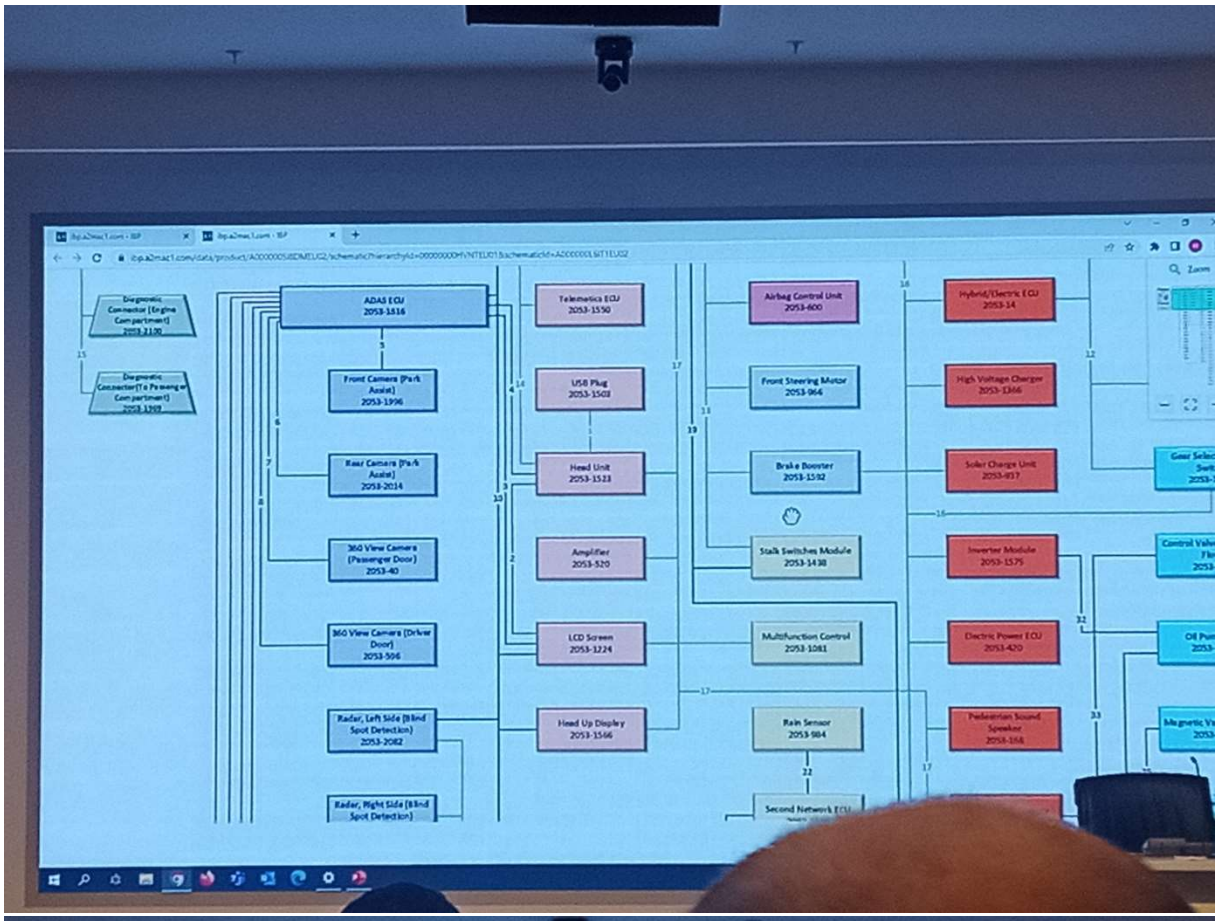
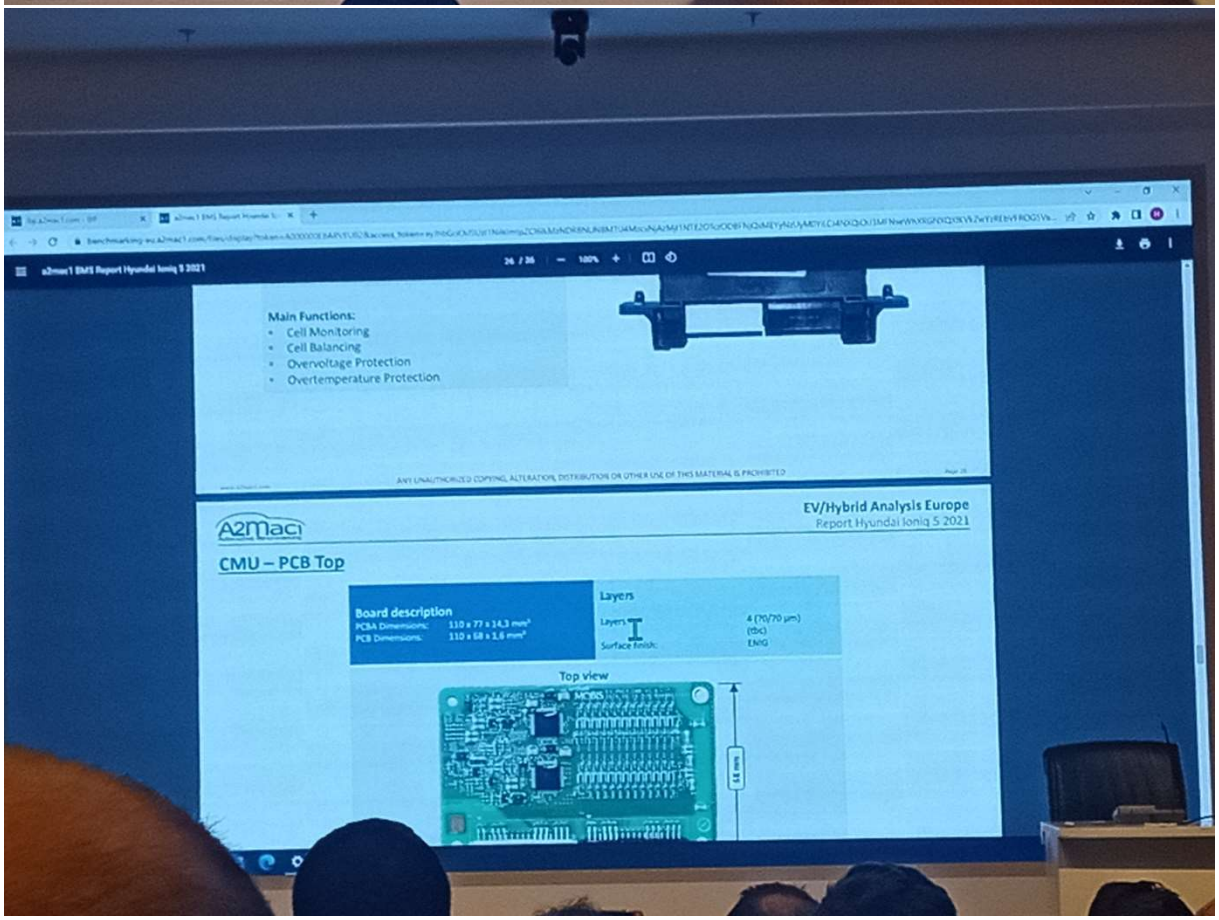

Diagnostic Connector (Engine Compartment)
2053-1130
Diagnostic Connector (To Passenger Compartment)
2053-1369
ADAS ECU
2053-1616
Front Camera (Park Assist)
2053-1396
Rear Camera (Park Assist)
2058-2014
360 View Camera (Passenger Door)
2053-40
360 View Camera (Driver Door)
2053-506
Radar, Left Side (Blind Spot Detection)
2053-2082
Radar, Right Side (Blind Spot Detection)
Telematics ECU
2053-1550
USB Plug
2053-1503
Head Unit
2053-1523
Amplifier
2053-520
LCD Screen
2053-1224
Head Up Display
2053-1566
Airbag Control Unit
2053-600
Front Steering Motor
2053-964
Brake Booster
2053-1592
Stalk Switches Module
2053-1438
Multifunction Control
2053-1081
Rain Sensor
2053-984
Second Network ECU
Hybrid/Electric ECU
2053-14
High Voltage Charger
2053-1366
Solar Charge Unit
2053-937
Inverter Module
2053-1575
Electric Power ECU
2053-420
Pedestrian Sound Speaker
2058-166


a2mac1 BMS Report Hyundai Ioniq 5 2021
Main Functions:
Cell Monitoring
Cell Balancing
Overvoltage Protection
Overtemperature Protection
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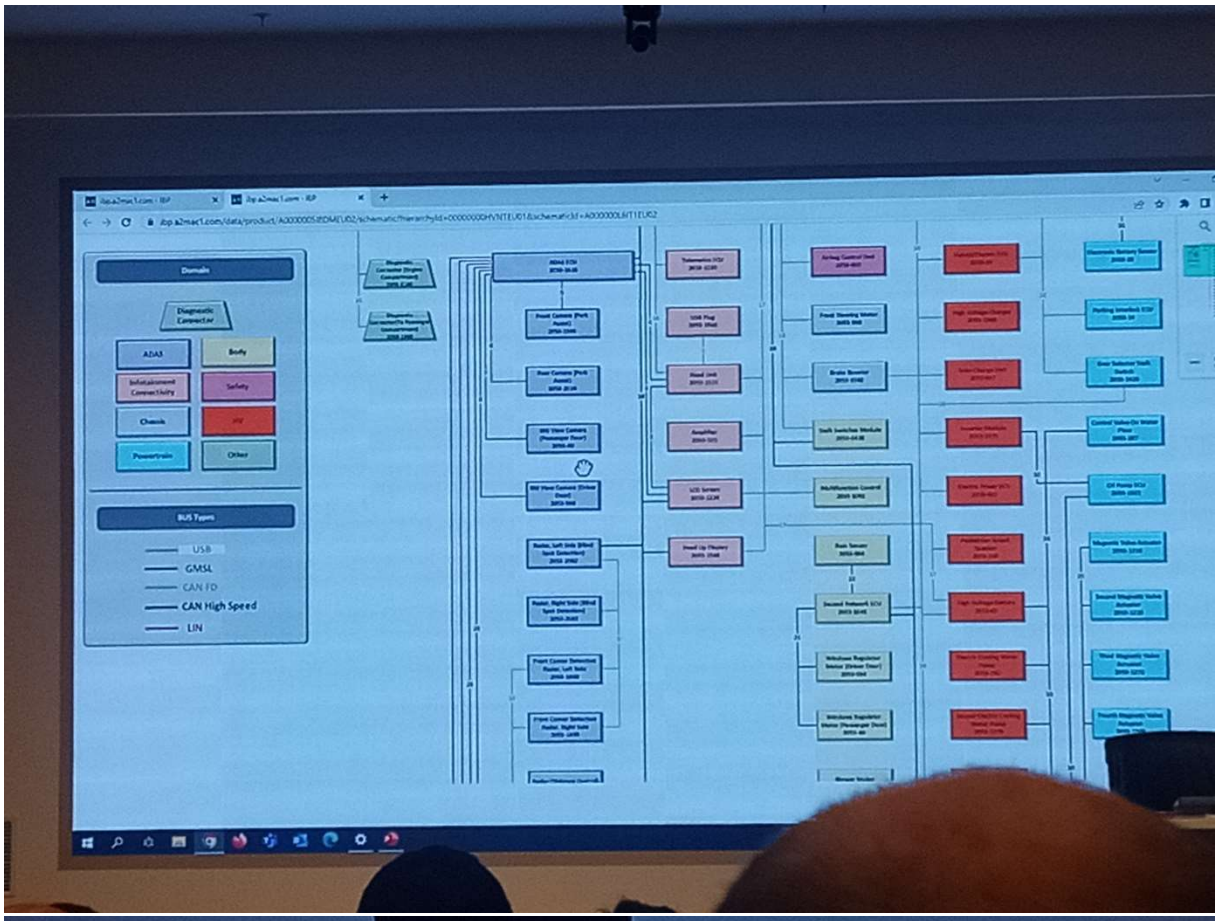
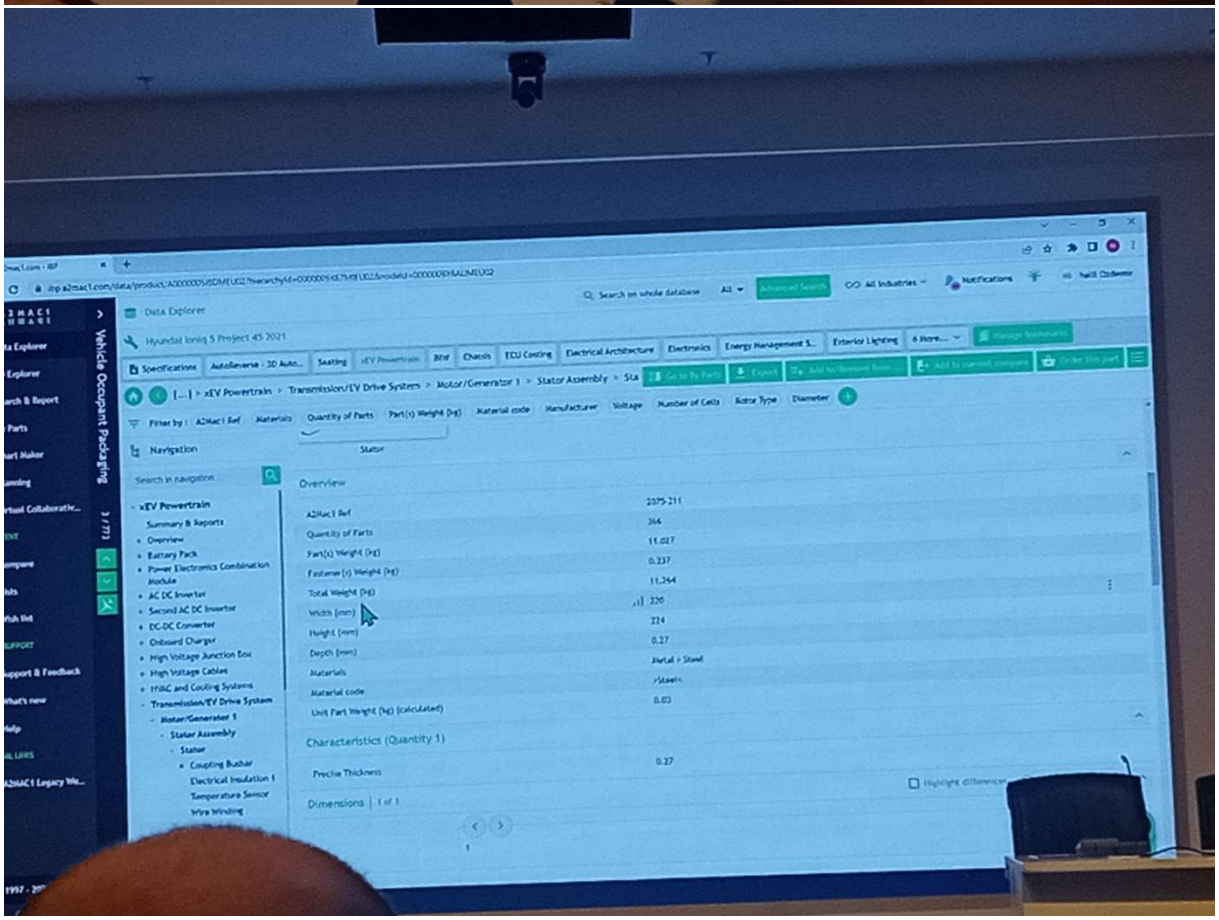
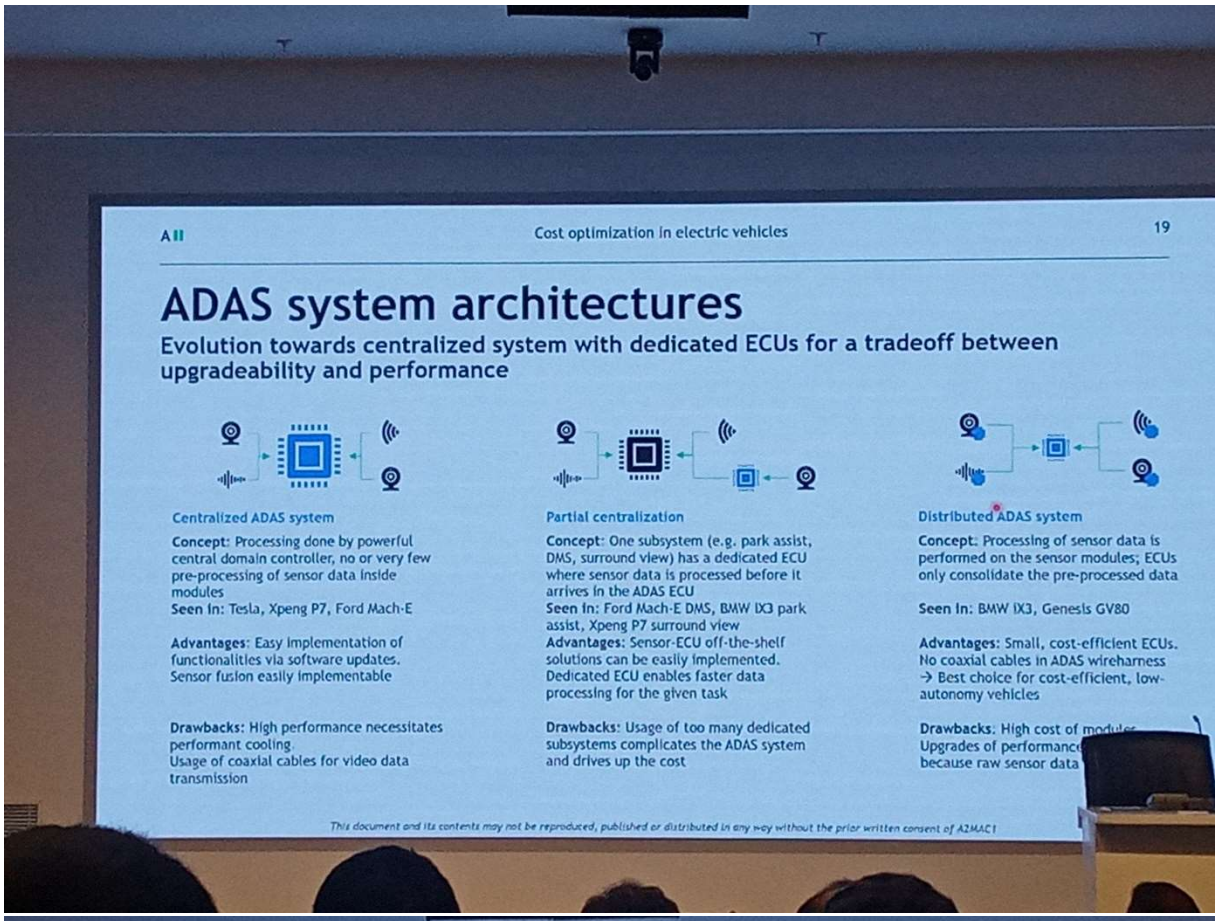
EV/Hybrid Analysis Europe
Report Hyundai Ioniq 5 2021
CMU – PCB Top
Board description
PCBA Dimensions: 110 x 77 x 14,3 mm²
PCB Dimensions: 110 x 68 x 1,6 mm²
Layers
Layers: 4 (70/70 µm)
(tbc)
Surface finish: ENIG
Top view
14.3 mm


Domain
Diagnostic Connector
ADAS
Body
Infotainment Connectivity
Safety
Chassis
HV
Powertrain
Other
BUS Types
USB
GMSL
CAN FD
CAN High Speed
LIN


Data Explorer
Hyundai Ioniq 5 Project 45 2021
Navigation
Overview
Characteristics (Quantity 1)
Dimensions


A II
Cost optimization in electric vehicles
19
ADAS system architectures
Evolution towards centralized system with dedicated ECUs for a tradeoff between upgradeability and performance
Centralized ADAS system
Concept: Processing done by powerful central domain controller, no or very few pre-processing of sensor data inside modules
Seen in: Tesla, Xpeng P7, Ford Mach-E
Advantages: Easy implementation of functionalities via software updates. Sensor fusion easily implementable
Drawbacks: High performance necessitates performant cooling.
Usage of coaxial cables for video data transmission
Partial centralization
Concept: One subsystem (e.g. park assist, DMS, surround view) has a dedicated ECU where sensor data is processed before it arrives in the ADAS ECU
Seen in: Ford Mach-E DMS, BMW IX3 park assist, Xpeng P7 surround view
Advantages: Sensor-ECU off-the-shelf solutions can be easily implemented. Dedicated ECU enables faster data processing for the given task
Drawbacks: Usage of too many dedicated subsystems complicates the ADAS system and drives up the cost
Distributed ADAS system
Concept: Processing of sensor data is performed on the sensor modules; ECUs only consolidate the pre-processed data
Seen in: BMW IX3, Genesis GV80
Advantages: Small, cost-efficient ECUs. No coaxial cables in ADAS wireharness → Best choice for cost-efficient, low-autonomy vehicles
Drawbacks: High cost of modules
Upgrades of performance
because raw sensor data
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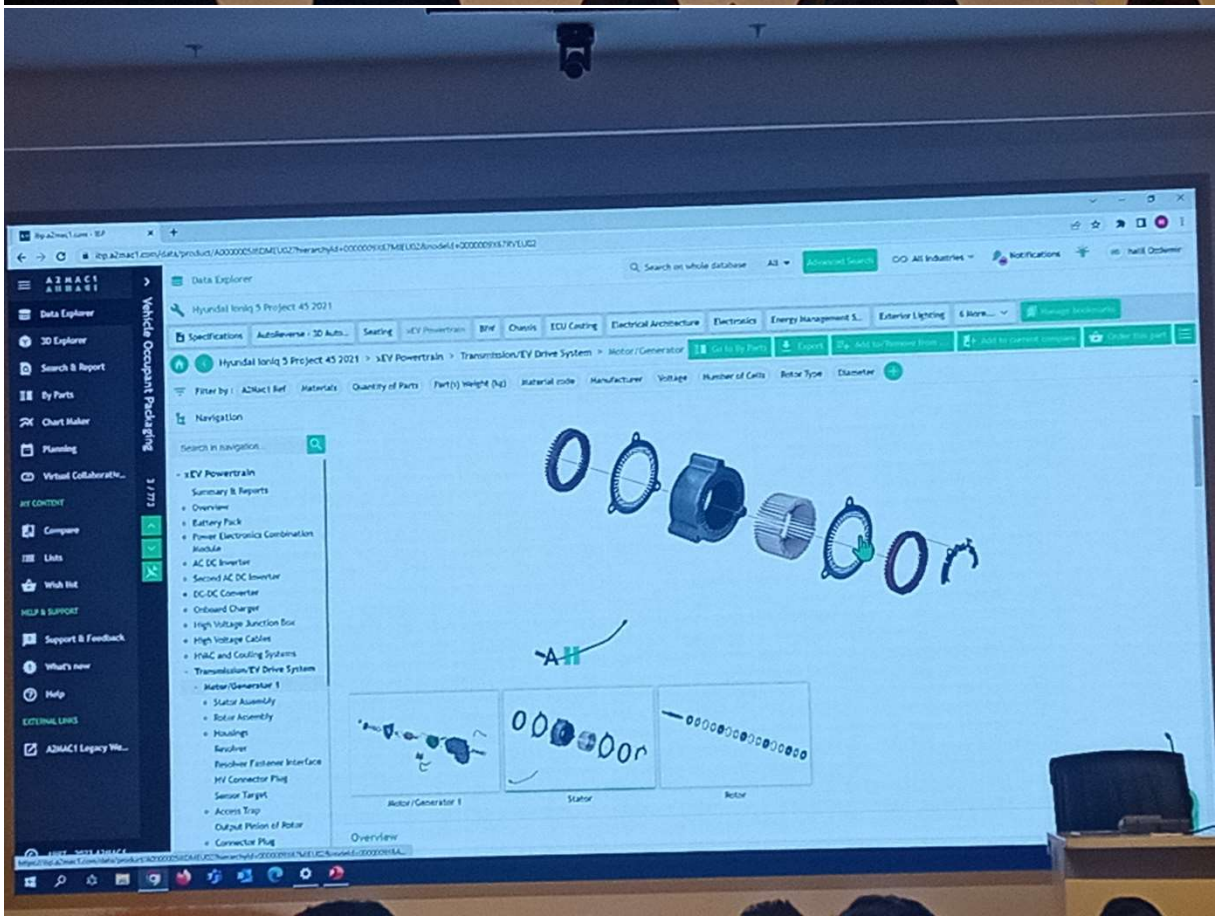
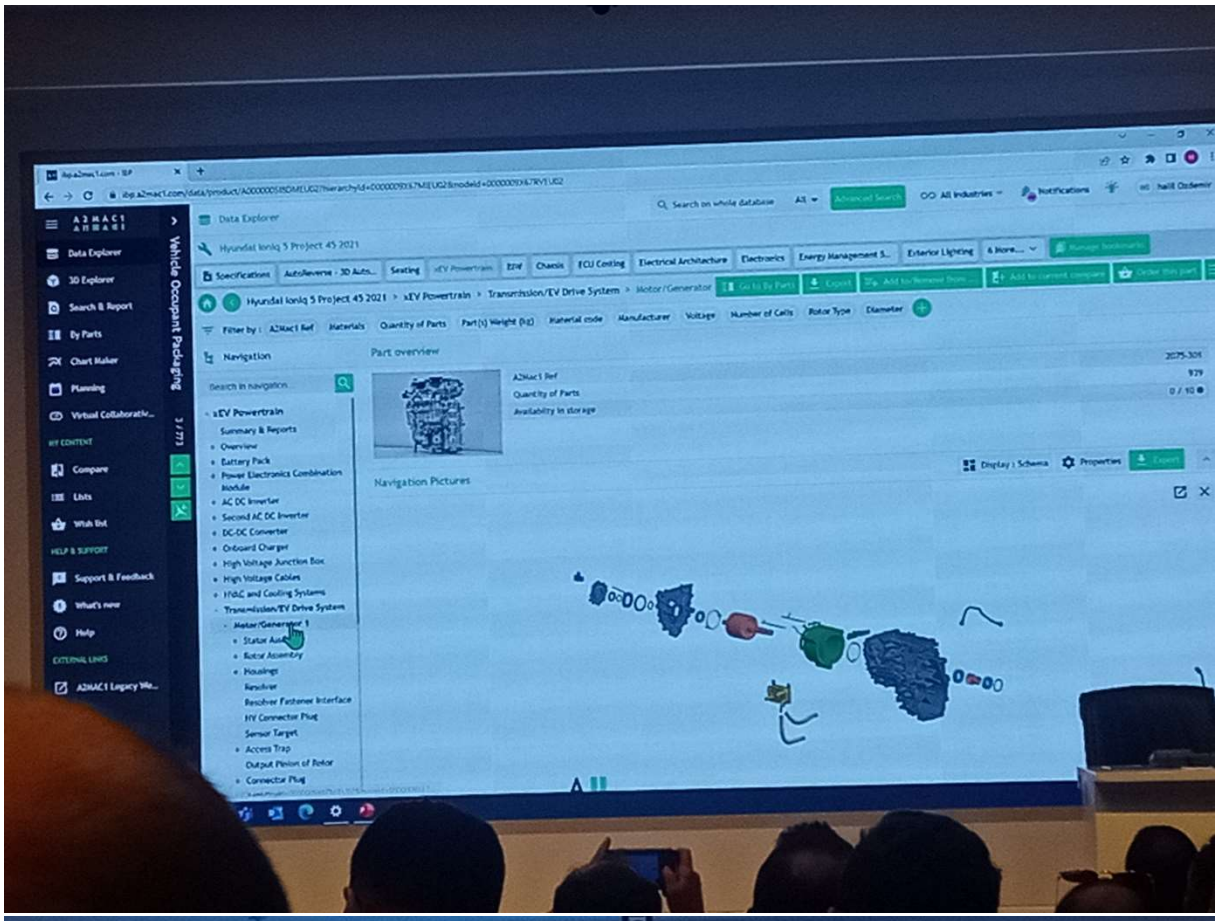
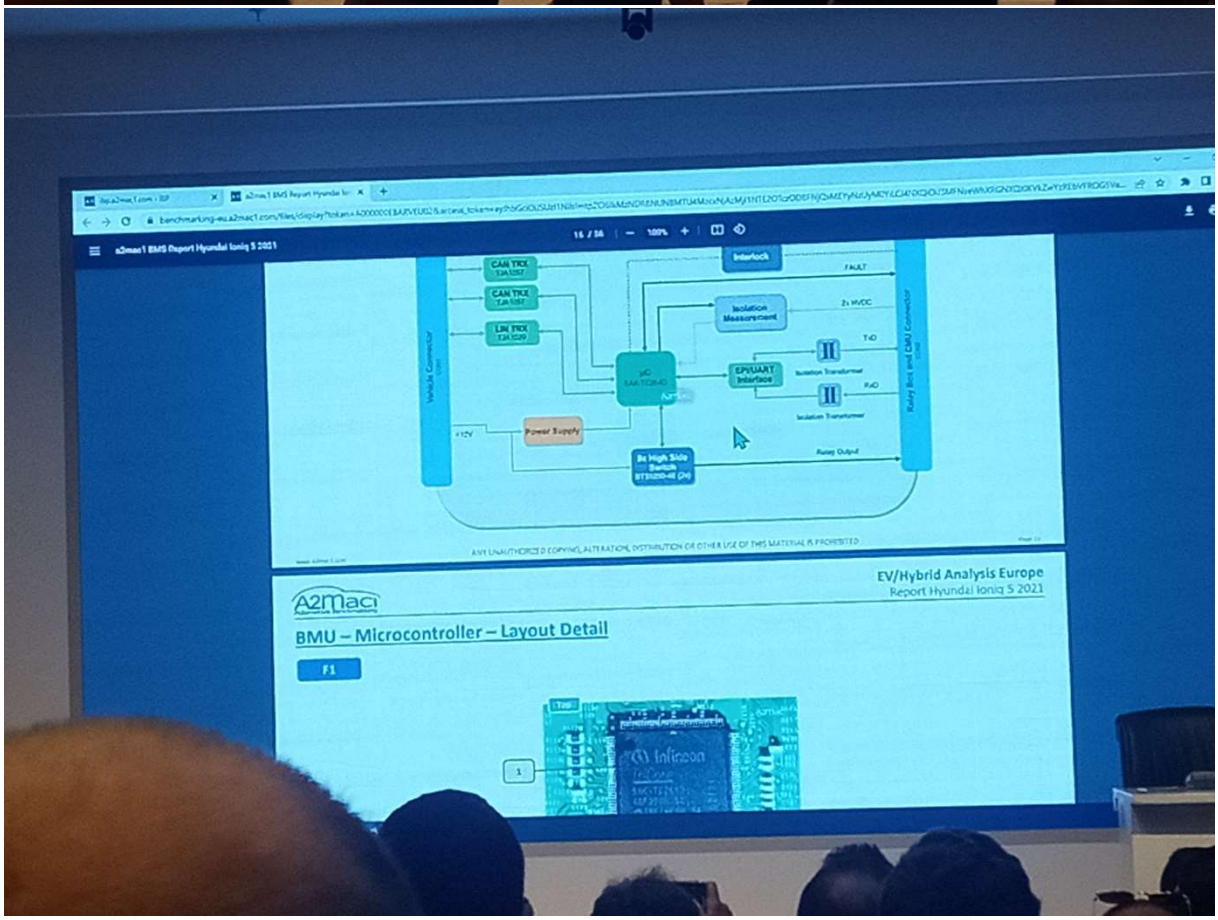
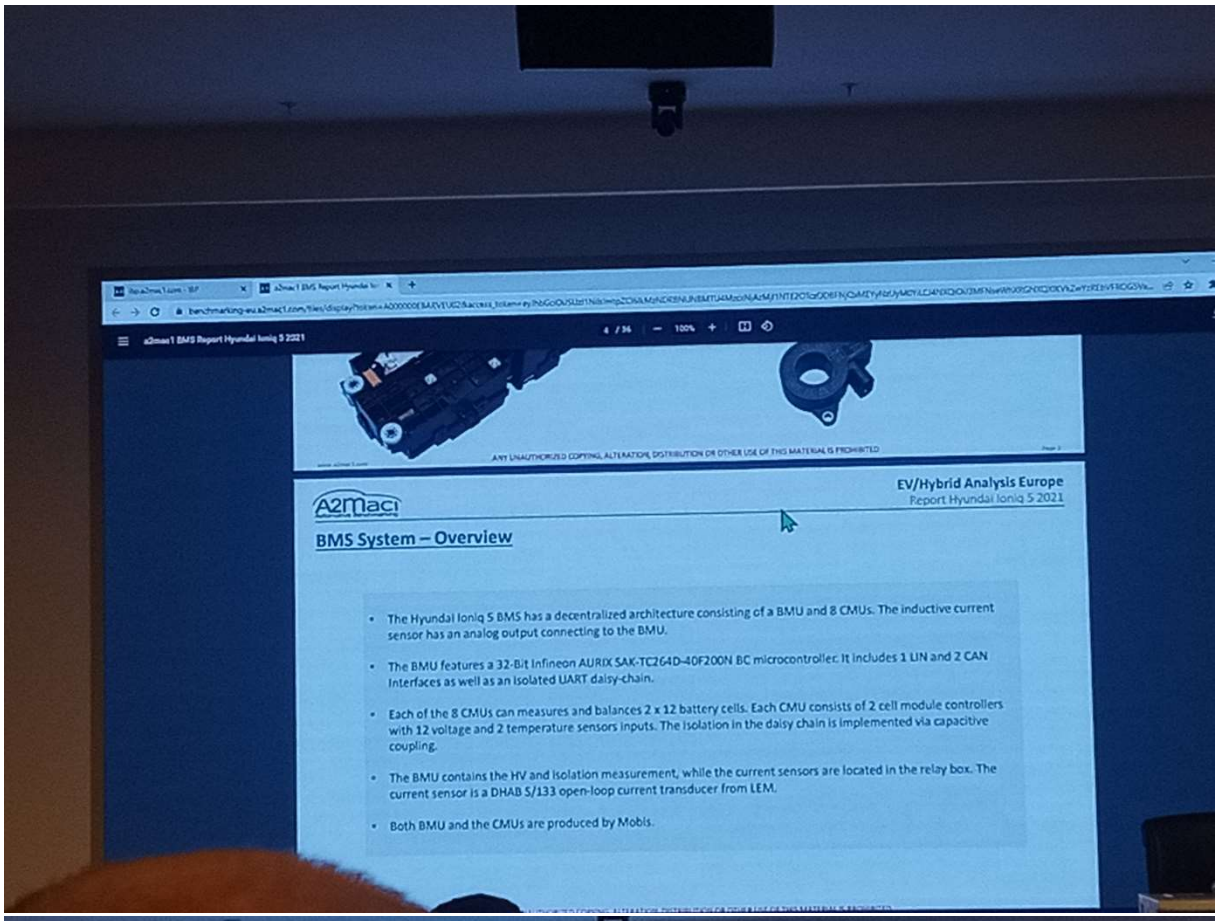

Data Explorer
Hyundai Ioniq 5 Project 45 2021
Vehicle Occupant Packaging
Navigation
Overview


Data Explorer
Hyundai Ioniq 5 Project 45 2021
Navigation
Part overview
Navigation Pictures
xEV Powertrain
Transmission/EV Drive System
Motor/Generator 1


a2mac1 BMS Report Hyundai Ioniq 5 2021
BMU – Microcontroller – Layout Detail
EV/Hybrid Analysis Europe
Report Hyundai Ioniq 5 2021
F1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4 / 36
100%
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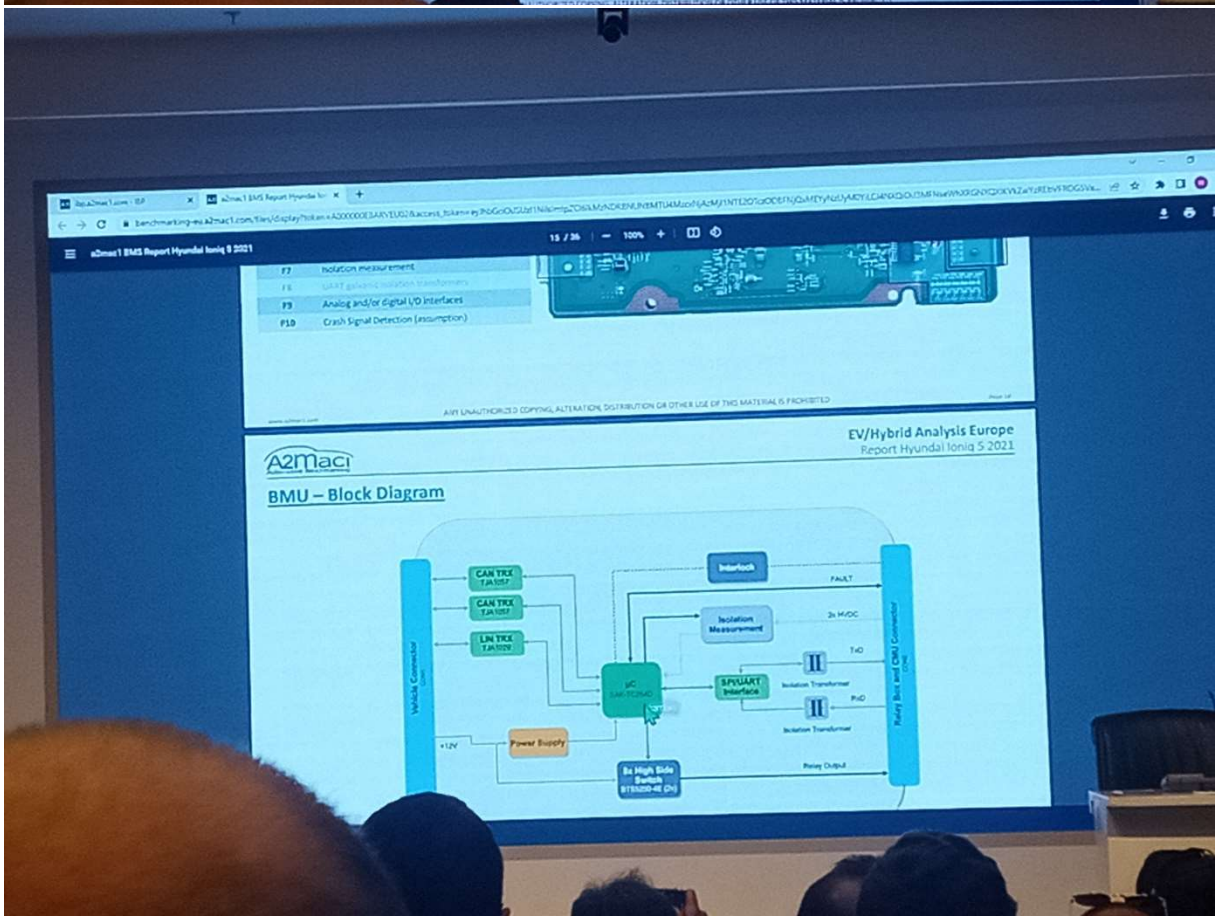
Report Hyundai Ioniq 5 2021
BMS System – Overview
The Hyundai Ioniq 5 BMS has a decentralized architecture consisting of a BMU and 8 CMUs. The inductive current sensor has an analog output connecting to the BMU.
The BMU features a 32-Bit Infineon AURIX SAK-TC264D-40F200N BC microcontroller. It includes 1 LIN and 2 CAN interfaces as well as an isolated UART daisy-chain.
Each of the 8 CMUs can measures and balances 2 x 12 battery cells. Each CMU consists of 2 cell module controllers with 12 voltage and 2 temperature sensors inputs. The isolation in the daisy chain is implemented via capacitive coupling.
The BMU contains the HV and isolation measurement, while the current sensors are located in the relay box. The current sensor is a DHAB S/133 open-loop current transducer from LEM.
Both BMU and the CMUs are produced by Mobis.


a2mac1 BMS Report Hyundai Ioniq 5 2021
15 / 36
100%
F7 Isolation measurement
F9 Analog and/or digital I/O interfaces
F10 Crash Signal Detection (assumption)
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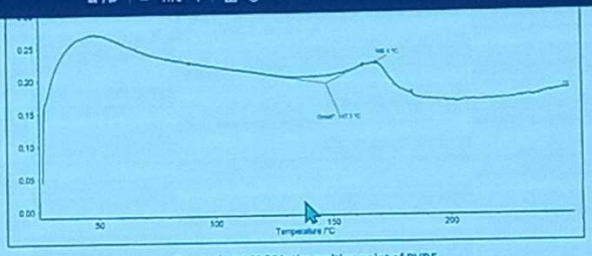
Report Hyundai Ioniq 5 2021
BMU – Block Diagram
CAN TRX
CAN TRX
LIN TRX
Interlock
FAULT
Isolation Measurement
2x HVDC
TxD
RxD
SPI/UART Interface
Isolation Transformer
Isolation Transformer
Isolation Transformer
Vehicle Connector
Relay Box and CMU Connector
Power Supply
+12V
8x High Side Switch
Relay Output

PVDF helps to determine the binder/carbon black ratio (active material content is measured by weight difference, before and after dissolution):

96.0 % active material (NMC)

Carbon black / binder ratio remain to be determined



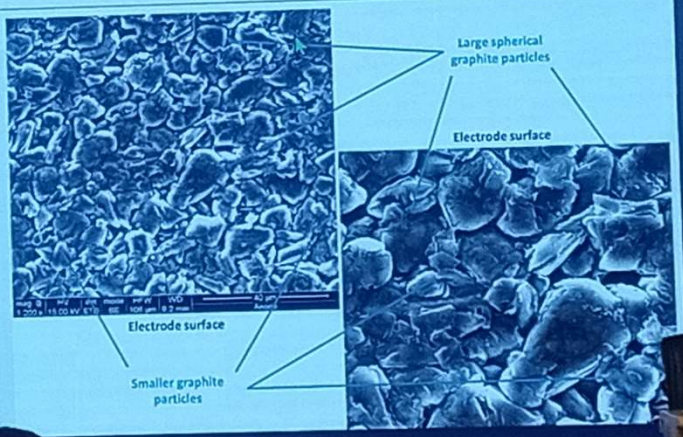
The peak at 168 °C is the melting point of PVDF

A2Mac1 Automotive Benchmarking

EV/Hybrid Analysis Europe
Hyundai Ioniq 5 Project 45 Cell Report

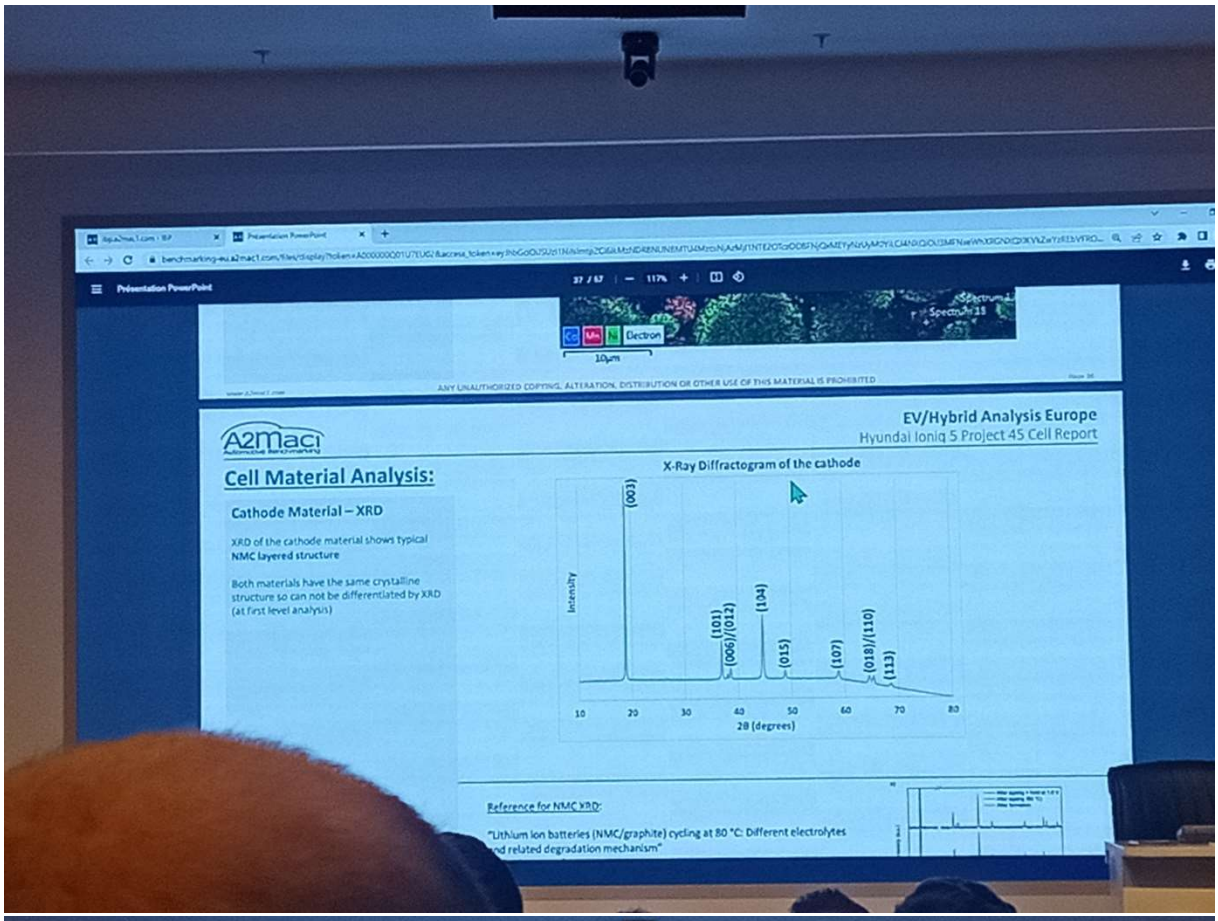
Cell Material Analysis:

Anode Material – Electrode morphology



A2Mac1 Automotive Benchmarking

EV/Hybrid Analysis Europe
Hyundai Ioniq 5 Project 45 Cell Report


Présentation PowerPoint
37 / 67
117%
Spectrum 18
Electron
10µm
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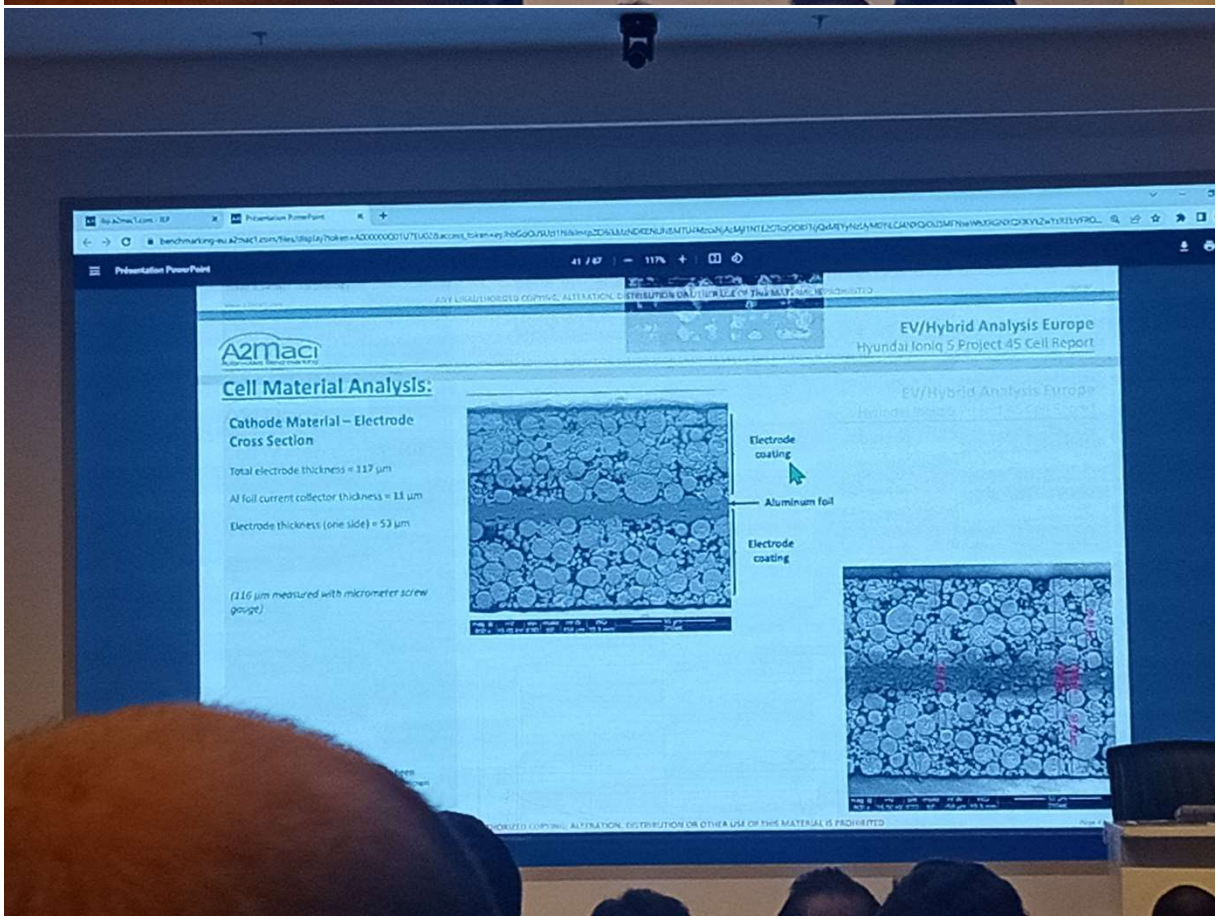
Hyundai Ioniq 5 Project 45 Cell Report
Cell Material Analysis:
Cathode Material – XRD
XRD of the cathode material shows typical NMC layered structure
Both materials have the same crystalline structure so can not be differentiated by XRD (at first level analysis)
X-Ray Diffractogram of the cathode
Intensity
(003)
(101)
(006)/(012)
(104)
(015)
(107)
(018)/(110)
(113)
10
20
30
40
50
60
70
80
2θ (degrees)
Reference for NMC XRD:
"Lithium ion batteries (NMC/graphite) cycling at 80 °C: Different electrolytes
nd related degradation mechanism"


Présentation PowerPoint
41 / 67
117%
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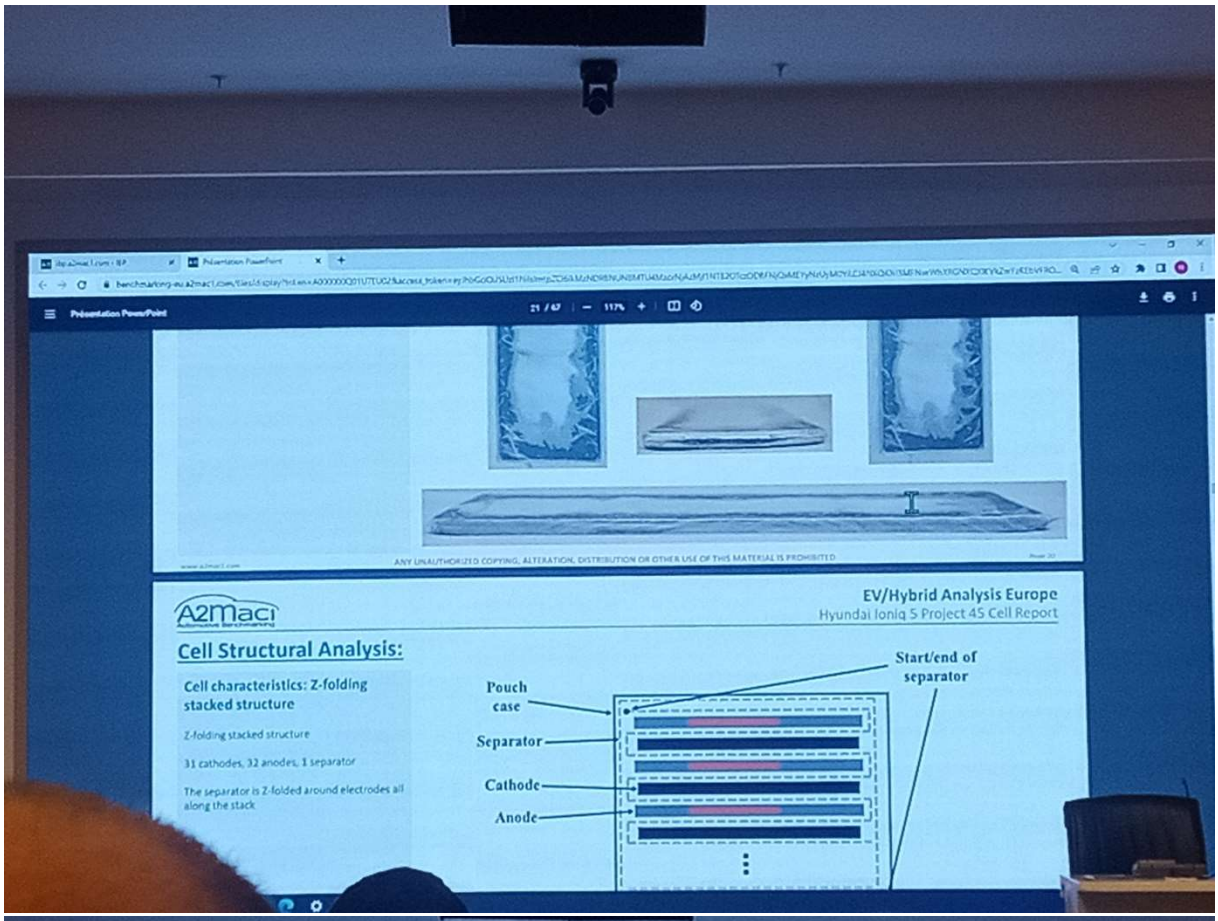
Hyundai Ioniq 5 Project 45 Cell Report
Cell Material Analysis:
Cathode Material – Electrode Cross Section
Total electrode thickness = 117 µm
Al foil current collector thickness = 13 µm
Electrode thickness (one side) = 53 µm
(116 µm measured with micrometer screw gauge)
Electrode coating
Aluminum foil
Electrode coating


Présentation PowerPoint
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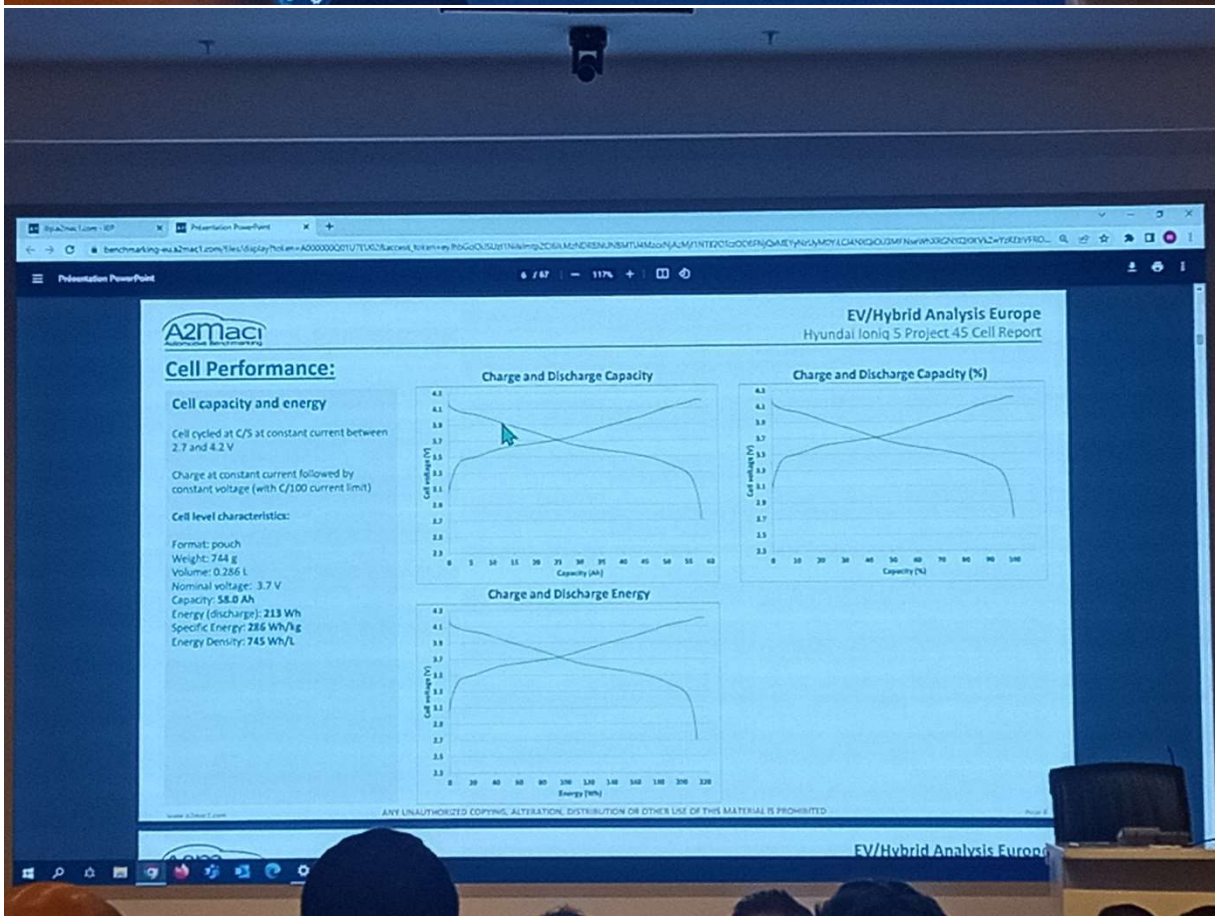
Hyundai Ioniq 5 Project 45 Cell Report
Cell Structural Analysis:
Cell characteristics: Z-folding stacked structure
Z-folding stacked structure
31 cathodes, 32 anodes, 1 separator
The separator is Z-folded around electrodes all along the stack
Pouch case
Separator
Cathode
Anode
Start/end of separator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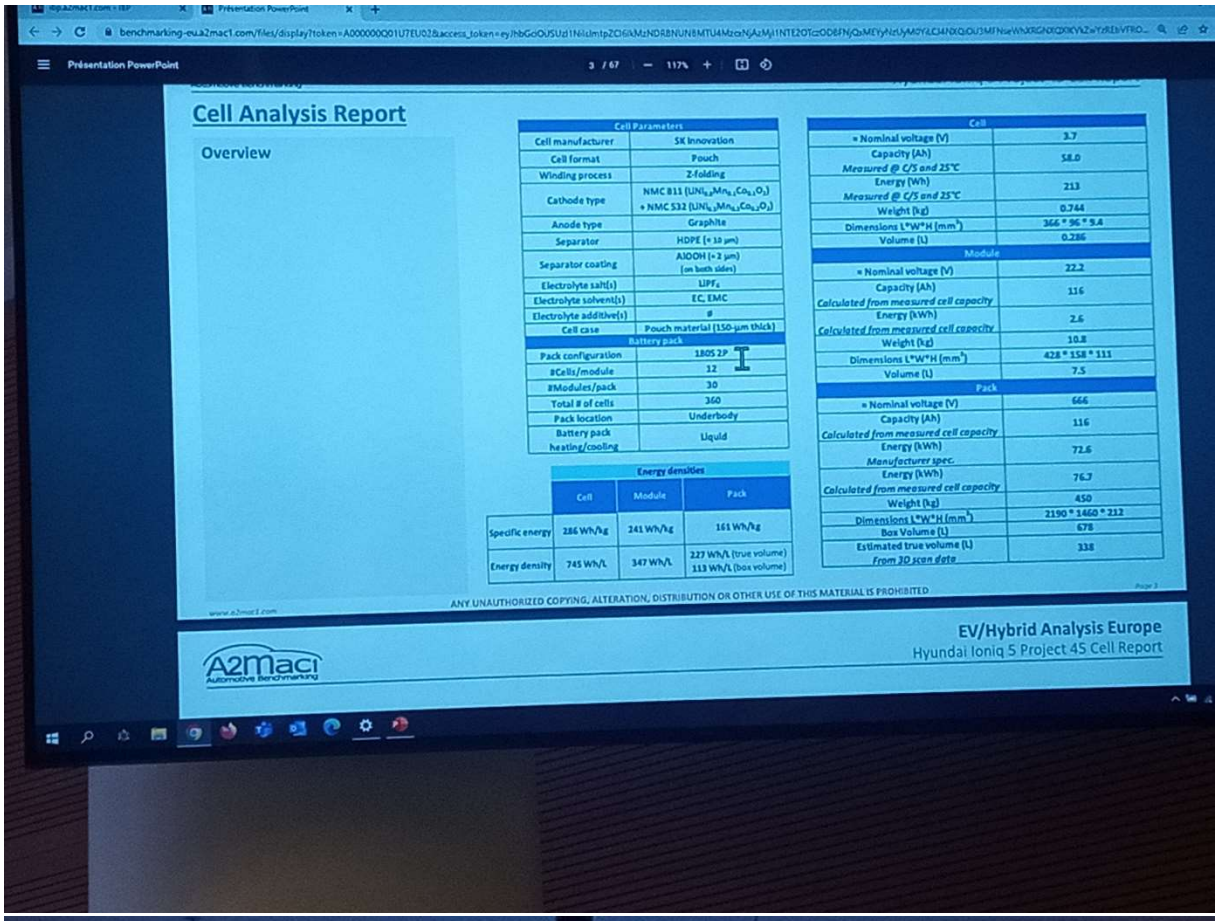
Hyundai Ioniq 5 Project 45 Cell Report
Cell Performance:
Cell capacity and energy
Cell cycled at C/5 at constant current between 2.7 and 4.2 V
Charge at constant current followed by constant voltage (with C/100 current limit)
Cell level characteristics:
Format: pouch
Weight: 744 g
Volume: 0.286 L
Nominal voltage: 3.7 V
Capacity: 58.0 Ah
Energy (discharge): 213 Wh
Specific Energy: 286 Wh/kg
Energy Density: 745 Wh/L
Charge and Discharge Capacity
Charge and Discharge Capacity (%)
Charge and Discharge Energy



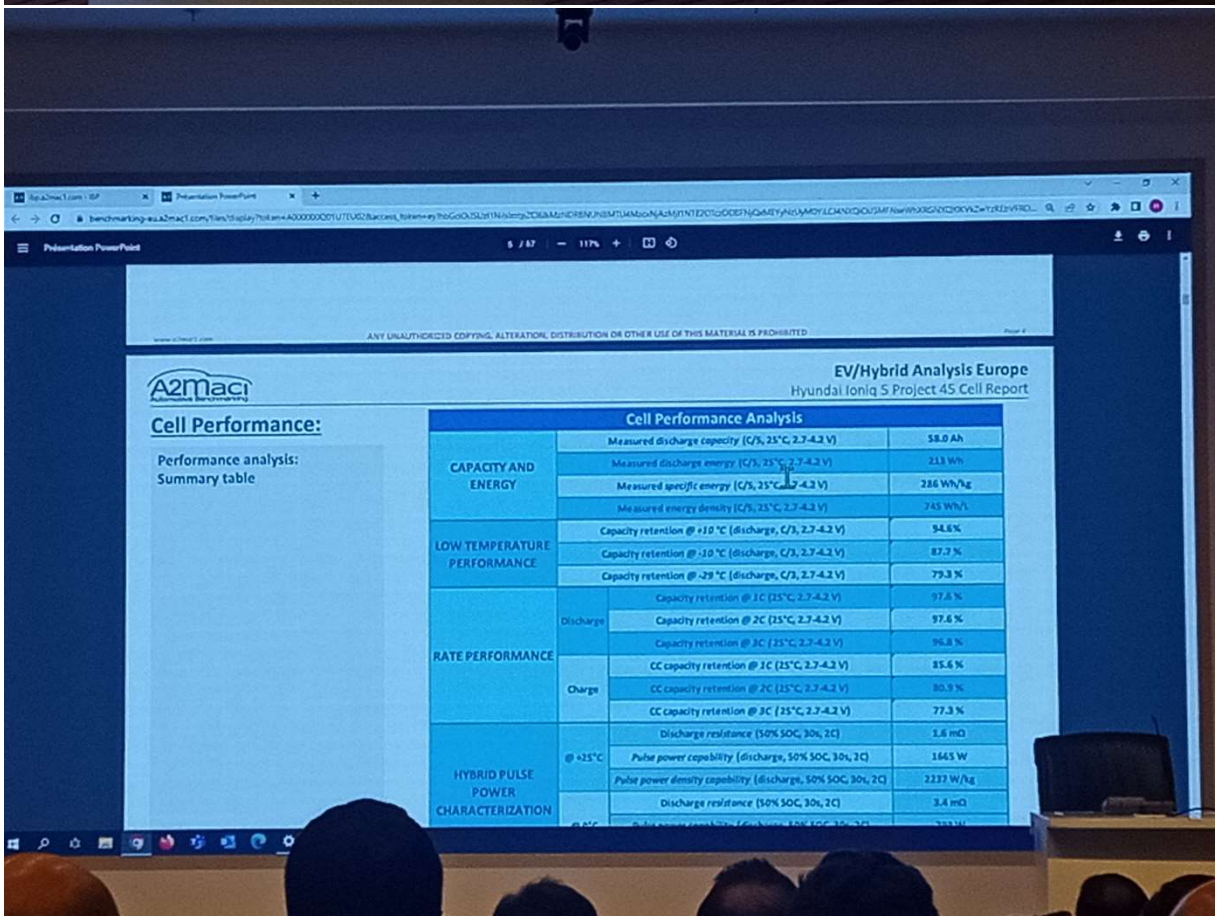
Cell Analysis Report

Overview

Cell Parameters	
Cell manufacturer	SK Innovation
Cell format	Pouch
Winding process	Z-folding
Cathode type	NMC 811 ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$) + NMC 532 ($LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$)
Anode type	Graphite
Separator	HDPE (~10 µm)
Separator coating	AlOOH (~2 µm) (on both sides)
Electrolyte salt(s)	$LiPF_6$
Electrolyte solvent(s)	EC, EMC
Electrolyte additive(s)	#
Cell case	Pouch material (150-µm thick)
Battery pack	
Pack configuration	180S 2P
#Cells/module	12
#Modules/pack	30
Total # of cells	360
Pack location	Underbody
Battery pack heating/cooling	Liquid

Energy densities	Cell	Module	Pack
Specific energy	286 Wh/kg	241 Wh/kg	161 Wh/kg
Energy density	745 Wh/L	347 Wh/L	227 Wh/L (true volume) 113 Wh/L (box volume)

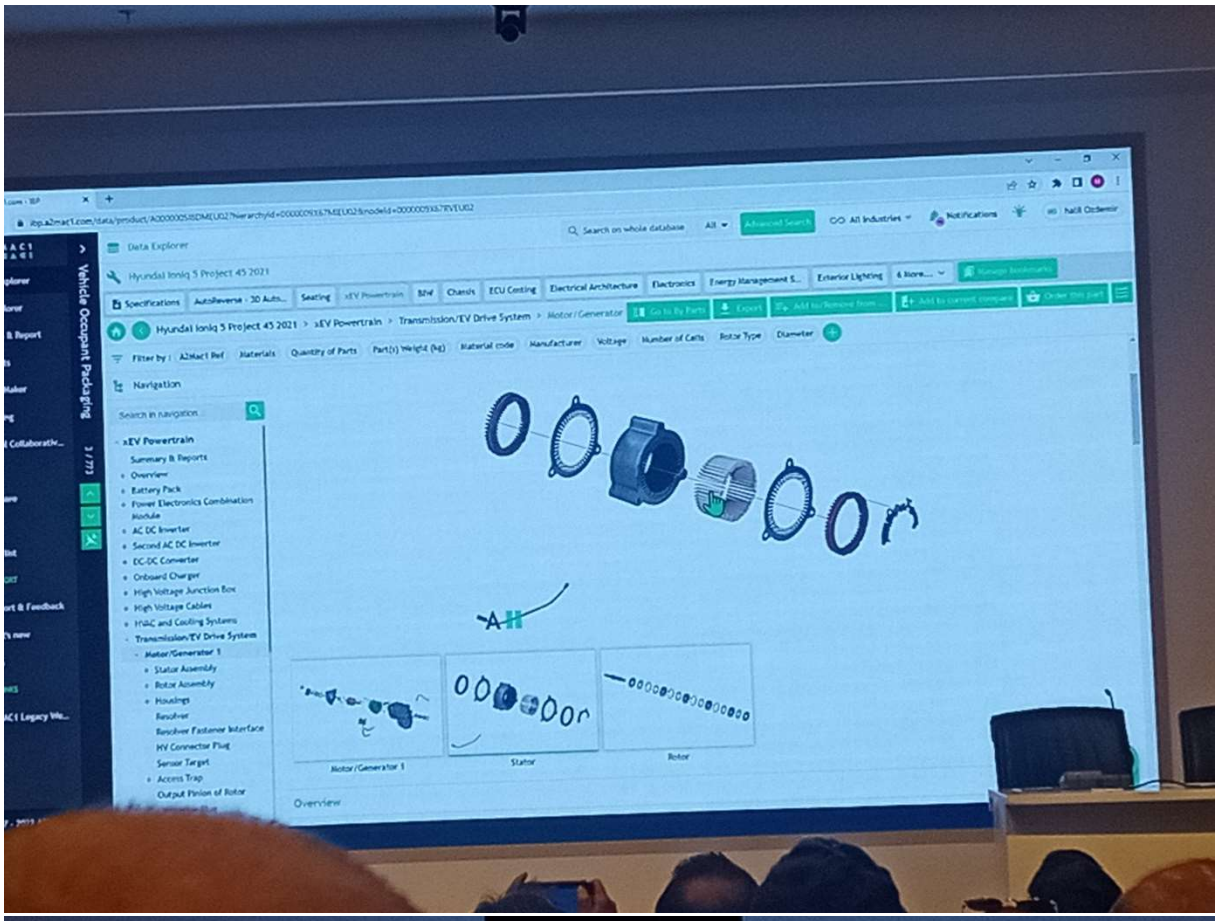
Cell	
= Nominal voltage (V)	3.7
Capacity (Ah) *Measured @ C/5 and 25°C*	58.0
Energy (Wh) *Measured @ C/5 and 25°C*	213
Weight (kg)	0.744
Dimensions L*W*H (mm^3)	366 * 96 * 9.4
Volume (L)	0.286
Module	
= Nominal voltage (V)	22.2
Capacity (Ah) *Calculated from measured cell capacity*	116
Energy (kWh) *Calculated from measured cell capacity*	2.6
Weight (kg)	10.8
Dimensions L*W*H (mm^3)	428 * 158 * 111
Volume (L)	7.5
Pack	
= Nominal voltage (V)	666
Capacity (Ah) *Calculated from measured cell capacity*	116
Energy (kWh) *Manufacturer spec.*	72.6
Energy (kWh) *Calculated from measured cell capacity*	76.7
Weight (kg)	450
Dimensions L*W*H (mm^3)	2190 * 1460 * 212
Box Volume (L)	678
Estimated true volume (L) *From 3D scan data*	338

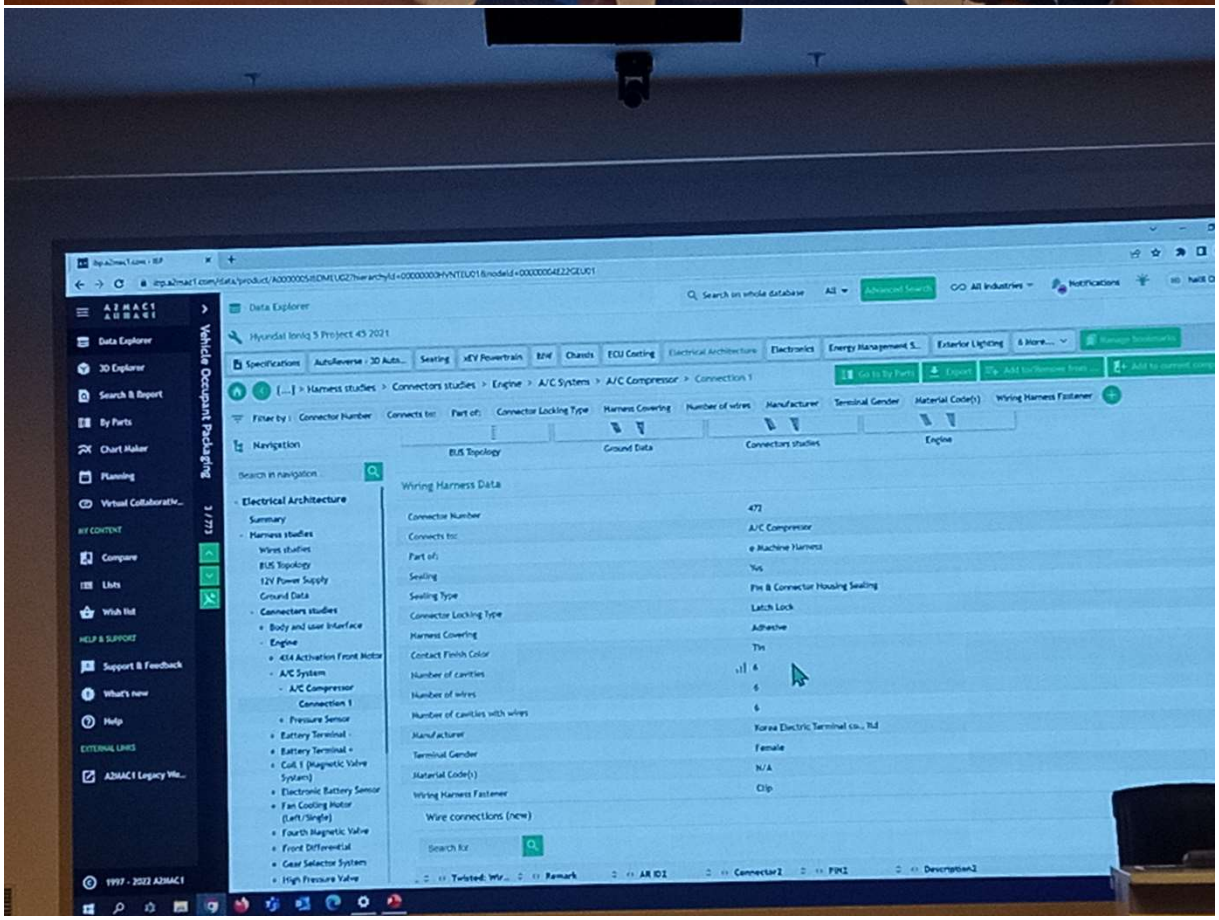


Cell Performance:

Performance analysis:
Summary table

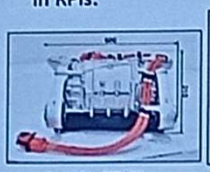
Cell Performance Analysis			
CAPACITY AND ENERGY		Measured discharge capacity (C/5, 25°C, 2.7-4.2 V)	58.0 Ah
		Measured discharge energy (C/5, 25°C, 2.7-4.2 V)	213 Wh
		Measured specific energy (C/5, 25°C, 2.7-4.2 V)	286 Wh/kg
		Measured energy density (C/5, 25°C, 2.7-4.2 V)	745 Wh/L
LOW TEMPERATURE PERFORMANCE		Capacity retention @ +10 °C (discharge, C/3, 2.7-4.2 V)	94.8%
		Capacity retention @ -10 °C (discharge, C/3, 2.7-4.2 V)	87.7 %
		Capacity retention @ -29 °C (discharge, C/3, 2.7-4.2 V)	79.3 %
RATE PERFORMANCE	Discharge	Capacity retention @ 1C (25°C, 2.7-4.2 V)	97.8 %
		Capacity retention @ 2C (25°C, 2.7-4.2 V)	97.6 %
		Capacity retention @ 3C (25°C, 2.7-4.2 V)	96.8 %
	Charge	CC capacity retention @ 1C (25°C, 2.7-4.2 V)	85.6 %
		CC capacity retention @ 2C (25°C, 2.7-4.2 V)	80.9 %
		CC capacity retention @ 3C (25°C, 2.7-4.2 V)	77.3 %
HYBRID PULSE POWER CHARACTERIZATION	@ +25°C	Discharge resistance (50% SOC, 30s, 2C)	1.6 mΩ
		Pulse power capability (discharge, 50% SOC, 30s, 2C)	1665 W
		Pulse power density capability (discharge, 50% SOC, 30s, 2C)	2237 W/kg
	@ -25°C	Discharge resistance (50% SOC, 30s, 2C)	3.4 mΩ


Data Explorer
Hyundai Ioniq 5 Project 45 2021
Vehicle Occupant Packaging
Navigation
Search in navigation
xEV Powertrain
Summary & Reports
Overview
Battery Pack
Power Electronics Combination Module
AC DC Inverter
Second AC DC Inverter
DC-DC Converter
Onboard Charger
High Voltage Junction Box
High Voltage Cables
HVAC and Cooling Systems
Transmission/EV Drive System
Motor/Generator 1
Stator Assembly
Rotor Assembly
Housings
Resolver
Resolver Fastener Interface
HV Connector Plug
Sensor Target
Access Trap
Output Pinion of Rotor
Motor/Generator 1
Stator
Rotor
Overview

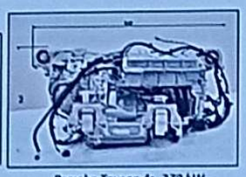

Data Explorer
Hyundai Ioniq 5 Project 45 2021
Vehicle Occupant Packaging
Navigation
Electrical Architecture
Summary
Harness studies
Wires studies
BUS Topology
12V Power Supply
Ground Data
Connectors studies
Body and user interface
Engine
A/C System
A/C Compressor
Connection 1
Pressure Sensor
Wiring Harness Data
Connector Number
Connects to:
Part of:
Sealing
Sealing Type
Connector Locking Type
Harness Covering
Contact Finish Color
Number of cavities
Number of wires
Number of cavities with wires
Manufacturer
Terminal Gender
Material Code(s)
Wiring Harness Fastener
Wire connections (new)

2022 EV Trends: Quantum leap in power density of eDrive

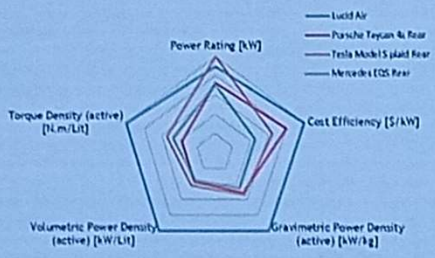
Disruptive Technological innovations, such as the first motor in market with continuous hairpins, enable a jump in KPIs.



Lucid Air, 410 kW



Porsche Taycan 4s, 270 kW



Main 2022 e-Drive Trends

- High integration of E-drive modules result in smaller volume and provide more space for occupant package.
- SiC provides better performance than IGBT but at a higher cost
- RC-IGBT (reverse current IGBT) is the best available alternative. This technology has been seen in BMW ad Ford EVs

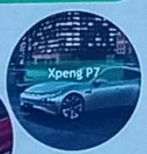
Case study: 2022 Lucid Air

- Outstanding performance of Lucid Air E-Motor versus main competitors thanks to:
  - High integration degree between motor and gearbox
  - Innovative continuous hairpin winding (wave winding) to maximize the power output
  - Higher e-drive input voltage (>900V) for higher rotation speed without loosing torque
  - SiC technology makes the Inverter unit compacter and more efficient

FACT: Lucid E-drive has 2.3x the volumetric power d… 8x gravimetric power density than the Tesla model … e-drive!

A2MAC1 leverages the full data to generate Insights & Improvement ideas

360° Vehicle Insights on all relevant Competitive Vehicles & Platforms, high-innovative vehicles as well as cost-challengers

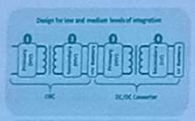


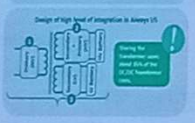
+1500 further vehicles

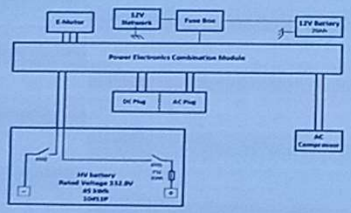
These 360° Vehicle Insights are then benchmarked vs. your vehicle… based…

2022 EV Trends: Next level of integration in Power Electronics

As technology matures, first OEMs are ready to launch fully-integrated Power Electronics concepts.







Integration of power electronics modules

- Even lowest degree of integration of power electronics modules (i.e., OBC and DCDC just share the housing) can lead to cost reduction.
- Higher degree of integration involves sharing of power path, power transformers and control functions.
- High degree of integration can improve the powertrain electrical architecture and therefore minimize HV cable cost.

Case study: BYD Dolphin Flagship

- BYD Dolphin is a good example of low cost, city car with relatively small battery capacity of 47kWh and cost of less than 15 k$.
- BYD Dolphin integrates inverter, OBC and DC/DC in one unit, which is mounted on top of e-motor assembly.
- With this special design, BYD also minimizes effort for HV cable cost, v… cable in powertrain

Holistic view is key to be cost competitive…

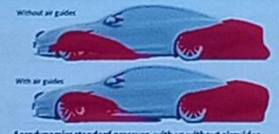
Aerodynamic improvements seen on the Model S plaid serve as performance optimization as well as cost reduction measures

Tesla Model S Plaid : front bumper air guides
PP-PE MD10, 0.57kg total, injection molding, glued and ultra-sonic welding on bumper

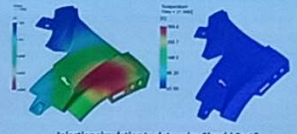
Tesla Model S Sales Volume
Note : 2021 based on Models S and X combined

PERFORMANCE IMPACT
Drag Coefficient: 0.003 Est. range impact*: 1.5km

COST IMPACT
Mfg Cost : 3.85€ Assembly cost : 3.42€

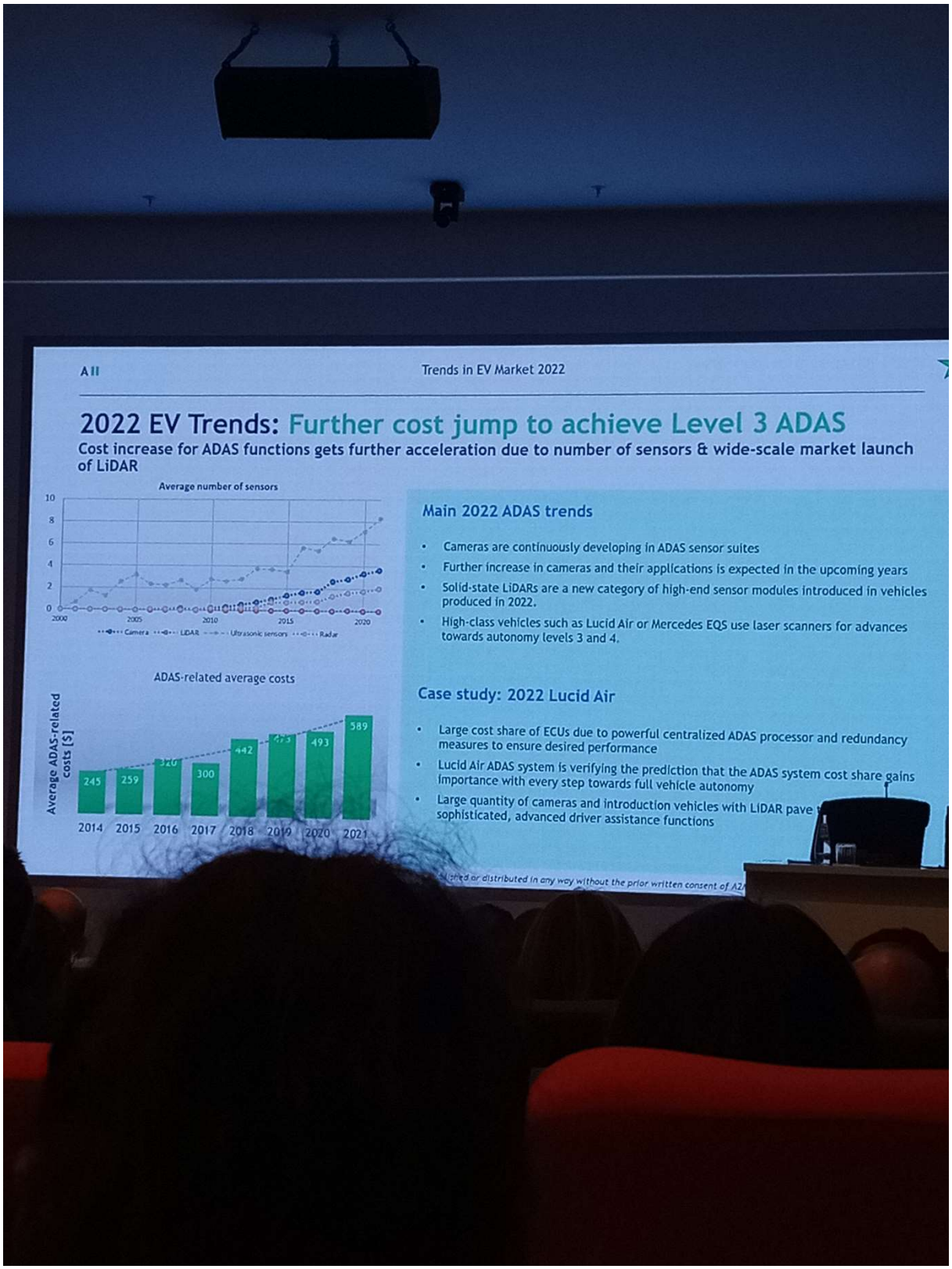


Aerodynamics standard pressure, with vs without airguides
Assumptions : standard body high, (*) 1 Cd point decrease = 0.5km range increase



Injection simulation to determine Should Cost*
Assumptions: 1000 unit/batch, 10 & 15 shifts/week, etc.
EXW Price, Product/Process engineering costs not included

Parameter	Value	Unit
Cost for Aero improvement guides:	8.9	$
Battery Cost: 2021	15.0	$
Battery Capacity:	100	kWh
Cost / Wh	0.15	$/Wh
Energy Consumption (WLTP, researched)	170	Wh/km
Battery Cost /km of range	0.15	$/km
Range Gain	1.7	km
Energy used for 1.5km	289	Wh
Battery Cost for 298 Wh or 1.5km Range	43.5	
Savings per Vehicle	**34.6**	


AII
Trends in EV Market 2022
2022 EV Trends: Further cost jump to achieve Level 3 ADAS
Cost increase for ADAS functions gets further acceleration due to number of sensors & wide-scale market launch of LiDAR
Average number of sensors
10
8
6
4
2
0
2000
2005
2010
2015
2020
Camera
LiDAR
Ultrasonic sensors
Radar
ADAS-related average costs
Average ADAS-related costs [$]
245
259
320
300
442
493
589
2014
2015
2016
2017
2018
2019
2020
2021
Main 2022 ADAS trends
Cameras are continuously developing in ADAS sensor suites
Further increase in cameras and their applications is expected in the upcoming years
Solid-state LiDARs are a new category of high-end sensor modules introduced in vehicles produced in 2022.
High-class vehicles such as Lucid Air or Mercedes EQS use laser scanners for advances towards autonomy levels 3 and 4.
Case study: 2022 Lucid Air
Large cost share of ECUs due to powerful centralized ADAS processor and redundancy measures to ensure desired performance
Lucid Air ADAS system is verifying the prediction that the ADAS system cost share gains importance with every step towards full vehicle autonomy
Large quantity of cameras and introduction vehicles with LiDAR pave
sophisticated, advanced driver assistance functions
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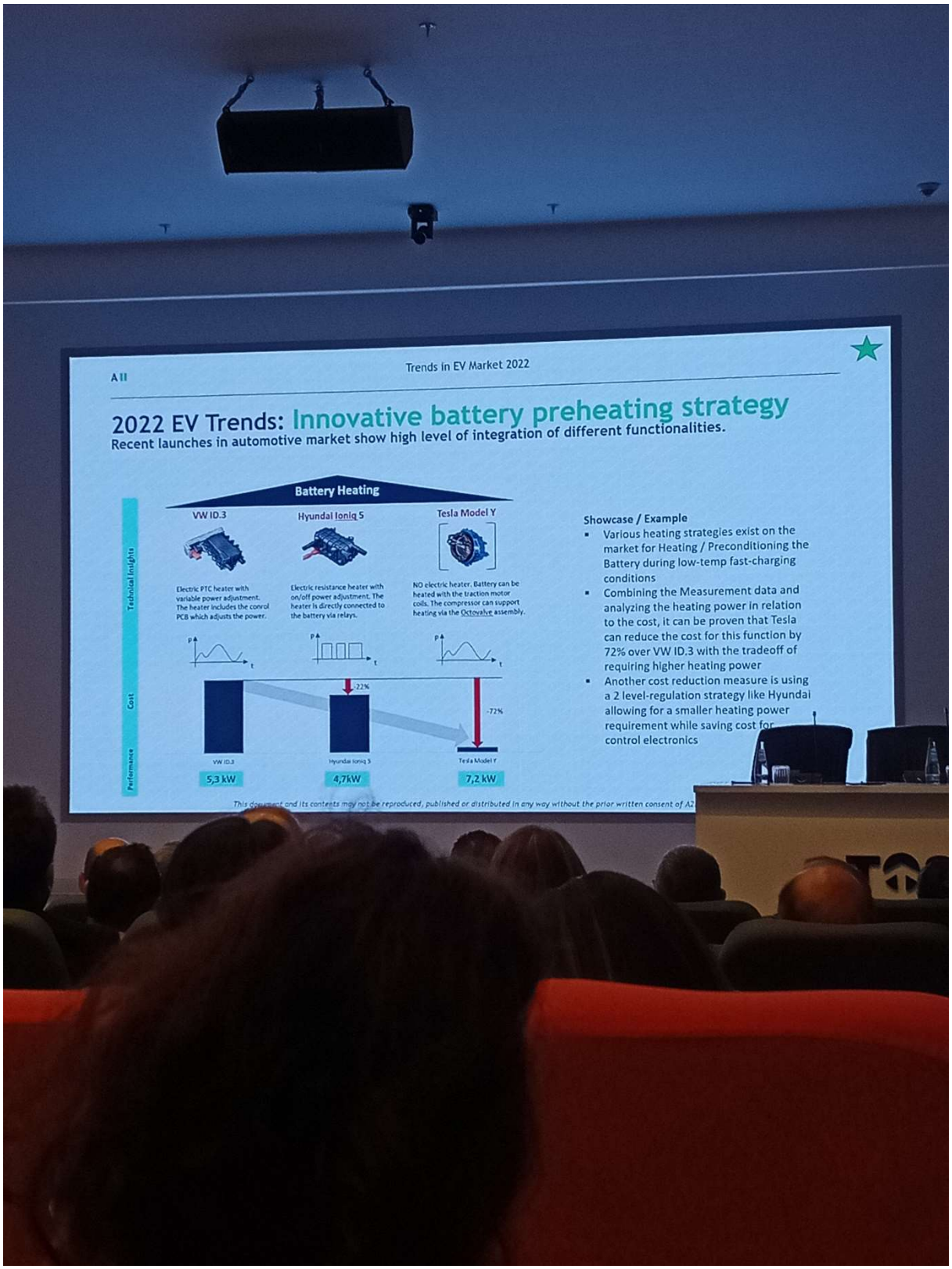
A II
Trends in EV Market 2022
2022 EV Trends: Innovative battery preheating strategy
Recent launches in automotive market show high level of integration of different functionalities.
Battery Heating
VW ID.3
Hyundai Ioniq 5
Tesla Model Y
Electric PTC heater with variable power adjustment. The heater includes the conrol PCB which adjusts the power.
Electric resistance heater with on/off power adjustment. The heater is directly connected to the battery via relays.
NO electric heater. Battery can be heated with the traction motor coils. The compressor can support heating via the Octovalve assembly.
Technical Insights
Cost
Performance
-22%
-72%
VW ID.3
Hyundai Ioniq 5
Tesla Model Y
5,3 kW
4,7kW
7,2 kW
Showcase / Example
Various heating strategies exist on the market for Heating / Preconditioning the Battery during low-temp fast-charging conditions
Combining the Measurement data and analyzing the heating power in relation to the cost, it can be proven that Tesla can reduce the cost for this function by 72% over VW ID.3 with the tradeoff of requiring higher heating power
Another cost reduction measure is using a 2 level-regulation strategy like Hyundai allowing for a smaller heating power requirement while saving cost for control electronics
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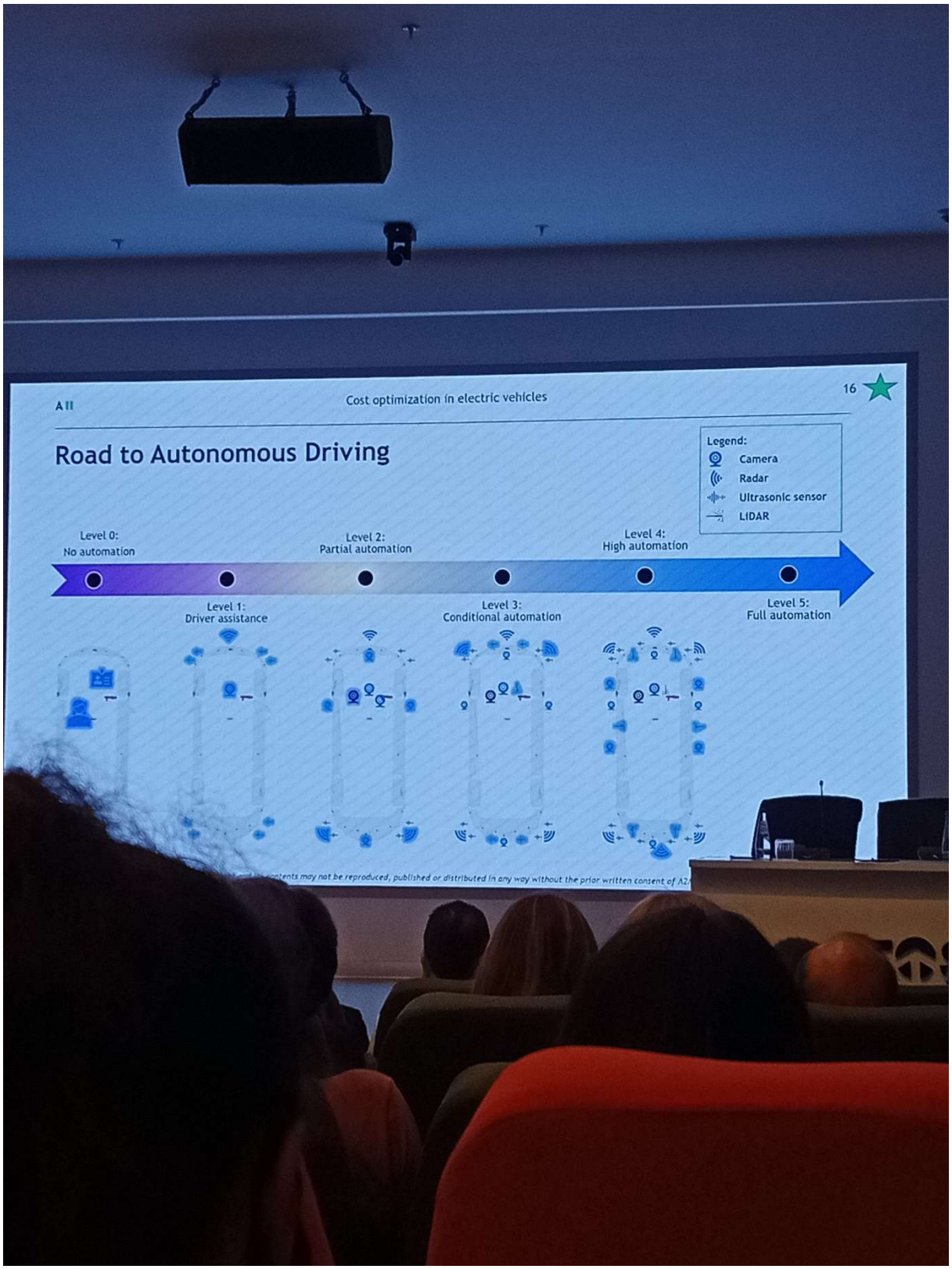
A II
Cost optimization in electric vehicles
16
Road to Autonomous Driving
Legend:
Camera
Radar
Ultrasonic sensor
LiDAR
Level 0:
No automation
Level 1:
Driver assistance
Level 2:
Partial automation
Level 3:
Conditional automation
Level 4:
High automation
Level 5:
Full automation
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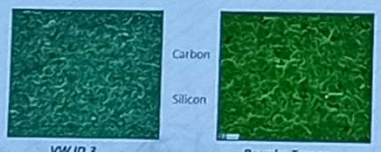
2022 EV Trends: Move towards alternative Cell chemistries

Market is moving away from conventional NMC cell chemistry to more application-tailored chemistries

BYD Han LFP Blade Battery



VW ID.3 *Porsche Taycan*

BEV Cell chemistry

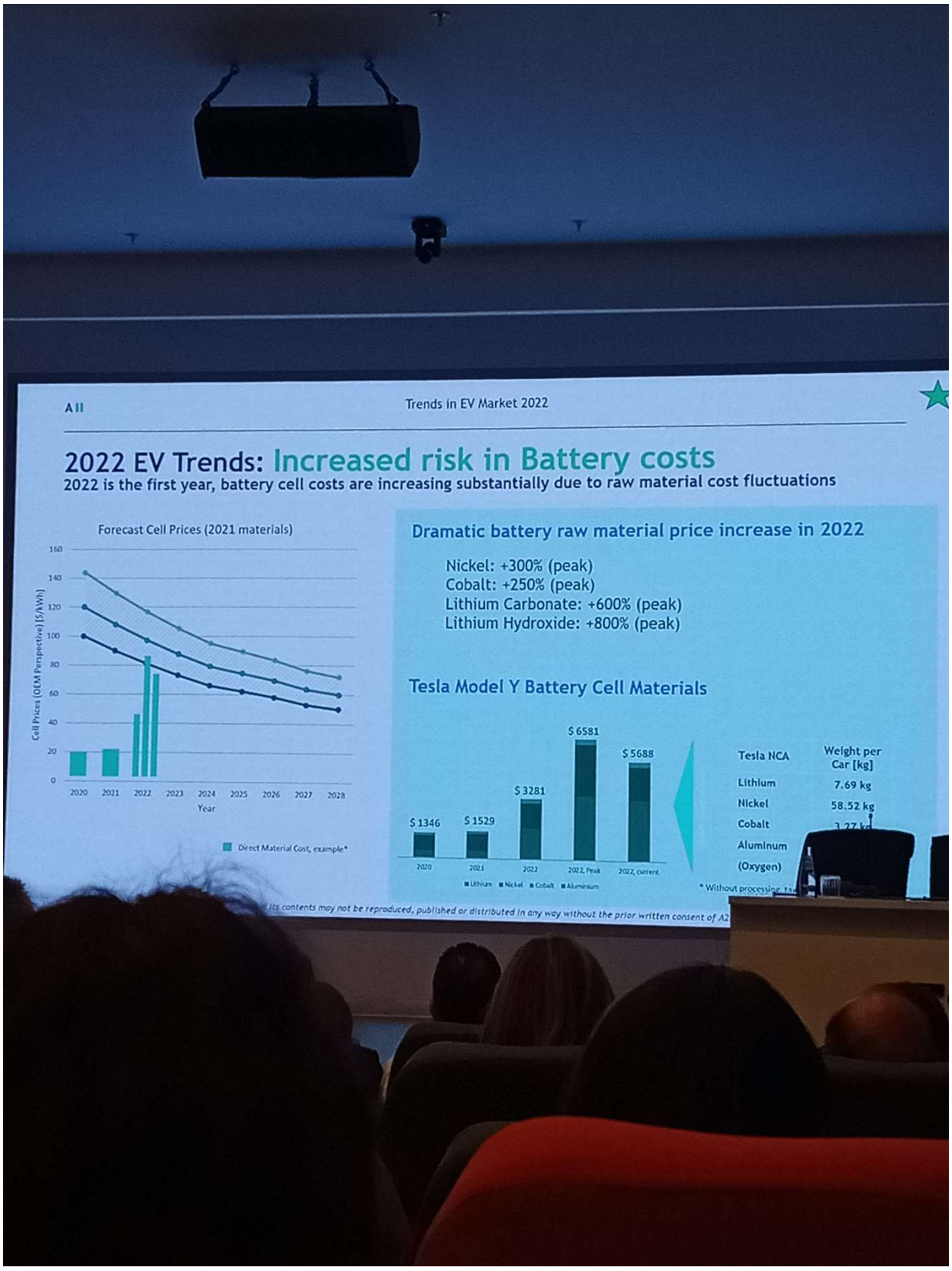
- Till date OEMs are driven by maximizing the range of vehicles by maximizing energy density and specific energy
- Range of 400-500km can be achieved easily, other parameters can be optimized

High performance / fast charging

- Anode chemistry must be adapted
- New solutions will be available next year
- Possible solutions:
  - Graphene instead of Graphite
  - Silicon anodes with adjusted electrolytes
  - Solid electrolytes

LFP Batteries

- Used in stationary applications and commercial vehicles (mainly in China)
- Latest developments lead to similar battery specific energy, whilst reducing cost and dependence on Nickel and Cobalt
- Tesla implements LFP cells to reduce cost of entry level vehicles in the Chinese market


A II
Trends in EV Market 2022
2022 EV Trends: Increased risk in Battery costs
2022 is the first year, battery cell costs are increasing substantially due to raw material cost fluctuations
Forecast Cell Prices (2021 materials)
Cell Prices (OEM Perspective) [$/kWh]
160
140
120
100
80
60
40
20
0
2020 2021 2022 2023 2024 2025 2026 2027 2028
Year
Direct Material Cost, example*
Dramatic battery raw material price increase in 2022
Nickel: +300% (peak)
Cobalt: +250% (peak)
Lithium Carbonate: +600% (peak)
Lithium Hydroxide: +800% (peak)
Tesla Model Y Battery Cell Materials
$ 1346
$ 1529
$ 3281
$ 6581
$ 5688
2020
2021
2022
2022, Peak
2022, current
Lithium
Nickel
Cobalt
Aluminium
Tesla NCA
Weight per Car [kg]
Lithium
7.69 kg
Nickel
58.52 kg
Cobalt
Aluminum
(Oxygen)
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