High Specific Energy VL10ES Cell Qualification Status

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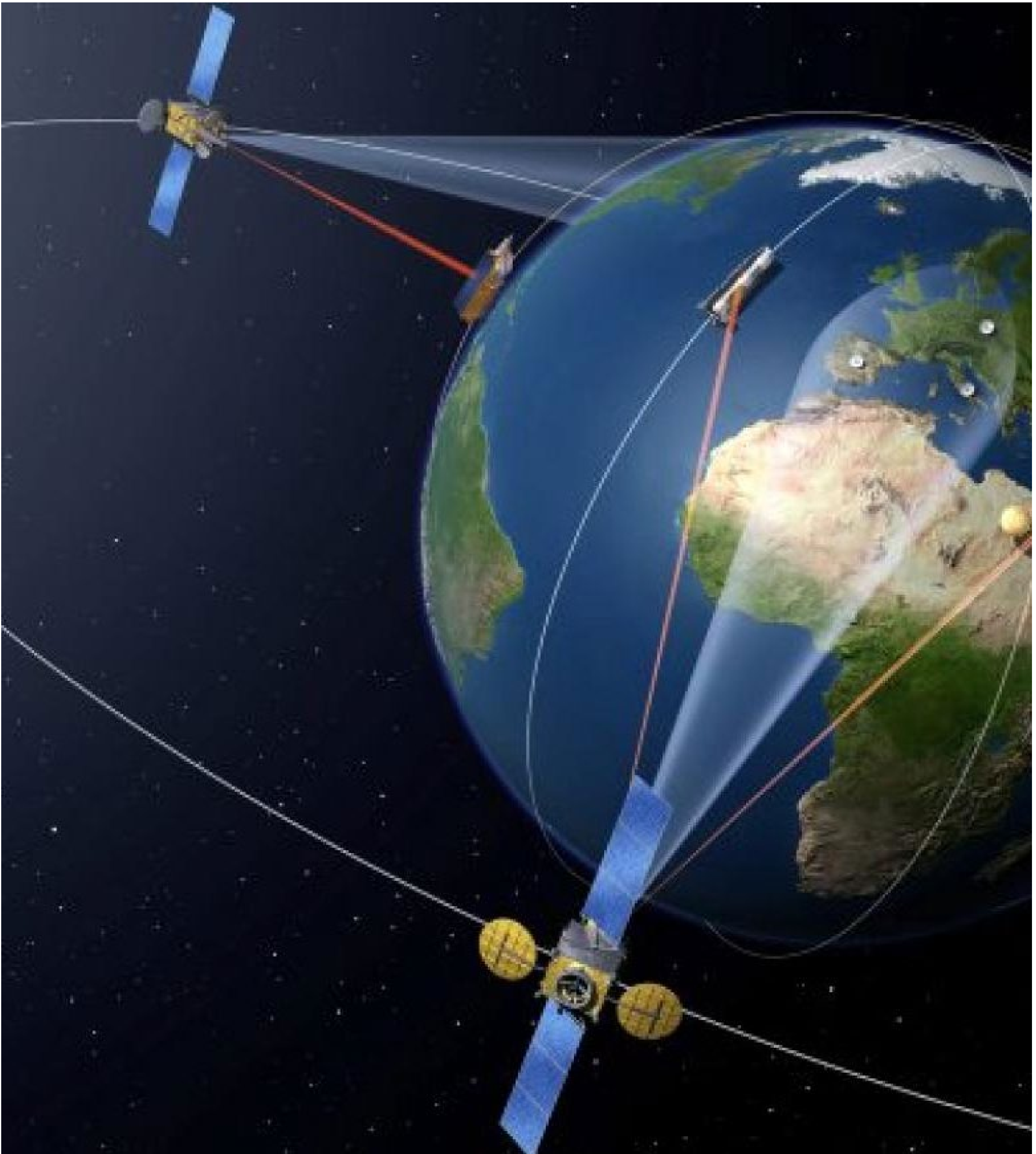
Summary

1. VL10ES Cell Development
2. Cell Qualification
3. Conclusions



VL10ES Cell Development

VL10ES Performances Objectives – Compared with VES16

TotalEnergies

TECHNICAL PERFORMANCE

- Over 220 Wh/Kg to reduce battery weight
- High DOD cycling ranges: LEO 30% and GEO 70%
- Innovation on densification of electrodes
- Specific materials to preserve long life

SAFETY ENSURED

- Compatible with safety launch pad
- Robust stainless steel casing

PRICE REDUCTION

- Reduce the battery price
- Address LEO, GEO, MEO, constellation markets
- Less cells in large batteries

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

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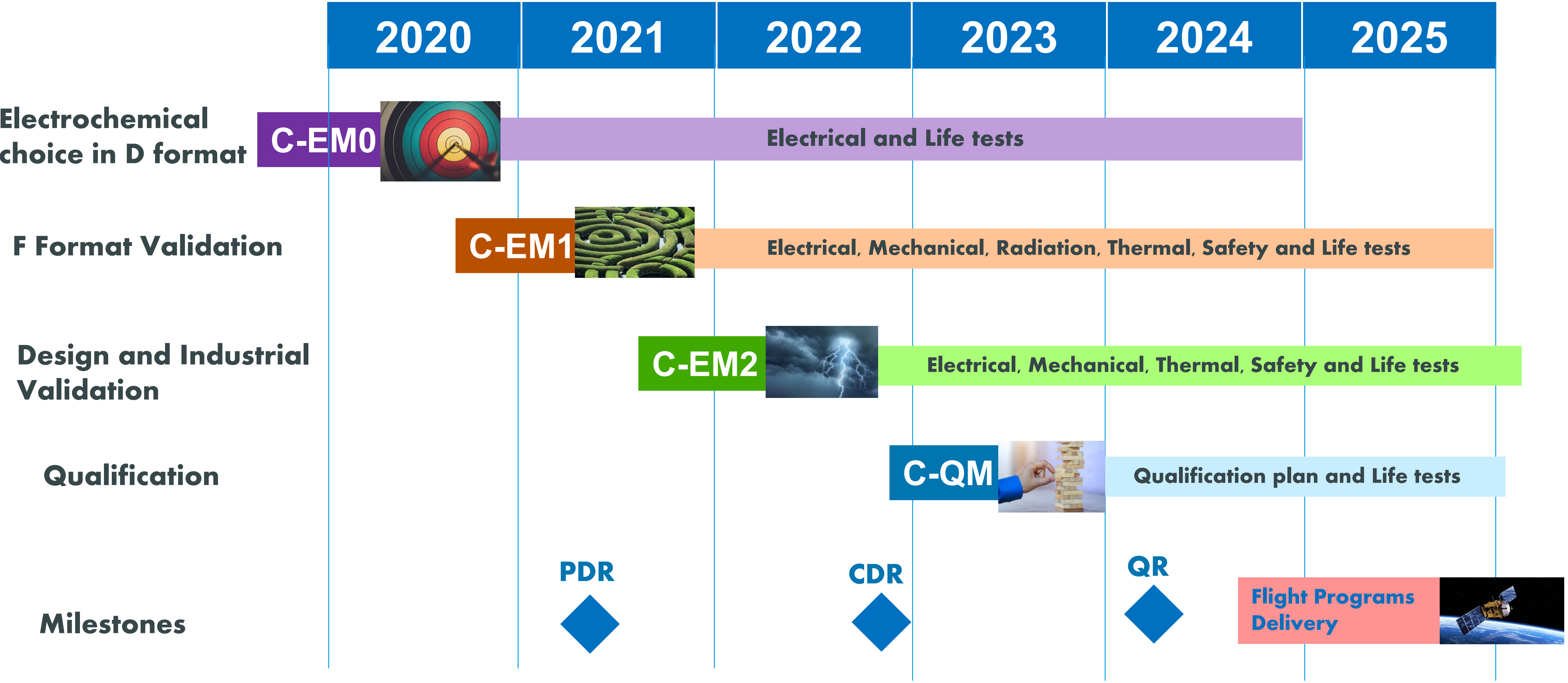
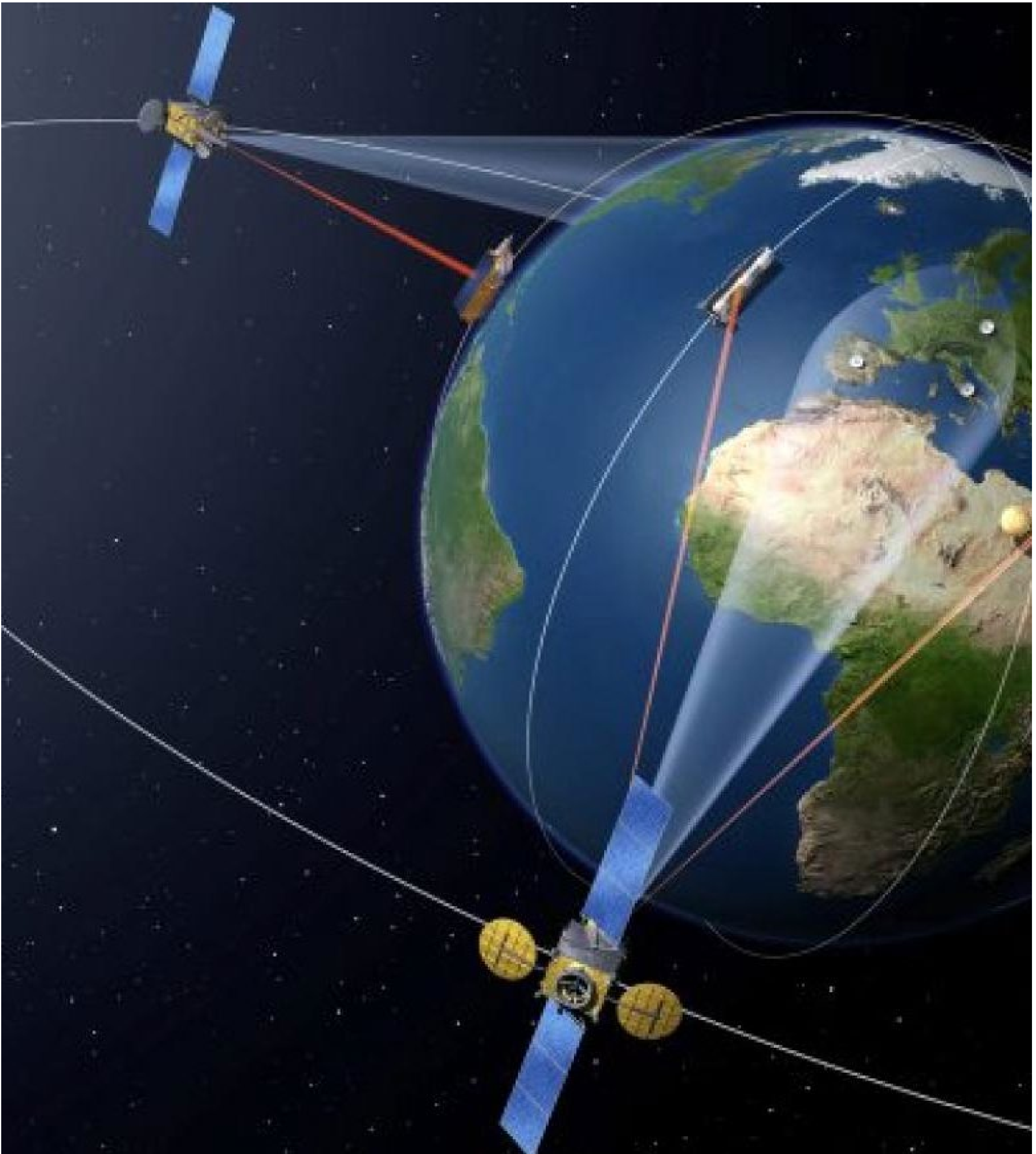
VL10ES Cell Development Plan

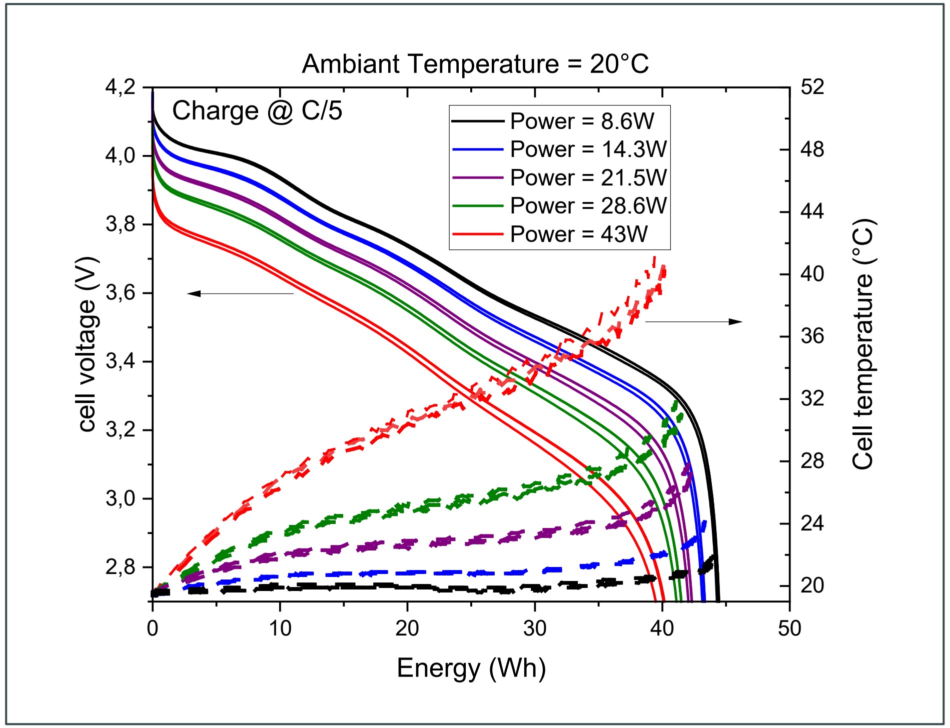




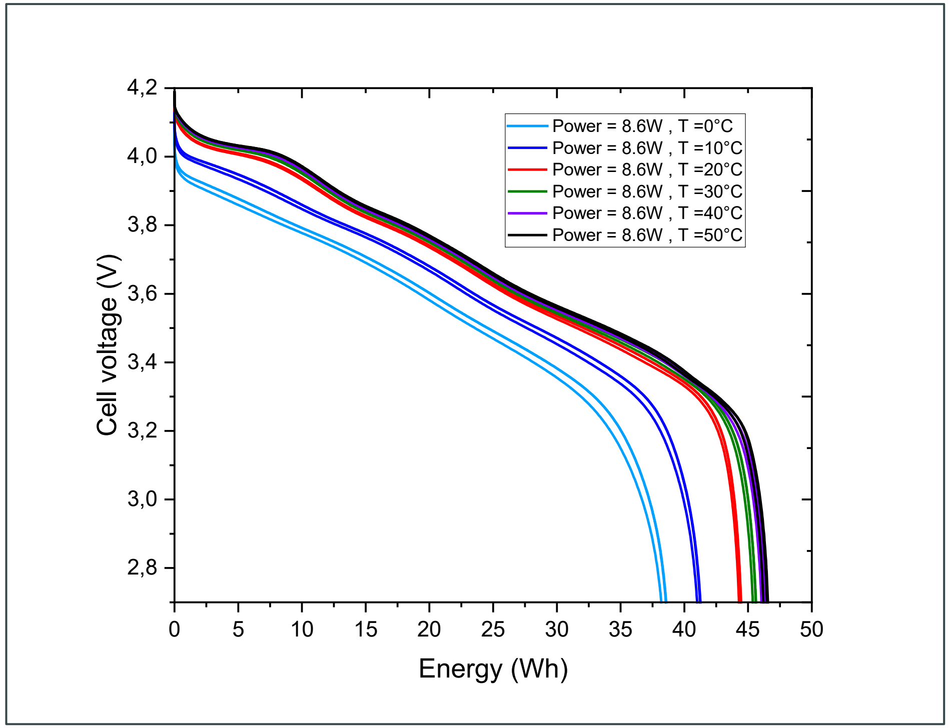
VL10ES Cell Qualification

2. BOL Electrical Performances EM2 /QM Design: Constant Power Discharge versus Temperature

Energy evolution vs Power at 20°C



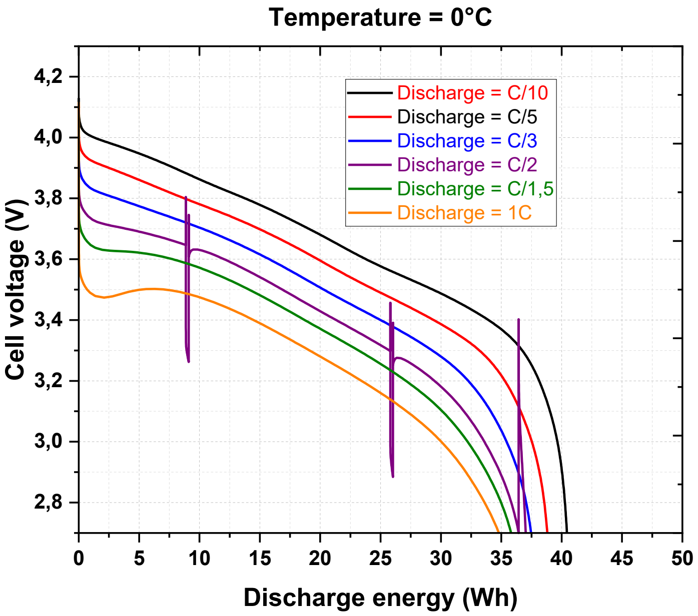
Energy evolution at constant Power vs Temperature



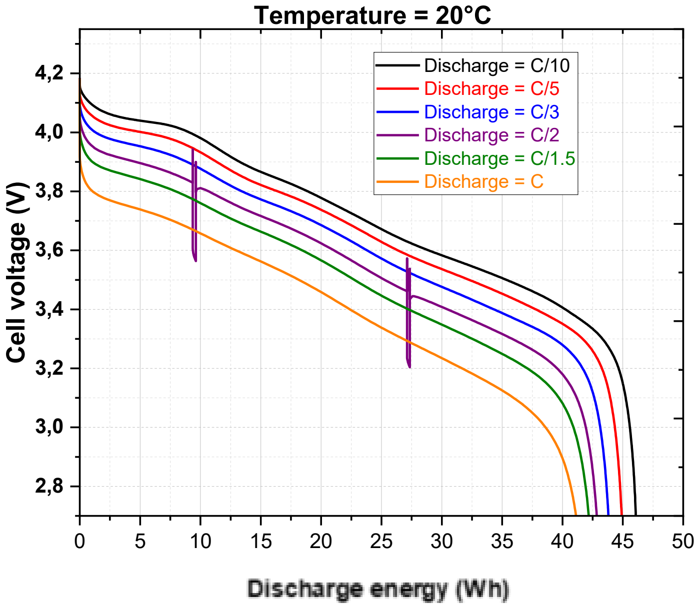
- Increasing discharge power leads to cell polarization together with a decrease in available energy and an increase in cell temperature.

BOL Electrical Performances EM2/QM Design : discharge current versus temperature

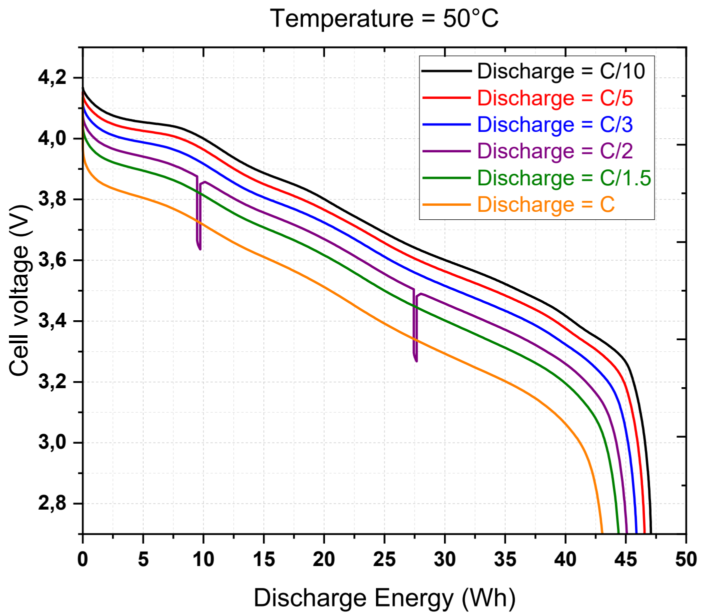
Energy evolution vs discharge rate at 0°C



Energy evolution vs discharge rate at 20°C



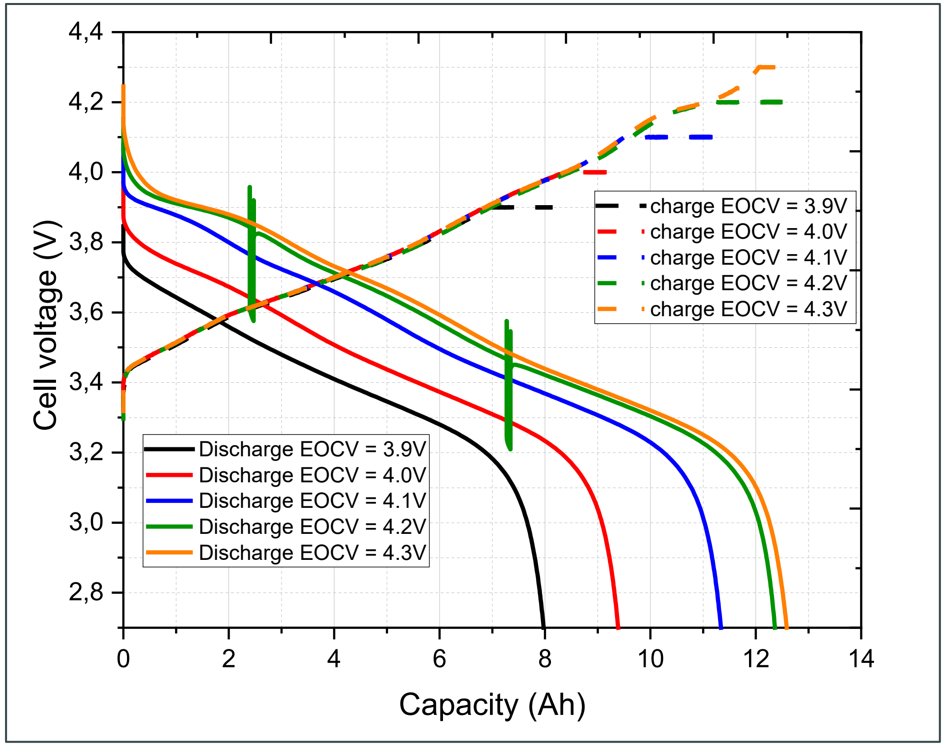
Energy evolution vs discharge rate at 50°C



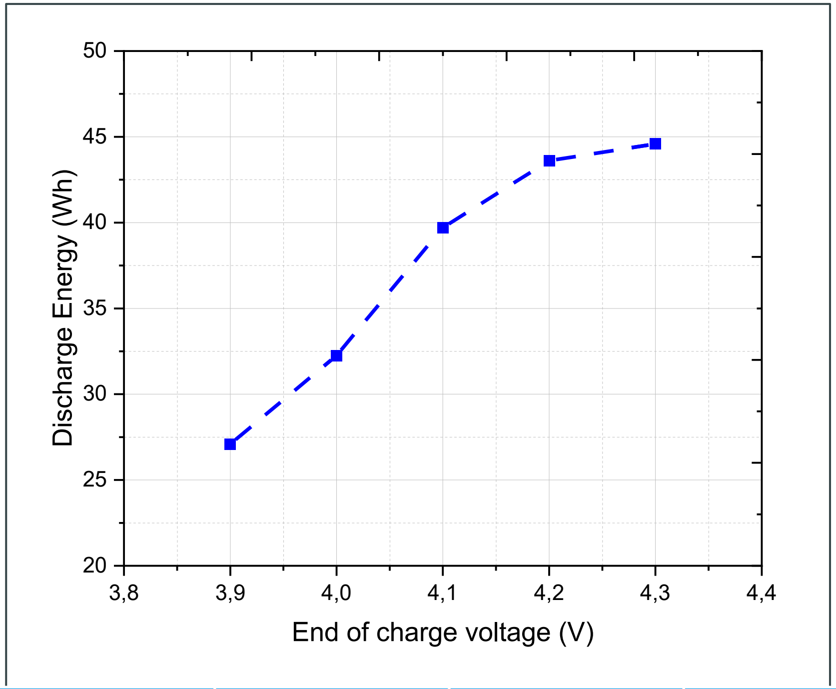
Average data	Temperature	0°C	20°C	50°C
Discharge energy	**Discharge = C/10**	40.3	**46.0**	46.9
	Discharge =C/5	38.7	44.9	46.4
	Discharge =C/3	37.3	43.7	45.7
	Discharge =C/2	36.2	**42.7**	44.8
	Discharge =C/1.5	35.5	42.0	44.3
	Discharge =C	34.4	40.9	42.9

BOL Electrical Performances EM2 Design : Discharge energy/capacity versus EOCV

Capacity evolution vs EOCV at 20°C



Energy evolution vs EOCV at 20°C

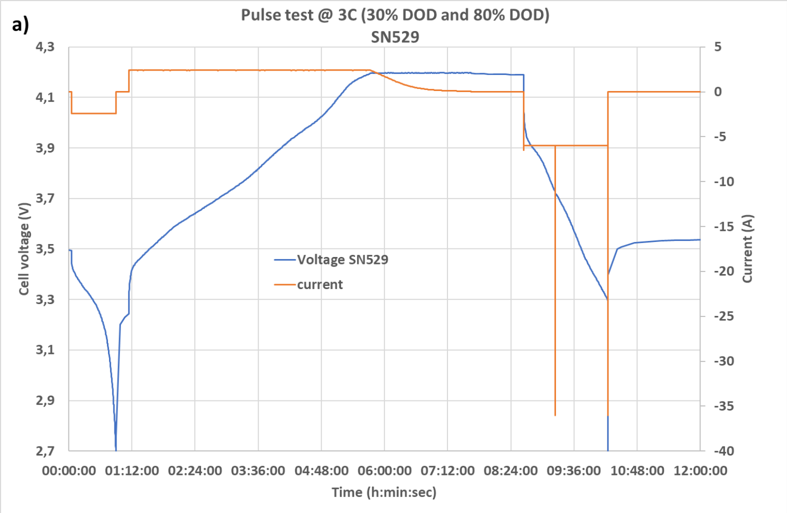


	Estimated Energy C/2 @20°C (Wh)	Capacity C/2 @20°C (Ah)	Ratio
4.0 V	32.5	9.4	77 %
4.1 V	40.0	11.2	93 %
4.15 V	42	11.7	96.5 %
4.2 V	43.5	12.2	100 %

- Gain in capacity and energy is 2.5 % from 4.2 V to 4.3V

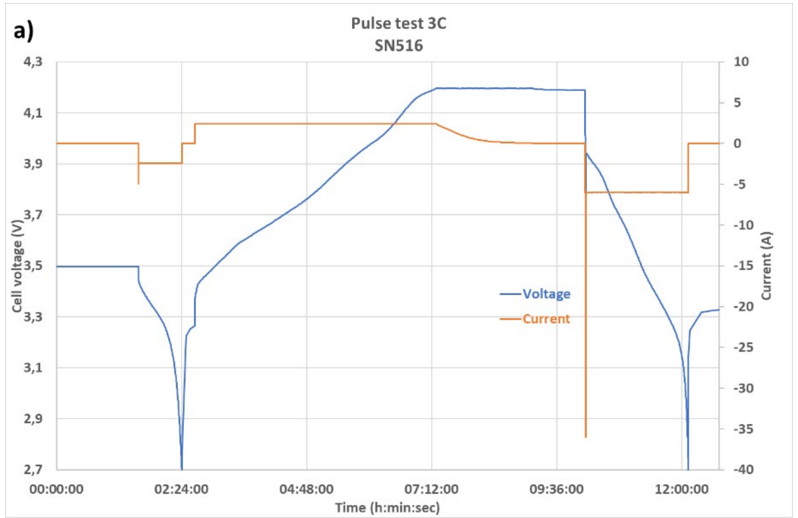
BOL Electrical Performances EM2 Design: Pulse test

Pulse test : 3C 1second (current fault test)



Pulse test 1second	SN529	SN558	SN570
U (30% DOD)	3.138	3.135	3.141
T @ 30% DOD (°C)	21.5	22.0	22.0
U (80% DOD)	2.690	2.690	2.690
T@80%DOD (°C)	22.0	22.0	22.7

Pulse test : 3C 15 seconds (Radar test)



Pulse test	SN516	SN519	SN522
U (3C, 15 seconds)	3.272	3.290	3.280
T (°C)	20.5	20.2	20.7

As per EM1, EM2 Design cells are compliant with pulse current :
- 3C for 1 second starting from 30% DOD and 80% DOD,
- 3C for 15 seconds criteria.

C-EM1/EM2/QM Safety Results

TotalEnergies

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	ISCD 100 %DOD
C-EM1-4 C-EM2 C-QM	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	(10/10 OK) (10 cycles) at -0.5V	Ok (1/1) EUCAR 2	OK (1/1) EUCAR 5	OK (3/3) EUCAR 5	OK (3/3) EUCAR 5

Tests results as good as VES16 : high level of safety

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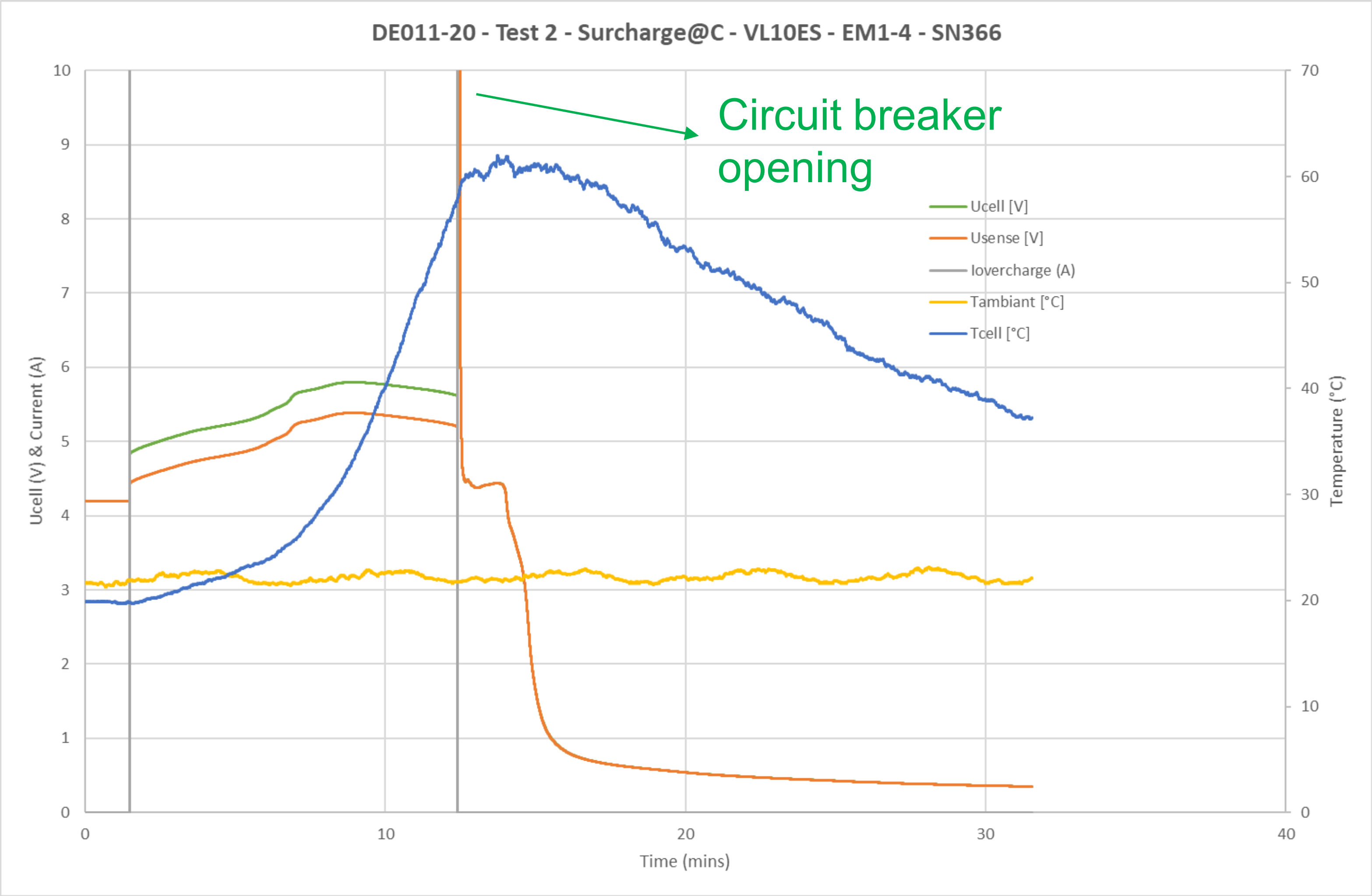
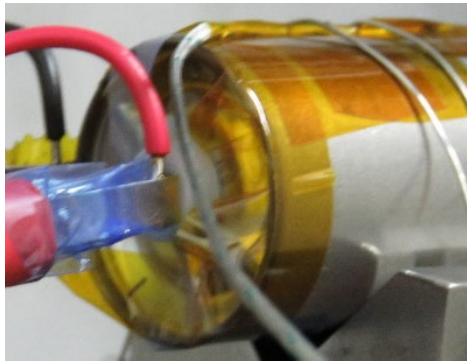
VL10ES EM1/EM2/QM : C over-charge



Before test



After test

T < 65°C EUCAR2

VL10ES C-EM1/EM2/QM : Pin test 100% SOC – 4.2V

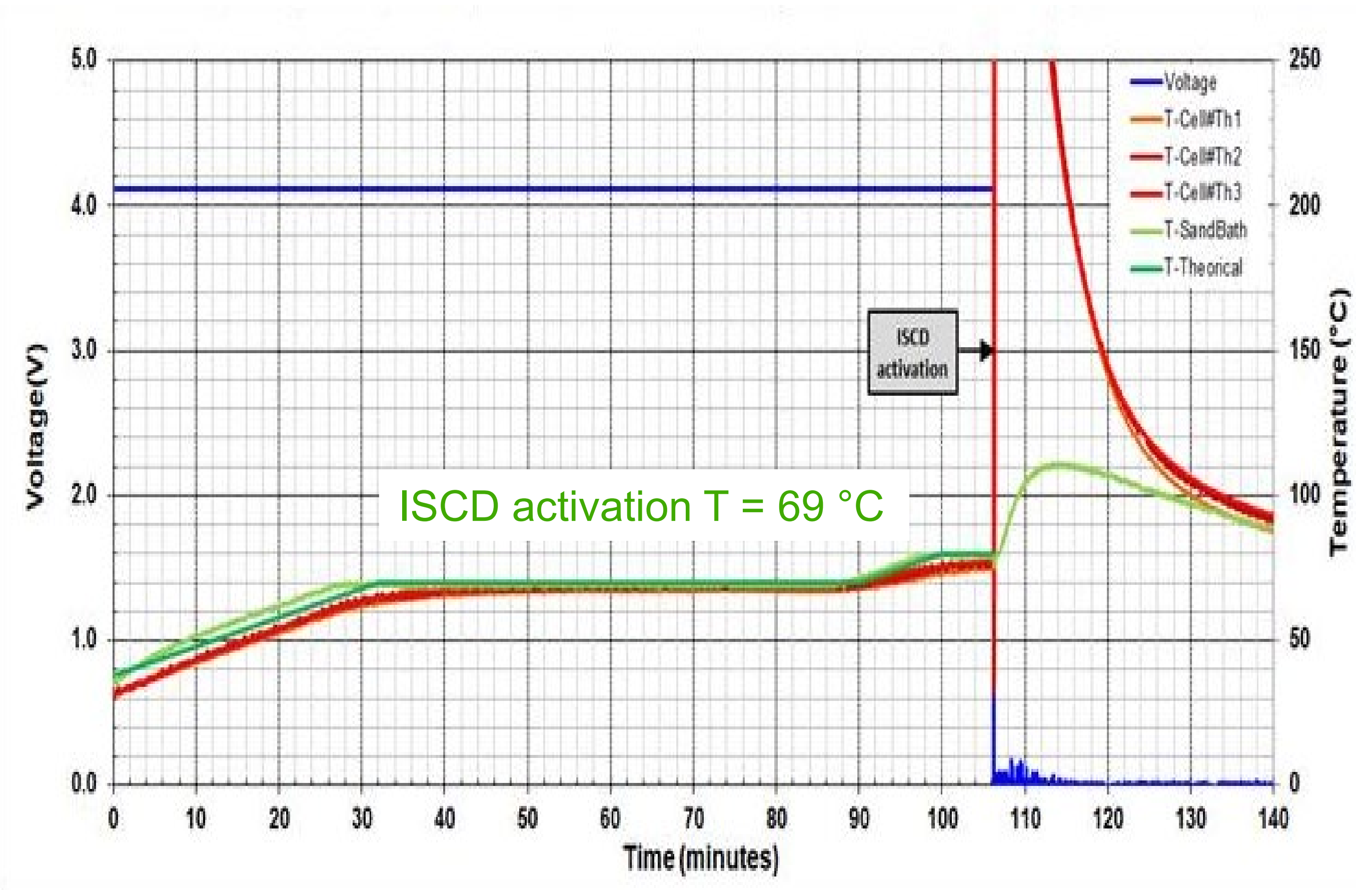
Before test

After test

EUCAR5
2 vents opening
No cover ejection
No explosion

VL10ES QM : ISCD 100% SOC

Tmax = 492 °C



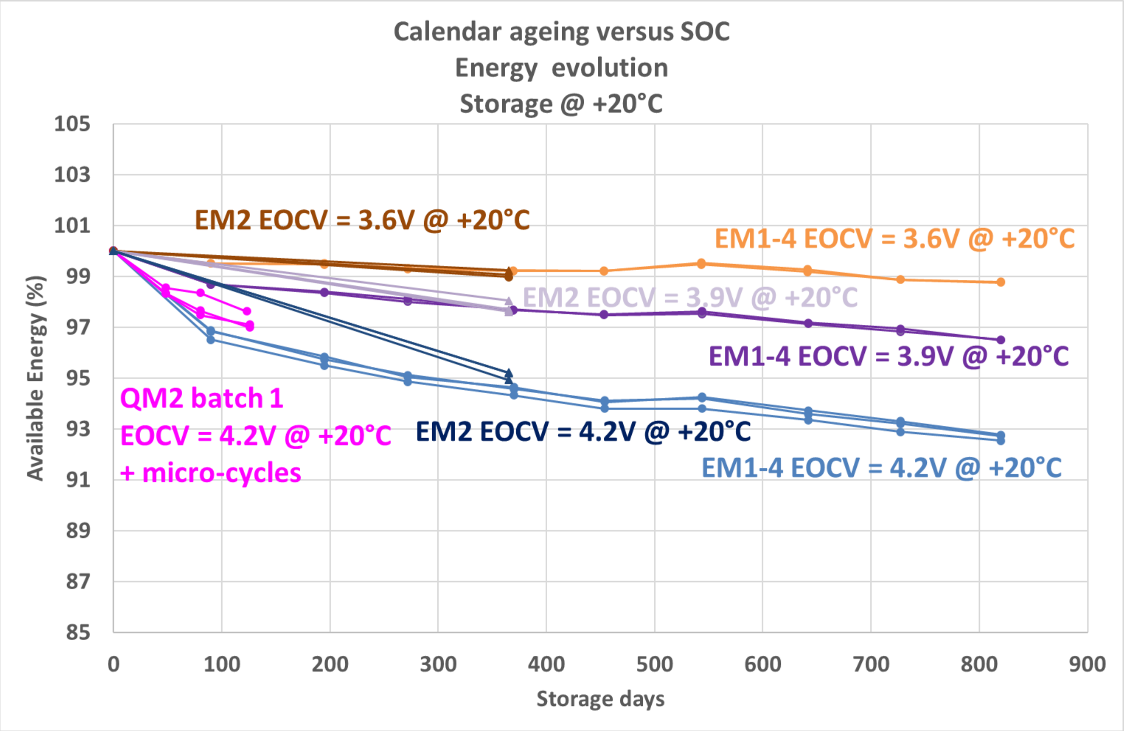
After test

EUCAR5
2 vents opening
No cover ejection
No explosion

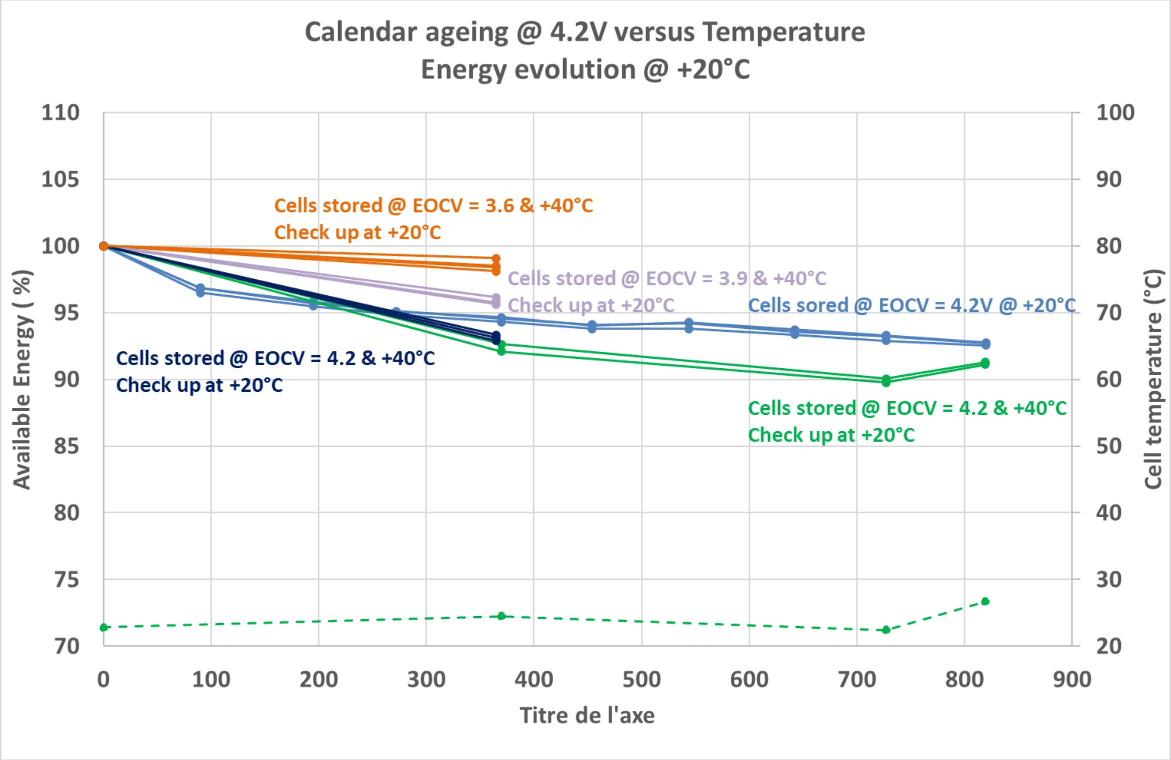
Lifetests : Cell Performances during Calendar Test at Different SOC and Temperature

TotalEnergies

20 °C vs SOC



4.2 V at 20 and 40 °C



- Energy loss increases with SOC after 820 days : similar to previous VES and VL cells
- Stable internal resistance

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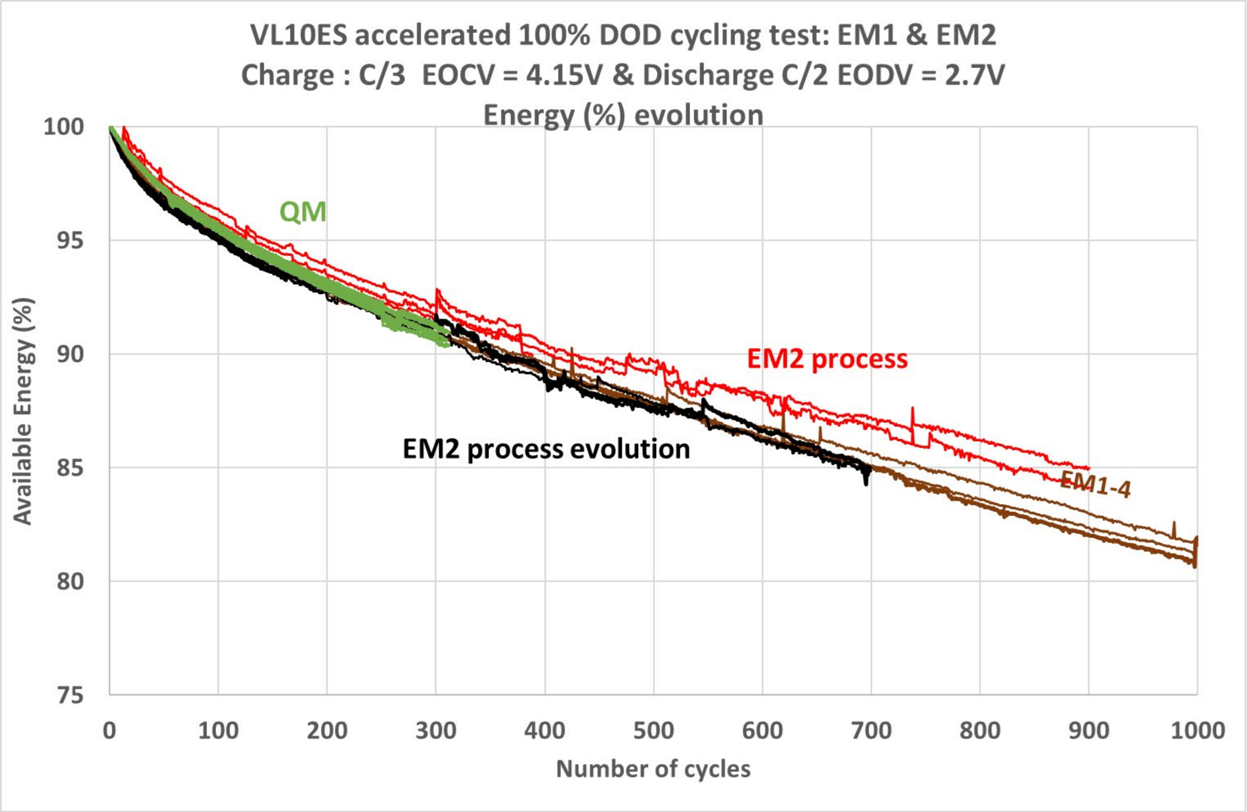
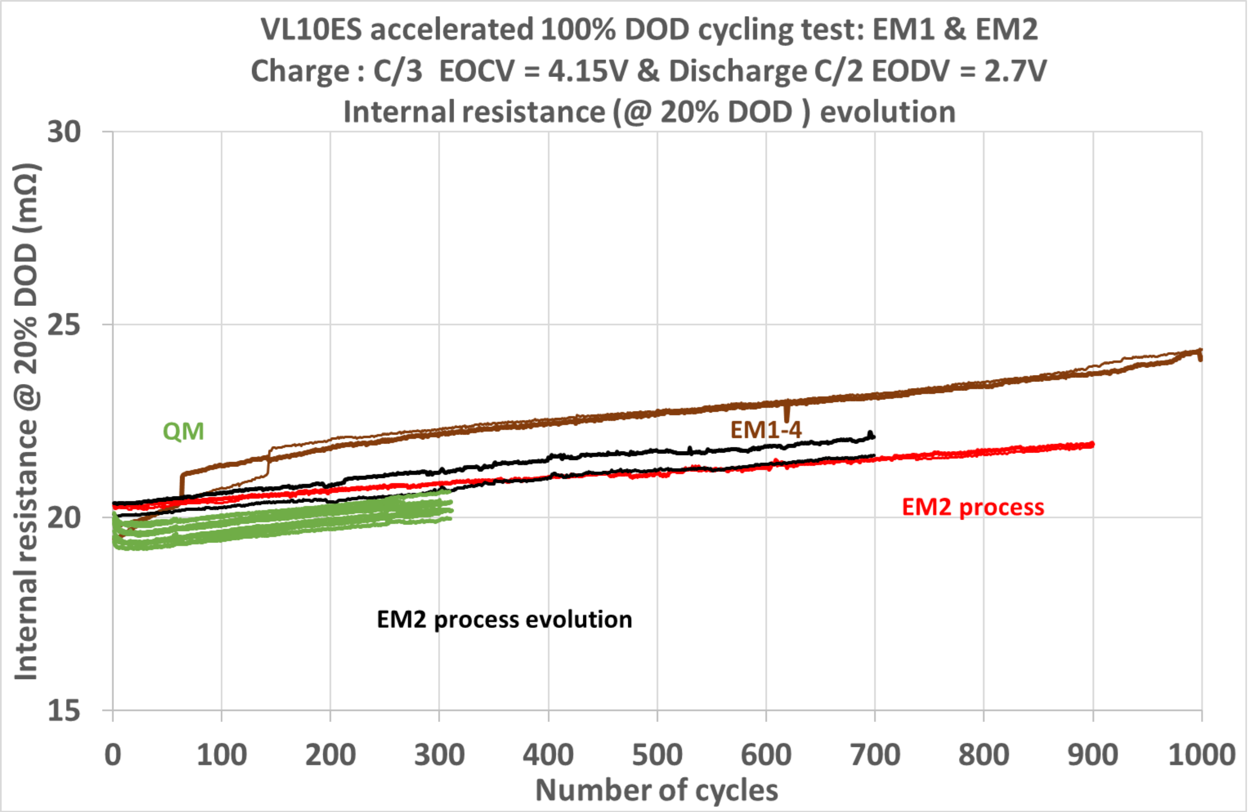
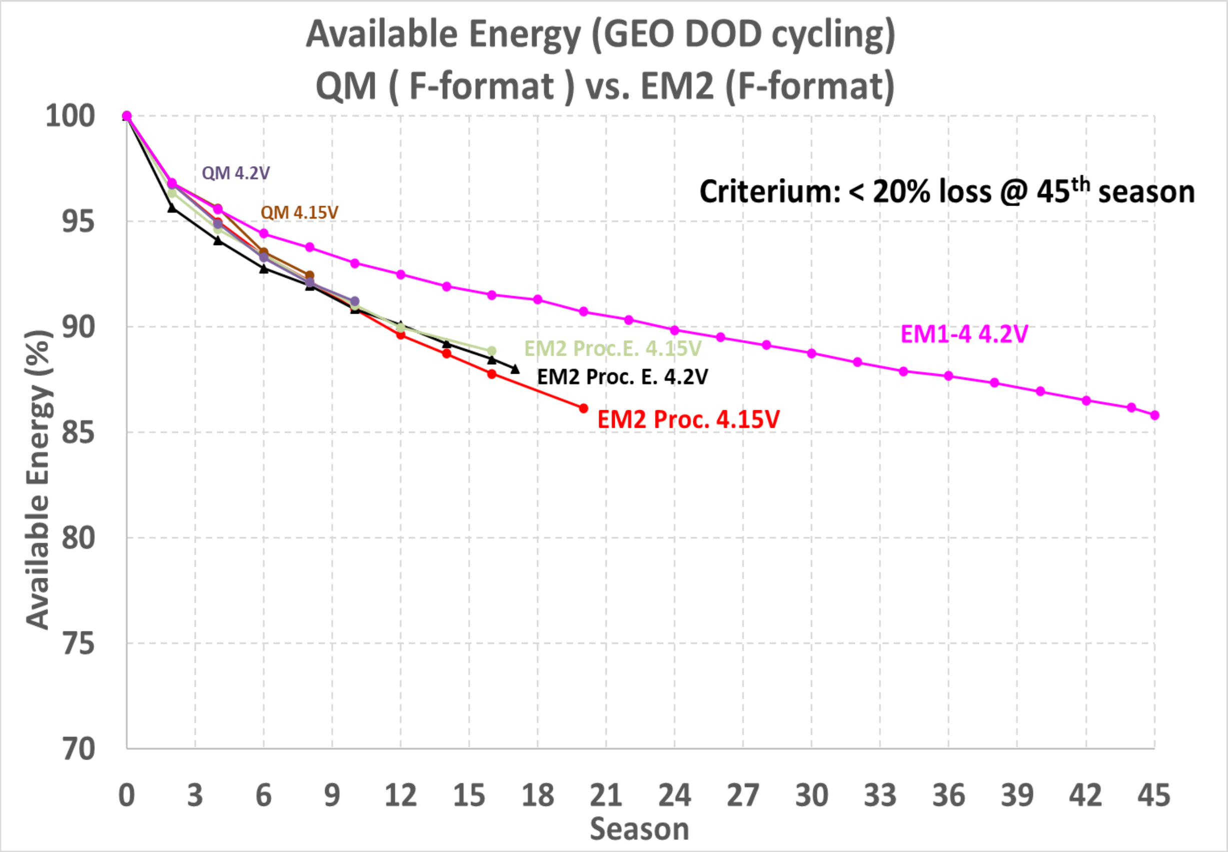
Accelerated 100%DOD cycling

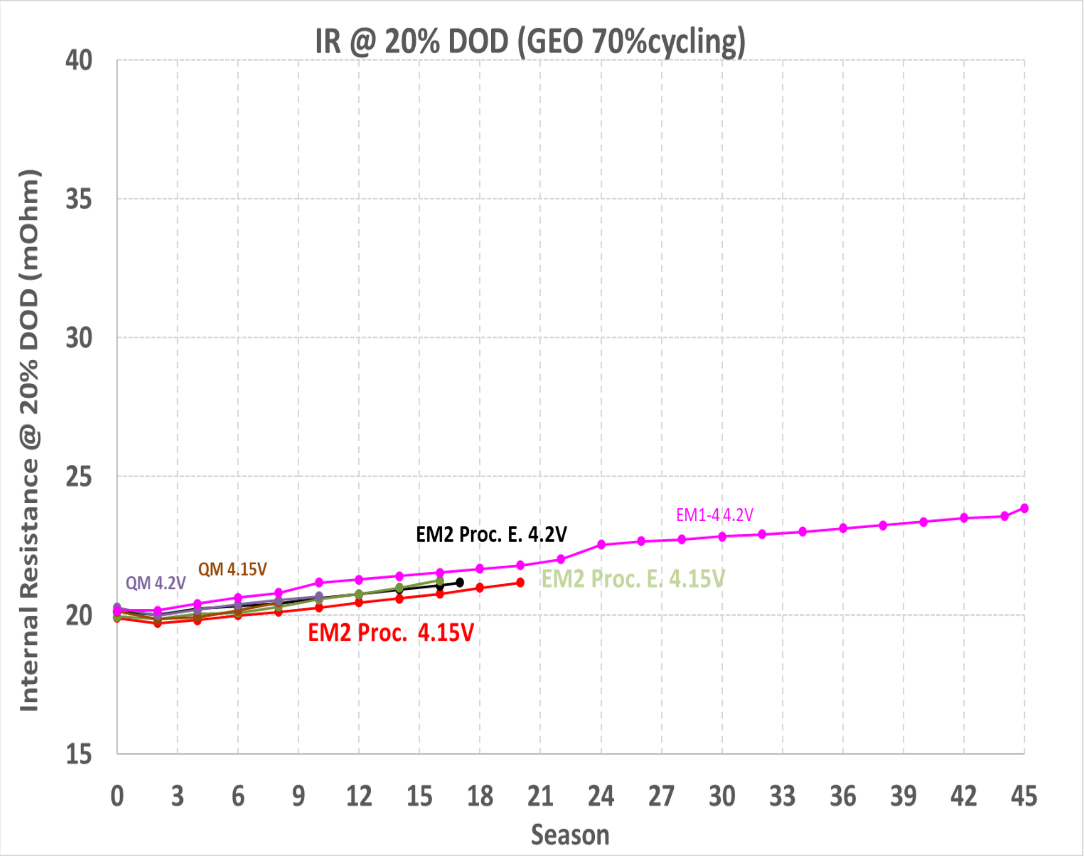
- EM2 cells (after 900 cycles) and QM are showing good trend





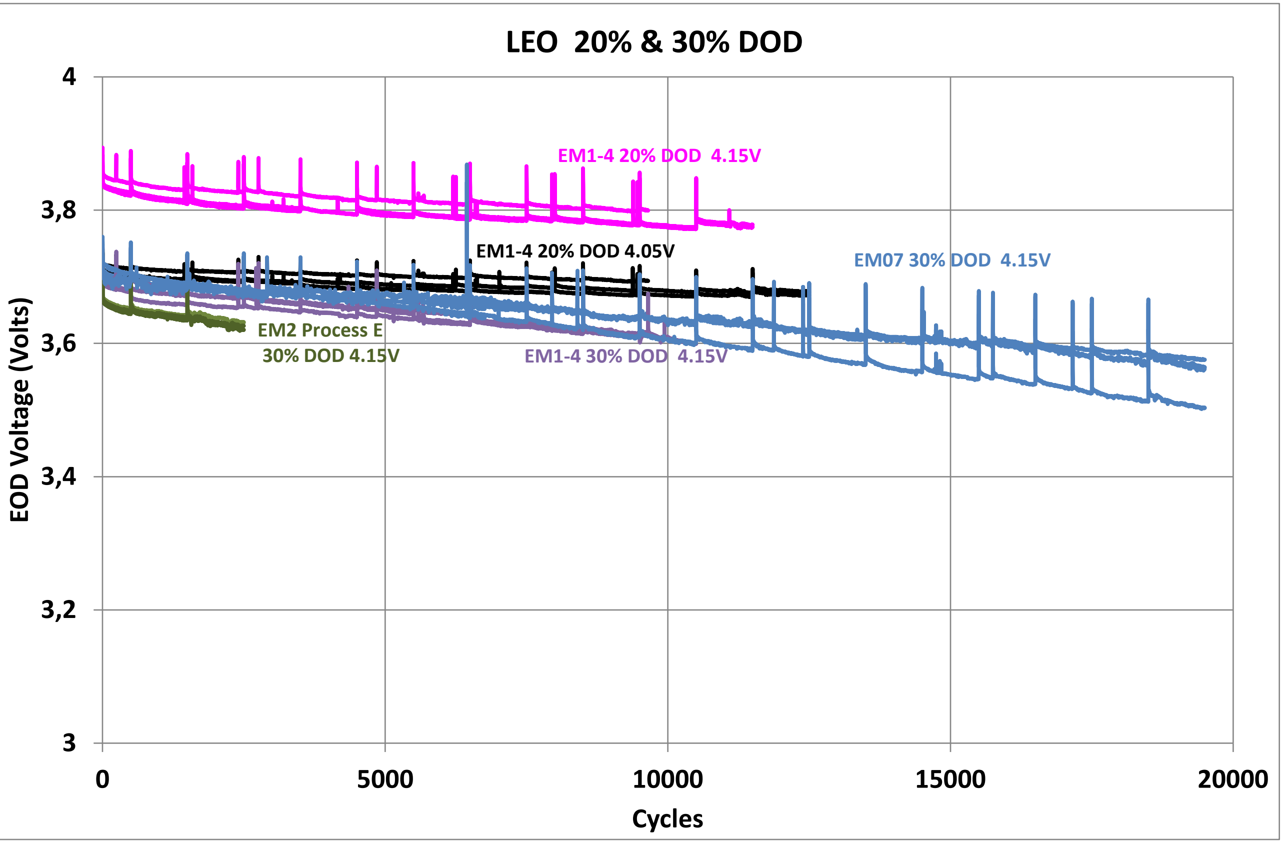
70 % GEO performances

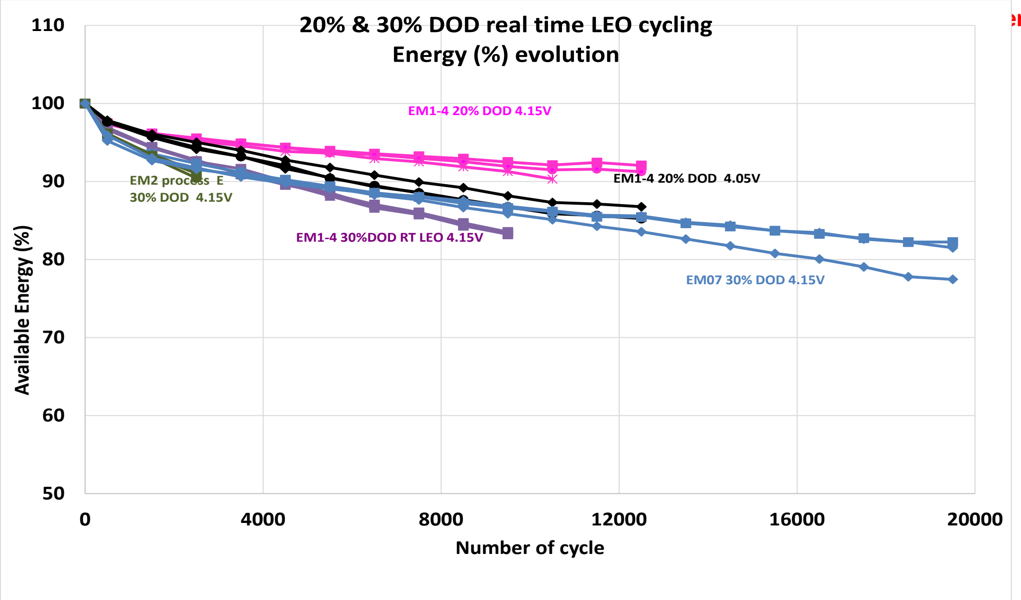


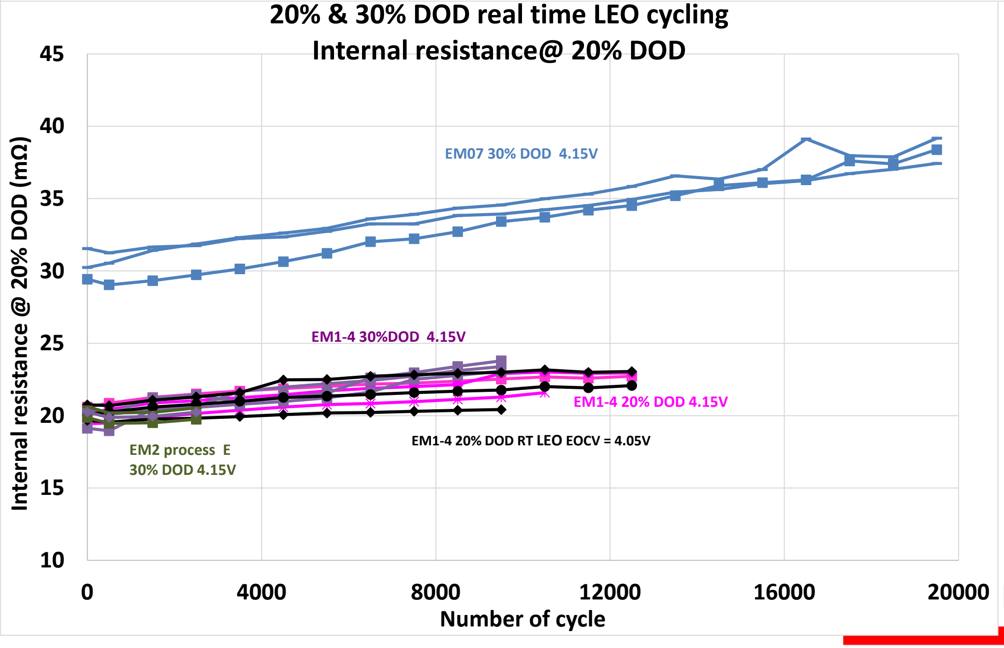


45 GEO seasons (equivalent to 22.5 years) successfully done on EM0 and EM1
EM2 life test are running : 20 Seasons
QM : 8 seasons

LEO cycling : Available capacity @ 20 and 30 % DOD

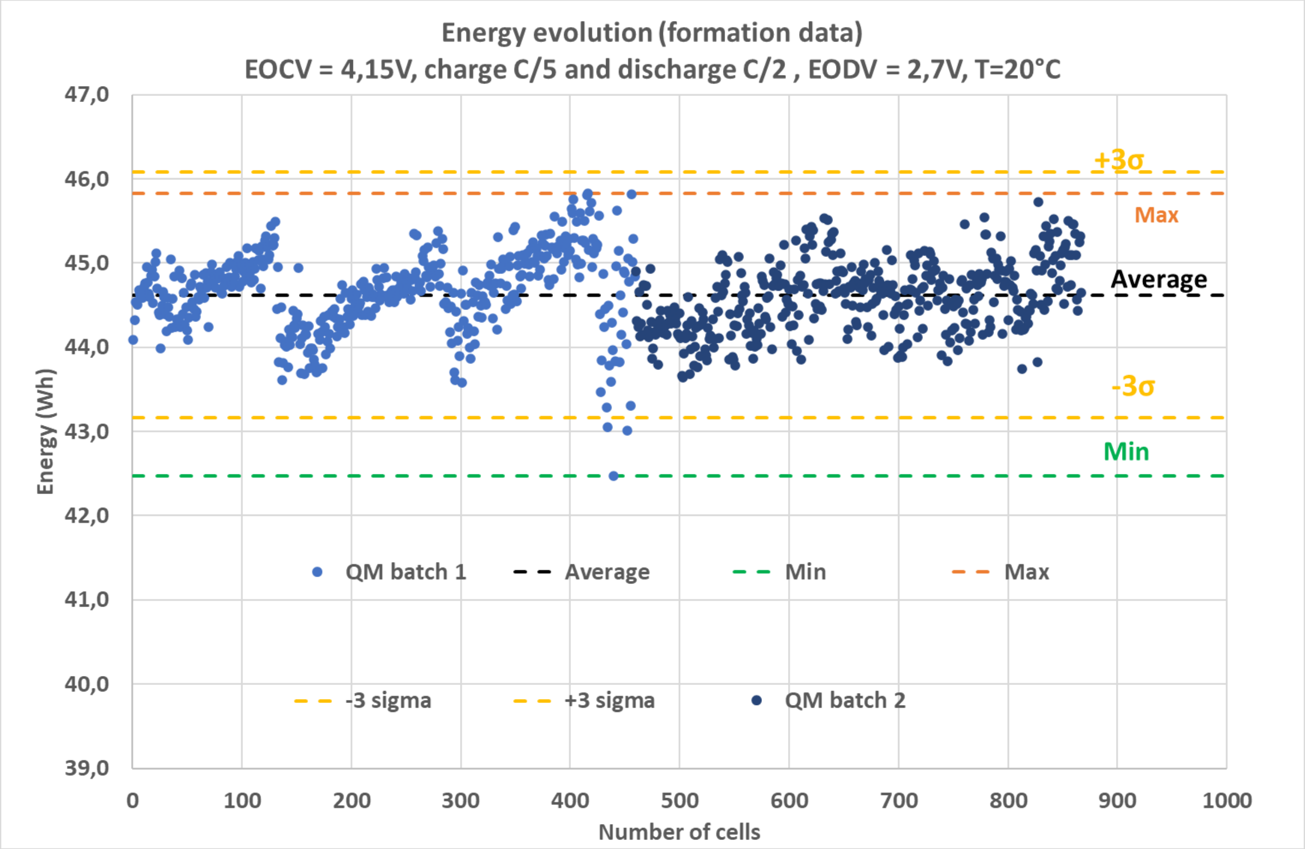






VL10ES QM cells

QM Cell performances



	Acceptance Energy (Wh) @ 4.2V & C/2 , T= 20°C
Average	45.4
Minimum	43.0
Maximum	46.5
Standard deviation	0.5

QM Cell average weight : 208.3 g

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	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

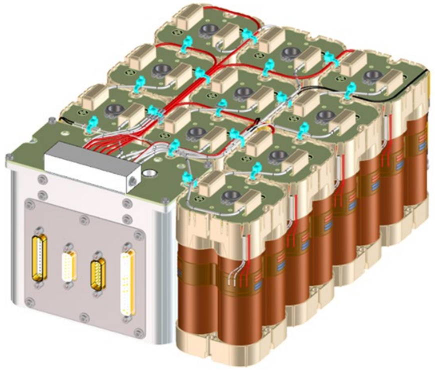
In green color: Tests performed on EM1 and EM2 cells are already covering the Qual Test Plan

Conclusion

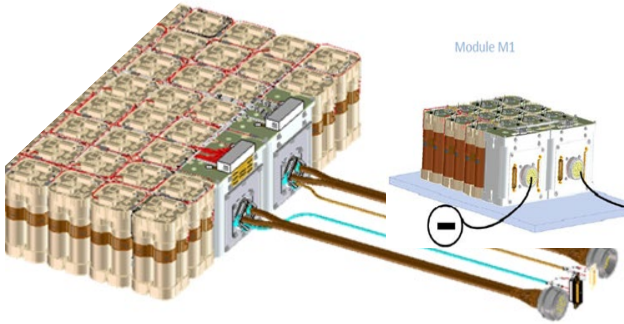
Conclusions

VL10ES cell qualification plan is running on 3 QM batches

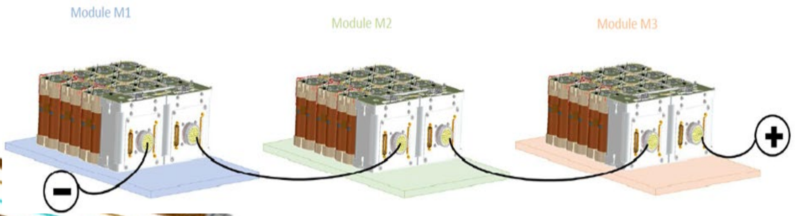
- **Performances are in line with expected values (**Electrical, Mechanical, Safety and Cycle life)
- **Battery qualification is running in parallel with 4 QM Models that are covering most used configurations**



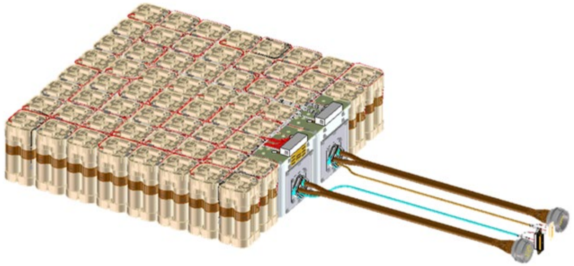
Batterie QM1
8S5P



Batterie QM2
11S6P



Batterie QM3
3x12S4P



Batterie QM4
12S20P

- **3 satellites contracts to be delivered starting** :
  6 GEO's
  2 LEO's with ESA
  14 LEO's

Acknowledgements

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Space Li-Ion Battery Book

Team work with most of the players: Authors/reviewers

- ABSL/Quallion : Sara Thwaite, Dave Curzon, Carl Thwaite, Joe Troutman
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- Boeing : Tom Barrera, Steven Core
- EPI : Rob Gitzendanner, Michel Lannes
- ESA : Evelyne Simon, Francois Bausier
- GS Yuasa : Curtis Aldrich, Tom Pusateri
- JPL : Marschall Smart, Kumar Bugga
- Lockheed Martin : Dick Shaw
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- Naval Surface Warfare Center : Lloyd Zilch, Samuel Stuart
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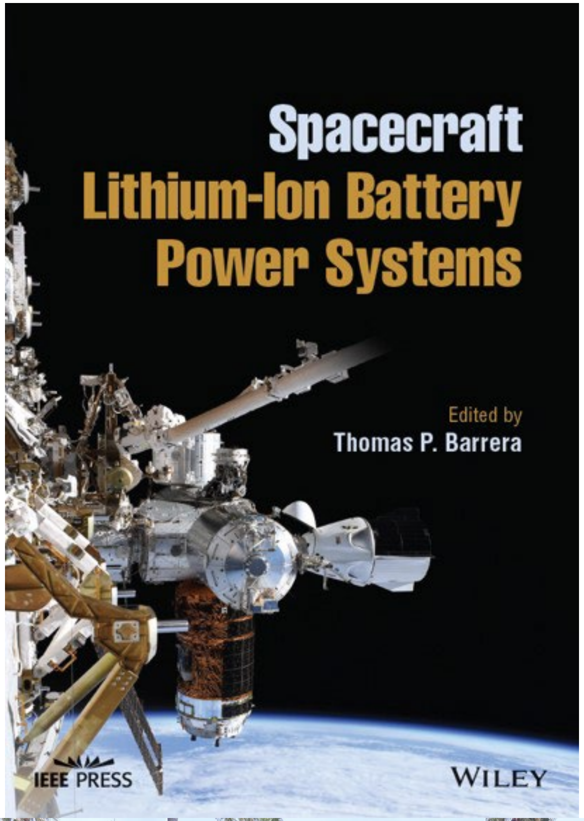
- Saft : Yannick Borthomieu



Thank you