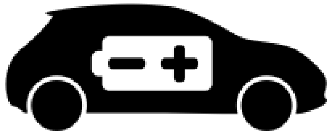
Emanuele Michelini

Tuesday, 10 October 2023

Second-Life Batteries: Potential Applications and Associated Risks

Graz University of Technology – Vehicle Safety Institute

End of first life | **Battery qualification** | **Second-life**

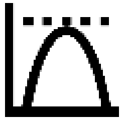


Aged battery

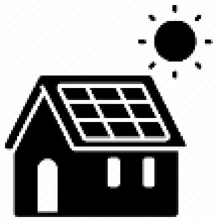
Is the battery safe for a second-life application?

Parameter 1
Parameter 2
Parameter 3
⋮
Parameter n

What parameters are aging and safety sensitive?

Param 1	
Param 2	
⋮	
Param n	

What are the parameters safety margins?

High demanding load profile	
Medium demanding load profile	
Low demanding load profile	
Recycle	

What is the optimal load case for the investigated battery?

What are potential second-life batteries applications?

Potential second-life applications

Potential second-life applications		
41 mobile applications (e.g. short-range EVs, industrial vehicles, micro-mobility, consumer electronics)	**7** semi-stationary applications (e.g. power-stations, power generators, mobile chargers)	**17** stationary applications (e.g. residential, commercial and industrial energy storage systems (ESS))

SOURCE: International cargo bike festival

SOURCE: Instaboost

SOURCE: FreeWire Technologies

SOURCE: Siemens

SOURCE: GenixGreen

Highlights

➔ There is a wide variety of potential second-life applications

➔ Potential second-life batteries are not only stationary but also mobile

What are the most promising second-life applications?

Most promising second-life applications

Most promising second-life applications

APPLICATION \ EVALUATION CRITERIA	Max discharge	Max charge	Required capacity	Mobility degree	Temp. range	Business model	Legal knockout	SCORE
AGV	++	++	++	+	o	o	o	7
Forklift	+	++	++	+	-	o	o	5
Pallet truck	+	-	++	+	o	o	o	3
Golf cart	x	++	++	+	-	o	o	X
Renewable firming industrial ESS	++	++	-	++	+	+	o	7
Peak shaving commercial ESS	o	+	o	++	+	+	o	5
Peak shaving industrial ESS	o	+	o	++	+	+	o	5
Buffer storage at charging station	-	+	+	++	x	+	o	X

AGV


SOURCE: KIVNON

Renewable firming


SOURCE: ©malp - stock.adobe.com

Highlights

➔ The applications' assessment was conducted considering technical, economic and legal aspects

➔ Two applications, with different degrees of mobility, were found to be the most promising

Second-life applications: associated risks

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Main takeaways

- There is a wide variety of potential second-life applications
- Second-life applications are not only stationary but also mobile
- Depending on the second-life application, the battery will experience different loads

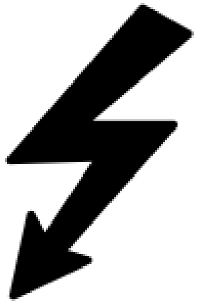
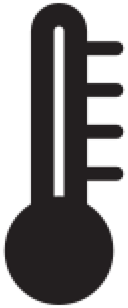
➔As for first life, safety must be ensured throughout second life

➔Safety is strongly influenced to the applied loads

SOURCE: Energy-Storage.News

What loads are experienced from the battery?

Loads applied to the battery

ELECTRIC LOADS	THERMAL LOADS	MECHANICAL LOADS
		

ELECTRIC LOADS

- Overcharge
- Overdischarge
- High C-rate

THERMAL LOADS

- High temperature
- Low temperature

MECHANICAL LOADS

- Mechanical shock
- Indentation
- Vibrations

What are the main risks related to each load?

Electrical load

ELECTRICAL LOAD

Overcharge

- Gas and heat generation[1-4]
- Active material/electrolyte decomposition[1-4]
- Lithium plating[1-5]

SOURCE: Epec Engineered Technologies

Electrical load

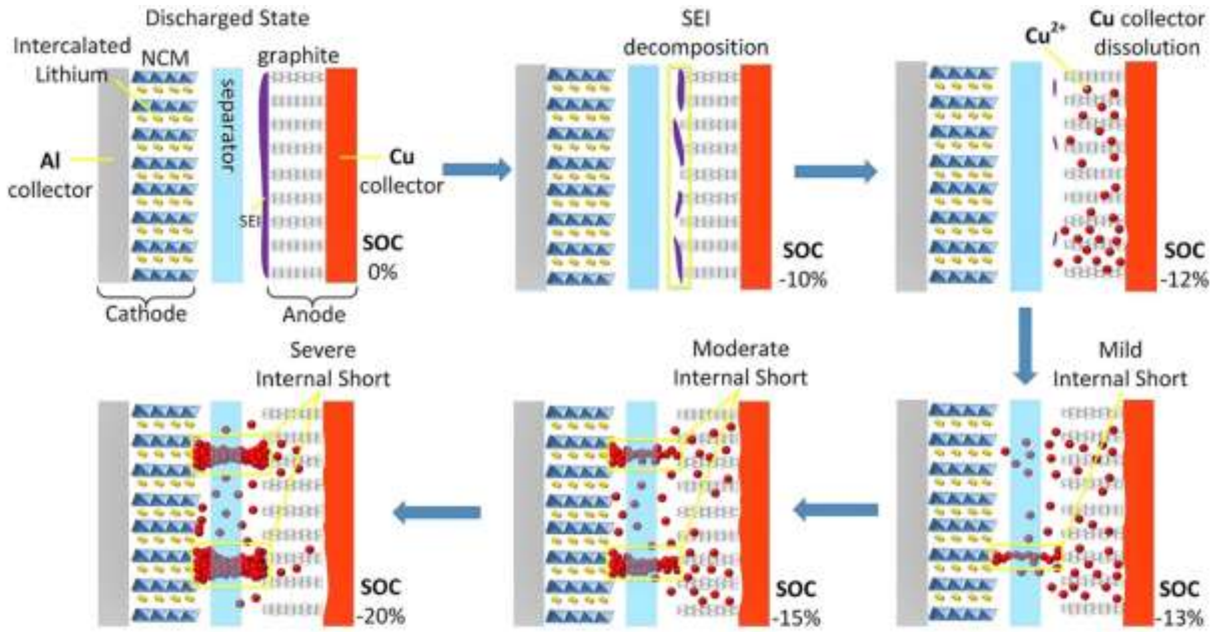
ELECTRICAL LOAD

Overcharge

- Gas and heat generation[1-4]
- Active material/electrolyte decomposition[1-4]
- Lithium plating[1-5]

Overdischarge

- Gas and heat generation[2,3]
- Irreversible solid-state amorphizazion[3]
- Dissolution of Cu current collector[1-3]



SOURCE: Guo et al. (2016)

Electrical load

ELECTRICAL LOAD

Overcharge

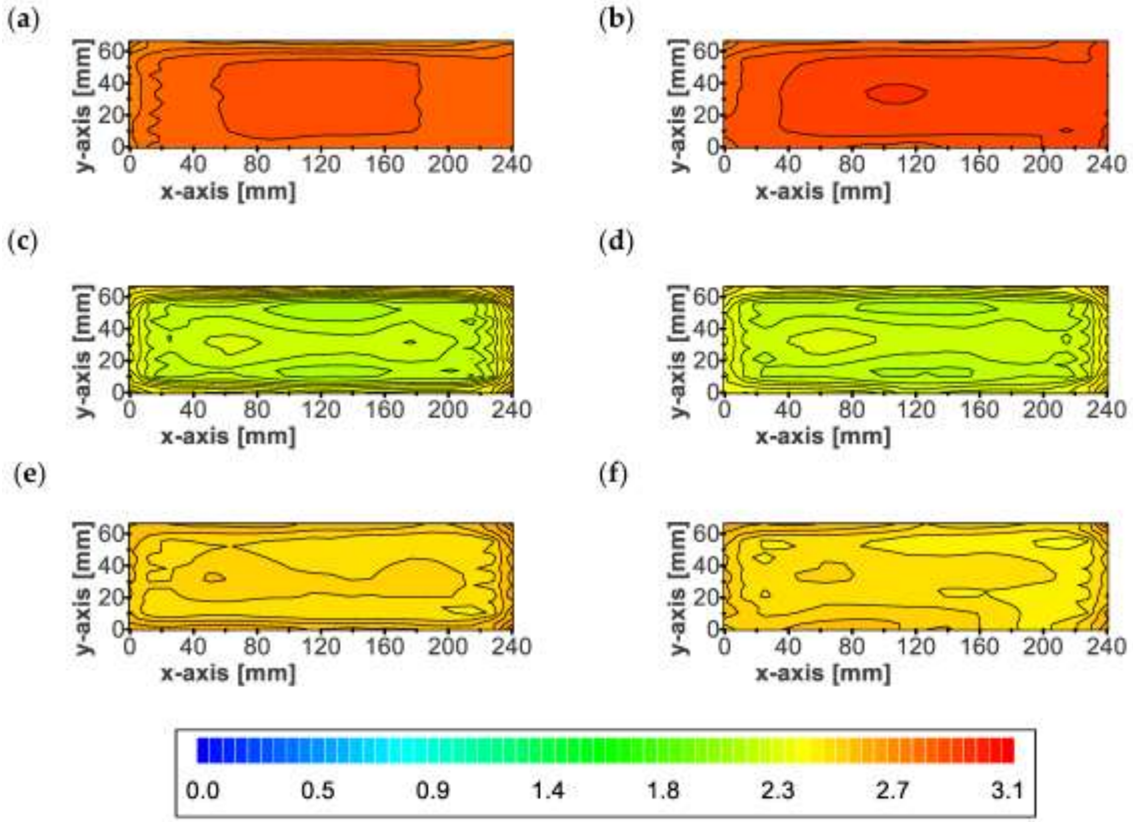
- Gas and heat generation[1-4]
- Active material/electrolyte decomposition[1-4]
- Lithium plating[1-5]

Overdischarge

- Gas and heat generation[2,3]
- Irreversible solid-state amorphizazion[3]
- Dissolution of Cu current collector[1-3]

High C-rate

- Heat generation[1-6]
- Lithium plating[1,6-8]
- Swelling[8,9]



SOURCE: Michelini et al. (2023)

Electrical load

ELECTRICAL LOAD

Overcharge
- Gas and heat generation[1-4]
- Active material/electrolyte decomposition[1-4]
- Lithium plating[1-5]

Overdischarge
- Gas and heat generation[2,3]
- Irreversible solid-state amorphizazion[3]
- Dissolution of Cu current collector[1-3]

High C-rate
- Heat generation[1-6]
- Lithium plating[1,6-8]
- Swelling[8,9]

Considerations

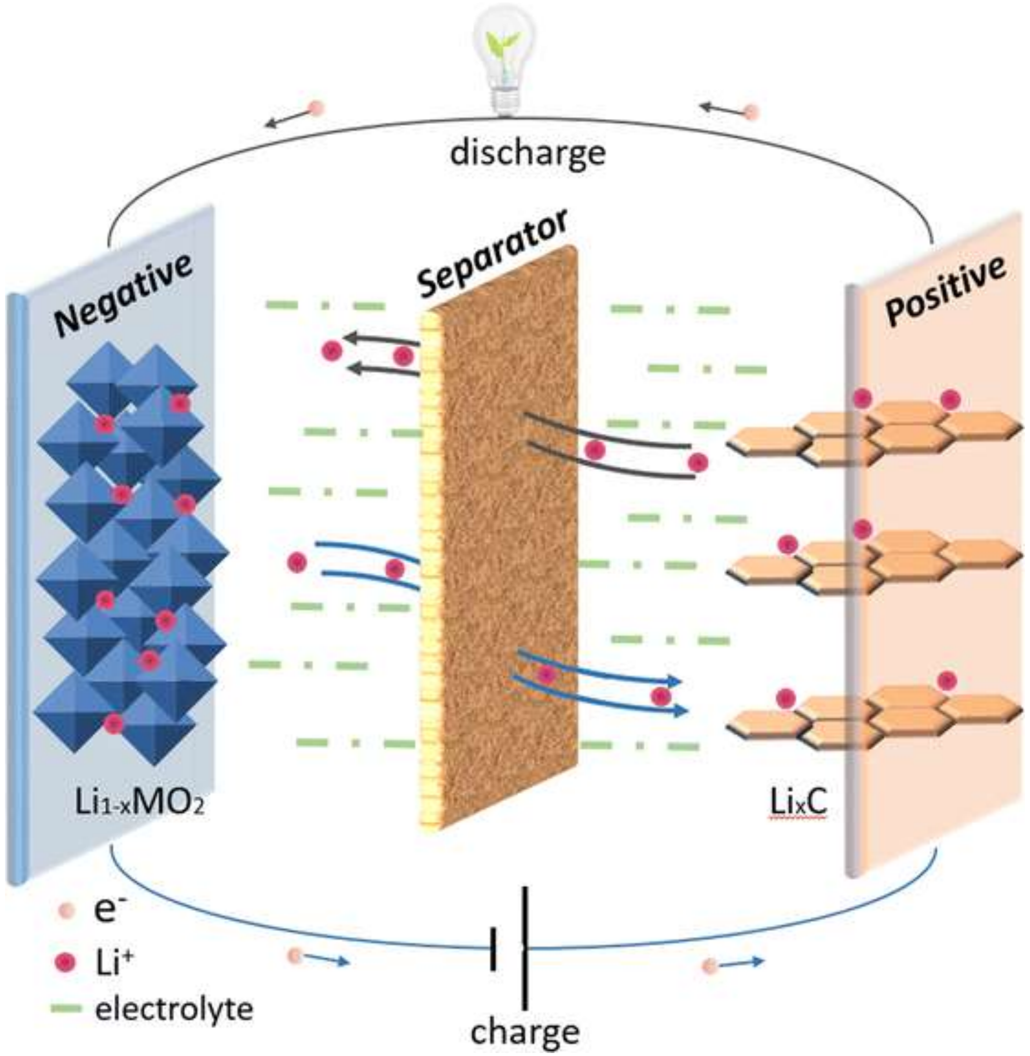
- Certain risks are more critical. Examples:
  - Swelling: under proper mechanical boundary conditions is not critical
  - Lithium plating: may be highly critical, especially in second-life use due to prior plated lithium
- The Battery Management System (BMS) is key for preventing the reach of critical voltage values
- Controlling the burst of current flowing through the battery pack with the BMS is more challenging

Thermal load

THERMAL LOAD

High temperature

- Decomposition of Solid Electrolyte Interphase (SEI)[1,2,7,10]
- Melting of the separator[1,2]
- Decomposition of the active material[1,2,7]
- Exothermic reactions[1,2,7]



SOURCE: Sheng et al. (2017)

Thermal load

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THERMAL LOAD

High temperature

- Decomposition of Solid Electrolyte Interphase (SEI)[1,2,7,10]
- Melting of the separator[1,2]
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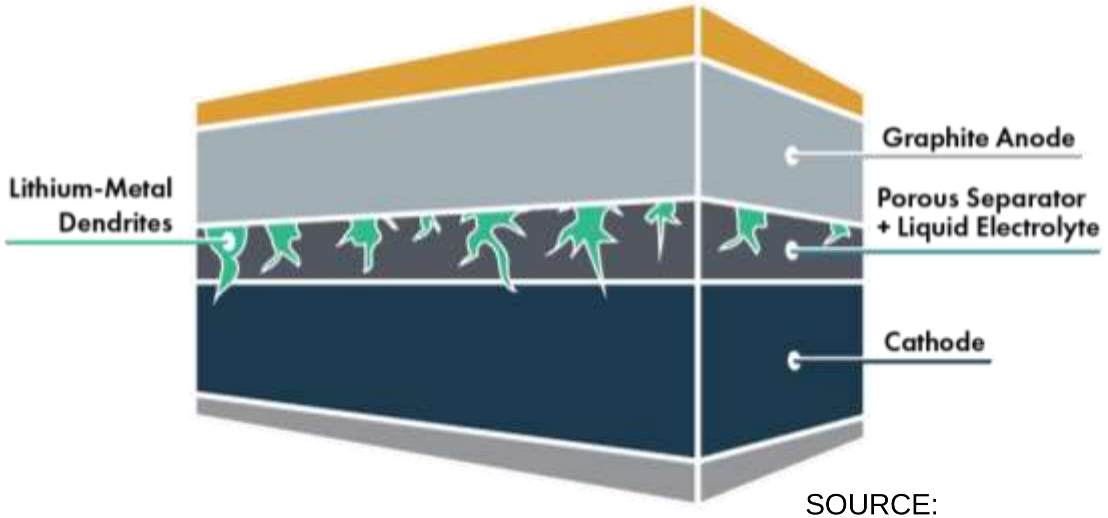
Low temperature

- Lithium plating[1,2,7,11]
- Cathode break down[2]



SOURCE: QuantumScape

Thermal load

THERMAL LOAD

High temperature

- Decomposition of Solid Electrolyte Interphase (SEI)[1,2,7,10]
- Melting of the separator[1,2]
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Low temperature

- Lithium plating[1,2,7,11]
- Cathode break down[2]

Considerations

- An optimal temperature range is designated for the cell's operation
- The Battery Thermal Management System (BTMS) helps to maintains the battery within this optimal temperature window
- The degree of mobility affects the likelihood of encountering critical temperatures
  - Stationary applications: operated in controlled environments, minimizing critical temperature risks
  - Mobile applications: Outdoor operation results in diverse temperature exposure, varying with time, season, and location

Mechanical load

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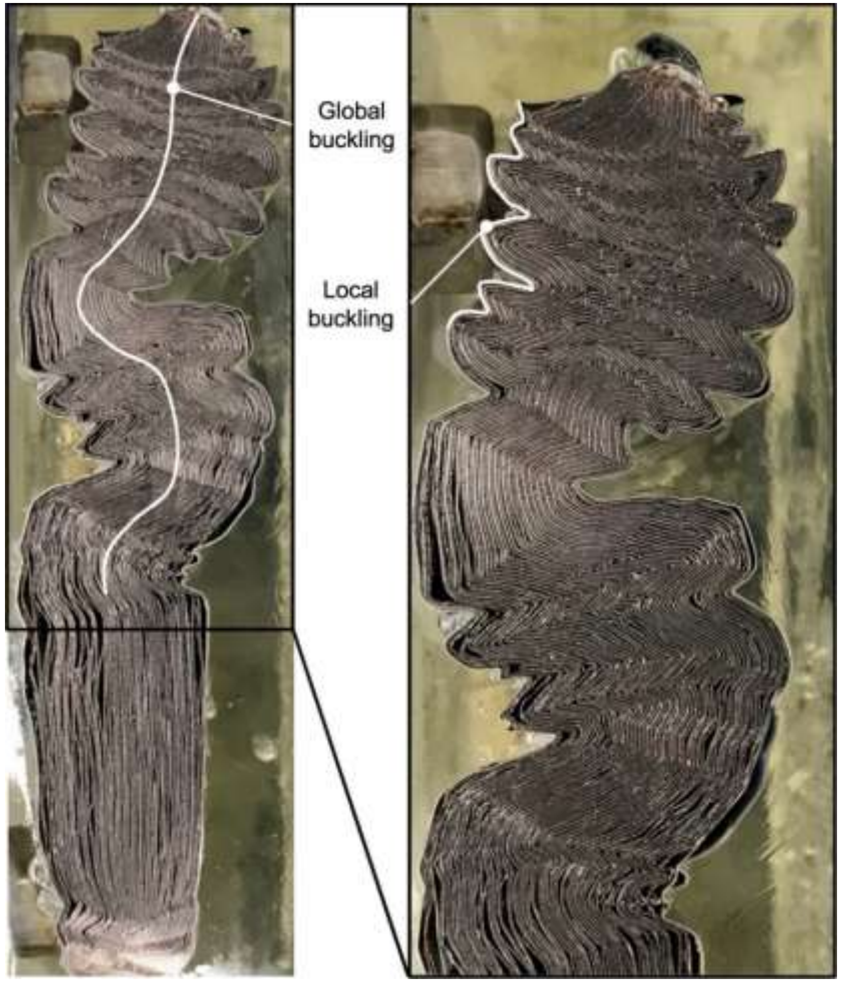
MECHANICAL LOAD

Mechanical shock

- Cell deformation[12,13,14]
- Gas generation[15]
- Internal short circuit[13-15]



SOURCE: Zhu et al. (2020)

Mechanical load

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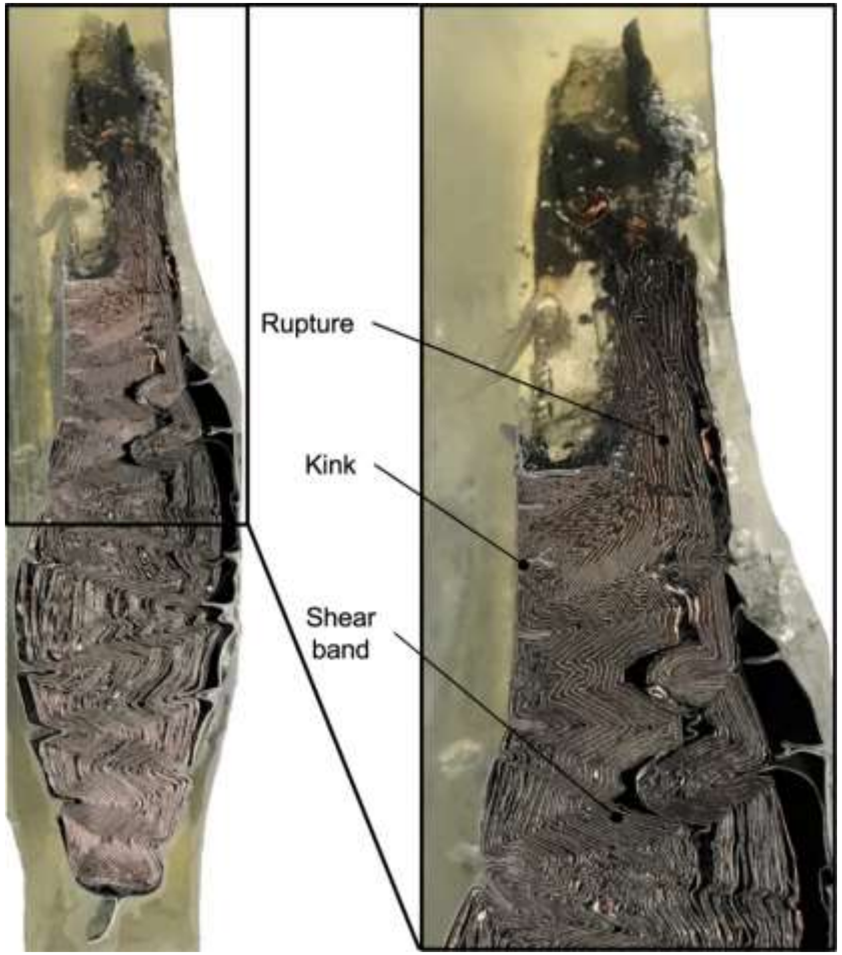
MECHANICAL LOAD

Mechanical shock

- Cell deformation[12,13,14]
- Gas generation[15]
- Internal short circuit[13-15]

Indentation

- Ripped pouch foil
- Gas generation[15]
- Internal short circuit[13-15]



SOURCE: Zhu et al. (2020)

Mechanical load

MECHANICAL LOAD

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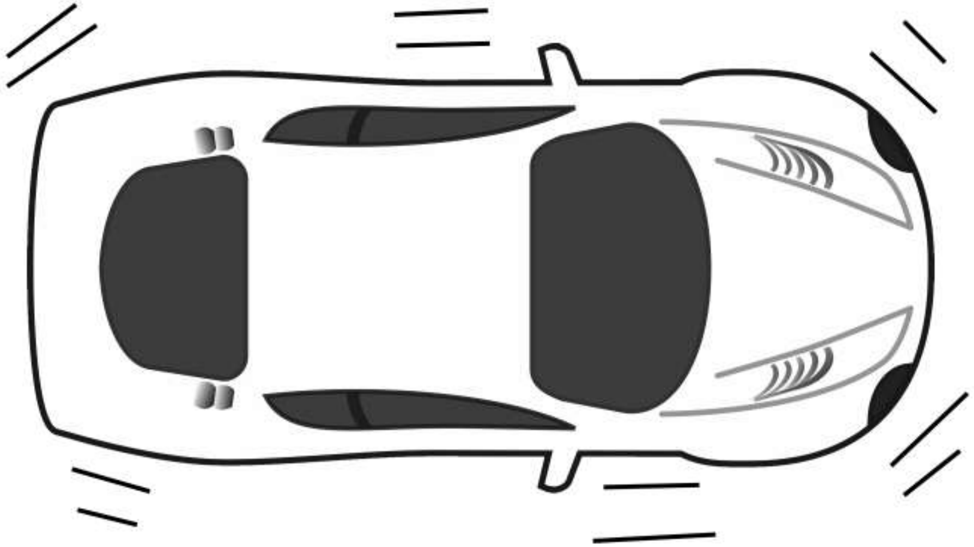
Indentation

- Ripped pouch foil
- Gas generation[15]
- Internal short circuit[13-15]

Vibrations

- No effect (on pouch cell)[16]



Mechanical load

MECHANICAL LOAD

Mechanical shock
- Cell deformation[12,13,14]
- Gas generation[15]
- Internal short circuit[13-15]

Indentation
- Ripped pouch foil
- Gas generation[15]
- Internal short circuit[13-15]

Vibrations
- No effect (on pouch cell)[16]

Considerations

- Preventing mechanical loads on the cell is challenging, the housing design can mitigate damage
- Vibrations affect cylindrical cells negatively, while they have no impact on pouch cells
- The degree of mobility influences load criticality
  - Mobile applications are more prone to be exposed to mechanical loads than stationary applications

Risk prioritization

- The risks associated with the loads are not equally critical
- A risk prioritization is required

Risk assessment methodology

- Direct correlation cause-effect
- Absolute number as output for prioritization
- Known method: already used in the field

➔ **Failure Mode and Effects Analysis (FMEA)**

Due to the great difference in loads experienced by mobile and stationary applications, the two cases were analyzed separately

FMEA Risk Assessment

Load	Risk	Effect	Severity	Mobile Probability	Mobile RPN	Stationary Probability	Stationary RPN
Electrical	Overcharge	Generation of gasses and heat	4	1	4	1	4
		Decomposition of the positive active material and electrolyte	7	1	7	1	7
		Lithium plating	7	1	7	1	7
	Overdischarge	Generation of gasses and heat	4	1	4	1	4
		Irreversible solid-state amorphization	4	1	4	1	4
		Dissolution of Cu current collector	7	1	7	1	7
	High C-rate ⚠	Heat generation	7	7	49	4	28
		Lithium plating	7	4	28	4	28
		Swelling	1	7	7	7	7
Thermal	High temperature	Decomposition of SEI	4	4	16	1	4
		Melting of the separator	7	1	7	1	7
		Decomposition of the positive active material	7	1	7	1	7
		Exothermic reactions	10	1	10	1	10
	Low temperature	Lithium plating	7	4	28	1	7
		Cathode break down	10	1	10	1	10
Mechanical	Mechanical shock ⚠	Cell deformation	4	7	28	0	0
		Gas generation	4	7	28	0	0
		Internal short circuit	10	4	40	0	0
	Indentation ⚠	Ripped pouch foil	7	7	49	0	0
		Gas generation	4	7	28	0	0
		Internal short circuit	10	7	70	0	0
	Vibrations	No effect (on pouch cells)	0	10	0	0	0

Conclusion

Final remarks

- Second-life is a promising opportunity
  - There is a wide variety of potential second-life applications
- Every opportunity comes with its challenges
  - Safety is an important issue to be addressed
- Safety critical scenario are correlated with the applied loads
  - Some loads have more critical associated risks, e.g., high C-rates, mechanical shock and indentation (for mobile applications only)
- An application-specific load assessment is key for a successful second-life transition

SOURCE: Firehouse Magazine

Next steps

- The critical load cases of promising applications (e.g. AGVs and ESSs for renewable firming purposes) will be studied in more detail in future investigations

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Further references

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Further relevant projects at Vehicle Safety Institute – Graz University of Technology

BioLIB

Biobased Materials in Batteryhousings - considering Design for Disassembly

Project budget: €1.65M
Project duration: 3 years
Project end: 31 March 2024

BattBox

Strategies for disassembling of batteries, aiming for a direct mechanical separation

Project budget: €1.96M
Project duration: 3 years
Project end: 31 December 2025

NEMO

Hardware and software concepts to identify electrochemical processes in the battery and track their evolution over time

Project budget: €4.90M
Project duration: 3 years
Project end: 30 April 2026

Partners


scientific partner
VSI
virtual vehicle
TU Graz
SYRION
Wacker Neuson Group
JKU
LIT Law Lab
icTM
UFG
SafeLIB
infineon
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DYNA MORE
Fill YOUR FUTURE
AVL
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Funding

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