Deliverable 4.2

Benchmarking results

Project acronym: ECO2LIB
Project title: Ecologically and Economically viable Production and Recycling of Lithium-Ion Batteries
Grant Agreement number: 875514
Coordinator: Martin Krebs

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875514.

Funding Scheme: **H2020-LC-BAT-2019-2020 / LC-BAT-2-2019**

Delivery Date from Annex I:	December 31th 2020
Start date of the project:	January 1st 2020
Project duration:	48 months

Work package:	WP4
Lead beneficiary for this deliverable:	VS
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Dissemination level		
PU	**Public**	**x**
CO	**Confidential, only for members of the consortium (including the Commission Services)**	
CI	**Classified**	

Document History

Date	Version	Author	Comment
15.12.2020	V1	B. Achzet, B. Fuchsbichler, B. Meir	Content and text
17.12.2020	V2	R. Stübler	Review

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Abbreviations and acronyms

KPI	Key performance indicators
VMB	VARTA Microbattery
VMI	VARTA Micro Innovation
VS	VARTA Storage
HE	High energy
HP	High power
DOD	Depth of discharge
ch	charge
dch	discharge
RES	Residential energy storage

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Executive Summary

The purpose of this document is to get an overview of the market situation of silicon-based materials for lithium-ion batteries. Therefore commercially available cells were scouted and purchased by VMI and VS. In this report two energy and two power cells that contain silicon in the anode material (<4 wt%) had been selected for further analysis.

The result of the electrochemical characterization and cycling tests show that all cell types are fitting the requirements defined in the ECO²LIB project. Therefore the measured performance will be taken as a reference in the ongoing tasks. The target of ECO²LIB will be to increase the Si-content in the anode material in order to achieve a higher energy density by keeping similar aging performances of the measured cells.

1 Cell Selection

VARTA continuously carries out benchmark tests to search for potential cells for VARTAs energy storage systems and high current applications. Table 1 shows an overview of the cell types selected for the ECO²LIB project and the previous project Sintbat (cell 1).

Table 1: Cell data of the tested cells within ECO²LIB and the previous project Sintbat

Cell type/ Format	application	Nom. capacity (Ah)	Energy density
Cell 1/ 18650 Cylindrical	High Energy	3.5	271 Wh/kg 753 Wh/L
Cell 2 21700 Cylindrical	High Energy	5	267 Wh/kg 750 Wh/L
Cell 3 21700 Cylindrical	High Power	4	217 Wh/kg 594 Wh/L
Cell 4 18650 Cylindrical	High Power	2.6	196 Wh/kg 566Wh/L

Cell 1 and cell 2 can be classified as high energy (HE) cells, meanwhile cell 3 and cell 4 can be classified as high power (HP) cells. Because the cells have different cylindrical formats (21700 and 18650) and are of different type (high energy/high power cells), they differ in nominal capacity, voltage, weight and in the end in their energy density.

Interestingly, cell 1 has with 753 Wh/L and 271 Wh/kg a slightly higher specific energy and energy density compared to cell 2, although the 18650 format should have a worse active/inactive material ratio compared to the 21700 cell. [1]

In all four cells, silicon was found in the anode (<4w%).

1.1 Purpose of the document

ECO²LIB is the successor of the research project Sintbat (ID: 685716) with the scope to improved battery materials for energy storage applications with significantly reduced costs per cycle (€/kWh/cycle).

Table 2: KPIs of the ECO²LIB project for the improvement of battery material compares to the European Strategic Energy Plan (SET Plan) [2]

Criteria	SET-Plan targets 2030	ECO²LIB
Specific energy	180 – 350 Wh/kg	260 Wh/kg
Energy density	350 – 800 Wh/L	800 Wh/L
Life time	> 10,000 cycles	> 5,000 cycles
Temperature	-20 / +70°C	-20 / +70°C
Energy price	200 €/kWh	< 150 €/kWh

In this document, commercially available lithium ion batteries will be benchmarked regarding their electrochemical performance. The obtained data will be the reference for the development with the ECO²LIB project. Therefore, this report ensures that the ECO²LIB cell targets are competitive with current available cell technologies.

2 Benchmark Test Plan

In order to compare the cells, different cycling tests were performed. In the benchmark tests, the selected cell types were tested according to the established standards for HE and HP cells and underwent accelerated ageing at 2C and elevated temperature.

In the following table, the performed tests including the applied parameters are described.

Table 3: Performed test series

Cell type	Cycling tests 1	Cycling test 2
Cell 1	0.5C ch, 0.5C dch, 23±3°C, Variation DOD	2C, 45°C 2.5 - 4.2 V
Cell 2	0.5C ch, 0.5C dch, 23±3°C, Variation DOD	2C, 45°C 2.5 – 4.2 V
Cell 3	1C ch, 10A / 20A dch, 23±3°C, Variation DOD	2C, 45°C 2.5 – 4.2 V
Cell 4	1C ch, 10A / 20A dch, 23±3°C, Variation DOD	2C, 45°C 2.5 – 4.2 V

2.1 High Energy Cells

The high energy cells (cell type 1 and 2) have been tested with charge and discharge rates of 0.5 C, at room temperature and under variation of the depth of discharge. Application specific cycle tests in laboratory are based on cycle tests with a constant current profile. This is due to the complexity of the parameter space of the dynamic load profiles in the field. Furthermore, ageing can be considered accelerated compared to cyclic ageing in the field.

Within the scope of Deliverable 4.1, the cell requirements for the residential energy storage (RES) application concerning cycle life have been defined as 4,000 cycles with a remaining capacity ≥ 80% at 0.5 C / 0.5 C and 80% DOD. As an intermediate target at 1,000 cycles, a remaining capacity of ≥ 90% is expected. Furthermore, the cells should still be able to be operated safely down to 60% after 4,000 cycles.

The current results of the benchmark cells are shown in Figure 1. Cell 1 (left diagram) could already be tested within the Sintbat project. A total of 6,000 cycles were run, which corresponds to test duration of more than 3 years. The remaining capacity at 1,000 cycles is ≥ 90% and at 4,000 cycles it is approximately 82%.

The cycle tests for cell type 2 (Figure 1, right diagram) were only started as part of the current project. The depth of discharge for the cycle tests is approximately 80% (red curves) and approximately 70% (green curves). At 460 cycles and 660 cycles, respectively, the remaining capacity is still > 90%. The green curves in particular show a good trend with regard to the intermediate requirement at 1,000 cycles. These cycle tests will be continued in the project and discussed in the consortium.

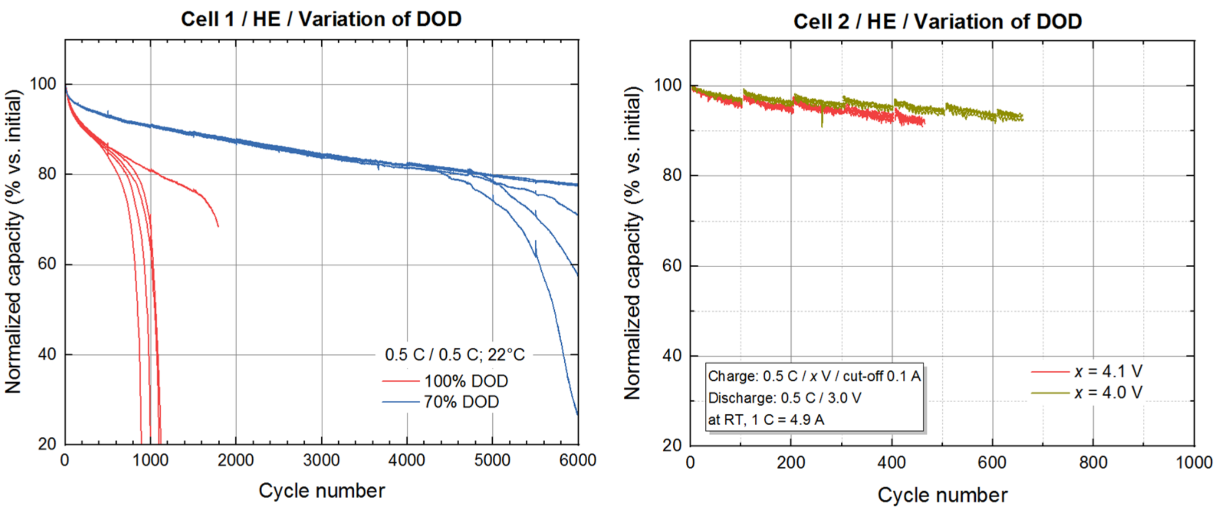

Figure 1: Cycling performance of the high energy samples at 0.5 C, room temperature and under variation of the depth of discharge.

At 2C and 45°C both high energy cells showed an excellent ageing behaviour. For cell 1, capacity retention of 80.3% after 500 cycles was observable. Cell 2 showed similar capacity retention of 80.3% after 500 cycles. Whereas cell 2 shows a linear loss of capacity, cell 1 shows an increased capacity loss in the first 100 cycles. From this, one can estimate that cell 1 might have better capacity retention over a longer cycle life.

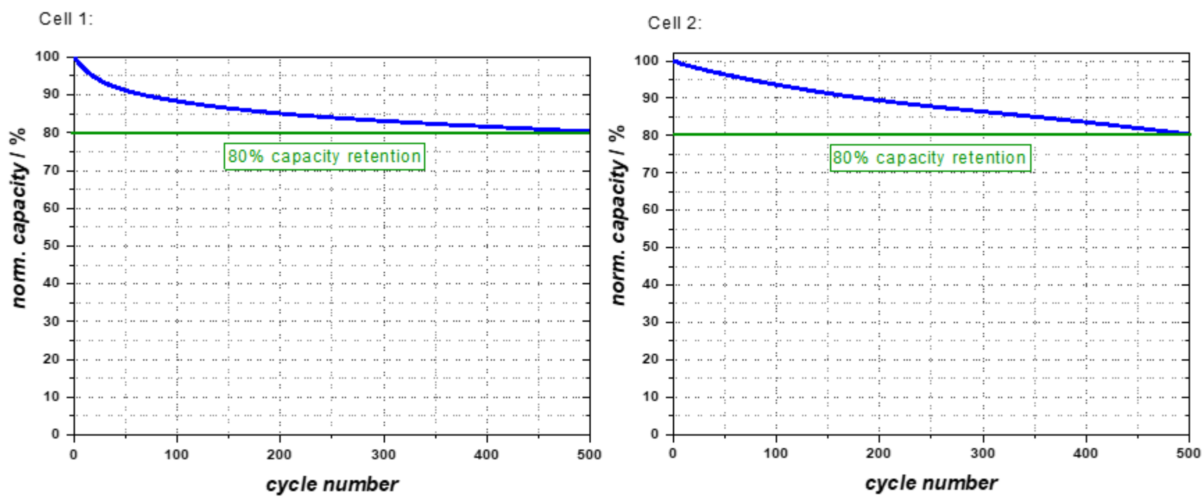

Figure 2: Cycling results (2C) of the high energy cells @45°C (left: cell 1, right: cell 2)

2.2 High Power Cells

The high power cells (cell type 3 and 4) have been tested with different discharge rates of 10 A and 20 A, at room temperature and under variation of the DOD. The cycle tests are based on a standard at VS, which is applied uniformly for the testing of high power cells in order to obtain good comparability of the data for different cell types.

Within the scope of Deliverable 4.1, the cell requirements for the high current application concerning cycle life have been defined as 600 cycles with a remaining capacity ≥ 80% at 0.5 C charge/ 50 Watt discharge (I_{max} ≈ 18 A – 20 A) and 90% DOD. The definition was based on the example of a cordless vacuum cleaner for private use. However, end-of-life criteria for high current applications depend very much on customer-specific requirements. Therefore, these specifications only represent an example.

The results of the benchmark cells are shown in Figure 3 (cell 3) and Figure 4 (cell 4). Basically, all cycle test results show an improvement in cycle stability with a reduction in the depth of discharge. The target of 600 cycles with 80% remaining capacity seems achievable for all samples at a discharge rate of 20A and in the reduced voltage range 2.7 V to 4.1 V.

A reduction in discharge rates to 10 A also seems to have a positive effect on the cycle stability in the tests carried out. However, this effect is much less pronounced for cell 3 than for cell 4, where the 80% limit in the voltage range 2.7 V to 4.1 V is only reached after more than 800 cycles (Figure 4, left diagram).

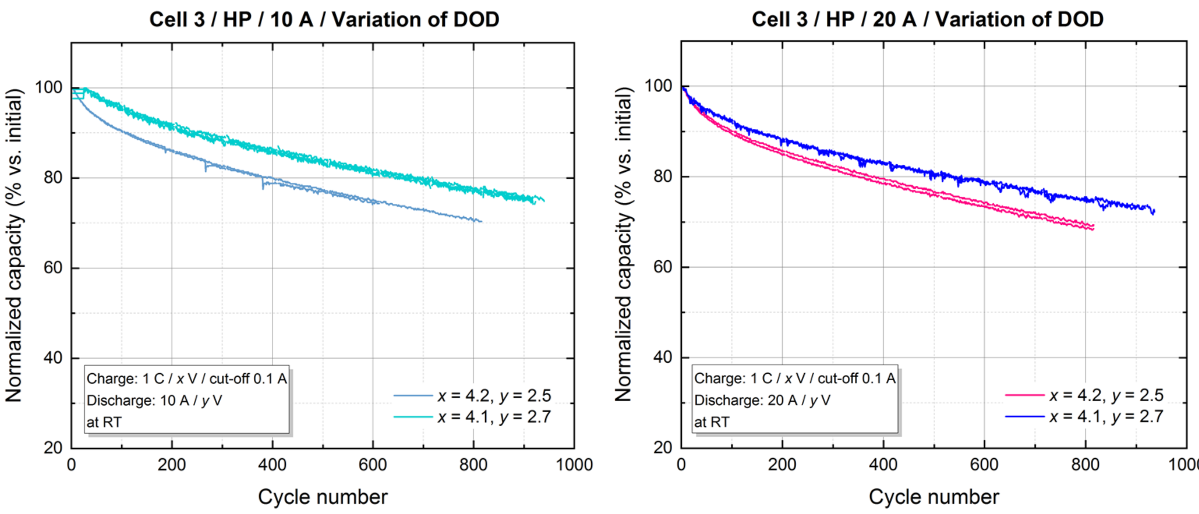

Figure 3: Cycling results of the high power samples cell 3 with a discharge at 10 A (left) and 20 A (right), room temperature and under variation of the DOD

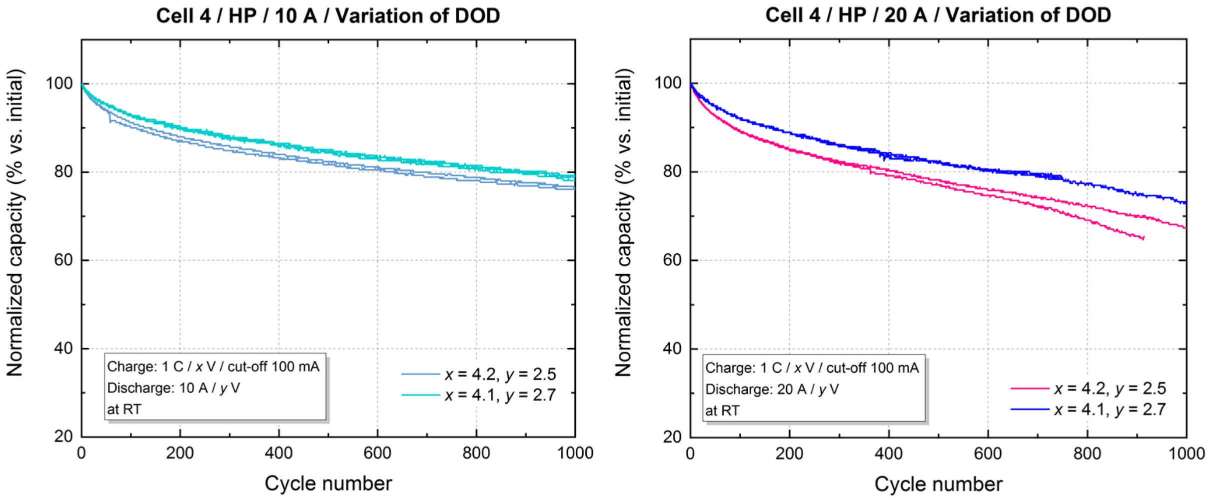

Figure 4: Cycling results of the high power samples cell 4 with a discharge at 10 A (left) and 20 A (right), room temperature and under variation of the DOD

The high power cells showed also a good ageing behaviour at 2C and 45°C. For cell 3, a slightly worse ageing behaviour was measured. After 500 cycles, capacity retention of 78.8% was noticeable for cell type 4. Cell 3 still showed capacity retention of 73.7% after 500 cycles.

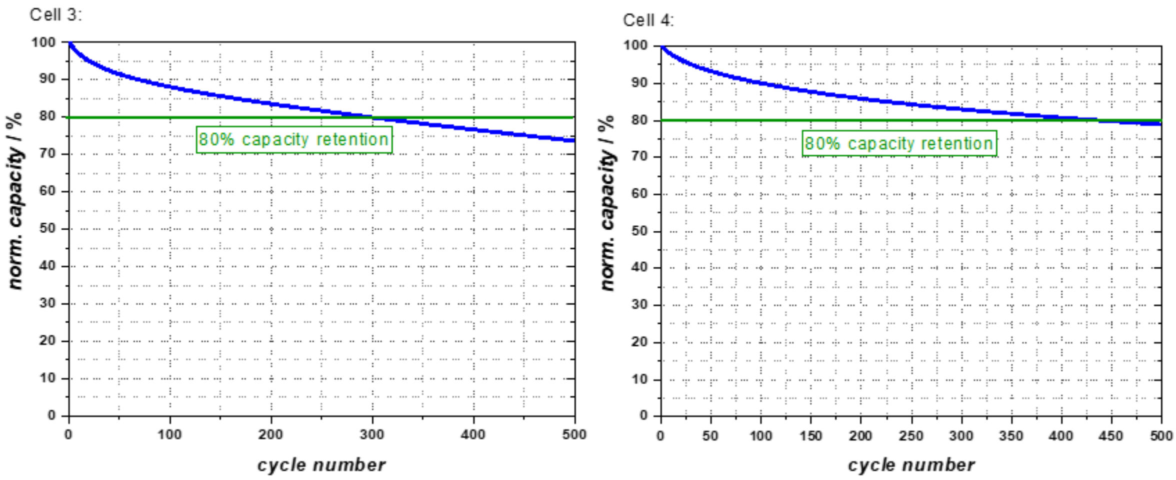

Figure 5: Cycling results (2C) of the high energy cells @45°C (left: cell 3, right: cell 4)

3 Conclusion

All benchmarked cells are compliant to the requirement for energy and power related energy storage applications defined in the deliverable 4.1. Especially cycling tests @ 2C/45°C are showing good performance in regards to the market standard which is frequently observed by VARTA. However it's clearly shown that the aging behaviour is significantly impacted by the applied parameters, like the DOD and the charge and discharge rates. The reported cycling tests will therefore be an on-going task in order to provide an extensive reference for the ECO²LIB project.

References

[1] T. Waldmann, R. G. Scurtu, K. Richter, M. Wohlfahrt-Mehrens
18650 vs. 21700 Li-ion cells – A direct comparison of electrochemical, thermal, and geometrical properties
Journal of Power Sources, Volume 472, 1 October 2020, 228614

[2] **Grant Agreement number: 875514 — ECO2LIB** — H2020-LC-BAT-2019-2020/H2020-LC-BAT-2019, page 162