FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

From Cell to System

A brief introduction to the design of a battery system

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Fraunhofer Institute for Solar Energy Systems ISE

Joint event - Improving energy efficiency in electric vehicles

Bologna, 24 November 2016

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AGENDA

- Introduction Team Battery Modules and Systems at Fraunhofer Institute for Solar Energy Systems ISE
- Lithium-Ion-Batteries an overview
- Chemistries and shapes
- State of charge estimation
- Battery longevity
- Battery system design

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Team Battery Modules and Systems at Fraunhofer ISE

- **Testing** of batteries (cells, modules, systems)
- **Lifetime** and **thermal optimization**
- Development of battery management systems (**BMS**)
- **Quality assurance** for PV power plants with battery storage
- Electrical, electrochemical and thermal **modeling** (SOC/SOH)
- Optimization of **operational management** of battery systems
- **Safety** concepts

ELAAN

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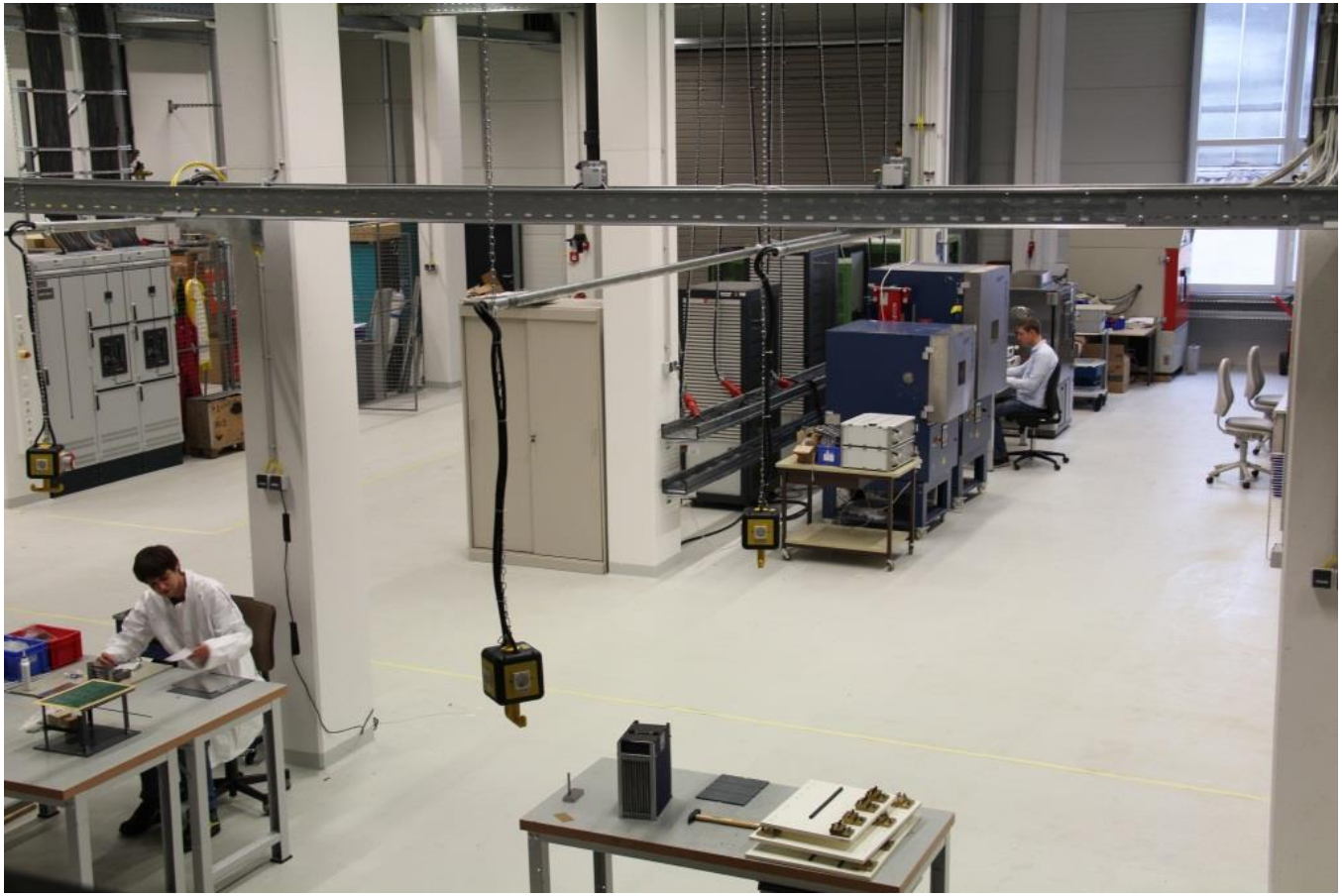
Team Battery Modules and Systems at Fraunhofer ISE

Battery testing and laboratory equipment



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Team Battery Modules and Systems at Fraunhofer ISE

Cell Testing

max. current	**10 A**
max. voltage	Bis 18 V
channels	84
cell example	2 Ah (18650)

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Team Battery Modules and Systems at Fraunhofer ISE

Battery testing and laboratory equipment

300 A Cell tester

IBC284 Calorimeter

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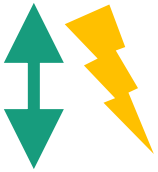
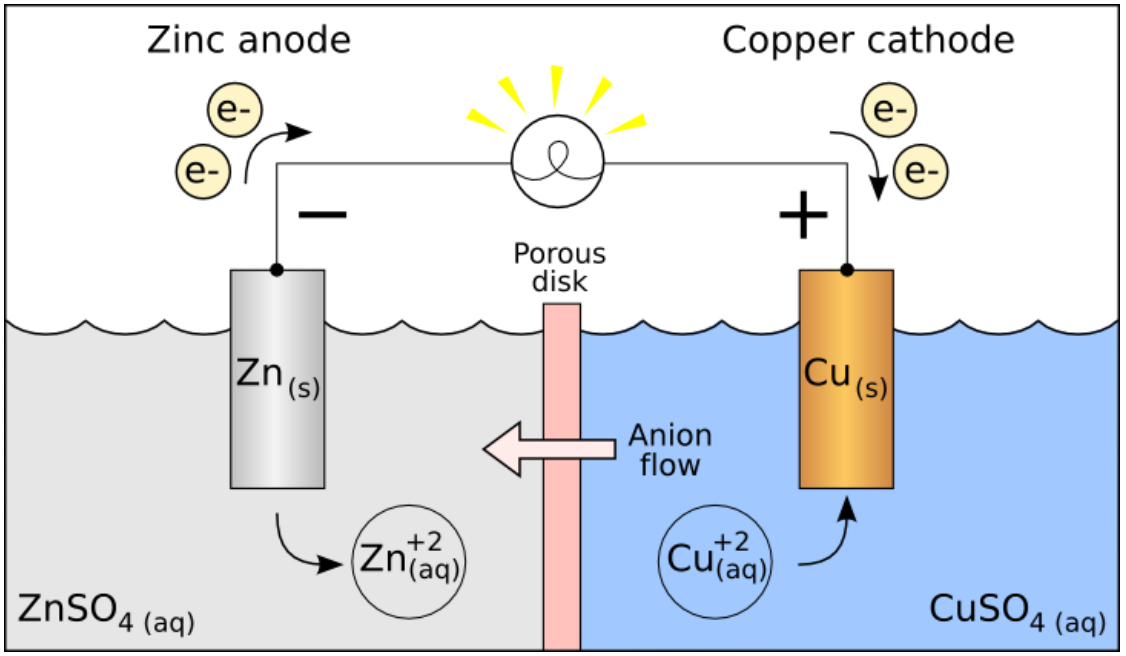
Lithium-Ion-Batteries an overview
Historical review

- 6. November 1780
  Luigi Galvani
  "animal electricity“



- **Alessandro Volta**
  voltaic pile
  (first battery)



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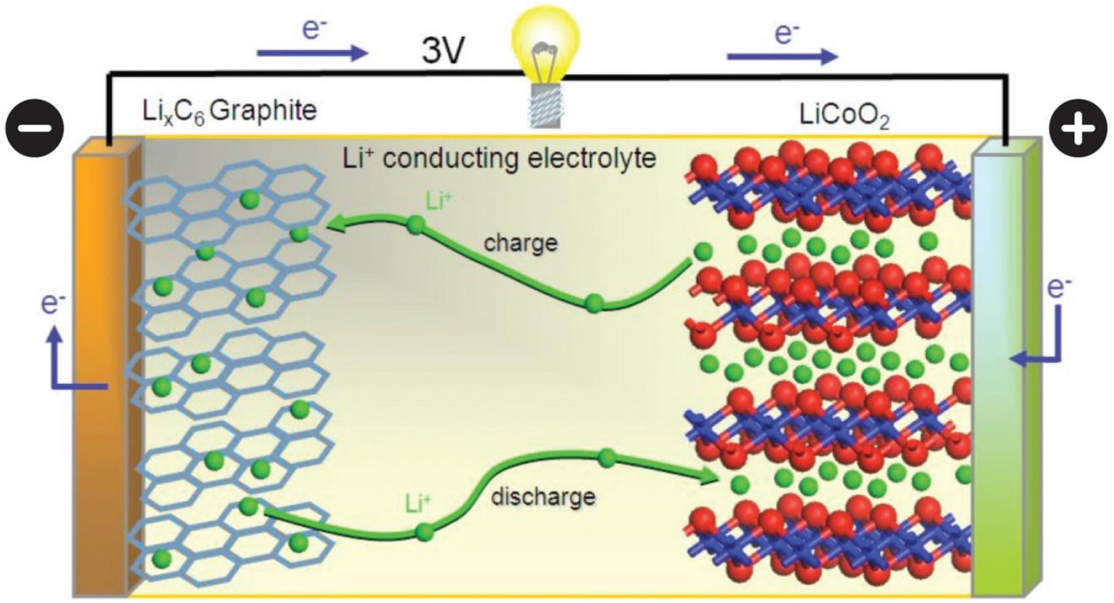
Lithium-Ion-Batteries an overview

Lithium ion (galvanic) cell

- Pro:
  - High energy density
  - No memory effect
  - Rechargeable
  - Long life expectancy
  - Low self-discharge
- Con:
  - Saftey
  - Sensible operating conditions



[Axeon: Our Guide to Batteries. [ONLINE], URL: http://www.jmbatterysystems.com/JMBS/media/JMBS/Technology/Axeon-Guide-to-Batteries-2nd-edition.pdf.]

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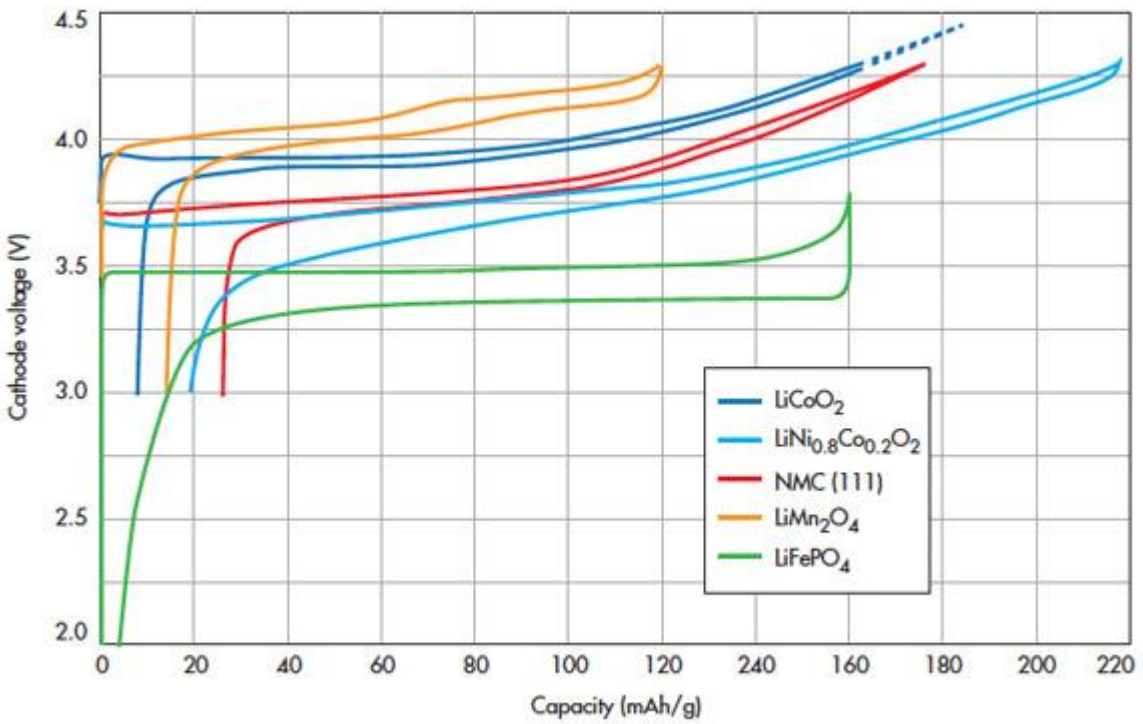
Lithium-Ion-Batteries an overview
Properties

- Voltage U [V]
- Capacity C [Ah])
  (= ∫ I · dt)
- Current I [A]
  - El. resistance
  - Temperature influence



[Don Tuite: Understanding The Factors In The Lithium-Battery Equation; Electronic Design; Jun 22, 2012 [ONLINE], URL: http://electronicdesign.com/power/understanding-factors-lithium-battery-equation.]

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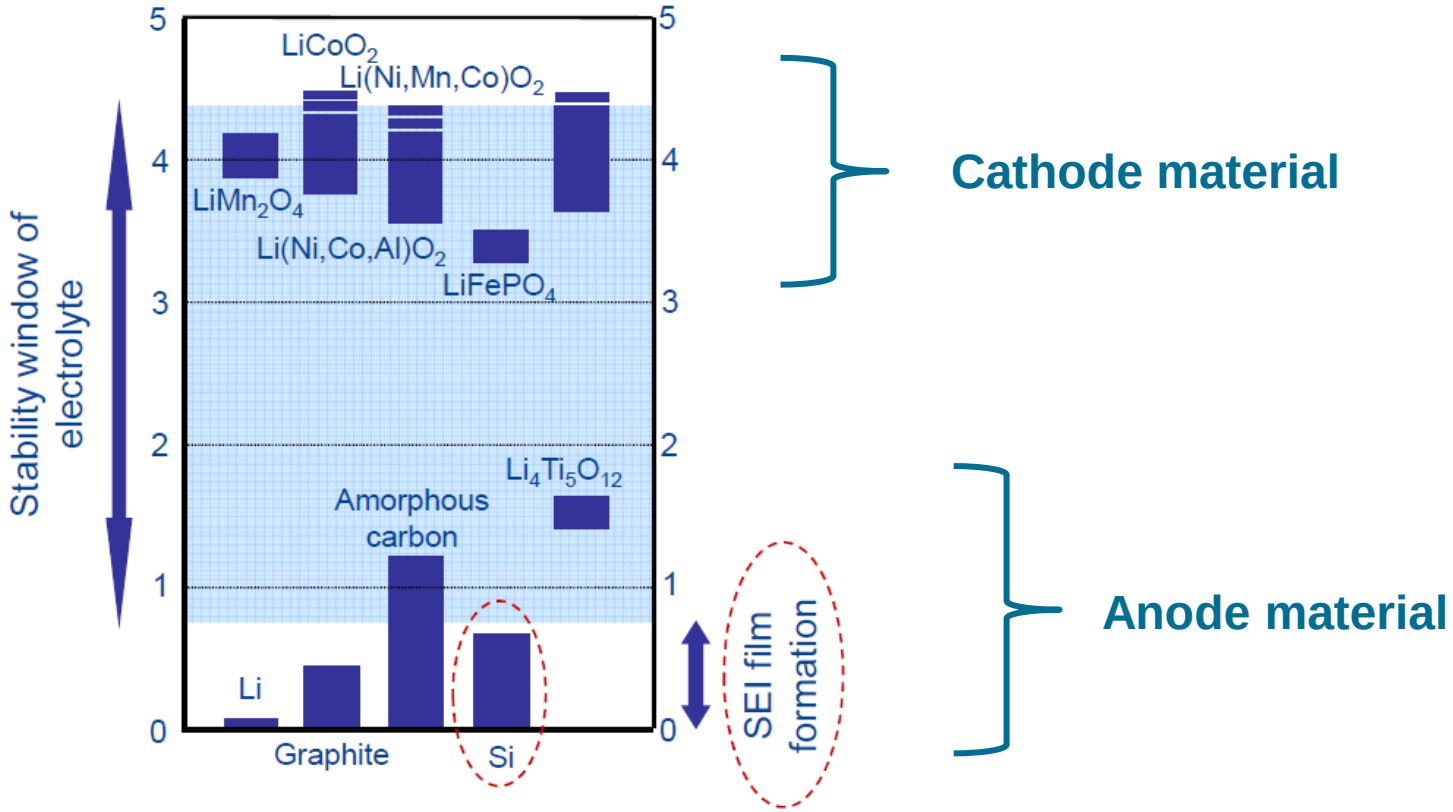
Chemistries and shapes



[Li, J. a.o.: Life cycle tests and resistance characterization of Li-ion cells with Si-based composite anodes. AAB Conference (26.-29. Januar 2015), Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Mainz, 2015.]

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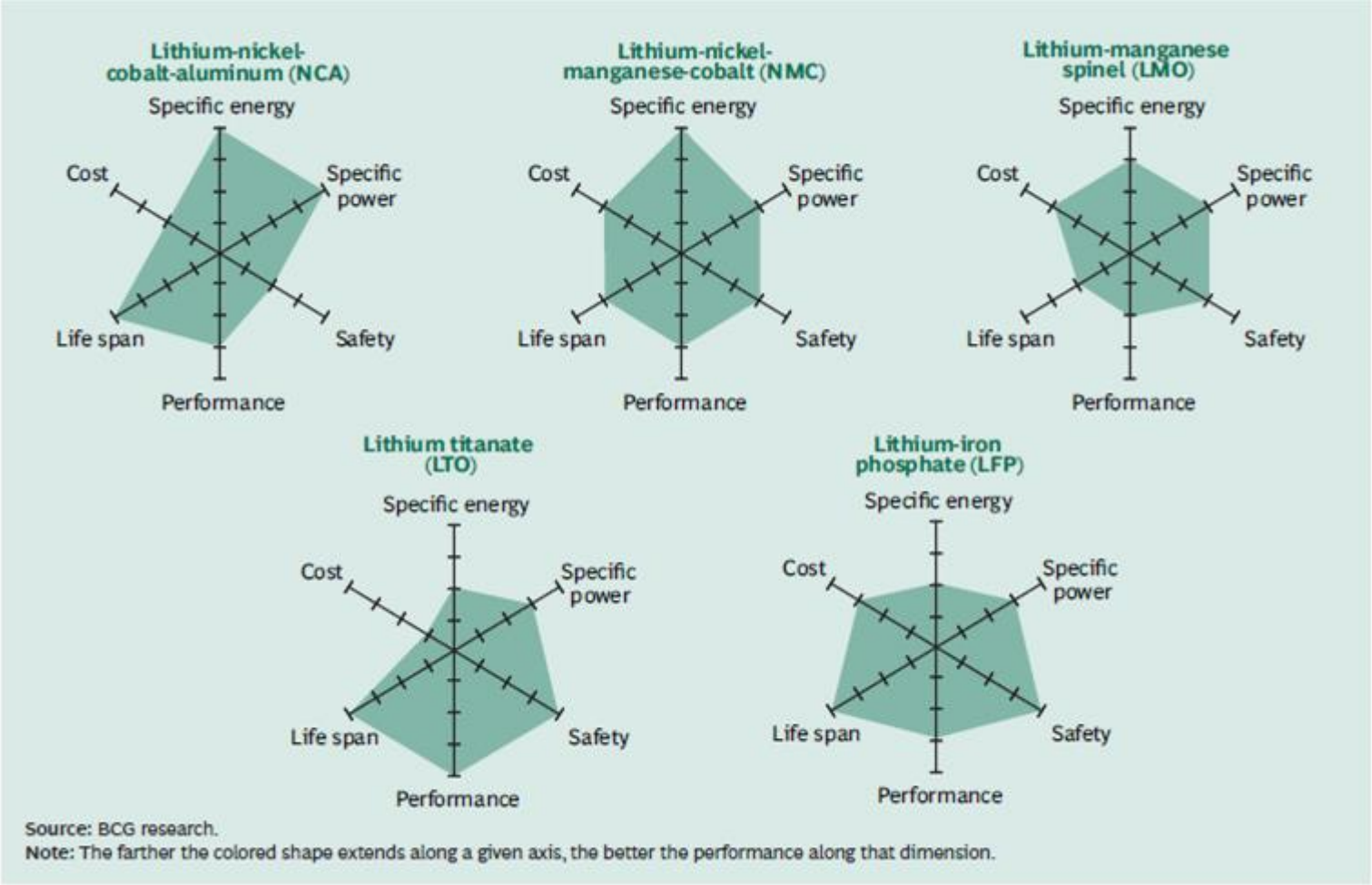
Chemistries and shapes



[Boston Consulting Group: https://www.bcg.com/documents/file36615.pdf 2010]

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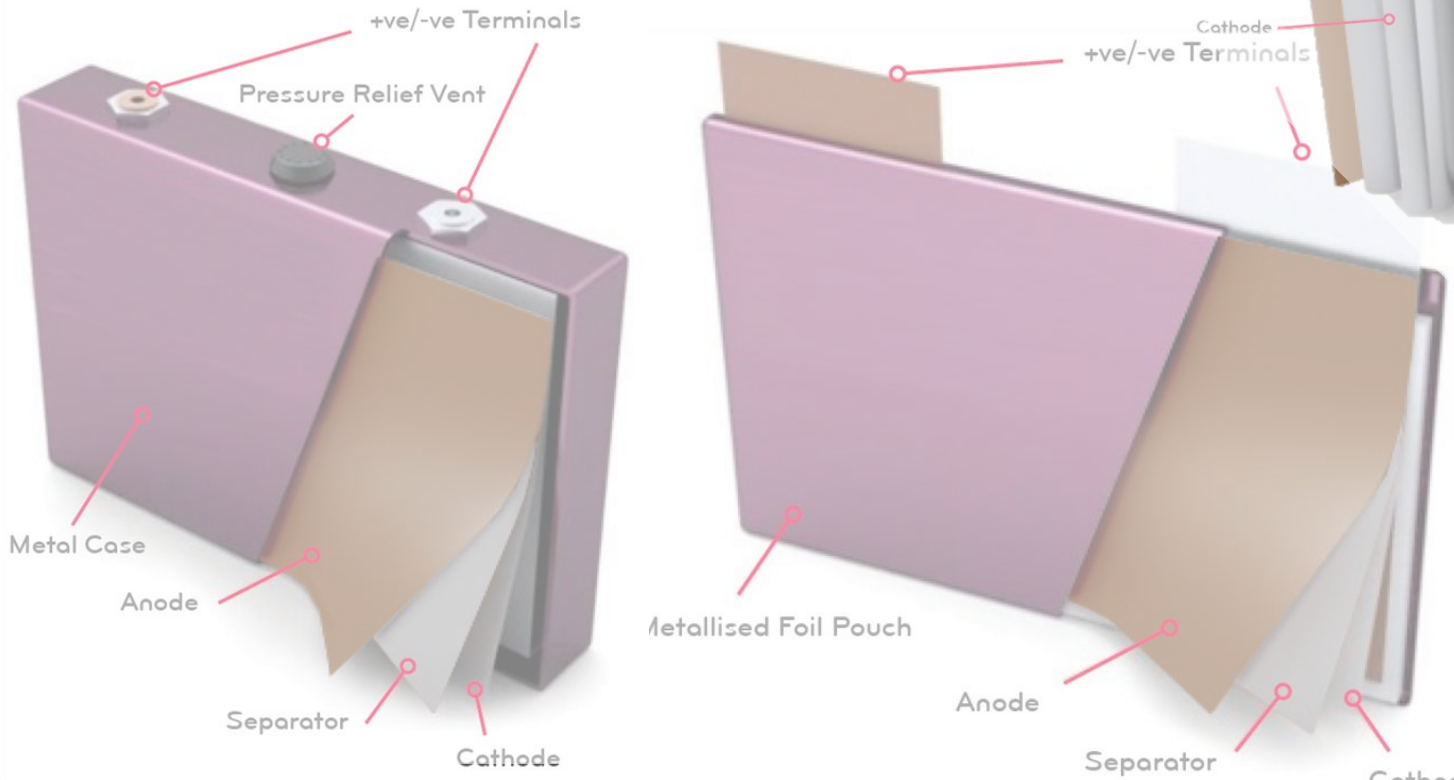
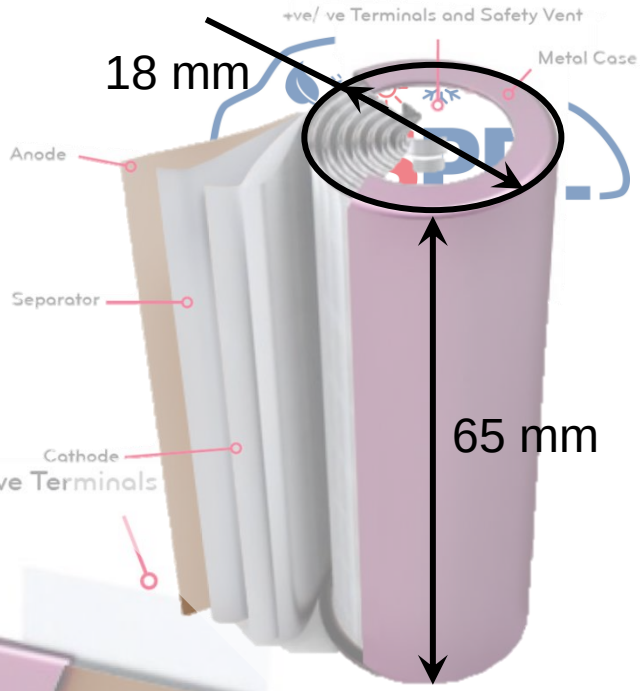
Chemistries and shapes

Shapes

- Three different main shapes





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Chemistries and shapes
Methodical selection

- Benefit analysis
  - Identification of important battery properties (= decision criteria)
  - Database of 49 different battery cells (u.a. lifespan, energy density, maximum charge and discharge currents, geometrie, …)
  - Rating of the decision criteria
  - Weighting by the project partners

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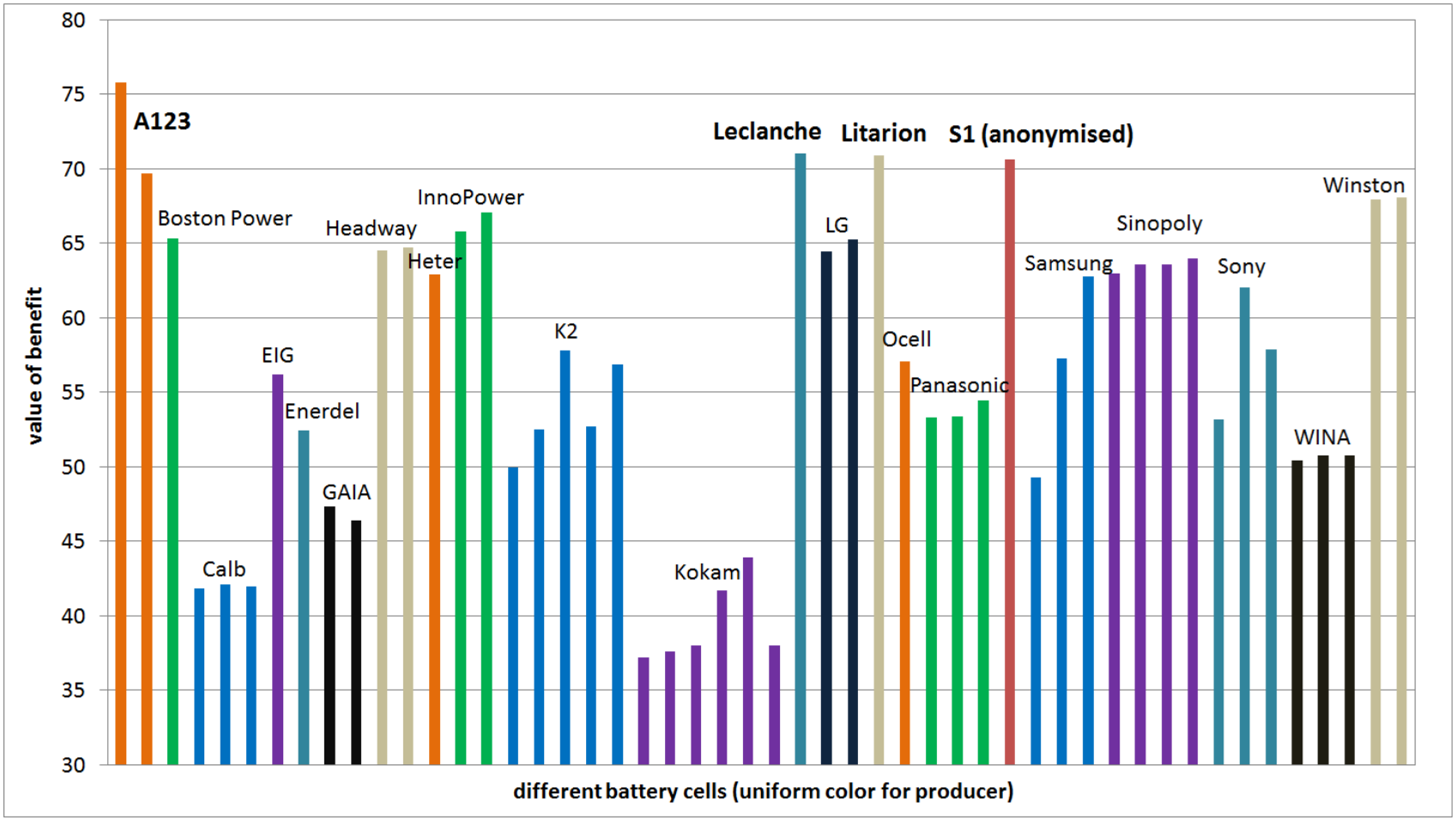
Chemistries and shapes

Methodical selection



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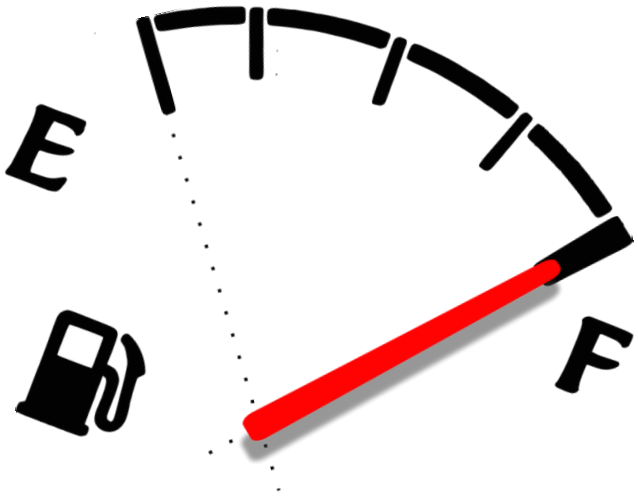
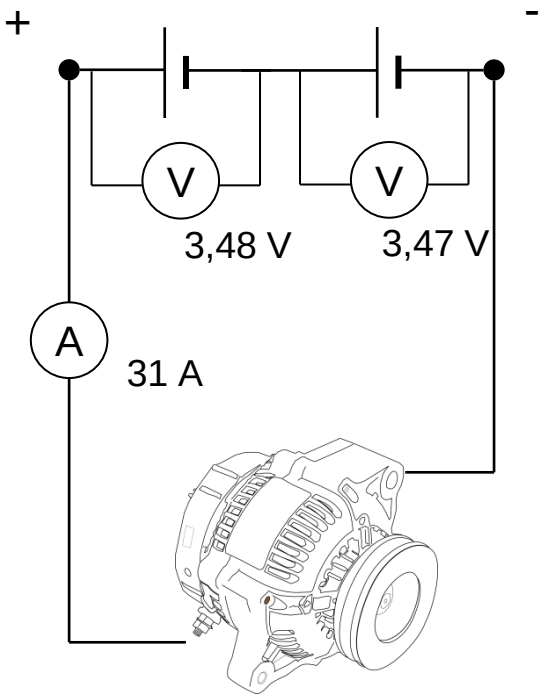
State of charge estimation

Two main methods





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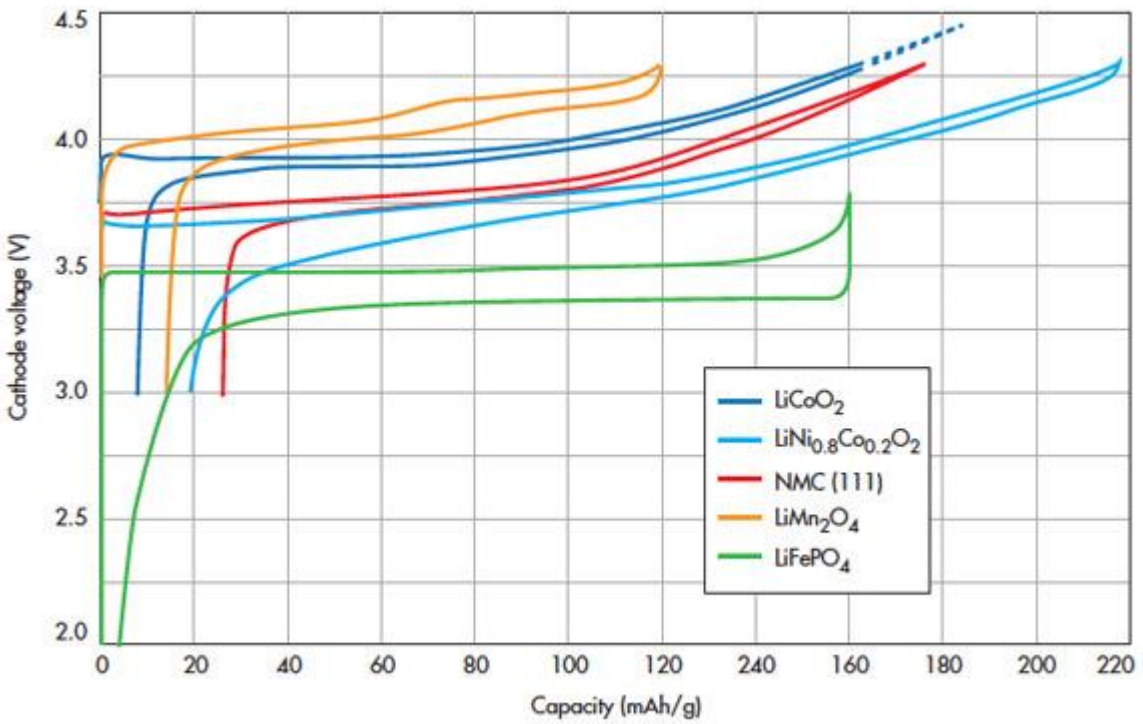
State of charge estimation

Two main methods

- Voltage U [V]
- Capacity C [Ah])
  (= ∫ I · dt)
- Current I [A]
  - El. resistance
  - Temperature influence



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State of charge estimation

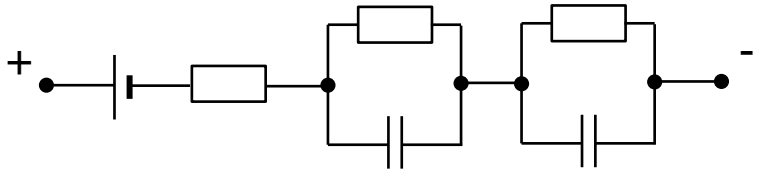
Two main methods

- Voltage U [V]
- Capacity C [Ah])
  (= ∫ I · dt)
- Current I [A]
  - El. resistance
  - Temperature influence

„Amp counting“

Voltage <-> SOC relationship

- Electrical model needed
- Statistic filter (kalman filter)



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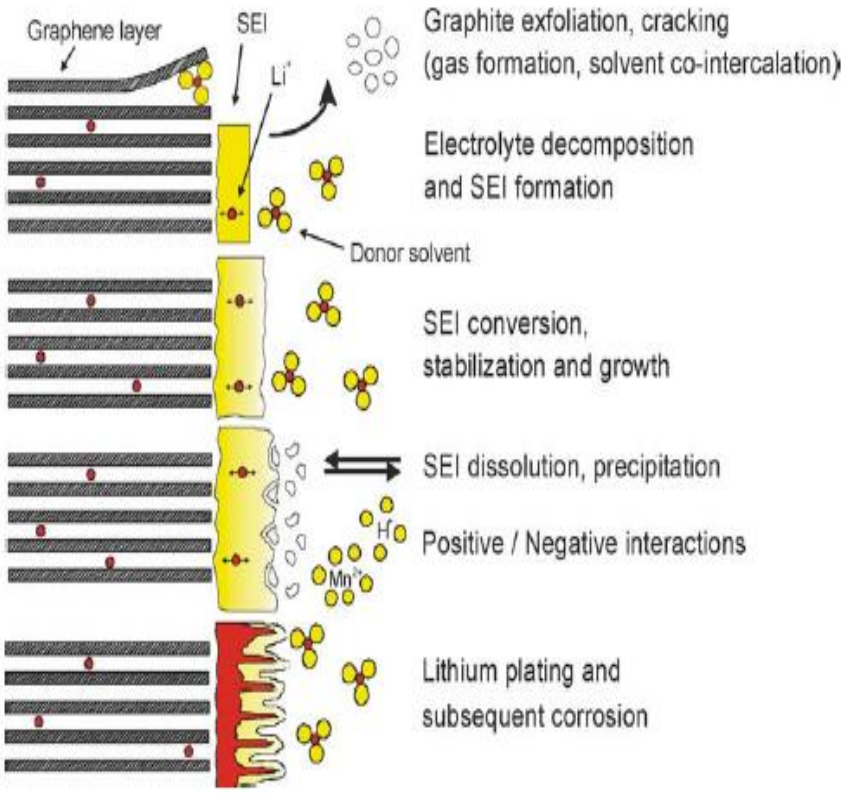
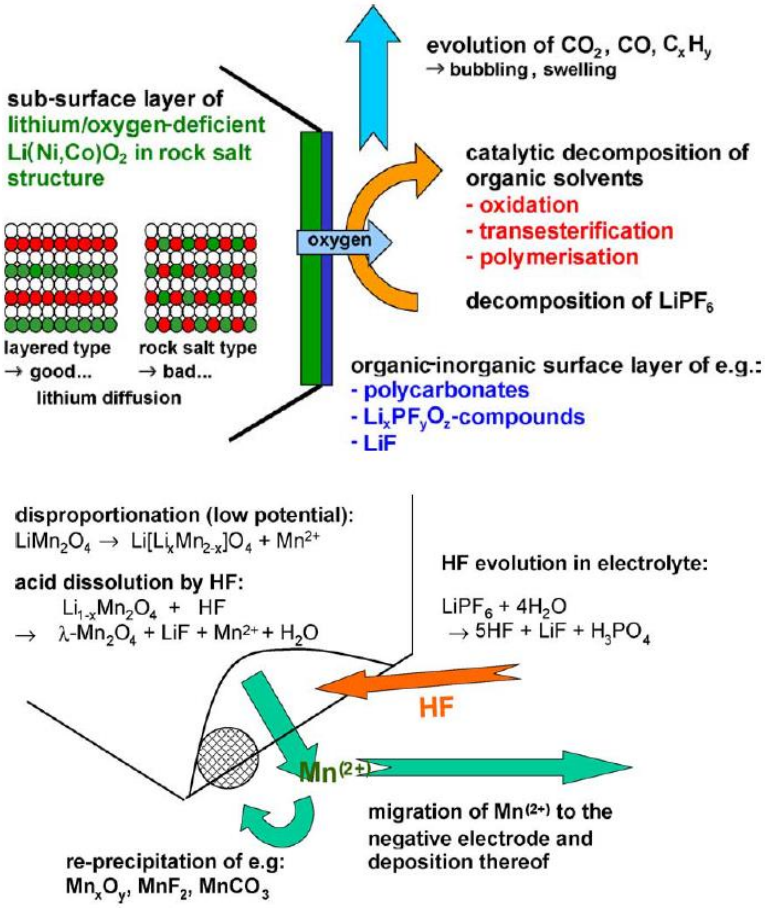
Battery longevity
Ageing processes





[J. Vetter et al, J. Power Sources 147(2005) 269-281]

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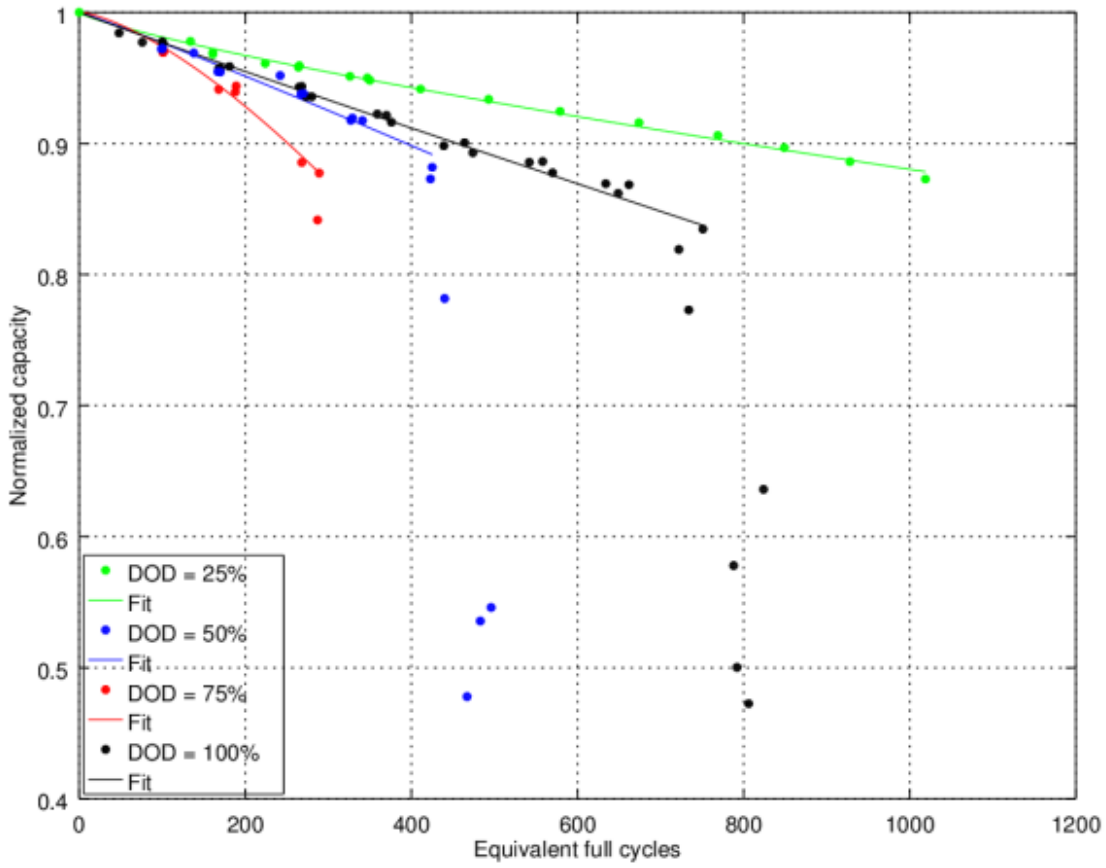
Battery longevity
Ageing behaviour



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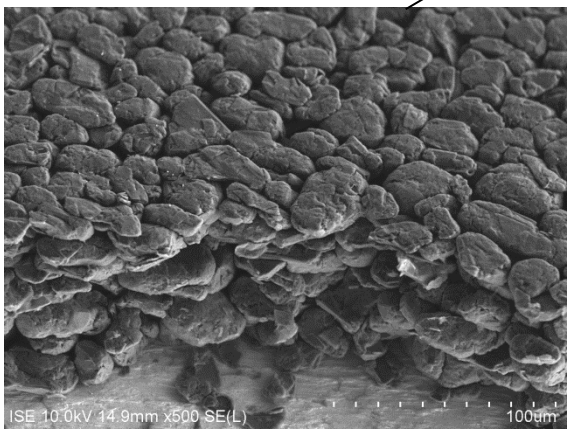
Battery longevity
Ageing behaviour

Graphite anode:



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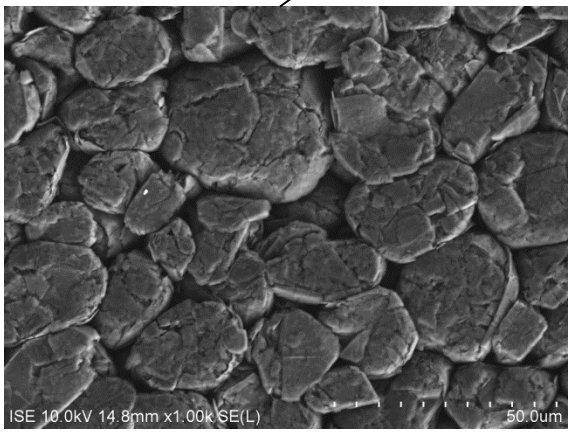
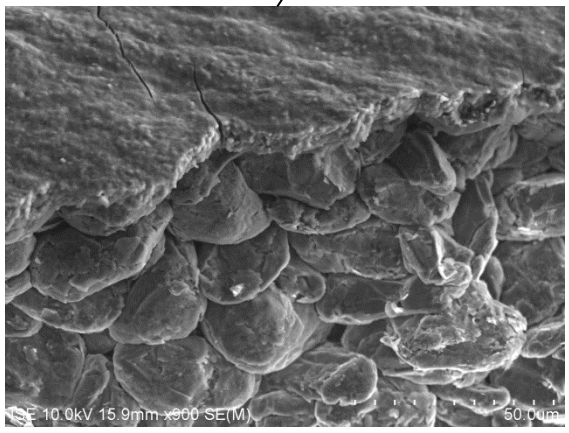


In linear aging stage



In non-linear aging stage

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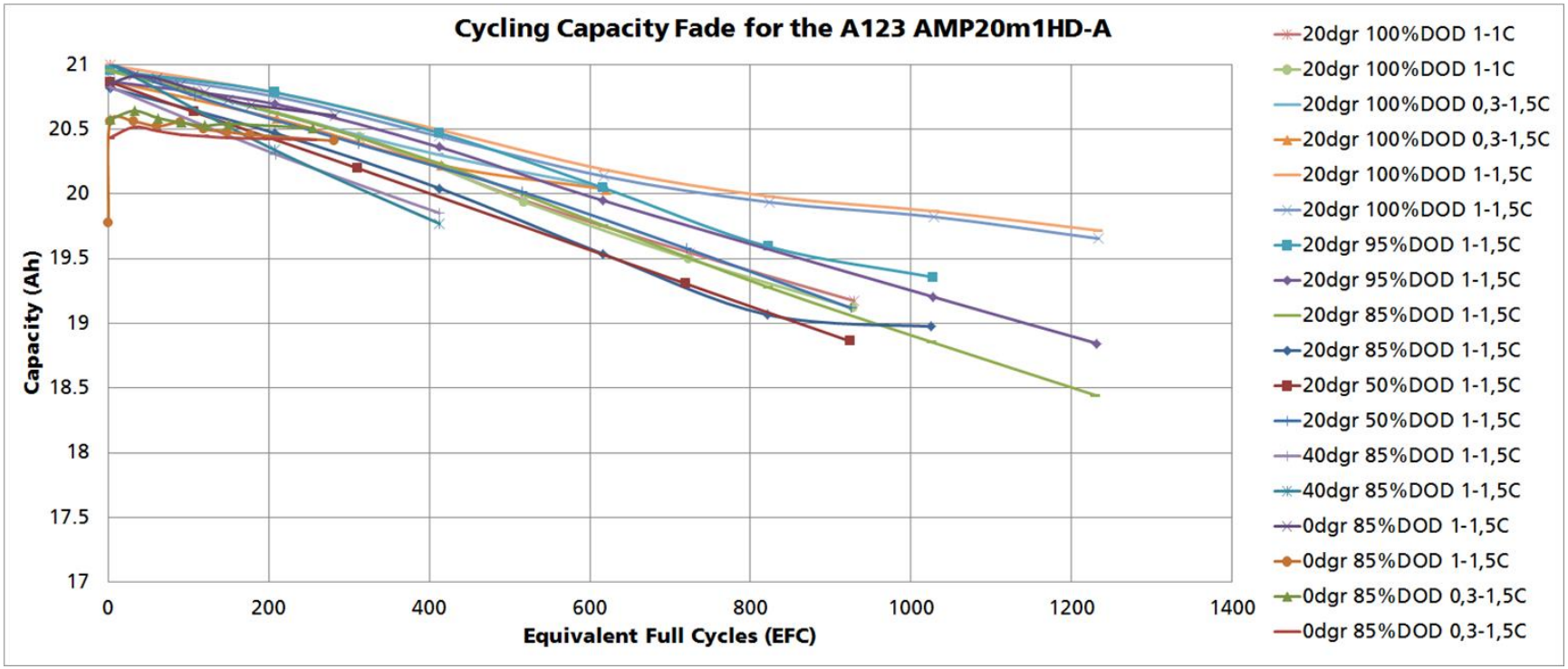
Battery longevity
Ageing behaviour in JOSPEL

- cycling



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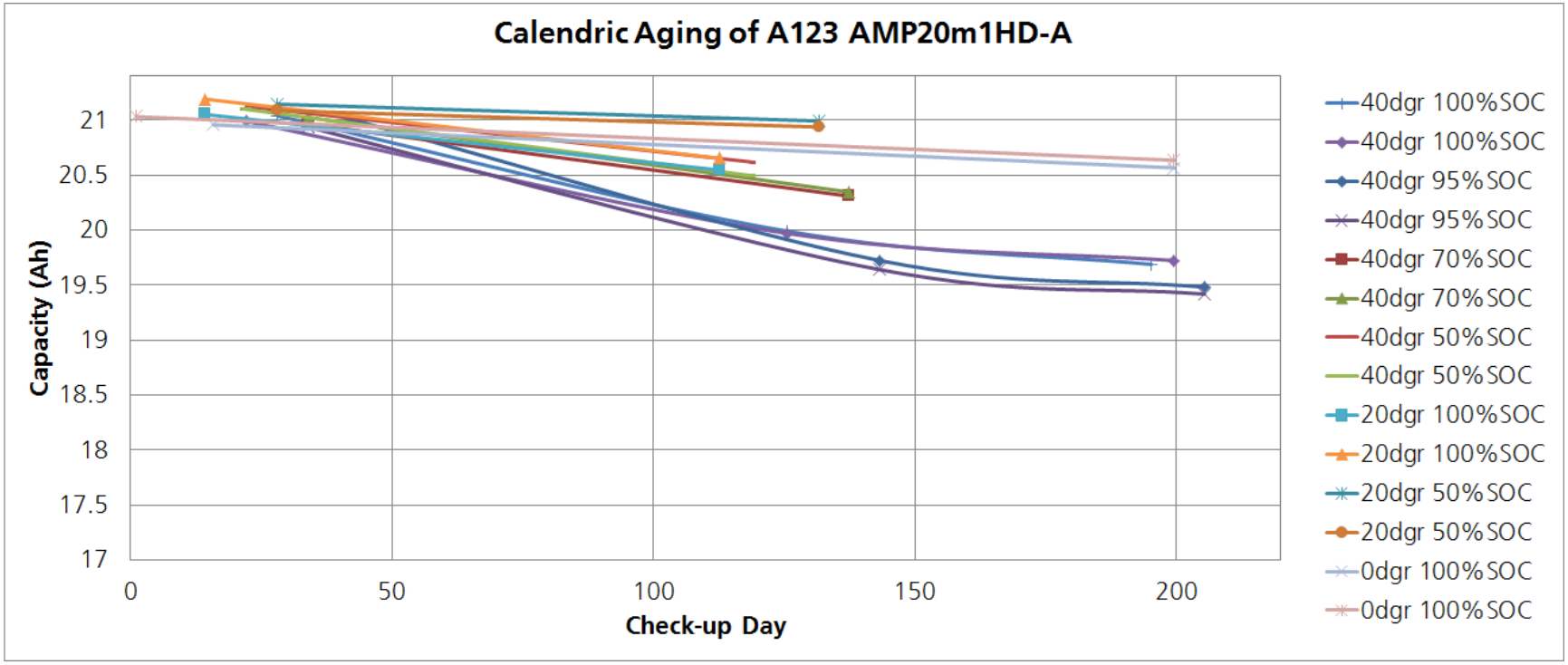
Battery longevity
Ageing behaviour in JOSPEL

- calendaric



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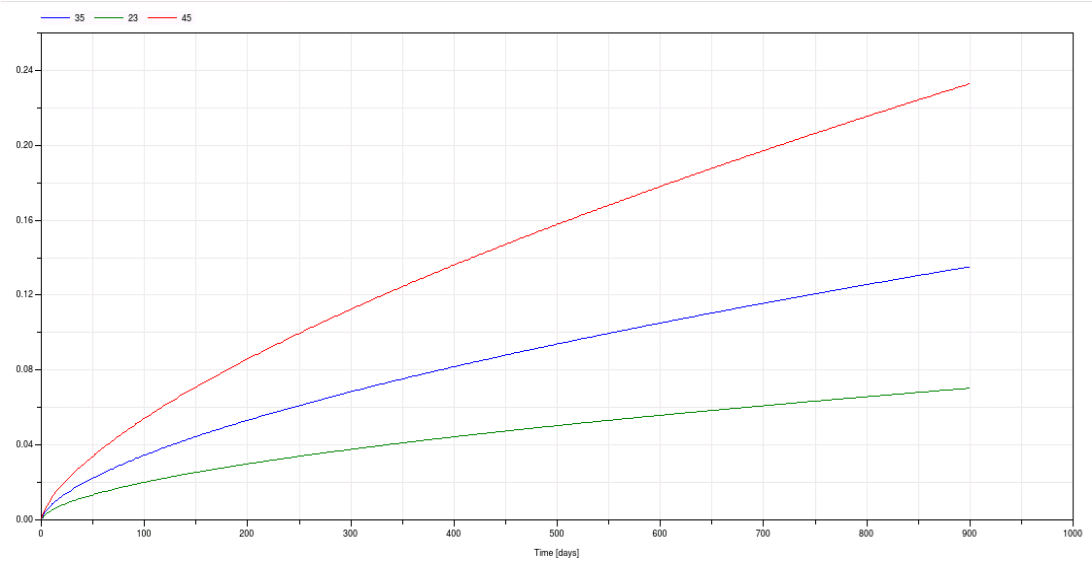
Battery longevity
Ageing model

- preliminary model
  - calendaric

C-loss = $f_{(SOC)} \cdot F_1 \cdot e^{(F_2 \cdot T)} \cdot t^{(F_3 \cdot T + F_4)}$



[Battery Pack Design, Validation, and Assembly Guide using A123 Systms AMP20M1HD-A Nanophosphate Cells]

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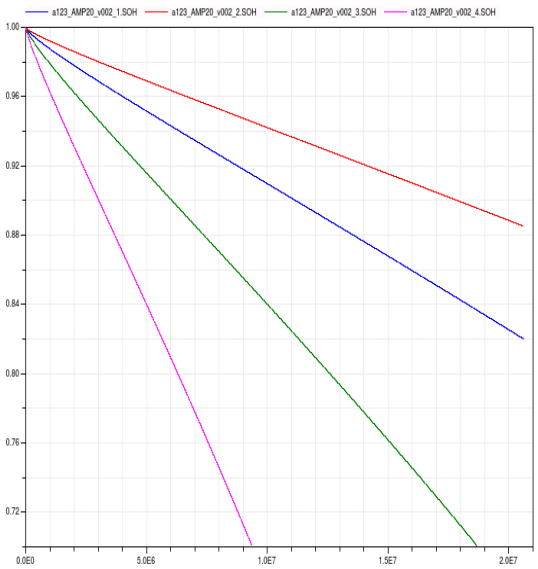
Battery longevity
Ageing model

- preliminary model
  - calendaric

$$\text{C-loss} = f_{(SOC)} \cdot F_1 \cdot e^{(F_2 \cdot T)} \cdot t^{(F_3 \cdot T + F_4)}$$

  - operation:

$$\text{C-loss} = F_5 \cdot e^{(F_6 \cdot T)} \cdot \underbrace{\int |I_{(t)}| \cdot dt}_{\text{State of Health (SOH)}}$$



[Battery Pack Design, Validation, and Assembly Guide using A123 Systms AMP20M1HD-A Nanophosphate Cells]

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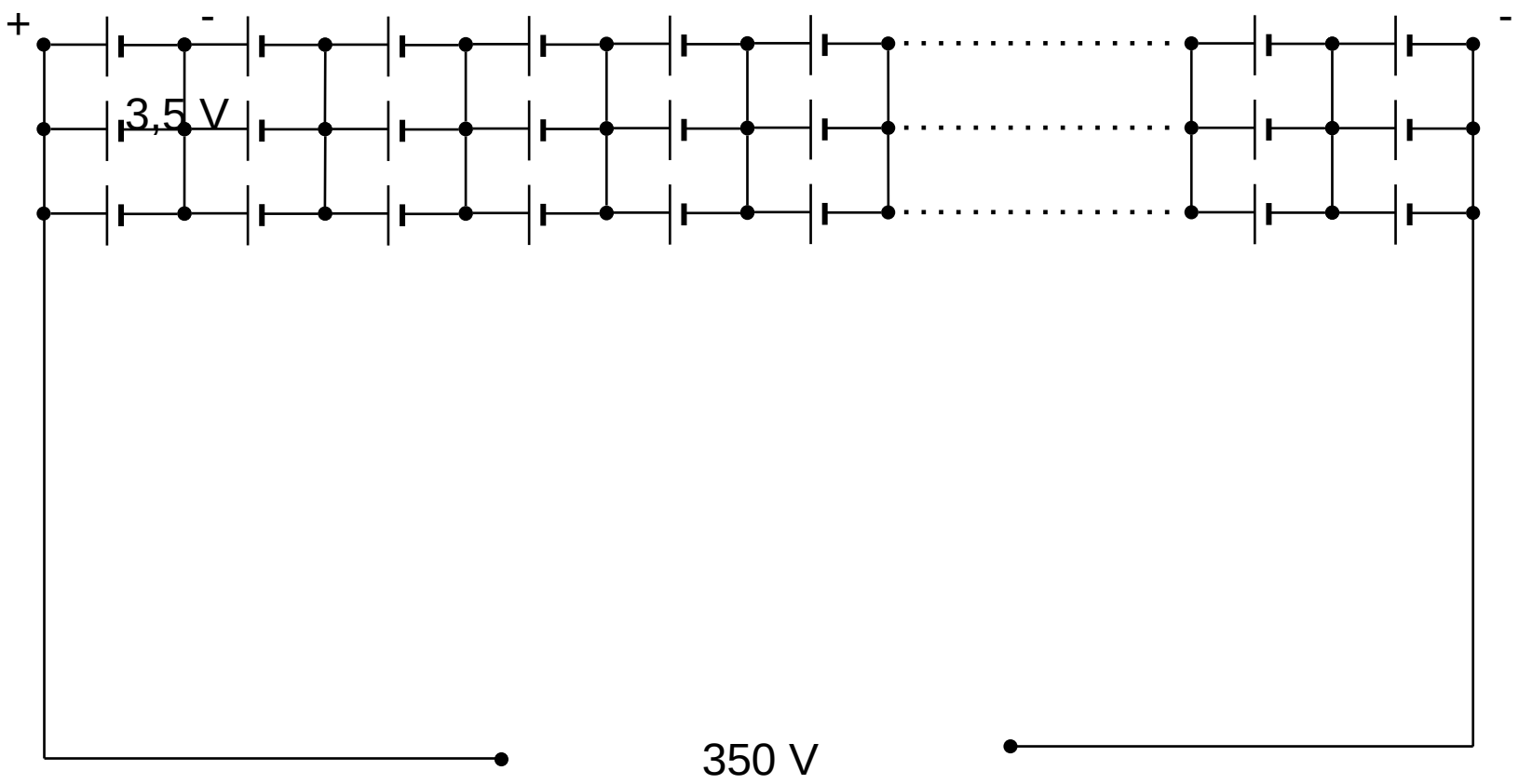
Battery system design
Electrical layout



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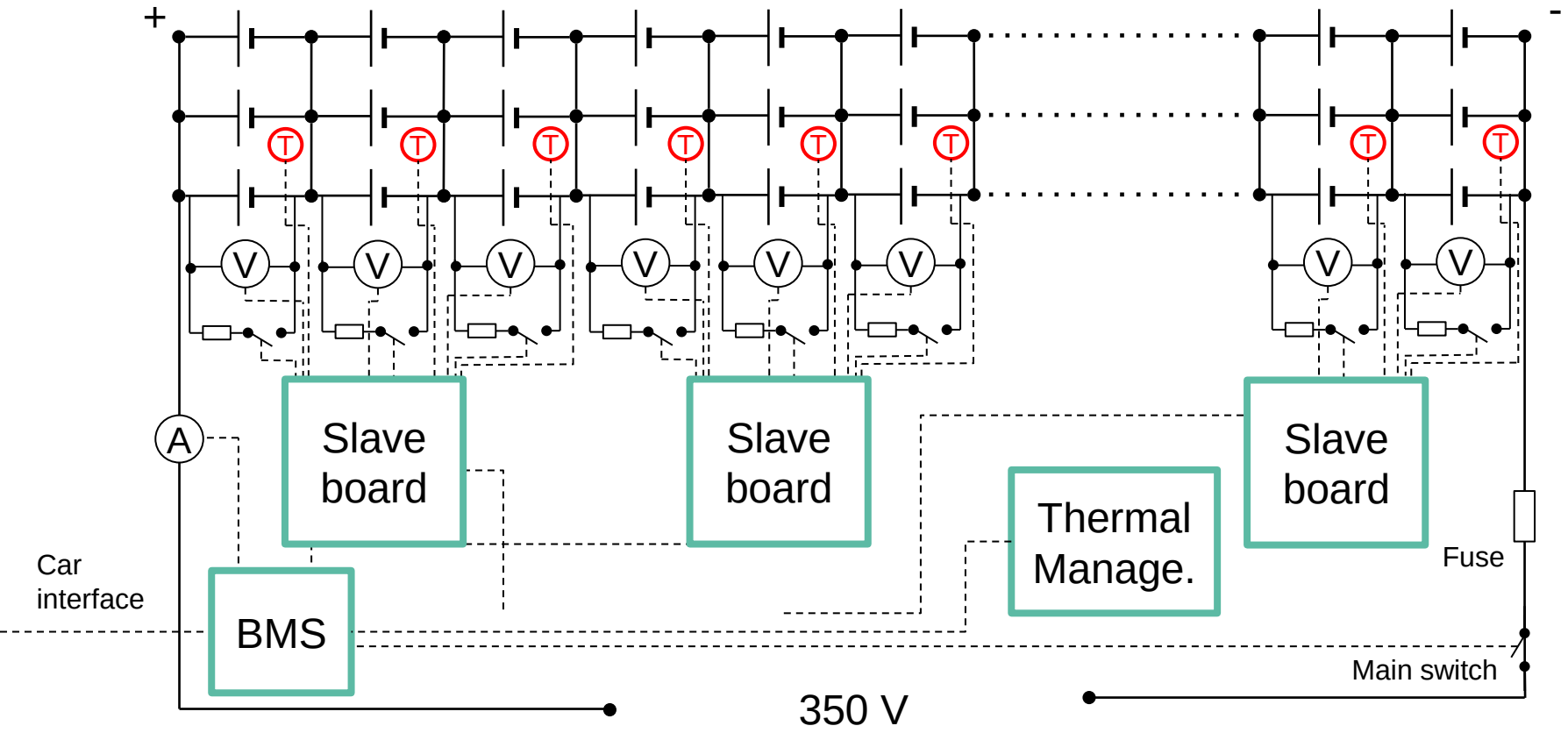
Battery system design
Battery management



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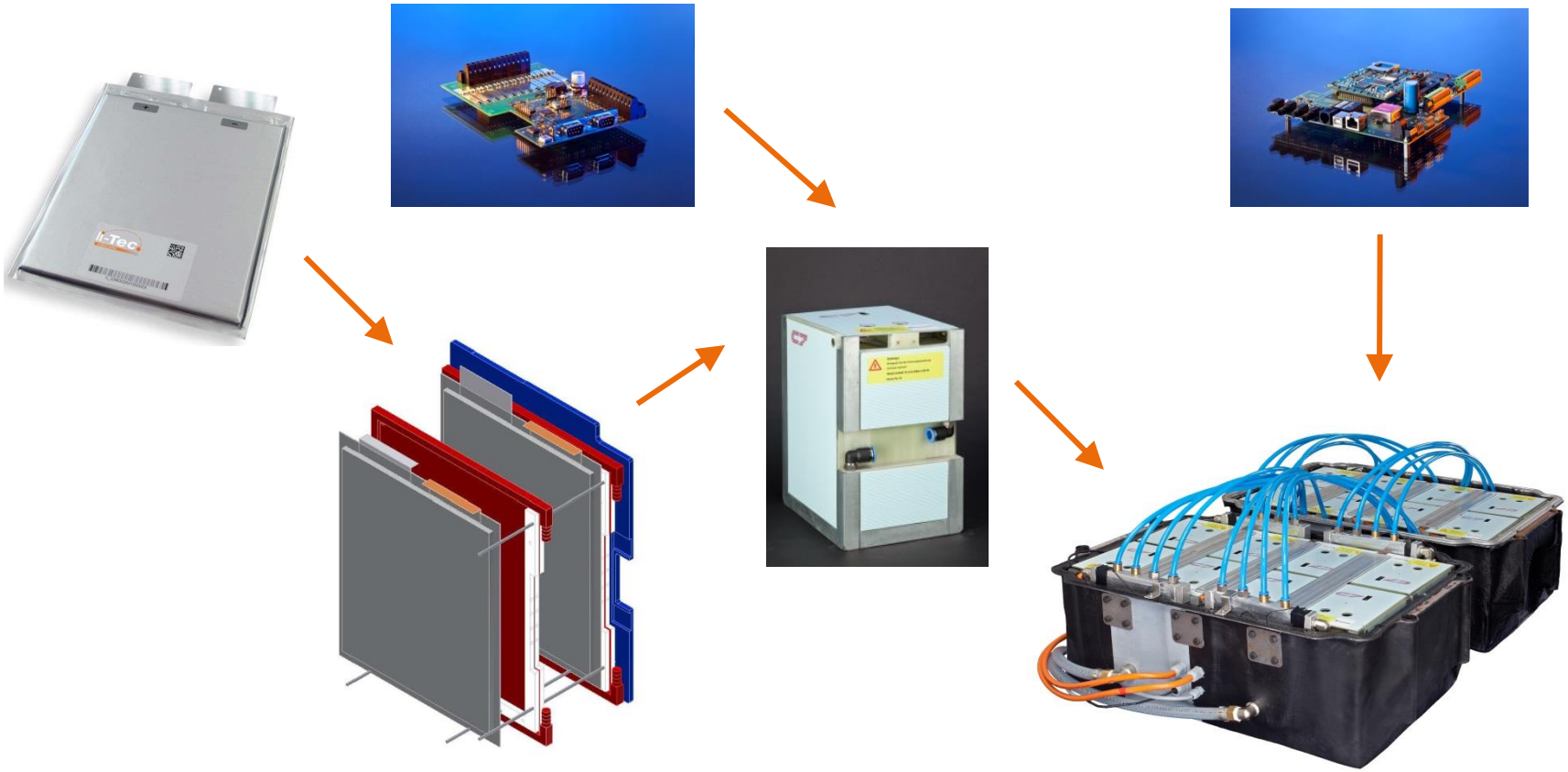
Battery system design

Battery system assembly



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Battery system design

Battery system assembly

Wheel-hub motor
(including power electronics)

Battery 28 kWh

Fraunhofer E-Concept Car Typ 0
FrECC0 (Photo Fraunhofer IFAM)

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Battery system design

Thermal Management examples – BMW i3

[Youtube: https://www.youtube.com/watch?v=pa5_tudyAF8]

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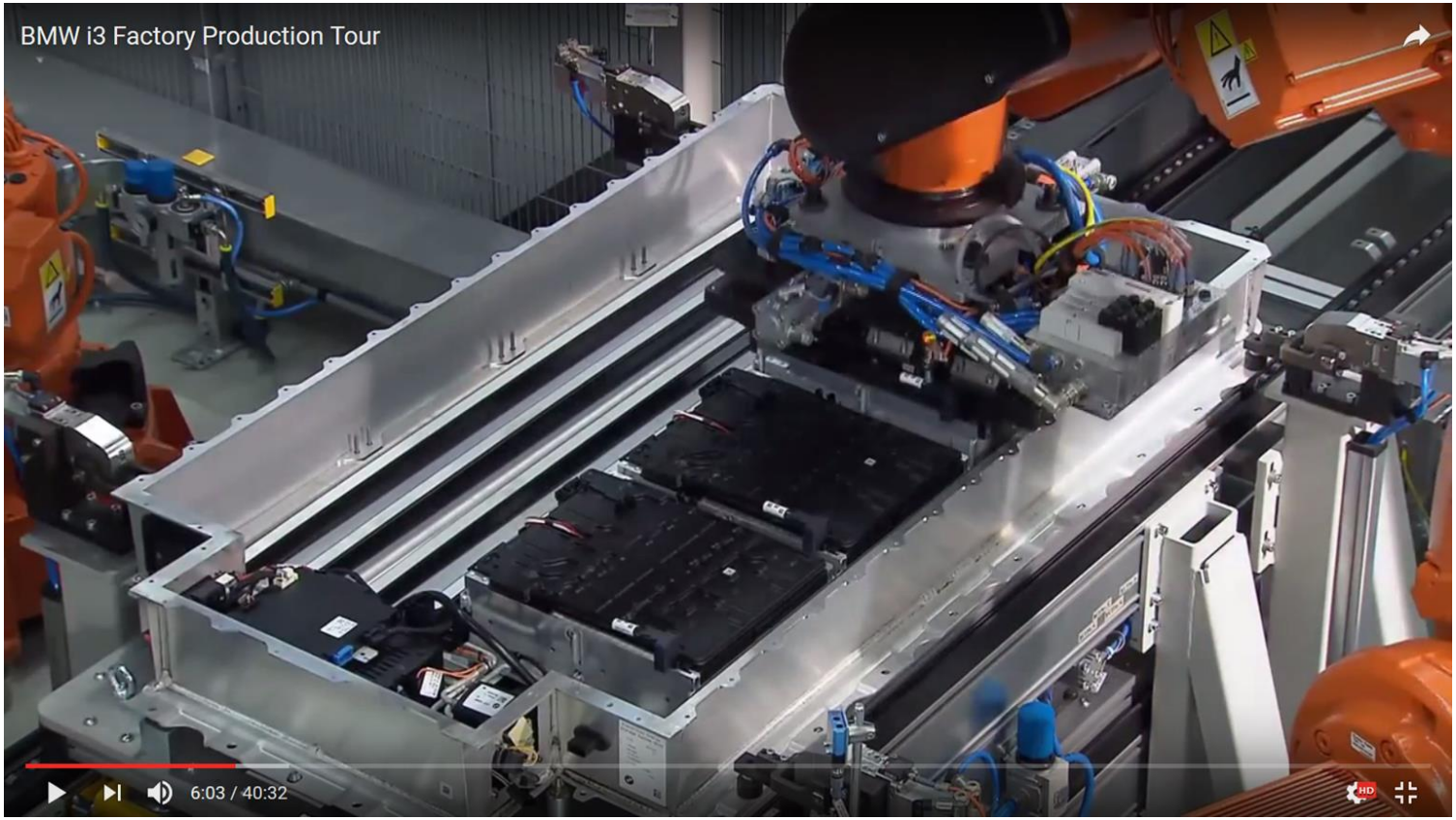
Battery system design

Thermal Management examples – BMW i3



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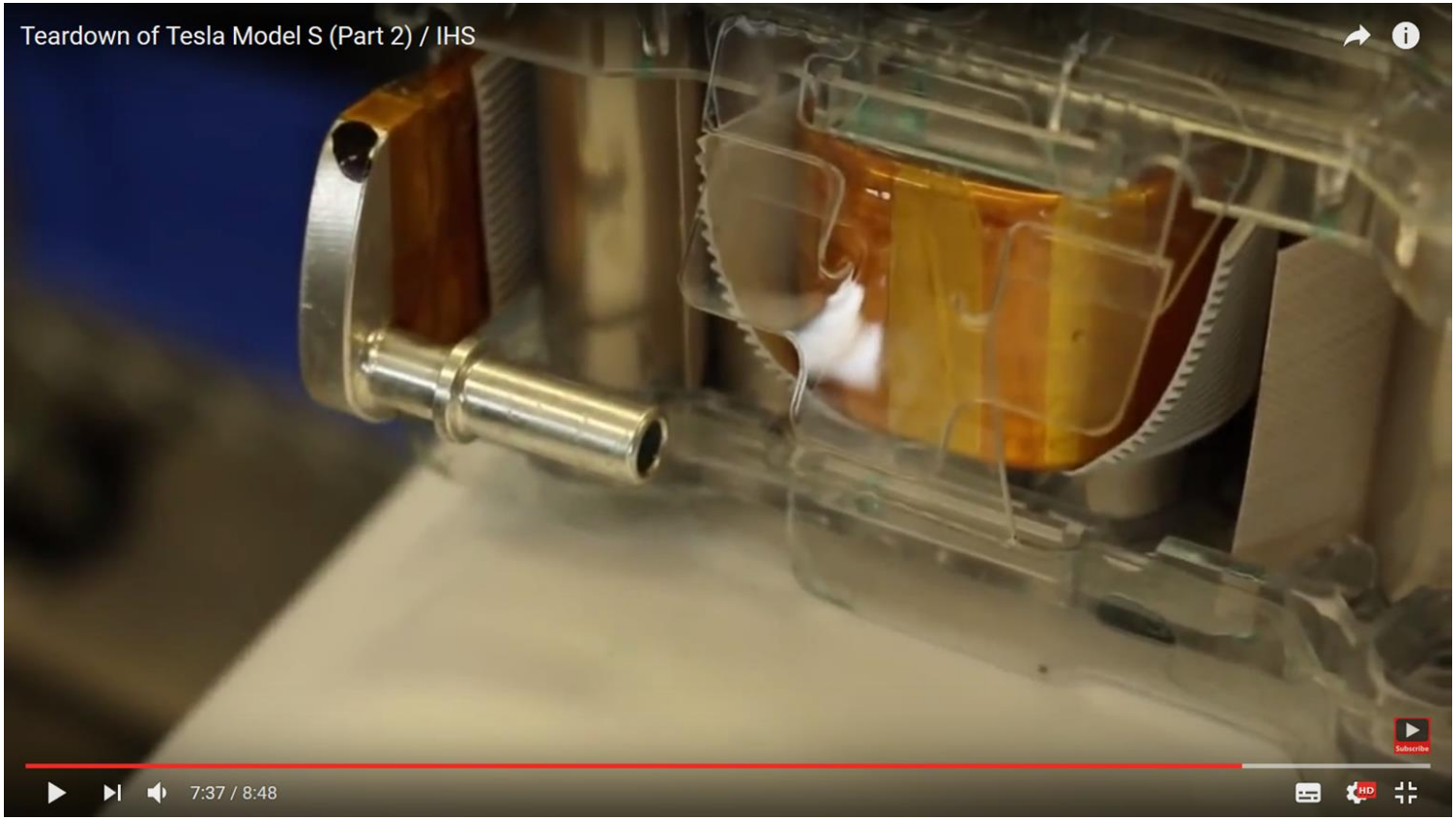
Battery system design

Thermal Management examples – Tesla



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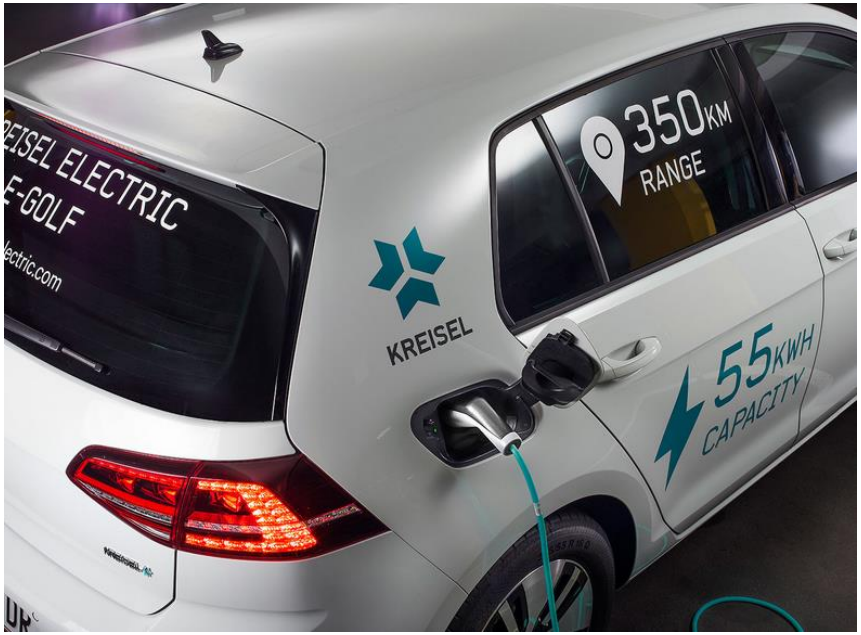
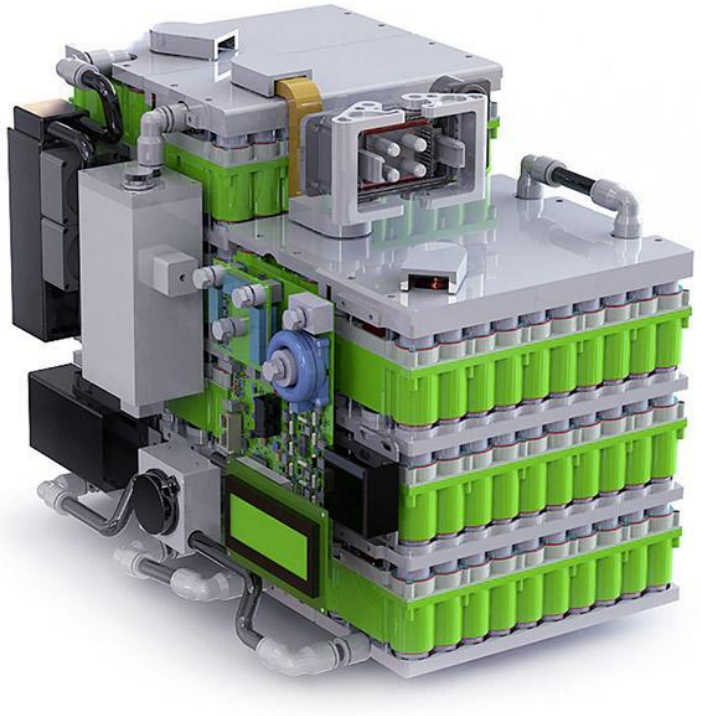
Battery system design

Thermal Management examples – KREISEL





[Kreisel: [Online] www.kreiselelectric.com/technologie/batteriesystem/akkupack/ www.kreiselelectric.com/projekte/electric-golf/]

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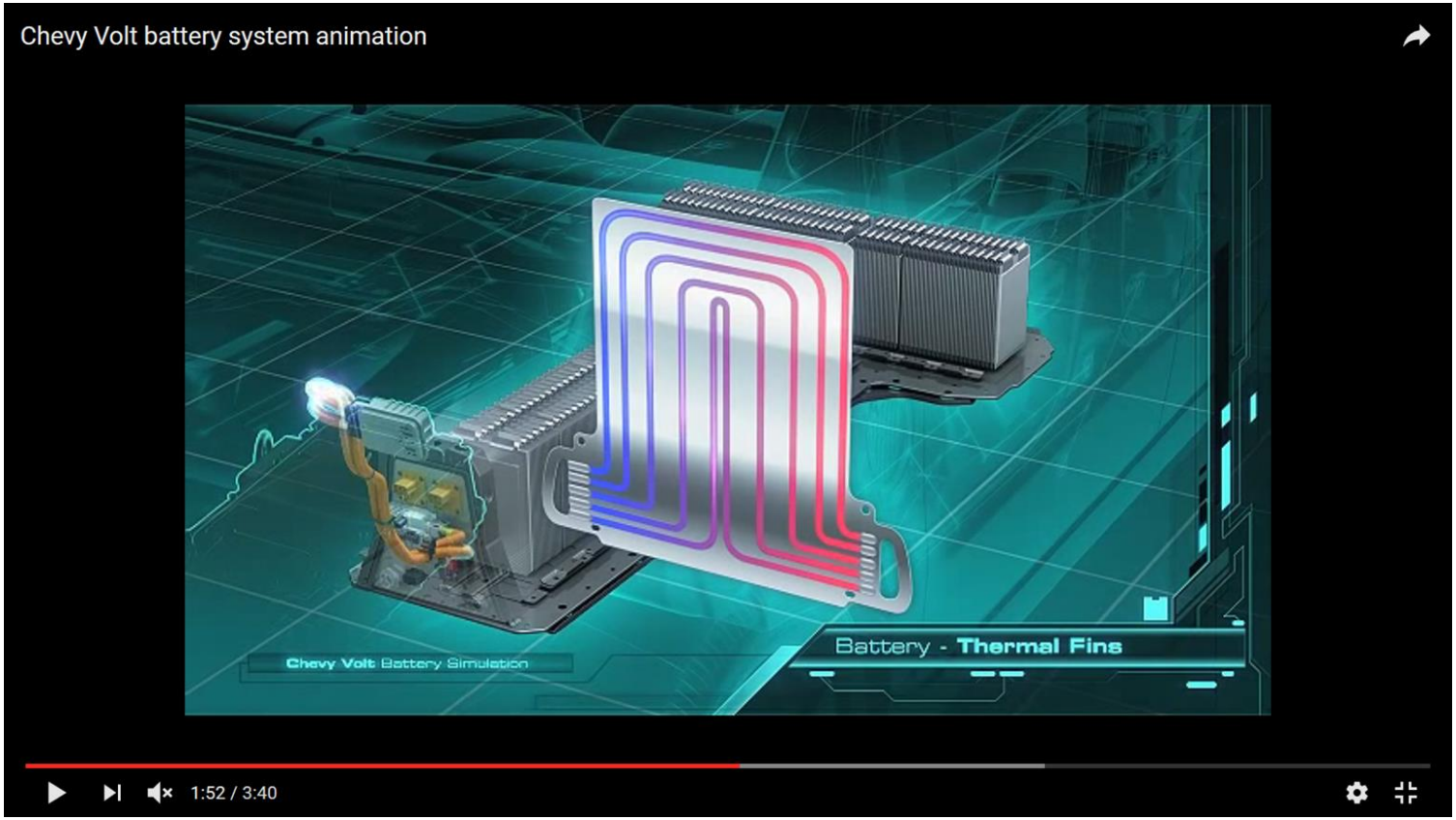
Battery system design

Thermal Management examples – Chevrolet Volt



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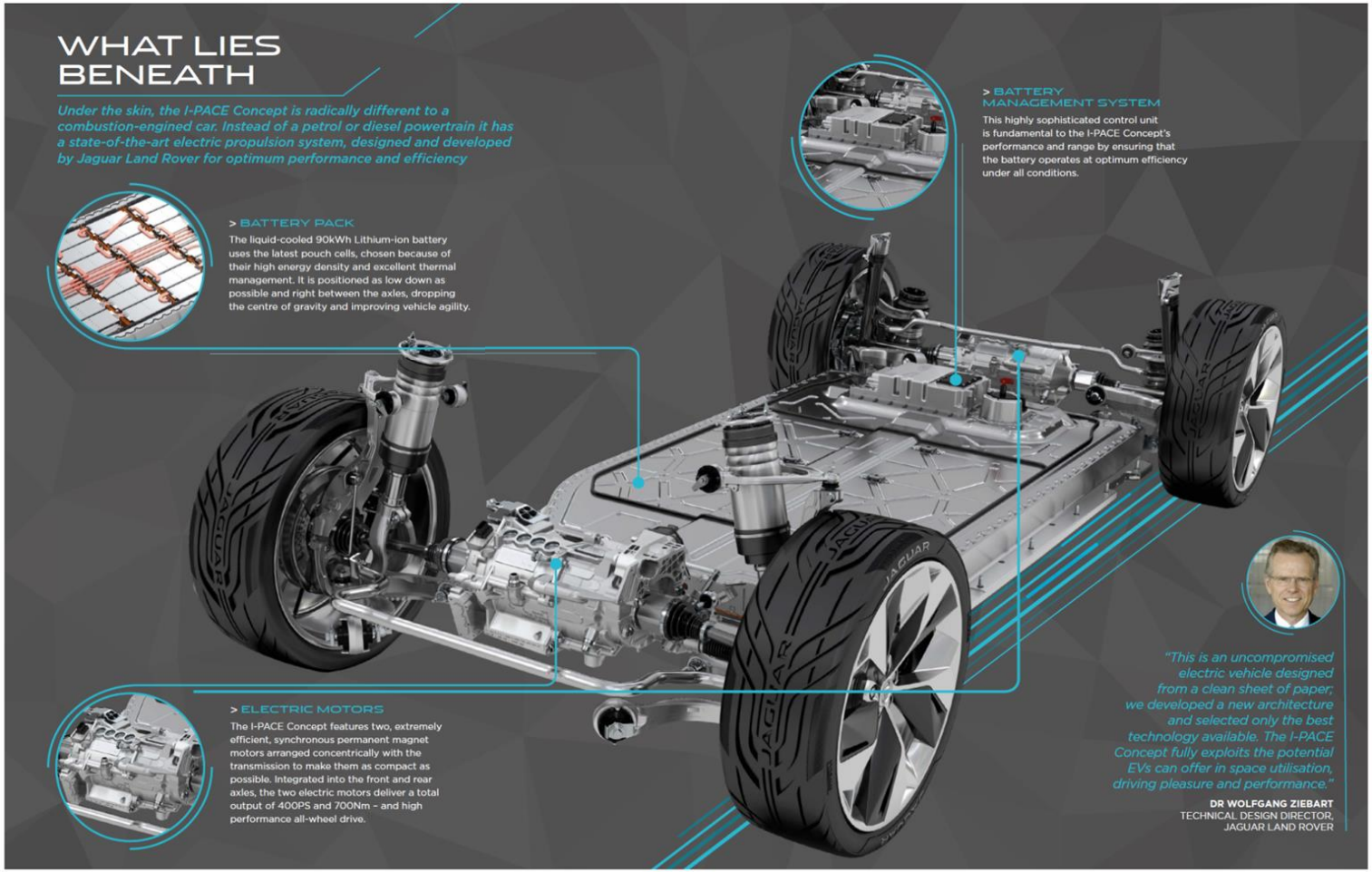
Battery system design

Thermal Management examples – Jaguar I-PACE CONCEPT



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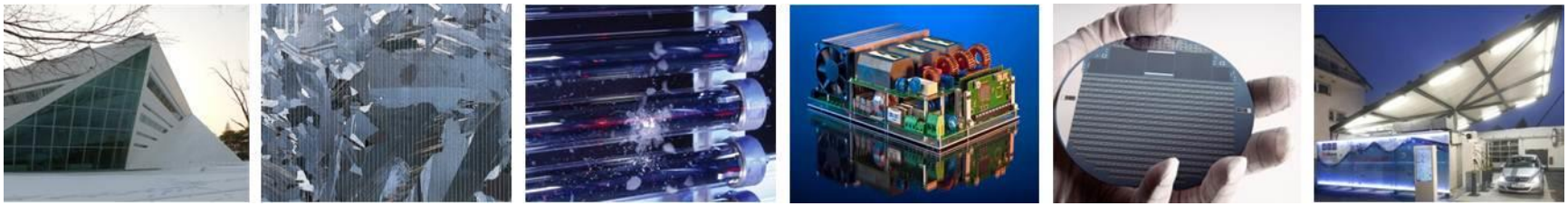
Thank you for your attention!



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