Evaluating Sodium-Ion for Low-Voltage Battery Applications

Brahim SOLTANI, IAV

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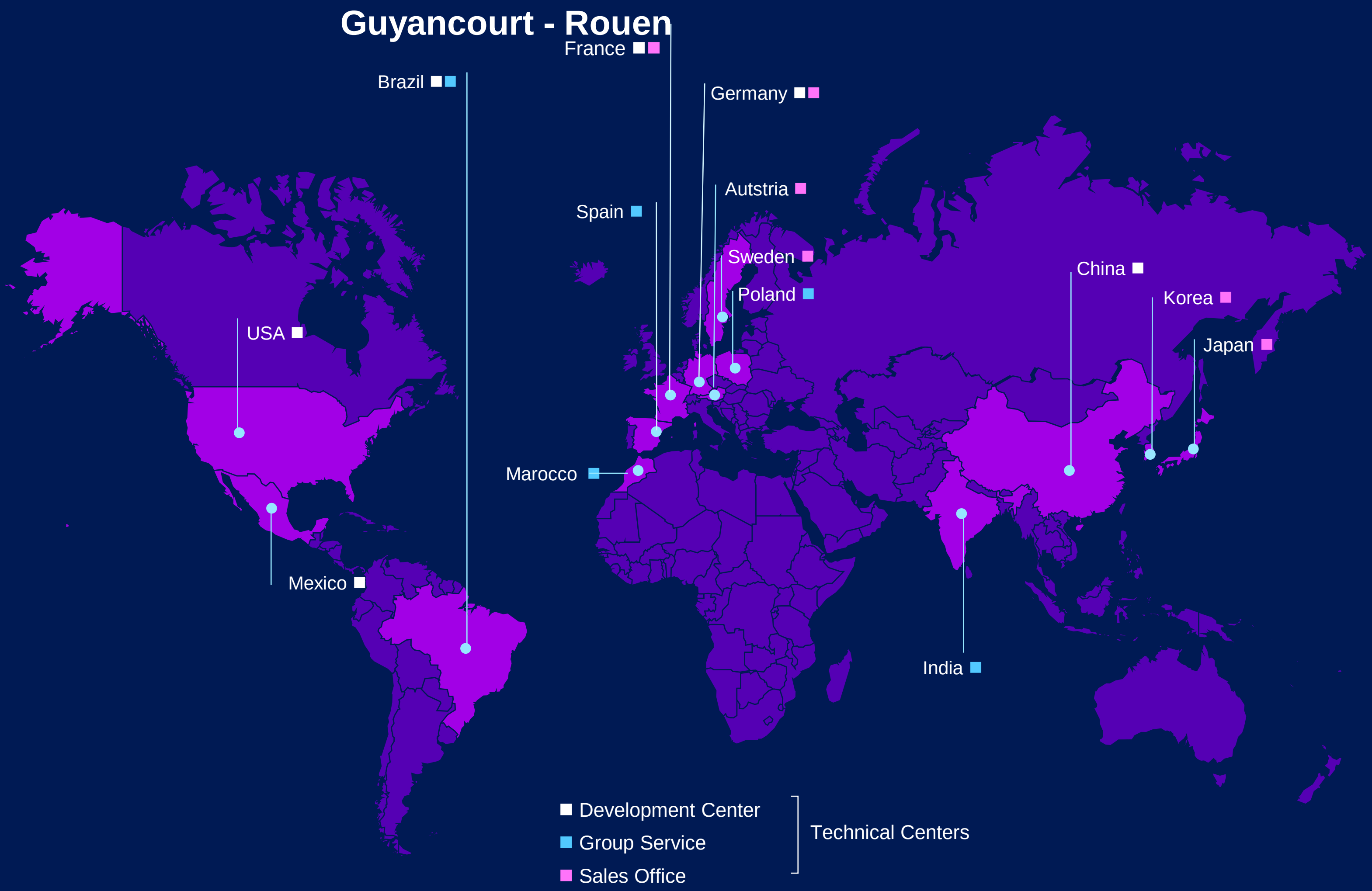

42 Years of experience

6,500 Employees

837 MEUR annual sales

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We are a tech solution provider for the framework – Development – Industrialization – Commercialization phases in automotive.

Core competencies

Connected software

Vehicle solutions & autonomous driving

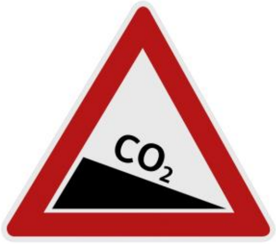
Powertrain systems

AI-infused tools & methods

Introduction and Study Objectives

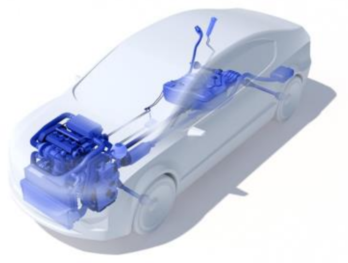
Challenges in the EV market

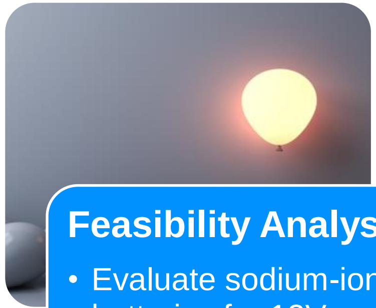
Emissions still a problem



What can be done to improve batteries in non-EV ?

Explore new paths to improve LV systems





Feasibility Analysis

- Evaluate sodium-ion batteries for 12V and 48V automotive systems.

System Engineering

- Explore cell selection, electrical architecture, thermal management, and control strategies.

Prototype Development

- Design proof-of-concept battery systems using off-the-shelf components.

Comparative Analysis

- Compare SIB performance against LFP solutions for 48V mHEV.

Why Sodium Ion?

Potential replacement for toxic battery elements facing future regulations

Promising electrical characteristics for automotive applications

Lower raw material costs with competitive performance metrics

Sodium is abundant, reducing geopolitical supply risks

→ **IAV analyzed the relevance of using Sodium Ion Battery (SIB) by considering 4 main areas.**

Text

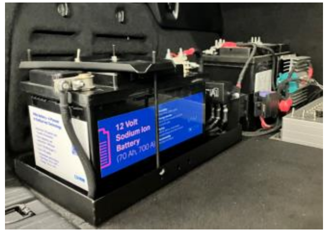
12V Concept

Performances

Based on the technology used in the IAV prototype

Prototype #1: L3

Configuration	7P4S
Nominal voltage (V)	12
Minimum capacity (Ah)	70
Weight (kg)	9.9
Volume (cells only L)	5.2
Max discharge current BOL (A) for 30 s at 25 °C	945
Max discharge current BOL (A) for 30 s at −20 °C	590



Compared to mid-range Pb-A (70 Ah / 760 A)
→ 50 % less weight and 20 % less volume

Prototype #2: L5

Configuration	10P4S
Nominal voltage (V)	12
Minimum capacity (Ah)	100
Weight (kg)	13.1
Volume (cells only L)	7
Max discharge current BOL (A) for 30 s at 25 °C	1350
Max discharge current BOL (A) for 30 s at −20 °C	850

Compared to high-end Pb-A (105 Ah / 950 A)
→ 55 % less weight and 10 % less volume

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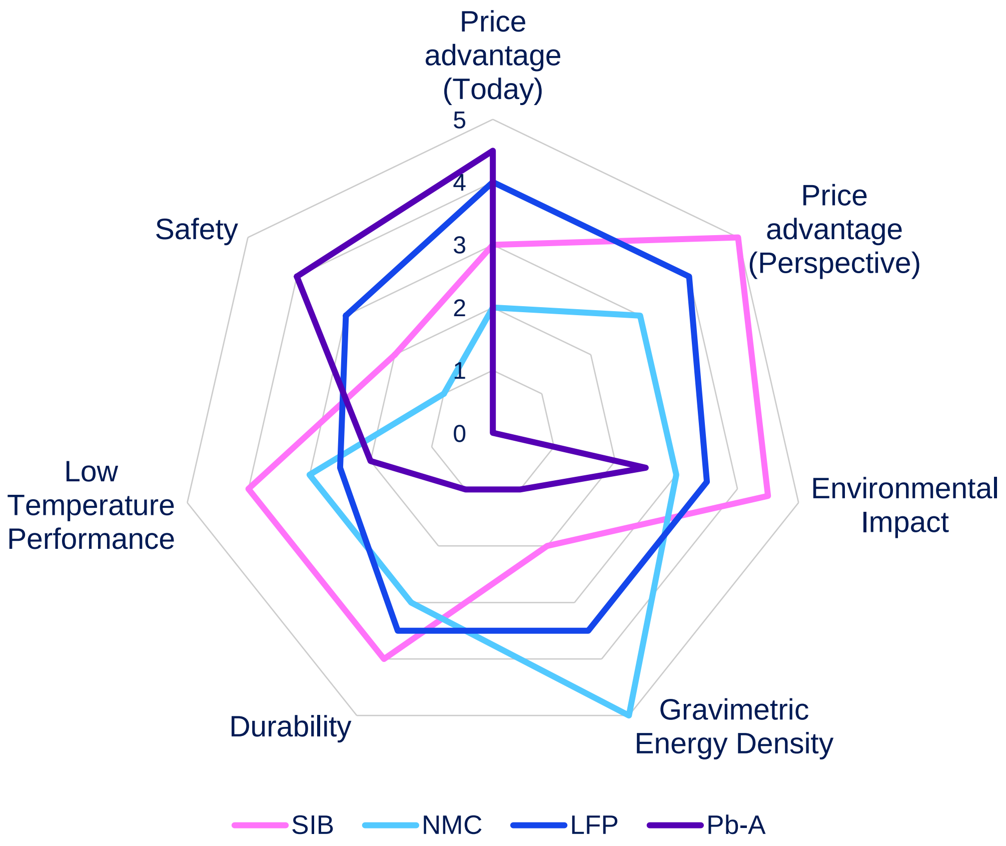
Conclusion

Is SIB Suitable for 12V Applications?

Comparison of different cell chemistries focusing on 12V applications



- **Pb-A technology**:

Dominates due to competitive price and safe chemistry but will lose relevance due to toxicity concerns

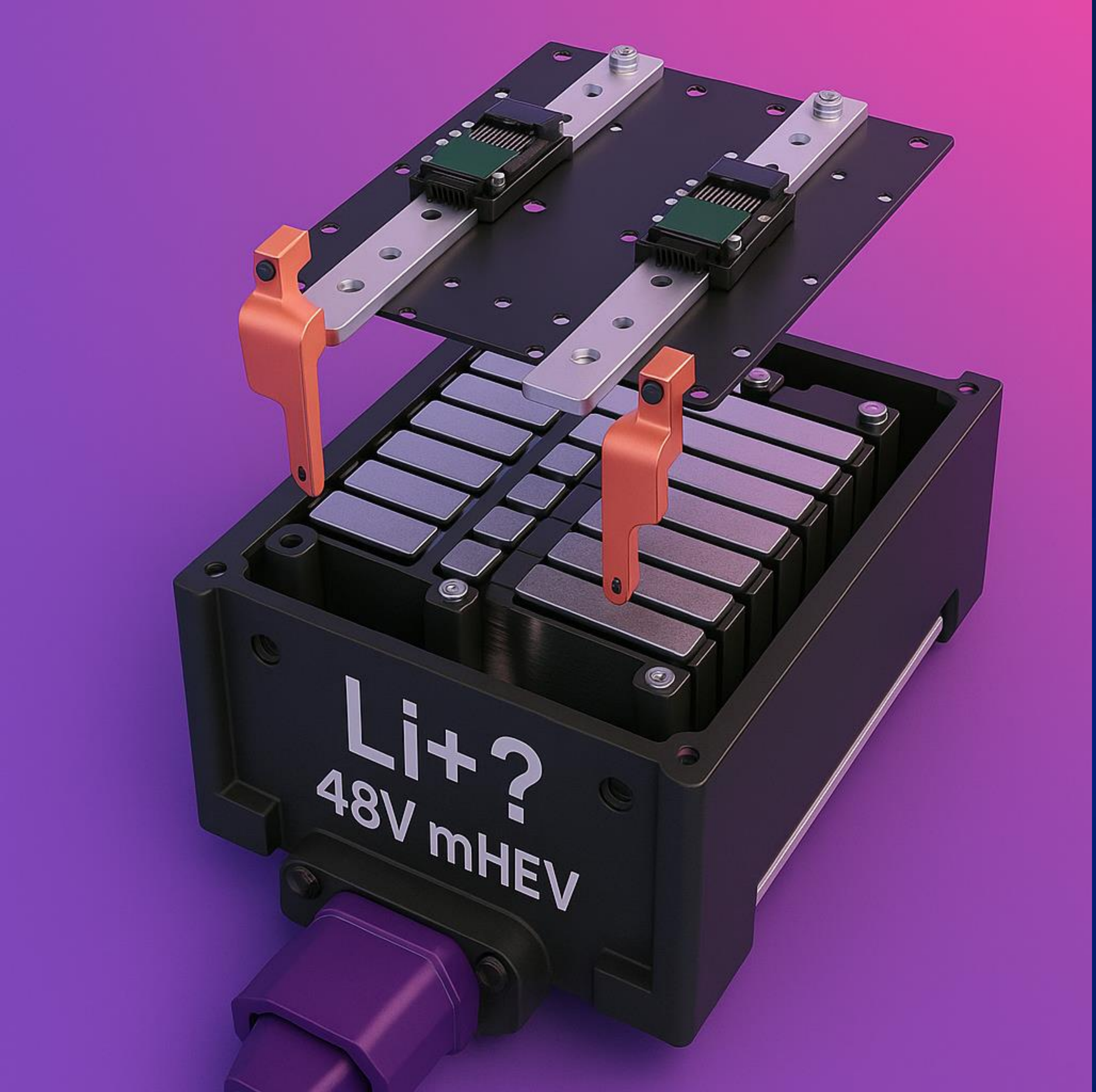
- **LIB alternatives**:

LFP and NMC are viable replacements today, offering availability and scalability

- **SIB potential**:

Best for sustainability, excellent performance, and promising for future price competitiveness

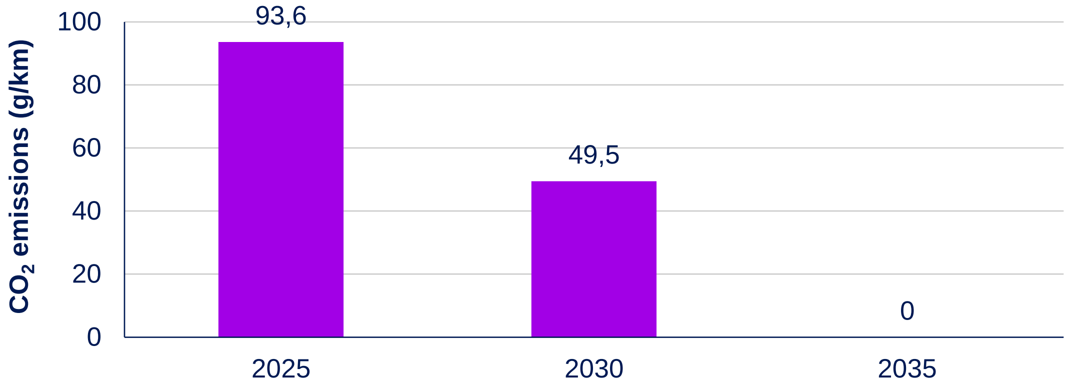
In collaboration with HiNa, we have demonstrated several proof-of-concept 12V batteries utilizing this emerging chemistry.



48V Concept

48V Concept: Motivation

EU Emissions Targets



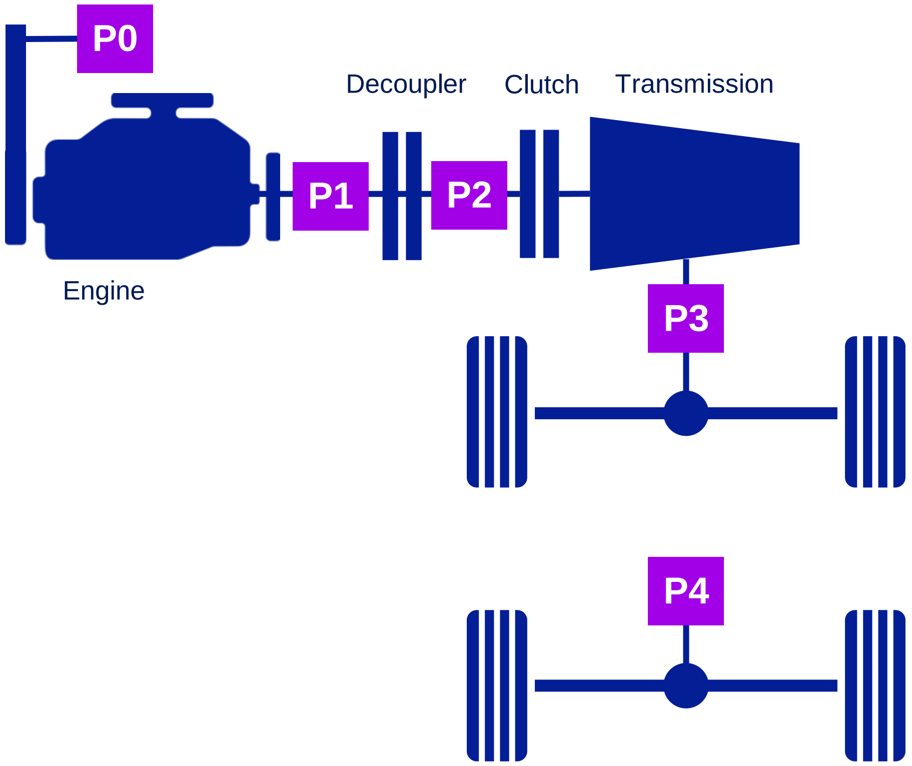
Year	Market size (48V mHEV)	CAGR (approx.)	Market share notes
2025	USD 15 billion	9 – 20 %	Europe, North America lead; Asia growing
2030	USD 28.8 – 50 billion	~ 15 – 20 %	40 – 45 % light vehicle market share in major regions
2040	Several hundred billion (overall mHEV)	Continued growth	mHEVs mature, > 50 % globally

- European Union regulations are driving efforts to reduce CO_2 emissions from new vehicles
- EV market situation makes it difficult for OEMs to rely solely on EV sales to meet emission targets in the near term
- mHEV emerges as a one of the viable options to lower the CO_2 emissions of the average fleet
- Despite the European ban on internal combustion engine (ICE) vehicles set for 2035, mHEVs hold a strong global growth potential beyond the present decade

→ **Currently, LIBs are the predominant technology for 48V batteries. Could SIBs emerge as a viable competitor?**

mHEV Architectures from P0 to P4

Why Was P2 Selected for Our Study?



Balance of cost and functionality

- More efficient than P0 or P1 layouts, cheaper and simpler than P3 or P4

Fuel efficiency and CO_2 reduction

- Enables significant fuel savings and emission reductions (~ 10 – 15 %) without a full hybrid powertrain

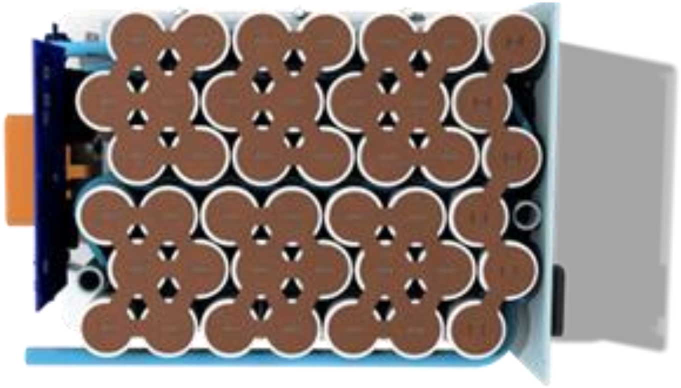
Compact integration

- Can be packaged within the drivetrain with relatively small changes to the vehicle architecture

→ **P2 is one of the emerging architectures in 48V mHEV.**

→ **It enables different kind of features (Start-stop, Regenerative braking, Torque assist/boost, Engine-off coasting, Electric-only driving).**

48V SIB Design
Performance



→ **Accessible SoC range of the battery restricted for durability considerations: Usable capacity < 60 % of all capacity.**

14s3p configuration with 32140 cylindrical cells

- Complies with the standard voltage and energy values (~ 0.9 kWh)

Electrical architecture

- Arranged in two banks of 21 cells
- Optimized busbars rooting

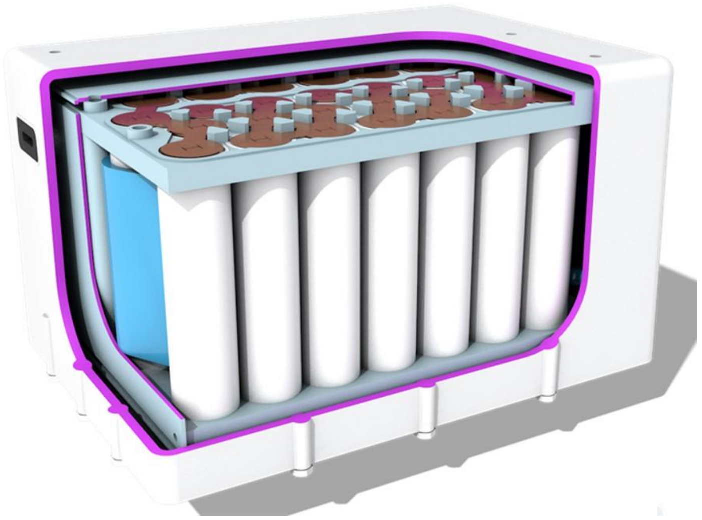
Mechanical integrity

- 2 cell holders ensuring stability and efficient use of volume

Thermal management

- Liquid cooling to enhance performances
- Cooling ribbon on every other cells row (opposite-terminal cells configuration does not allow to use cooling plates)

48V SIB Design
Safety



- Venting channels implemented in the cell holders
- Burst membrane for in-pack pressure management
- BMS board, fluidic and electric connectors are located at the front end of the casing and are isolated from any venting gas
- All abuse tests at cell level have been passed successfully (no fire, no explosion) according the GB/T31485 norm

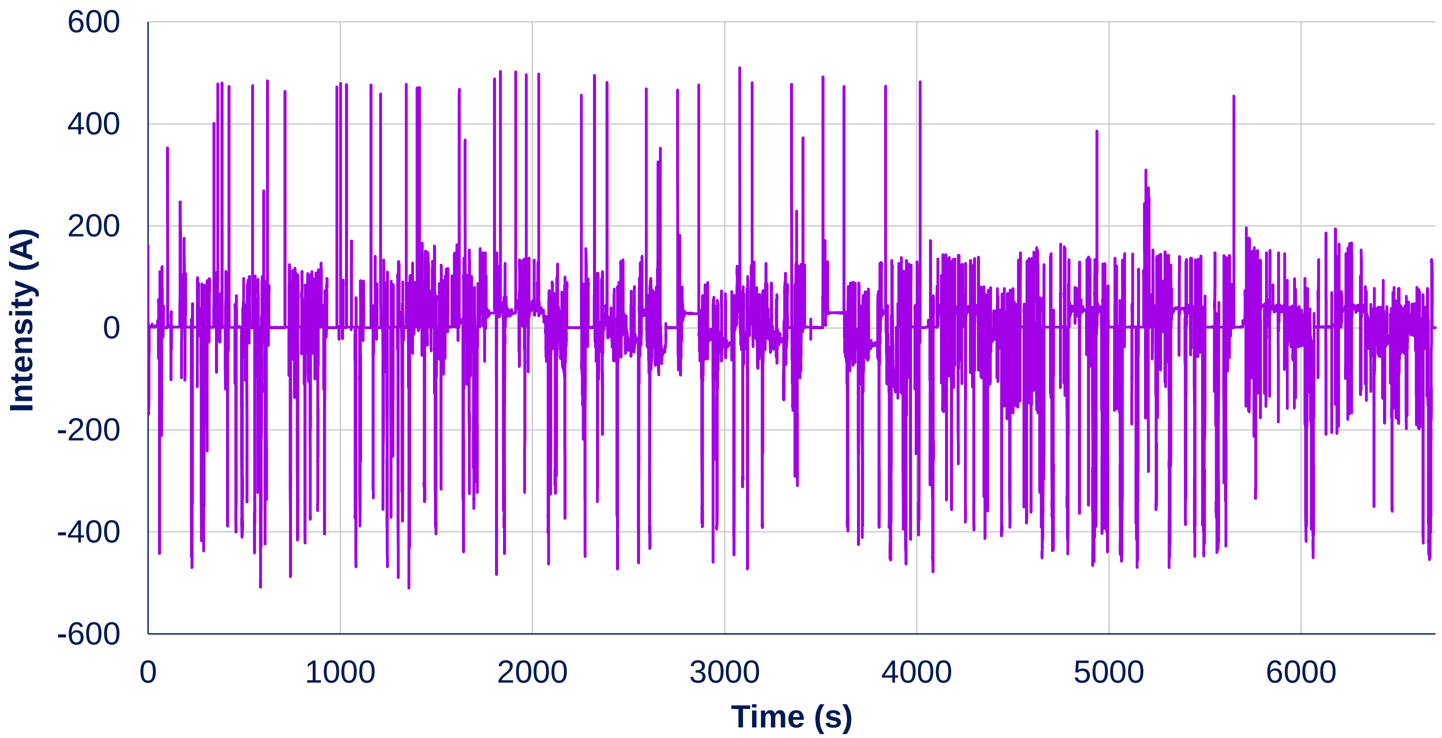
Test Item GB/T31485	Result
Nail penetration	No fire, No explosion
Short circuit	No fire, No explosion, No smoke, No swelling
Over charge	No fire, No explosion, No smoke, No swelling
Over discharge	No fire, No explosion, No leakage
Extrusion	No fire, No explosion, No leakage
Heavy impact	No fire, No explosion, No leakage
Thermal shock	No fire, No explosion
Saltwater immersion	No fire, No explosion
150 °C chamber	No fire, No explosion

- No fire
- No explosion
- No smoke
- No swelling
- No leakage

→ **During development, we addressed all safety constraints with the same rigor as a high-voltage battery project, resulting in a safe system.**

Representative Mission Profile

Hot 48V battery mission profile



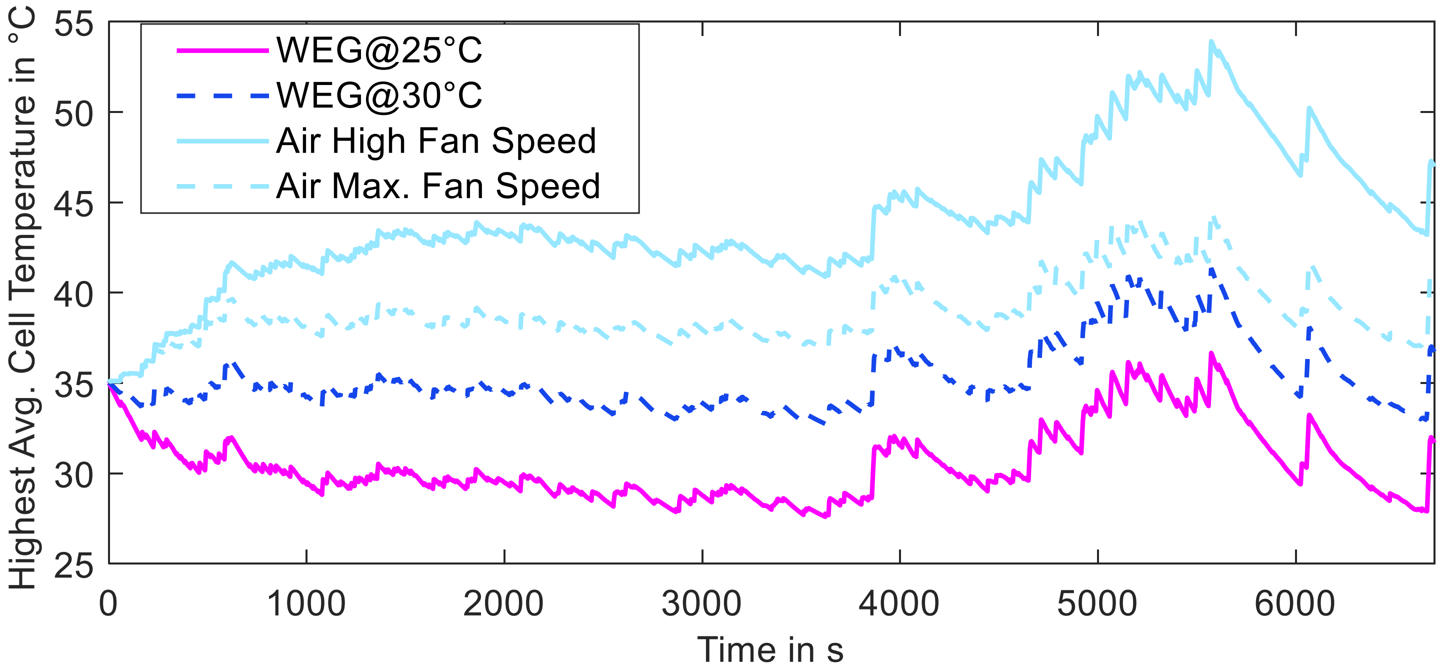
Mission profile characteristics

- Based on a roller dyno measurement
- Performed with a P2 mHEV with a LIB ≈ 1 kWh
- Ambient temperature 35 °C
- Combined cycle: city and highway
- Frequent high peak charge (positive) and discharge (negative)

→ **Real use case not only focusing on acceleration and recuperation support, but also powering high power auxiliary systems (active anti rollbars, e-compressor, e-turbocharger …)**

1D Simulation Model
Thermal Management Assessment

Cooling solution comparison in a hot mission scenario



→ **The simulation shows that despite the complexity and cost, it will be difficult to further optimize and simplify the design by removing active cooling.**

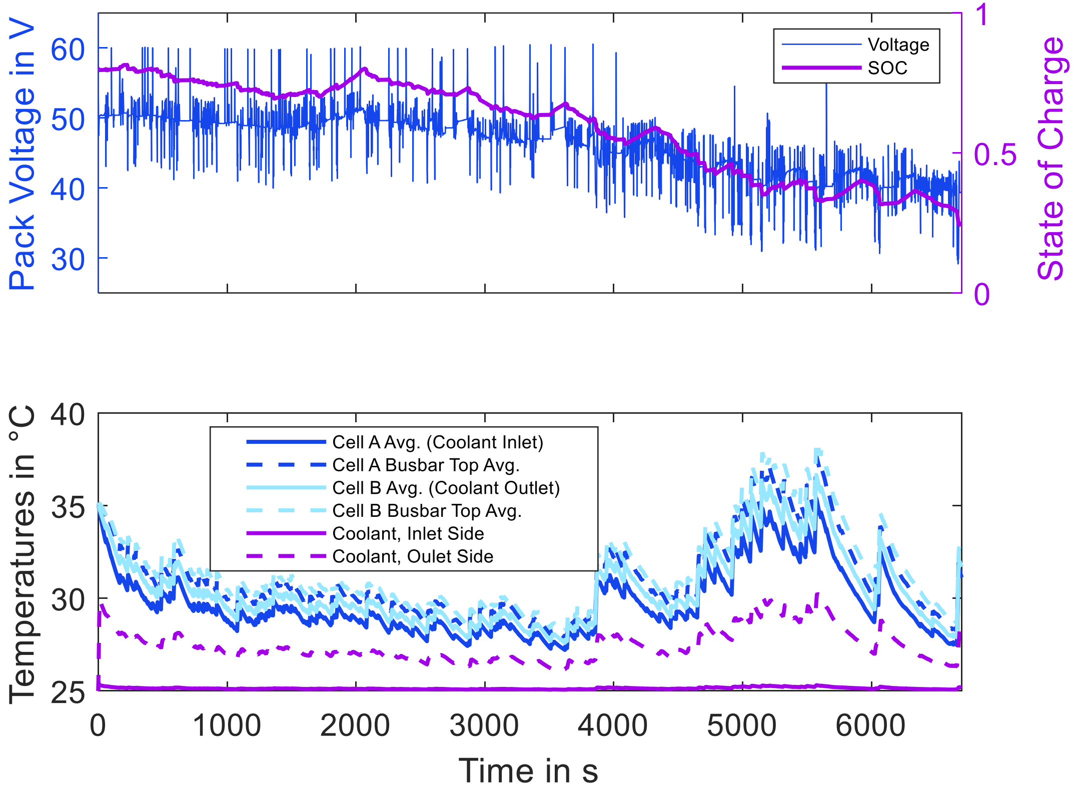
1D model of the 48V SIB is setup

- It includes representations of all relevant components such as cells, holders, busbars and thermal interface materials
- Cell behavior is verified with dynamic cell data provided by the supplier
- Target is T_{max} < 45 °C to insure the cell durability
- Even strong air-cooling leads to cell temperatures around 45 °C, nearing durability limits
- Liquid cooling is more effective, maintaining cell temperatures below 41 °C with 30 °C coolant

1D Simulation Model

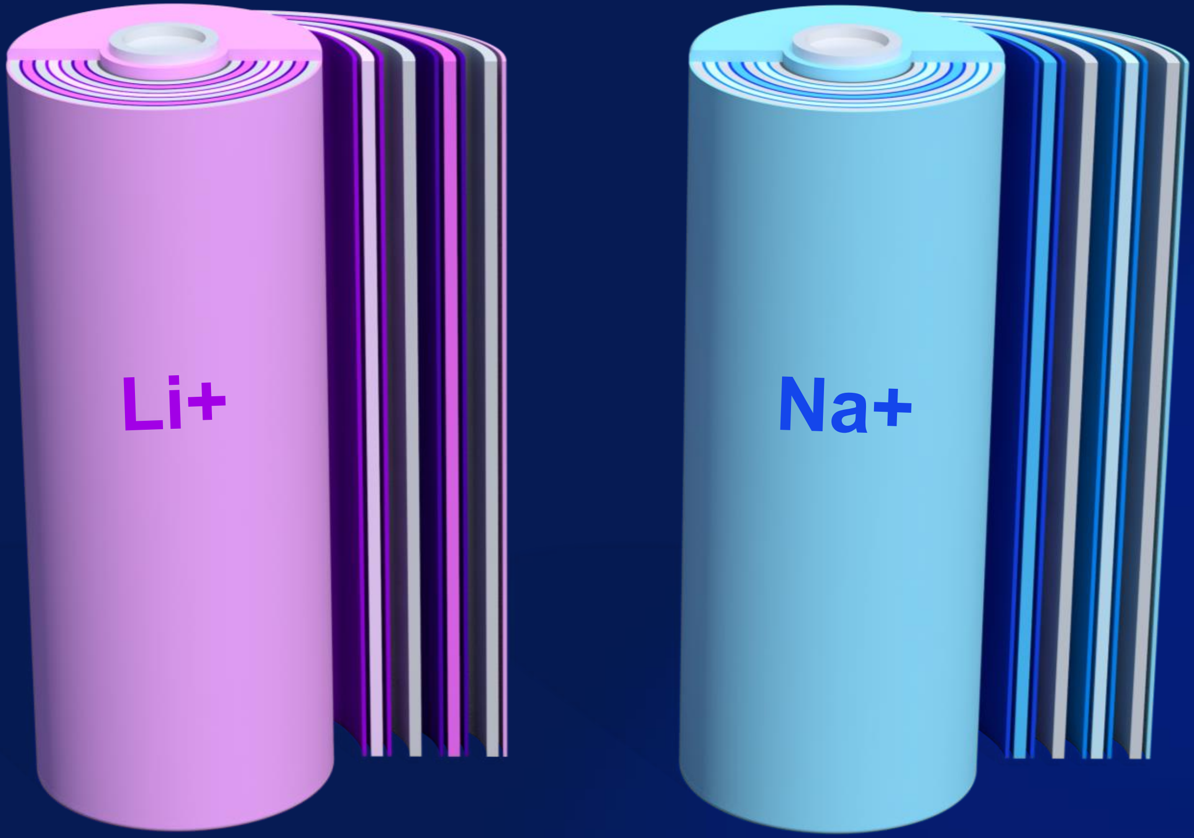
Thermal Performance of the 48V SIB Design

48V System Performance



- Thermal performance assessed via 1D modeling with a tailored liquid cooling strategy
- Coolant temperature 25 °C
- Initial SoC 80 %
- Both voltage and SoC remain stable in city driving and drops faster on highways
- Cell temperatures show good uniformity
- Minimal difference between coolant inlet and outlet
- Relatively high bus bar temperatures due to resistive losses

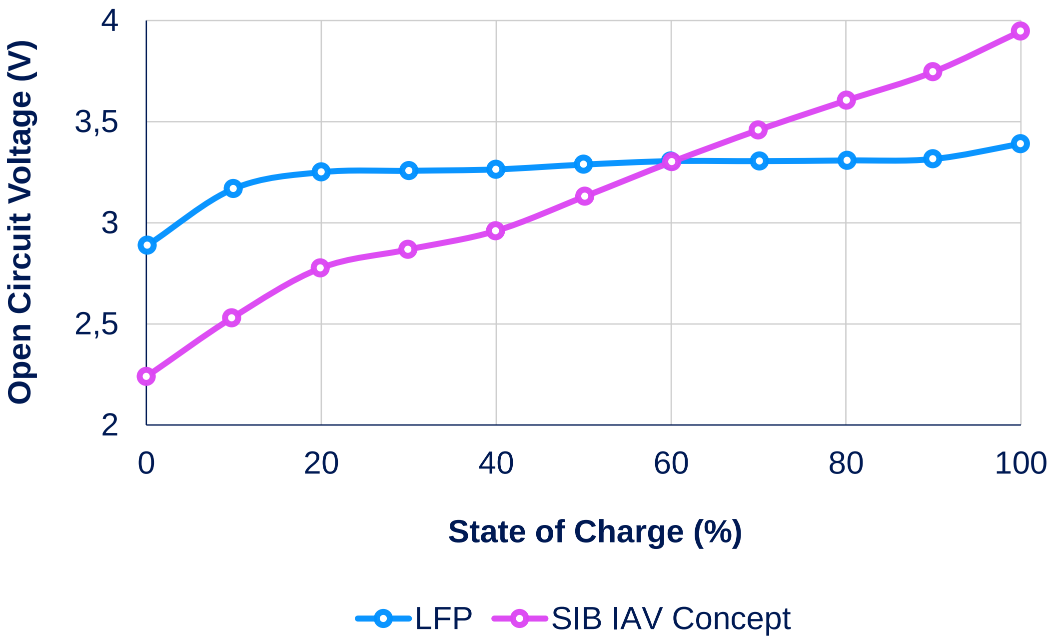
→ **Confirms effective component sizing and robustness of the cooling system.**



Comparative Study

Comparative Study
KPI at Cell Level

OCV vs. SoC

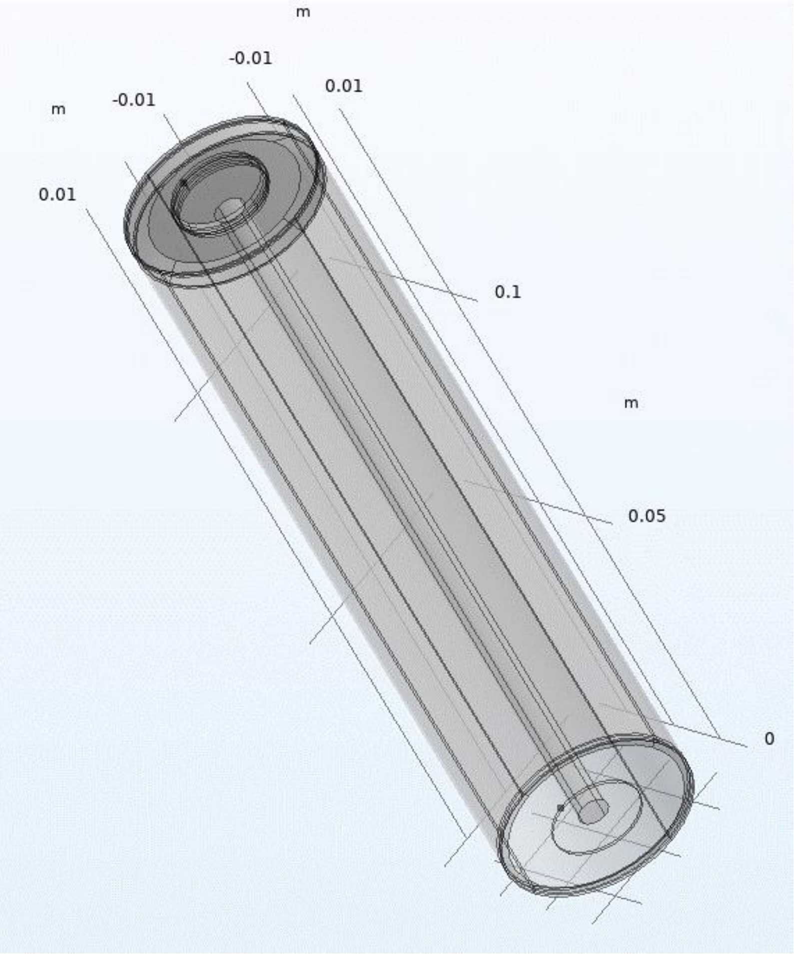


KPI	Sodium-ion	LFP – HE	LFP – HP
Gravimetric energy density [Wh/kg]	100 – 175	160 – 205	70 – 100
Gravimetric power density [W/kg]	3,000+	1,600+	2,200 – 3,500
Cycle life (80 % BoL; 80 % DoD)	4,000+	3,000+	6,000+
Peak C rate (2 sec. @ 25 °C)	24 – 100+	8.5	60
Low temperature performance	Good to moderate	Moderate	Moderate
Safety performance	Good to moderate	Good	Good

→ **LFP OCV curve has flatter plateau than SIB.**

→ **The diversity in cathode chemistries (Prussian blue analog, metal oxide or polyanion) results in broad performance characteristics for SIBs.**

Pseudo-2D Model
A Key Approach to Comparative Studies

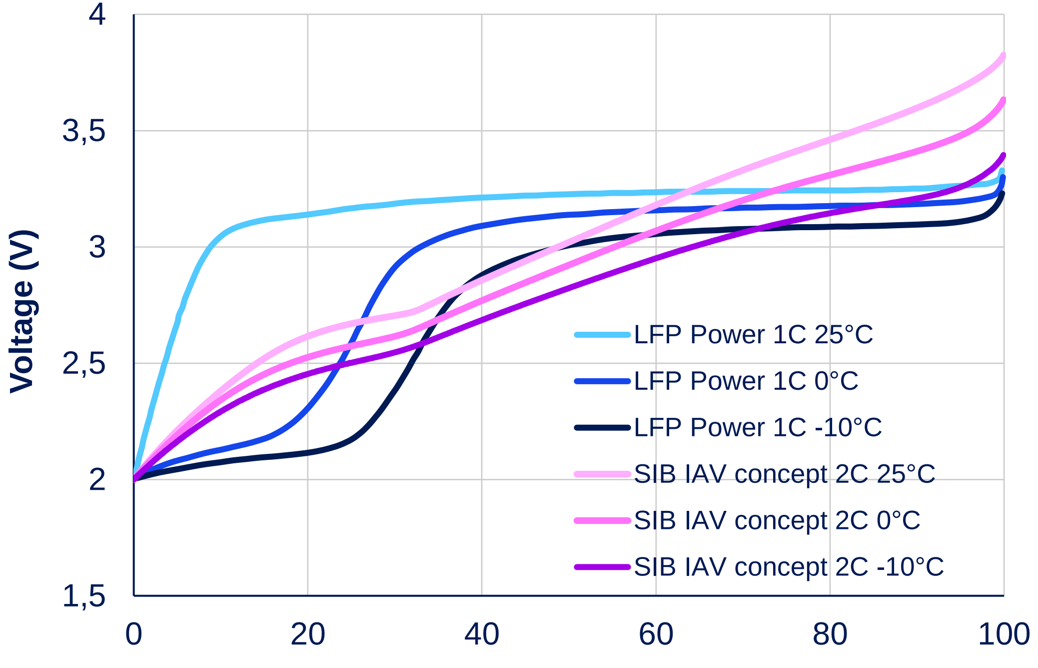


- No data available for 32140-format LFP cells; developed in-house P2D model
- Parameters derived from an electrochemical-thermal model (EPCM), validated via literature
- P2D simulations used to assess LFP cell power performance
- LFP microstructures (high energy/power) based on literature data
- Simplified P2D models (no SEI, no ageing) used to estimate optimal values
- Real LFP power and energy data used to calibrate model outputs

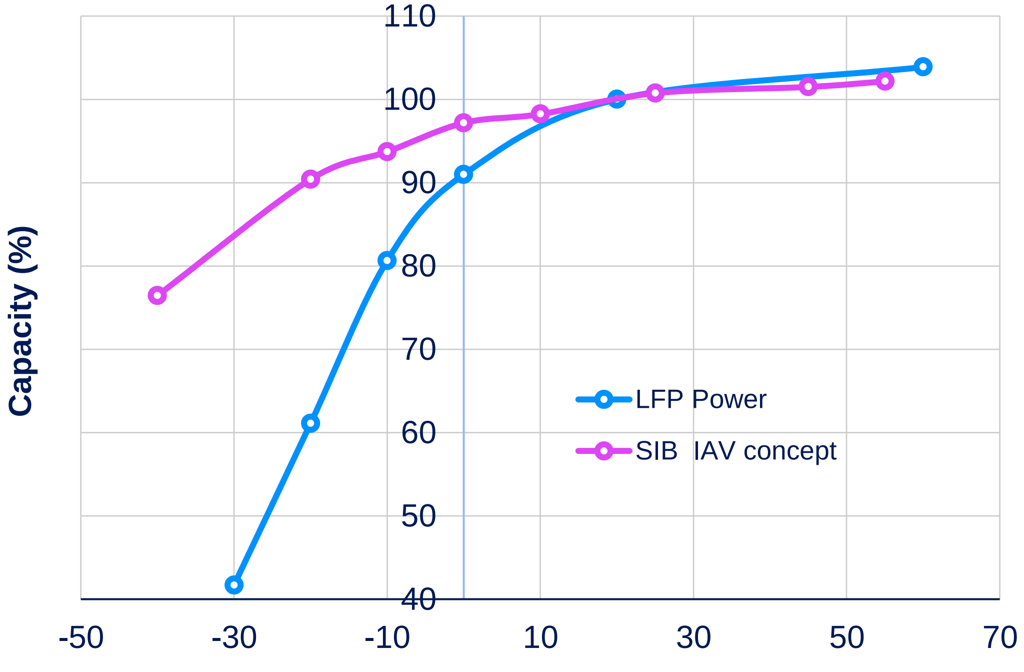
→ **The simulations provided useful data on LFP cells power capabilities based on their type, high energy or high power, the SoC and the temperature.**

Comparative Study
LFP and SIB Properties vs. Temperature

Voltage profile vs. Temperature



Capacity vs. Temperature (1C rate)



→ **SIBs can offer better low-temperature resilience than LFP, regarding voltage profile and capacity.**

→ **LFP may require added heating system or suffer reduced availability in cold conditions.**

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Performances of 48V batteries
Based on the Technology Used in the IAV Prototype

48V pack parameters	Target	Sodium-ion IAV concept	LFP – high energy	LFP – high power
Number of cells		42	34	34
Configuration		14s3p	17s2p	17s2p
Approx. total cell weight [kg]	**10**	**11.2**	**8.9**	**9.1**
Approx. total cell volume [L]	**6**	**7.3**	**5.9**	**5.9**
Discharge power (2 sec. @ 25 °C) [kW]	**24**	**30.8**	**22.6**	**38.4**
Discharge power (2 sec. @ 0 °C) [kW]	**24**	**25.6**	**8.9**	**19.0**
Gross energy [kWh]	**0.9**	**1.26**	**1.61**	**0.71**

SIB compared to a reference LFP P2 system

Due to lower voltage at high SoC, 48V LFP requires 17 cells in series leading to a 17s2p configuration

48V SIB design contains 42 cells, assuming the little volume excess and higher weight to be acceptable

→ **48V LFP High Power has a limited energy = Higher DoD under use → Accelerated aging.**

→ **Discharge power at 0 °C is challenging for the LFP batteries while SIB is still complying with the power requirement.**

Comparative Study

Safety Aspects – Thermal Runaway Tests on Comparable Chemistries

Capacity-normalized gas volume (L/Ah)

Max Temperature during TR (°C)

Temperature Rise during TR (K/s)

- Individual TR tests were conducted using a heating pad on similar chemistries (layered oxide SIB cells and LFP power cells)
- The gas compositions released were comparable
- LFP cells emitted a slightly lower volume of gas compared to SIB cells
- While the peak temperatures were very similar between the two chemistries, the rate of temperature rise was observed to be slightly steeper for LFP cells than for SIB cells

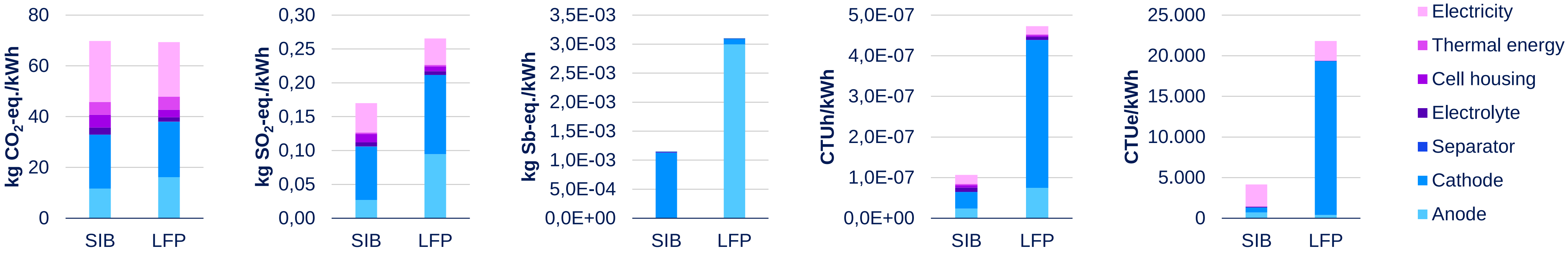
→ **Overall, SIB exhibits a thermal runaway behavior comparable to that of LFP.**

→ **Both chemistries demonstrate a high level of safety, with no fire or explosion observed during the test.**

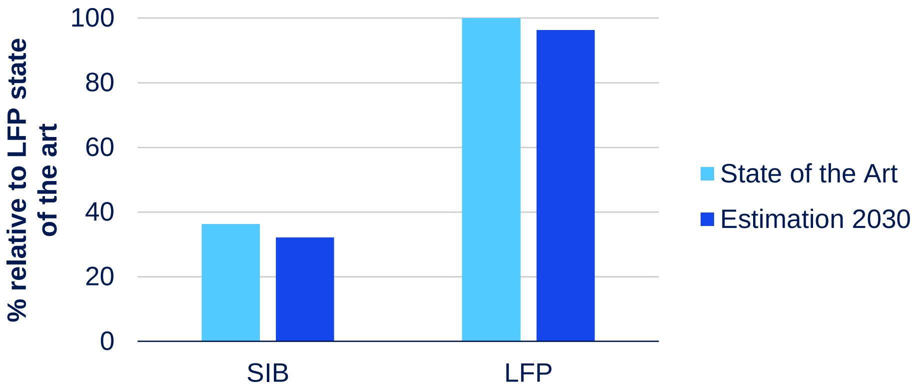
Comparative Study

Sustainability LCA Cradle to Gate

Global warming potential | **Acidification potential** | **Abiotic depletion potential** | **Human toxicity potential cancer** | **Ecotoxicity potential**



Environmental footprint (EF3.1)



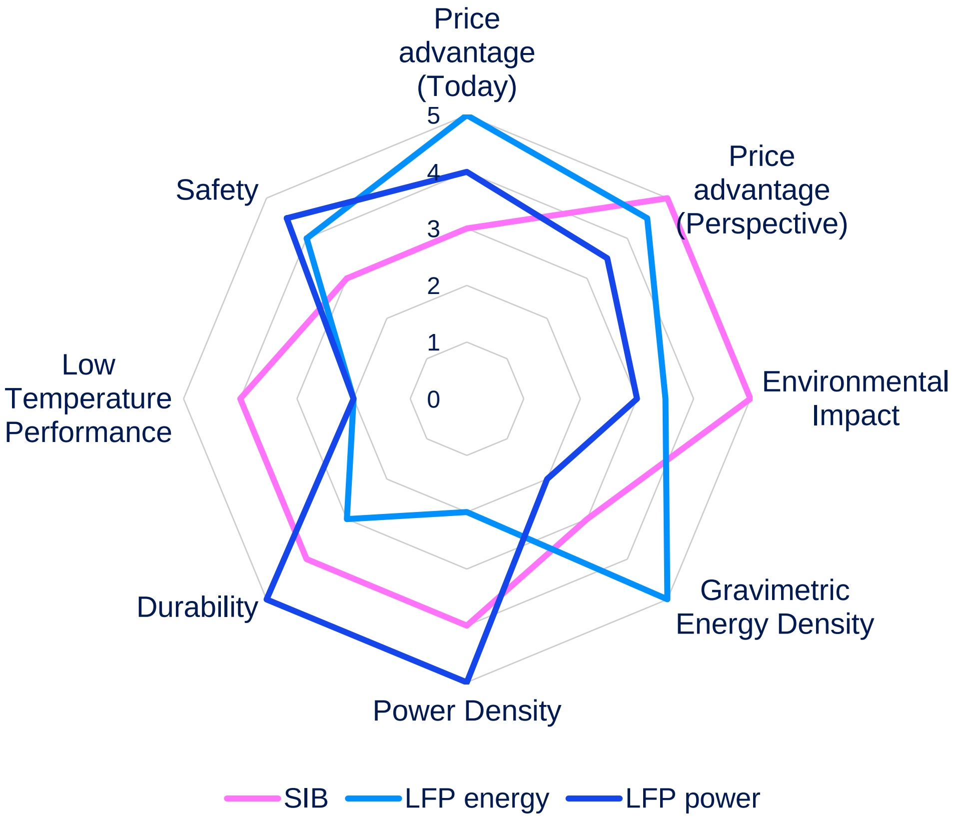
Compared to a reference LFP:

→ **SIB has globally an environmental impact is 62 % lower.**
It should remain similar in 2030.

Conclusion

Is SIB Suitable for 48V?

Comparison of different cell chemistries focusing on 48V applications



LIB is today the main battery technology used for the mHEV. can SIB compete?

Cost-effective materials: Sodium is more abundant and much cheaper than lithium.

Thermal stability and safety: SIB have better thermal tolerance and lower risk of thermal runaway.

Suitable energy and power density: While smaller than the one of LIBs, the energy density of SIBs are sufficient for 48V applications, which do not require high energy storage.

Improved sustainability: SIB reduces reliance on critical and rare materials.

Conclusion and Outlook

SIBs offer a promising alternative to lead-acid and lithium-ion batteries in low-voltage mobility due to their robustness, raw material abundance, durability, safety, and potential for lower cost.

Environmental benefits are significant, as SIBs contain no lead or lithium.

Consistent performance across temperature ranges ensures reliable discharge energy and supports stable high-power delivery.

→ **While not superior in every performance category, SIBs serve as a well-rounded, sustainable solution with strong potential for widespread adoption in future LV mobility applications.**

→ **With recent developments in high-energy SIBs, this technology could potentially serve as an alternative for HV systems in future PHEV and EV.**

THANK YOU FOR YOUR ATTENTION

Brahim Soltani
IAV France
4 rue Guynemer,
78280 Guyancourt (France)
Phone +33 6 66 74 07 91
brahim.soltani@iav.de
www.iav.com

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