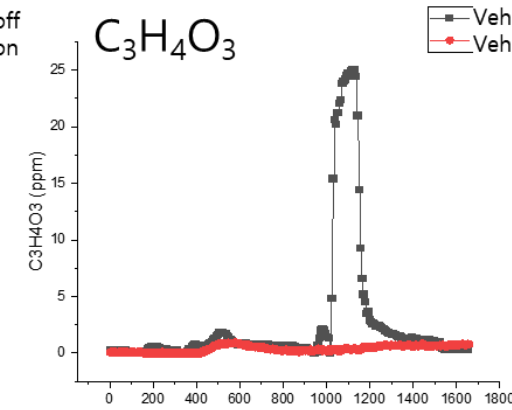
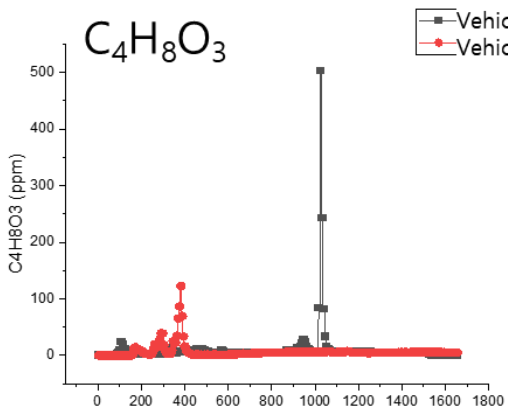
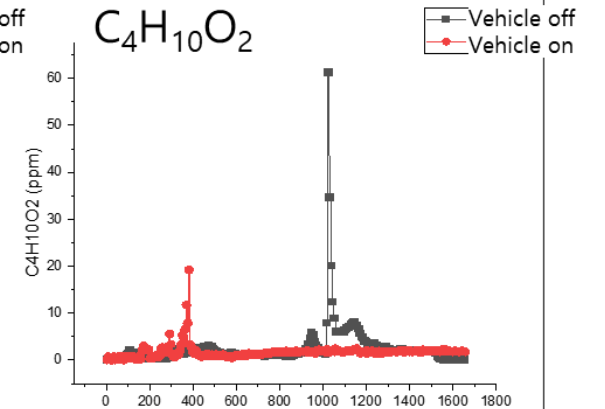
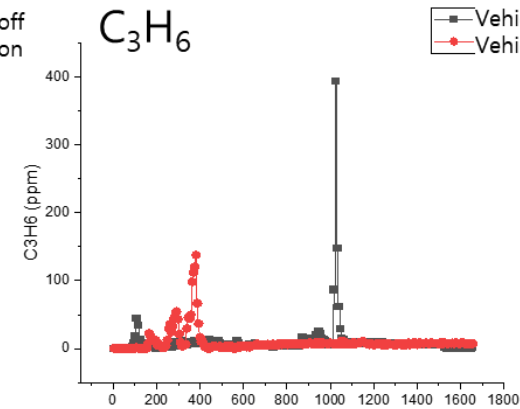
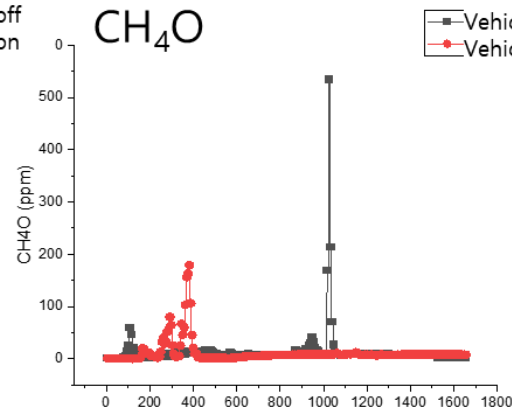
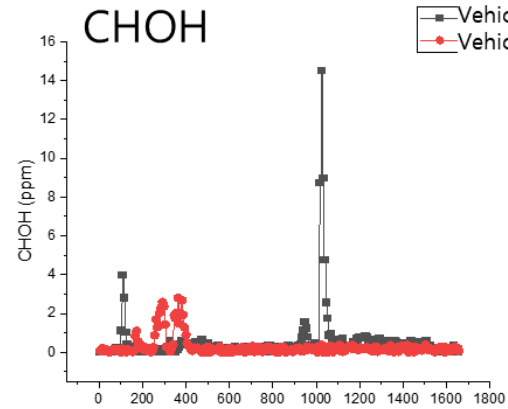


Gas analysis



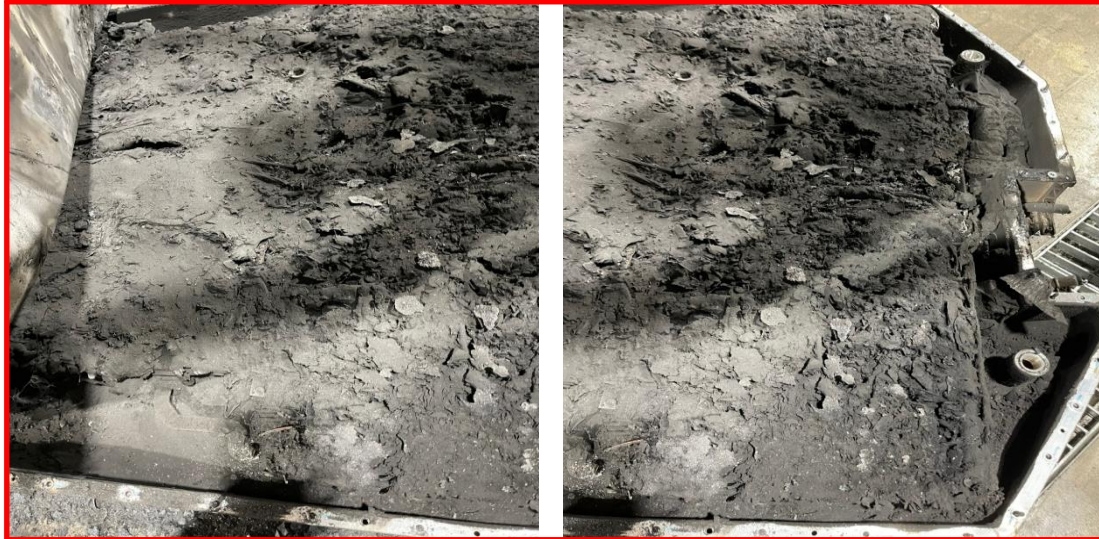
Gas analysis - FTIR

Gas analysis



After the TP test

Pack 1 – Vehicle off



Pack 2 – Vehicle on



Vehicle TP test


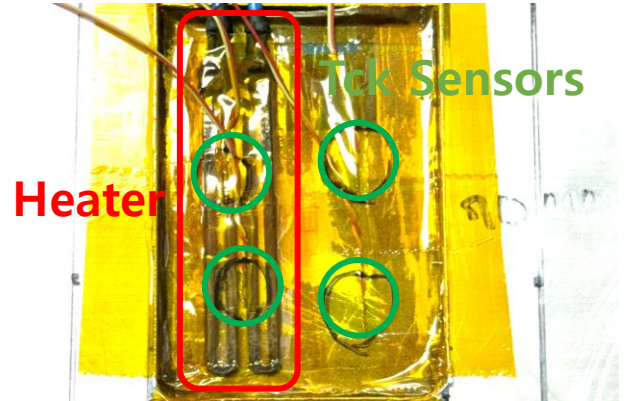

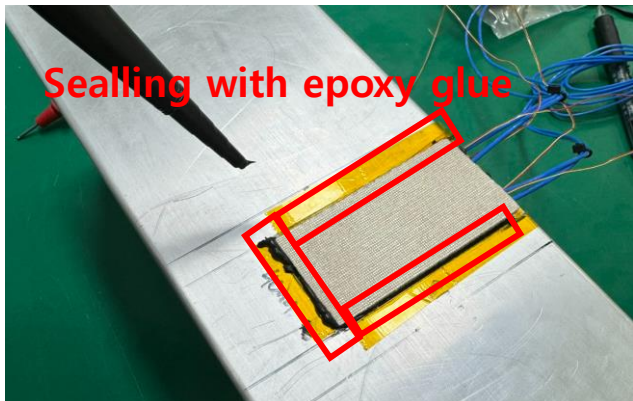

Test : 17 January 2023

Korea



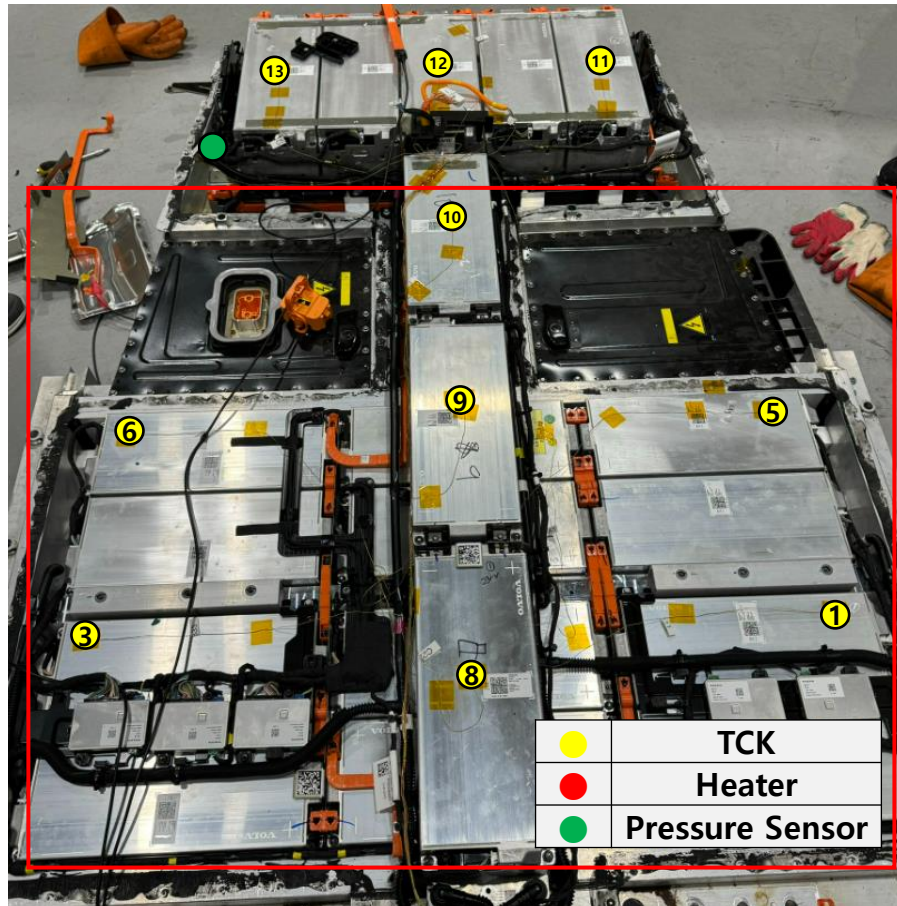
Heater Installation in module/cell

Heater Resistance is 300 mΩ using the 4-wire method.

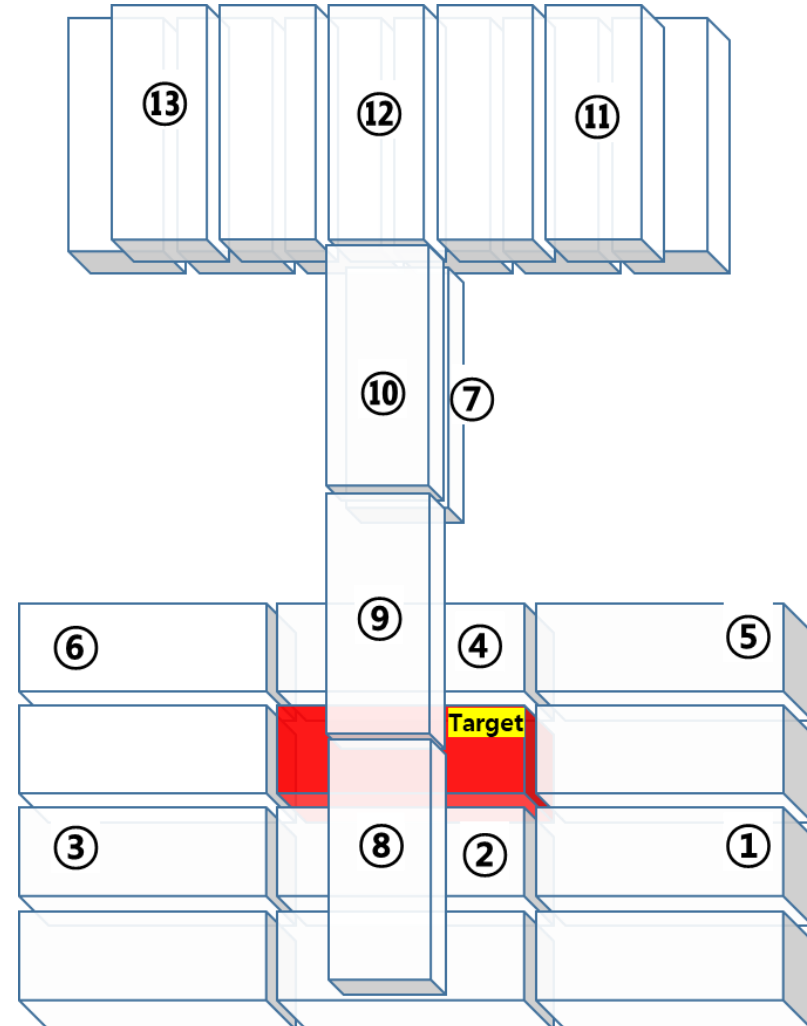
a) Housing cutting (40*70mm)	b) Attach heater, Tck sensors	c) Attach non-combustible pad
 <p>Attaching glass tape to sharp surfaces</p>	 <p>Heater</p> <p>Tck Sensors</p>	 <p>Non-combustible pad</p>
d) Sealling with epoxy glue	e) Closely attach aluminum tape	<p>► Installation of temperature sensor</p> <ul style="list-style-type: none">- Heater surface: 2 point (independent measurement)- target cells in front: 2 point
 <p>Sealling with epoxy glue</p>		

TEST SETUP (Battery pack)

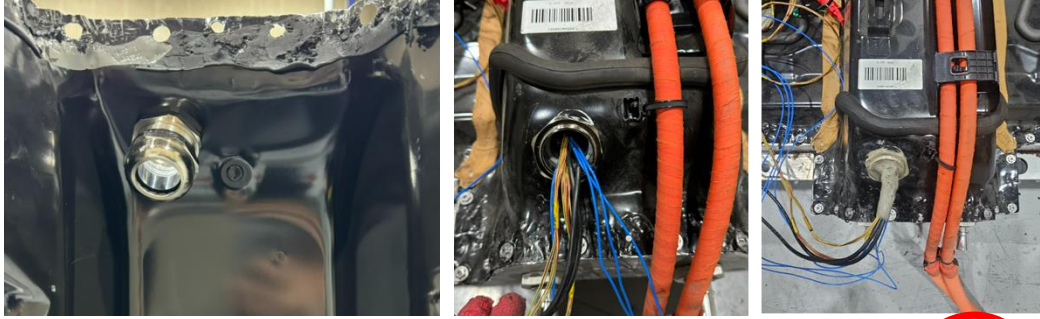
- Attach the TCK sensor to the top of the module case
- After attaching the TCK sensor, secure it with glass tape (non-flammable)



bottom
of pack



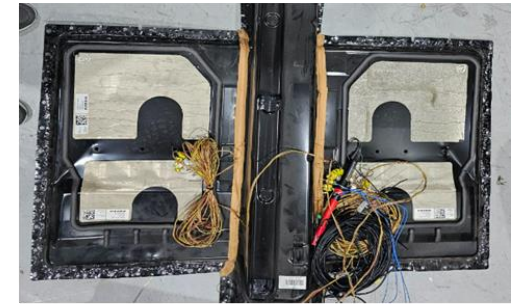
TEST SETUP (Battery pack)



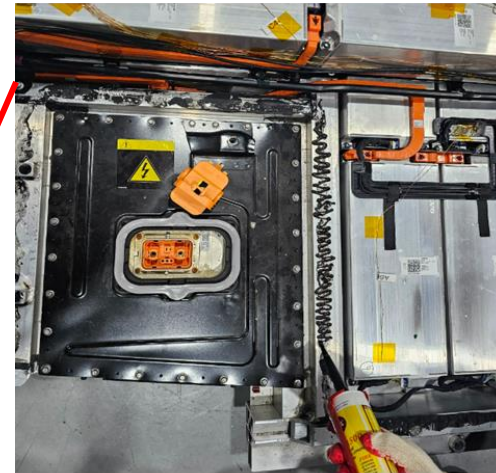
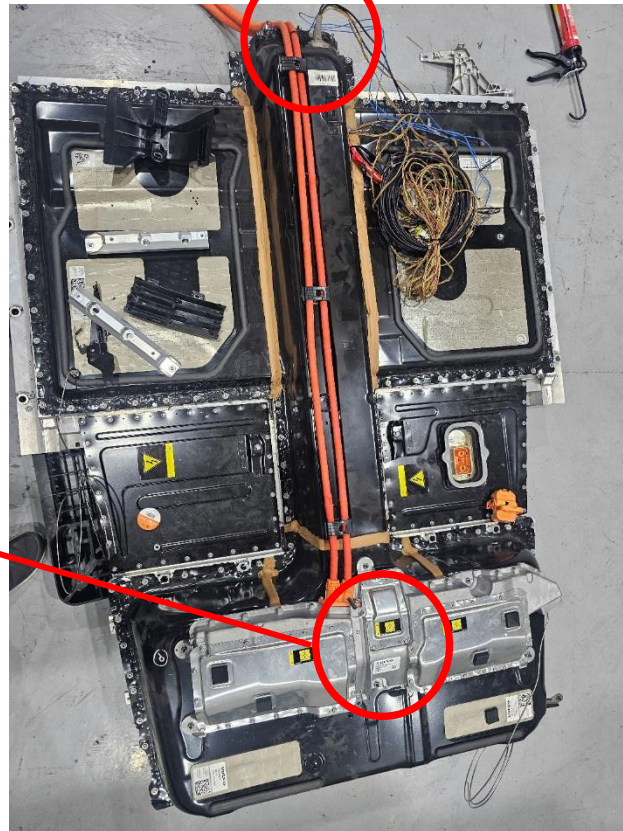
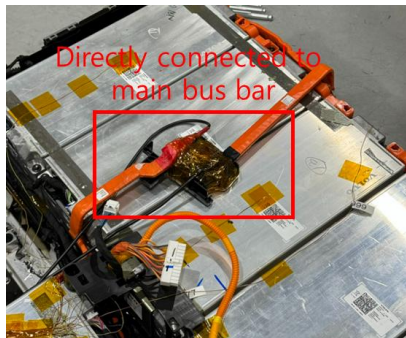
<Cable gland for sensors>



<Before flattening>



< After flattening >



< Epoxy silicone application before/after attaching pack cover >



Cabin interior sensor installation

► Temperature sensor installation



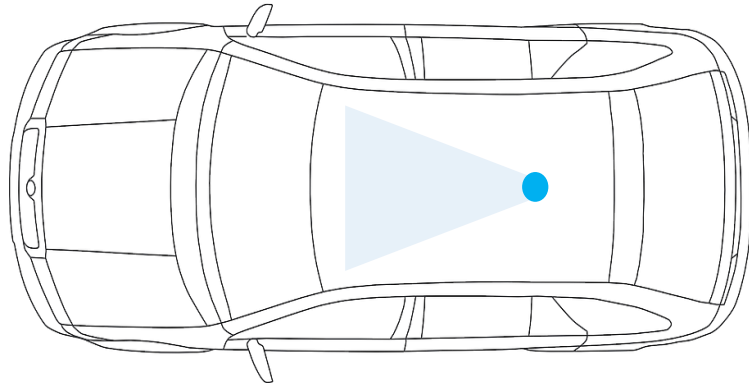
- a) Installation location_TOTAL 10 points in the cabin
- Each seat seating area : 4 points
 - Each seat headrest : 4 points
 - Front seat foot mat : 2 points
- B) Vehicle upper cable gland installation
- Pass all sensor wiring
 - Sealed with epoxy silicone



Cabin interior camera and gas sensor installation

► Camera installation

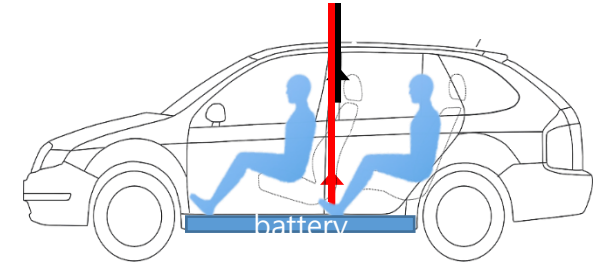
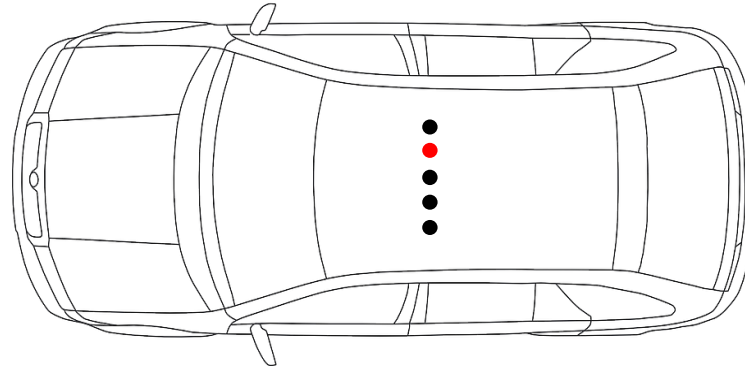
- a) Install so that the dashboard (front seat) is visible.



● : Camera

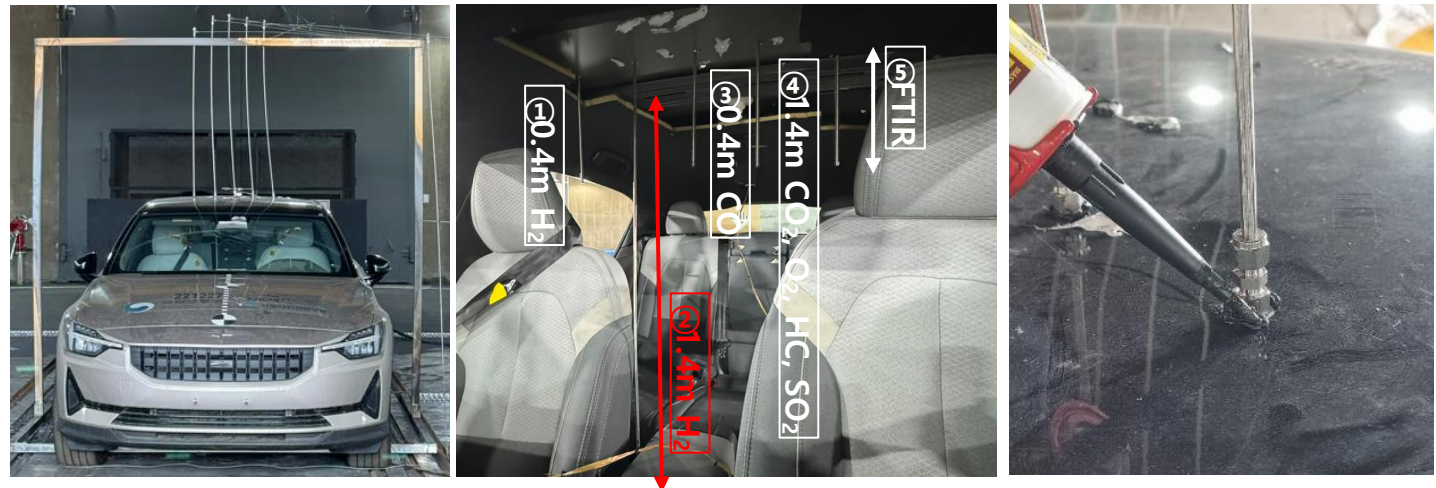
► Installation of organic matter measurement sensor

- A) Pipe connection after working on the hole in the upper part of the vehicle
- B) After connecting the pipe, seal it with epoxy silicone.



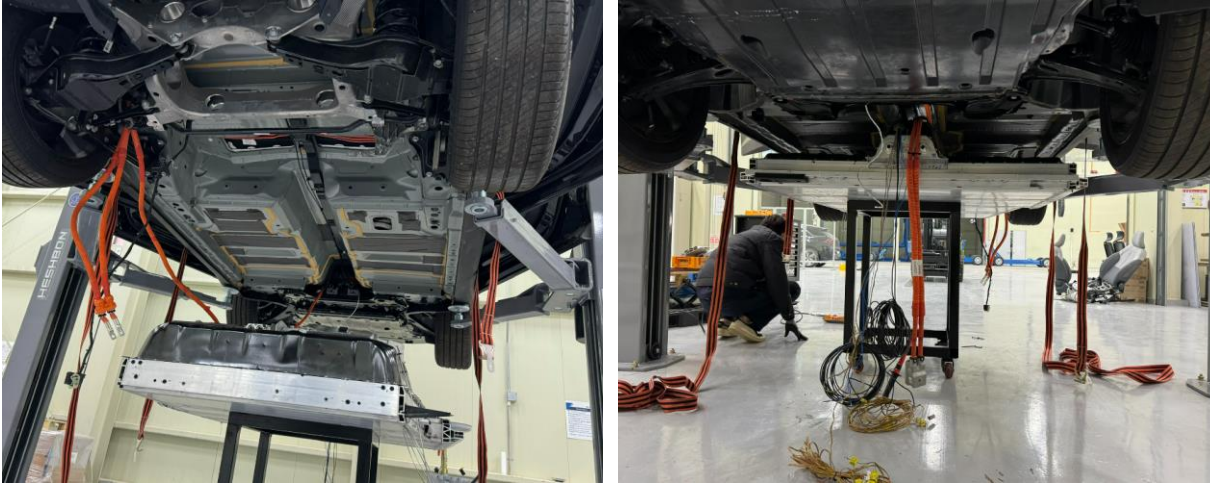
●● : Gas line

Measuring gases : CO, O₂, H₂ Particles, Combustible gases

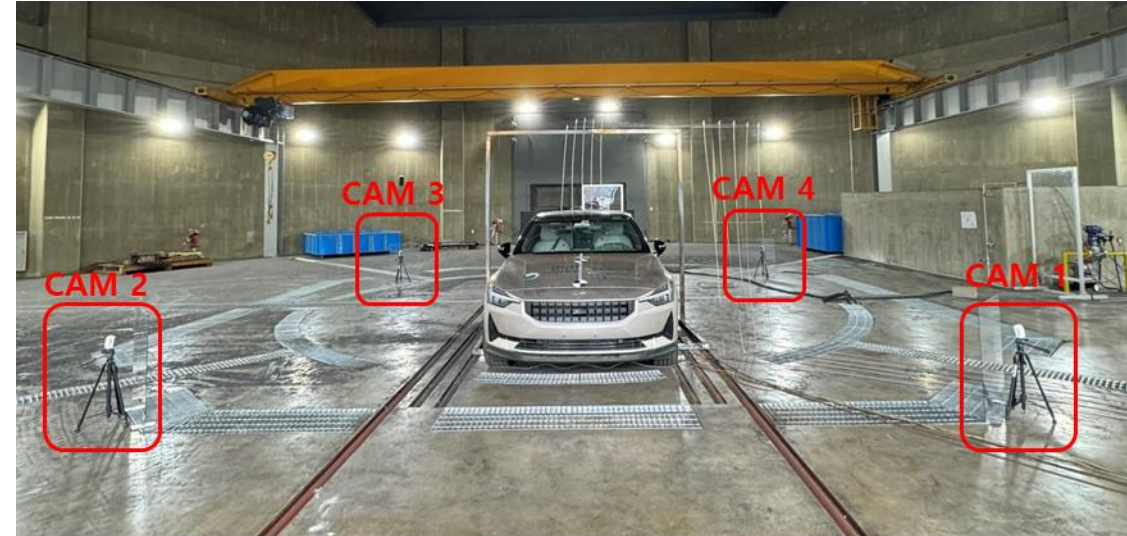


TEST SETUP (Vehicle)

- ▶ Reassemble the battery pack into the vehicle



- ▶ TP test preparing



- ▶ Vehicle-level test condition

Usual parking status

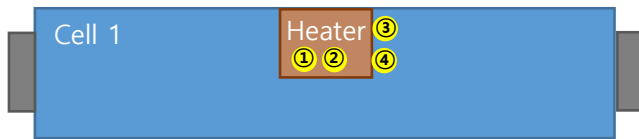
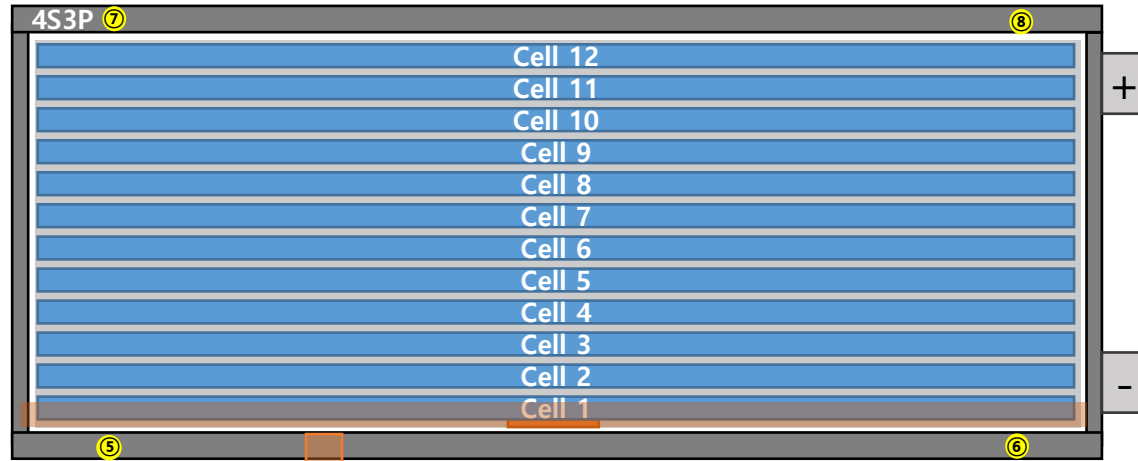
No BMS warning signal

Detached main relay



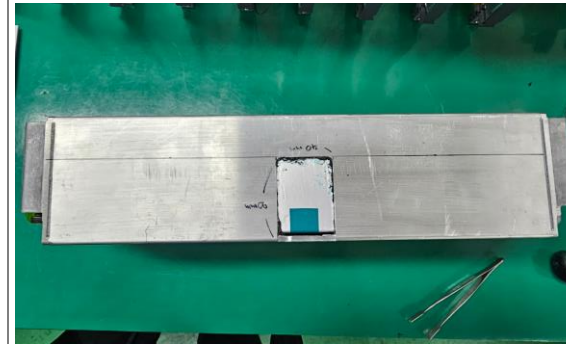
Module TP test (For TR check)

► Sensor attachment

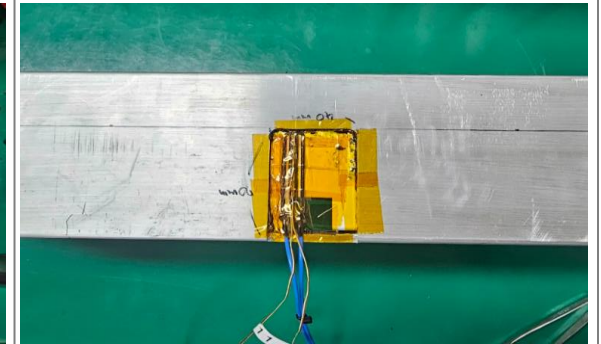


- Heater controller (heater): ①, ②
 - Near target cell: ③, ④
 - Module housing: ⑤, ⑥, ⑦, ⑧
- } Temperature sensor
8 points attached

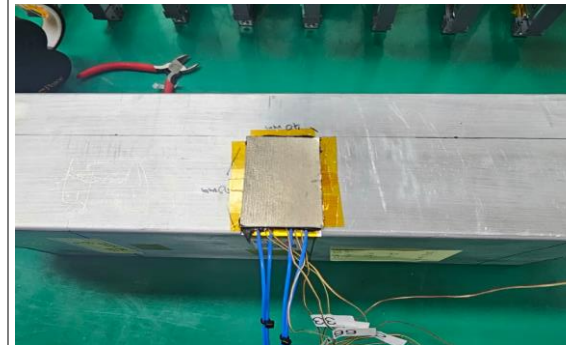
a) Housing cutting(40*70mm)



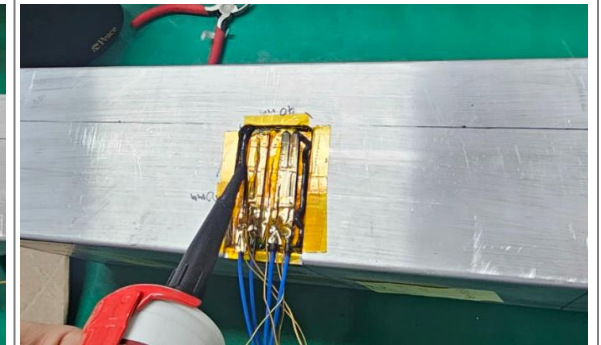
b) Attach heater, Tck sensors



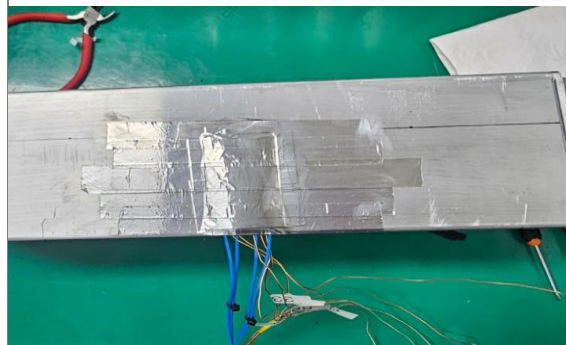
c) Attach non-combustible pad



d) Sealing with epoxy glue

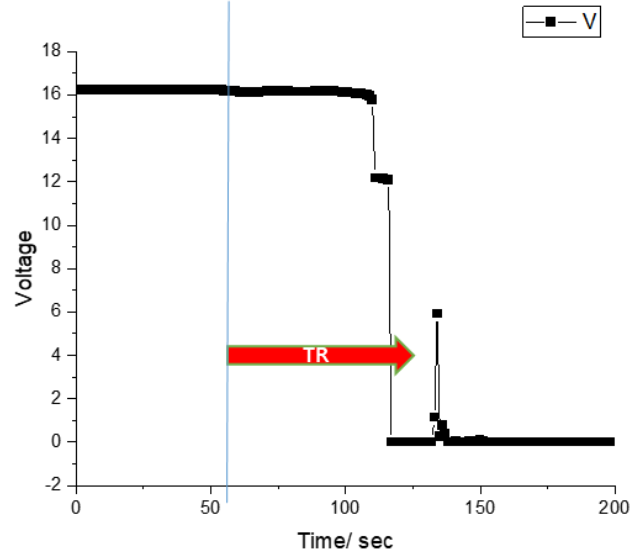


e) Closely attach aluminum tape



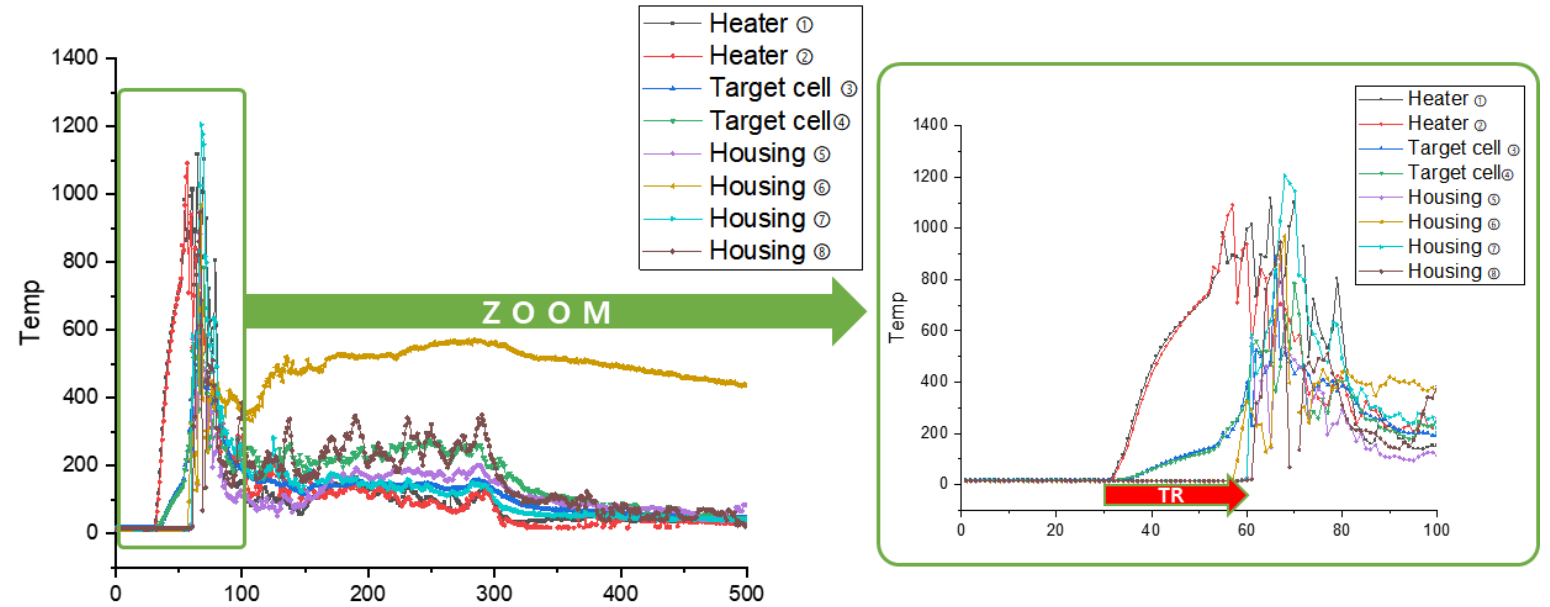
Module TP test (For TR check)

▶ Voltage data



Point	Voltage(V)	Time(s)
Venting	16.15 V	28 s
Drop Voltage	12.17 V	51 s
0V record	0 V	57 s

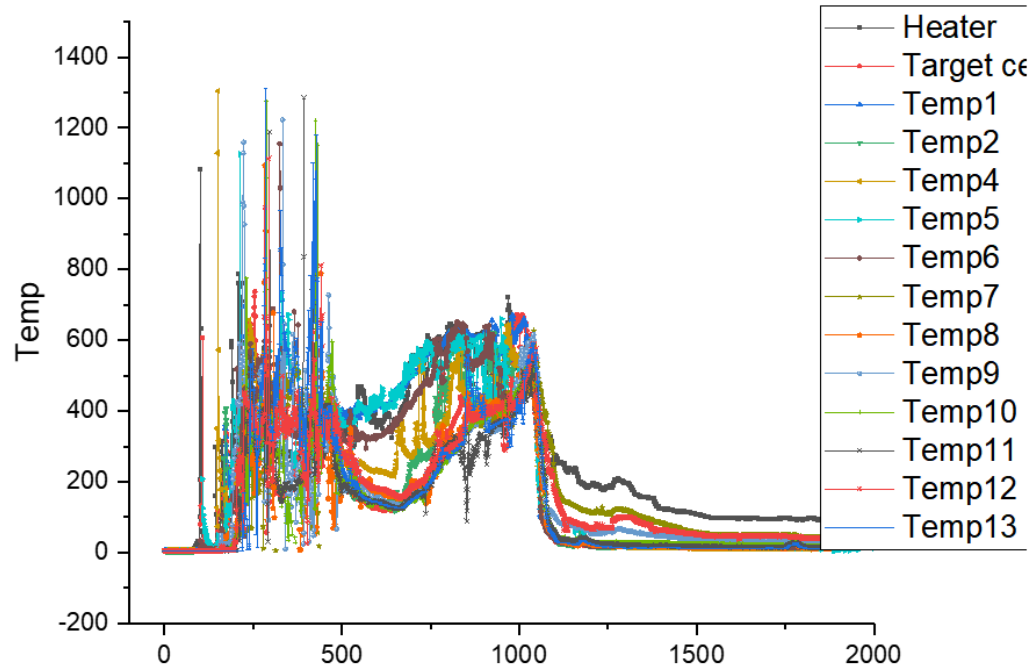
▶ Temperature data



TR Time(s)	Temperature('C)
28 s	536 'C

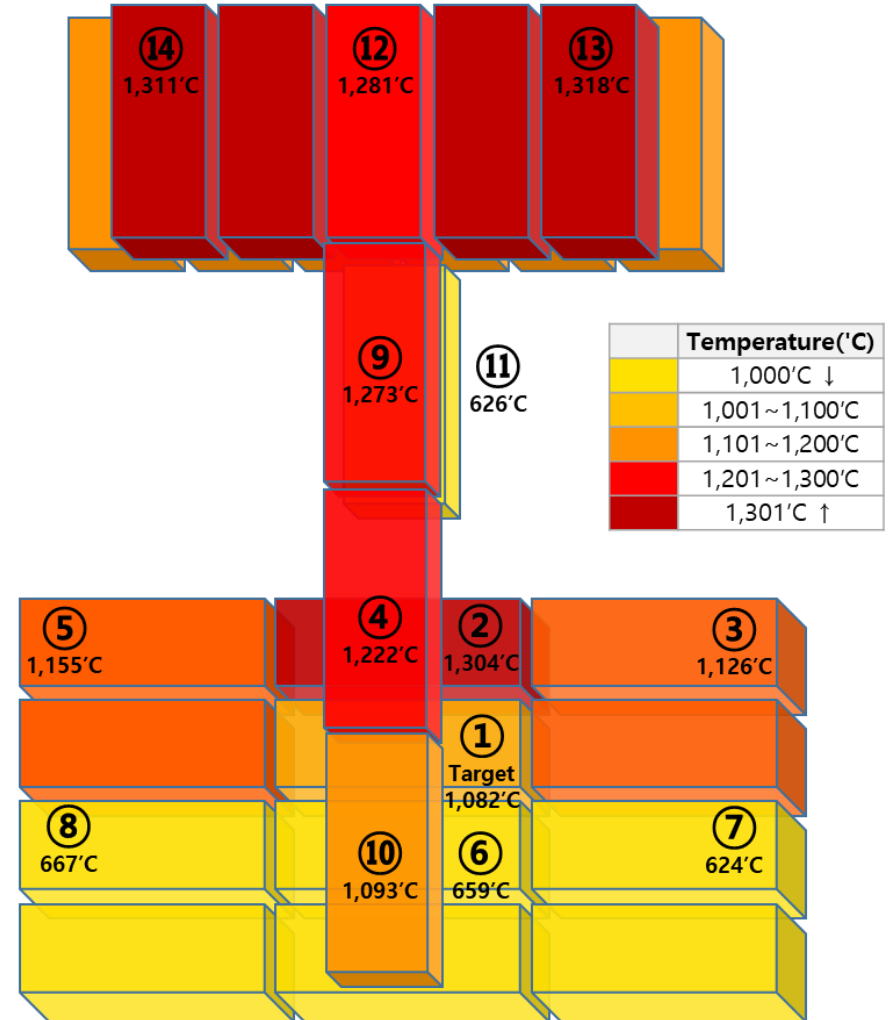
Vehicle TP test

► Temperature inside the pack



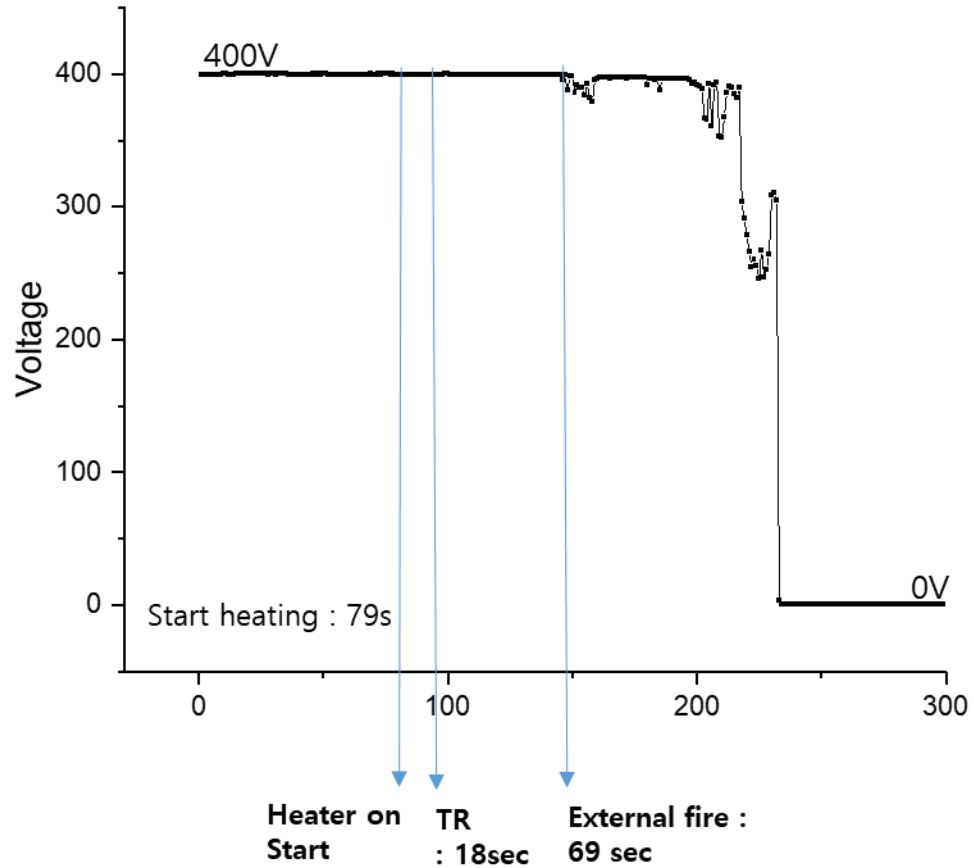
TR Time(s)	External fire
18 s	69 s

► Heat runaway sequence inside the pack












Vehicle TP test – Voltage analysis

► Voltage of the pack



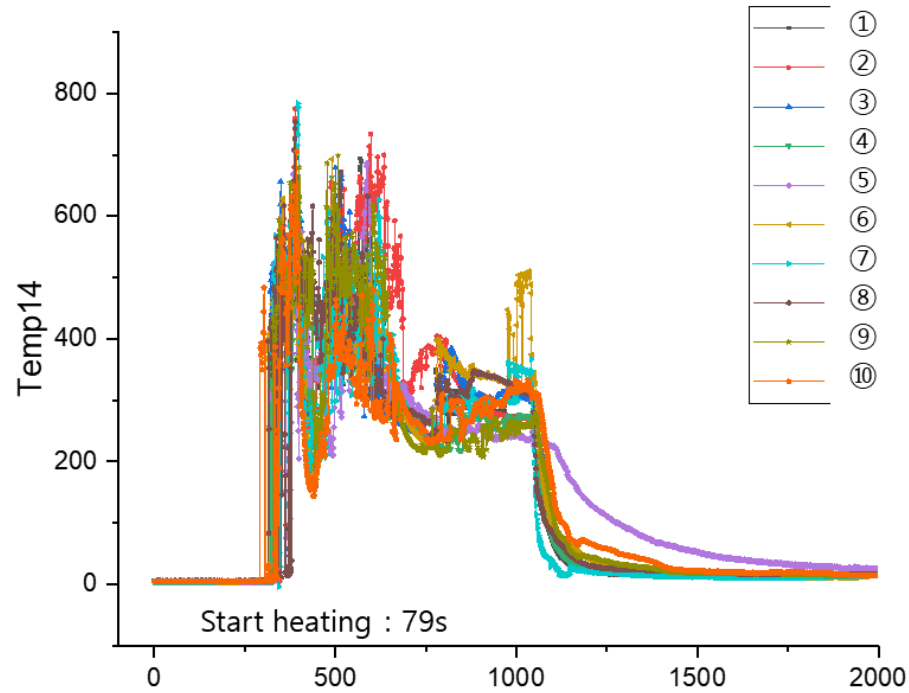
Point of view	Voltage(V)	Time(s)
TR	399.5 V	18 s
External fire	388 V	69 s
Initial voltage drop	395.5 V	67 s
Voltage step down	393 V	119 s
0V record	0 V	155 s

Vehicle TP test

<p>Ready</p>			
<p>Target cell TR 28sec</p>			
<p>External Fire 69sec</p>			

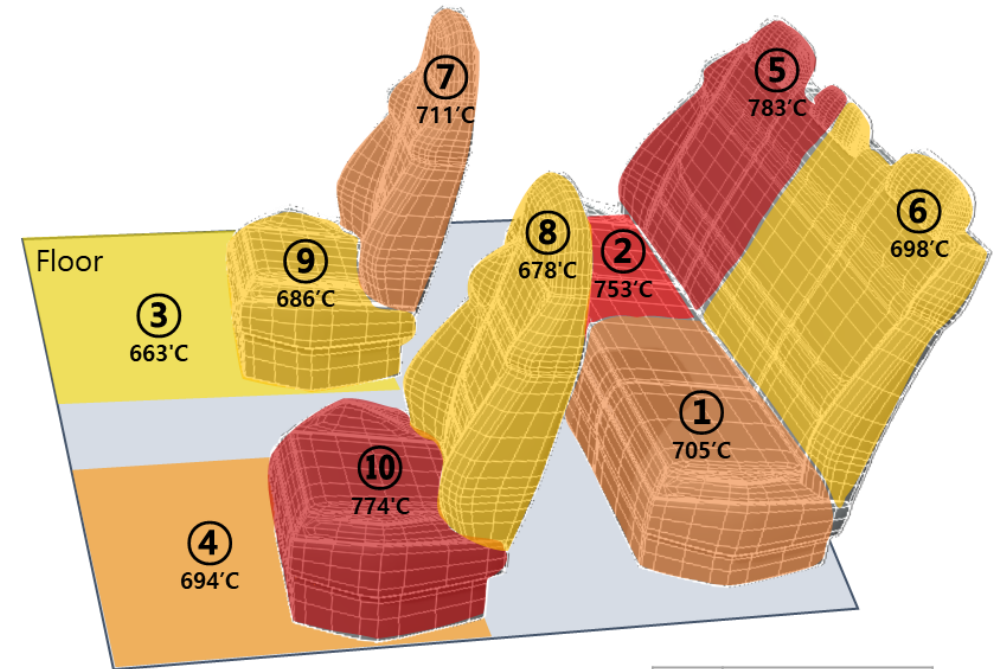
Vehicle TP test – Temperature analysis

► Cabin temperature



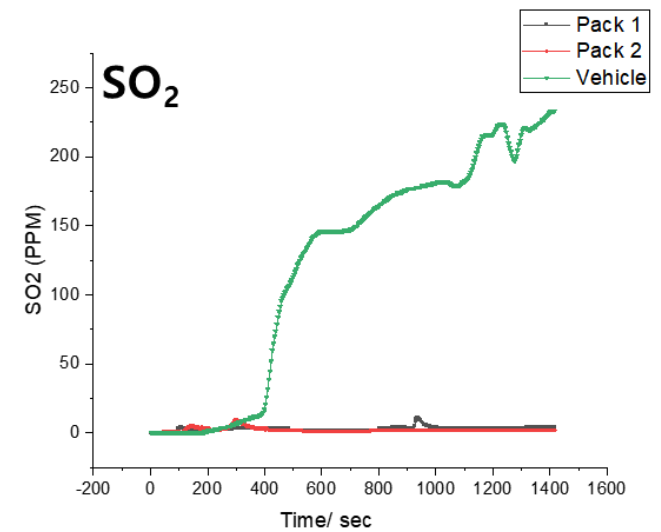
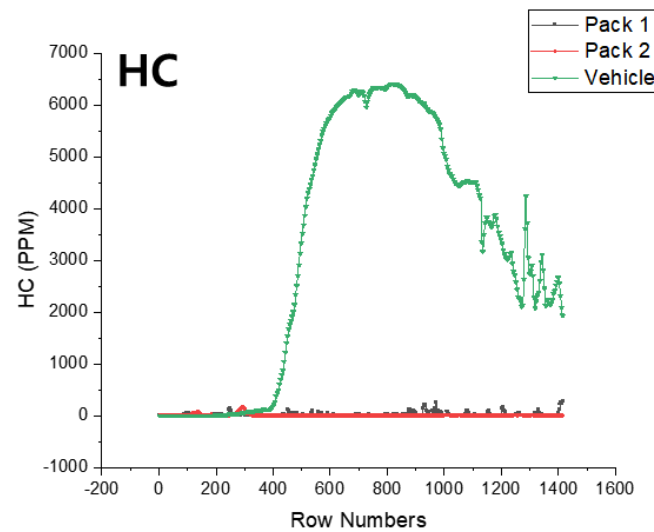
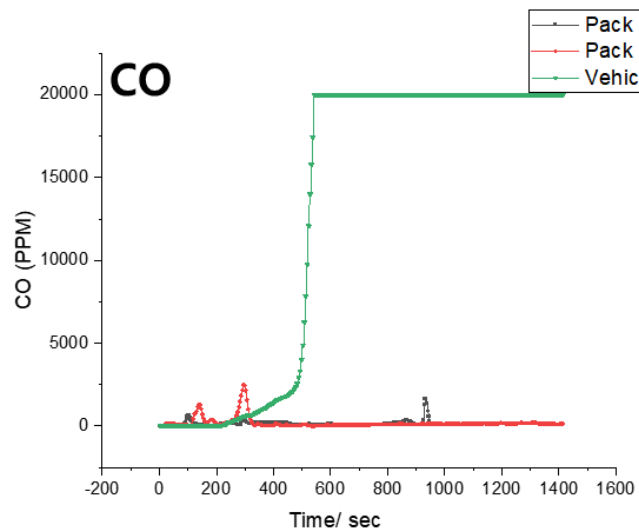
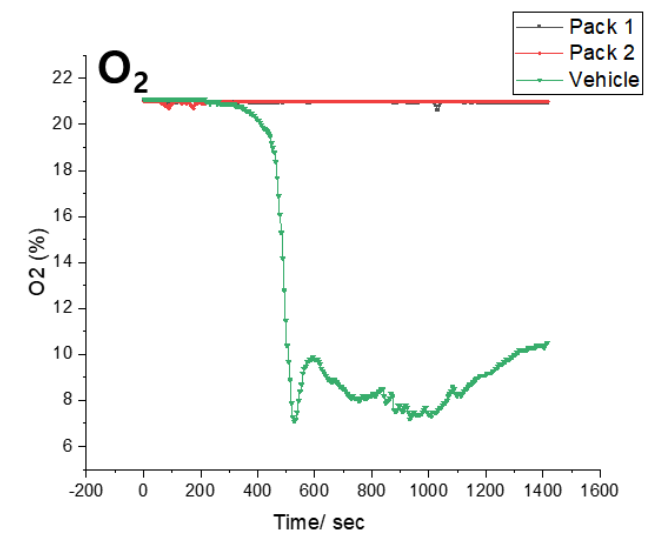
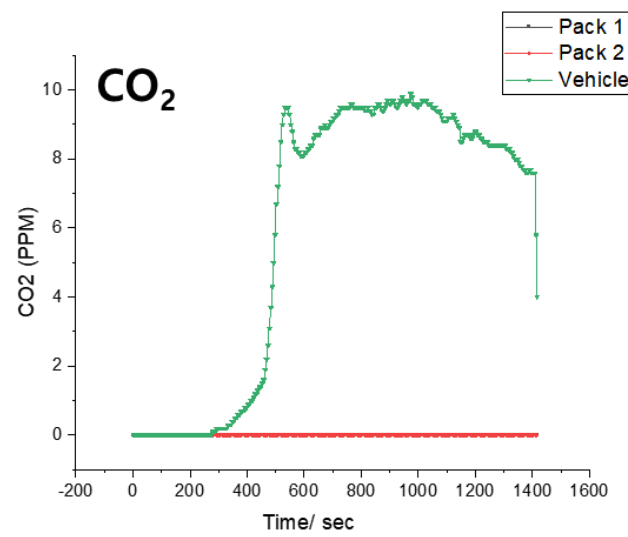
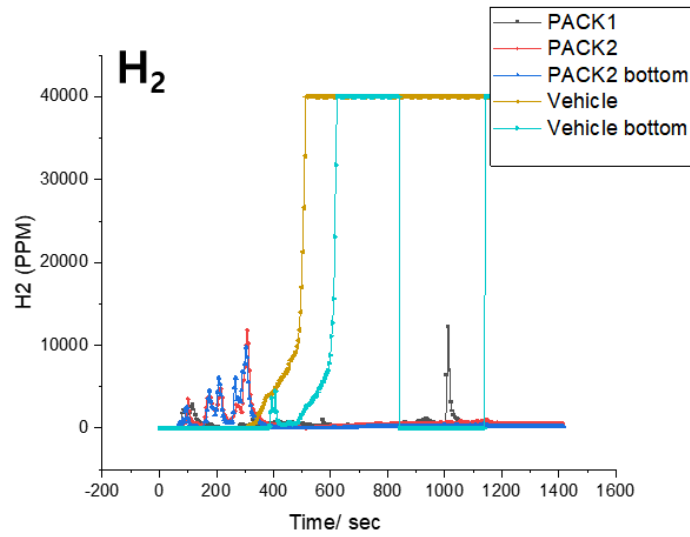
Location		Time(s) after TR	Spread	Max Tc('C)	-
Driver's seat	Floor ①	225 s	4	694 °C	
	Sitting ②	235 s	10	774.8 °C	
	Head ③	232 s	8	678.6 °C	
Passenger seat	Floor ④	223 s	3	663.8 °C	
	Sitting ⑤	233 s	9	668.3 °C	
	Head ⑥	230 s	7	711.6 °C	
Bback seat	Left head ⑦	226 s	5	783.6 °C	
	Left sitting ⑧	210 s	2	753.7 °C	
	Right head ⑨	227 s	6	686.5 °C	
	Right sitting ⑩	195 s	1	705 °C	

► Thermal propagation sequence Cabin



Temperature('C)	
Yellow	670°C ↓
Light Orange	671~700°C
Orange	701~730°C
Red	731~760°C
Dark Red	761°C ↑

Vehicle TP test – Gas analysis





<vehicle front>



<vehicle side>



<rear of vehicle>

Conclusion

Forced cooling is an effective way to delay heat transfer during the TP test at the component level. However, measuring toxic gases like CO presents challenges in these open area tests.

Conducting a vehicle-level TP test, which lacks manufacturer support, may pose challenges related to BMS control and may incur substantial costs and environmental pollution compared to component-level testing.

Exploring the option of using component-level tests is feasible if we can ensure the safety of toxic gases in the passenger compartment or demonstrate the representativeness of vehicle-level tests based on the severity of component test results.