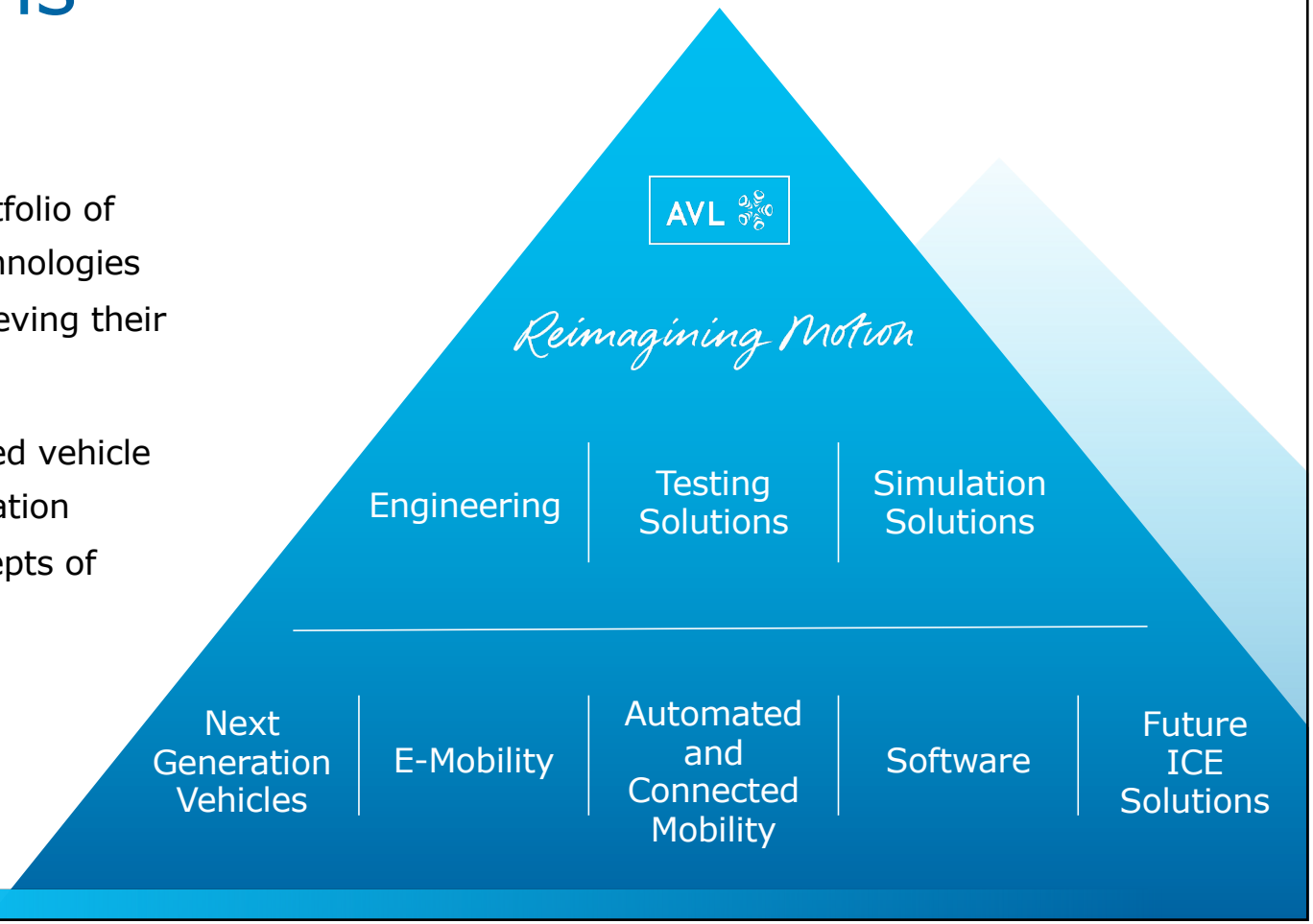
Einblicke in die Batterie- und Ladetechnik

Erwin Reisinger

Turning Visions Into Reality

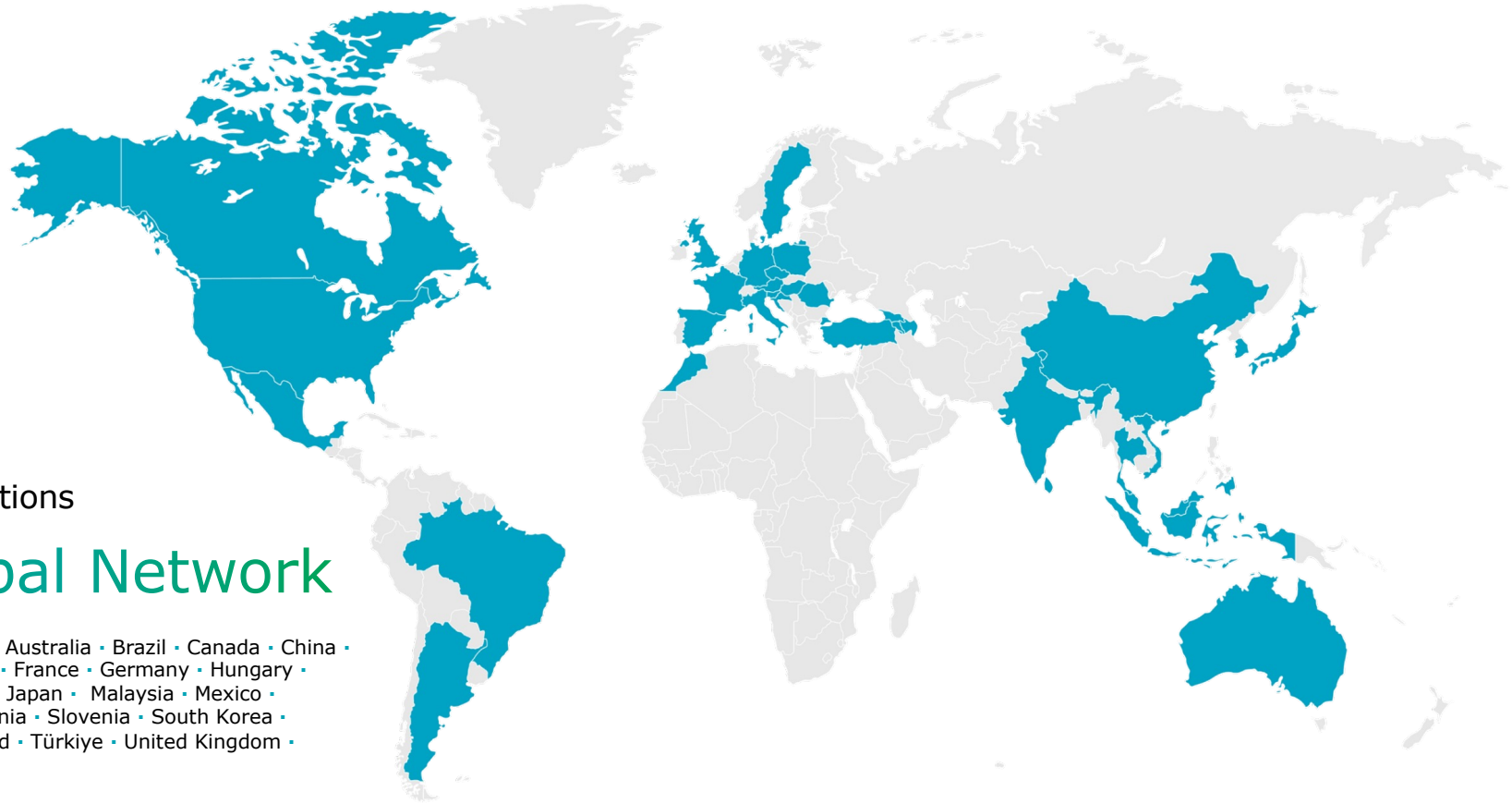
We constantly transform our portfolio of high-end methodologies and technologies to support our customers in achieving their ambitions.

From future fuels to the connected vehicle ecosystem, we are driving innovation today, to build the mobility concepts of tomorrow.



Testing Solutions

- Advanced tools and methodologies for energy-efficient, fast, and reliable development, testing and validation
- Great variety of application solutions connecting different development environments
- Seamless integration of AVL and third-party products, system and software solutions tailored to the user workflow



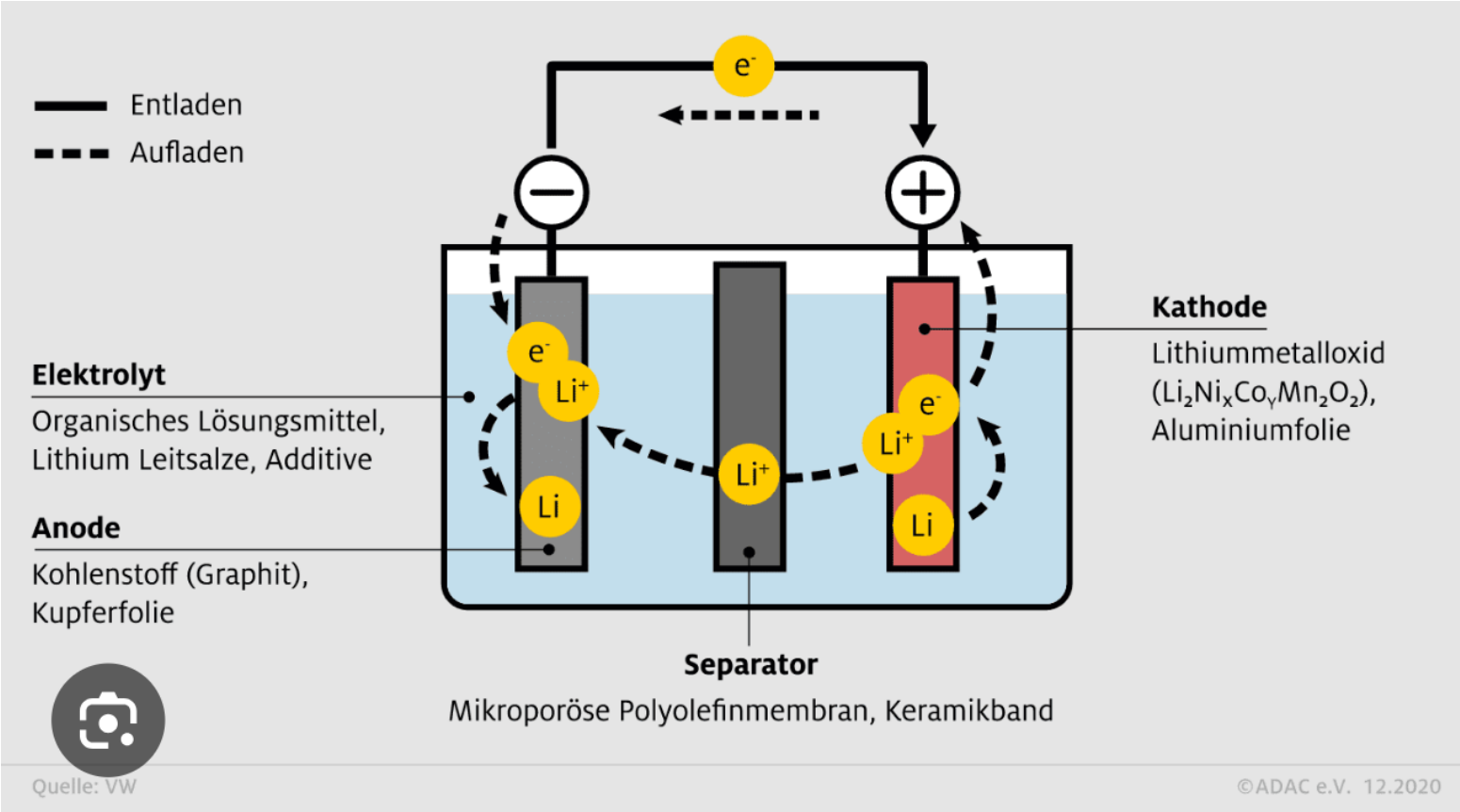
Worldwide Locations

Our Global Network

Austria, HQ | Argentina · Australia · Brazil · Canada · China · Croatia · Czech Republic · France · Germany · Hungary · India · Indonesia · Italy · Japan · Malaysia · Mexico · Morocco · Poland · Romania · Slovenia · South Korea · Spain · Sweden · Thailand · Türkiye · United Kingdom · United States · Vietnam

Inhalt

Zelle: Lithium-Ionen



Auswahl populärer Materialkombinationen für Lithium-Ionen-Batterien aus der heutigen Fertigung und Entwicklung

Kathodenmaterial

$LiNi_xMn_yCo_zO_2$

Große Variabilität in Mischmaterialien, Trend zu hohen Nickelanteilen. Kommerziell von x=z=1/3 bis x=0,8, y=z=0,1

NCA

Hohe Energiedichte

$LiFePO_4$

„3,3 V Material“, geringe Energiedichte, günstig, sicherer

$LiMn_2O_4/LiMnO_2$

Begrenzte Lebensdauer, Ni- und Co-frei

Anodenmaterial

Hard Carbon/Graphit LiC_6

„3,7 V Material“, begrenzte Laderate (Plating-Gefahr)

Graphit + Silizium

„3,7 V Material“, hohe Energiedichte, Mischmaterial, begrenzte Lebensdauer

Silizium $Li_{22}Si_6$

„3,7 V Material“, sehr hohe Energiedichte, bis jetzt nicht kommerziell verfügbar

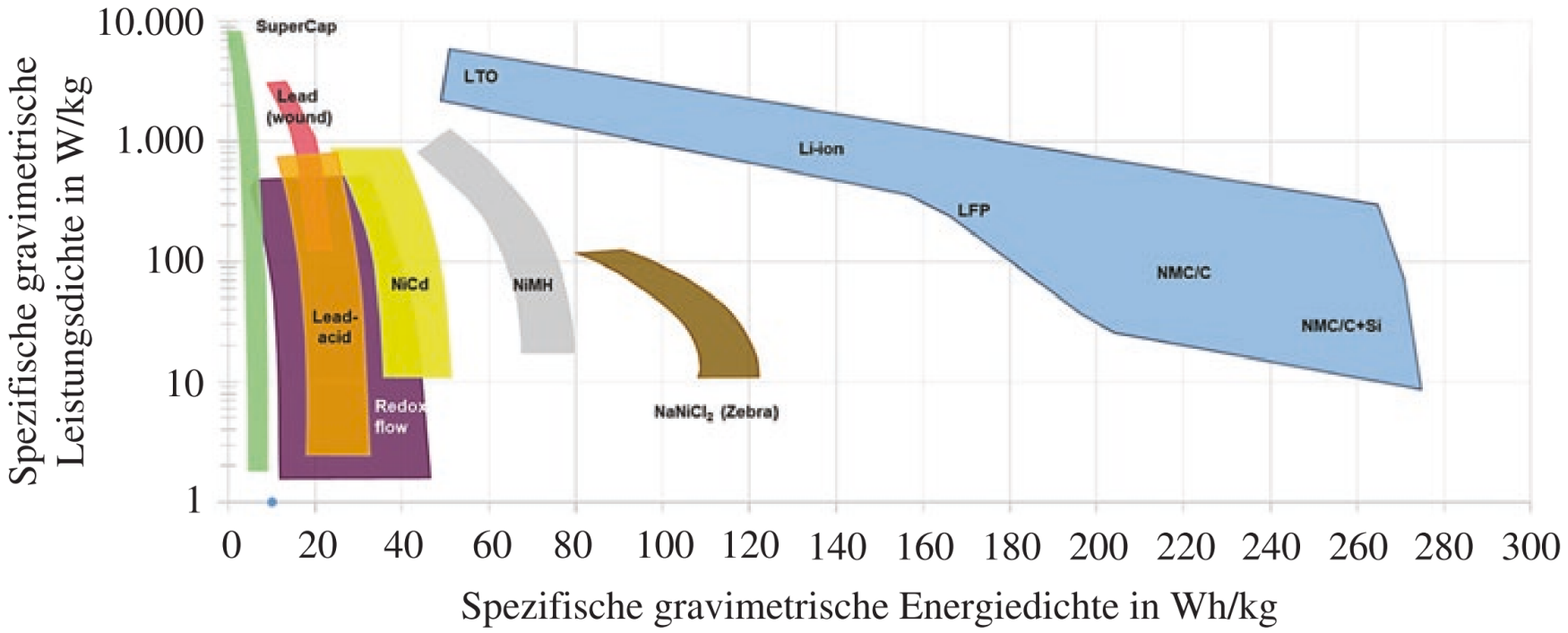
Titanat $Li_4Ti_5O_{12}$

„2,2 V Material“, sicher, geringere Energiedichte

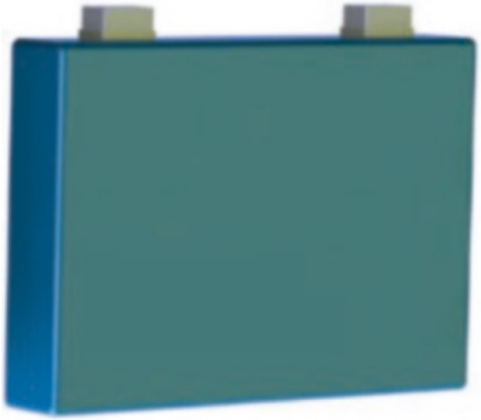
Lithium-Metall

„3,7 V Material“, sehr hohe Energiedichte, nur mit Festkörperelektrolyt

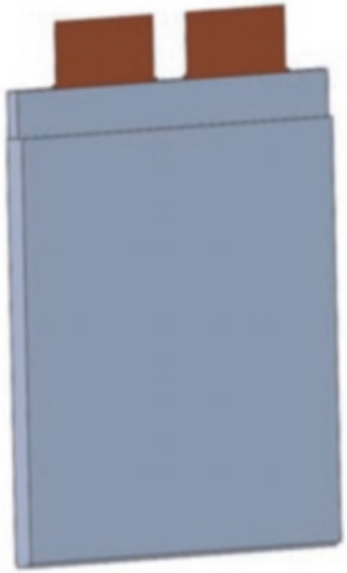
Spezifsche Leistung und spezifsche Energie für verschiedene Speichertechnologien (Ragone-Diagramm)



Zellgeometrien



Prismatische Zelle

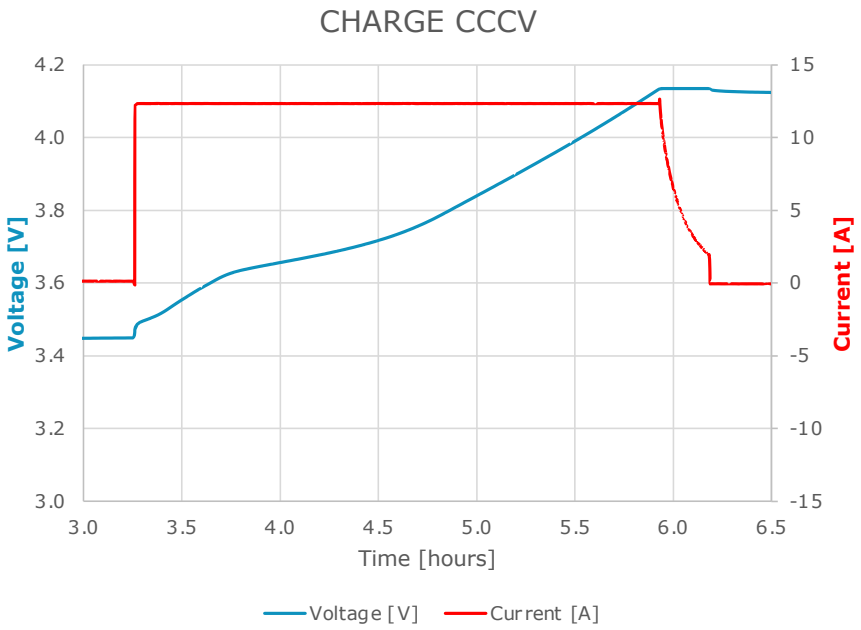


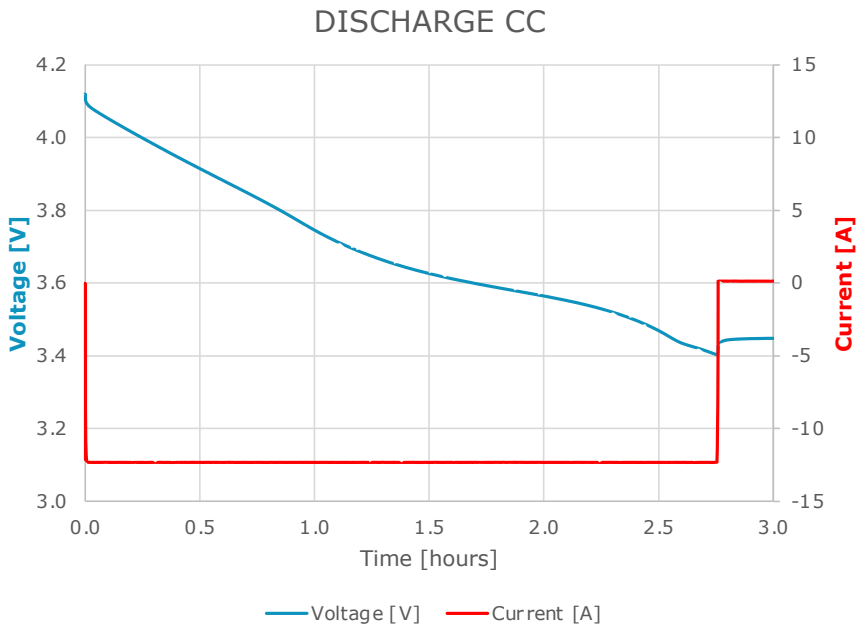
Pouch-Bag-Zelle

Zylindrische Zelle

Typischer Ladevorgang

Charge or Discharge Profile





Lebensdauer von Batterien

- Kalendarische Lebensdauer

  wie lange die Batterie auch ohne Belastung leben würde

- Zyklenlebensdauer

  welchen Ladungsdurchsatz die Batterie liefern kann

- Ende der Lebensdauer ist definiert über
  - die Zunahme des Innenwiderstands - typischerweise um 100 %
  - die Abnahme der nutzbaren Kapazität - typischerweise auf 70 respektive 80 % der Nennkapazität

„Eigenschaften“ von Lithium-Ionen Batterien

- Thermische Verhalten
  - Sicherheit – „Thermal Runaway“ – selbstverstärkende, chemische Reaktion ➔ Brand bzw. Explosion
  - Höhere Alterung bei höheren Temperaturen
  - Höhere Selbstentladung bei höheren Temperaturen
  - Bei niederen Temperaturen und hohen Strömen ➔ Lithium Plating

  ➔ optimale Betriebstemperatur 30-40GradC

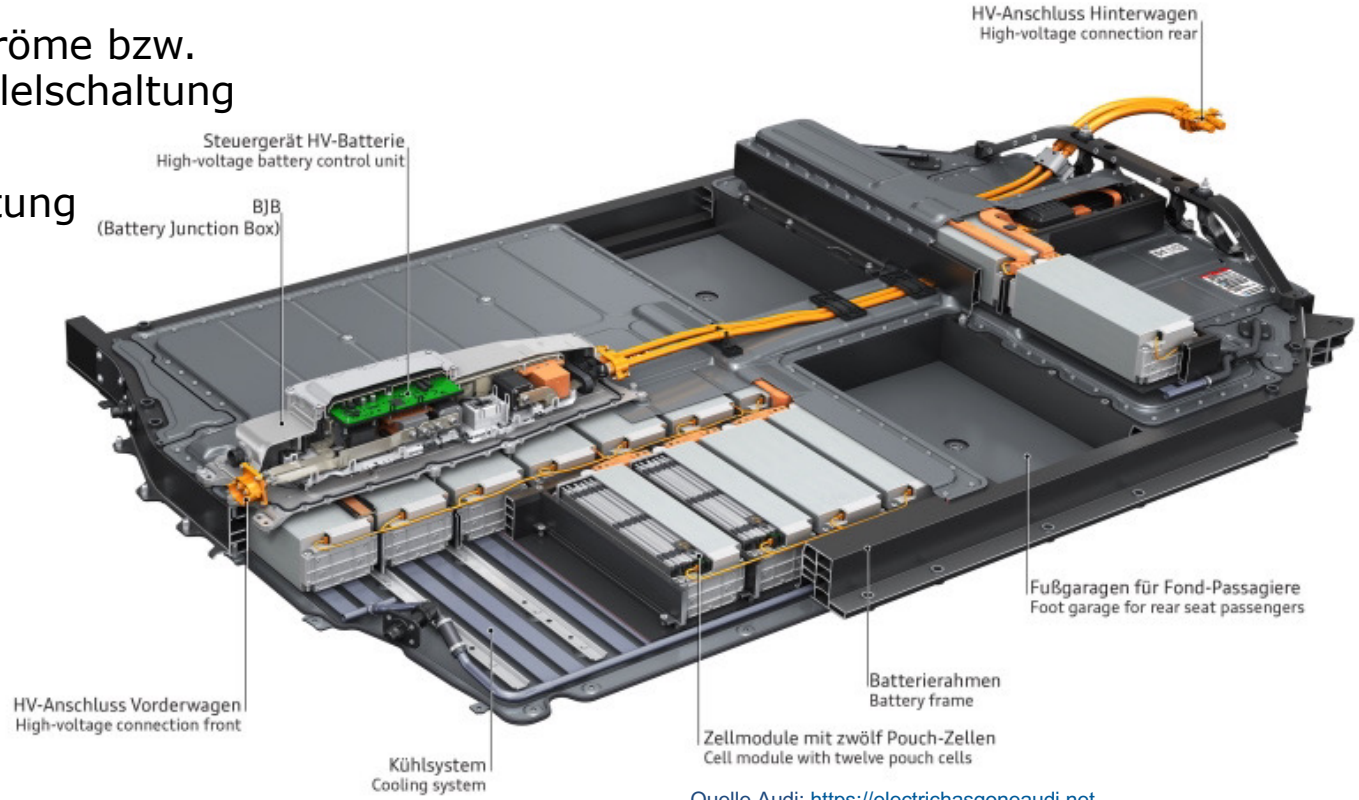
Batteriemanagementsystem

Sorgt für einen sicheren und zuverlässigen Betrieb

- **Batteriemonitoring:** Messung von Strömen, Strang- und Zellspannungen, Temperaturen und Impedanzen
- **Thermisches Management:** für gleichmäßige Zelltemperaturen und Betrieb innerhalb eines idealen Temperaturbereichs (Leistungsfähigkeit, Alterung)
- **Batteriediagnostik:** Auswertung und Verknüpfung aller Informationen aus dem Batteriepack zur Bestimmung des Ladezustands (State of Charge – **SoC**), der Leistungsfähigkeit (State of Power – SoP), der Funktionsfähigkeit (State of Function – SoF) oder des Alterungszustands (State of Health – **SoH**)
- **Ladungsausgleichssystem:** Symmetrierung des Ladezustands der Zellen (passiv oder aktiv - kann unterschiedliche Alterungszustände ausgleichen)
- **Steuerung der Switchbox:** Ansteuerung der Schütze zum Ein- und Ausschalten, Notabschaltung im Fall von Crash oder sicherheitskritischer Batterieüberlastung

Von der Zelle zum Pack

- Höhere Spannungen, Ströme bzw. Leistungen (serien/parallelschaltung von Zellen)
- Thermische Bewirtschaftung
- Sicherheit



Quelle Audi: https://electrichasgoneaudi.net

Anforderungen an Packs

- Typische Belastungen im **Fahrbetrieb**

  0,05 C (25 km/h mittlere Geschwindigkeit in der Stadt bei einer Batteriereichweite von 500 km) und **0,5 C** (mittlere Geschwindigkeit von 120 km/h auf der Autobahn bei 240 km Batteriereichweite).

  Die Spitzenleistungen im Entladebereich von etwa **2 bis 2,5 C**

  Extreme Belastungen z.B. Rimac Nevera bei einer Batteriekapazität von 120 kWh eine Antriebsleistung von mehr als 1400 kW ca. **12 C**

➔ Abgesehen von einer **verstärkten Erwärmung** und deren negativer Auswirkung auf die **Lebensdauer** sind keine beschleunigten Schädigungen von Lithium-Ionen-Batterien bei höheren Entladeleistungen bekannt.

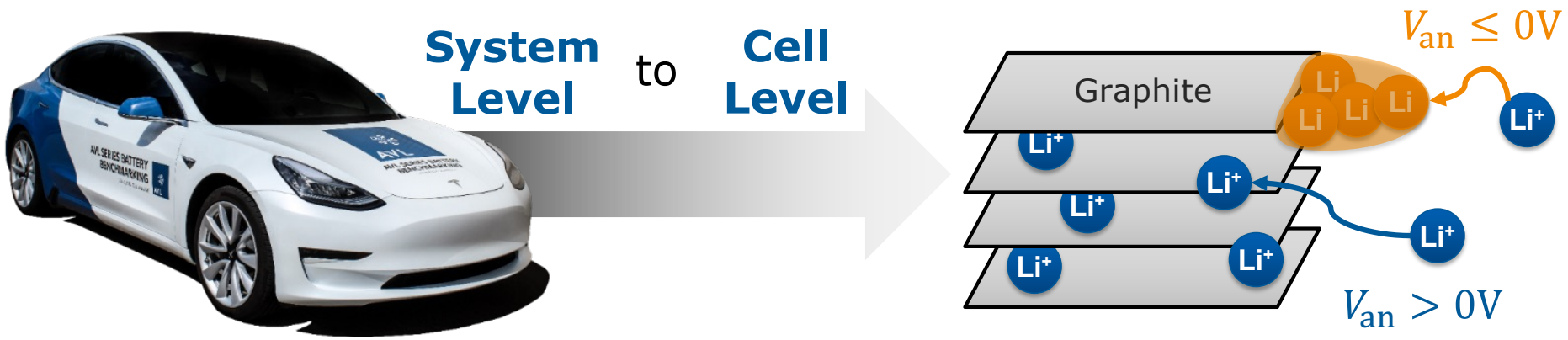
- Belastung beim Aufaden ist vomLadegeräte abhängig

0,1 C beim Laden eines Fahrzeugs mit 40 kWh Batteriekapazität an der Haushaltssteckdose

>**3,5 C** beim Laden eines Fahrzeugs mit 100 kWh Batteriekapazität an einer „Ultra-Fast-Charging"-Station.

➔ **schnelles Laden in allen Fällen eine deutlich höhere Belastung für die Batterien als der eigentliche Fahrbetrieb.** Das Laden entspricht einer Dauerleistung im Vergleich zu einer mittleren Entladeleistung

Fast-Charging Obeys 5 Limits



1
Power
Limited by power grid

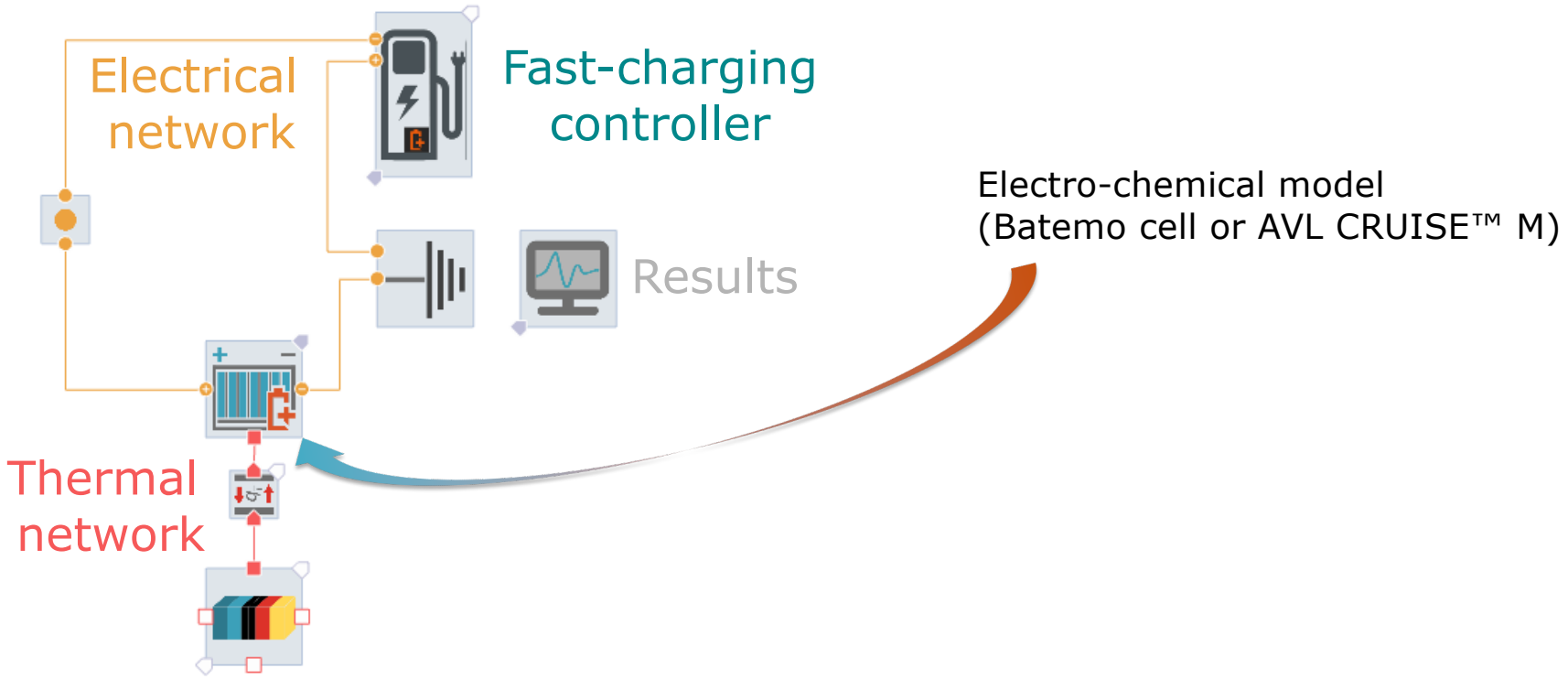
2
Current
Limited by charger current

3
Temperature
Limited by battery cell
(temperature-induced aging)

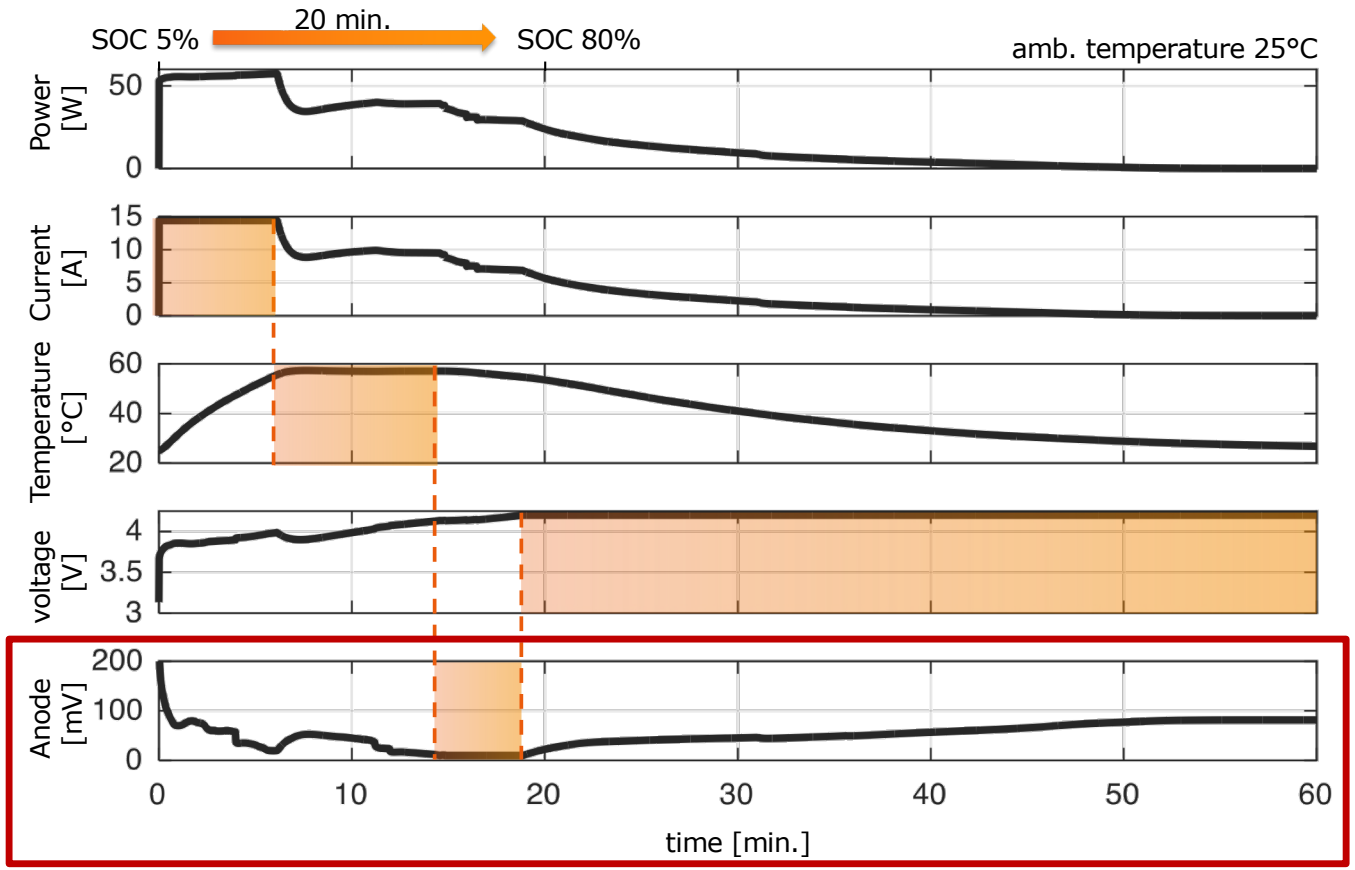
4
Voltage
Limited by battery cell
(voltage-induced aging)

5
Anode
Limited by battery cell
(lithium-plating aging)

Fast-Charging in AVL CRUISE™ M



Fast-Charging in AVL CRUISE™ M

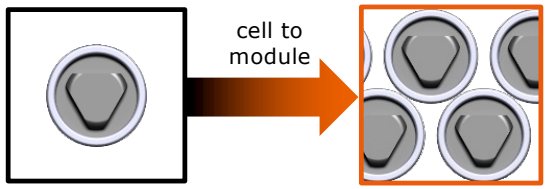


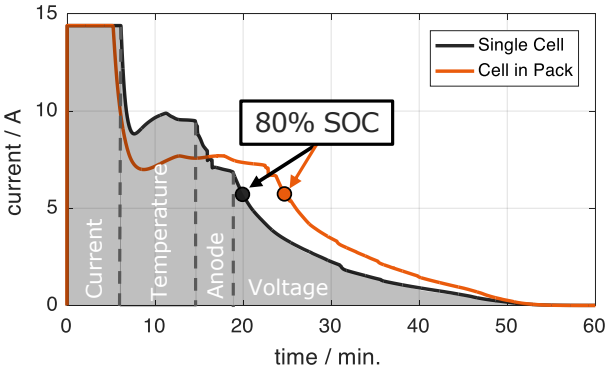
Result: 5% to 80% ≈ 20 min.

Available only in experimental (3-electrode) cells

Fast-Charging in AVL CRUISE™ M

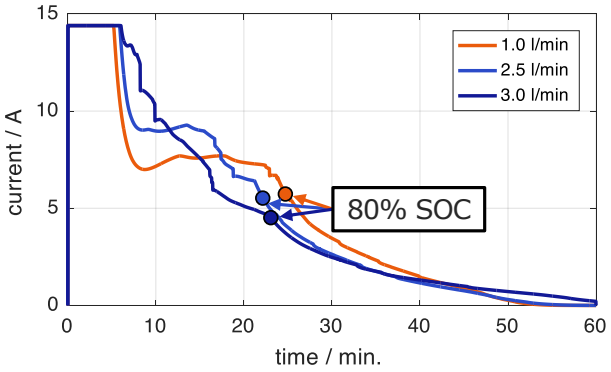
Analyze
Your Module



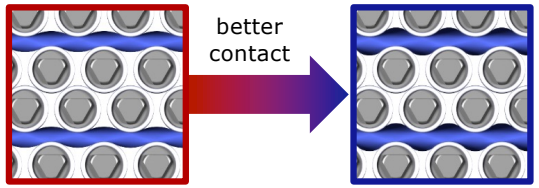


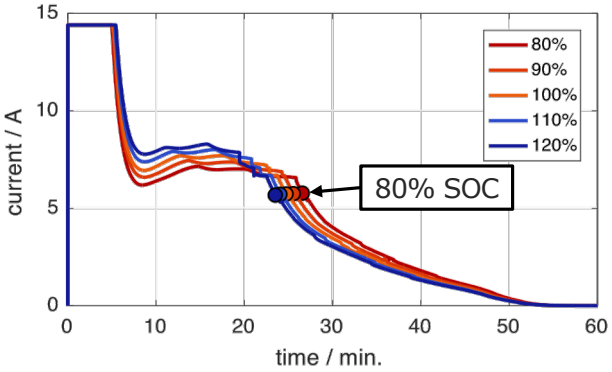
Optimize
Operational Strategies

Increase or reduce
cooling flow rate



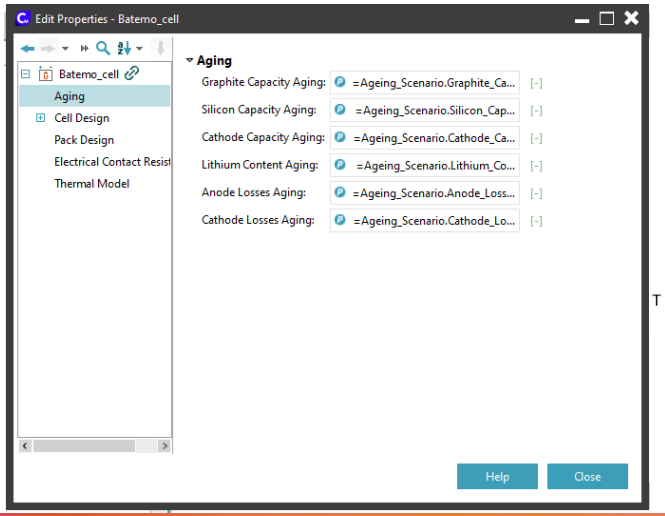
Improve
Pack Design

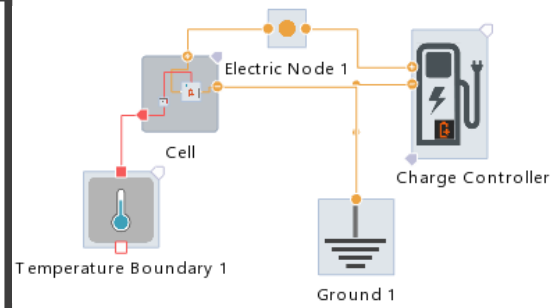


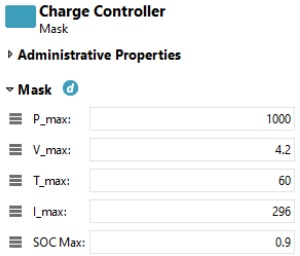


Aging Scenarios

	Aging Scenario			
Aging Parameter	New	Aged	Li Plated	Si Loss
Graphite Capacity Aging	0 [-]	0,05 [-]	0 [-]	0 [-]
Silicon Capacity Aging	0 [-]	0,4 [-]	0 [-]	0,8 [-]
Cathode Capacity Aging	0 [-]	0,1 [-]	0 [-]	0 [-]
Lithium Content Aging	0 [-]	0,12 [-]	0,2 [-]	0,1 [-]
Anode Losses Aging	0 [-]	0,1 [-]	0,2 [-]	0,2 [-]
Cathode Losses Aging	0 [-]	0,8 [-]	0 [-]	0 [-]

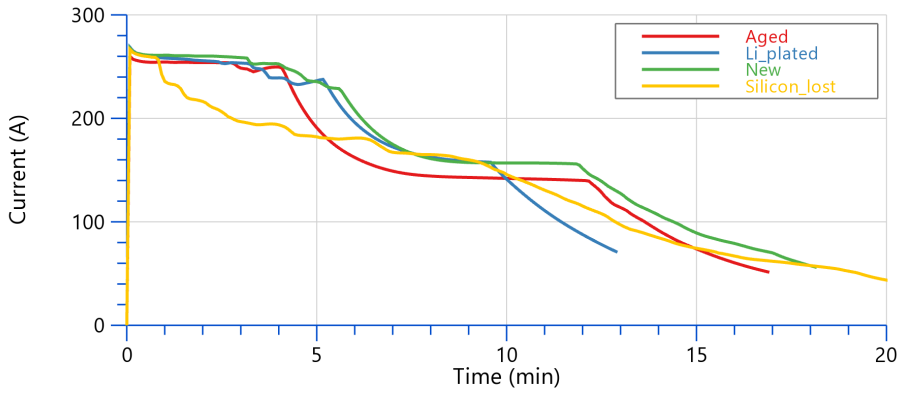


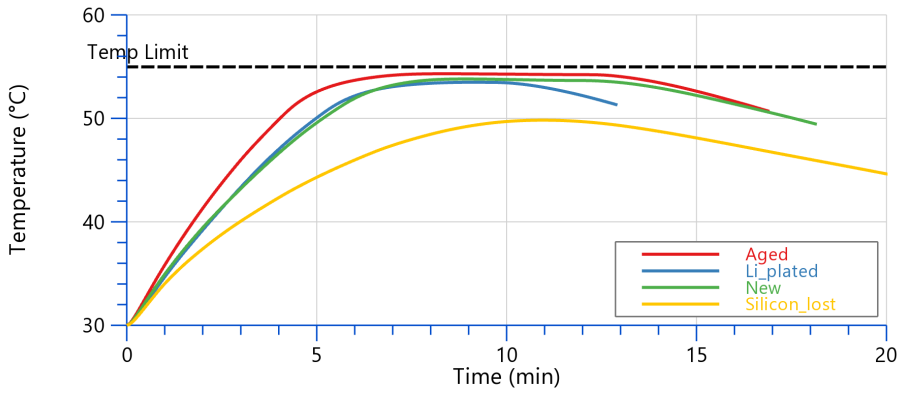


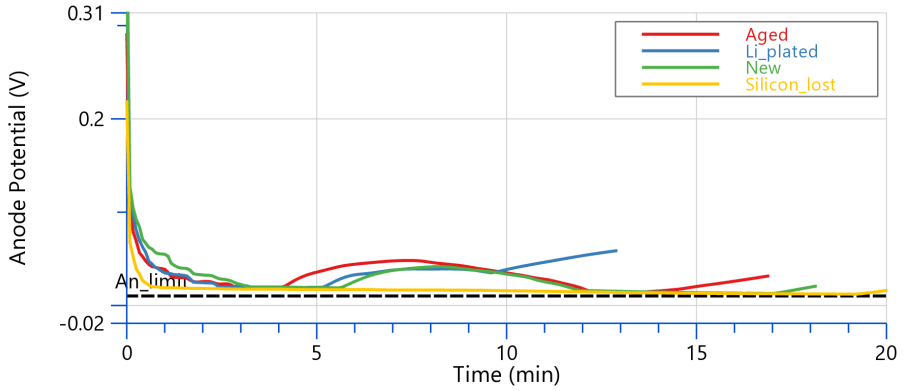


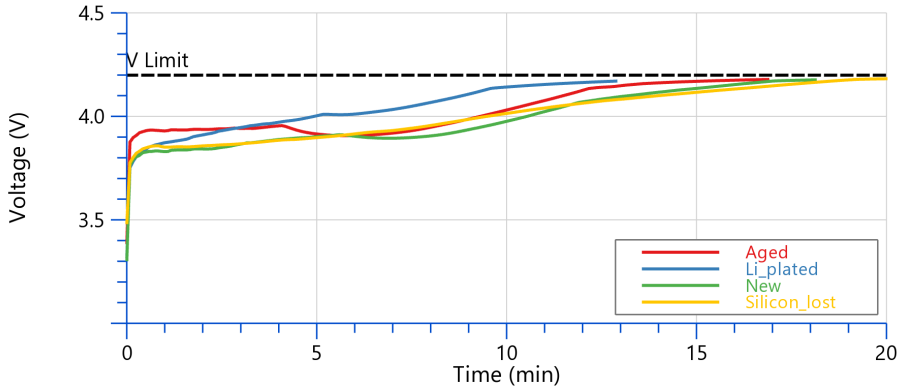
Technical Data	**Value**
Manufacturer	LG Chem
Type	E66A
Picture	
Housing	pouch
Dimensions	350 mm x 104 mm x 11.7 mm
Weight	0.897 kg
Capacity	65.0 Ah nominal 63.5 Ah C/10
Energy	232.2 Wh C/10
Current	121.1 A continuous 296.6 A peak
Power	408 W continuous 1.04 kW peak
Energy Density	259 Wh/kg gravimetric 648 Wh/l volumetric
Power Density	1.16 kW/kg gravimetric 2.90 kW/l volumetric

Aging Scenarios: Optimization of Charging Profile

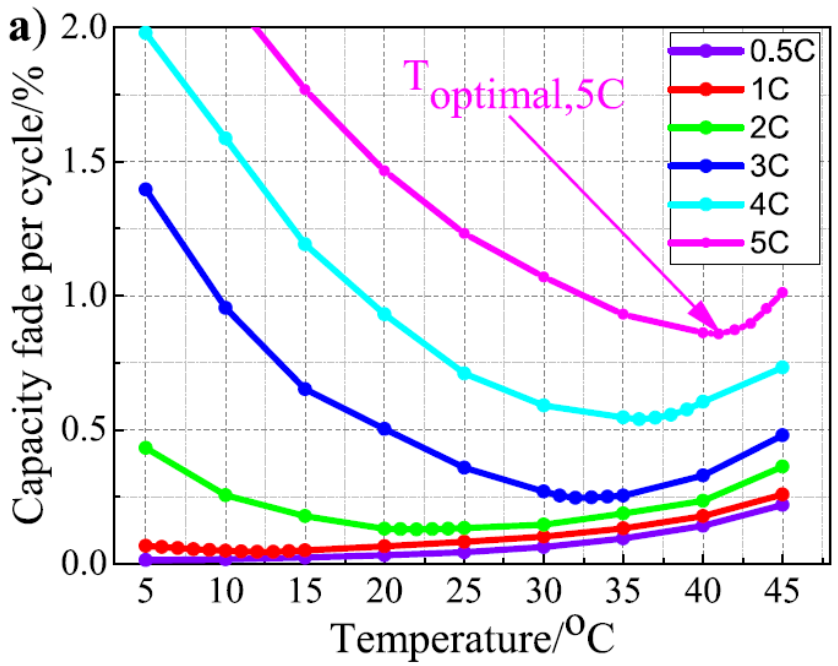


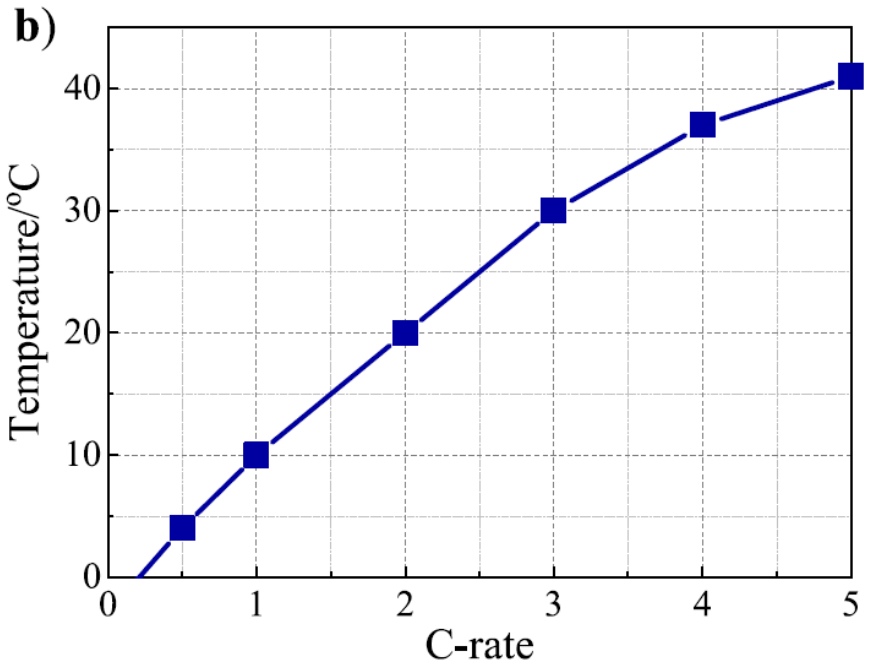






Charging concepts
Fast charge optimization

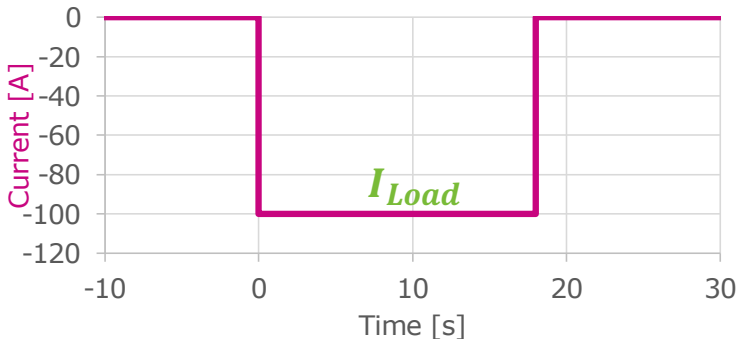




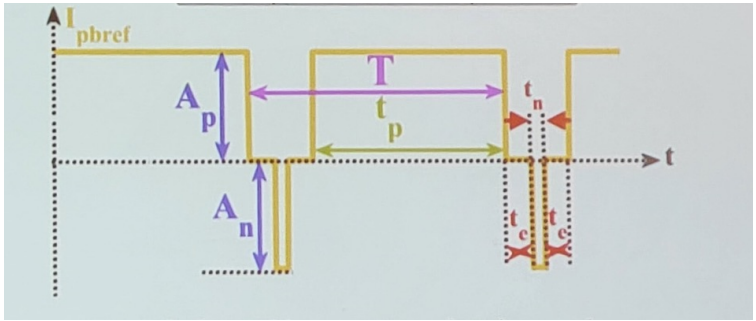
Source:
Y. Yin et al; Applied Energy 271 (2020) 115232
https://doi.org/10.1016/j.apenergy.2020.115232

Pulse & Pulse and Burp Charging

- pulse



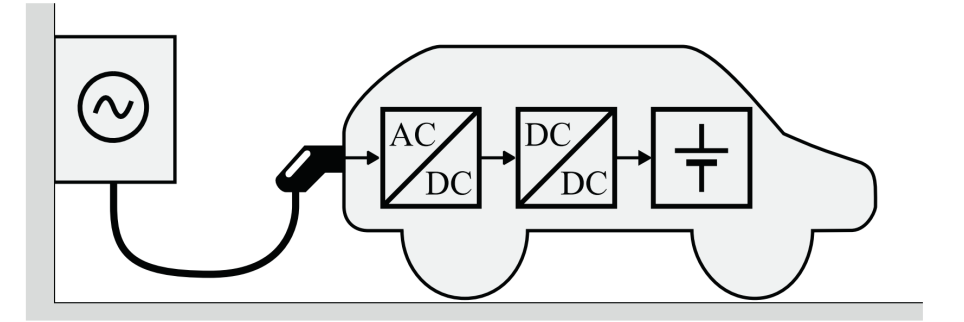
- Pulse and Burp



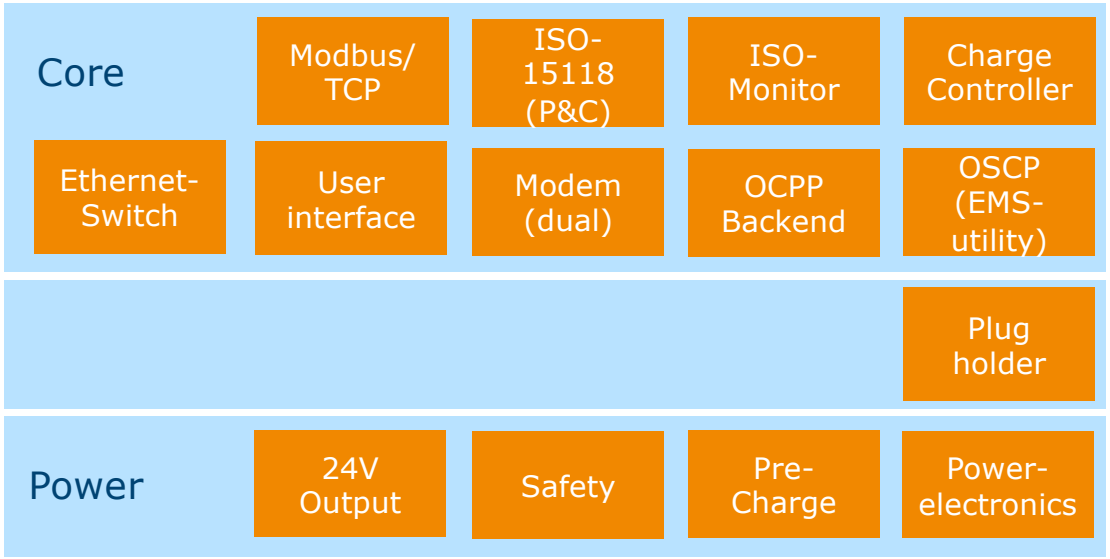
Ladekonzepte

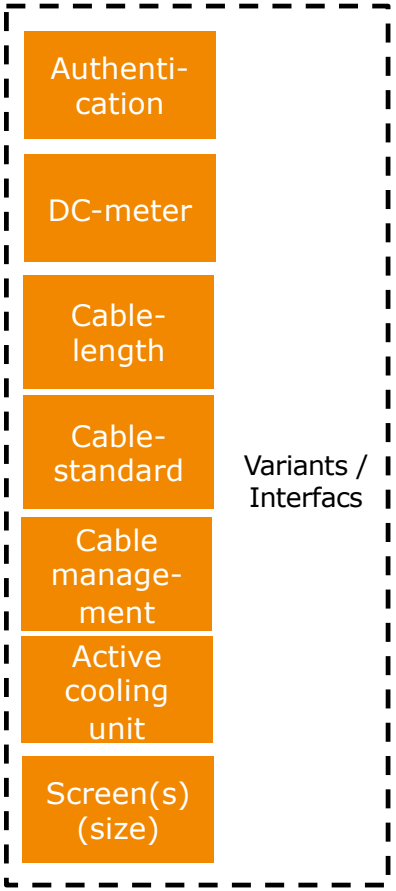
- Stationäres Laden
  - Wireless
  - Conductive
- Dynamic charging
  - Wireless
  - Conductive
- Opportunity charging
- Battery swapping

AC-Laden – DC-Laden

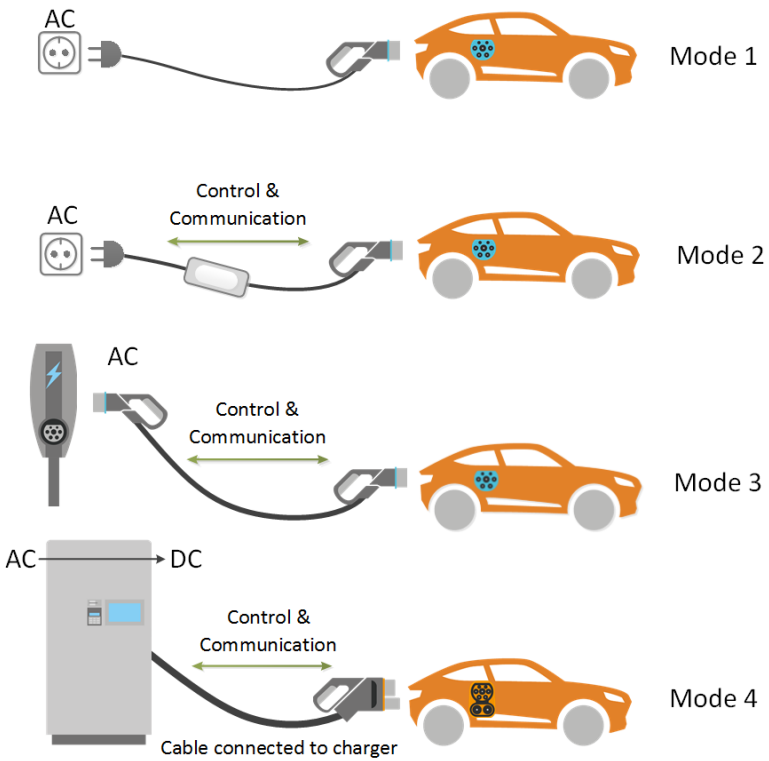


Architecture *PCI*

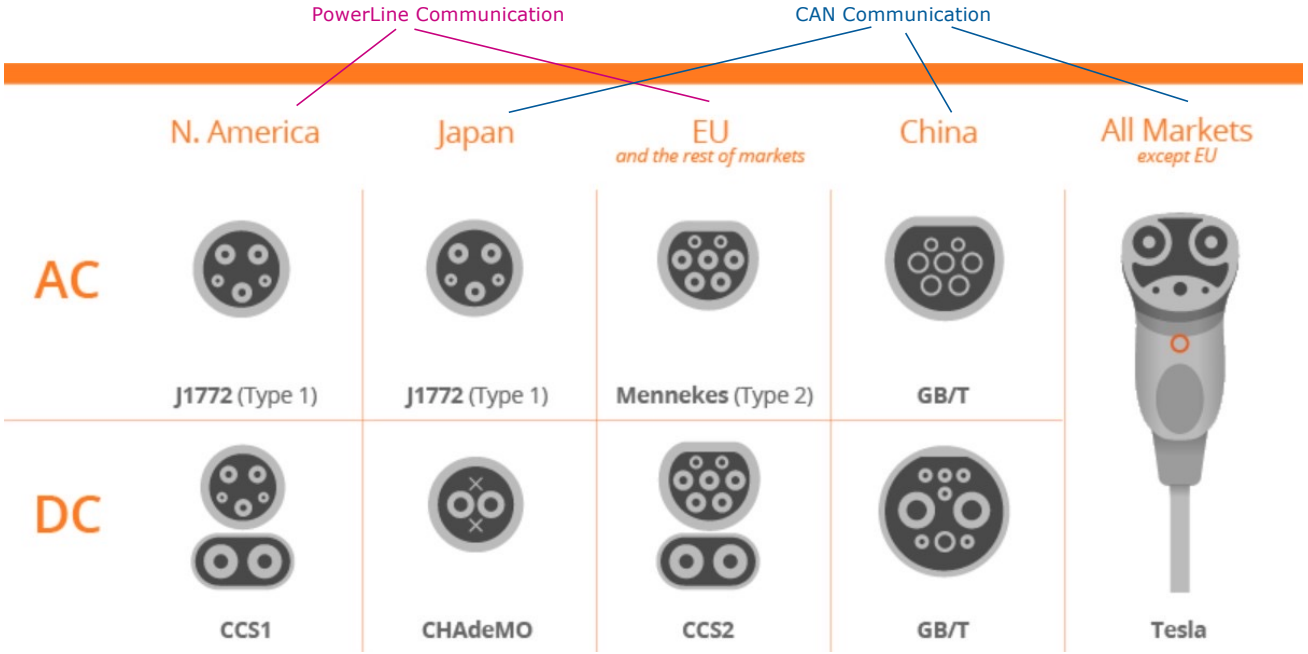




Different charging modes - result in different charging speed

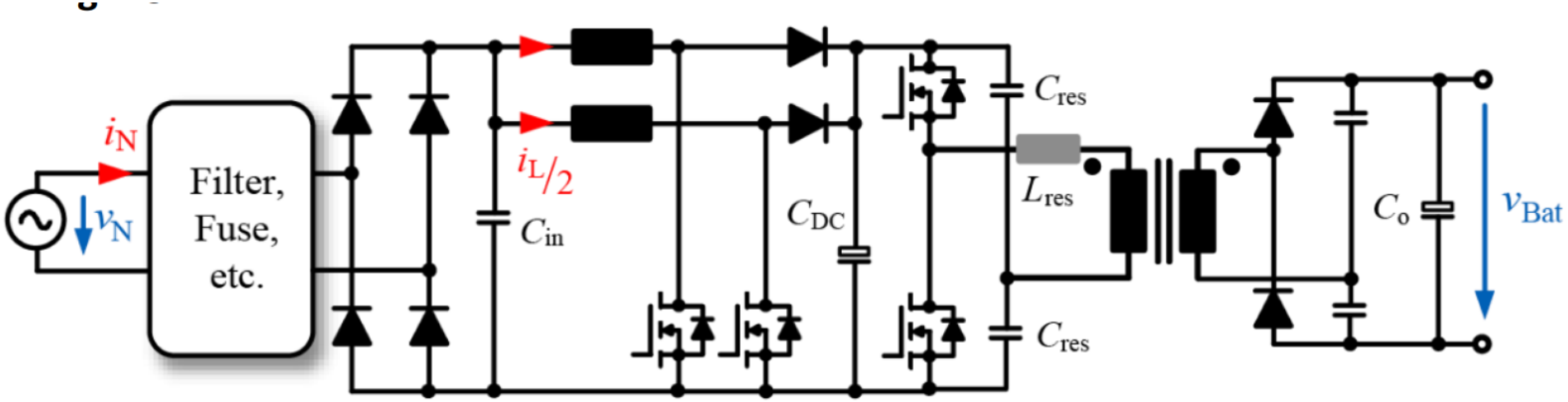


Different markets – different charging connectors, different communication protocols and different communication technology



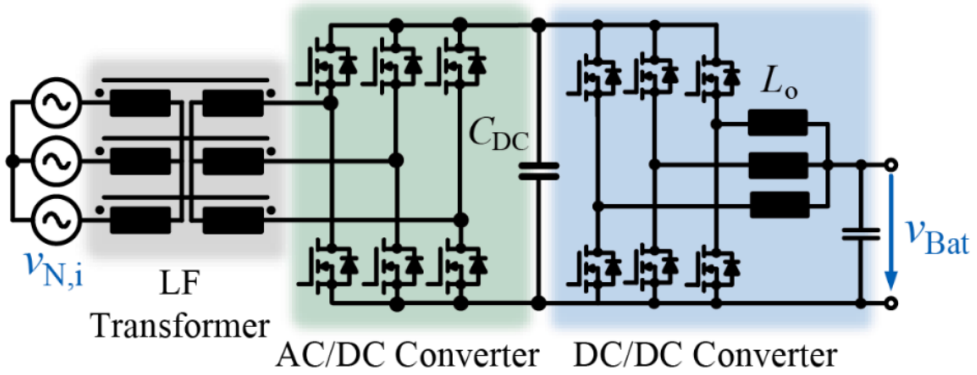
plus: different Charging standards for heavy duty
ChaoJi (China), MCS (Europe) MegaCharger (Tesla)

On-board or off-board charger

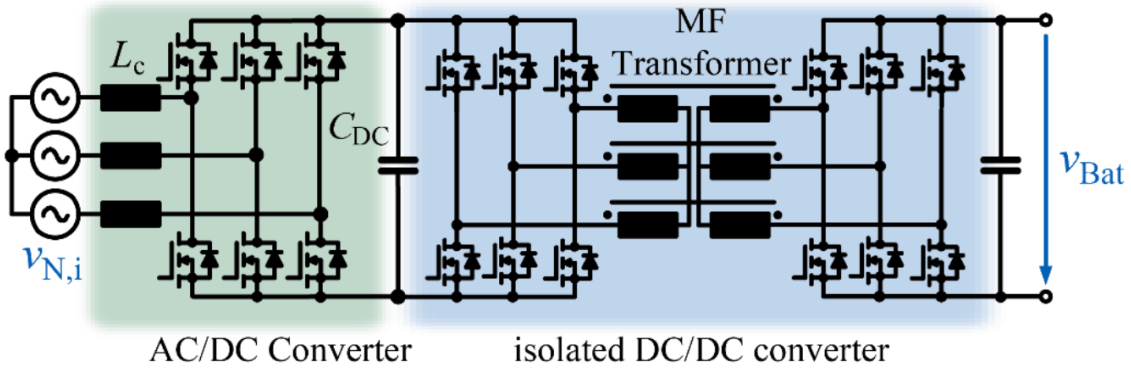


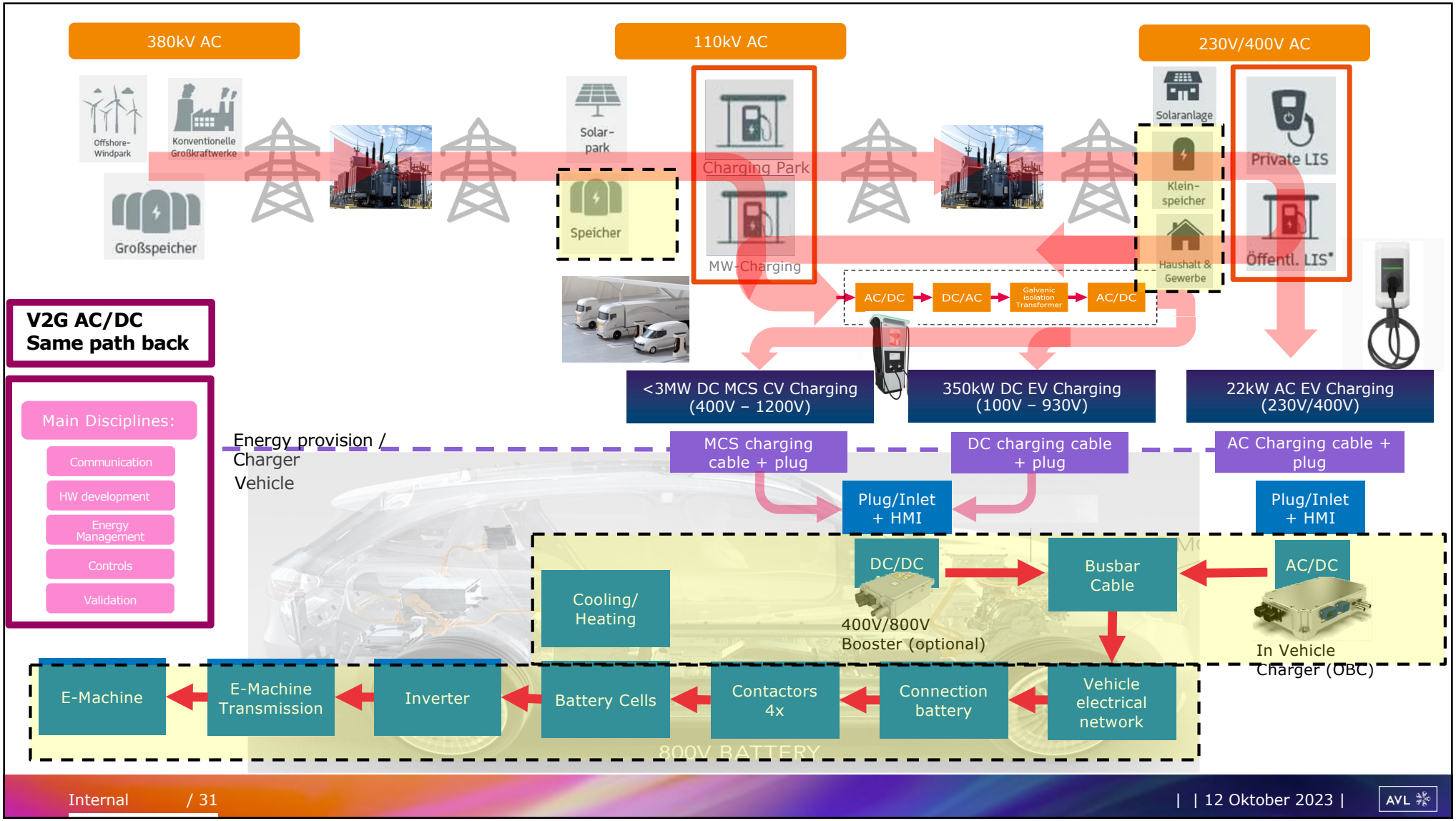
DC Fast Charger

Galvanische Trennung Netzseitig

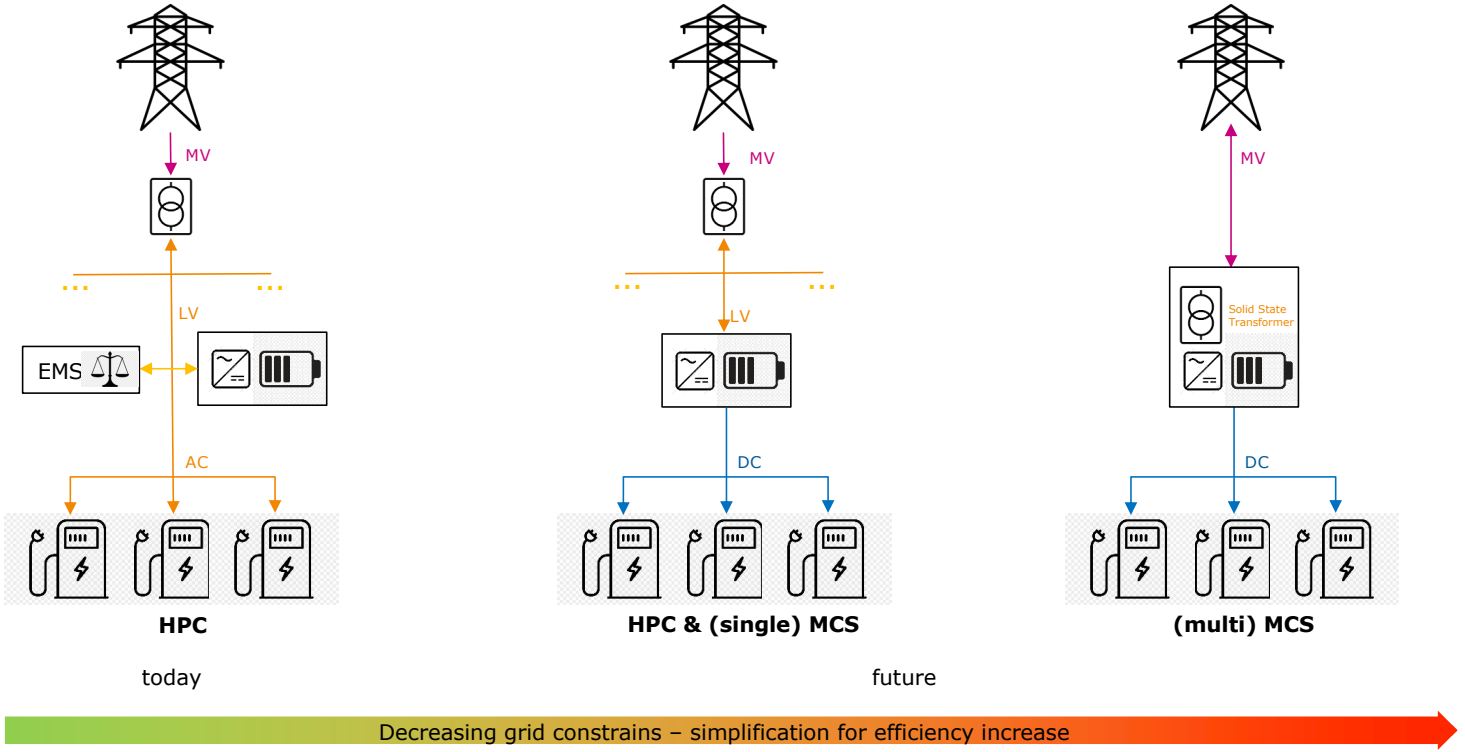


Galvanische Trennung DC-seitig

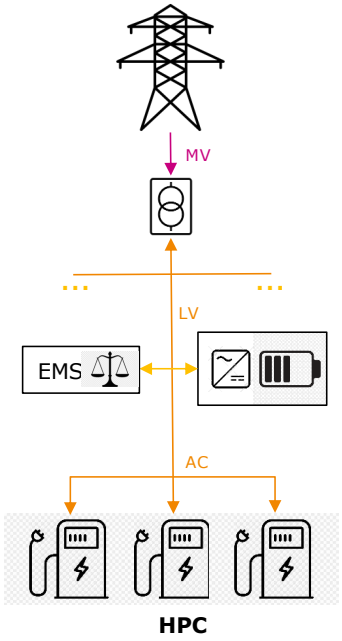



380kV AC
110kV AC
230V/400V AC
Offshore-Windpark
Konventionelle Großkraftwerke
Großspeicher
Solar-park
Speicher
Charging Park
MW-Charging
Solaranlage
Klein-speicher
Haushalt & Gewerbe
Private LIS
Öffentl. LIS*
AC/DC
DC/AC
Galvanic isolation Transformer
AC/DC
V2G AC/DC
Same path back
Main Disciplines:
Communication
HW development
Energy Management
Controls
Validation
<3MW DC MCS CV Charging (400V – 1200V)
350kW DC EV Charging (100V – 930V)
22kW AC EV Charging (230V/400V)
Energy provision / Charger Vehicle
MCS charging cable + plug
DC charging cable + plug
AC Charging cable + plug
Plug/Inlet + HMI
Plug/Inlet + HMI
DC/DC
Busbar Cable
AC/DC
Cooling/ Heating
400V/800V Booster (optional)
In Vehicle Charger (OBC)
E-Machine
E-Machine Transmission
Inverter
Battery Cells
Contactors 4x
Connection battery
Vehicle electrical network
800V BATTERY

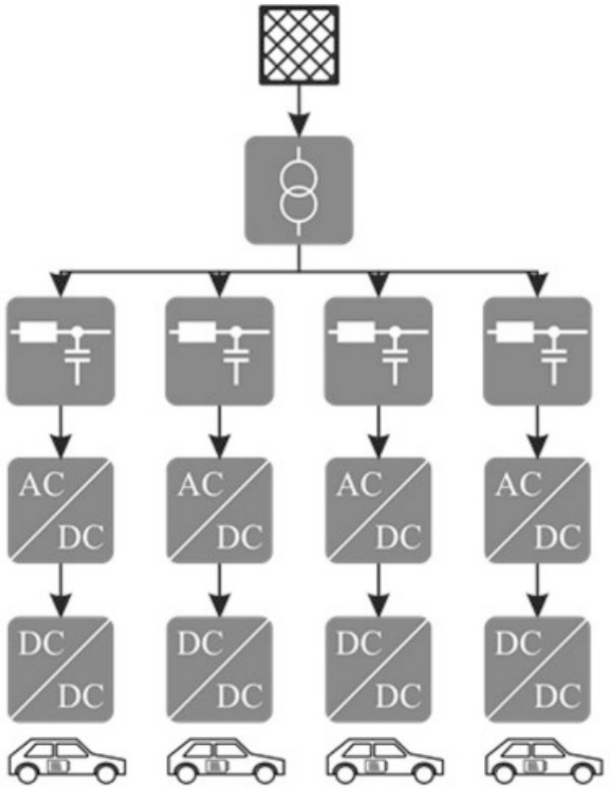
Laden aus dem Mittelspannungsnetz (HPC, MPC)



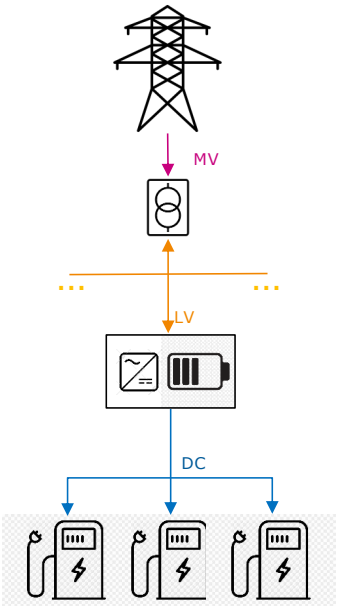
Laden aus dem Mittelspannungsnetz



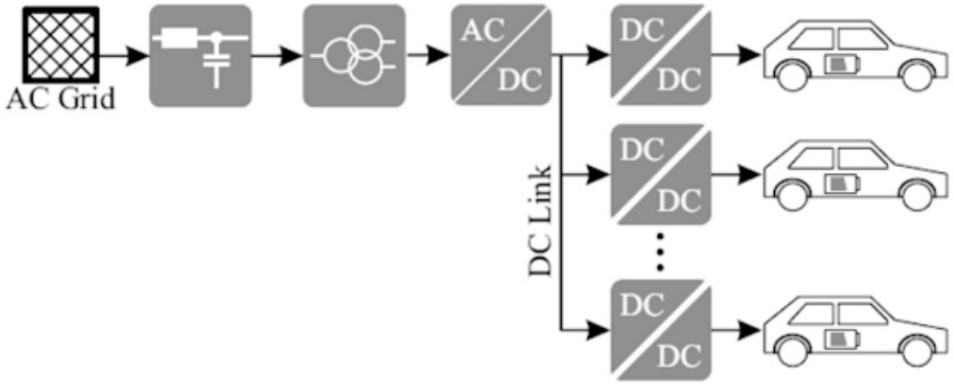
today



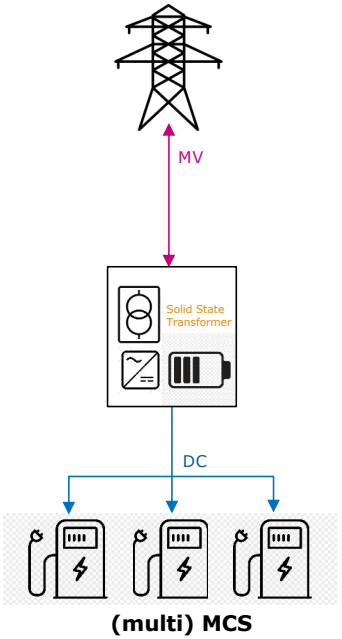
Topologies HPC, MPC

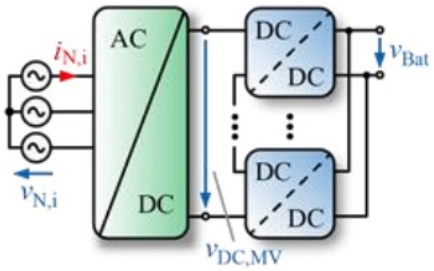


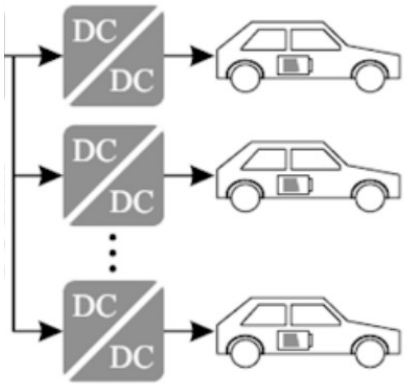
HPC & (single) MCS



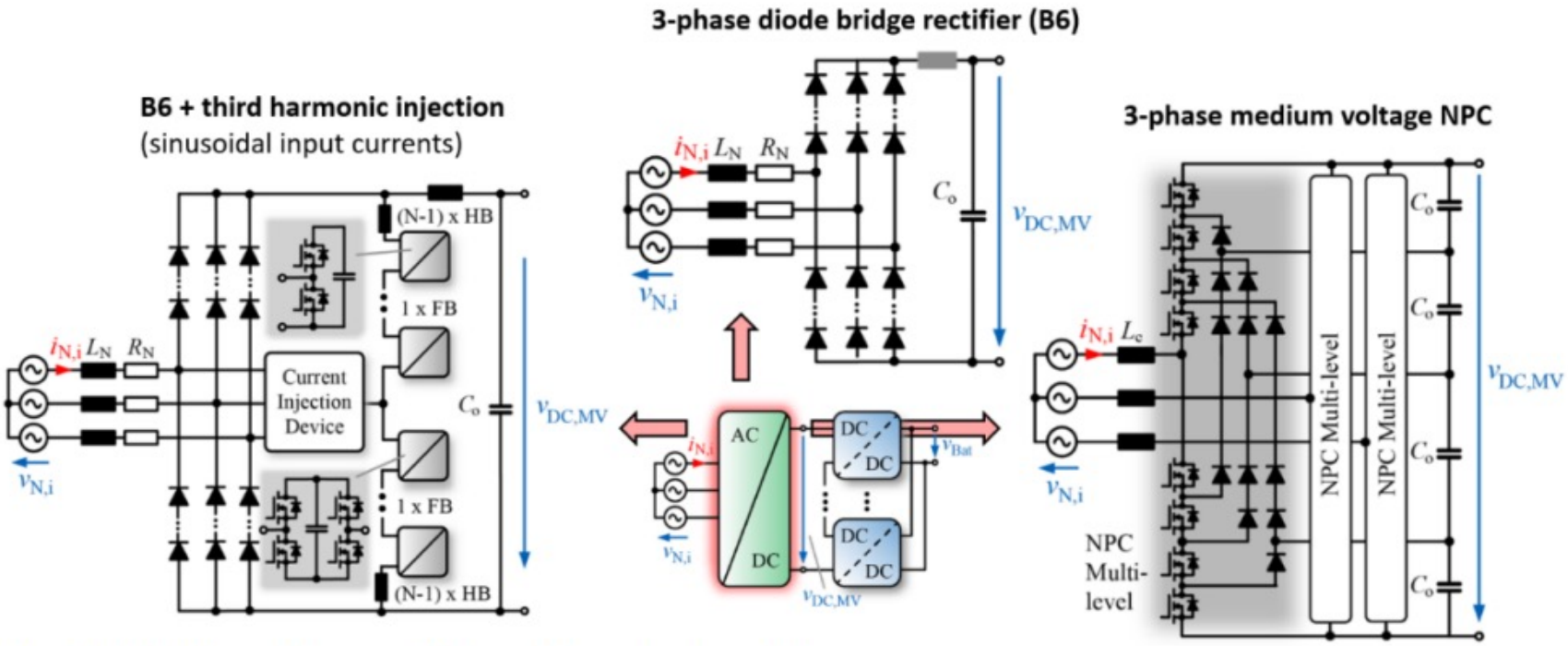
Laden aus dem Mittelspannungsnetz (HPC, MPC)



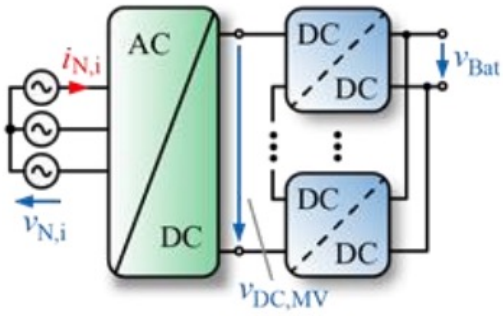


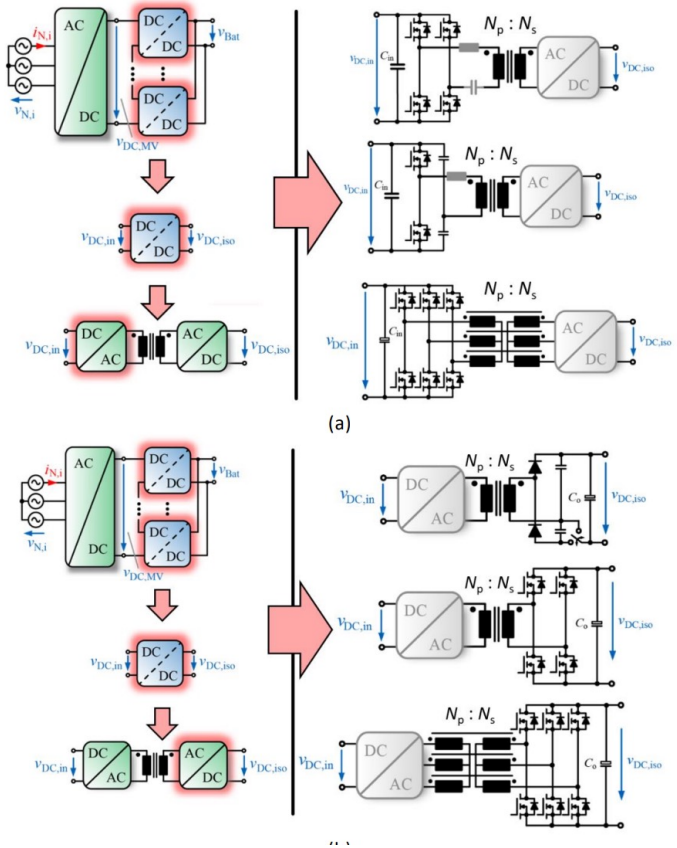


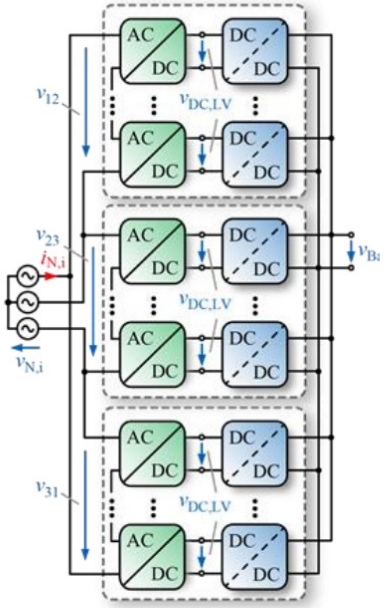
Mittelspannungsgleichrichtung



Solid State Transformer



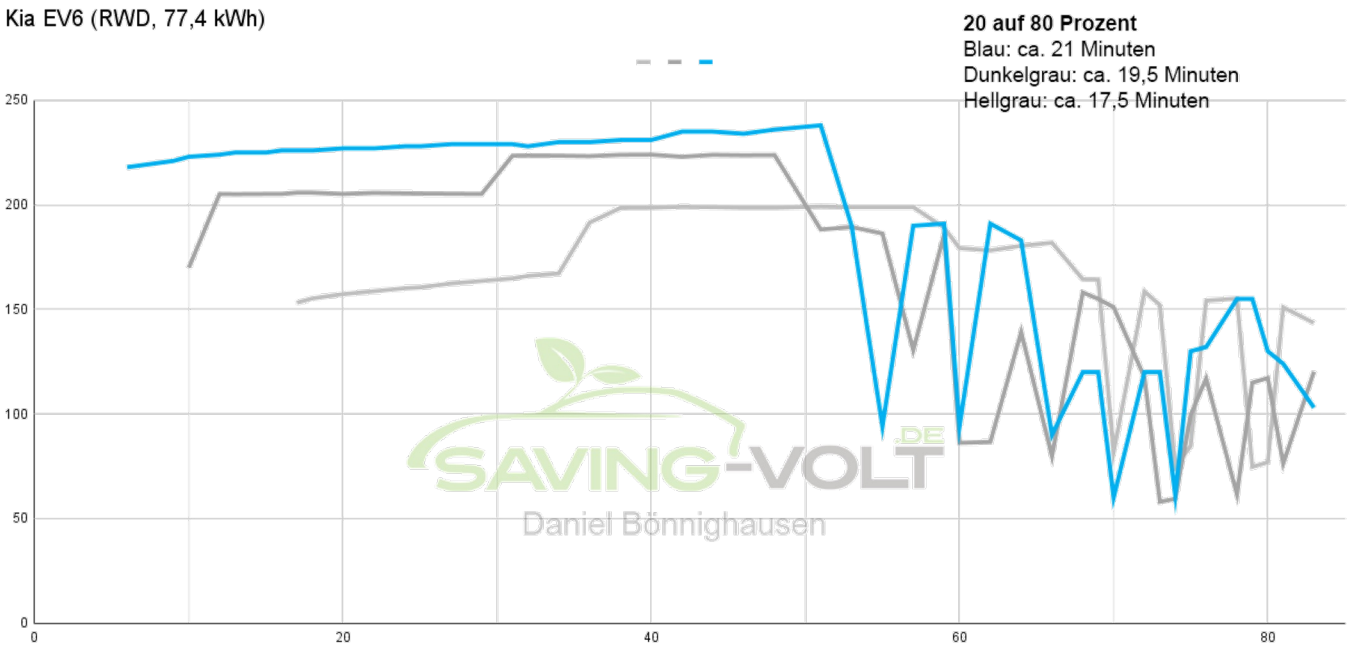




Impact to the grid - BMS rules!

charging profiles …

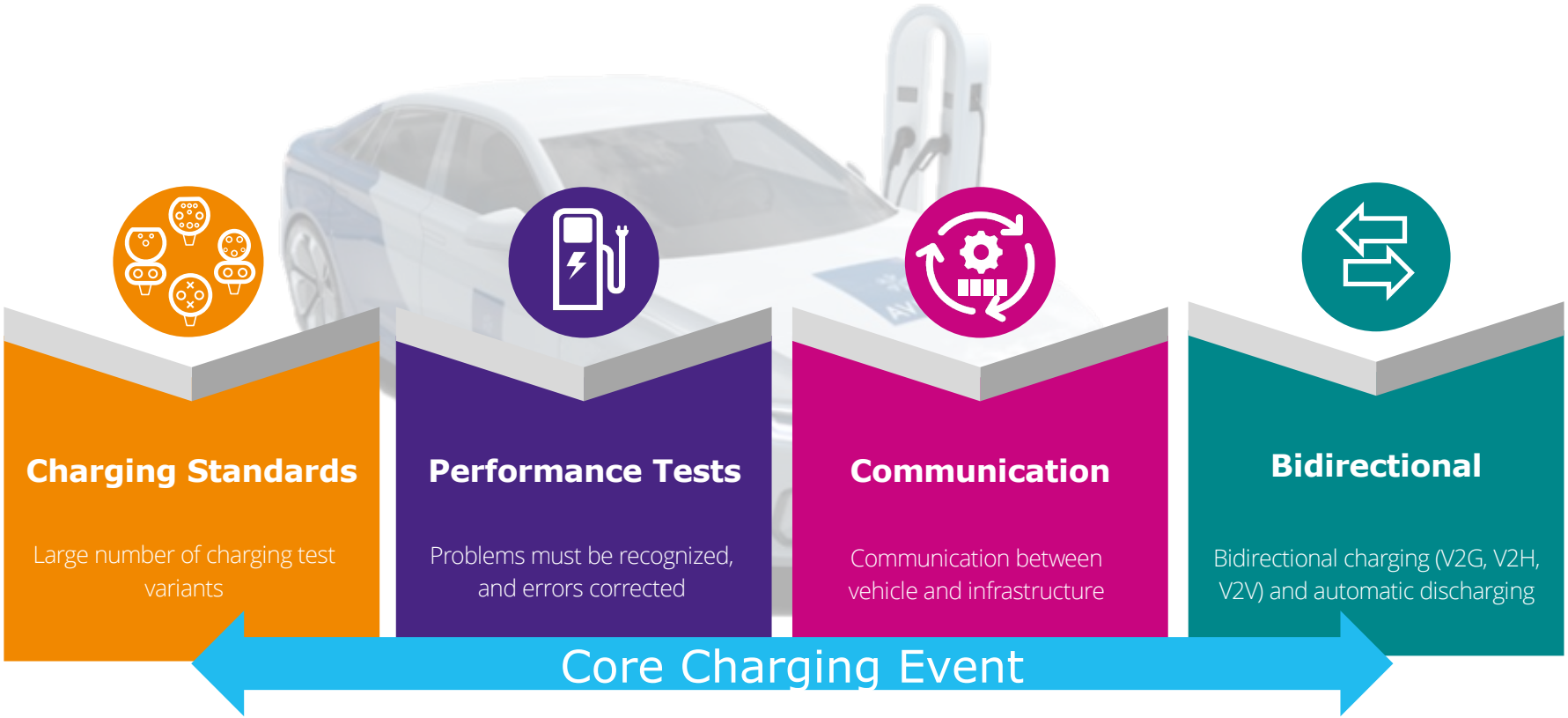
Different use-cycles on the same car



Powerjumps of 100kW to sync with battery container

-> Grid influence!

Testing Equipment **AVL Power Charging TS ™**



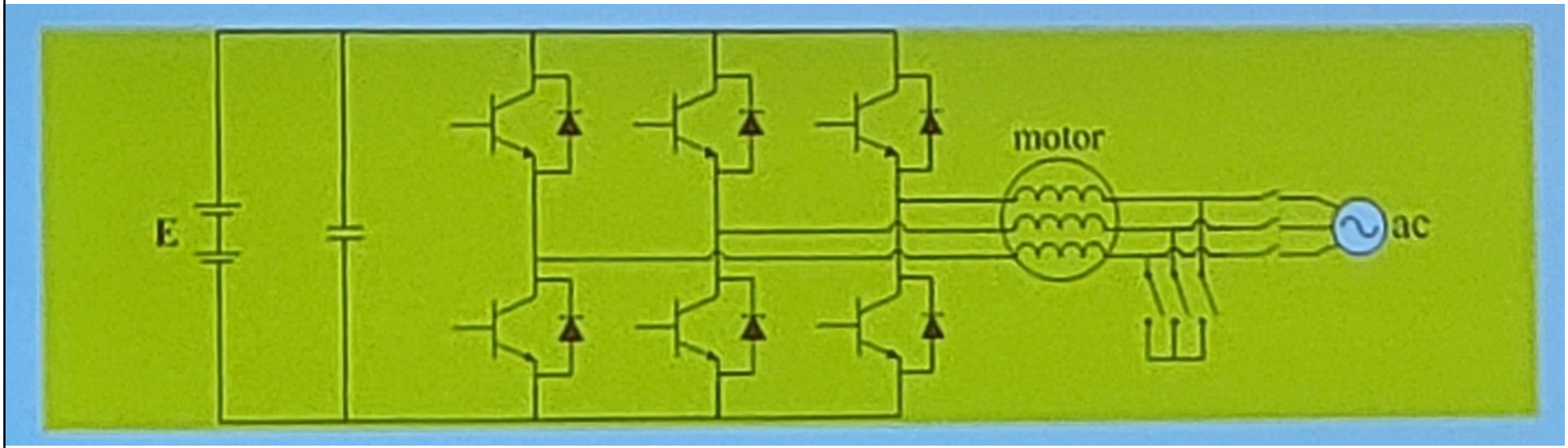
AVL Power Charging TS ™

testing vehicles and testing Charging Infrastructure products

AVL Universal Charger ™

AVL Universal Charger Tester ™

Voll integrierte Onboard Charger die Fahrzeugkomponenten verwenden

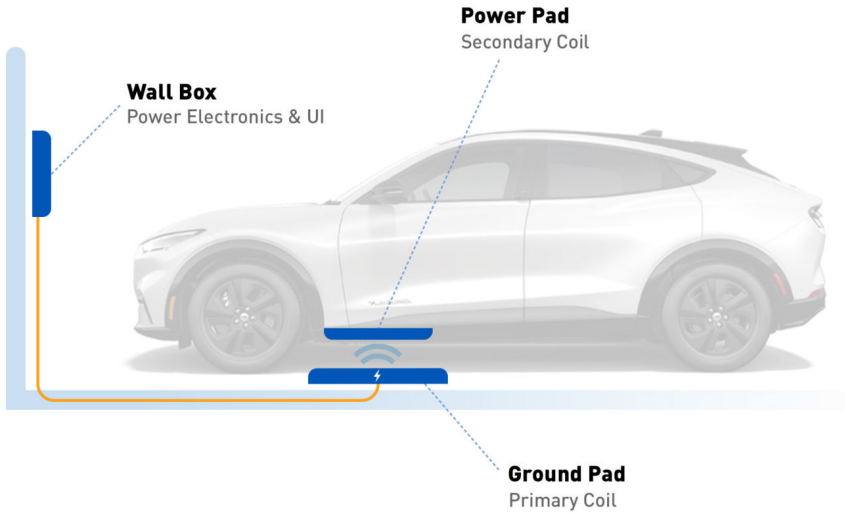


Charging concepts

Beispiele

Internal

Charging concepts
Wireless charging / inductive charging

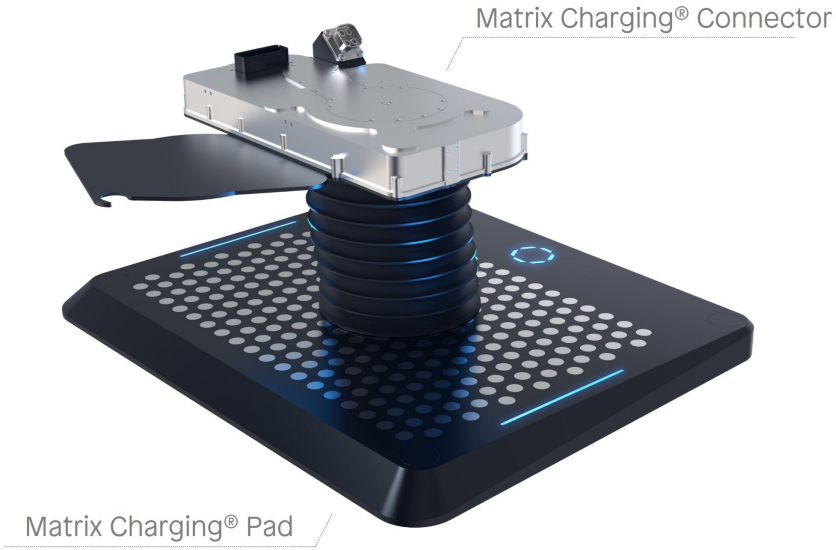


Description

- Several companies & startups working in this field
- Charging pad can be integrated in newly built parking lots or afterwards placed on existing ones
- Communication vehicle to charger needs to be standardized
- Actual systems are said to work with an efficiency of 90 %
- Misalignment tolerance is improving
- 20 kW for EVs, up to 250 kW for busses on the market or in prototype status

Source:
https://www.eetasia.com/wireless-charging-empowers-the-future-of-e-mobility/
(2023-09-20)

Charging concepts
Self contacting connectors – example Easelink Graz

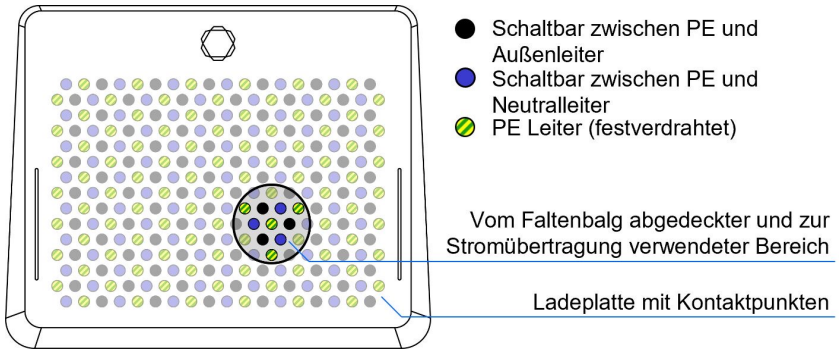


Description

- Pad is placed on the floor / might be integrated in the street, in parking lots
- Vehicle needs to be parked over the pad
- Flap opens and a self connecting unit is lowered to the pad
- Some unevenness of the floor can be compensated

Source:
https://www.oeamtc.at/thema/elektromobilitaet/matrix-charging-automatisiert-konduktives-laden-43945088 (2023-09-20)
https://easelink.com/matrix-charging/

Charging concepts
Self contacting connectors – example Easelink Graz



Description

- Some cleaning for the pad surface integrated in the connecting unit

Source:
https://www.oeamtc.at/thema/elektromobilitaet/matrix-charging-automatisiert-konduktives-laden-43945088 (2023-09-20)
https://easelink.com/matrix-charging/

Charging concepts
Dynamic charging – Overhead lines

Description

- Dynamic charging => charging while driving
- Overhead lines similar to trains along the highways
- Road unevenness and the pantographs ability to compensate the later are engineering challenges
- Technique might be combined with autonomous driving

Source:
https://www.faz.net/aktuell/rhein-main/frankfurt/teststrecke-bei-frankfurt-elektro-highway-im-vollbetrieb-16824051.html (2023-09-20)

Charging concepts
Dynamic charging – Power rail

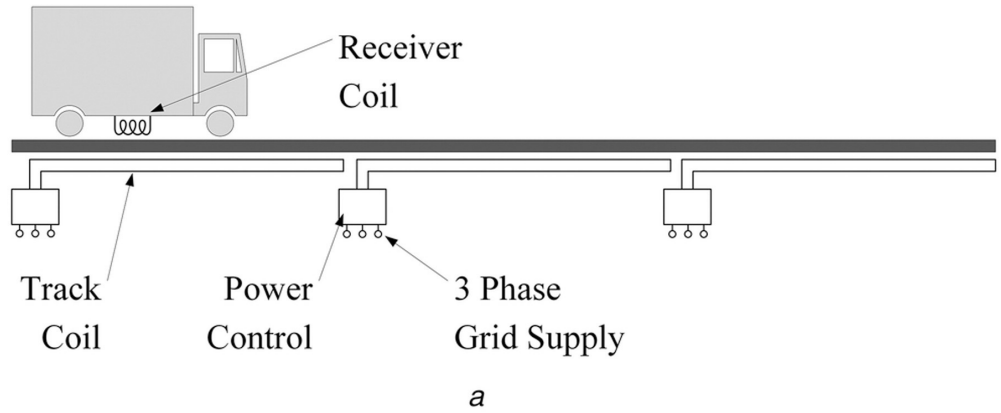
Description

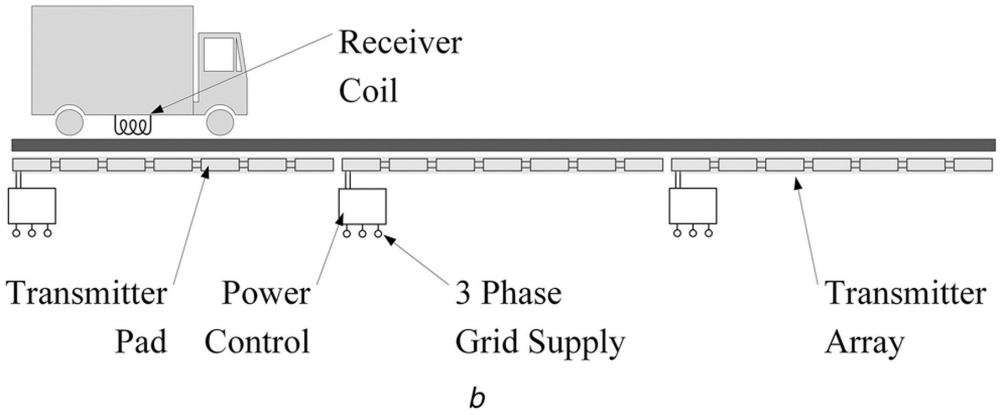
- First concepts for electrification of heavy duty mining vehicles
- Underground mining operation (beside conveyor belts) is already electrified today to a large extend to avoid exhaust gases

Source:
https://thedriven.io/2023/05/31/australian-company-pioneers-dynamic-charging-for-electric-mining-trucks/ (2023-09-27)

Charging concepts

Dynamic charging – inductive charging / wireless power transfer (WPT)





Description

- Dynamic charging => charging while driving
- Overhead lines similar to trains along the highways

Source:
https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/iet-its.2018.5221
(2023-09-21)

Charging concepts

Dynamic charging – inductive charging / wireless power transfer (WPT)

(a) DWC-EV power track under construction **(b) DWC-EV in operation**

Source:
J.J. Young et al; Energies 2016, 9, 483
https://doi.org/10.3390/en9070483

Charging concepts
Opportunity charging

Description

- Recharge electric vehicles at every opportunity with small amounts energy
- Often used for on-route public transport, also for trucks; hybrid vehicles and electric vehicles
- In industry applications often called in-process charging

Source:
https://cleantechnica.com/2017/11/26/goteborg-energi-orders-two-450-kw-abb-electric-bus-fast-chargers/
(2023-09-21)

Charging concepts
Battery swapping

Description

- Rapid exchange of discharged battery packs
- Battery usage likely only rental basis only; this might be a big advantage to mitigate battery durability concerns
- Widespread standardization of batteries between OEMs needed
- Nio system needs about 3 min for a battery exchange
- Battery swapping already used for forklifts

Source:
By bfishadow - https://www.flickr.com/photos/bfishadow/50725568717/, CC BY 2.0 https://commons.wikimedia.org/w/index.php?curid=116590017

Thank you

www.avl.com