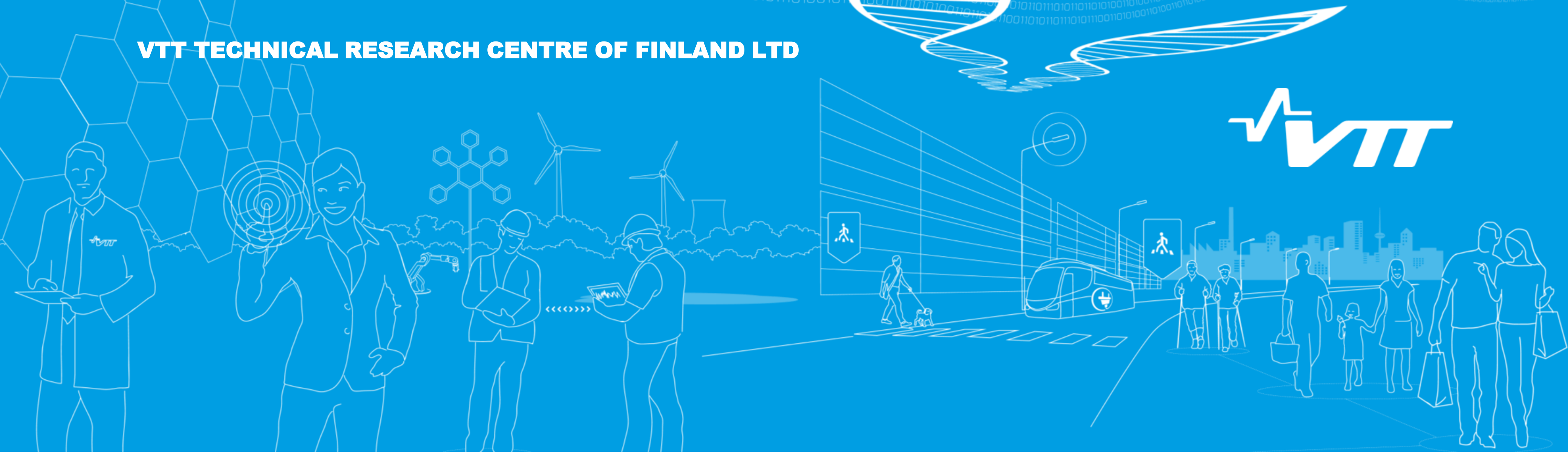


VTT Battery Research Activities and Selected Results

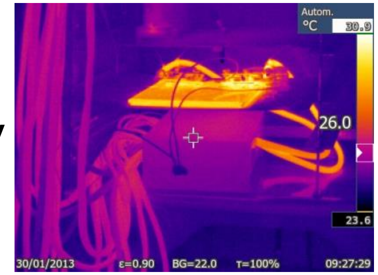
Requirements-driven design of heavy duty traction battery systems

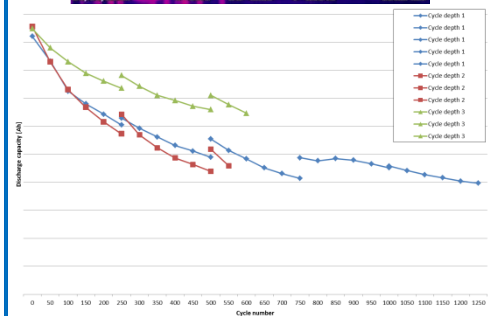
NordBatt 2015, 2-3 Dec.2015, Trondheim

Mikko Pihlatie, Samu Kukkonen, Ville Erkkilä, Aino Manninen, Jari Haavisto (mikko.pihlatie@vtt.fi)

Electricity storage technologies research at VTT

1. **Technologies for electrochemical electricity storage**
   - Battery cell performance and lifetime testing, test methodology
   - Impact of environmental conditions
   - Critical technology reviews
2. **Design tools**
   - Electrical modelling
   - Heat transfer and thermal modelling
   - Battery safety
   - Lifetime estimates
   - Techno-economic evaluations
3. **Energy storage system development platform**
   - Instrumented battery research module
   - Concepts of thermal management
   - Battery management systems
   - System-level requirements for batteries



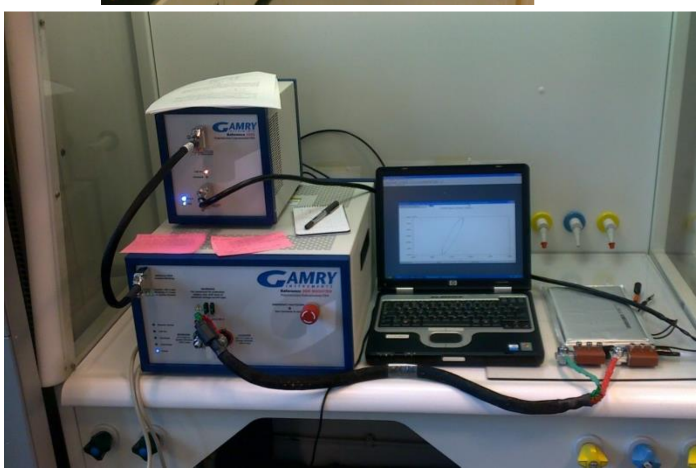


$$\frac{€}{Lifetime}$$

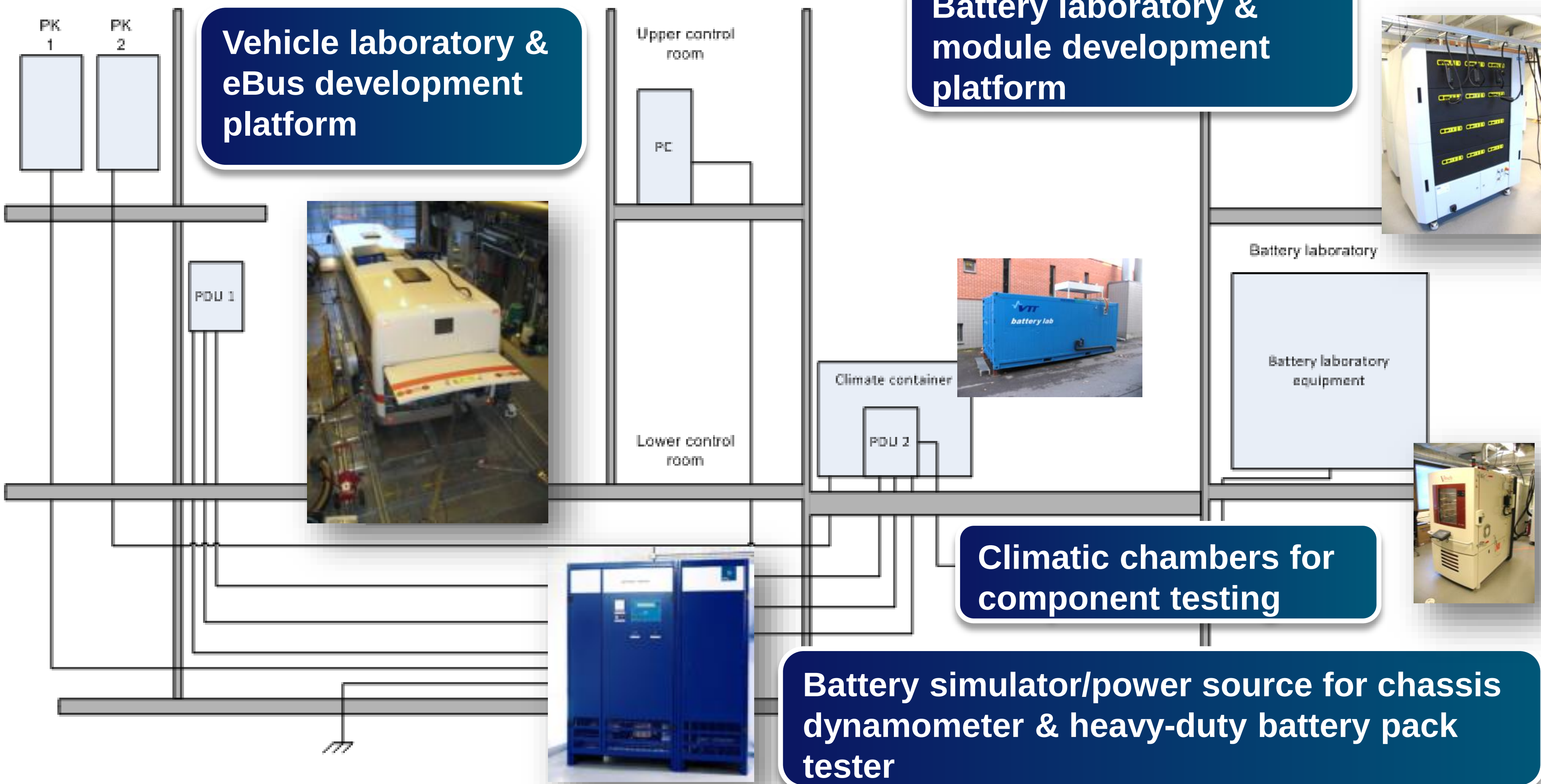
VTT Energy Storage Research Facilities

Topic	Battery cell	Battery module	Battery pack
Charging/ discharging	Up to 5 V, 600 A, and 3 kW. Multiple channels	Up to 100 V, 600 A, and 30 kW. Multiple channels	Up to 1000 V, 600 A and 320 kW
Electrochemical characterization	Impedance spectroscopy	Impedance spectroscopy up to 20 V	
Environmental testing	-72…+155 °C temperature range and 10…98 % humidity range	-72…+155 °C temperature range and 10…98 % humidity range	-32…+50 °C temperature range
Thermal management (liquid cooling/ heating)	Natural cooling, forced cooling, and liquid cooling plates	Several kW liquid cooling capability	10 kW cooling/heating between -10…45 °C temperature range
Mechanical testing	To be decided	Up to 4000 kg, 5…2000 Hz vibration, shock and drop testing	Up to 4000 kg, 5…2000 Hz vibration, shock and drop testing

VTT Energy Storage Research Facilities



Integrated research capabilities for electric vehicle R&D



Vehicle laboratory & eBus development platform

Battery laboratory & module development platform

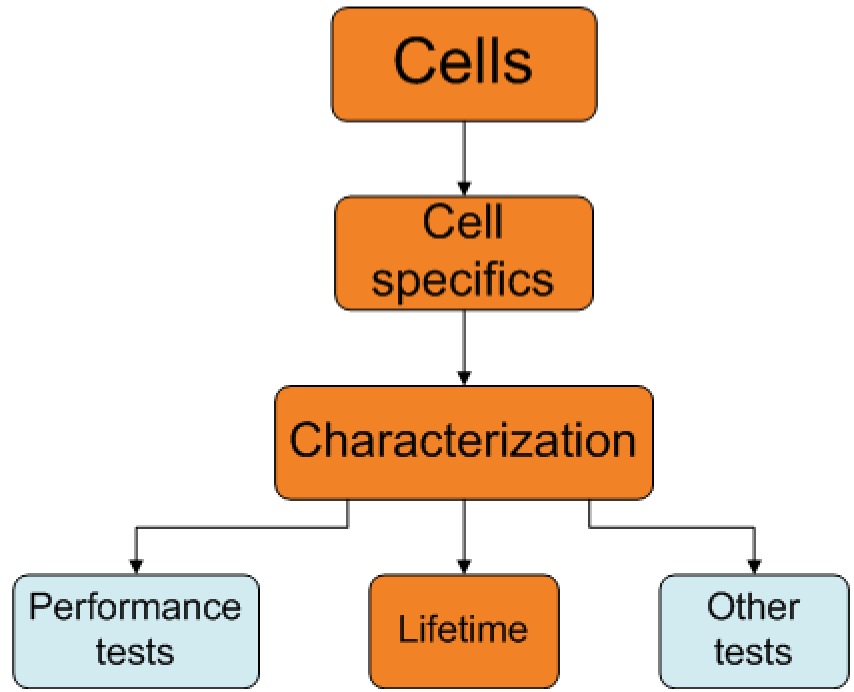
Climatic chambers for component testing

Battery simulator/power source for chassis dynamometer & heavy-duty battery pack tester

Battery Cell Level Research Results

Test Procedures for Battery Cells

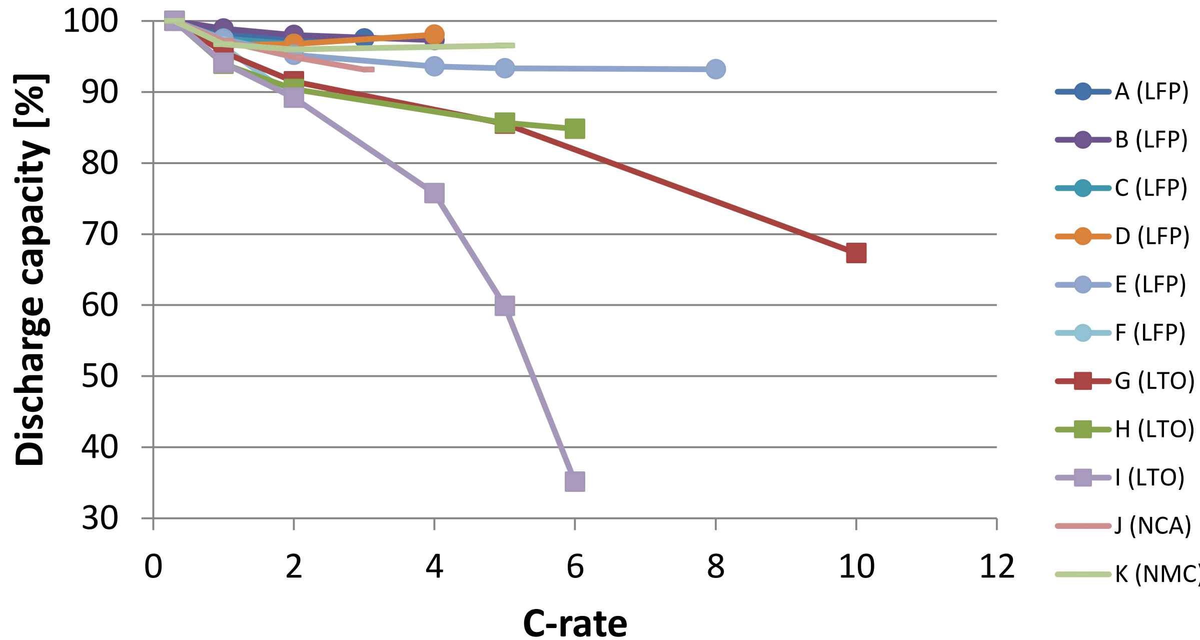
- Comprehensive characterization tests
  - Pre-conditioning
  - Capacity
  - Dynamic
  - Pulse
  - Electrochemical Impedance Spectroscopy
- Environmental testing
- Lifetime testing
- Calendar life

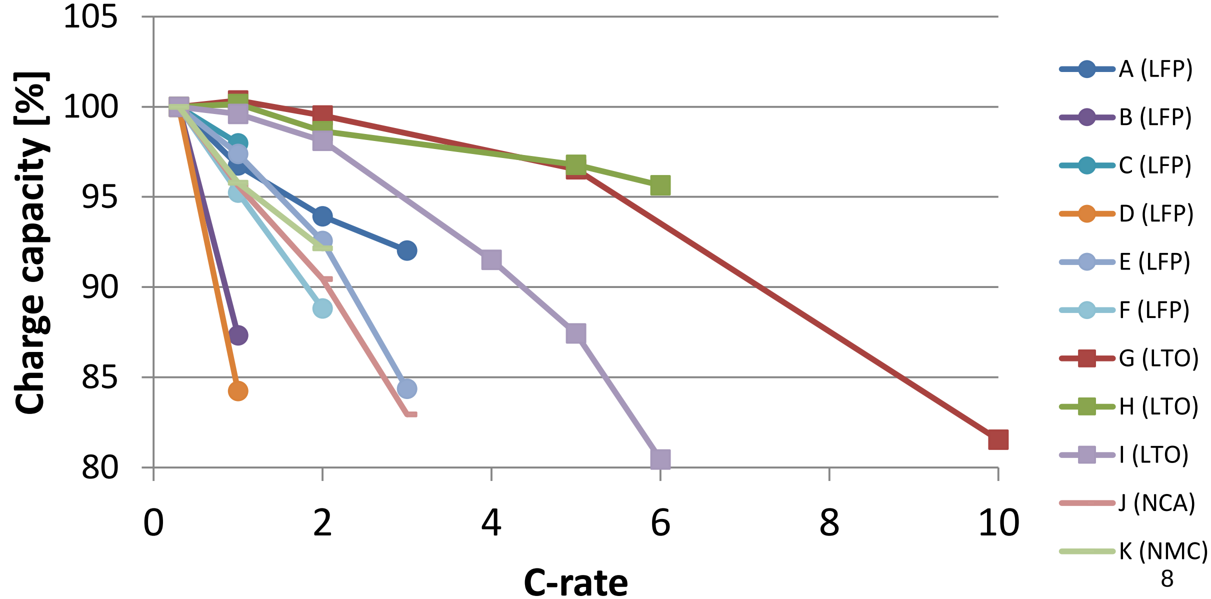


- Over 100 cells from several manufacturers have been tested

Rate Capabilities

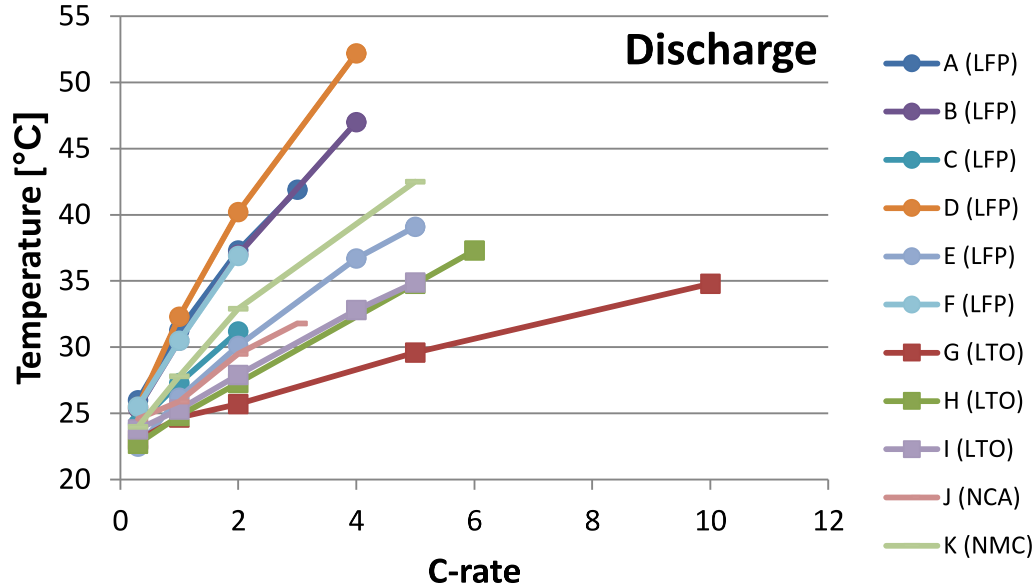
- Discharge rate capability less important in HD mobile applications
- Different Li-ion types in the database
  - LFP
  - LTO
  - NCA
  - NMC
- LTO cells show good charge capability performance

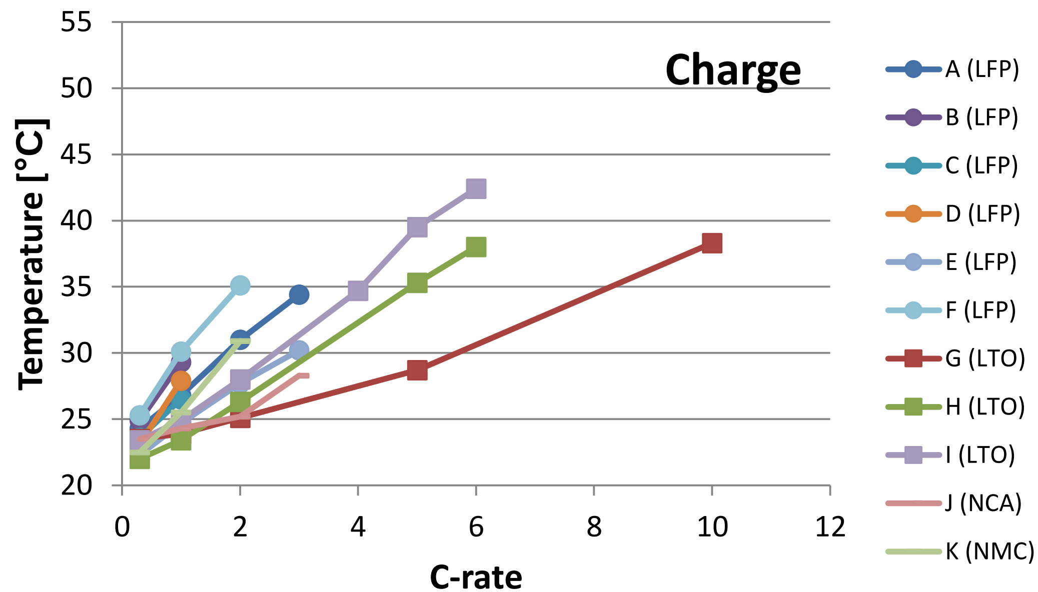




Cell Surface Temperature

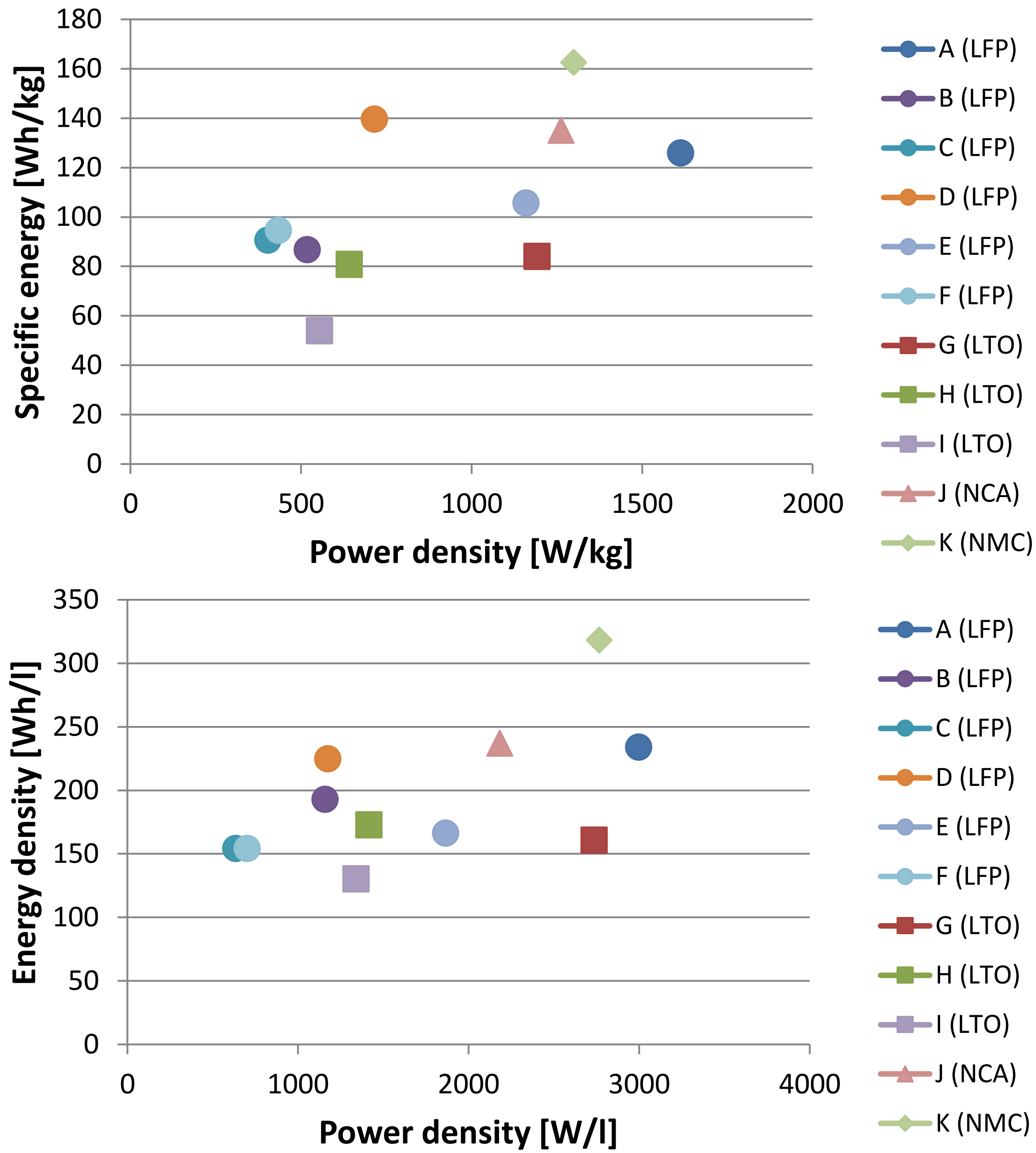
- Electrical losses dissipate heat in the materials
- Cells tend to heat up less during charge
- LTO cells do not warm up as much as LFP cells



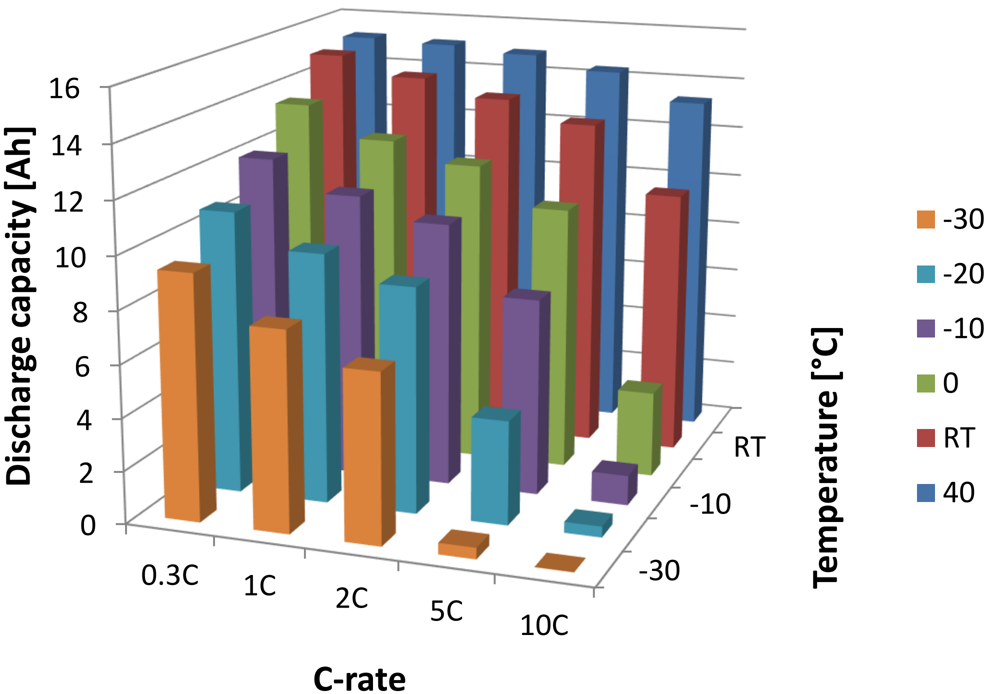


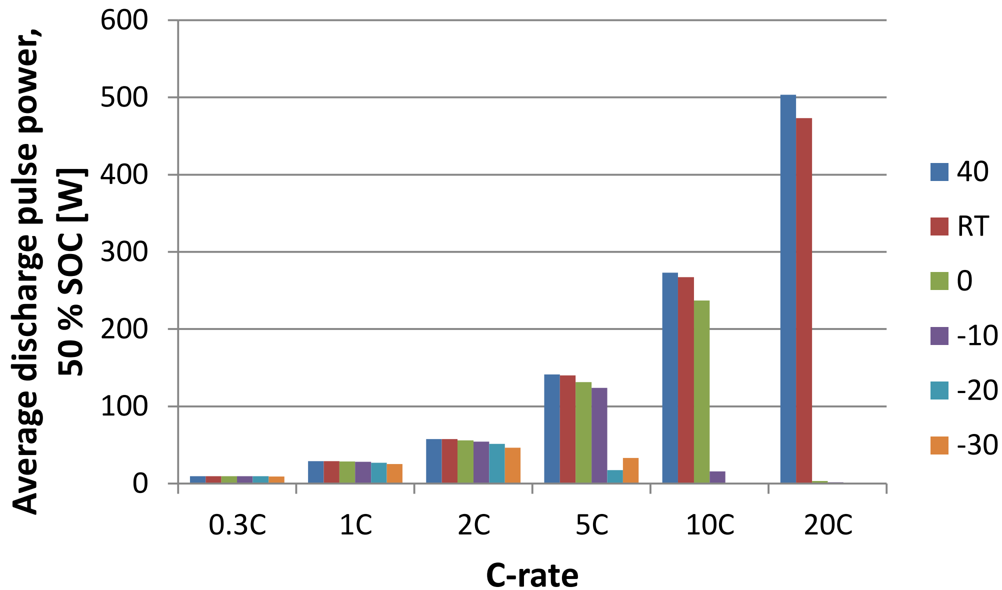
Ragone Charts

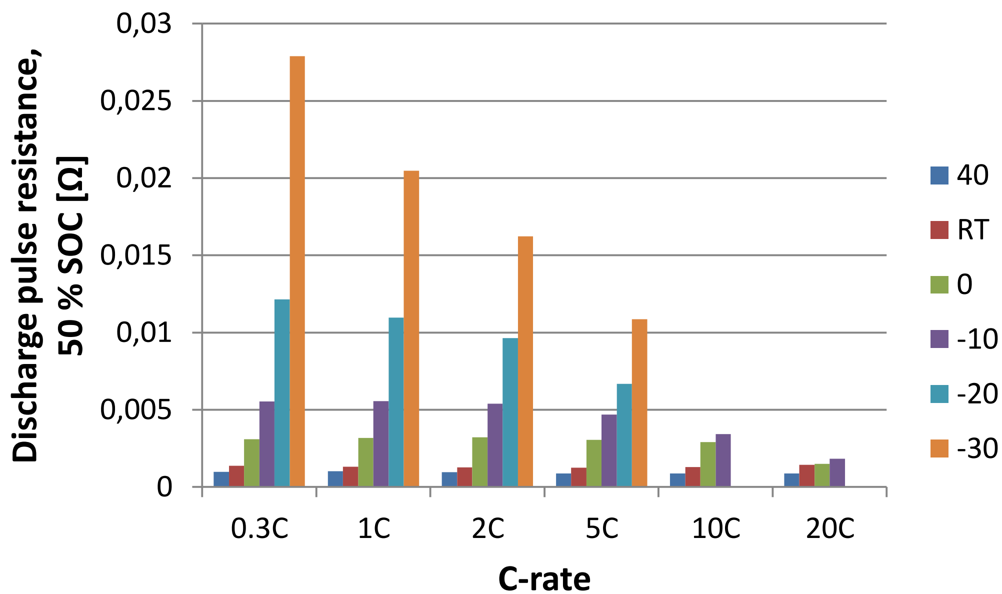
- Room temperature measurements
- Big differences inside chemistries (cell design, manufacturing)
- Scatter is smaller when compared per liter
- LTO compares better per liter



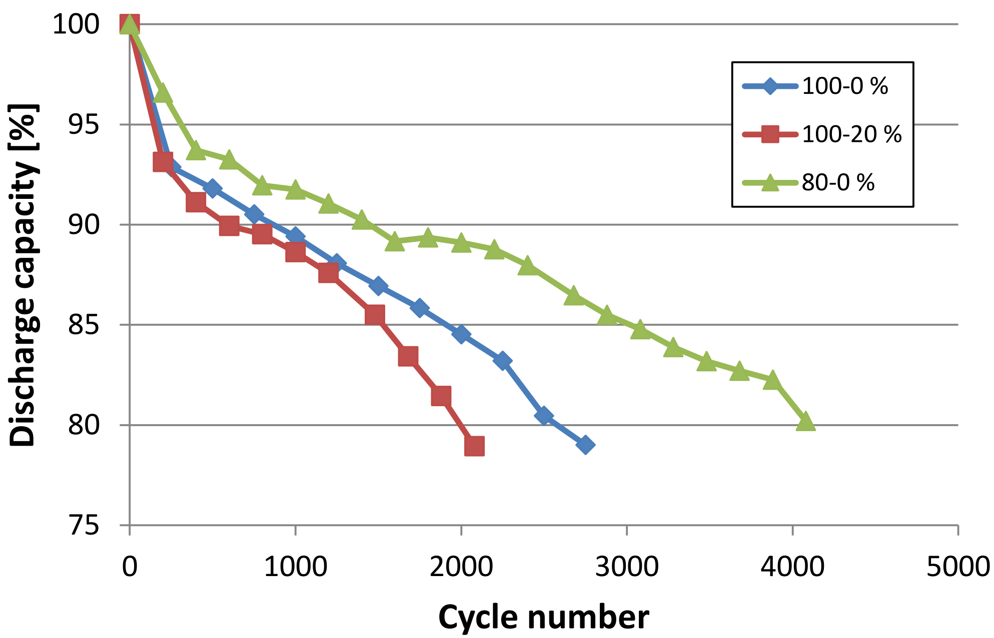
Environmental Testing

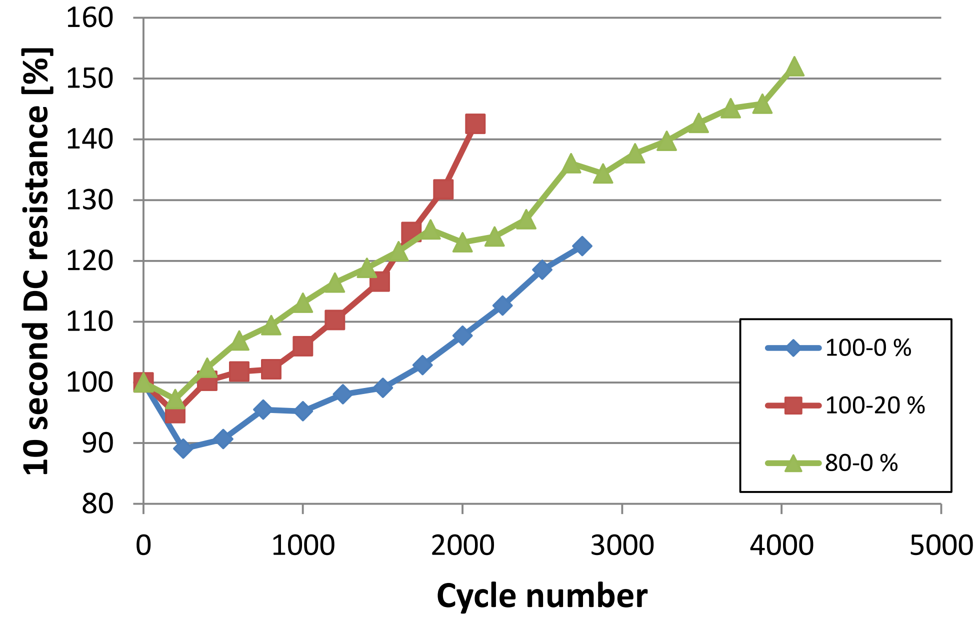


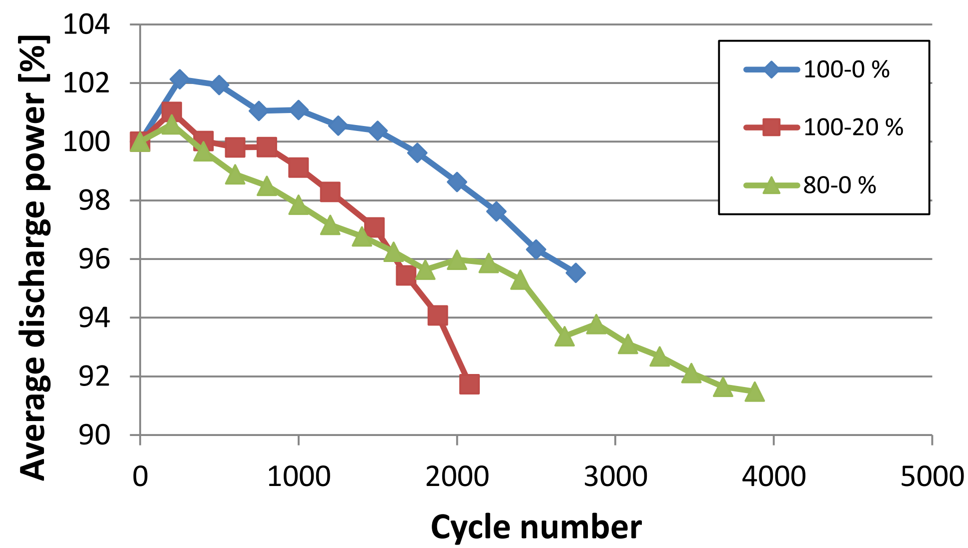




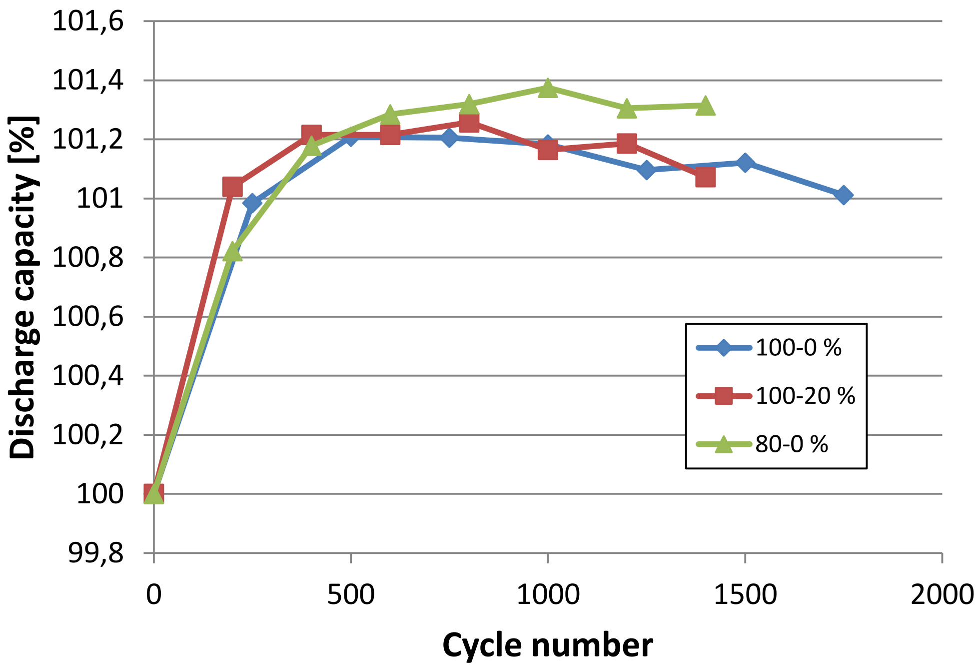
Lifetime Testing - LFP

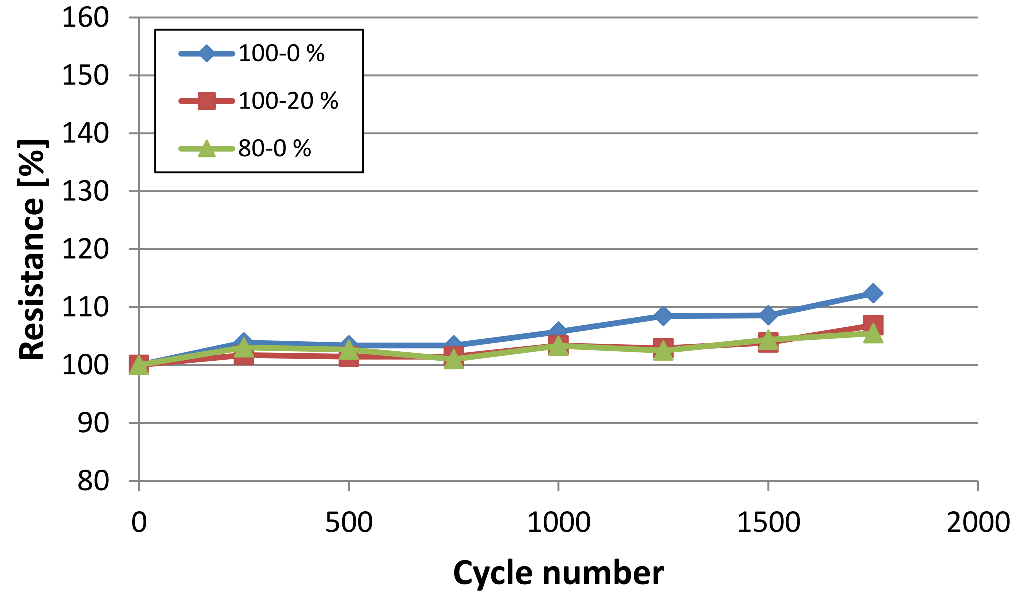


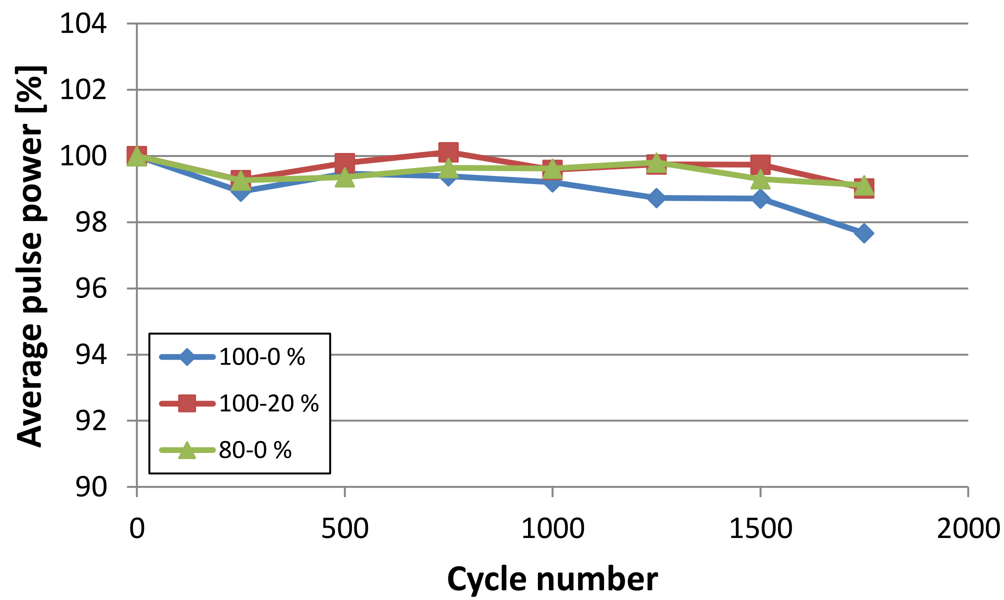


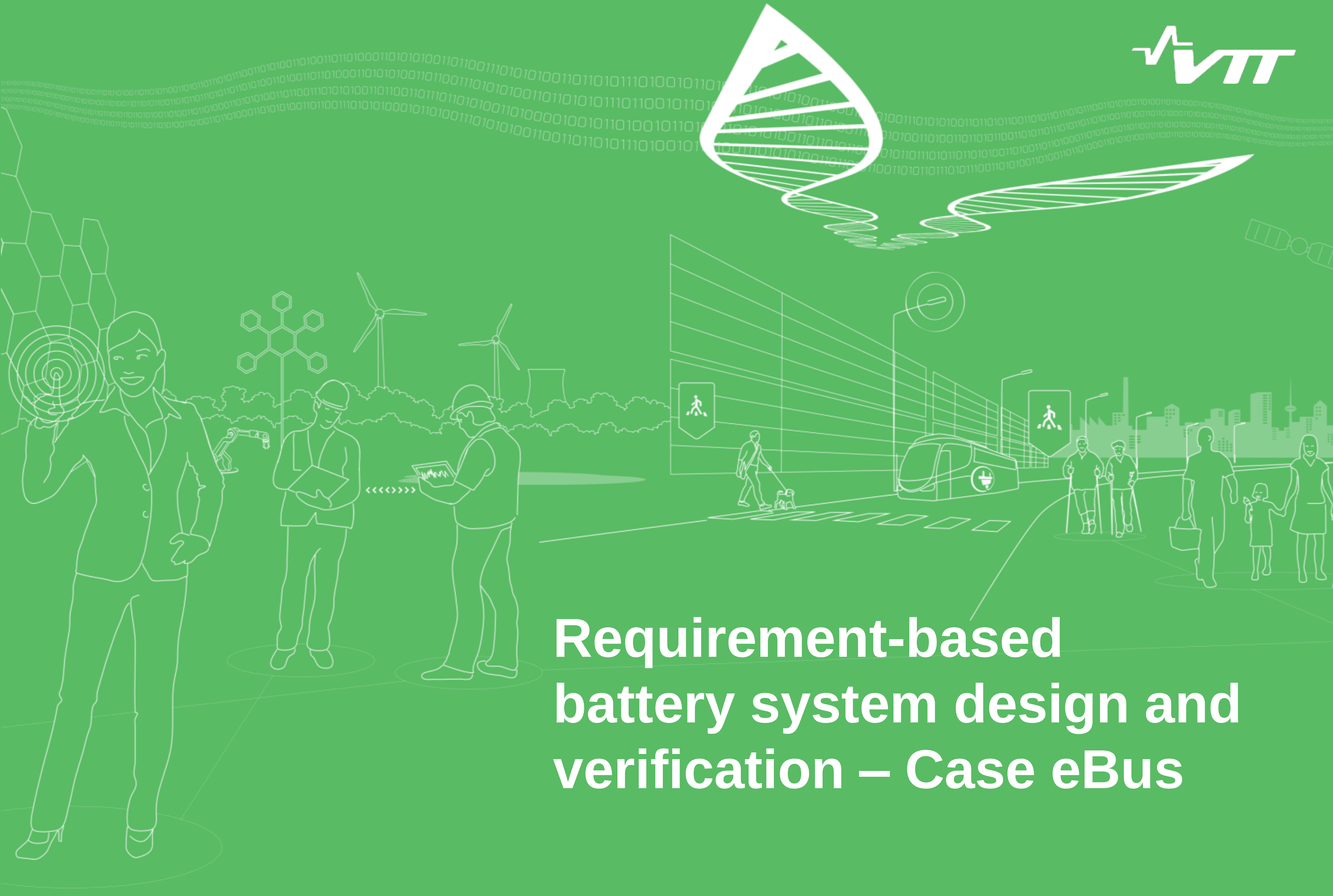


Lifetime Testing - LTO









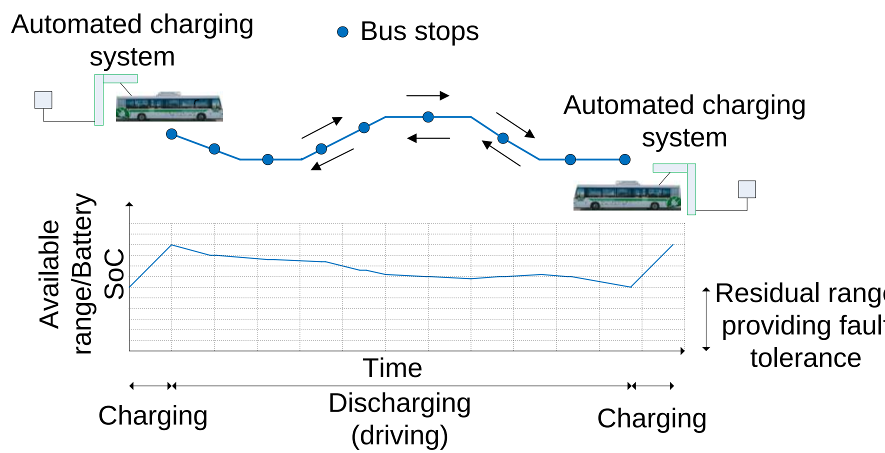
Requirement-based battery system design and verification – Case eBus

Requirements for optimal battery from application and system analysis

- For passenger EV’s (utilisation rate ~5%) the R&D task is to maximise energy content of the battery (EV range)
  - The sales task is to convince the customer to pay the high CAPEX / rely on subsidies
- For (HD) commercial vehicles (utilisation rate 50-75%) the R&D task is to find optimal battery-powertrain-system minimising TCO
  - Ensure high productivity and operability of the systems
  - Analyse and minimise system-level total cost of ownership → aiming at operation on commercial terms
  - Arrange charging infrastructure and energy management
  - Downsize battery (reduce CAPEX) to the extent possible

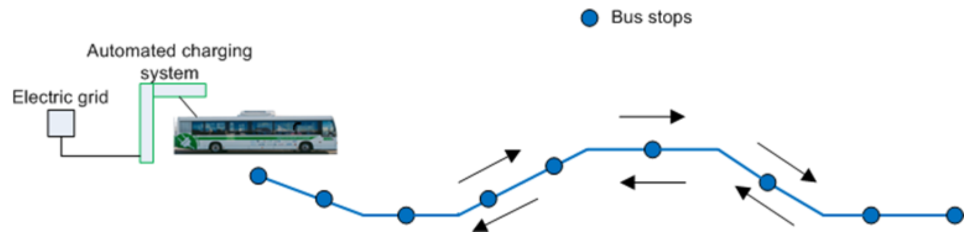
Case example: opportunity charged electric city bus

- Electric city buses are already commercially viable (Pihlatie, M.; Kukkonen, S.; Halmeaho, T.; Karvonen, V.; Nylund, N.-O., "Fully electric city buses - The viable option," *Electric Vehicle Conference (IEVC), 2014 IEEE International* , vol., no., pp.1,8, 17-19 Dec. 2014)
- How to achieve low total cost of ownership:
  - Reduce the battery capacity
  - High charging power acceptance
  - Charging points installed at the end of the bus lines



Bus line 11 - work cycle and current profile

- One round trip:
  - Length: 18,8 km, ~50 min
  - Energy consumed (net): 15,1 kWh
- Charging system at one end
  - Power: 250 kW
  - Charging time for 15,1 kWh: ~4 minutes



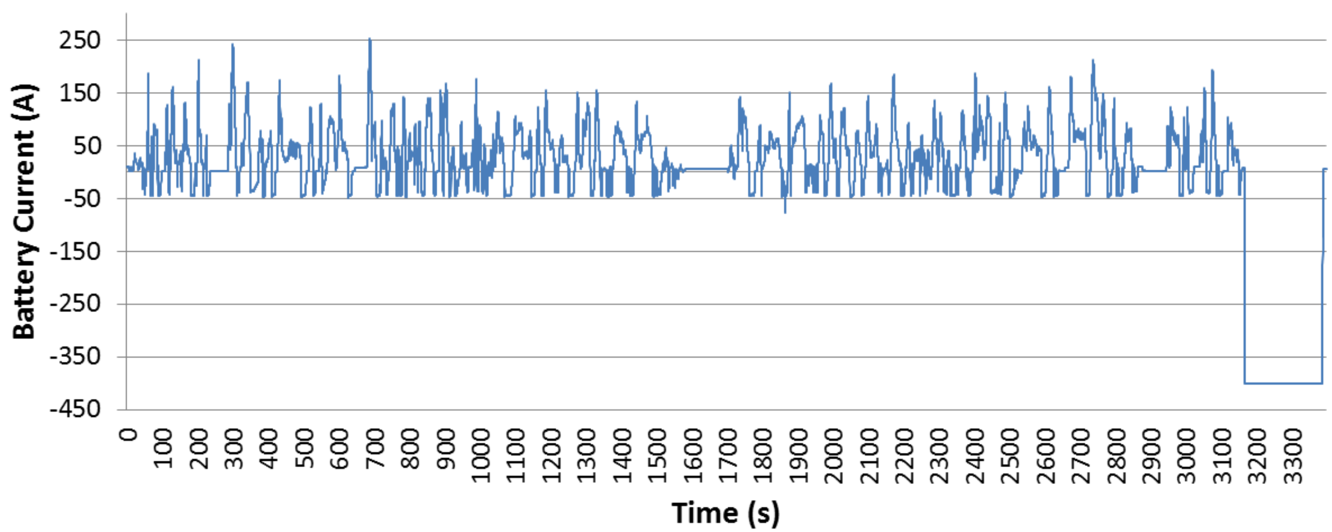


Fig. Measured battery current profile with simulated charging

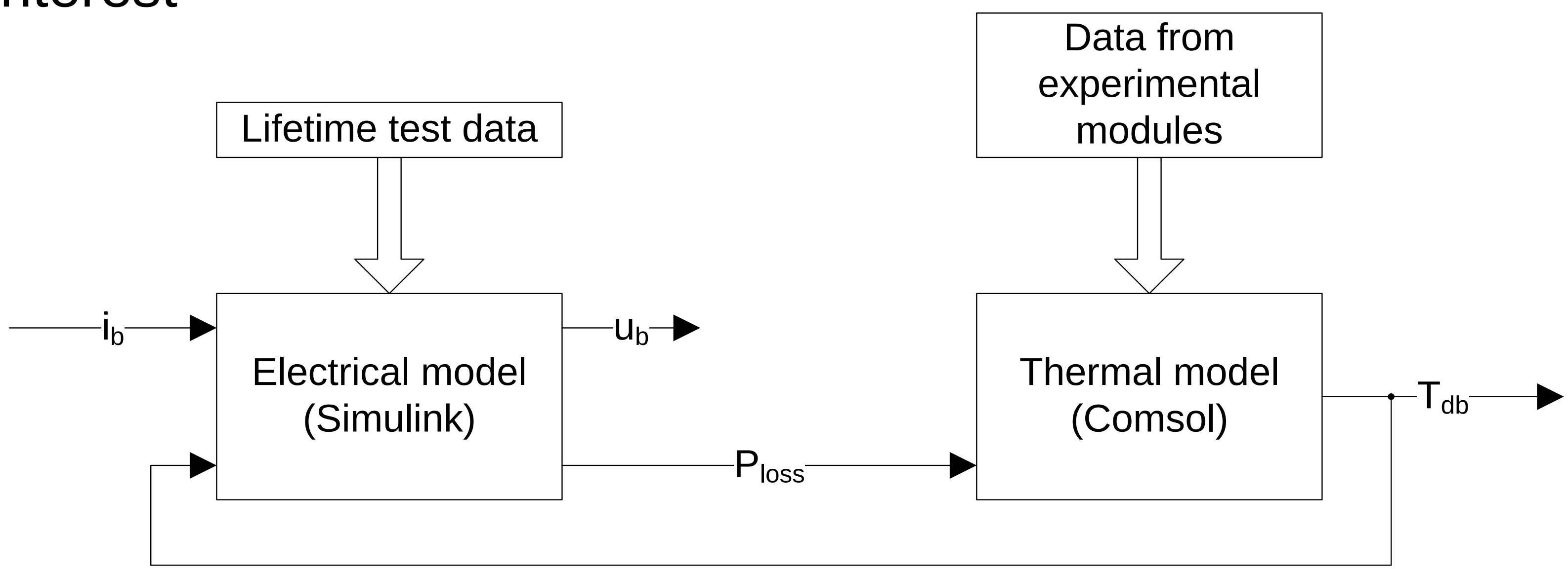
Electric bus battery dimensioning for line 11

- Battery dimensioning:
  - Cell type: A123 Li-Ion g-LFP
  - 192s8p configuration: 633,6 Volts, 160 Ah, 101 kWh
  - 480 A/300 kW continuous discharging/charging
  - 1536 cells divided in 24 modules

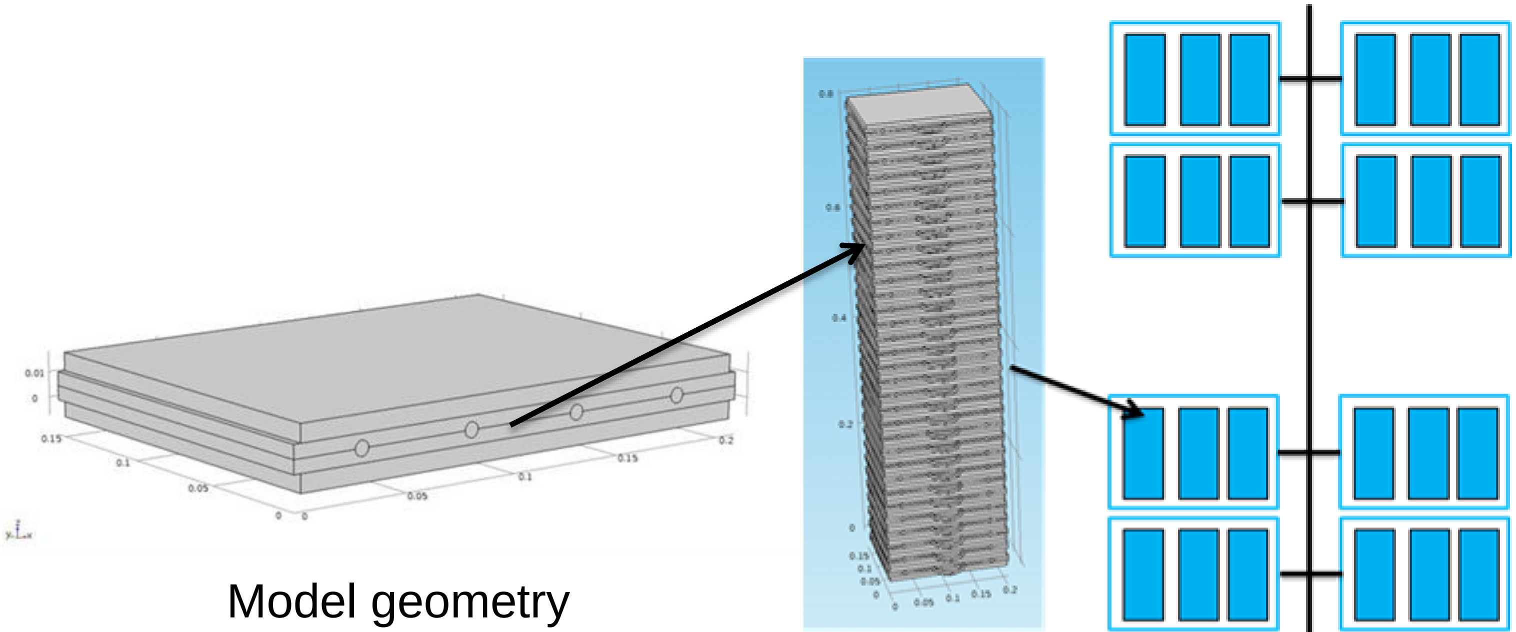
- Next, design is checked based on Simulink/Comsol modeling and validated with experimental data

Modelling

- Models are used to verify dimensioning at different battery lifetime points. The examination is done at cell level.
- Battery voltage under driving profile (u_b) and cell thermal response in the modules T_{db} under different lifetime points are of interest



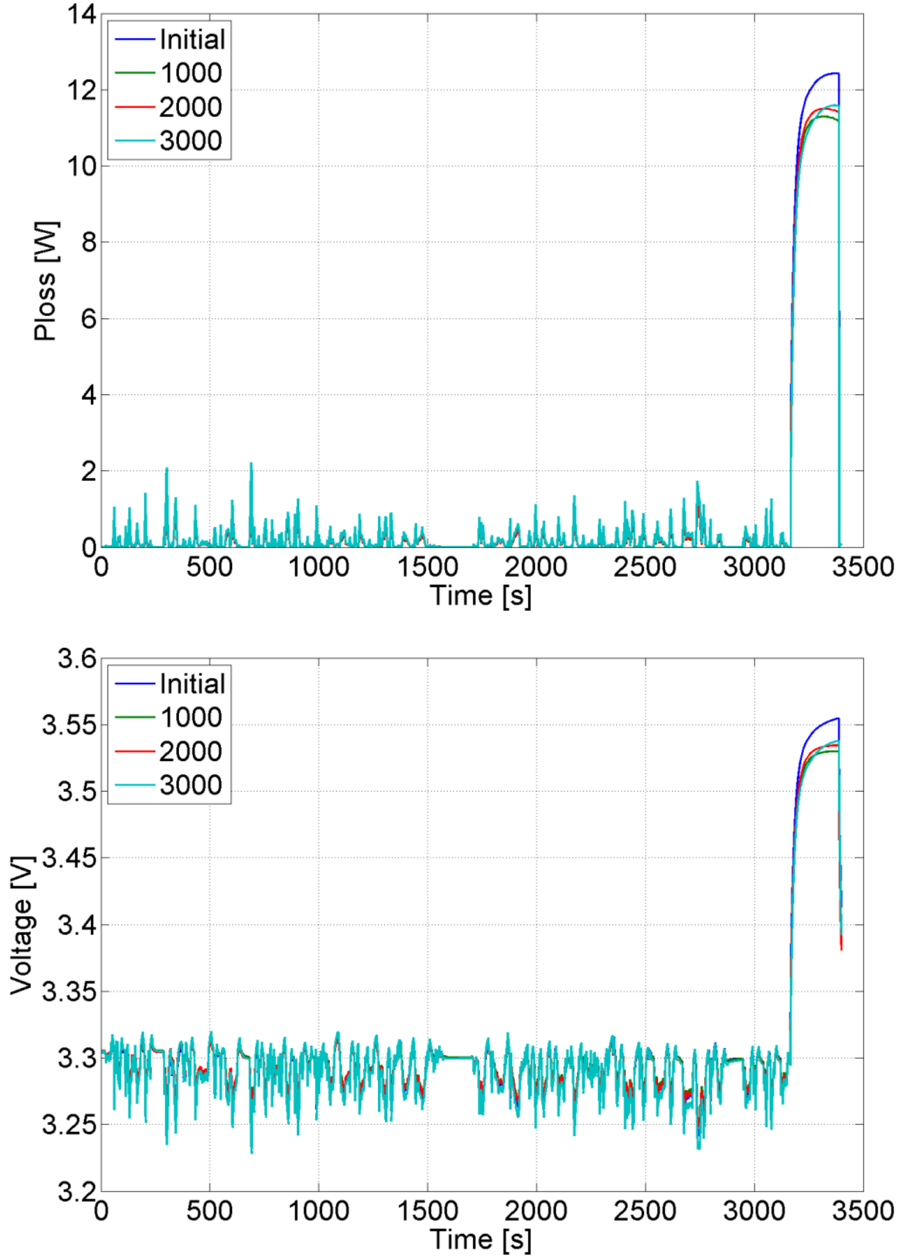
Comsol model



- The model geometry consists of one liquid cooling element between two cells
- These are then assembled to modules and packs

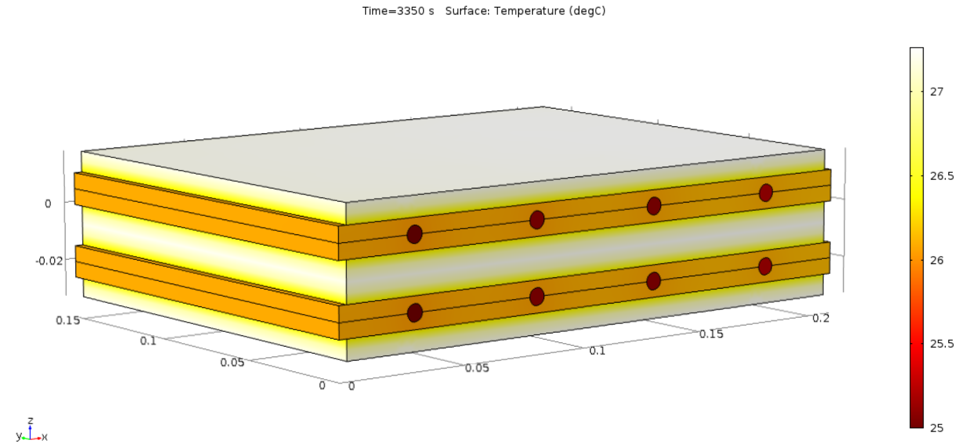
Results – Power loss

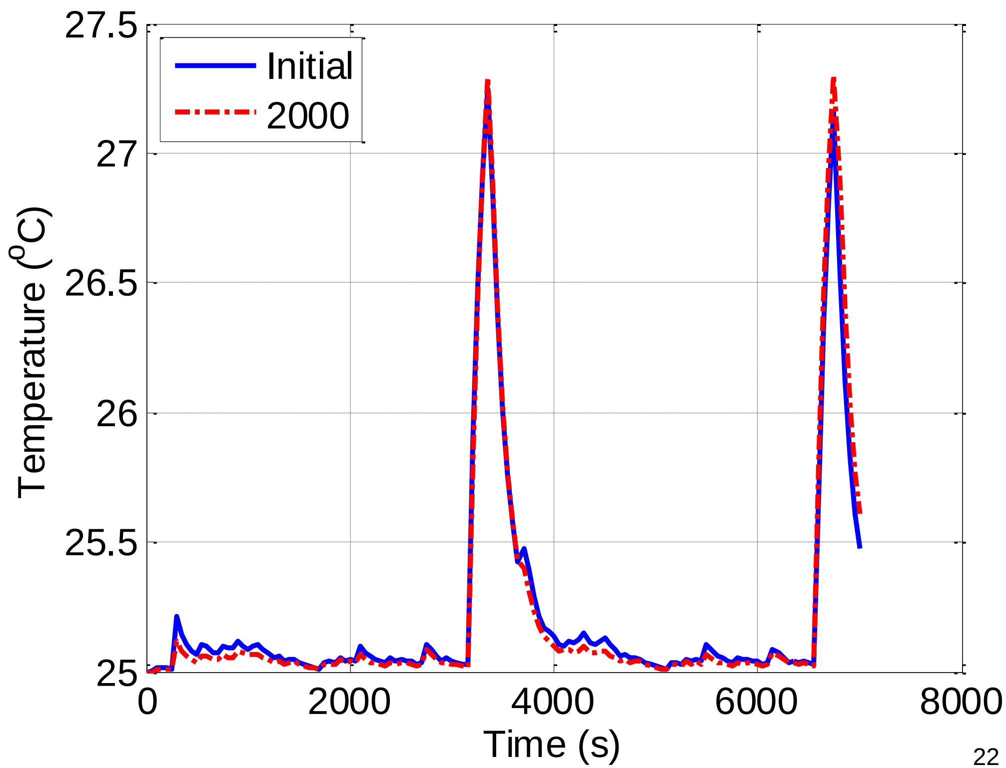
- Although the cell has degraded considerably in capacity, there is no increase in power loss
- The charging capability is retained even after 3000 cycles
  - → The bus can still operate normally aside from decreased range.



Results

- The highest temperatures are at the top of the cell, where the distance to the cooling element is large
- The variance in the temperature is less than 3°C
- There is no big difference in the temperature between degraded and non-degraded cells
- With less effective cooling, larger differences could be seen
- Further research: lighter thermal management systems incl. heat exchangers and different temperatures.





Conclusions

Conclusions

- Research infrastructure from 5 Volts, 600 A to 1000 Volts, 600 A including environmental testing capabilities
- ”Battery database” on the performance of several different automotive grade Li-Ion cells
- Self-built experimental modules for thermal management, BMS and module level lifetime testing
- Modelling tools for product development
    - Electrical performance
    - Power loss calculations
    - Thermal management
- Requirements-driven design approach at system level based on systemic TCO – focus on commercial vehicles and machinery

Final seminar of www.ecv.fi / call for papers

Currently, we have one research position open in applied battery research: https://jobs.vtt.fi/vacancies/5402