VL10ES Cell and Battery Up-Date

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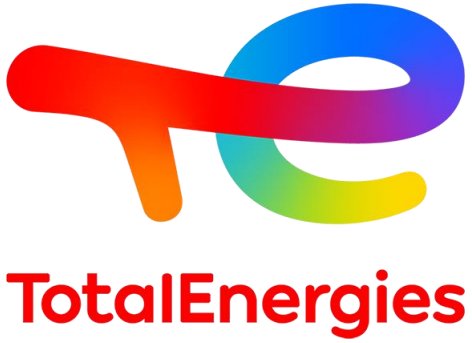
Summary



1. Space Li-Ion Batteries Heritage
2. VL10ES Cell Battery Design Overview
3. VL10ES Cell Battery Development status

saft

Saft Li-ion in orbit heritage and reliability

359 satellites in-orbit with Li-ion (GEO, MEO & LEO) : 341 operational

More than 2,5 Billion of cell hours in orbit with no failure or deviations

Total over 3,8 MWh in-orbit with 650 batteries and more than 45 000 cells in orbit

- **199 GEO satellites** Launched + **1 Moon Mission** :

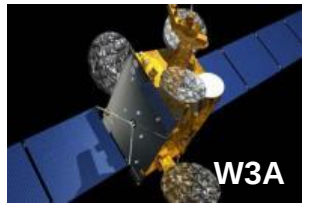
  2003 : Smart 1 has been able to reach Moon orbit thanks to ion thrusters' engines powered with Li-Ion battery

  1rst GEO Telecommunication satellite W3A launched 18 years ago (March 2004) with VES140 batteries

- **5 MEO satellite** flying with VES technology:

- **155 LEO satellites including** :

  75 first Iridium Next satellites with VES16 batteries



VL10ES
Cell/Battery Design Overview

VL10ES Performances objectives – compared with Saft VES16

Specific energy

Higher DOD in GEO and LEO compared to 18650

Safety : SS thick can, welded cover, 2 vents

CELL TYPE	VES16 (D-size)	VL10ES (F-size)
Dimensions (Ø x H)	33 x 60 mm	**33 x** 103 mm
Weight	≤ 115 g	**210 g**
Volume	0.051 dm^3	0.086 dm^3
Voltage range	2.7 V - 4.1 V	2.7 V - 4.2 V
Nominal capacity	4.5 Ah @ 4.1V, 20°C	**> 12 Ah @ 4.2V, 20°C**
Nominal energy	16 Wh @ 4.1V, 20°C	**> 46 Wh @ 4.2V, 20°C**
Specific energy	> 140 Wh/kg	**> 220 Wh/kg**
Internal resistance	≤ 35 mΩ @ 20% DoD	≤ 22 mΩ @ 20% DoD / TBC
Operating temperature	+10°C / +40°C	+10°C / +40°C
Mechanical design margins	EWR & ECSS compliant	EWR & ECSS compliant

VL10ES Innovative Battery Concept

To answer to modularity (SP / PSP), to limits the no-recurring cost, a battery concept based on one main 4S pack

Independent block

With independent electrical, mechanical and thermal interface allowing easy replacement

Modularity

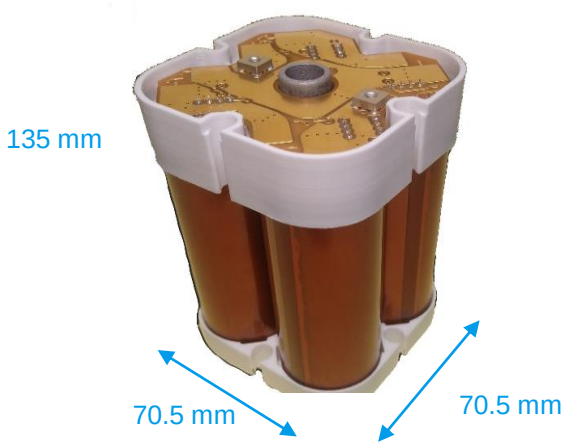
Blocks are mechanically linked to each other like the pieces of a puzzle in order to reach larger S-P configuration

Autonomous electronics

Each block is carrying its own autonomous electronics (4 Simplified Balancing System per block)

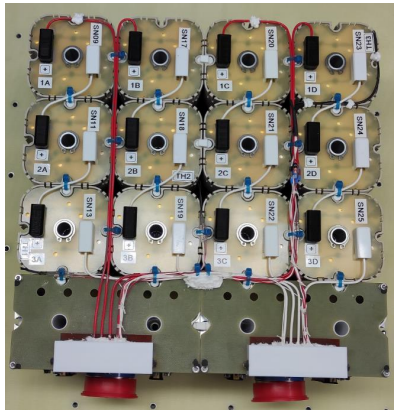
Assembly innovation

Each block is attached to the panel through a unique central screw.



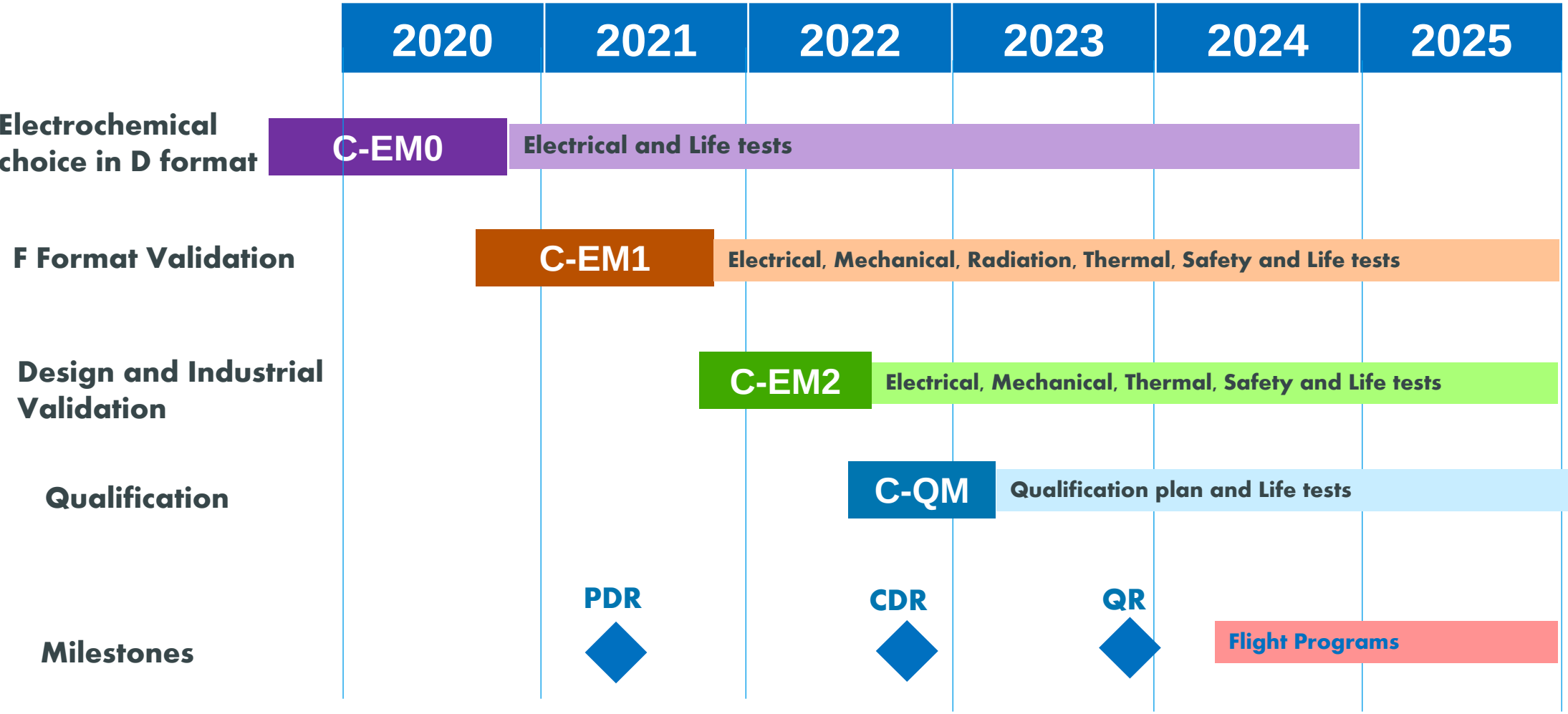
4S1P Block with SBS
Weight 1.03 kg

Bat-EM2 12S4P

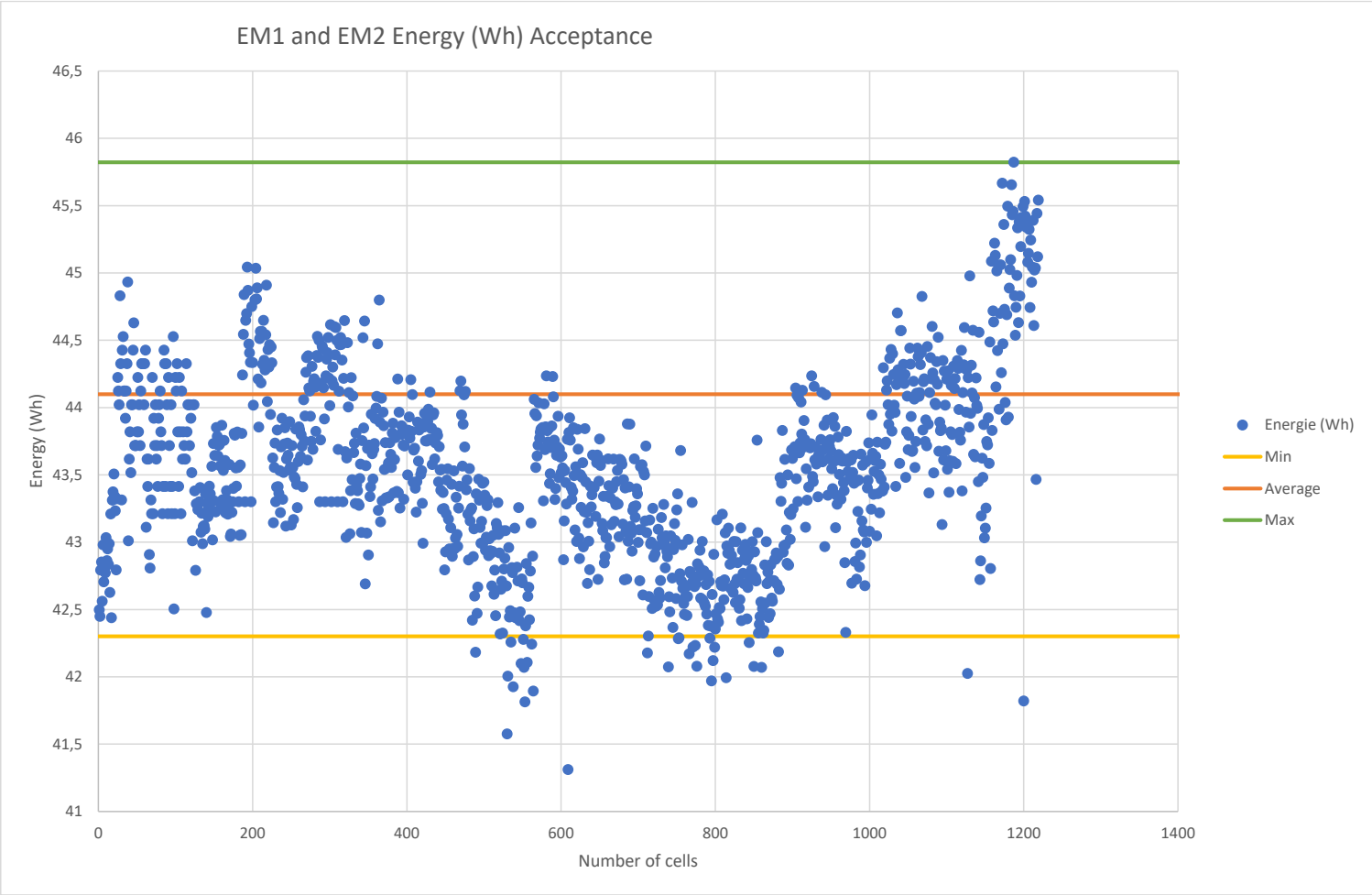


VL10ES Cell/Battery Development status

VL10ES Cell Development Plan



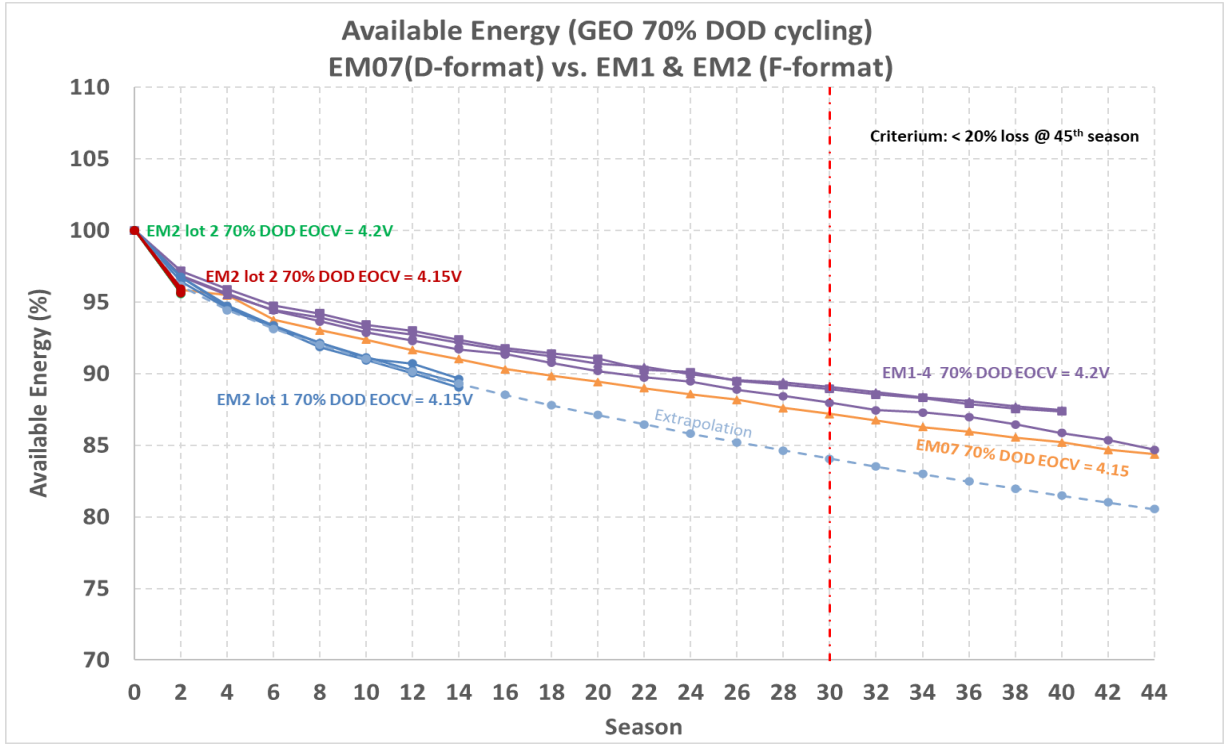
EM1/EM2 Cell acceptance performances



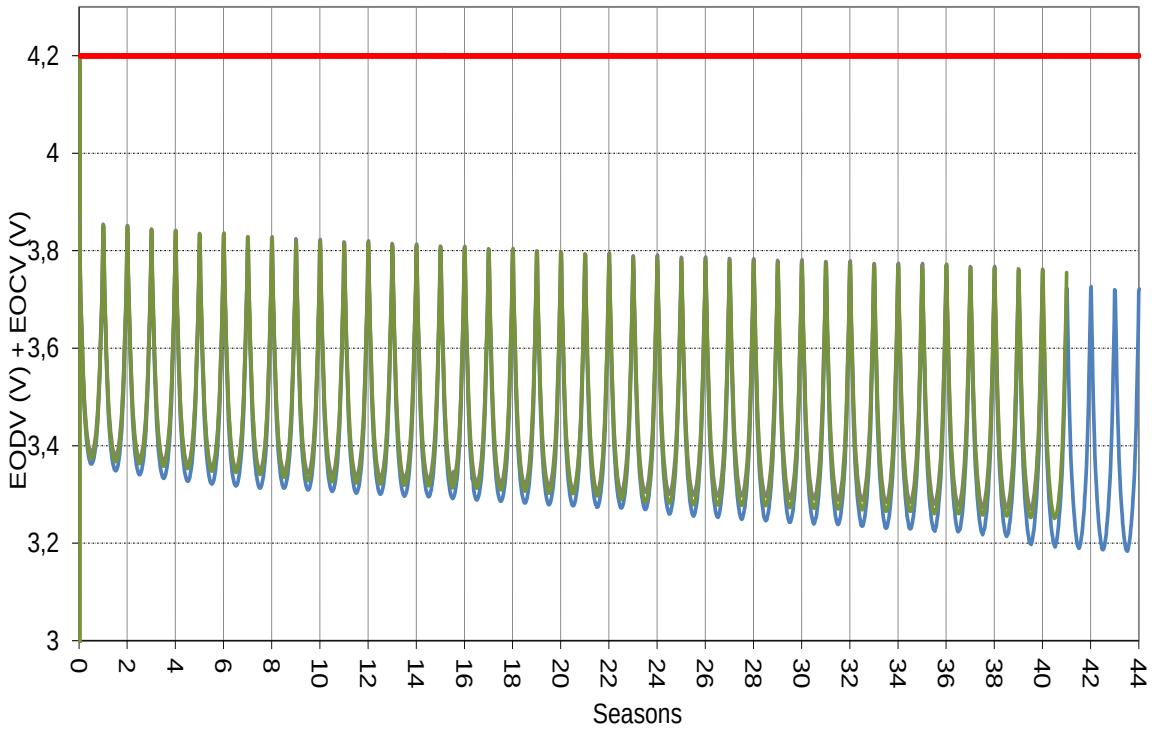
	EM2 Acceptance Energy (Wh) 4.2 V @C/2 20°C
Average	45.1
Minimum	43.0
Maximum	46.4
Standard deviation	0.6

More than 1200 cells have been built and fully tested (equivalent to the QM design and test plan).

EM1-EM2 Cell 70 % GEO performances



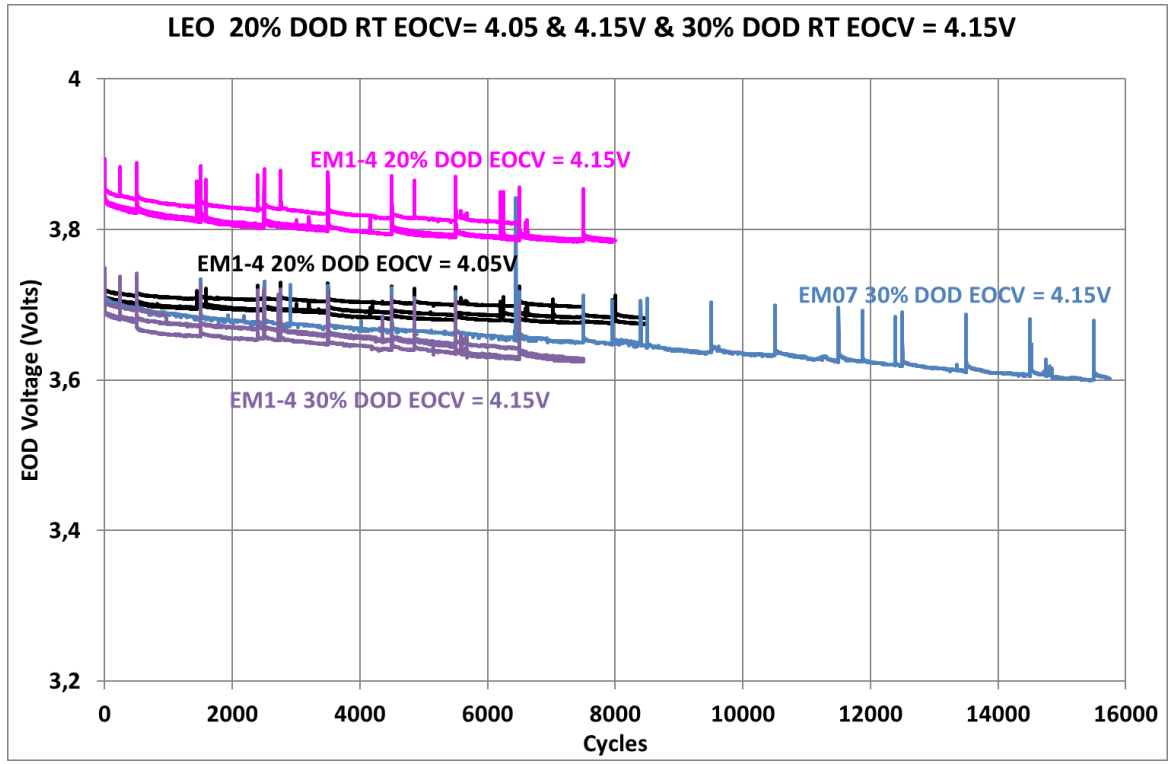
EODV - EOCV for EOCV = 4.2V

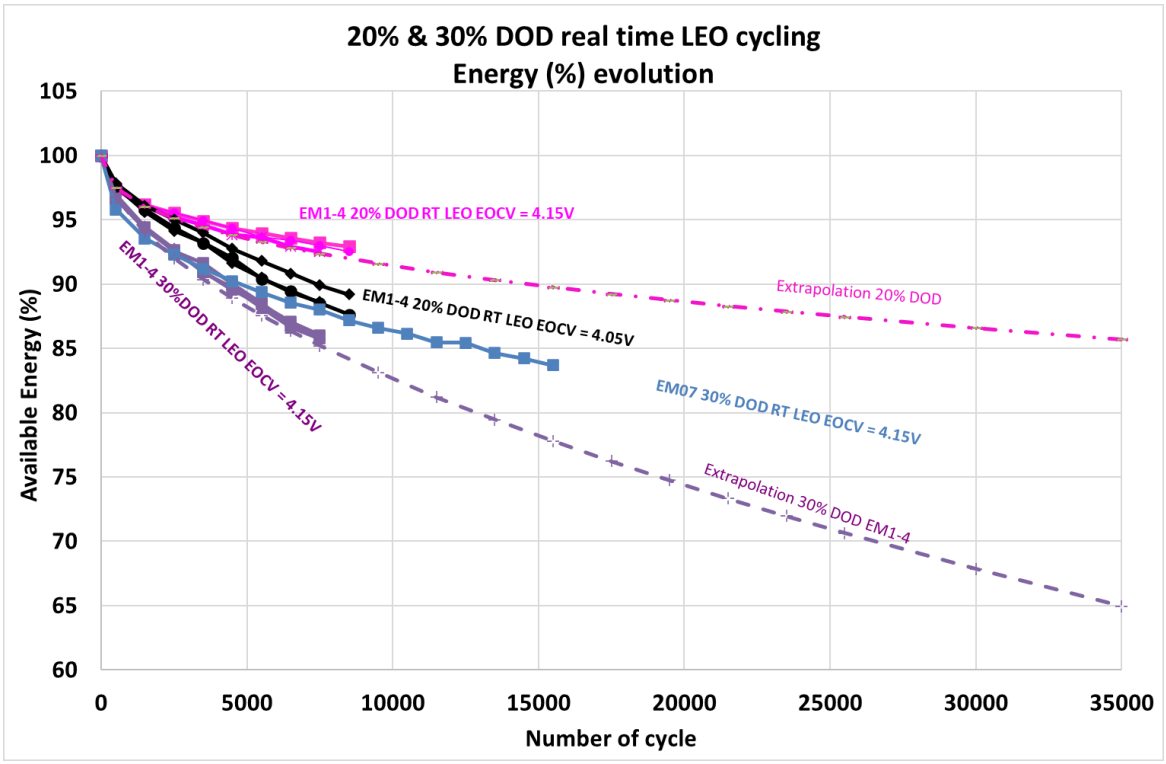


45 GEO seasons (equivalent to 22.5 years) successfully done on EM0 and EM1
EM2 life test are running

LEO cycling : C-EM1 Available capacity @ 20 and 30 % DOD

EODV and Energy





C-EM1 LEO performances at 20 and 30 % DOD are in line with EOL requirements

C-EM1/EM2 Safety Results

VL10ES safety as good as VES16 thanks to thick can, cover welding and 2 vents

VL10ES	Crush test 50 & 100% SOC	C/3 & C over-charge	Impact test 100% SOC	Pin test 100%SOC	Pin test 50% SOC	Heating test	External-short 10mohm 100%SOC	Over-discharge	Drop test 100%SOC	ARC test 100%SOC	Nail test 100% SOC
C-EM1-4 C-EM2	100% SOC OK (2/2) EUCAR 2 50% SOC OK (2/2) EUCAR 2	C/3 OK (3/3) EUCAR 2 C OK (3/3) EUCAR 2	100% SOC OK (3/3) EUCAR 2 50% SOC OK (3/3) EUCAR 2	OK (3/3) EUCAR5	OK (3/3) EUCAR5	OK (3/3)	OK (2/2) EUCAR 3	(1/1 OK) in progress C/2 (10 cycles) at -0.5V	Ok (1/1) EUCAR 2	OK (1/1) EUCAR 5	OK (3/3) EUCAR 5

Tests results as good as VES16 : high level of safety

VL10ES Cell Qualification Matrix

VL10ES cell qualification

Electrical	Mechanical	Thermal	Life Tests	Safety
Dch vs T°	Vibration	T/V	LEO real time	Overcharge
Dch vs C rates	Shock	Dissipation	GEO semi-accelerated (EOR, PPS ,U cycles)	Over discharge / Reversal
Dch vs EOCV	T/V Cycling	Thermal Capacity	GEO accelerated	Ext. short
Dch vs Power rates	Leak Rate	Thermoneutral potential	Storage vs T° & SOC	Over temperature
Impedance, Ri	DPA		100% DoD	Nail / Pin Test
EMF vs SOC			Radiation Test	UN Transportation
			DPA	Exposure 60°C – 24 Hours

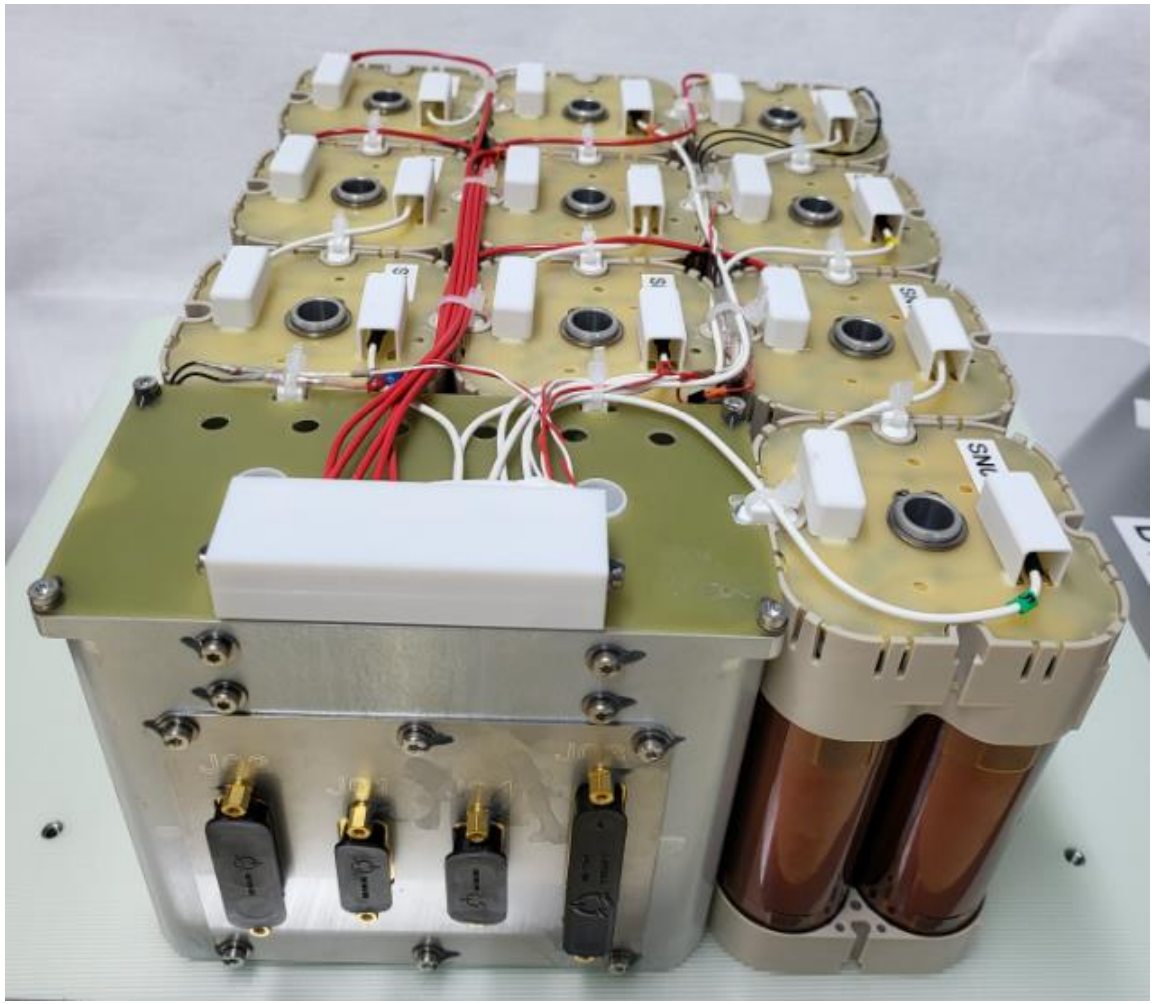
In green color: Tests performed on EM1 and EM2 cells are already covering the Qual Test Plan

VL10ES

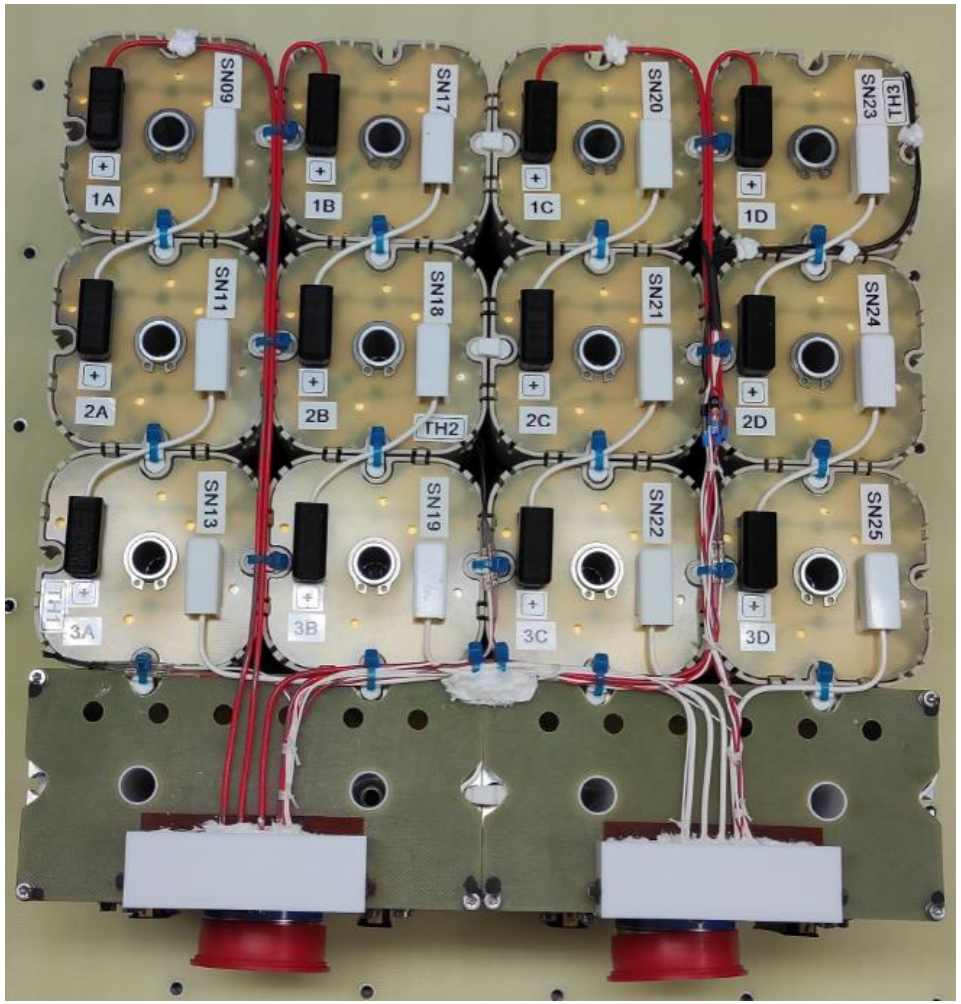
Battery development status

Bat-EM1 & Bat-EM2 : test plan done same as per qualification

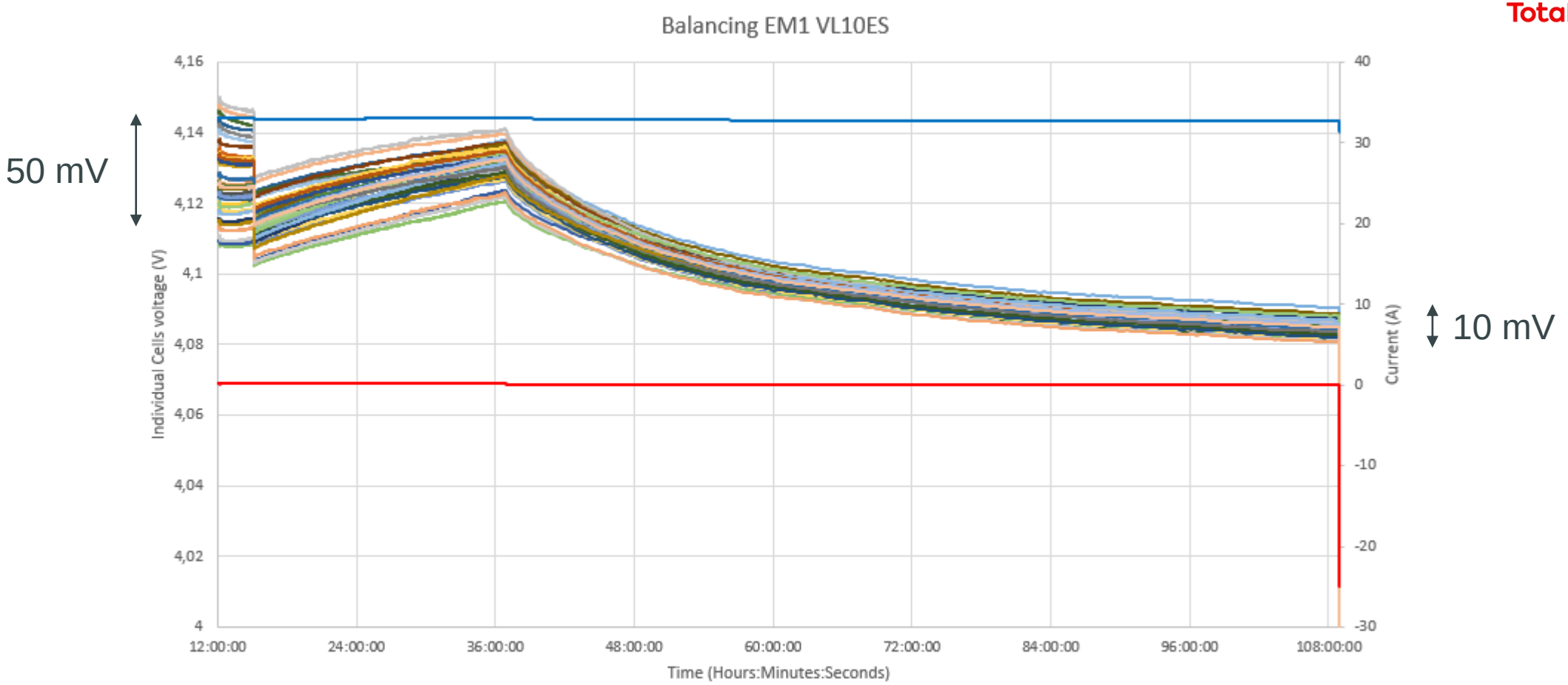
B-EM1 8S5P battery



B-EM2 12S4P battery

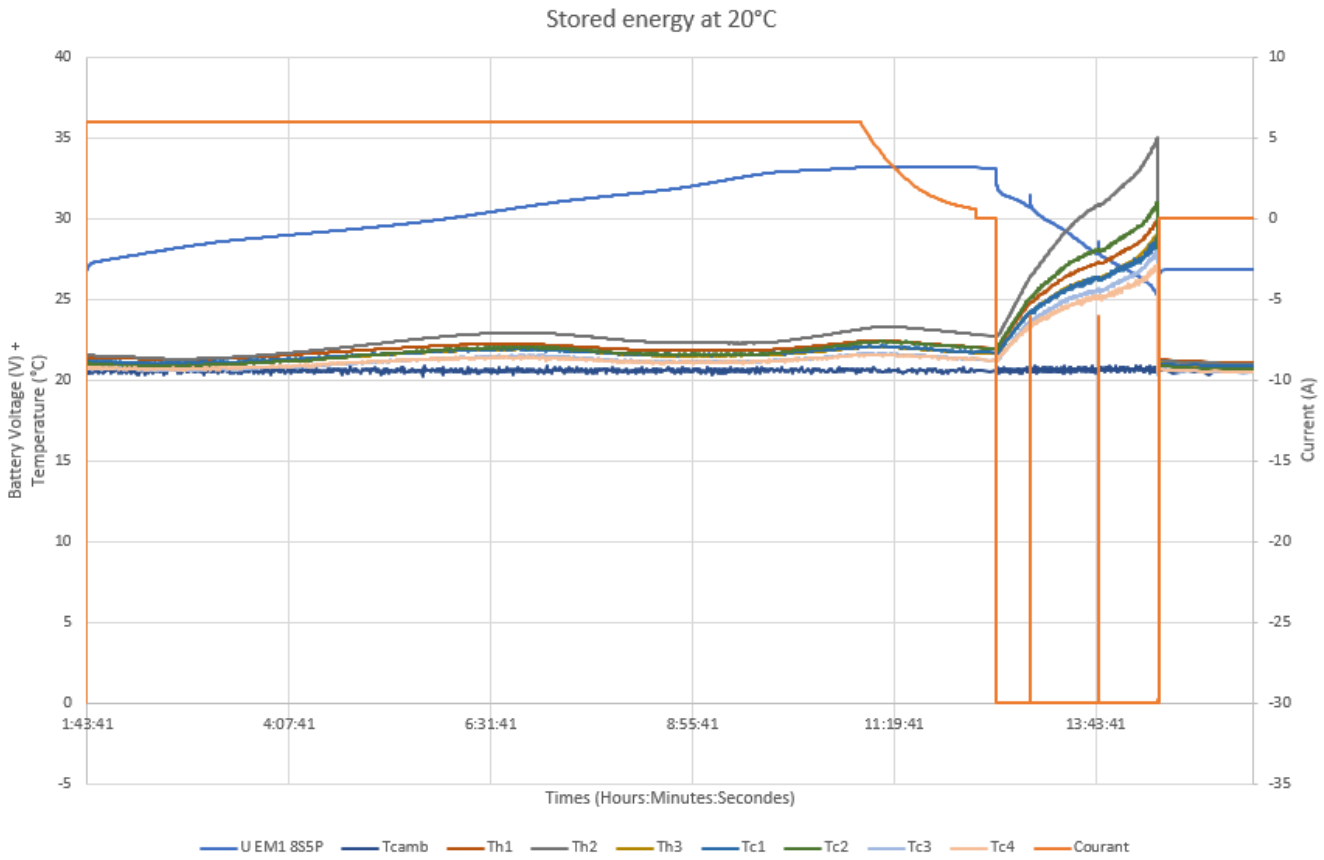


Bat-EM1 Test results – Balancing test



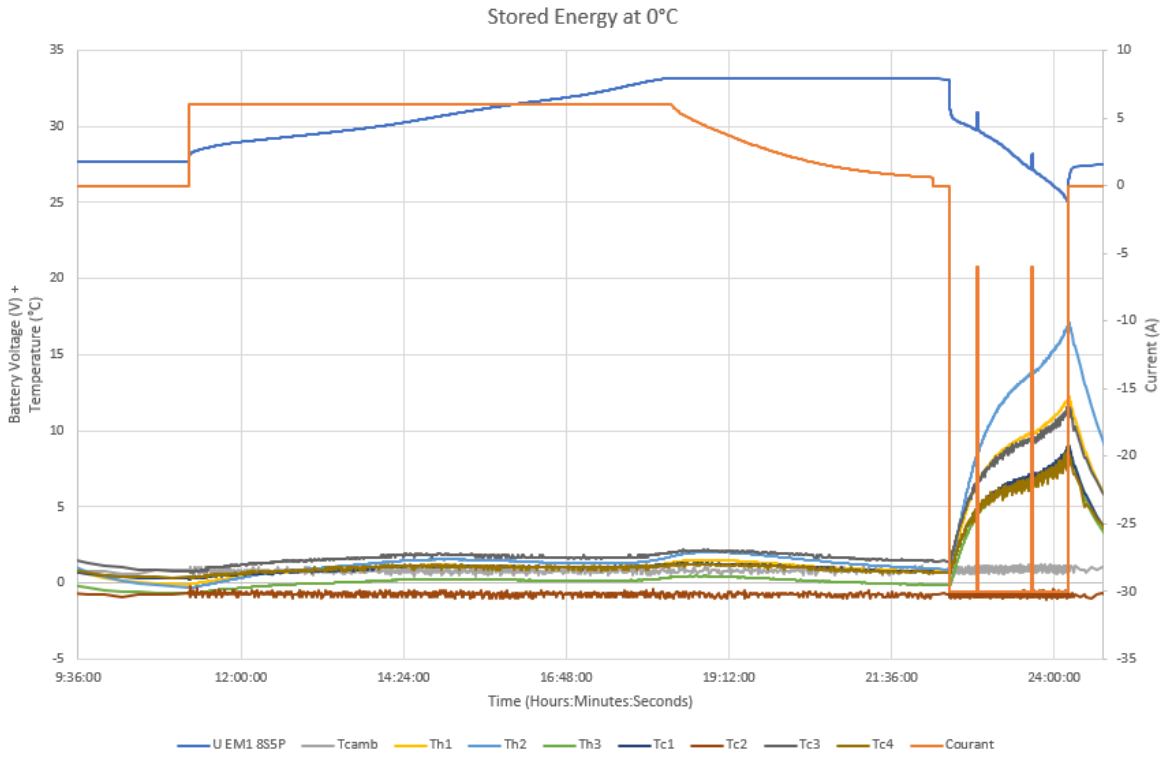
SBS capability : Cell to cell voltage spread criteria reaches in less than 48 hours

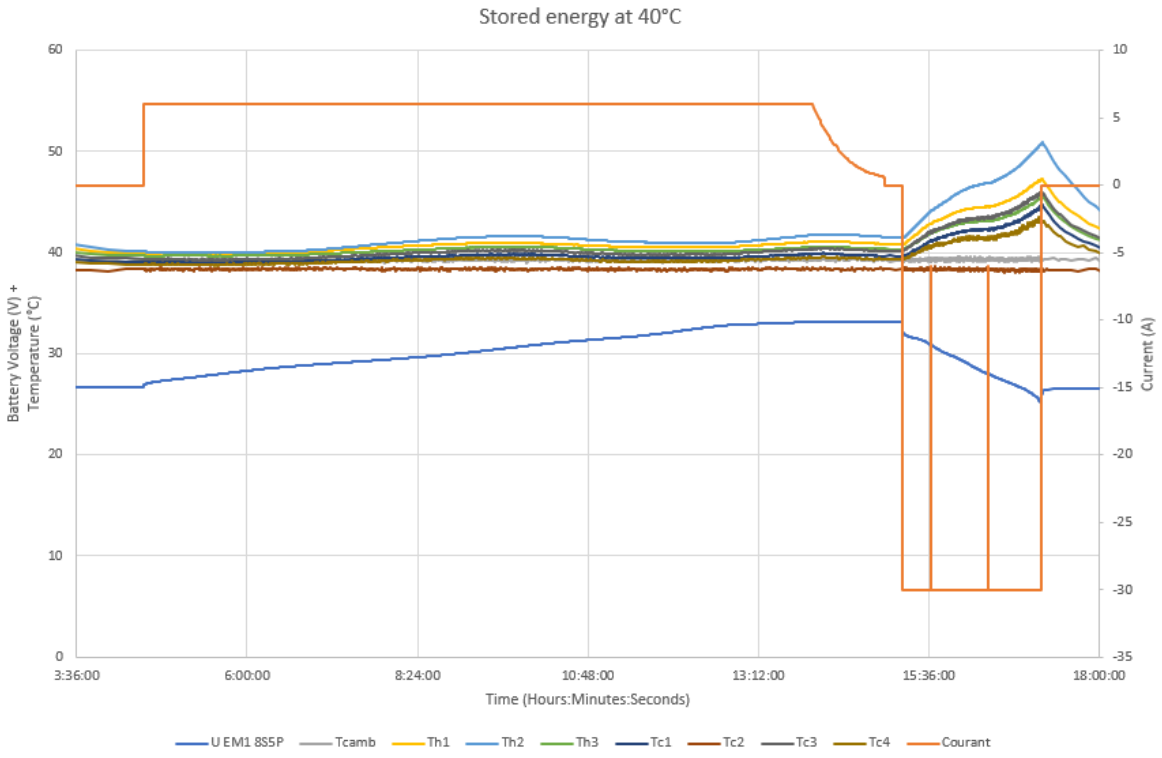
Bat-EM1 Test results – Capacity 20°C & Retention



20°C capacity check with internal resistance checks.
Max cell Temperature gradient at end of discharge +5°C

Bat-EM1 Test results – 0°C & 40°C capacity

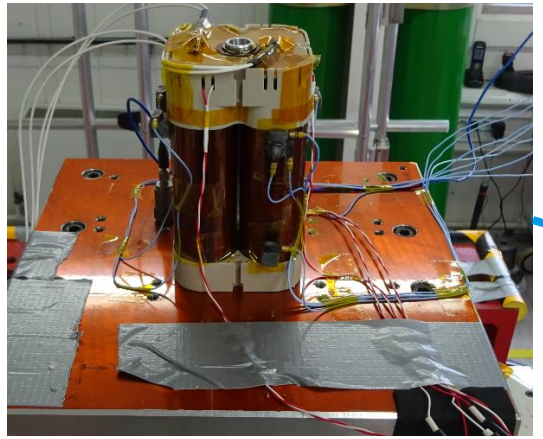


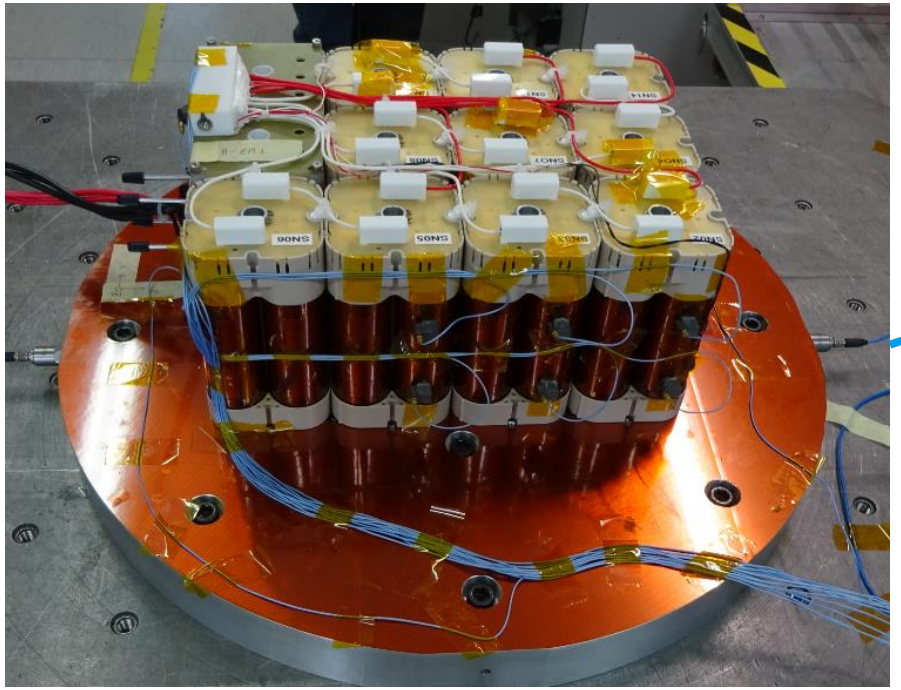


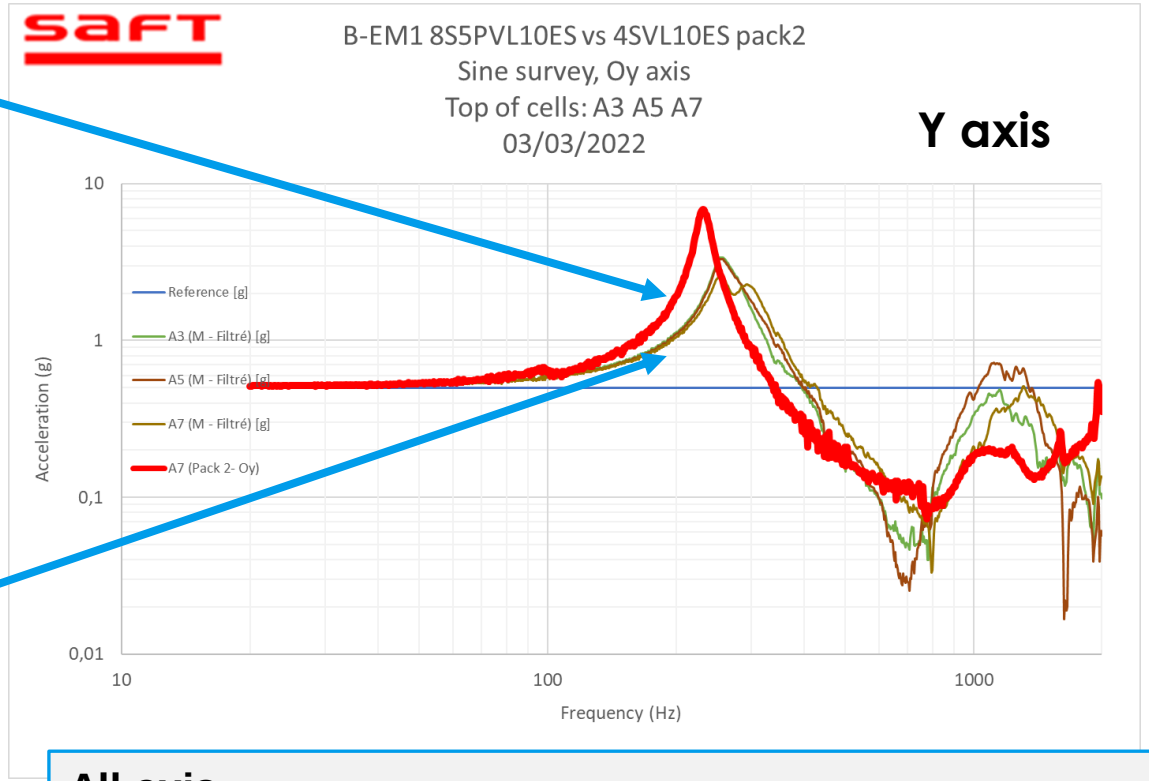
0°C and 40°C characterization tests are conform to requirements

Bat-EM1 Test results – vibration 3 axis

Bat-EM1 8S5P





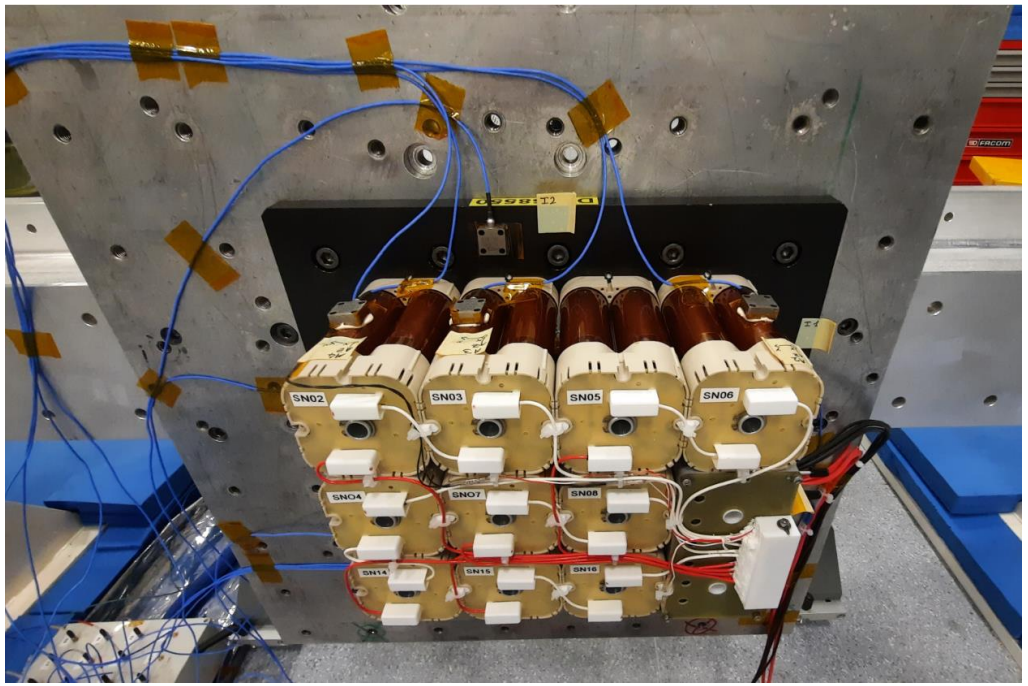


All axis :

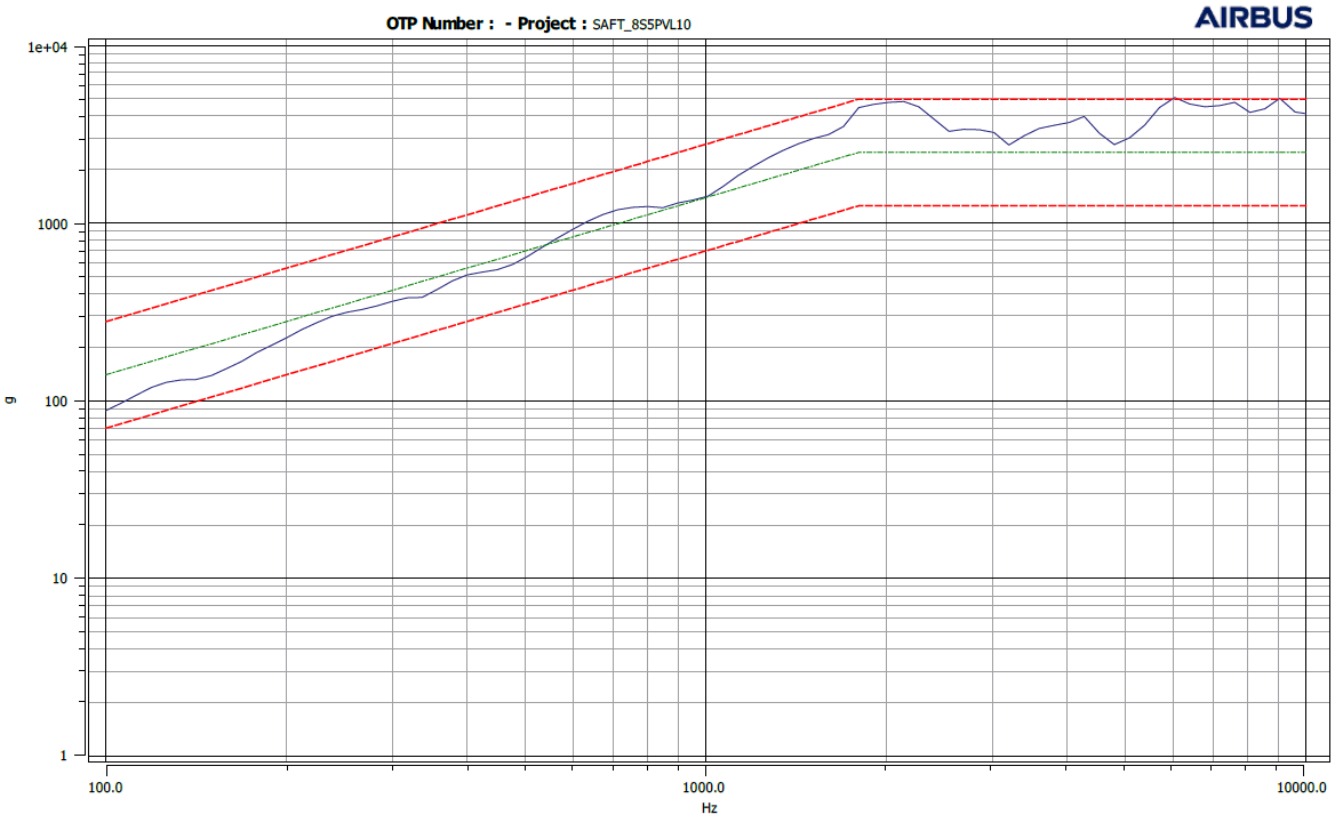
- Confirmation of result obtained at pack4S level, higher amplification (battery effect)

Bat-EM1 Test results – Shocks 3 axes

Z axis



Bat-EM1 8S5P



	Model	Test Name	Test Date	Type	Measurement Point	Maximum		Model	Test Name	Test Date	Type	Measurement Point	Maximum
—	B-EM1	Shock3_VL10_OZ	16/03/2022 15:55:22	SpectreDeChoc	I1_Z	5069	—		specificationXYZ				1253
--		specificationXYZ				1253	—		specificationXYZ				1253

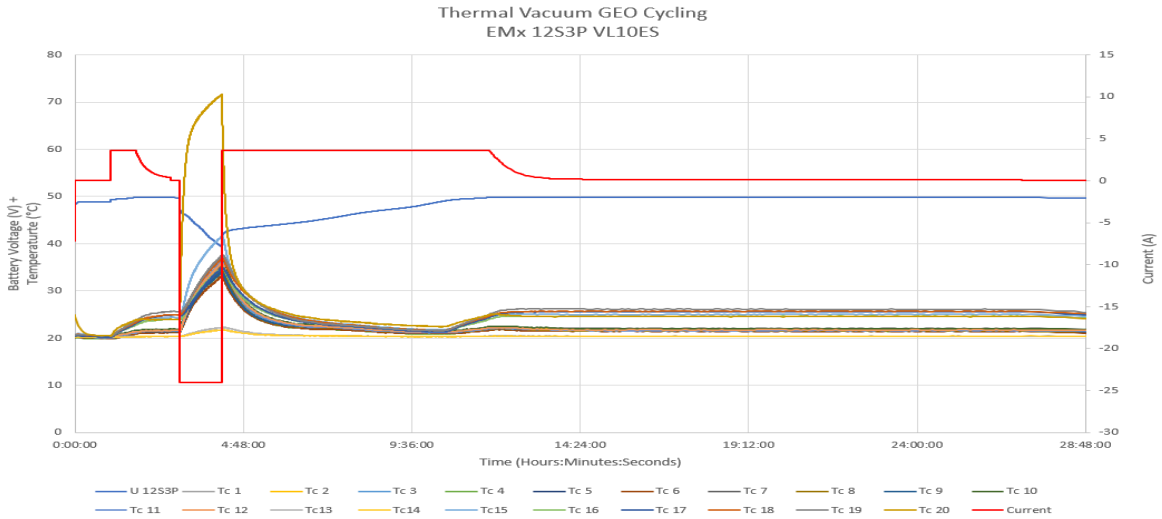
All axis

- No frequency drift, no degradation and DPA OK

Bat-EM3 12S3P Additionnal test

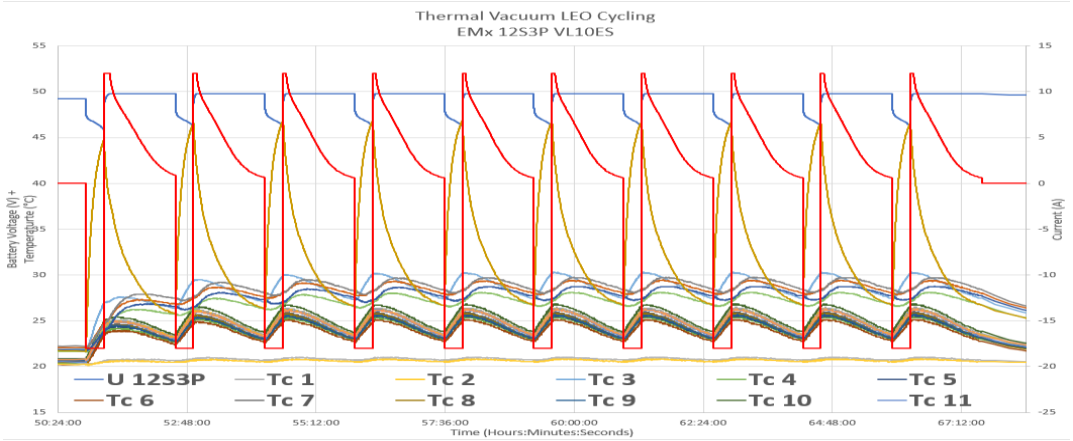
Thermal vacuum: GEO – 72mn discharge

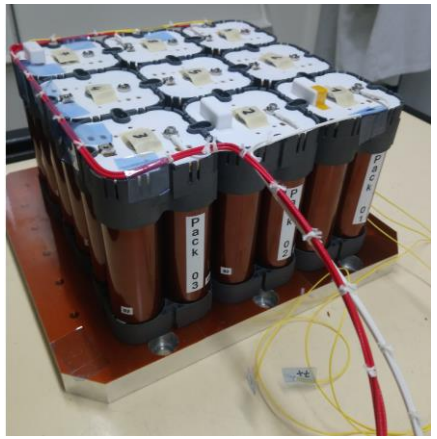
- 10°C increase of cell temperature at end of discharge



Thermal vacuum: LEO – C/3 charge / D/2 discharge

- Stabilisation at 5°C over the interface





Batt-EM3 12S3P

Bat-EM1/EM2 Test results

- Bat-EM's were successfully tested as per QM plan

  → Balancing system tests

  → Electrical Tests

  → Thermal tests

  → Environment tests : Vibration and Shock tests

  →Safety tests

  All successful

Battery Development plan

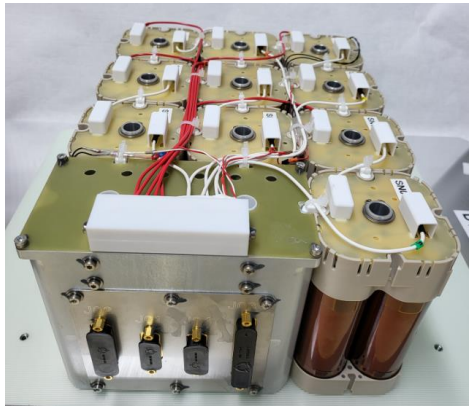
EM's Test plan **successfull**
- Batt-EM1 **8S5P**
- Batt-EM2 **12S4P**
- Batt-EM3 **12S3P**

Electrical, Thermal, Mechanical (vibration, shocks), SBS tests

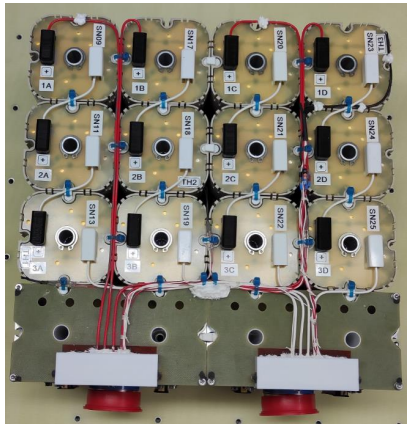
CDR held June 2022

Full Qualification test plan
- Batt-QM1 **8S5P**
- Batt-QM2 **11S6P**
- Batt-QM3 **3x12S4P**
- Batt-QM4 **12S20P**

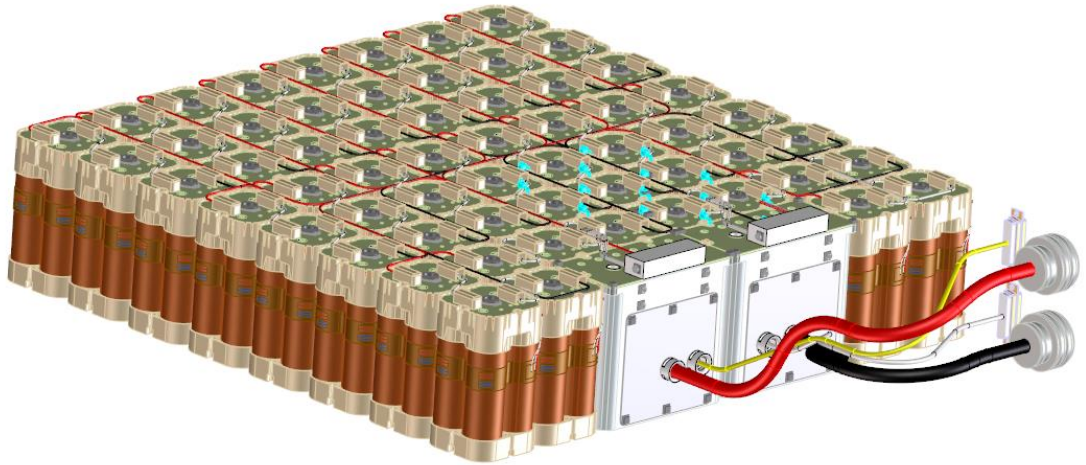
QR planned Q3 2023



Bat-EM1 8S5P



Bat-EM2 12S4P



Bat-QM4 12S20P VL10ES

Acknowledgments

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Thank you