Evaluation of the Benefits of Lithium -Titanate Based Batteries for Heavy-Duty Vehicles

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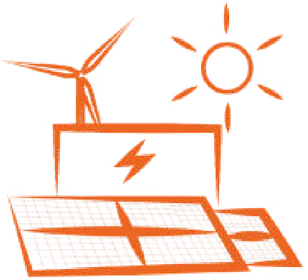
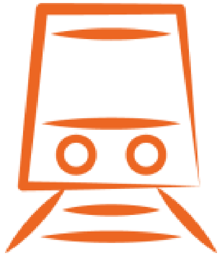
Introduction

Intilion GmbH

- The INTILION GmbH - formerly named as HOPPECKE Advanced Battery Technology GmbH, was founded in 2008.
- The INTILION GmbH is 100% owned by the HOPPECKE Group.
- Development, production of lithium-ion energy storage solutions and innovative business models.
- Focus on three areas of application:
  - stationary energy storage
  - traction
  - rail





Lithium Activities

trak

- Batteries, chargers, adapter trays
- OEM solutions (fully integrated):
  24 V, 48 V, 2…25 kWh
  80 V, … 40 kWh
- Replacement solutions:
  24 V, 48 V, 2…25 kWh
  80 V, …40 kWh

Available

stationary energy storage (medium)

- Range of 30…500 kWh
- Off-grid application possible
- Modular systems with 68 kWh
- Inverter technology included (30 kW)
- Air conditioning unit integrated
- Fire protection rack to fulfill latest standards
- Monitoring via cloud connection

Available

rail



Available

Traction:

- Stadler Regional Train: 550 kWh, first prototype operating.
- Gmeinder Hybrid Shunting Locos: 100 kWh, 2 batteries running at end customer.

stationary energy storage (large BESS)

- Energy content >500 kWh
- Modular and scalable
- Fire protection system
- Monitoring via cloud connection
- Reference #1: 3.4 MWh in realization

Available

Motivation

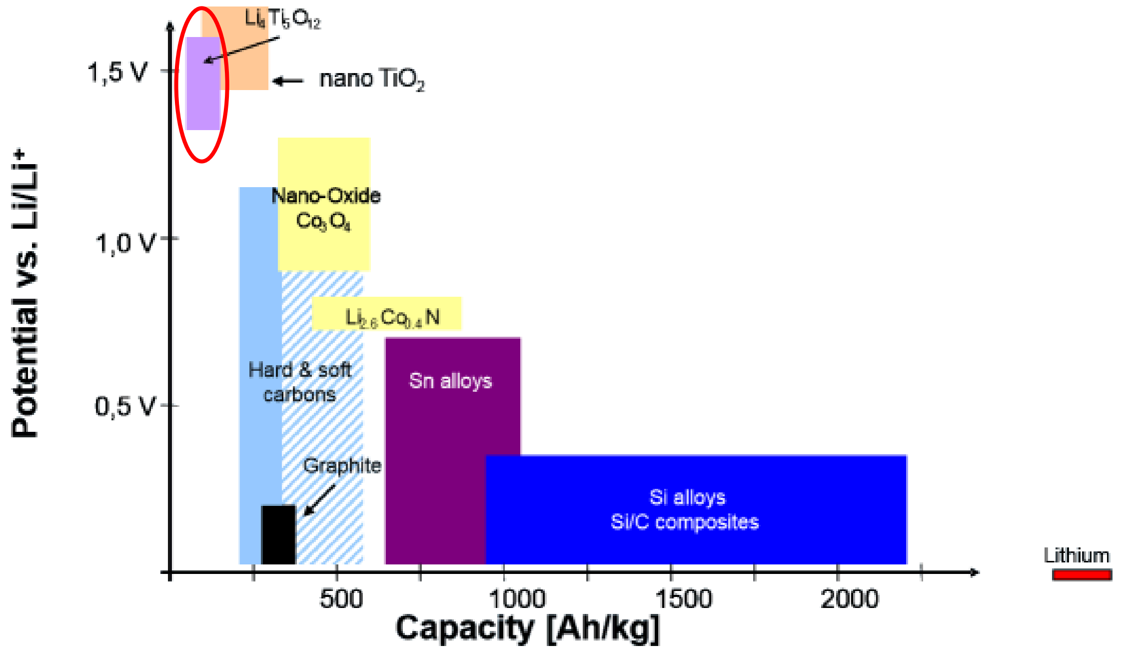
LTO-Technology

Lithium-titanate (LTO) technology has benefits like:

- fast battery charging
- good low temperature performance
- long lifetime

But…

- the poor energy density and
- the higher price per kWh **seems** to prevent a real breakthrough of the LTO cells



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Agenda

Application
- Requirements

Benchmark
- Suitable cell
- LTO vs. LFP and NMC

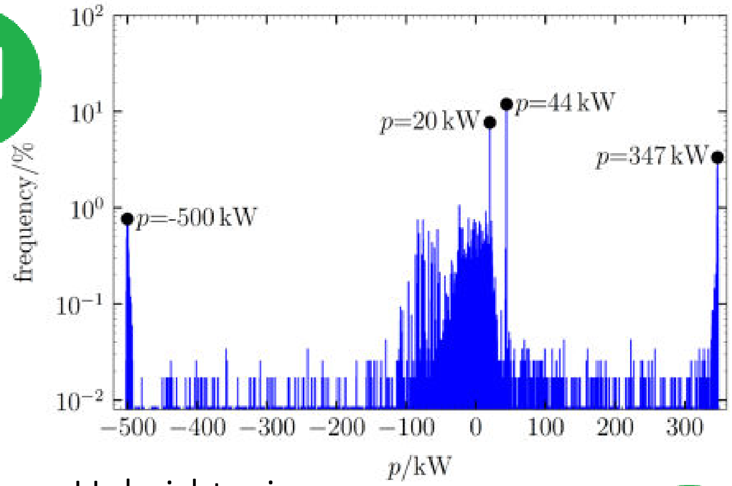
System design
- Modelling
- Topology
- Prototype

Comparison with other systems
- Evaluation of the benefits of LTO technology

Conclusion
- Conclusion
- Outlook

Application Analysis

Load profiles from field testing systems

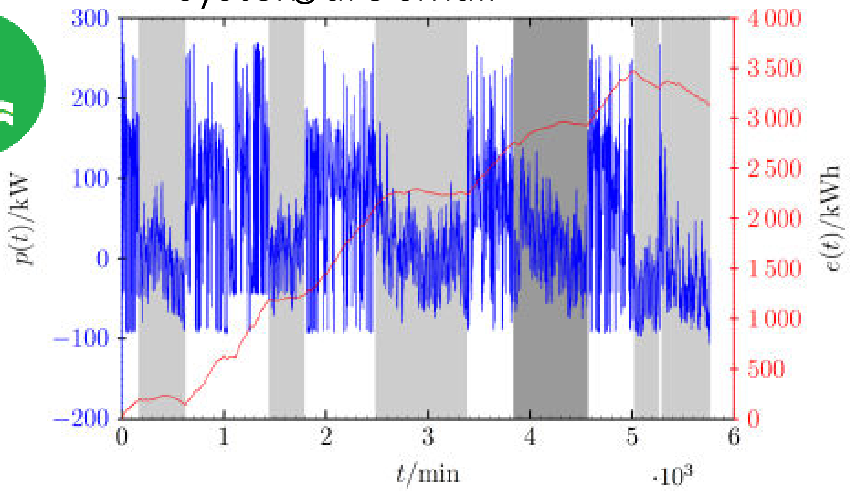


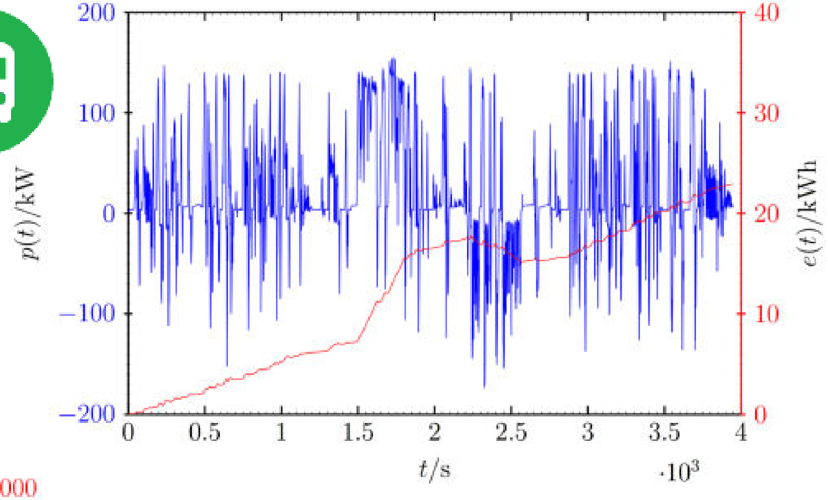
Hybrid train
- -500 kW recuperation during braking
- 20 kW when turning
- 44 kW while entering the railway station
- 347 kW drive power
- approx. 38 kWh for the trip

➢ Fixed routes
➢ Electrically travelled routes are comparatively short
➢ Offer the possibility of opportunity charging

Inland waterway vessel
- Port times are basis for capacity design
- 350 kWh for this application during this time without diesel generator

➢ Applications with high energy consumption
➢ Battery system has to be designed larger
➢ C-rates for such a systems are small





Electric buses
- Up to 500 kW via a pantograph
- approx. 150 kW power output
- -180 kW during recuperation
- 23 kWh for the trip

➢ Fixed routes
➢ Electrically travelled routes are comparatively short
➢ Offer the possibility of opportunity charging

Benchmark

Experimental setup for cell testing

The focus of cell testing was mainly on the following properties in order to evaluate the benefits of LTO-based batteries for heavy-duty vehicles:

- charge/discharge behavior vs. temperature,
- temperature increase during charge/discharge,
- cycle and calendar life,
- cell impedance vs. temperature as well as power capability.

LTO screening process (extract)

Initial inspection

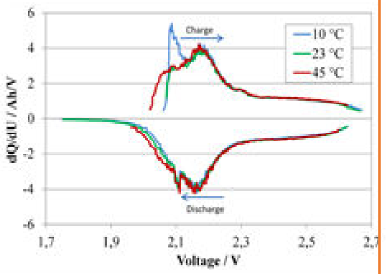
Measurement of weight and dimensions and comparison with data sheet.

Performance

Evaluator-B test system (± 0.1 % accuracy of measuring range).

ICA/DVA

Deter-mined with LIM at diff. Temp.



EIS

Ref3000 with 1 mHz to 1 kHz at 50 % SoC.

Detailed Investigation (extract)

Electrical model

Thermal model

Cells Sourcing

Extensive Benchmark of commercial LTO-cells > 10 Ah

MFG	Pos. El.	Type	Q / Ah	U / V	Discharge behavior		Charge behavior		Status	Available	Tested
					I_{cont} / C	T /°C	I_{cont} / C	T /°C			
M1	LMO	Cylindric	16	2.5	50	-40 … +60	20	-40 … +60	Serial production	Yes	x
M1	LMO	Coffee-bag	20	2.4	6		4		Prototype	No	x
M2	LMO	Cylindric	50	2.4	3	-40 … +55	3	-40 … +45	Small batch series	Yes	x
M3	LMO	Prismatic	26	2.4	10	-30 … +60	10	-30 … +60	Serial production	No	x
M4	LMO	Cylindric	25	2.3	6	-40 … +55	10	-40 … +55	Prototype	No	
M2	LFP	Cylindric	45	1.8	3	-40 … +55	3	-40 … +45	Small batch series	Yes	x
M5	LFP	Coffee-bag	20	1.85	1	-10 … +40	1	-10 … +40	Small batch series	No	x
M1	LFP	Coffee-bag	20	1.8	4		2		Prototype	No	x
M6	NMC-Blend	Prismatic	20	2.3	5	-30 … +55	5	-30 … +55	Serial production	Yes	x
M7	NMC-Blend	Prismatic	23	2.3	4.3	-30 … +55	4.3	-30 … +55	Serial production	Yes	x
M4	NMC	Coffee-bag	20	2.3	6	-40 … +55	6	-40 … +55	Prototype	No	
M4	NMC	Prismatic	30	2.3	10	-40 … +55	10	-40 … +55	Serial production	Yes	
M8	NMC	Coffee-bag	11	2.3	9	-10 … +45	9	-10 … +45	Small batch series	No	x
M8	-	Coffee-bag	5	2.3	-	-30 … +55		-30 … +55	Small batch series	No	
M9	-	-	20	-	10				Prototype	No	
M10	NMC	Coffee-bag	50	2.3	5				unknown	No	x
M10	NMC	Coffee-bag	65	2.3	8		4		unknown	No	x
M11	NMC	Coffee-bag	70	2.23	6	-20 … +50	6	-20 … +45	Serial production	Yes	x
M11	NMC	Coffee-bag	30	2.23	6	-20 … +50	6	-20 … +45	Serial production	Yes	x
M12	NMC	Cylindric	25	2.3	6	-40 … +55	6	-40 … +45	Serial production	Yes	x
M13	NMC	Coffee-bag	60	2.2	6	-30 … +60	6	-30 … +60	Serial production	Yes	x
M14	NCO	Coffee-bag	30	2.3	4	-20 … +55	4	-20 … +55	Serial production	Yes	x

- 17 different cells of 22 have been tested
- 12 of 22 cells are prototypes or small batch series

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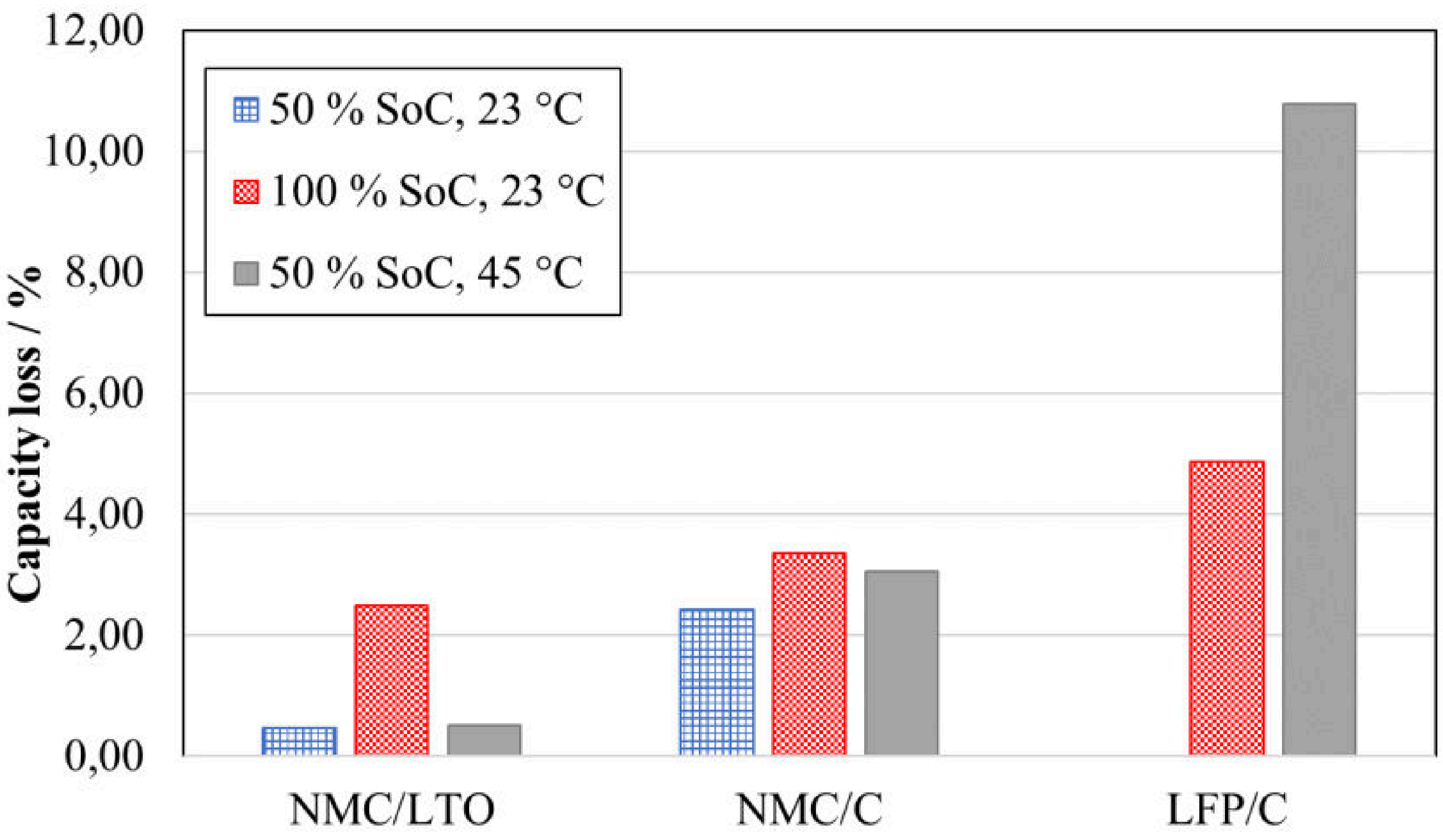
M6	NMC-Blend	Prismatic	20	2.3	5	-30 … +55	5	-30 … +55	Serial production	Yes	x
M7	NMC-Blend	Prismatic	23	2.3	4.3	-30 … +55	4.3	-30 … +55	Serial production	Yes	x

- 3 cells preselected, good results in terms of:
  - Cycle life
  - Drift during aging
  - Deviations in capacity

➢ 23 Ah prismatic NMC-blend cell has been chosen

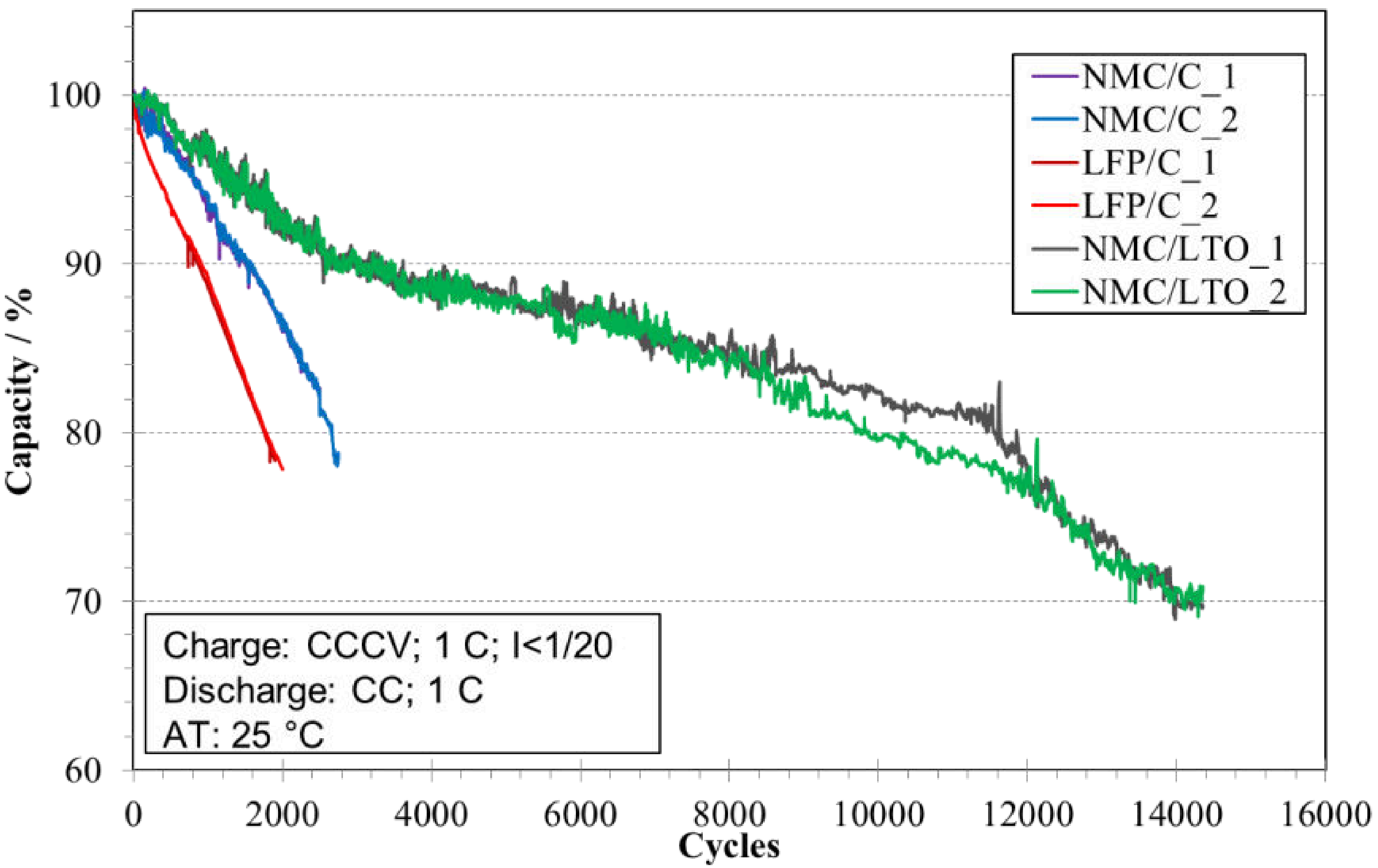
Calendar Aging

- Test duration was in total 12 months.
- The main influence of calendar aging of the LTO cell is the SoC range.
- Compared to LTO, the calendar aging of NMC/C as well as LFP/C are substantially higher.



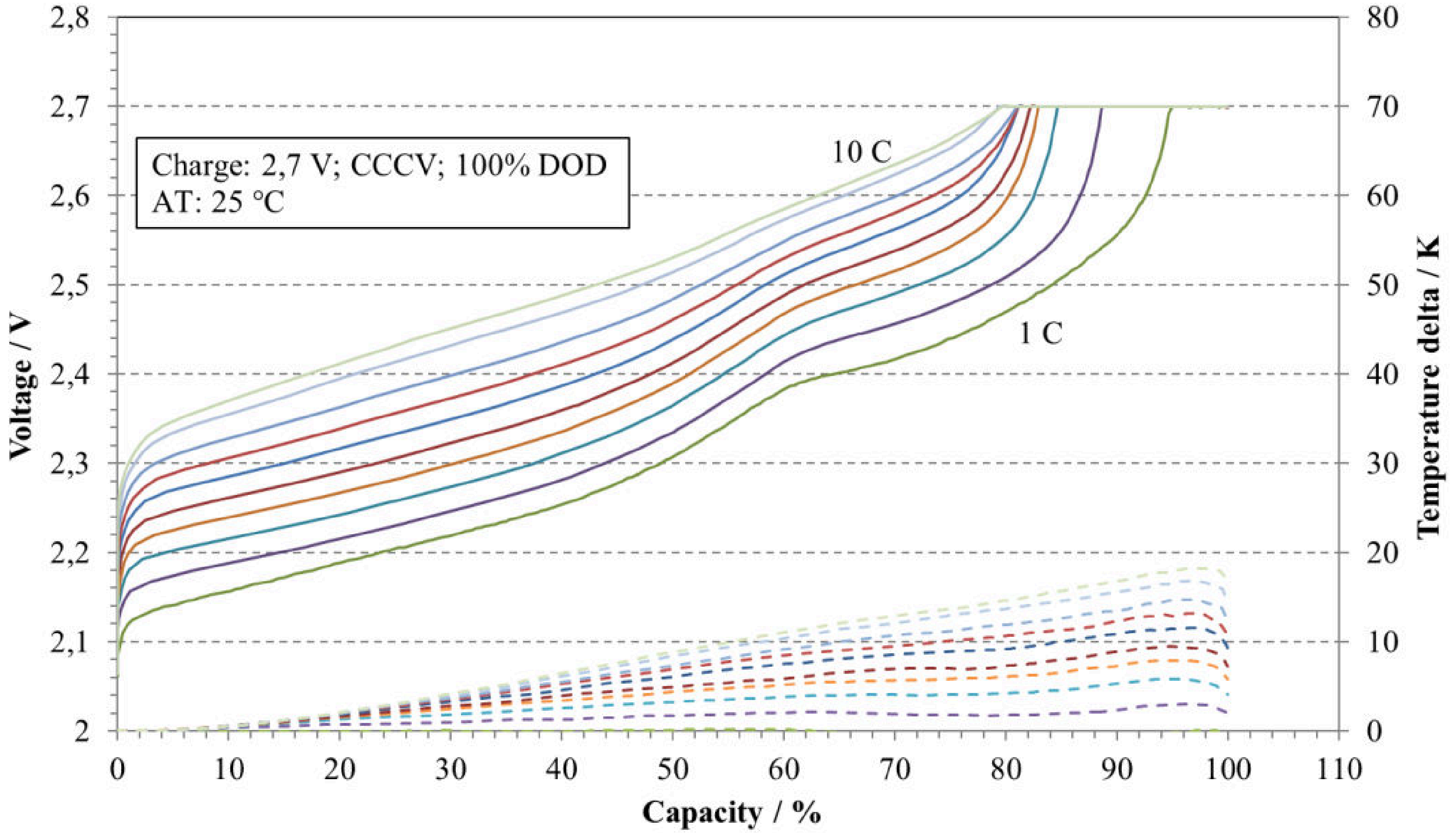
Cycle-Life Tests

- Cells were cycled with a current rate of 1 C and a depth of discharge (DoD) of 100 % at 25 °C.
- NMC/C and LFP/C cells reaches the end of life (EoL, 80 % nominal capacity) after approximately 2.150 and 1.900 full cycles.
- ➢ LTO technology provides a very high cycle life compared to the other cells studied.



Charge Performance

- The charge current was varied between 1 C and 10 C.
- At a current rate of 10 C, the cell can be charged up to almost 80 % during the constant current (CC) phase.
- The increase of cell temperature is one quantity (~20 K at current rate of 10 C), for which an appropriate cooling must be provided.



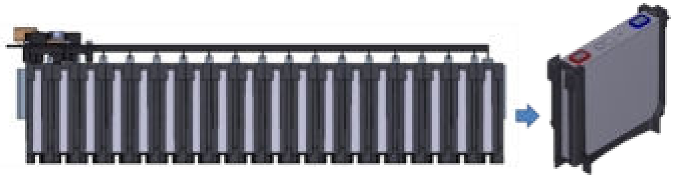
Safety Appraisal

Comparison of the likelihood of different reactions occurring

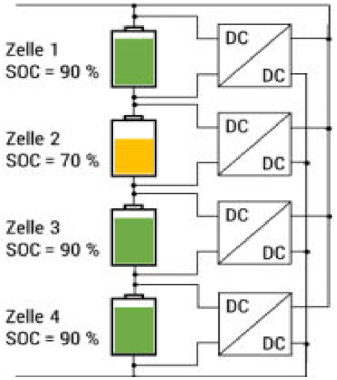
Risk of fire, explosion or gassing	NMC/LTO	NMC/C	LFP/C
Charge at low temperatures	low	high	high
Overcharge	high	high	high
Deep discharge until 0 V	low	moderate	moderate
Charge after deep discharge	low	moderate (Cu)	moderate (Cu)
External temperatures up to 130 °C	low	high (SEI)	high (SEI)
External temperatures up to 180 °C	moderate	high	moderate
External temperatures above 180 °C	high	high	high
High charge currents	moderate (less plating)	high	high
Operation at SoH < 80 % SoH	low	moderate	moderate
Polarity reversal	high	high	high
External short	moderate	moderate	moderate
Internal short	low	moderate	moderate

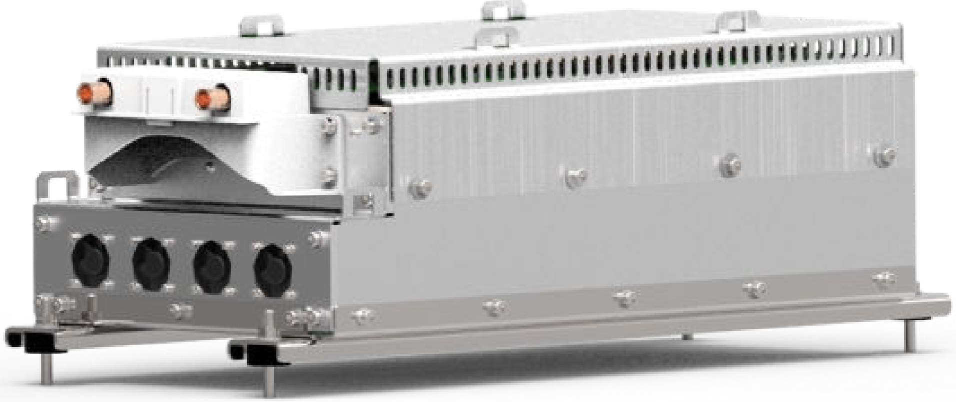
Battery Module

Module concept based on single cell frames for modular design.



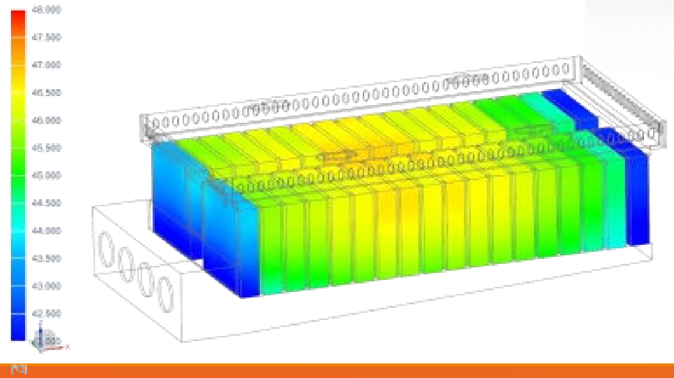
Active bidirectional and synchronous balancing with equalization currents up to 10 A.



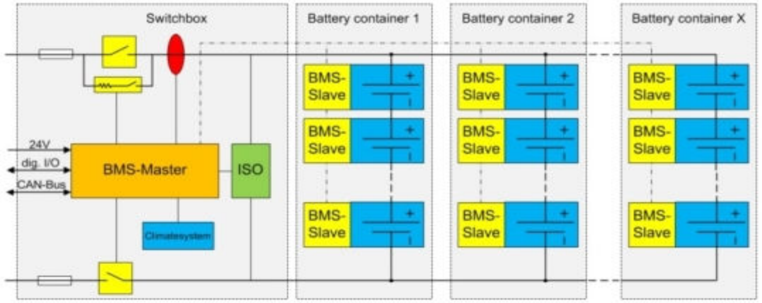


Battery module prototype of 36S-1P, 82.8 V, 23 Ah.

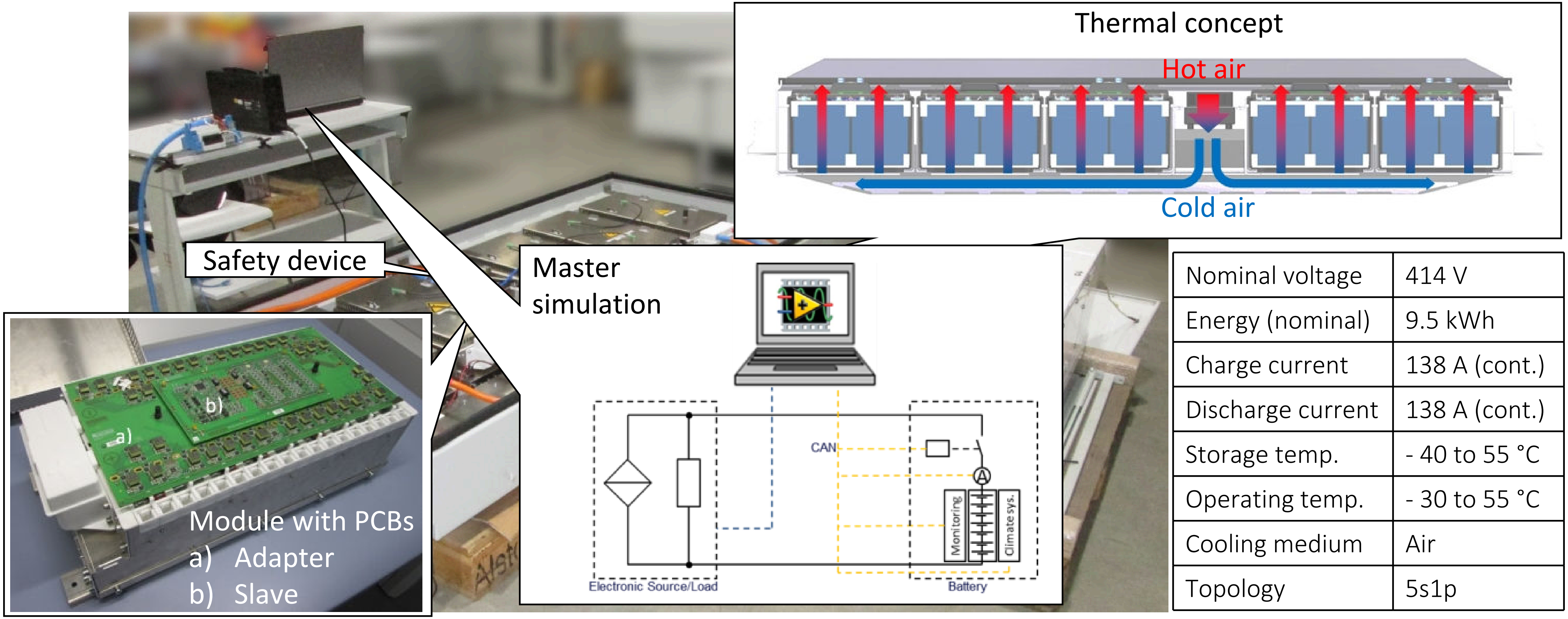
Thermal management by air cooling for continuous loads up to 6C.



Master-slave approach for flexible design of high-voltage systems.



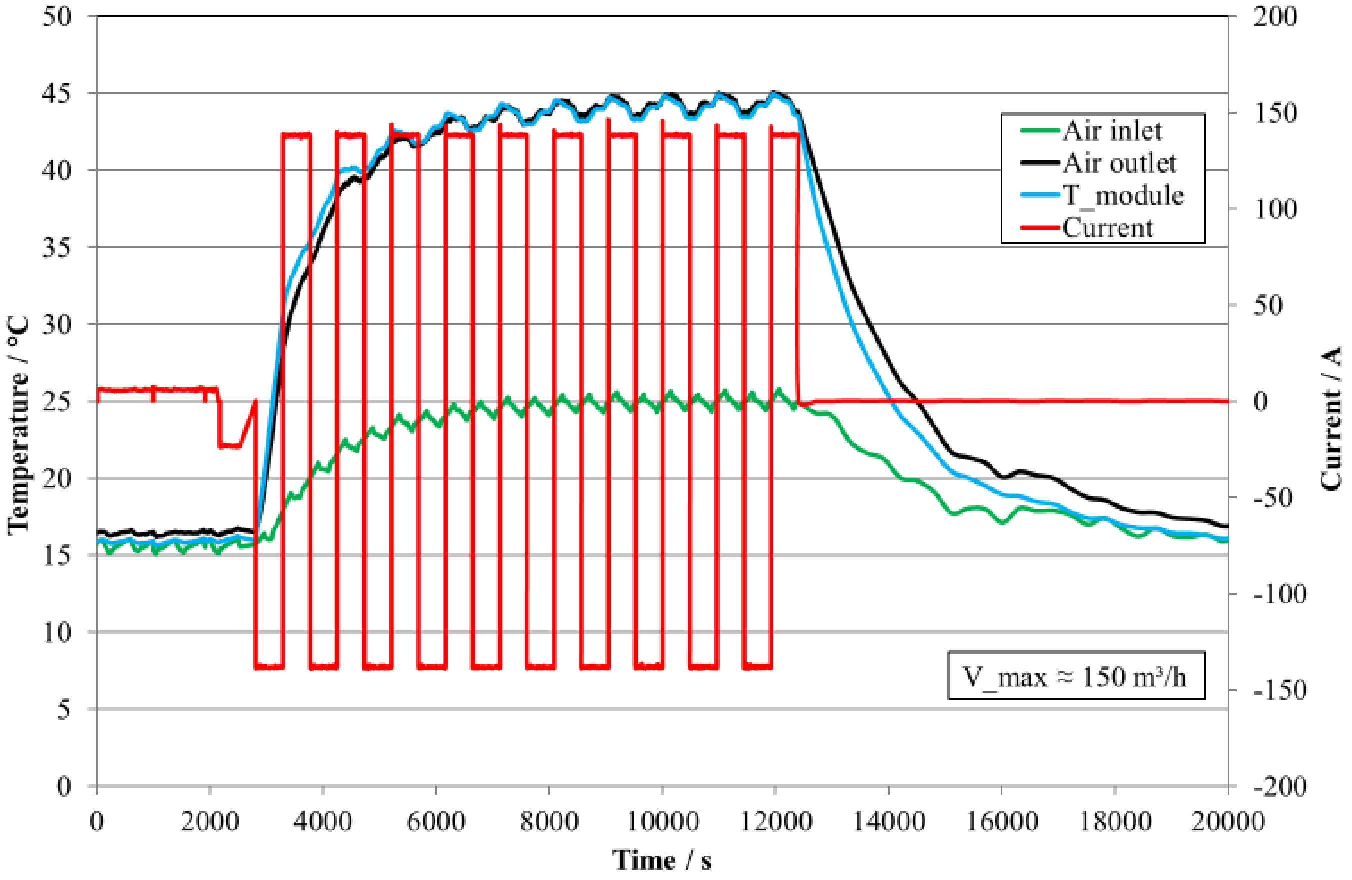
LTO System



Nominal voltage	414 V
Energy (nominal)	9.5 kWh
Charge current	138 A (cont.)
Discharge current	138 A (cont.)
Storage temp.	- 40 to 55 °C
Operating temp.	- 30 to 55 °C
Cooling medium	Air
Topology	5s1p

Thermal Behavior

- Stress test consists of 10 cycles with a rate of 6 C.
- No rest times within the cycles.
- The cooling system is able to keep the temperature at maximum of approximately 43 °C.



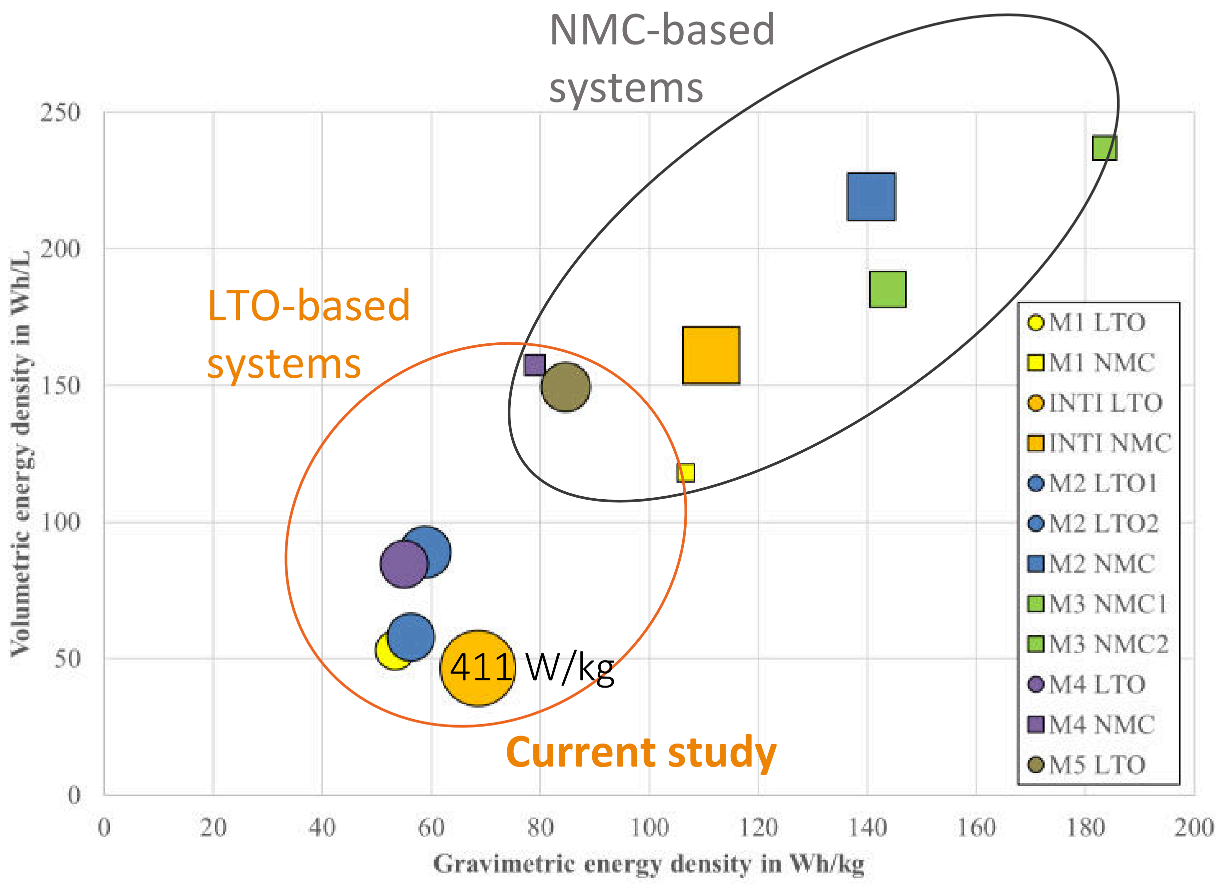
Comparison With Other Systems

Different Intilion systems

Module	NMC-blend/LTO	NMC/C	LFP/C
Temperature range discharge	-30…55 °C	-40…60 °C (0.3…2.3 C)	-20…60°C
Temperature range charge	-30…55 °C	**-5**…60 °C (**0.2**…1.2 C)	**0**…45 °C
Battery energy	76 kWh	187 kWh	180 kWh
Power (cont.)	457 kW	187 kW	180 kW
Weight	100 %	103 %	69 %
Volume	100 %	88 %	100 %
Cycle life (80 % EoL)	15.000 (90 % DOD)	3.000 (90 % DOD)	2.000 (90 % DOD)
Invest	100 %	80 %	52 %
Required cycles (12 years)	14400	7200	7200
Replacements	0	2-3	3-4
Life-cycle costs	**100 %**	**160 %**	**157 %**

Conclusion

- Benchmark tests were done to show the benefits of the LTO technology compared to other technologies.
- LTO module with air cooling and active balancing was developed.
- Low Life-cycle costs.
- Weight and volume reduction possible.
- Future work will focus on the optimization of operating strategies as well as diagnosis by means of EIS by on-board electronics.



Acknowledgments

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Thank you for your attention!

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