MAT4BAT
Project Final Report

Tables and figures

Grant Agreement number: 608931

Project acronym: MAT4BAT

Project title: ADVANCED MATERIALS FOR BATTERIES

Funding Scheme: Collaborative project

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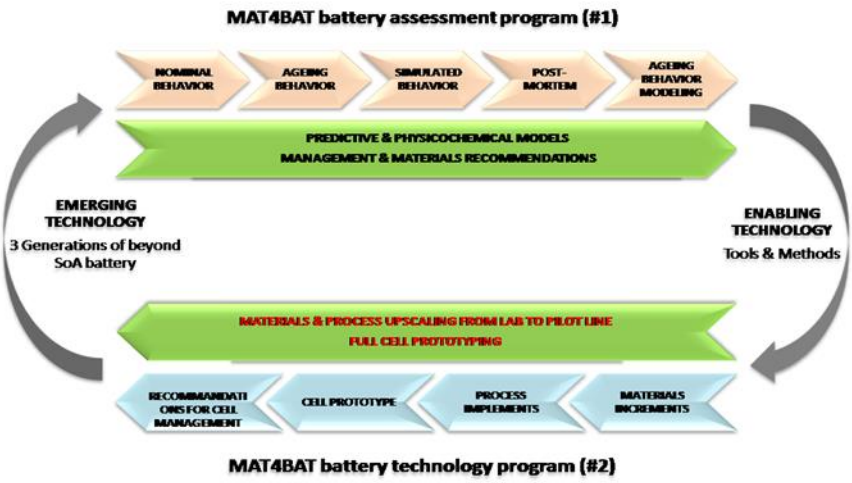
[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.



Introduction Figure: MAT4BAT battery technology programmes

TABLES

Table 1. Ageing conditions performed on Kokam Li-ion cells; on the left: calendar conditions; on the right: cycling conditions

T [°C] \ SOC [%]	50	90	100
60	x2 | VITO	x2 | VITO	x3 | VITO x1 | CEA
45	x2 | CEA	x3 | CEA	x3 | CEA
25	x3 | EIGSI	X3 | EIGSI	x3 | EIGSI
5	x2 | CIDETEC		x3 | CIDETEC

T [°C] \ CH rate	1C ≡ 16A (1 hour)	2C ≡ 32A (30 min.)	3C ≡ 48A (20 min.)
45	1C/1C SOC = 0-80% x2 | VITO 1C/1C SOC = 10-90% x2 | CEA 1C/1C SOC = 20-100% x2 | VITO 1C/1C SOC = 0-100% x2 | EIGSI	2C/1C SOC = 0-80% x2 | VITO 2C/2C SOC = 10-90% x2 | CEA 2C/1C SOC = 20-100% x2 | VITO	3C/1C SOC = 0-80% x2 | VITO 3C/3C SOC = 10-90% x2 | CEA 3C/1C SOC = 10-90% x2 | CEA 3C/1C SOC = 20-100% x2 | VITO 3C/1C SOC = 0-100% x4 | EIGSI
25	1C/1C SOC = 10-90% x2 | CEA 1C/1C SOC = 0-100% x2 | KIT	2C/1C SOC = 10-90% x3 | ZSW 2C/1C SOC = 0-100% x2 | KIT	3C/1C SOC = 10-90% x2 | ZSW 3C/1C SOC = 0-100% x3 | KIT
5	1C/1C SOC = 10-90% x2 | CIDETEC	2C/1C SOC = 10-90% x2 | CIDETEC	3C/1C SOC = 10-90% x2 | CIDETEC

Table 2. Overview of sensors results

Sensors		Main conclusions
Internal	Temperature	Intrusive but without perturbation demonstrated over ~2 years Not necessary for pouch cells (very low dispersion with external measurements), but can be relevant for hard casing prismatic cells or cylindrical cells
	Reference electrode	Intrusive but without perturbation demonstrated at BOL Current stability of the reference electrode limited to ~1 month Relevant for modeling and understanding studies
External	Temperature	Required due to the major influence of the temperature, and the important differences between ambient temperatures and the skin temperatures of cells
	Strain gauge	Erratic measurements on pouch cell Could be more relevant on hard casing prismatic cells or cylindrical cells

Table 3. Overview of ageing tests results

Ageing conditions		Capacity evolution	Resistance evolution
Calendar	All conditions	Increase of the capacity fade with T and SOC	Proportional increase with capacity fade
	High SOC+T	Same + overaging due to Local Li deposition during the charges	
Cycling	5°C	Sudden drop and then stabilization Increase of the capacity fade with the charge C-rate	No evolution
	25°C, 45°C	Significant influence of the upper SOC more than the DOD	Proportional increase with capacity fade Significant impact of the upper SOC

Table 4. Ageing conditions performed on MAT4BAT GEN#1 Li-ion cells; on the left: calendar conditions; on the right: cycling conditions

T [°C] \ SOC [%]	30	50	90	100
60				x2 | CEA
45	x2 | VITO	x2 | VITO	x2 | VITO	x2 | VITO
25				x2 | EIGSI

T [°C] \ CH rate	1C ≡ 16A (1 hour)	2C ≡ 32A (30 min.)	3C ≡ 48A (20 min.)
45	1C/1C SOC = 10-90% x2 |VITO	2C/1C SOC = 10-90% x2 |VITO	3C/1C SOC = 0-80% x2 |VITO 3C/1C SOC = 10-90% x2 |VITO 3C/1C SOC = 20-100% x2 |VITO 3C/1C SOC = 0-100% x2 | EIGSI
25	1C/1C SOC = 10-90% x2 |CEA 1C/1C SOC = 0-100% x2 | KIT		3C/1C SOC = 10-90% x2 | KIT 3C/1C SOC = 0-100% x2 | KIT
5	1C/1C SOC = 10-90% x2 |CIDETEC	2C/1C SOC = 10-90% x2 |CIDETEC	3C/1C SOC = 10-90% x2 |CIDETEC

Table 5. Synthesis of MAT4BAT GEN#1 cell performances, compared to initial objectives indicated in the proposal

	GEN#1		
ENERGY	150 Wh/kg	✓	157Wh/kg @ 1C/1C, 25° C
DOD	80 %		
LIFETIME **Standard charging**	2000 cycles	✓	2000 cycles @ **1C**/1C, 45° C, 10-90% **3000 cycles @ 1C/1C, 25° C, 10-90%**
LIFETIME **Fast charging**	1500 cycles	✓ ✗	1500 cycles @ **2C**/1C, 45° C, 10-90% certainly > @ 25° C *but not tested* *@ 3C → < 500 cycles both @ 25° C and 45° C*

Table 6. Resin selected for hard casing development

Process	Product ref.	Type of product	Supplier	Distributor	Price VAT non included (€/kg)
Vacuum infusion	Ly1564sp	Epoxy resin based on DGEBA	Huntsman	Gaches chimie.	44.20
	Aradur 3487	Hardener based on amine	Huntsman	Gaches chimie.	25.43
RTM *(Resin Transfert Molding)*	Resoltech 1800	Structural epoxy	Resoltech	SFcomp.	15.79
	Hardener 1805	Hardener based on amine	Resoltech	SFcomp.	33.41

Table 7. Fibers selected for hard casing development

Process	Fibre type	Fabric type	Weight (g/m^2)	Supplier	Distributor.	Price VAT non included (€/m^2)
Vacuum infusion	Glass	2*2 twill	285	Hexcel	SFcomp.	5,5
	Carbon 3K	twill	245	Chomarat	Chomarat	16.00
	Aramide	Satin weave 4	175	Hexcel	SFcomp.	17.82
	non treated Flax	twill	200	Biotex	SFcomp.	14,15
RTM	Flax	2*2 twill	200	Biotex	VELOX	23.35

FIGURES

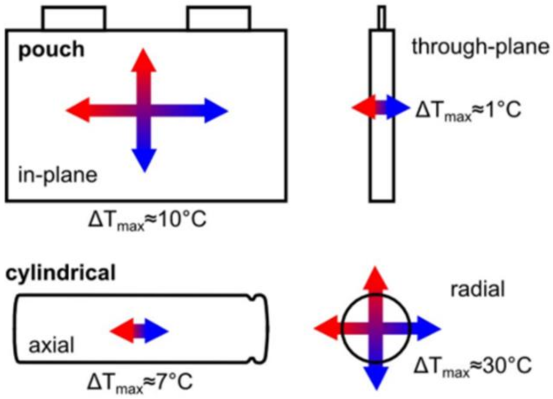


Figure 1. Main results obtained on pouch and cylindrical cells by thermographic imaging

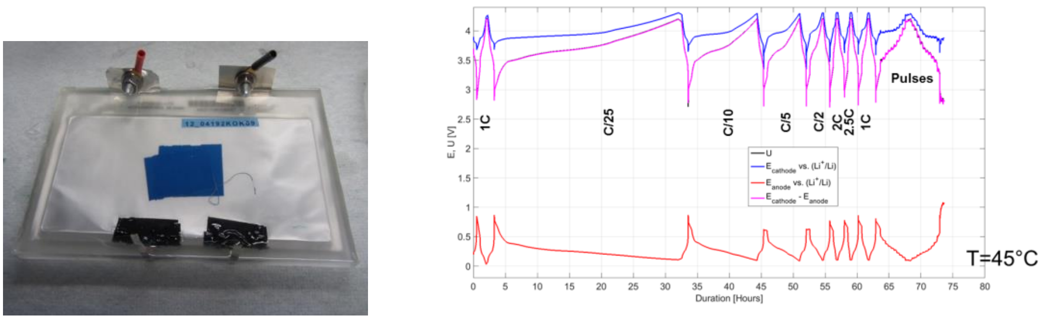


Figure 2. On the left: picture of a Kokam 16Ah cell instrumented with 2 reference electrodes; on the right: illustration of positive and negative potential evolution during a check-up

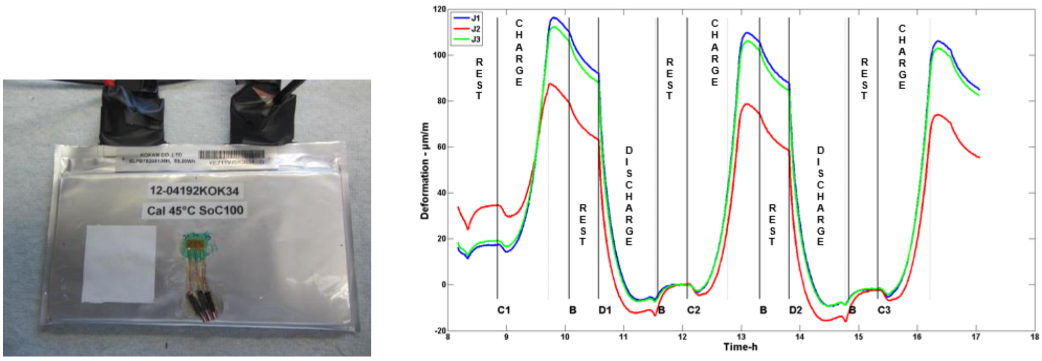


Figure 3. On the left: picture of a Kokam 16Ah cell instrumented with 1 strain gauge; on the right: illustration of the breath of the cell during 3 consecutive cycles

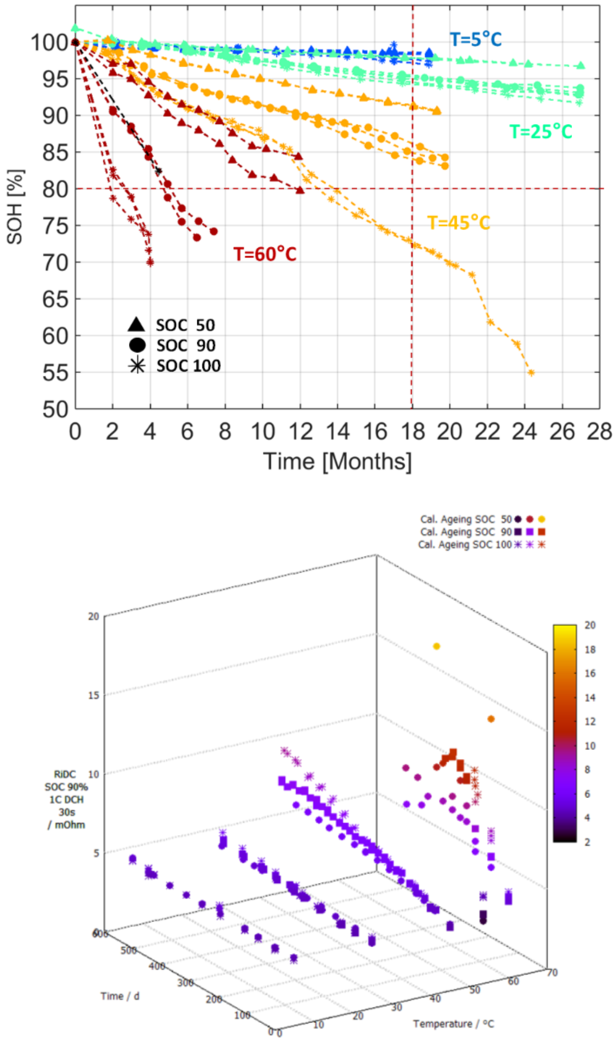


Figure 4. Calendar ageing results on Kokam 16Ah cells; on the left: capacity evolution; on the right: 30s DC resistance at SOC=90 evolution

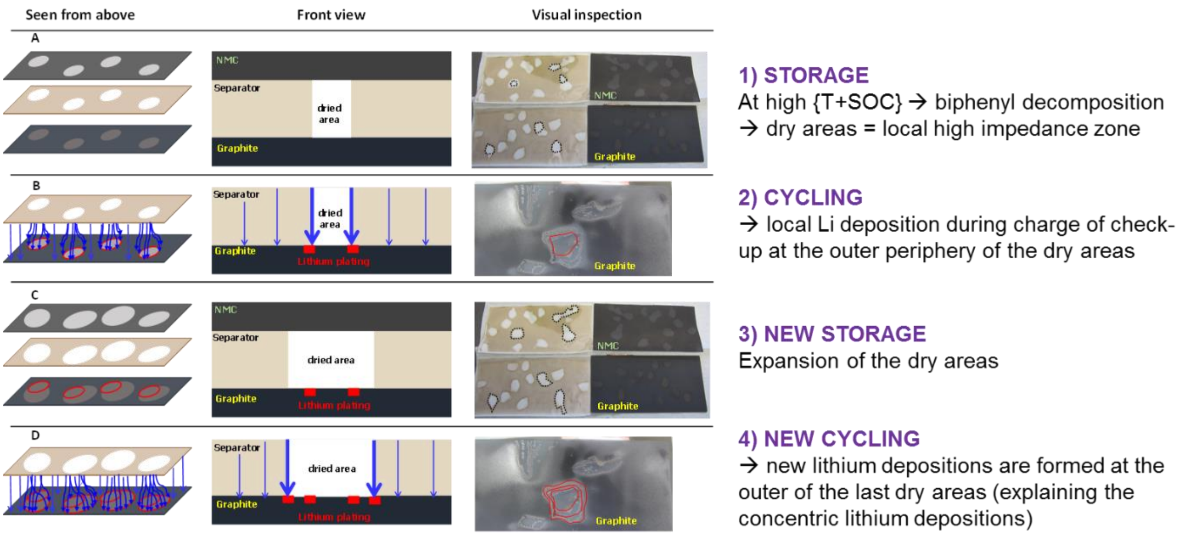


Figure 5. Lithium plating development process in high temperature conditions with biphenyl-containing electrolyte in C/NMC Li-ion cell

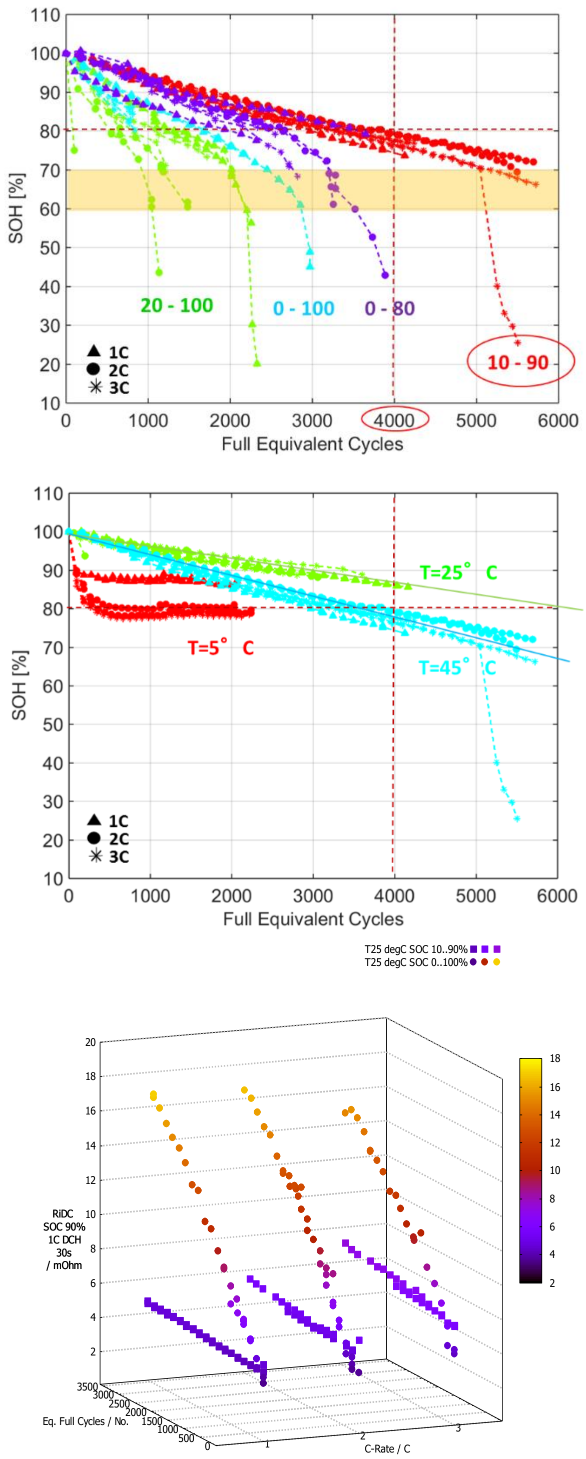


Figure 6. Cycling ageing results on Kokam 16Ah cells; up on the left: influence of SOC windows at 45°C on capacity evolution; up on the right: influence of temperature at ΔSOC=10-90; down: 30s DC resistance at SOC=90 evolution

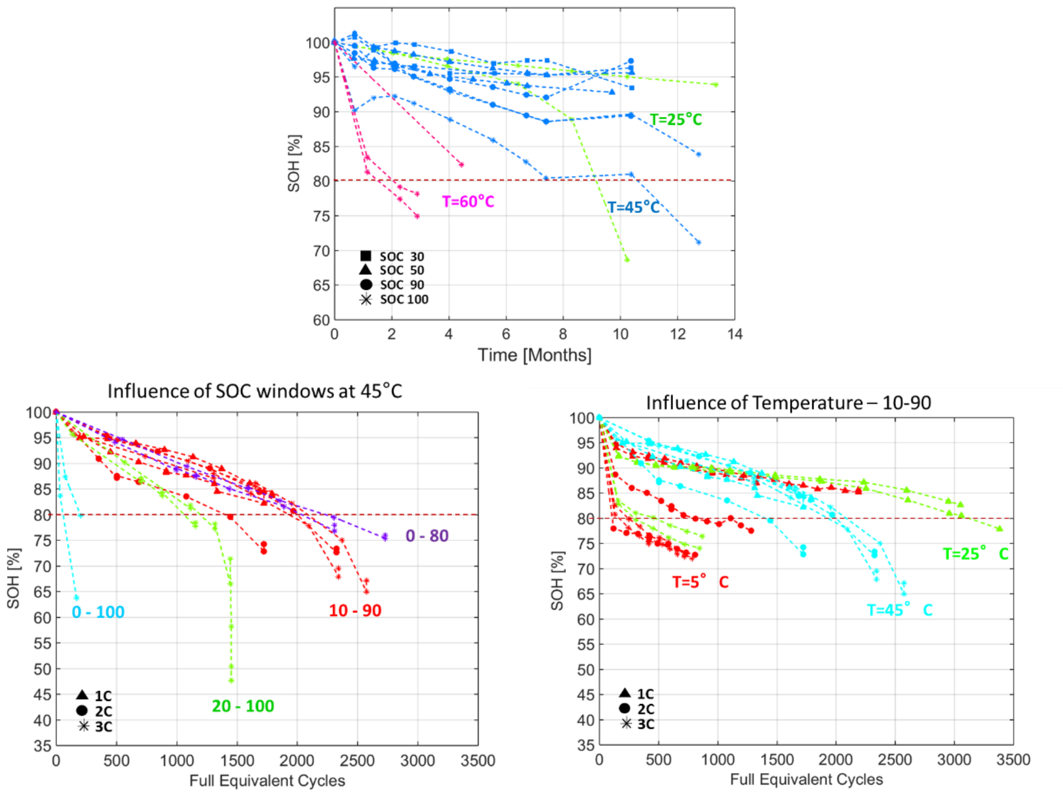


Figure 7. Ageing results on MAT4BAT GEN#1 cells; up on the left: calendar ageing; down on the left: cycling ageing, influence of SOC windows at 45°C on capacity evolution; down on the right: cycling ageing, influence of temperature at ΔSOC=10-90

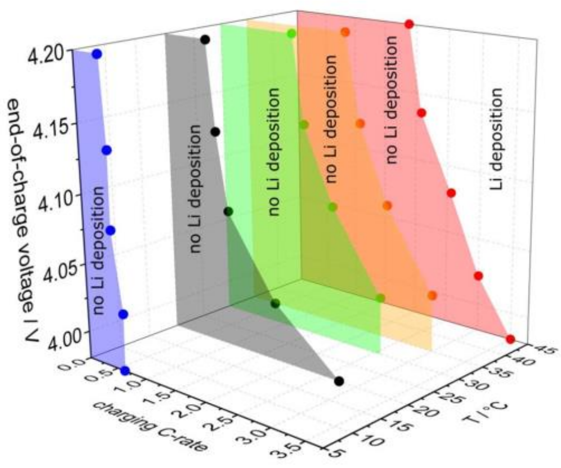


Figure 8. Experimental results on critical combinations of charge C-rates and end-of-charge voltages for 5°C, 20°C, 30°C, 35°C, and 45°C. The shaded regions behind and in front of the experimental data points correspond to absence Li deposition and presence of Li deposition on anodes, respectively. The shaded areas were obtained by linear connection of the data points. Each data point corresponds to the mean value calculated from tests with two reproduced cells

$$Q_{loss}(t) = a(T, SoC) \cdot \sqrt{t} + b(T)$$

$$a(T, SoC) = K_a(SoC) \cdot \exp\left[-\frac{E_a(SoC)}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

$$\boldsymbol{K_a(SoC) = k_{a,1} \cdot SoC + k_{a,2}}$$

$$\boldsymbol{E_a(SoC) = E_{a,1} \cdot SoC + E_{a,2}}$$

$$b(T) = K_b \cdot \exp\left[-\frac{E_b}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

Figure 9. Capacity loss

Figure 10. Sealed dry Gen#1 cells before supply to KIT for activation

(a) 

(b) 

Figure 11. GEN#2A cells: a) Winded assemblies, b) Cell with final soft packaging

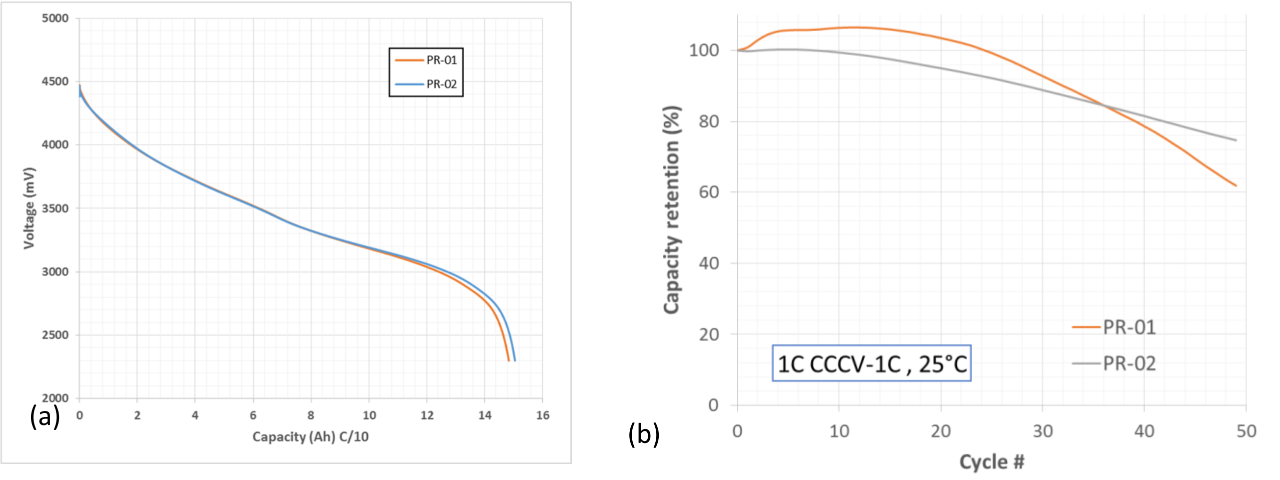


Figure 12. Cycling performances of GEN#2A cells: a) Discharge curve after formation, b) Cell capacity evolution over 1C CCCV-1C cycling test at 25°C

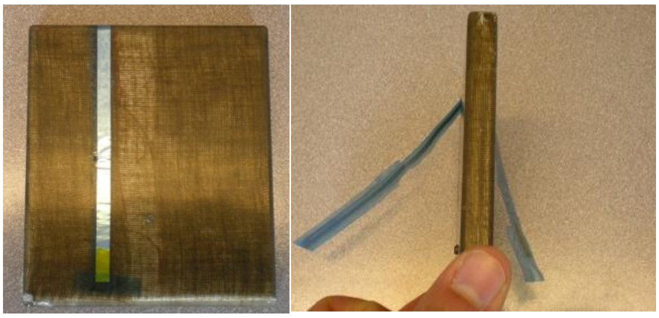


Figure 13. 7.5A.h Kokam cells overpackaged by RTM process

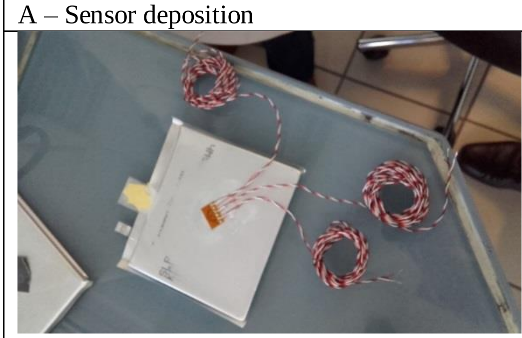
A – Sensor deposition	B – Sensor deposition
	

Figure 14. Strain gauges deposit A - on pouch foil, B - on the overpackaging

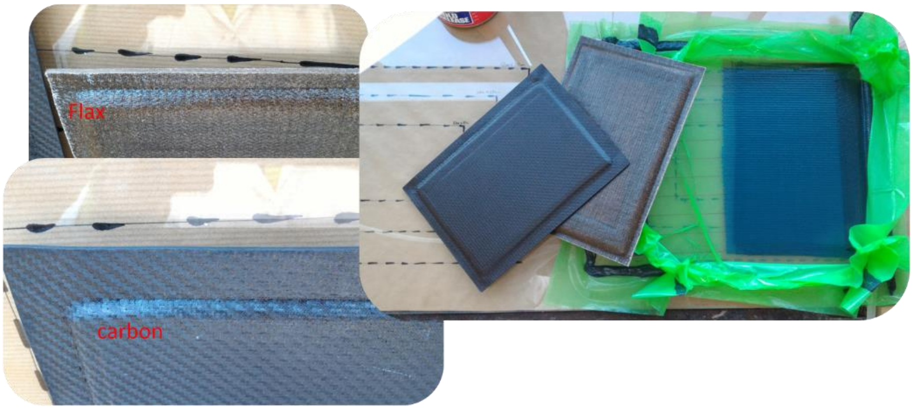


Figure 15. Over-packaging processed with the draping method 3

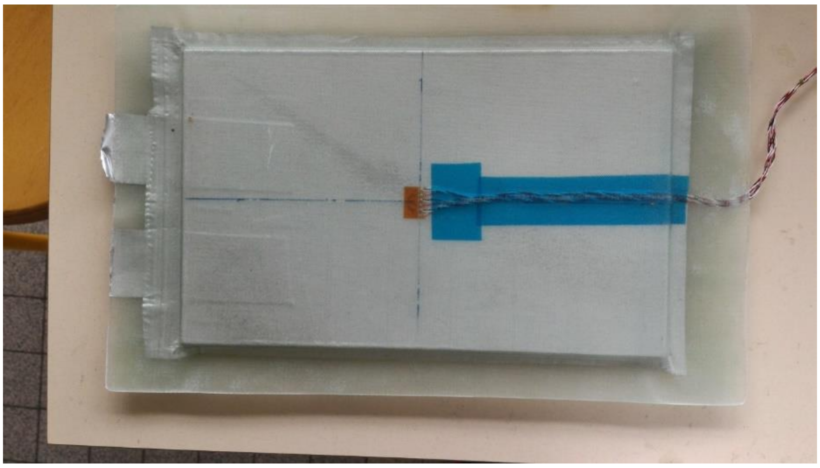


Figure 16. Strain gauges deposition

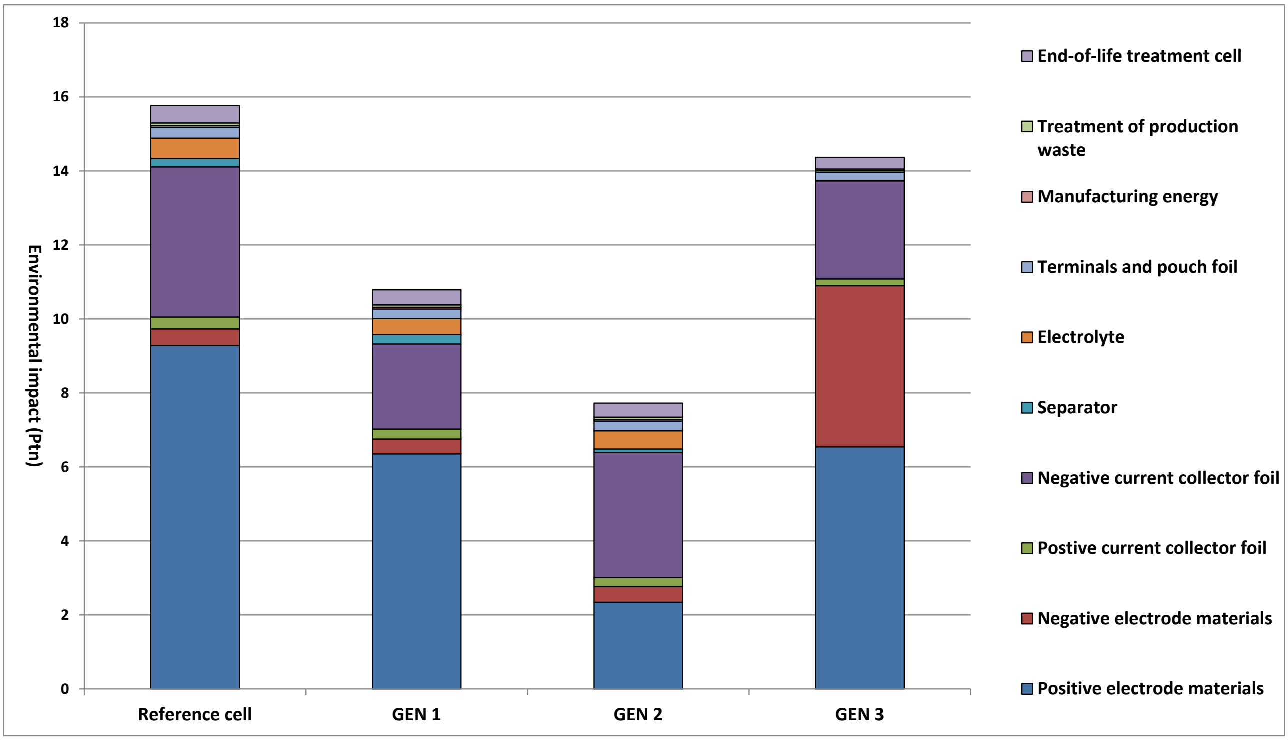


Figure 17. Single score comparison of the different cells on production level

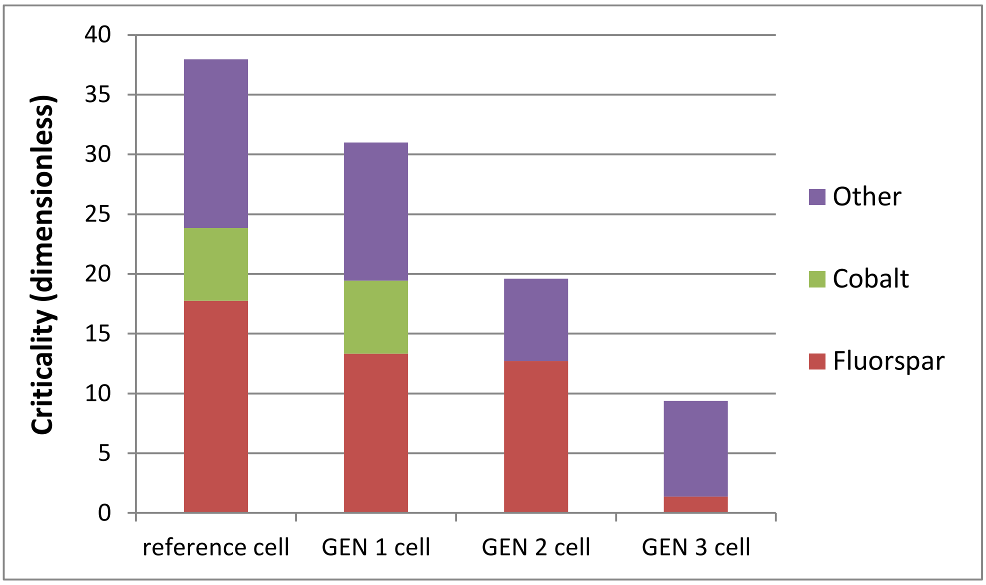


Figure 18. Criticality comparison for the different cells

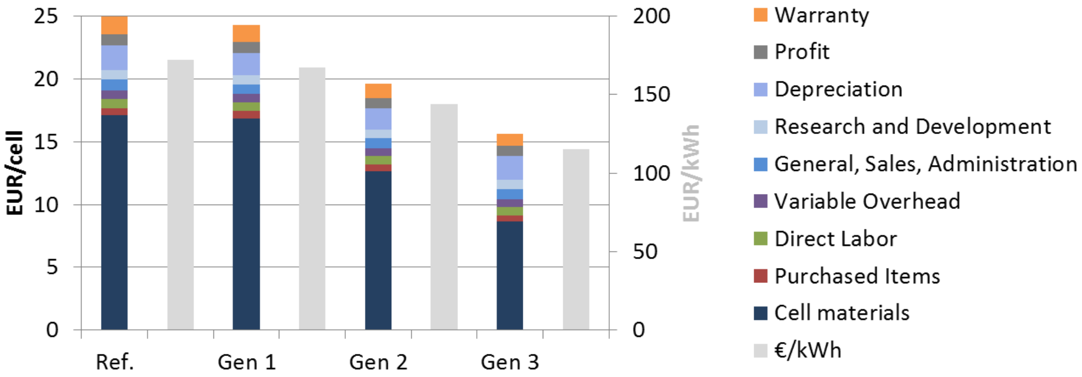


Figure 19. Unit cell price components for the different cells (40Ah cell)

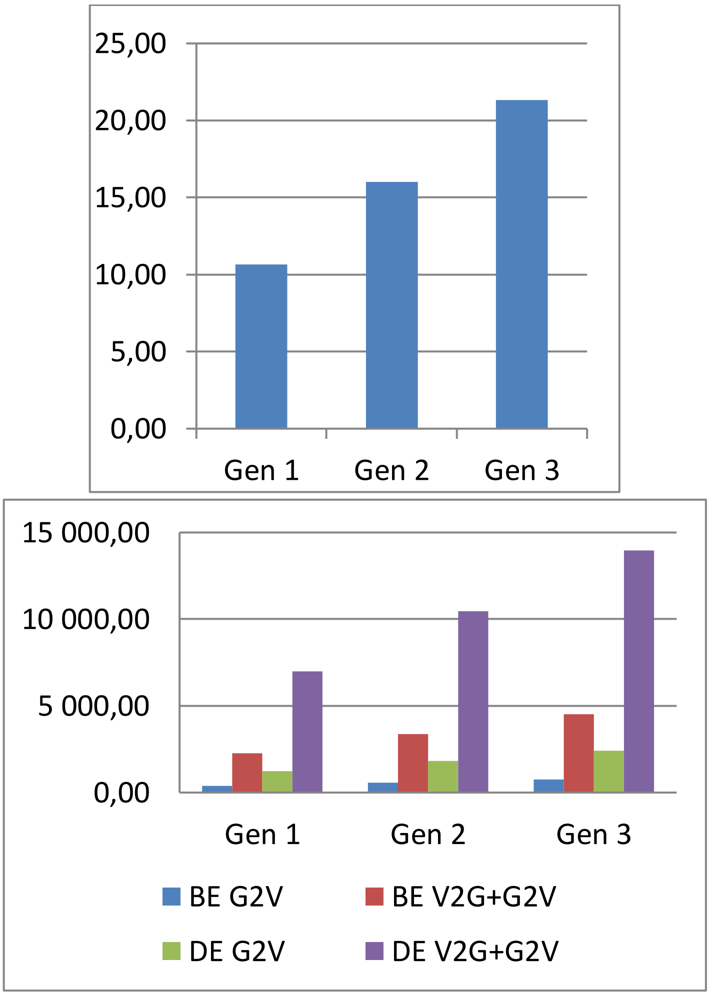


Figure 20. Yearly revenues in the business cases grid congestion management (left) and portfolio management case 2 (right) in €/EV/year for the different cells

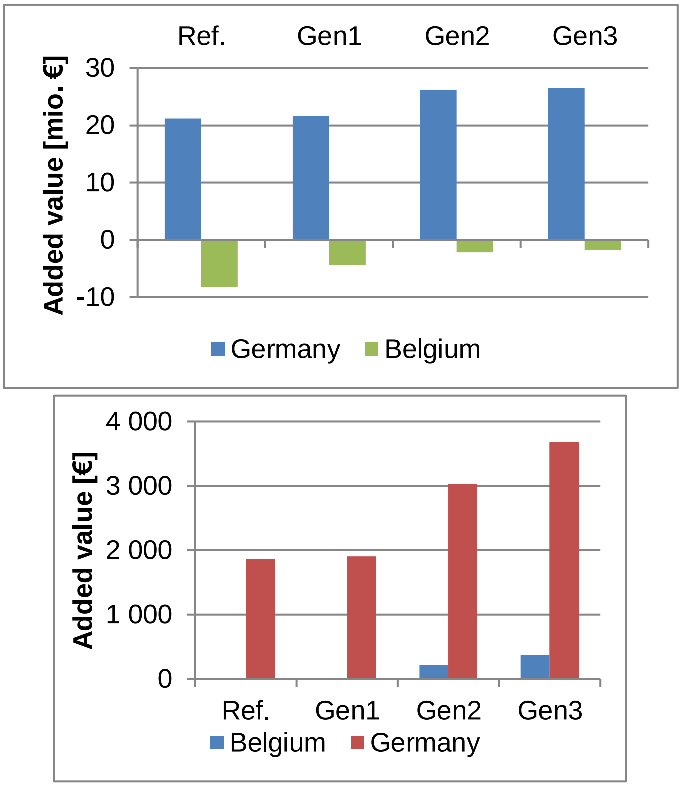


Figure 21. Added value of batteries connected to wind farms (left) and residential PV systems (right) for the different cells.