
Space Power Workshop
Commoditization of Space:
Maintaining Resiliency in the Age of Faster and Cheaper
April 29–May 1, 2025
Torrance Marriott Redondo Beach, Torrance, CA
saft
VL10ES Cell and Battery Qualification Update
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TotalEnergies

Summary

1. Products Roadmap
2. Cell development
3. Battery Performances
4. Conclusions

Saft Satellite Technology Road-Map

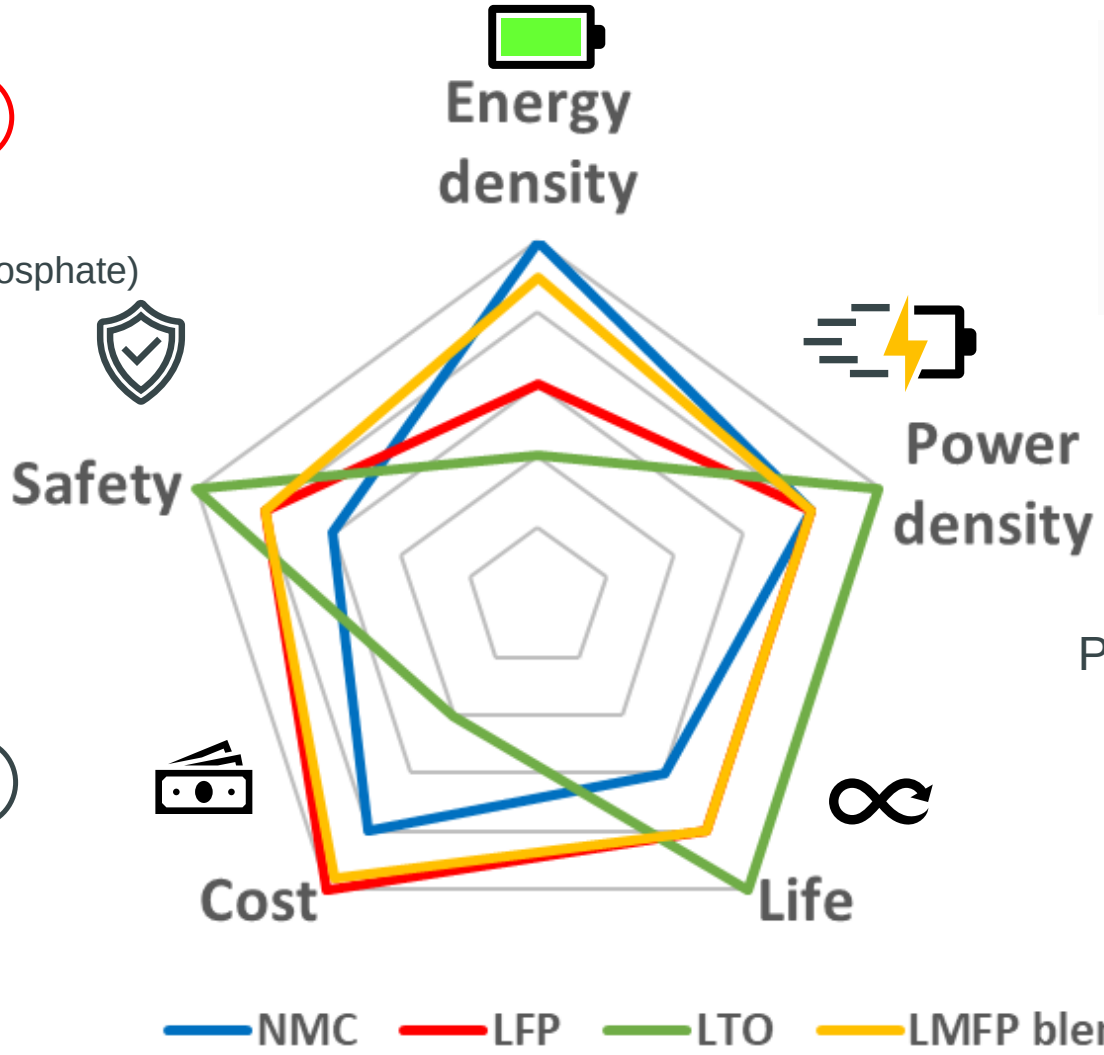
CURRENT LITHIUM CELL TECHNOLOGY
Overview

CATHODE (+)

- NCA (Nickel Cobalt Aluminum)
- NMC (Nickel Manganese Cobalt)
- LFP (Lithium Ferrous Phosphate)
- LMFP (Lithium Manganese Ferrous Phosphate)

ANODE (−)

- Graphite
- LTO (Lithium Titanate Oxide)
- Silicon



Cylindrical

Prismatic hard casing

Prismatic Pouch

Saft Li-ion in Orbit Heritage and Reliability

398 satellites in-orbit with Li-ion (GEO, MEO & LEO) : 377 operational

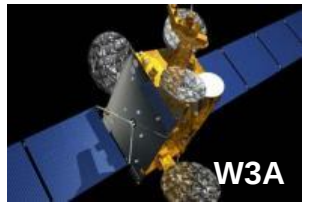
More than 3,4 Billion of cell hours in orbit with **no failure or deviations**

Total over 4,2 MWh in-orbit with 702 batteries and more than 50 800 cells in orbit

- **214 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 20 years ago (March 2004) with VES140 batteries



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

- **178 LEO satellites including** :

  80 first Iridium Next satellites with VES16 batteries

VL10ES Cell Development

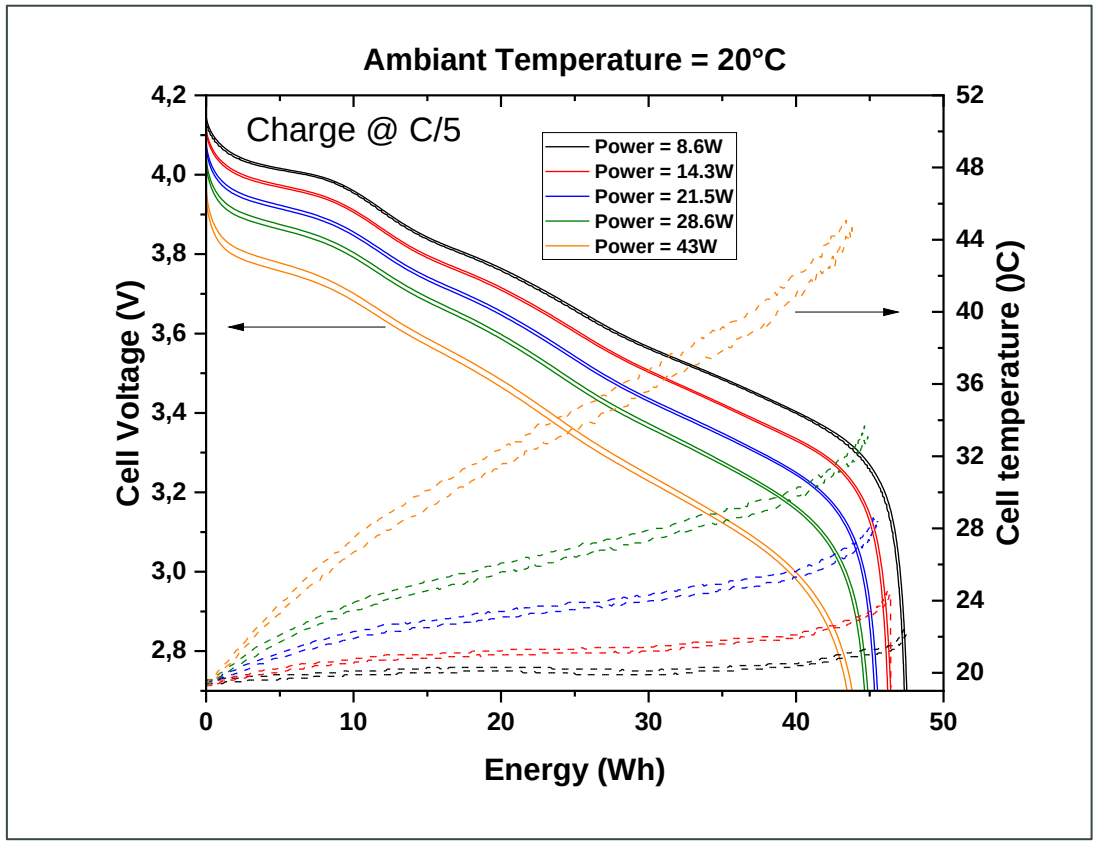
VL10ES Cell Qualification Matrix

VL10ES cell qualification Plan				
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		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

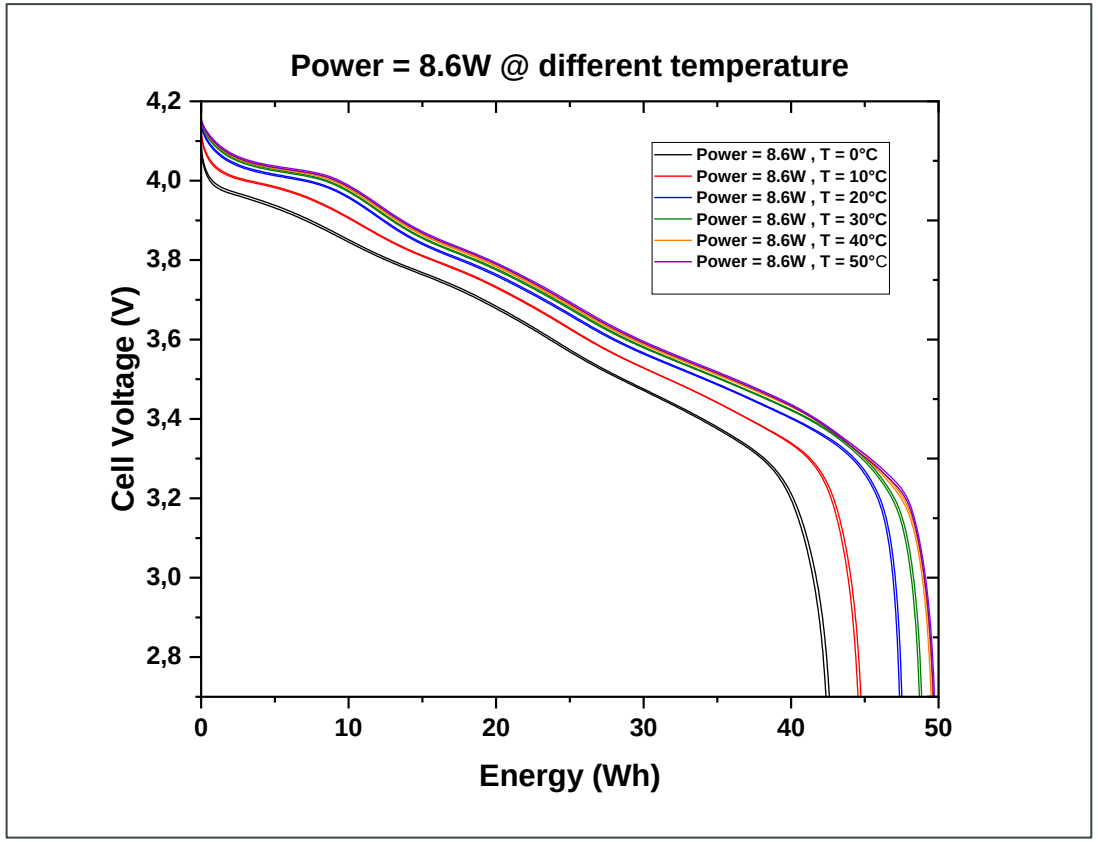
In orange color : Tests still running on QM cells

BOL Electrical Performances QM Cells : Constant Power Discharge versus Temperature

Energy evolution vs Power at 20°C



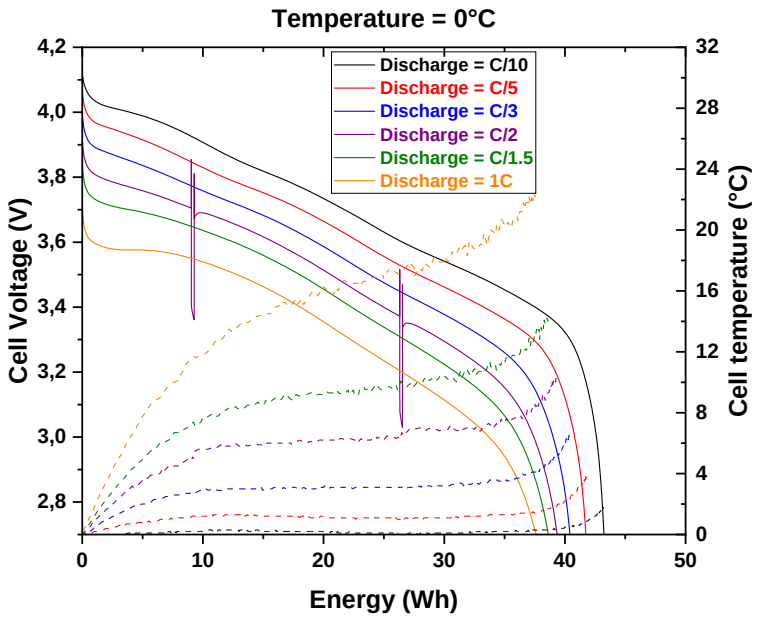
Energy evolution at constant Power vs Temperature



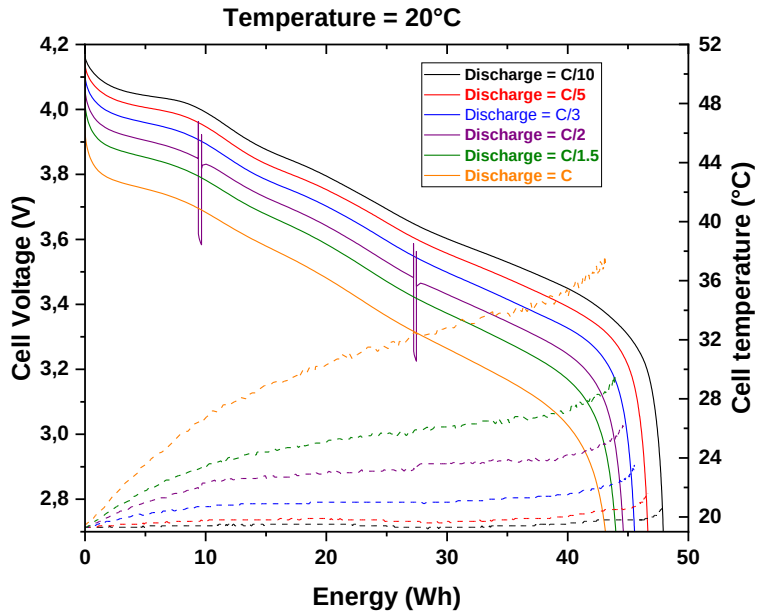
- Increasing discharge power leads to cell polarization together with a decrease in available energy and an increase in cell temperature.

BOL Electrical Performances QM Cells : Discharge Current versus Temperature

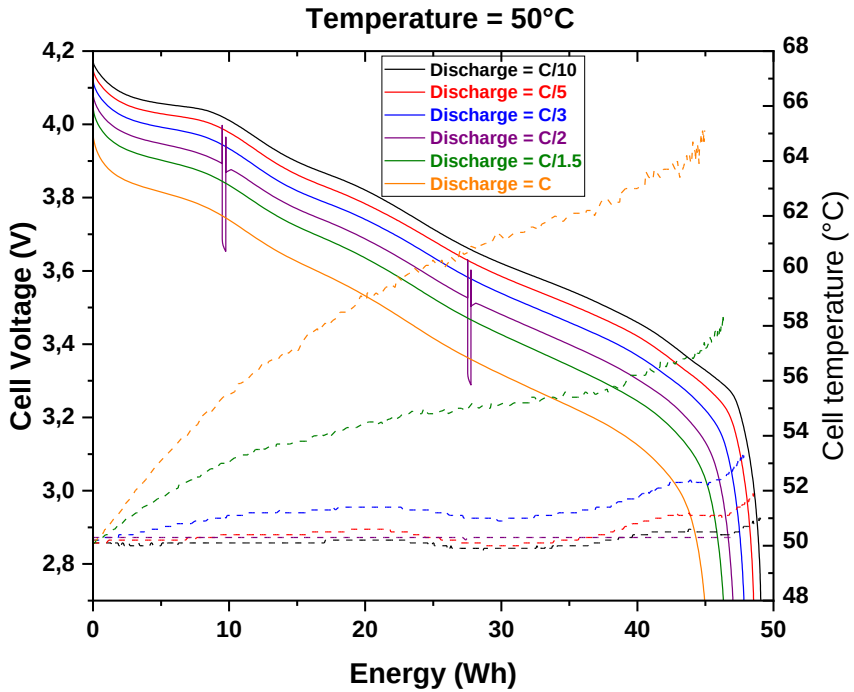
Energy evolution vs discharge rate at 0°C



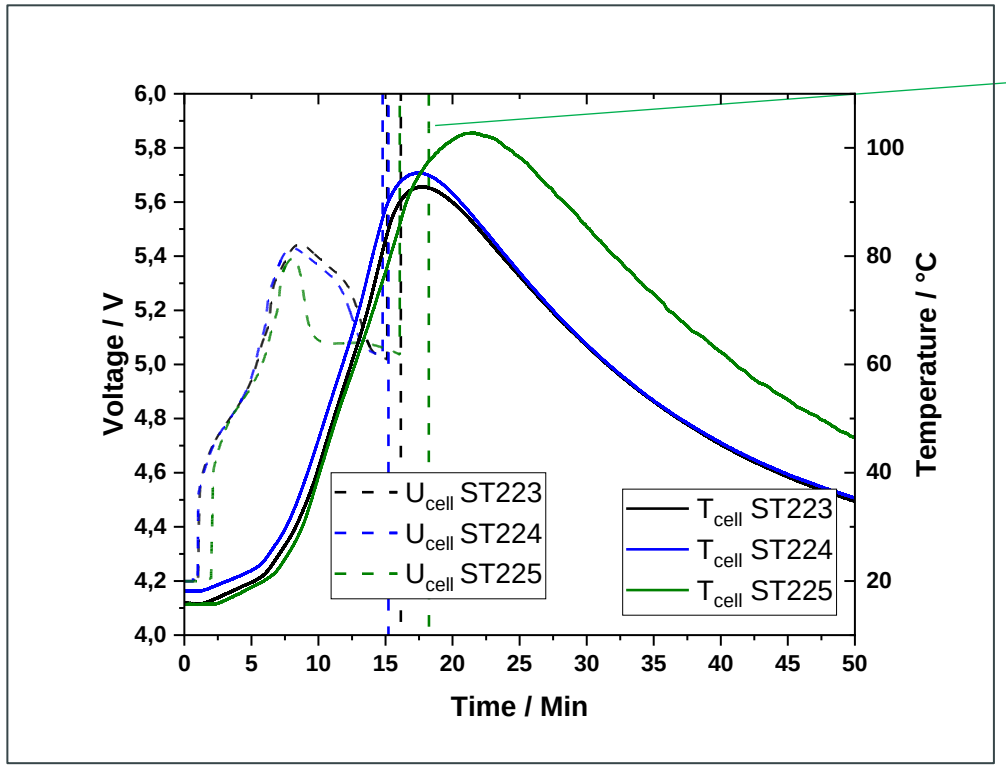
Energy evolution vs discharge rate at 20°C



Energy evolution vs discharge rate at 50°C



Safety Test QM: C Over-charge

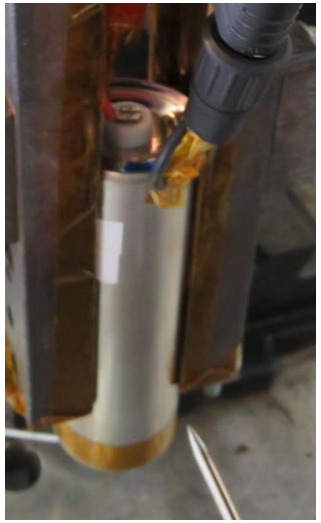


Circuit breaker opening

Cell	Event	Circuit breaker opening			Max Cell voltage (V)	Max Temperature (°C)	EUCAR
		Temperature (°C)	Time (mins)	Cell voltage (V)			
ST223	Circuit breaker opening	84.2	15	~5.0	5.7	92.9	2
ST224	Circuit breaker opening	86.9	15	~5.0	5.4	95.3	2
ST225	Circuit breaker opening	85.9	16	~5.0	5.4	102.8	2

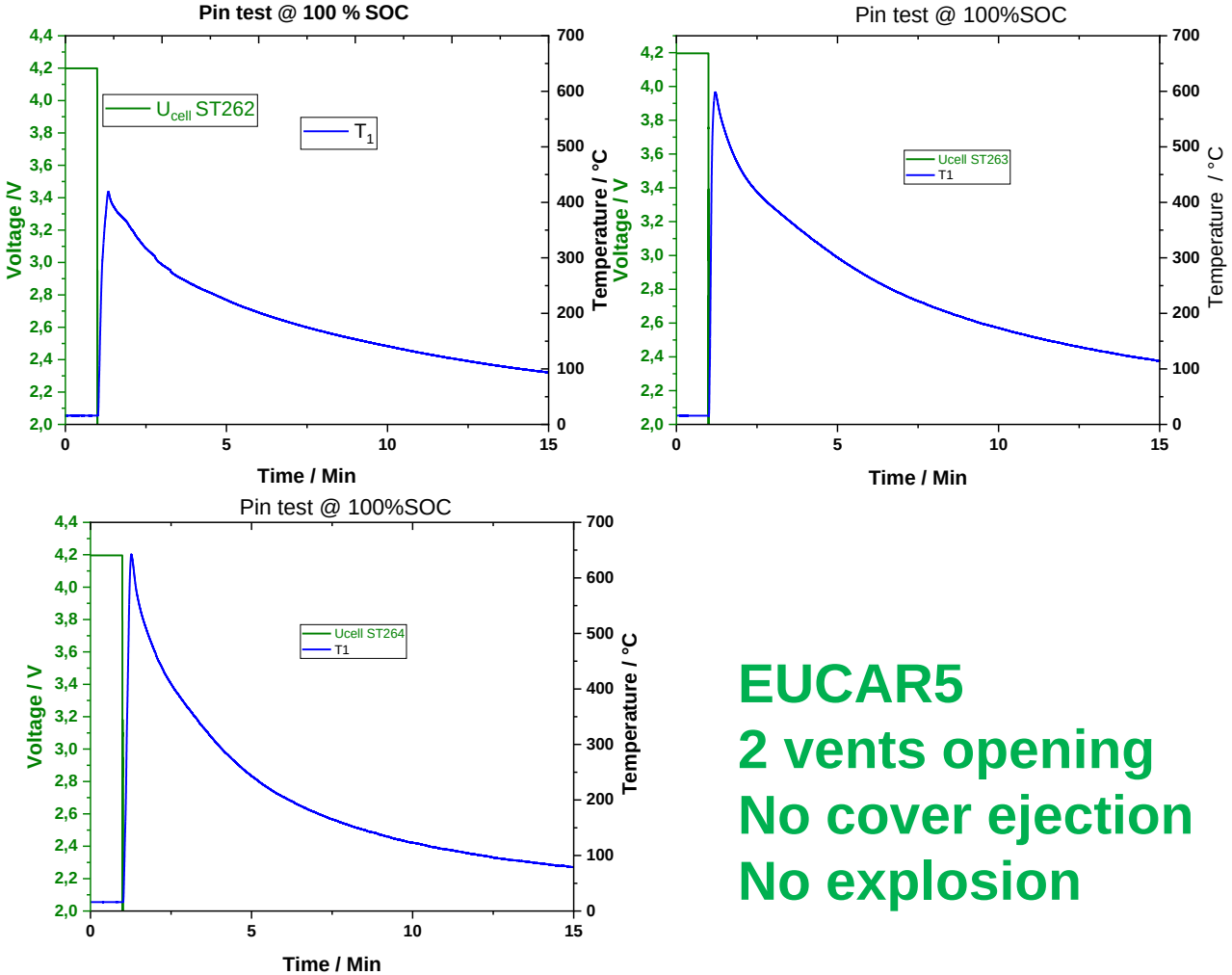
before test

After test



Compliant Eucar 2

Safety Test QM: Pin Test 100% SOC – 4.2V

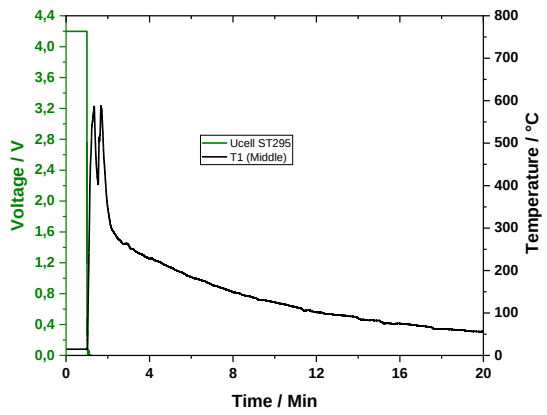


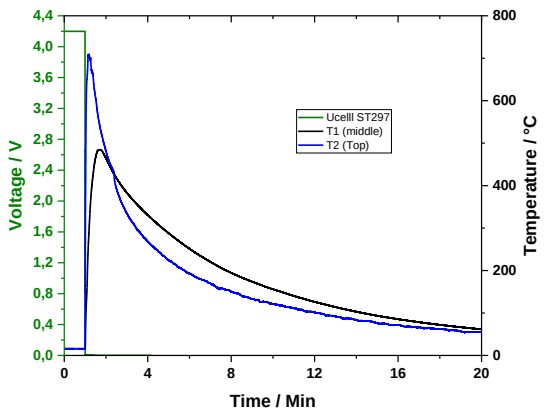
EUCAR5
2 vents opening
No cover ejection
No explosion

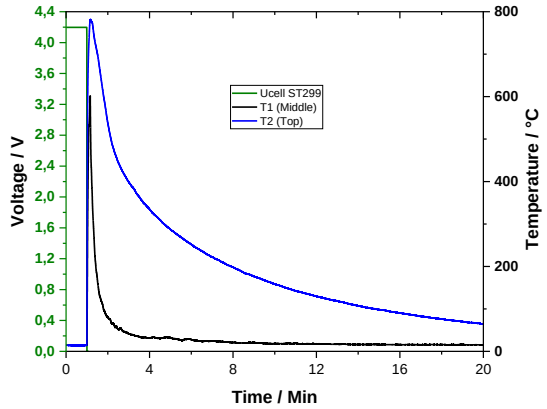
Before test

After test

Nail Test



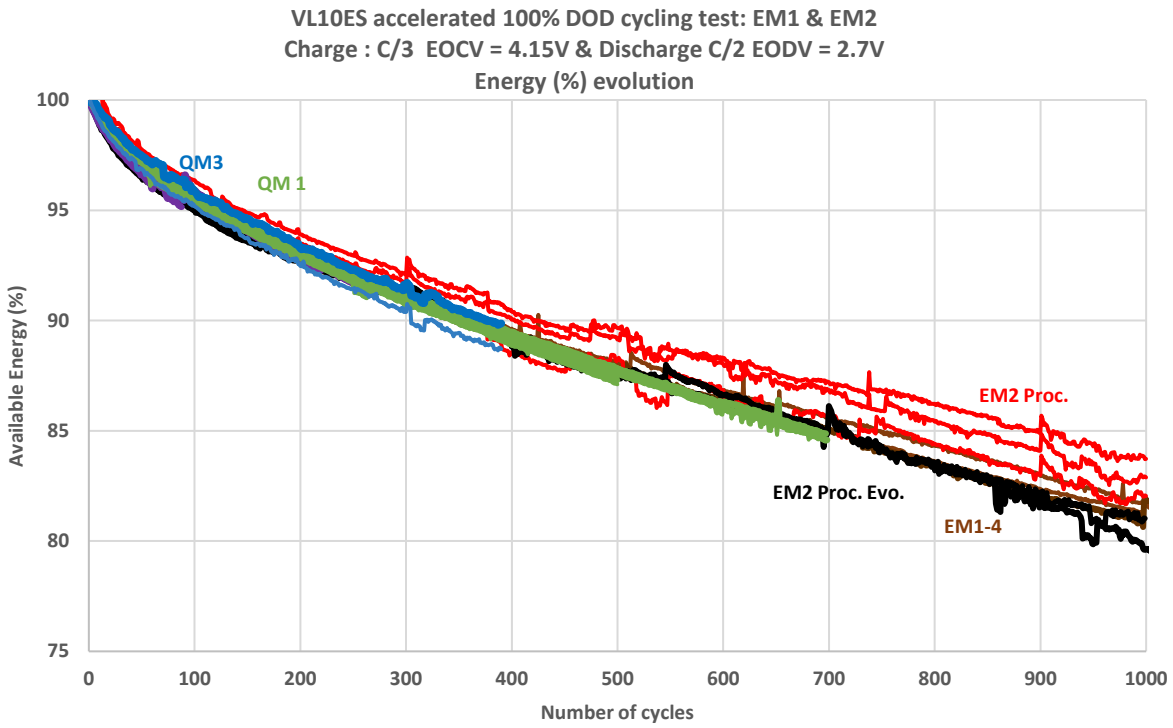


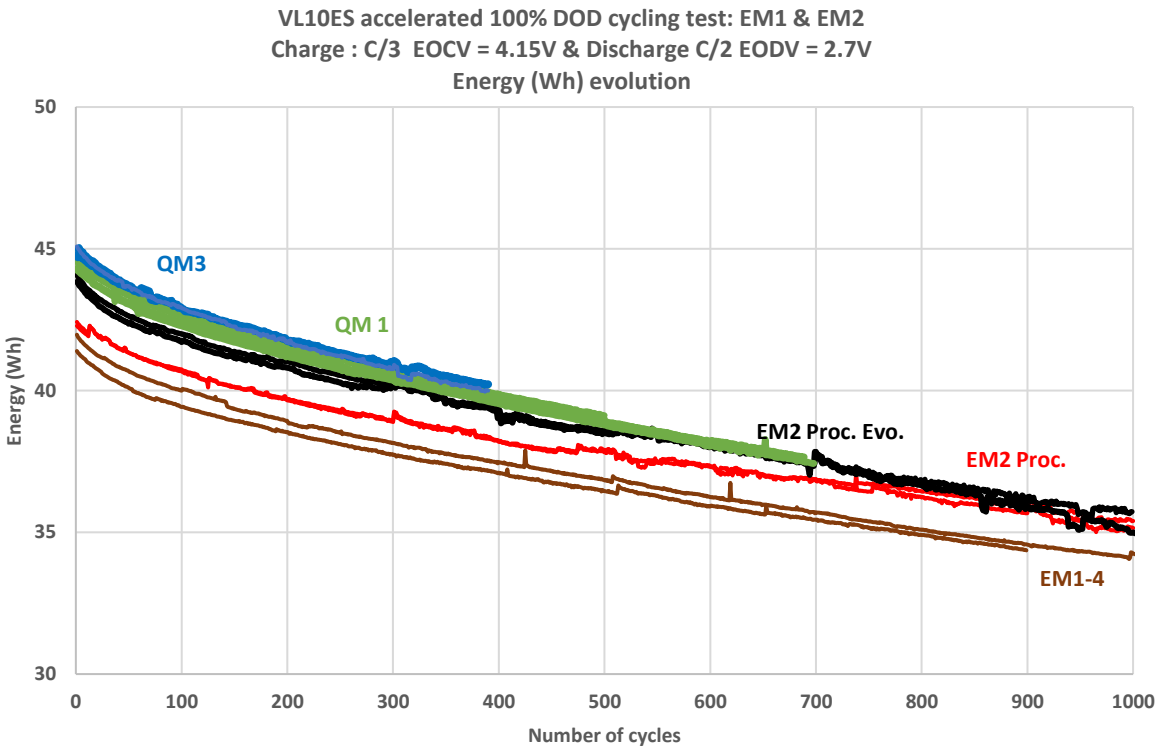


Nail test @ 20°C	Cell	Event	Time of event (sec)	Cell temperature (°C)	EUCAR	Observation
100% SOC	ST295	Circuit breaker opening	yes	yes	5	CC opening & Venting Electrolyte leakage, flames & no ejection of the jelly roll.
		Venting	yes	yes		
		Thermal runaway	yes	yes		
		Max temperature	-	586		
	ST297	Circuit breaker opening	yes	yes	5	
		Venting	yes	yes		
		Thermal runaway	yes	yes		
		Max temperature	-	709		
	ST264	Circuit breaker opening	yes	yes	5	
		Venting	yes	yes		
		Thermal runaway	yes	yes		
		Max temperature	-	781		

Compliant Eucar 5

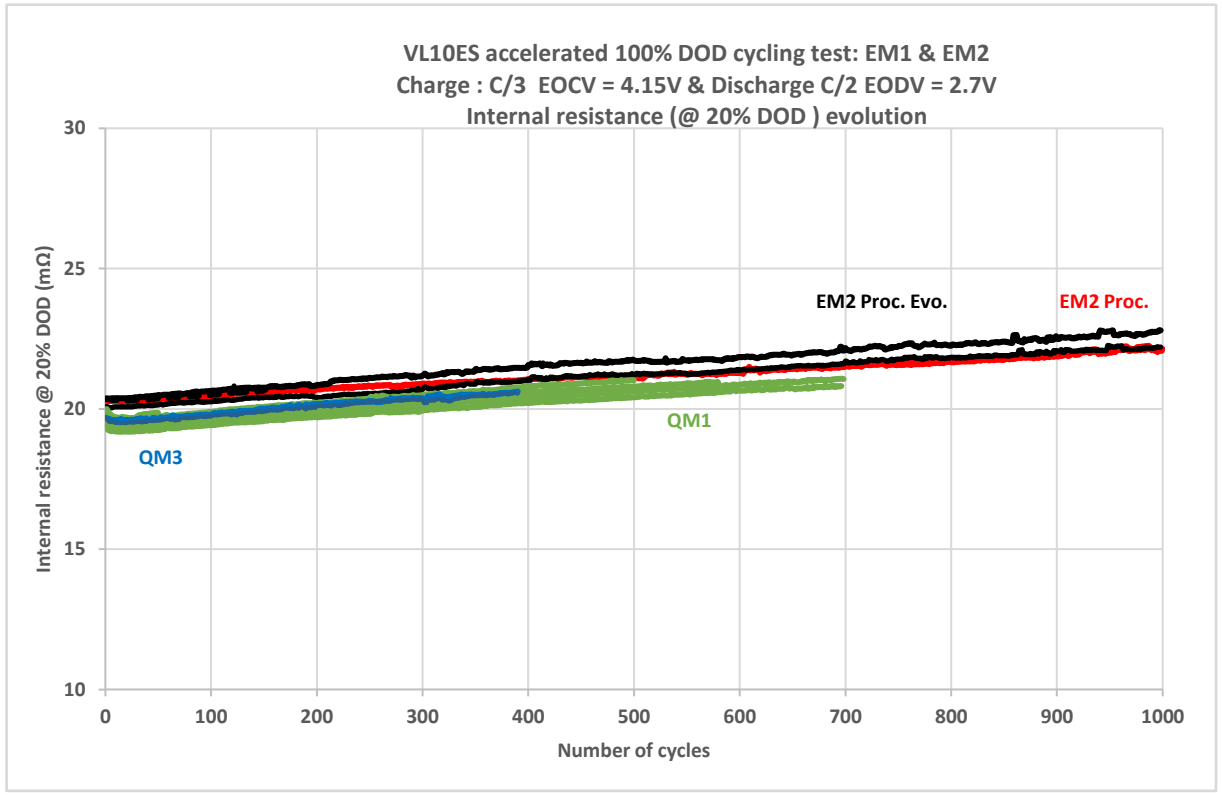
Accelerated 100% DOD Cycling: Energy Evolution

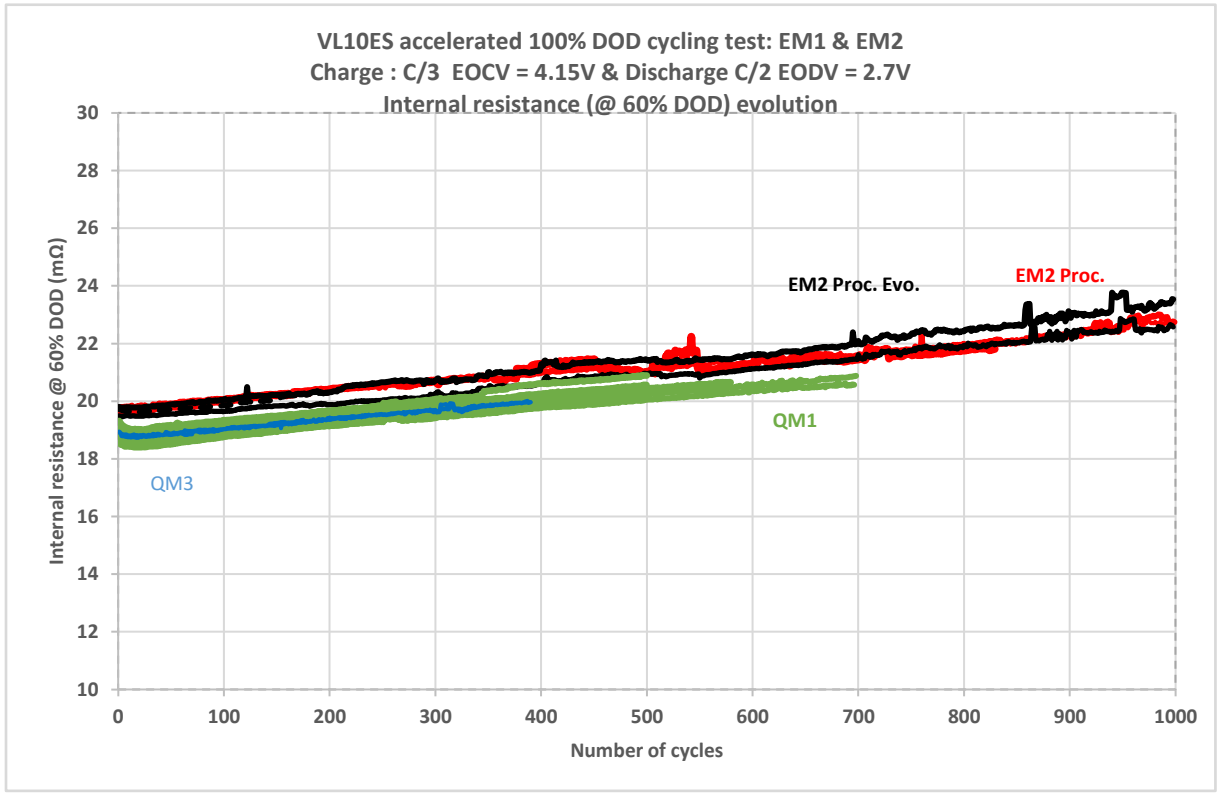




- All the batches (EM's, QM's and FM's) have been tested in Wear-out using 100 % DOD profile :
  - Similar EOL energy for all batches
  - Limited impact of BOL energy

Accelerated 100% DOD Cycling : IR Evolution

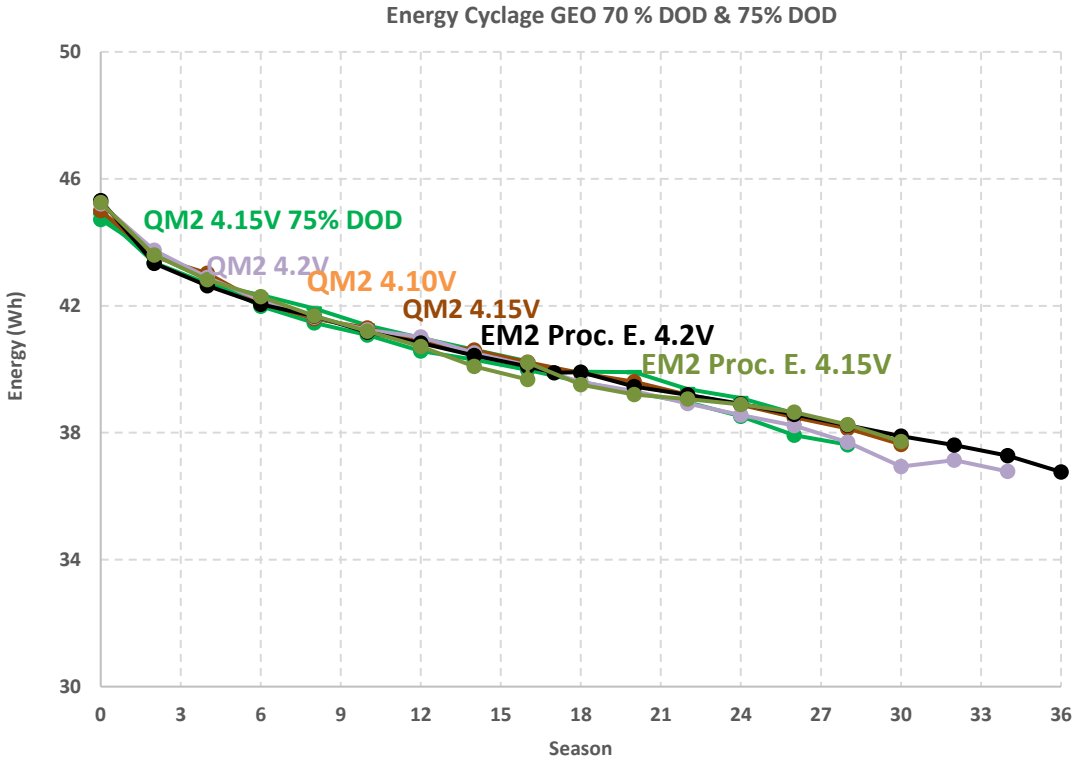


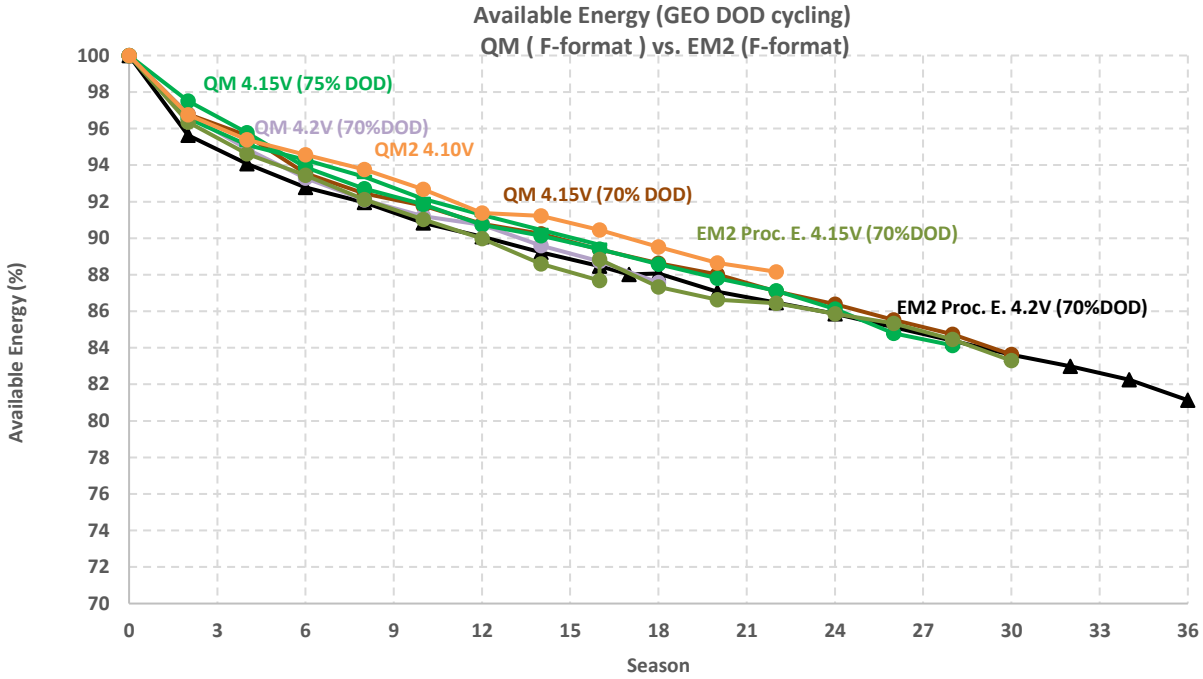


- VL10ES is showing a good stability of internal resistance during cycling.
- 20 % and 60 % DOD internal resistance evolution is linear with less than **10 % increasing** after 1000 cycles

Constant Internal Resistance (IR) evolution with cycling

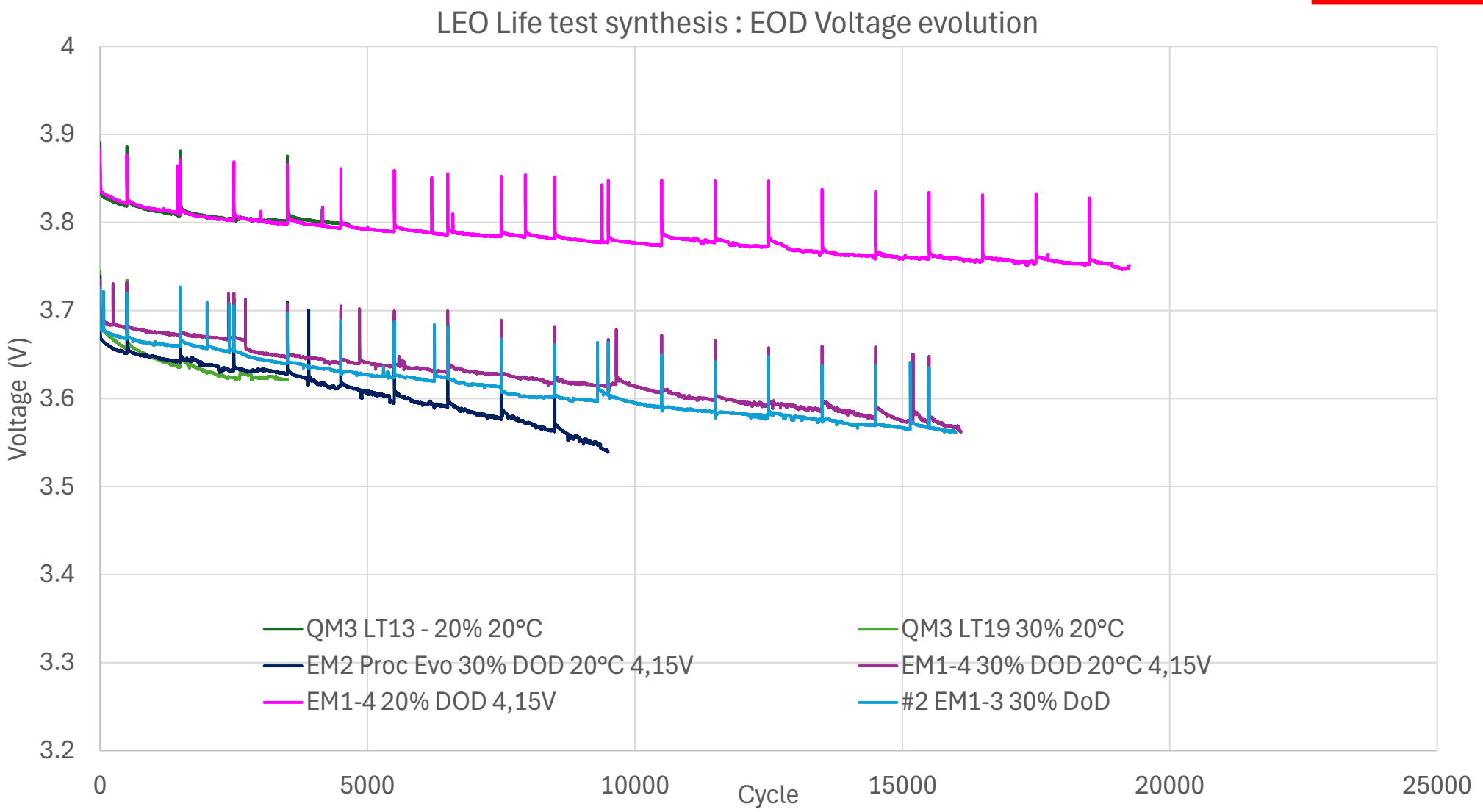
QM2 versus EM2 Process Evolution : GEO Life Energy Trend





- 70% DOD EOCV = 4.15V & 4.2V (average data)
  - QM2 cells followed the same trend as EM2 cells
- 75% EOCV= 4.2V (average data)
  - QM2 cells cycled at higher DoD displayed similar losses as cells cycled at 70% DOD

VL10ES#1 – 20%-30% DOD LEO Qualification LT at 20°C



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

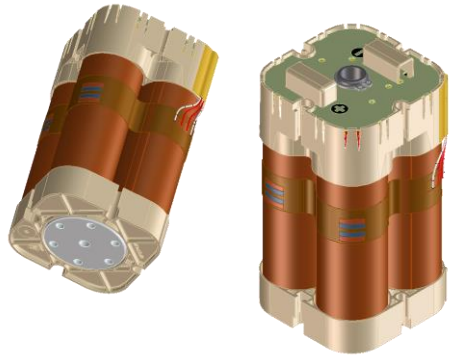
Each block is carrying its own autonomous electronics (4 Simplified Balancing System per block)

Assembly innovation

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

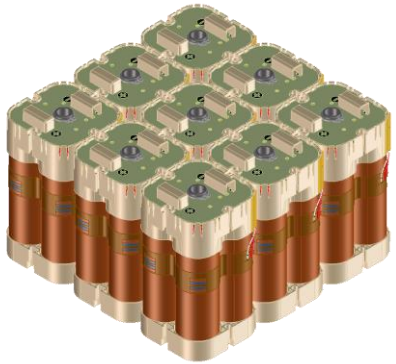
4S1P Block with SBS

4S1P block



Individual Footprint
(mechanical / Thermal)

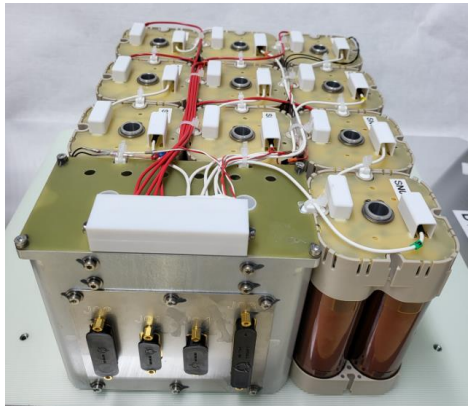
12S3P Example



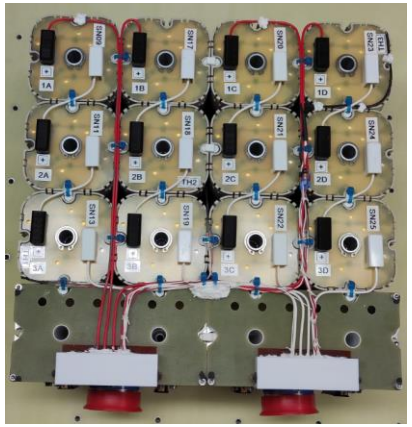
Battery Development Plan

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

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



Bat-EM1 8S5P



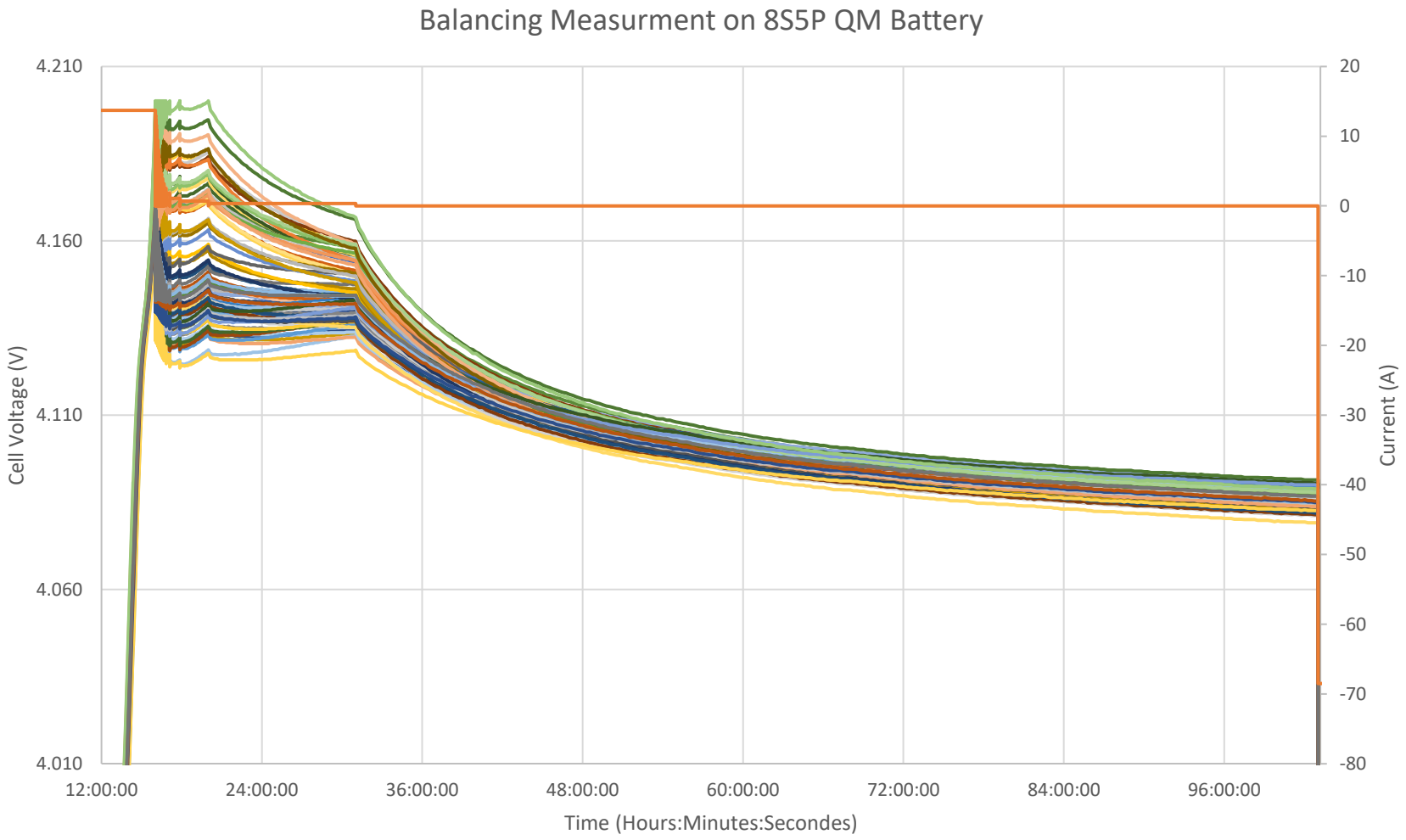
Bat-EM2 12S4P

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

Bat-QM4 12S20P VL10ES

Balancing on 8S5P VL10ES QM

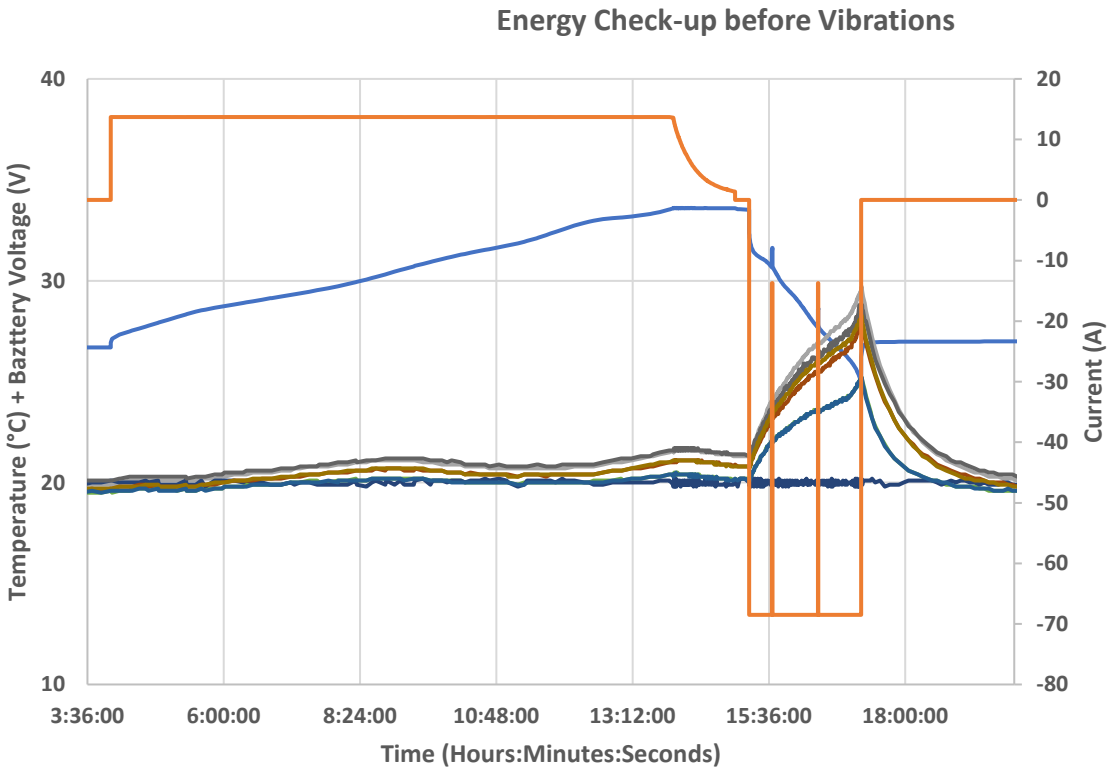
- 10 mV cell to cell spread obtained in 82 hours from 80 mV

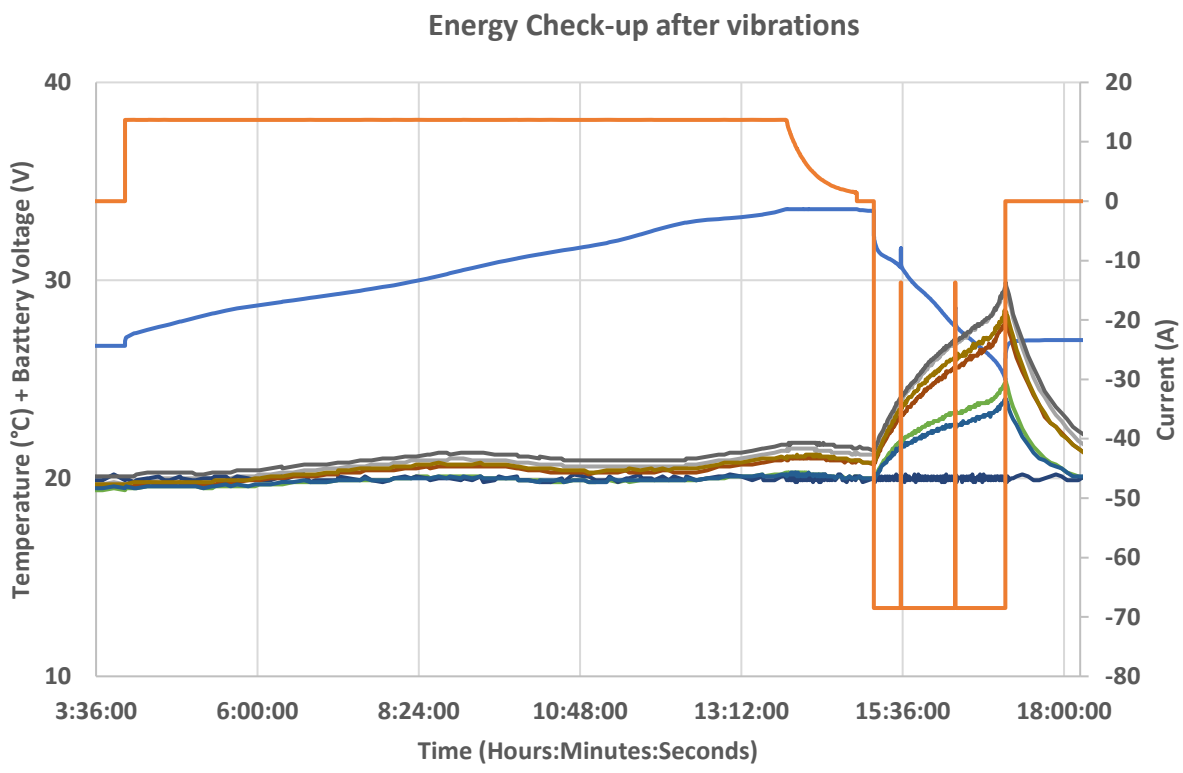


QM VL10ES Vibration Tests

- Sequence :
  - Sine 3 axis
  - Random 3 axis
  - Sine with frequency search
  - Energy Check-up

Energy Check before and after Vibrations





No energy or internal resistance evolution before and after mechanical tests

Conclusions

- VL10ES cell and battery development QR program is close to the end with QR successfully done
  - Cell Life Tests are running : 30 seasons GEO already performed (15 years) and >20,000 LEO cycles
  - For battery qualification plan :
    - Electrical tests including performance in temperature, balancing
    - Environment tests
    - Safety tests

- 20 FM’s have been already delivered to customers for satellite AIT

Thank you