



# Amphenol's sensor analysis

09 November 2022

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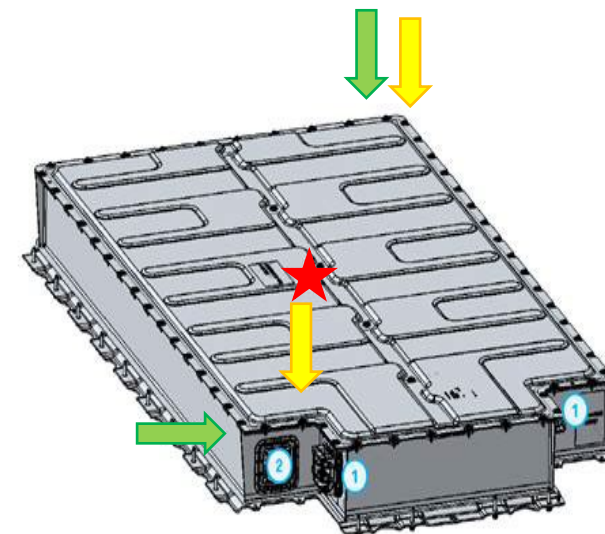
# Outline

- Test conditions
- Pressure data analysis
- H<sub>2</sub> and CO<sub>2</sub> analysis
- Detailed comparison plots
- Amphenol observations and Experiences

# Test conditions

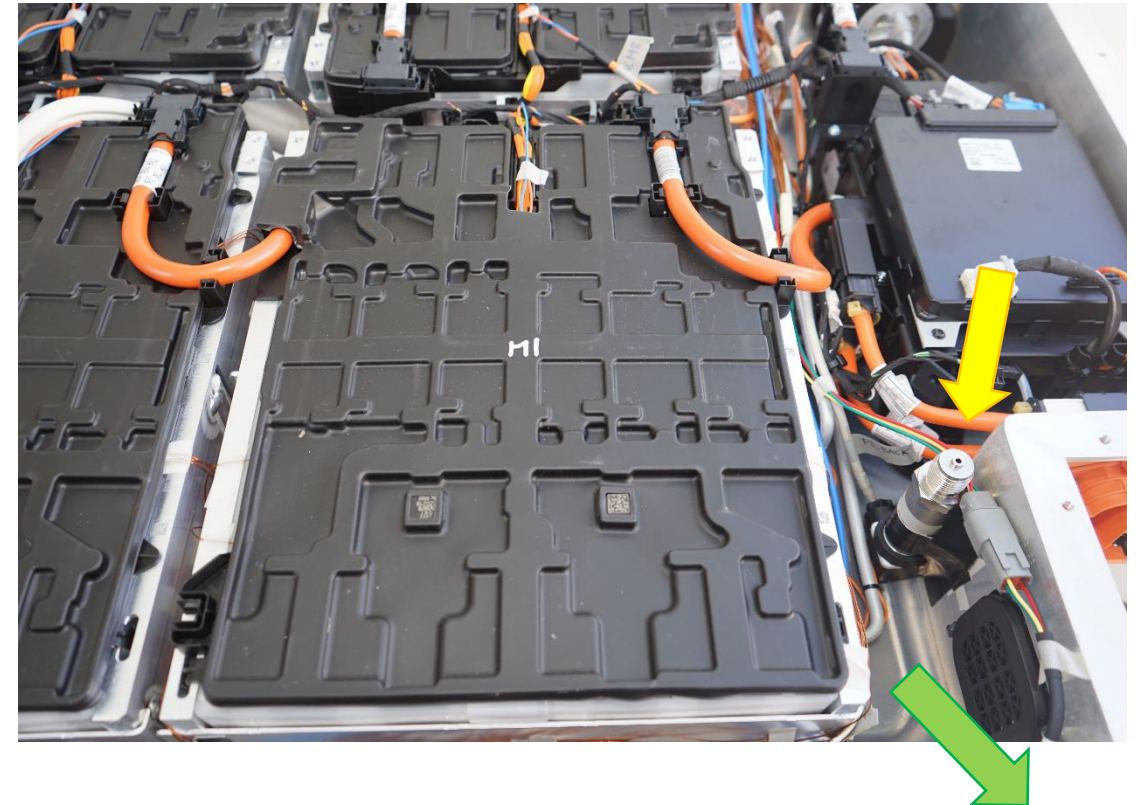
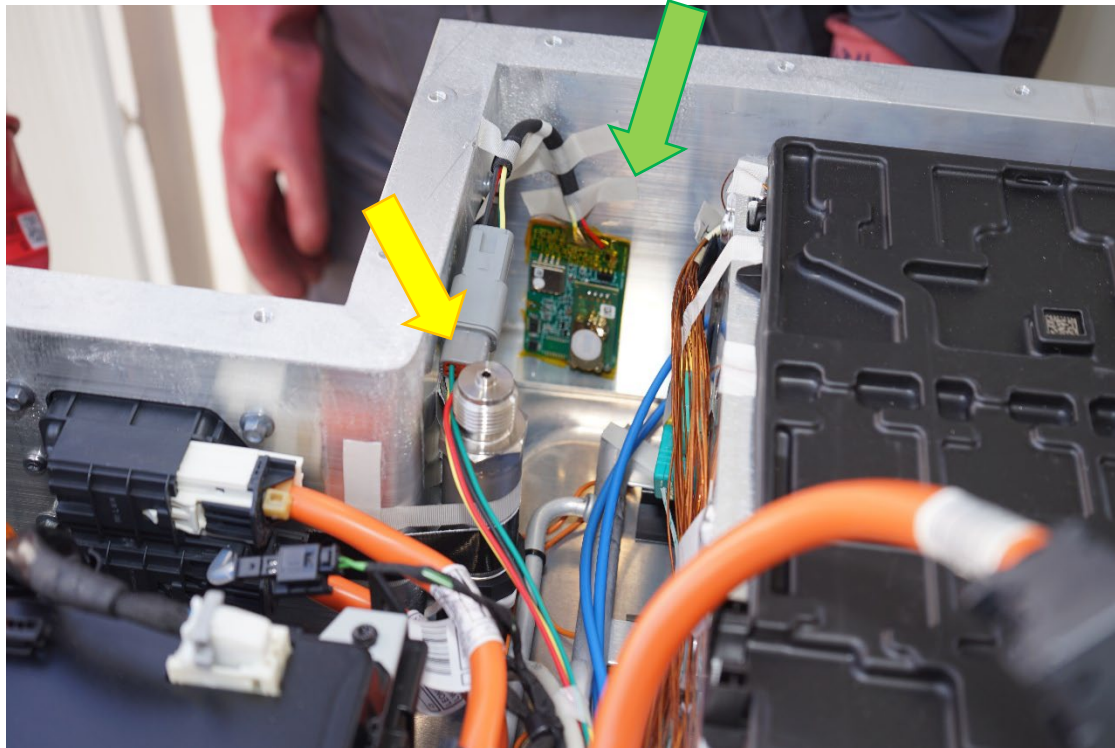
- The thermal propagation test was performed in a full vehicle;
- Two Amphenol sensors were positioned in opposite sides of the vehicle's battery pack;
- Two "off-the-shelf" commercially available pressure sensors were installed next to the Amphenol sensors.

-  Position of Amphenol sensors
-  Position of pressure sensors
-  Position of initiation cell



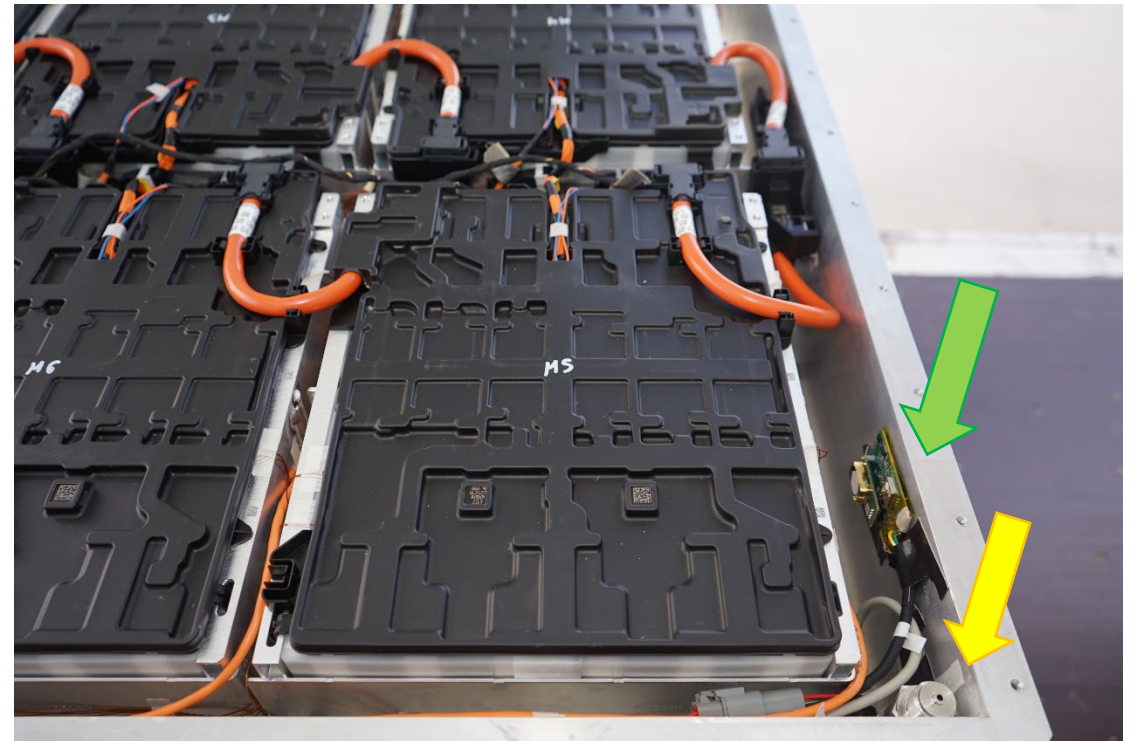
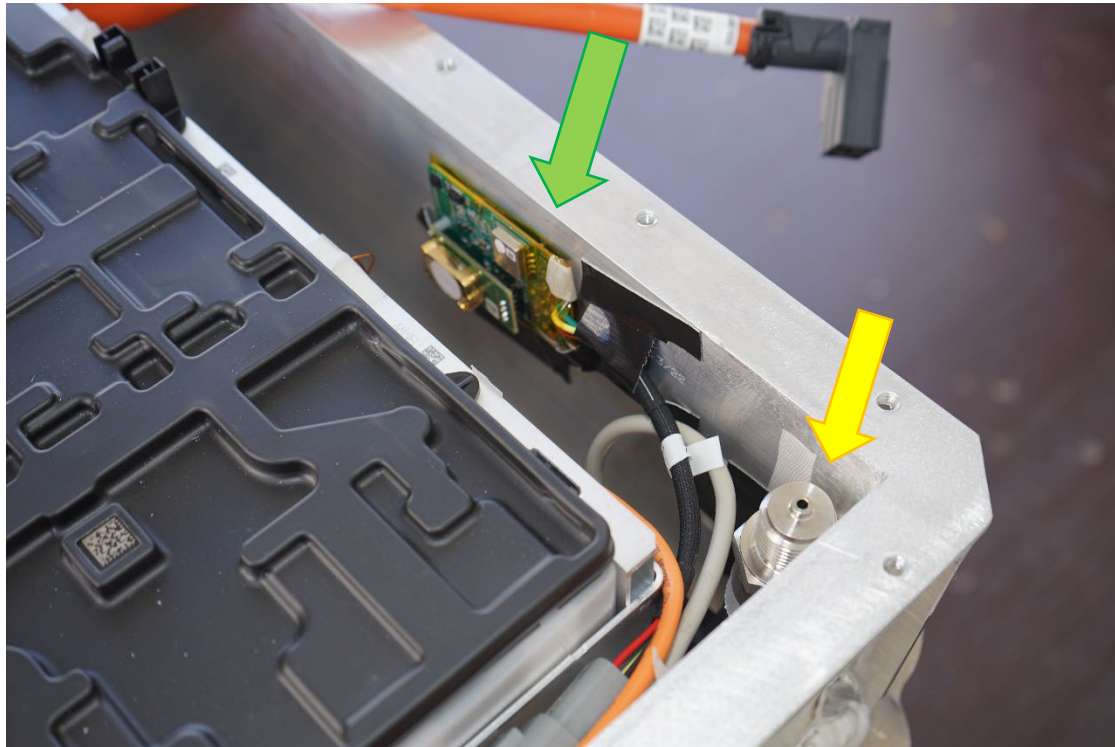
- 1 Electric plugs
- 2 Pack's vent

# Test conditions



“Back” sensors

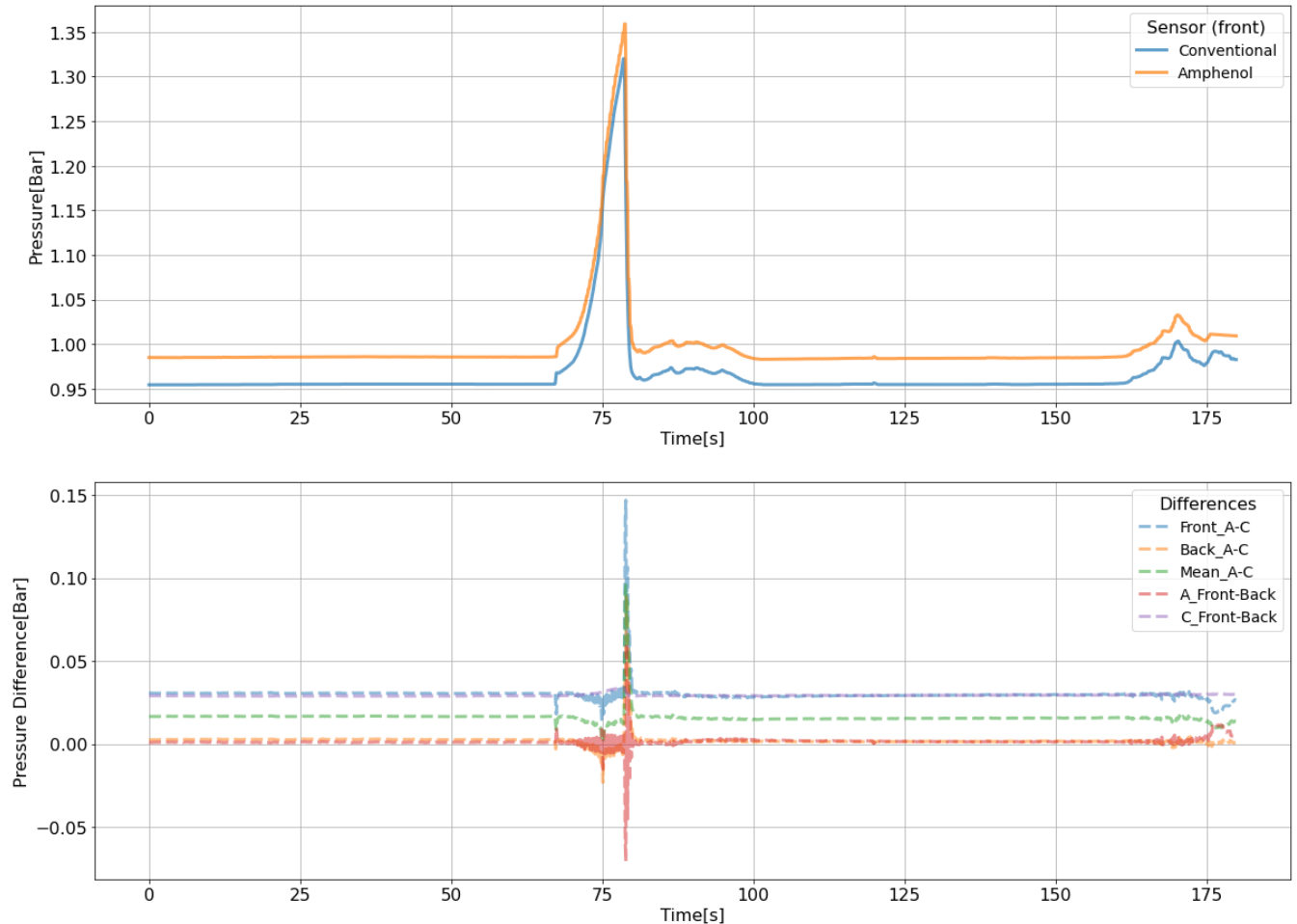
# Test conditions



“Front” sensors

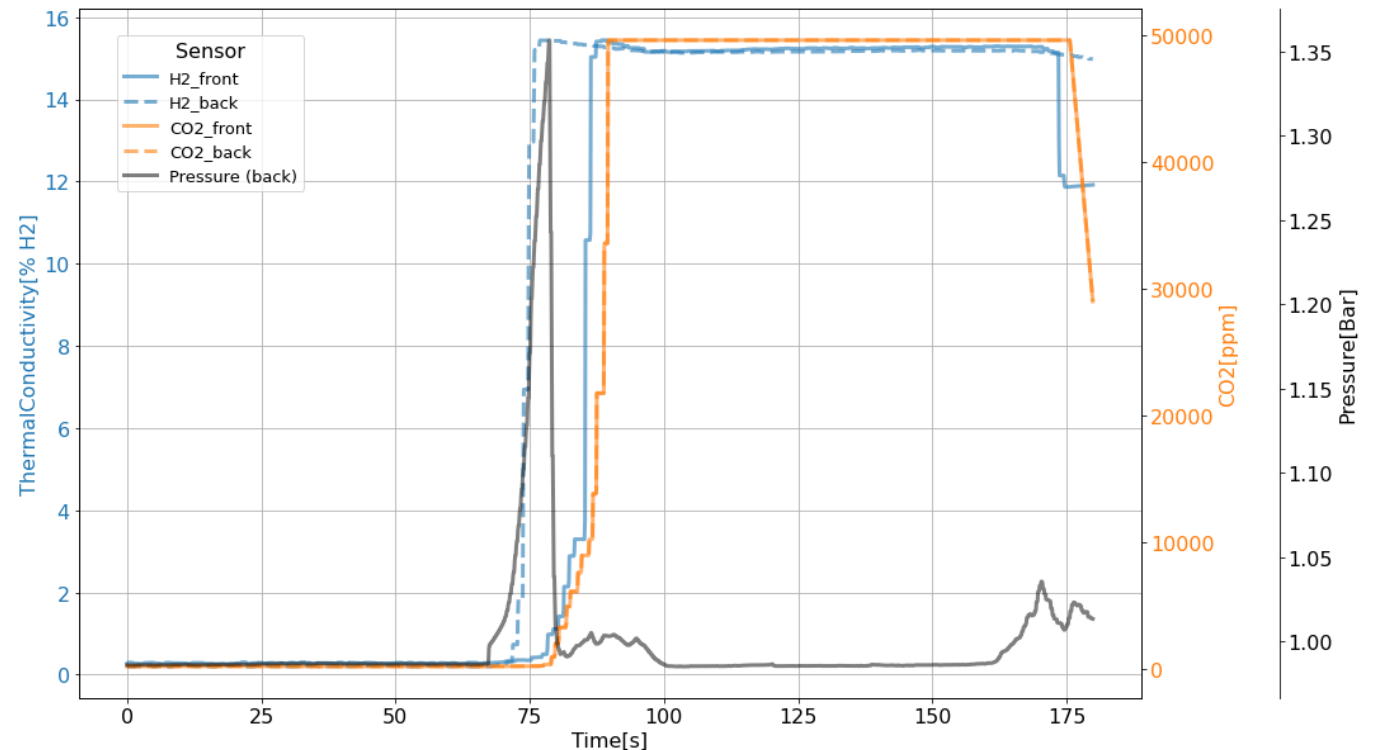
# Pressure data analysis

- Comparable results between sensors;
- Front “off-the-shelf” sensor has an offset
- Smaller difference between position (front and back) readings for Amphenol’s sensor compared to the conventional ones;



# H<sub>2</sub> and CO<sub>2</sub> analysis

- Small delay, ca. 12 sec, between H<sub>2</sub> readings from the front and back of the battery pack;
- CO<sub>2</sub> readings are synchronised and delayed compared to H<sub>2</sub>;
- Gas readings happen slightly after pressure spike, ca. 11 sec;
- CO<sub>2</sub> base values were not representative (~185 ppm).



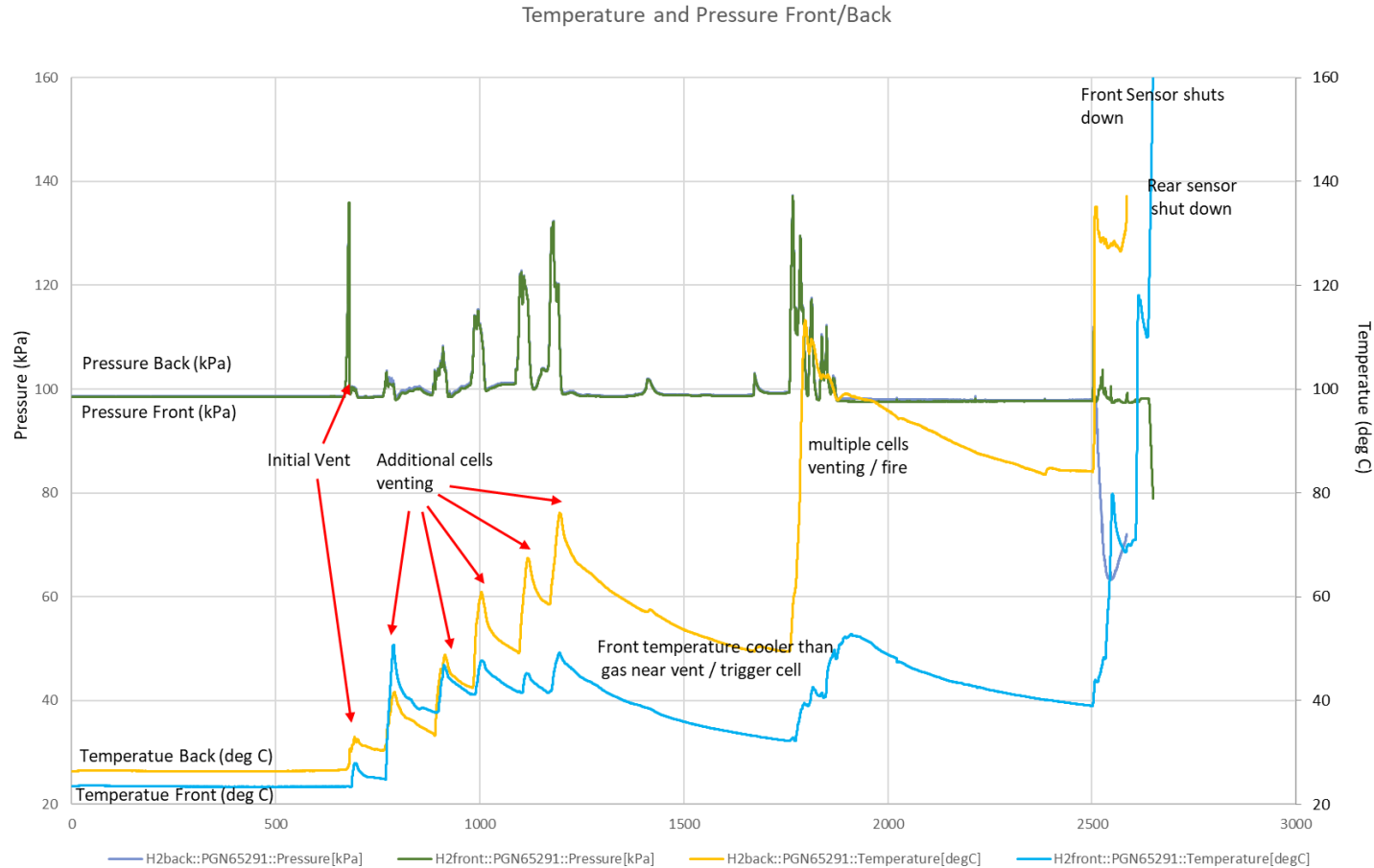
# Conclusions

- Pressure readings from two Amphenol sensors and two “off-the-shelf” commercially available sensors were observed to be consistent and largely independent from their position in the pack.
- Amphenol sensors are significantly smaller compared to the “off-the-shelf” commercially available pressure sensors. This is an advantage for the “in-pack” installation.
- The pressure rise was detected before the H<sub>2</sub> and CO<sub>2</sub> gases, ca. 11 seconds earlier;
- The timing of H<sub>2</sub> signal was found to be location-dependent unlike CO<sub>2</sub> signal, which was found to be location-independent.



# Pressure & Temperature Response

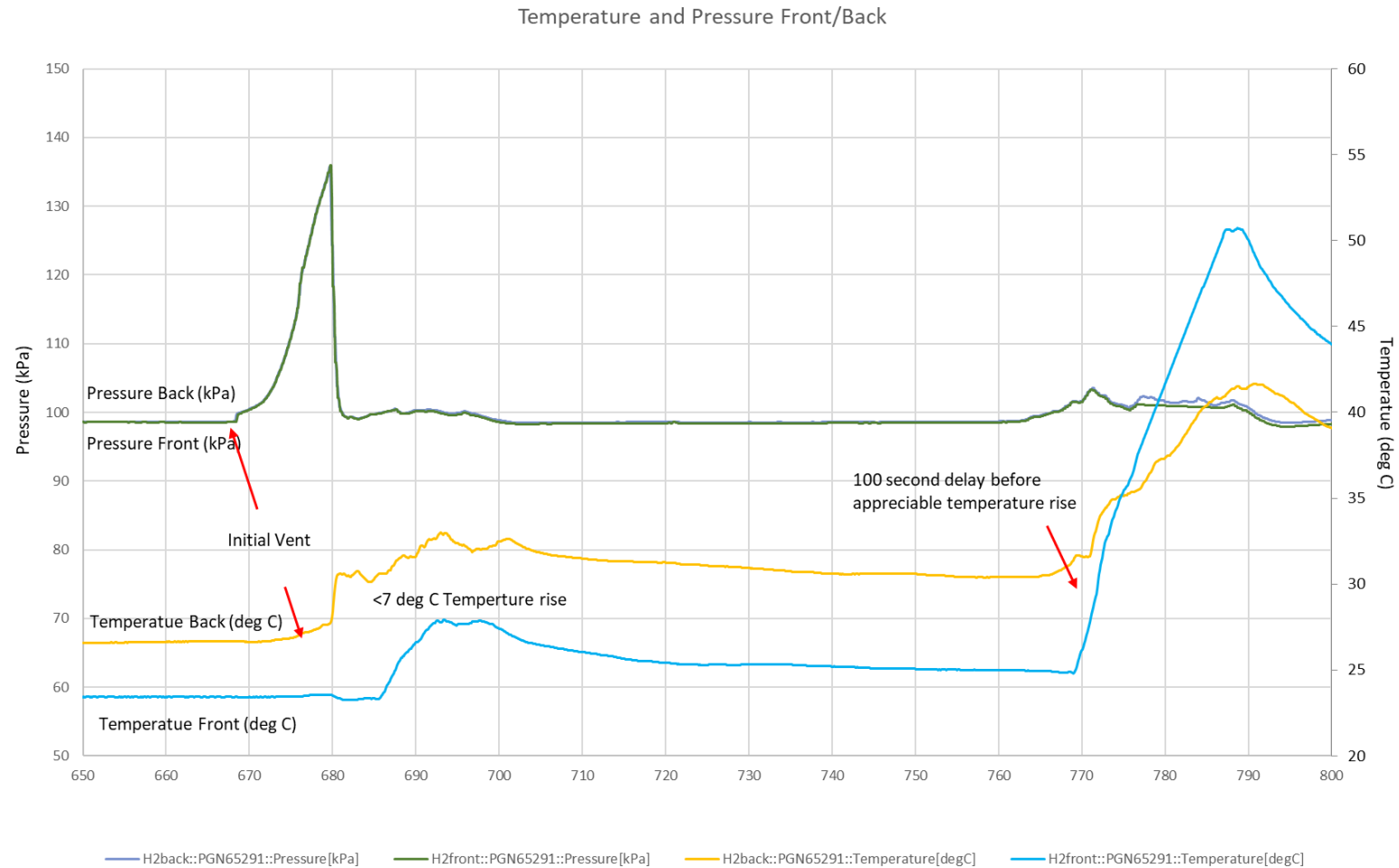
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- 100% SOC cell with thermal trigger is highly energetic – engages additional cells almost immediately

# Pressure & Temperature initial venting

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- Pressure leads temperature; pressure is uniform in pack air space
- Small initial temperature change with first vent
- Front lower temperature than back until turbulent mixing

# Rear Sensor Gas response

MTA 36415, 21/09/2022

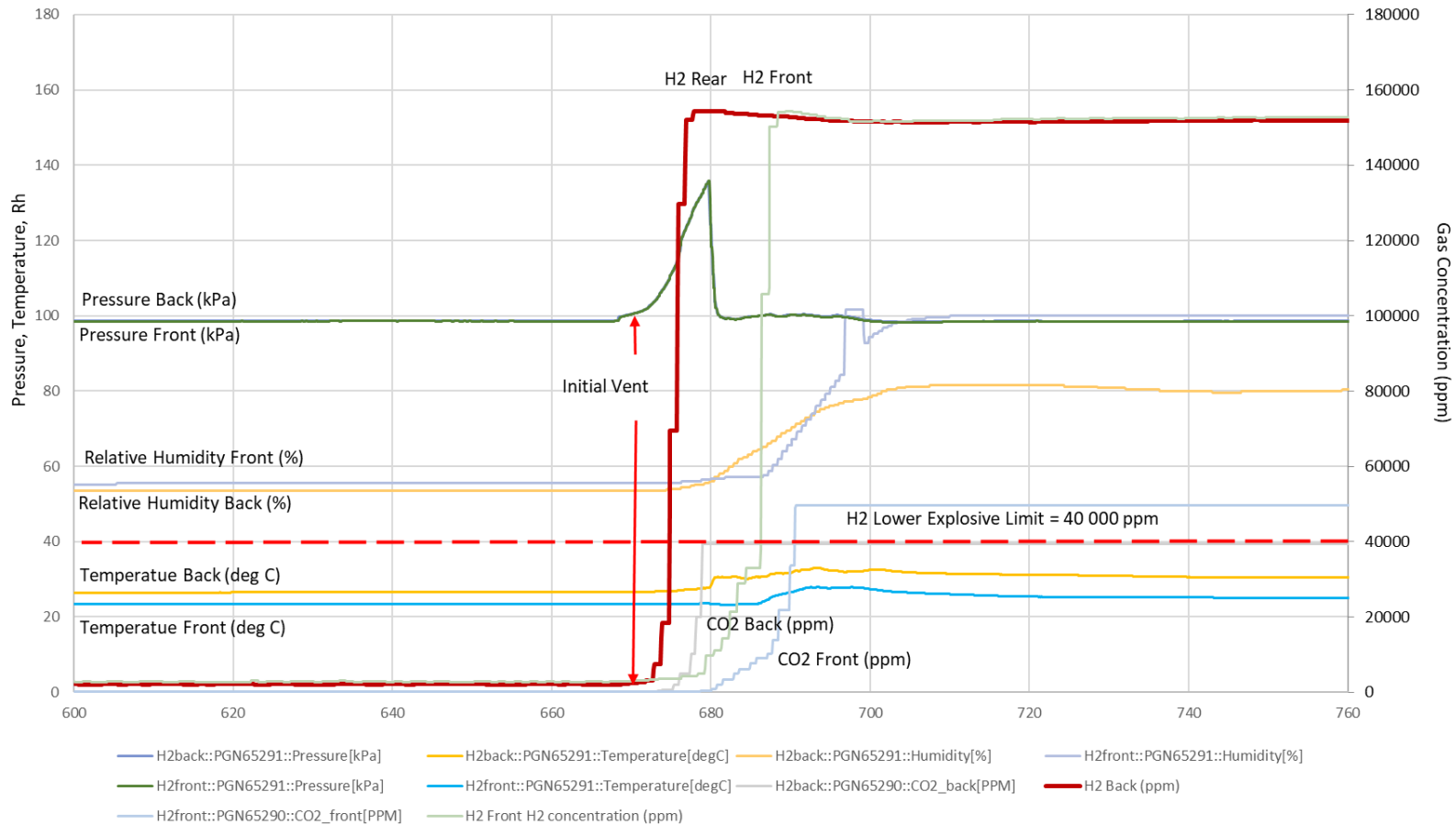


- H2 exceeds 40 000 ppm Lower explosive limit within ~3-5 seconds; reaching ~150 000ppm
- CO2 sensor exceeds 40 0000ppm, then damaged by gas release, setting fault flag
- Relative humidity climbs from ~50% to 100%

# Front/Rear Sensor Gas response

MTA 36415, 21/09/2022

P, T, Gases & Humidity Front/Back



- Front H2 lags rear by ~12 seconds
- Front CO2 lags Rear CO2 by ~10 seconds
- Front RH% peaks ~80%, while rear ~100%

# Amphenol Observations / Experiences

- **Lower SOC /slower venting can result in minimal pressure change inside pack**
  - Pressure sensors challenged to operate in field for low SOC/SOH cells, “slow” venting
- **Hydrogen release occurs quickly and above LEL in typical pack**
- **CO2 responds in similar timeframe with concentrations in excess of 40 000 up to 200 000ppm; acts to inhibit combustion**
- **Substantial water vapor release with cell venting from combustion products**
- **Use of H2 and/or CO2 detection consistent across:**
  - Cell electrochemistry
  - Cell configuration (cylindrical, prismatic, pouch)
  - Variations in venting systems
- **H2 and CO2 tend to indicate presence of other hazardous, flammable gases in similar proportions**
- **Sensor placement optimal near pack vents for best response**
- **Additional Observations from testing / validation:**
  - Pressure-based systems have exhibited missed detection and false positive events
  - Minimizing free air volume within pack reduces risk of gas combustion inside pack
  - Gas, water vapor, and particles highly conductive, and can lead to arc flash inside pack