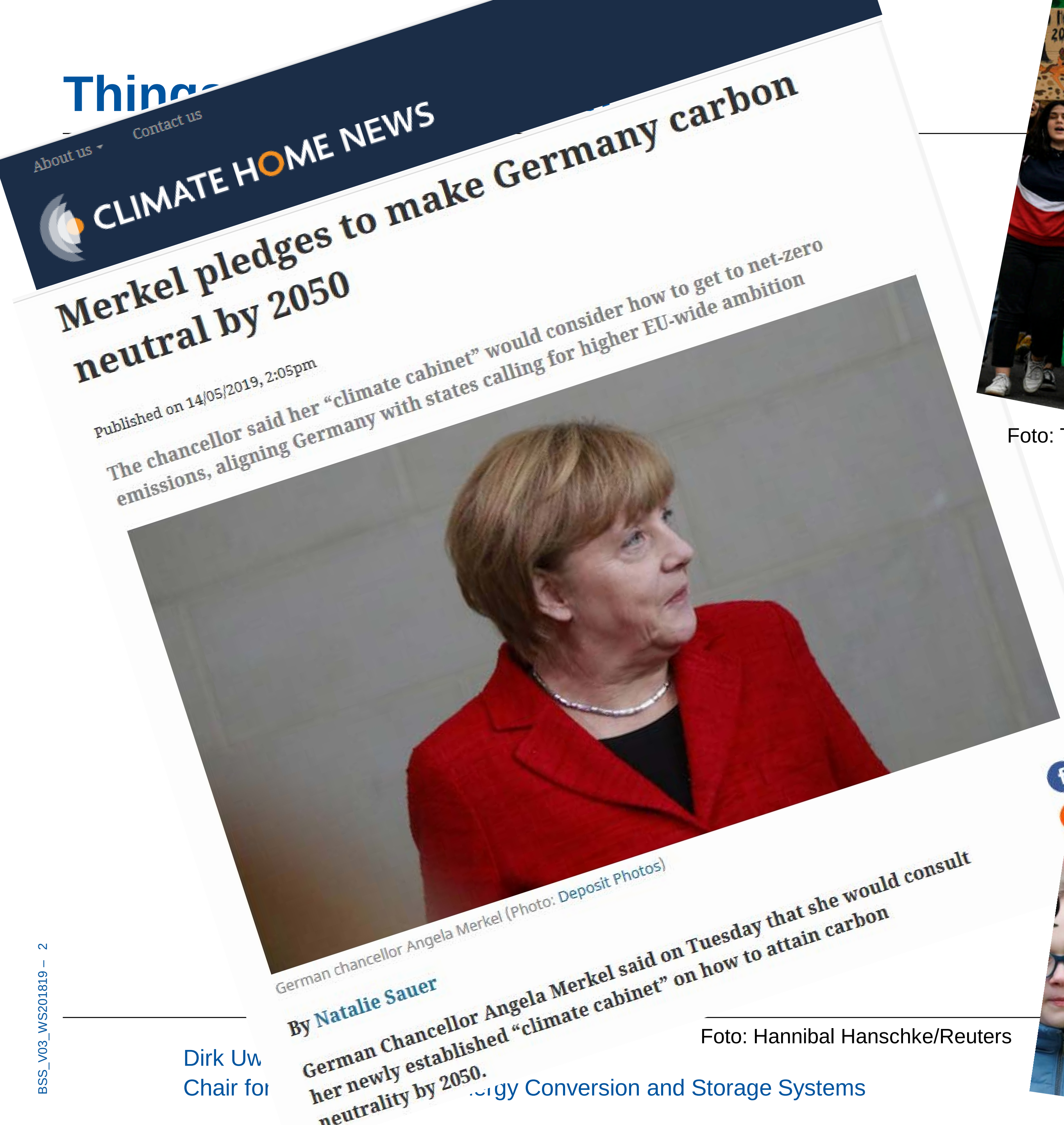
Battery-electric vehicles at the eve to make the major breakthrough – Upcoming challenges on materials, batteries, and the energy system

Dirk Uwe Sauer, Florian RIngbeck

Chair for Electrochemical Energy Conversion and Storage Systems

Thing…



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Merkel pledges to make Germany carbon neutral by 2050

Published on 14/05/2019, 2:05pm

The chancellor said her "climate cabinet" would consider how to get to net-zero emissions, aligning Germany with states calling for higher EU-wide ambition

German chancellor Angela Merkel (Photo: Deposit Photos)

By Natalie Sauer

German Chancellor Angela Merkel said on Tuesday that she would consult her newly established "climate cabinet" on how to attain carbon neutrality by 2050.

Foto: TAZ

Foto: Hannibal Hanschke/Reuters

Things are changing …

FINANCIAL TIMES

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Volkswagen reveals plan to enter battery cell production

Carmaker to consider options for its heavy-industry focused businesses

VW's electric dreams are the most ambitious of Europe's traditional car groups. Some €30bn in investments are planned by 2023 © Reuters

Peter Wells in New York MAY 13, 2019

Volkswagen on Monday announced it would enter battery cell production, and also revealed it would kick-start a process to determine the future of some of its heavy industry-focused businesses as well as prepare to float its truck unit before summer.

The German automaker said it would set up a battery cell production facility in Lower Saxony under a partnership, and that its supervisory board also approved just under €1bn of investments, according to a statement late on Monday following a board meeting.

The developments continue Volkswagen's pivot to an electrified future, as it moves past 2015's emissions scandal and joins industry rivals trying to gain a foothold in the market for electric vehicles.

"We are pressing ahead with the electrification and digitalisation of our fleet like no other automotive company," Herbert Diess, Volkswagen chief executive said in a statement on the eve of the company's annual meeting.

"At the same time, we are building up innovative business areas over the coming years to cater for innovative mobility services. This is about aligning the Volkswagen Group to play a decisive role in shaping the sweeping transformation of our industry," Mr Diess added.

Dirk Uwe Sauer
Chair for Electrochemical Energy Conversion and Storage Systems

How much battery capacity is needed and what does is mean for resources?

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Chair for Electrochemical Energy Conversion and Storage Systems

Assumptions based on different announcements for 2025

VW plans with 150 to 250 GWh battery capacity demand in 2025

Extrapolation to the world market results in 700 to 1300 GWh

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Chair for Electrochemical Energy Conversion and Storage Systems

Example for Material Demand for Lithium-Ion Battery Cells

- Necessary material amounts for about 380 Wh battery capacity (Cell with 100 Ah, NMC (811) = $Ni_{0,8}Mn_{0,1}Co_{0,1}$) and a battery pack with 100 kWh (no housing, BMS, cooling, etc.)

	Battery Cell	Battery Pack
	100 Ah / 3,8 V	100 kWh
Nickel	325 g	85,5 kg
Manganese	37 g	9,7 kg
Cobalt	41 g	11,1 kg
Lithium	35 g	9,2 kg
Aluminum (without housing)	144 g	37,9 kg
Copper	281 g	73,9 kg

- Very high energy and resource consumption calls the ecology of the approach into question

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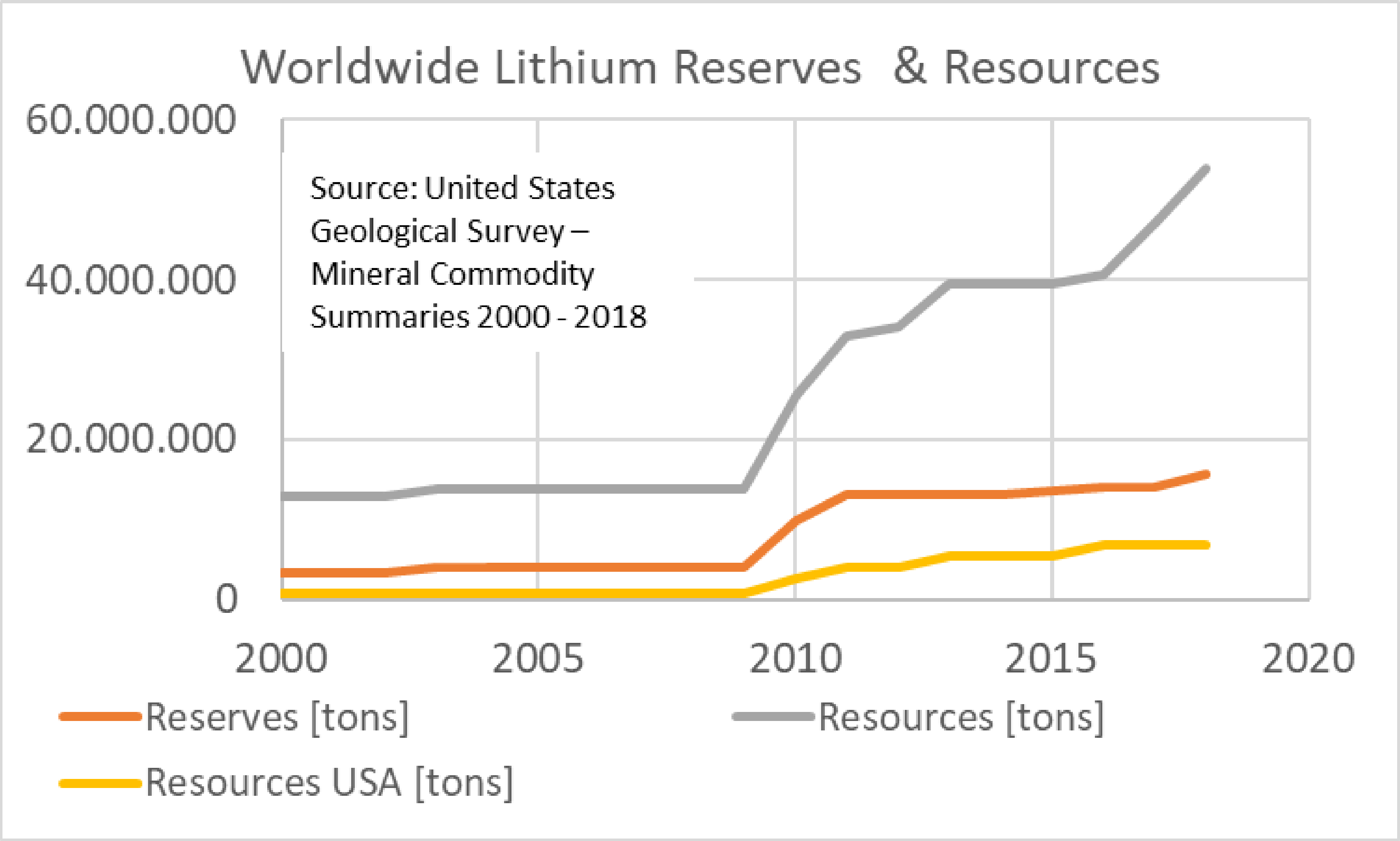
Growing Demand Motivates Increased Activities in Finding new Raw Material Deposits



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Material demand for different battery market development
(Assumption of 2025: 20 Mill. BEV with 50 kWh capacity each results in 1000 GWh)

Material	Demand for 100 kWh battery capacity [kg]	Demand in metric tons for 700 GWh battery capacity/year	Demand in metric tons for 1000 GWh battery capacity/year	Demand in metric tons for 1200 GWh battery capacity/year	todays production per year (metric tons) (Source: US Geological Survey 2017)	Share at 1000 GWh/year of todays annual production
Nickel	85,5	598.500	855.000	1.026.000	2.100.000	41%
Manganese	9,7	67.900	97.000	116.400	16.000.000	1%
Cobalt	11,1	77.700	111.000	133.200	110.000	101%
Lithium	9,2	64.400	92.000	110.400	43.000	214%
Aluminium	37,9	265.300	379.000	454.800	60.000.000	1%
Copper	73,9	517.300	739.000	886.800	19.700.000	4%

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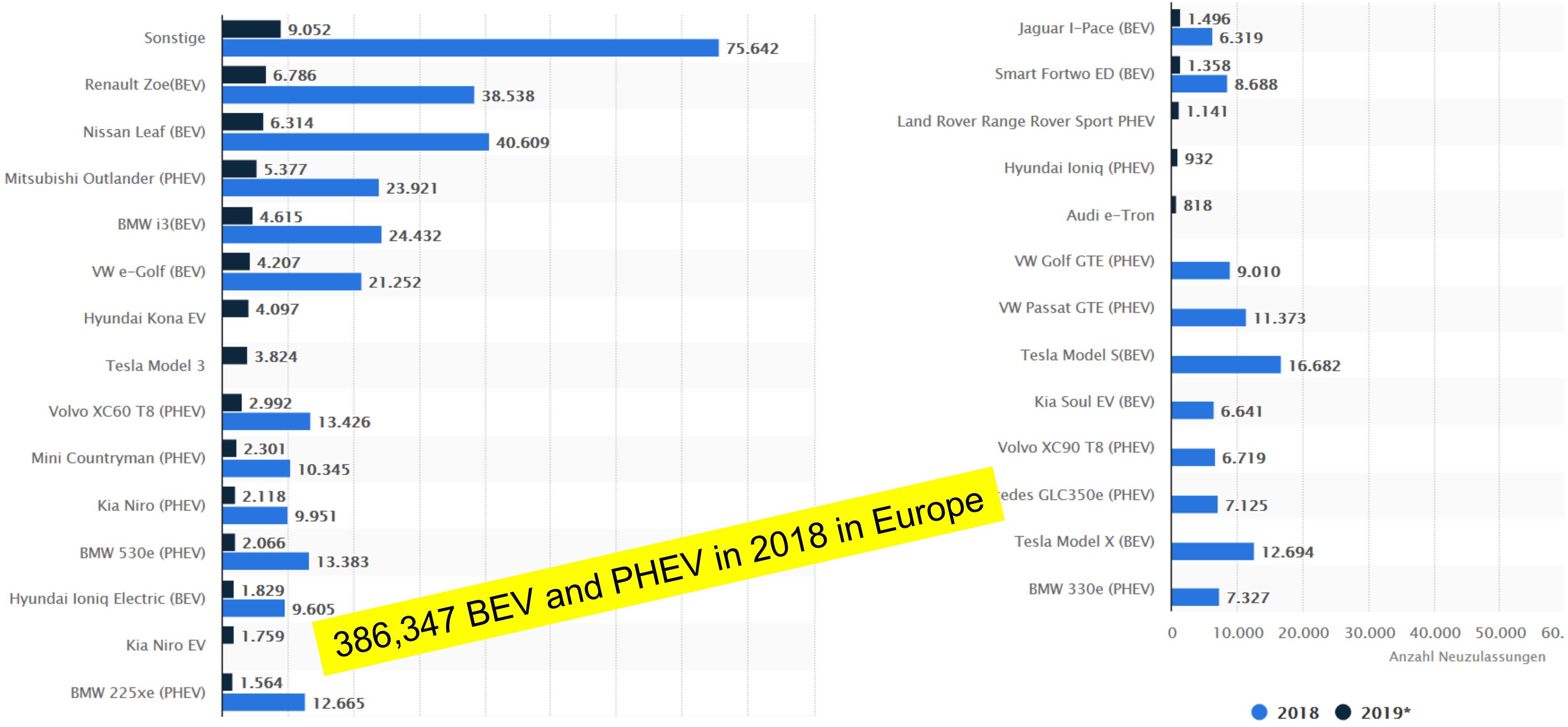
Sales of electric vehicles in Europe in 2018 and beginning of 2019



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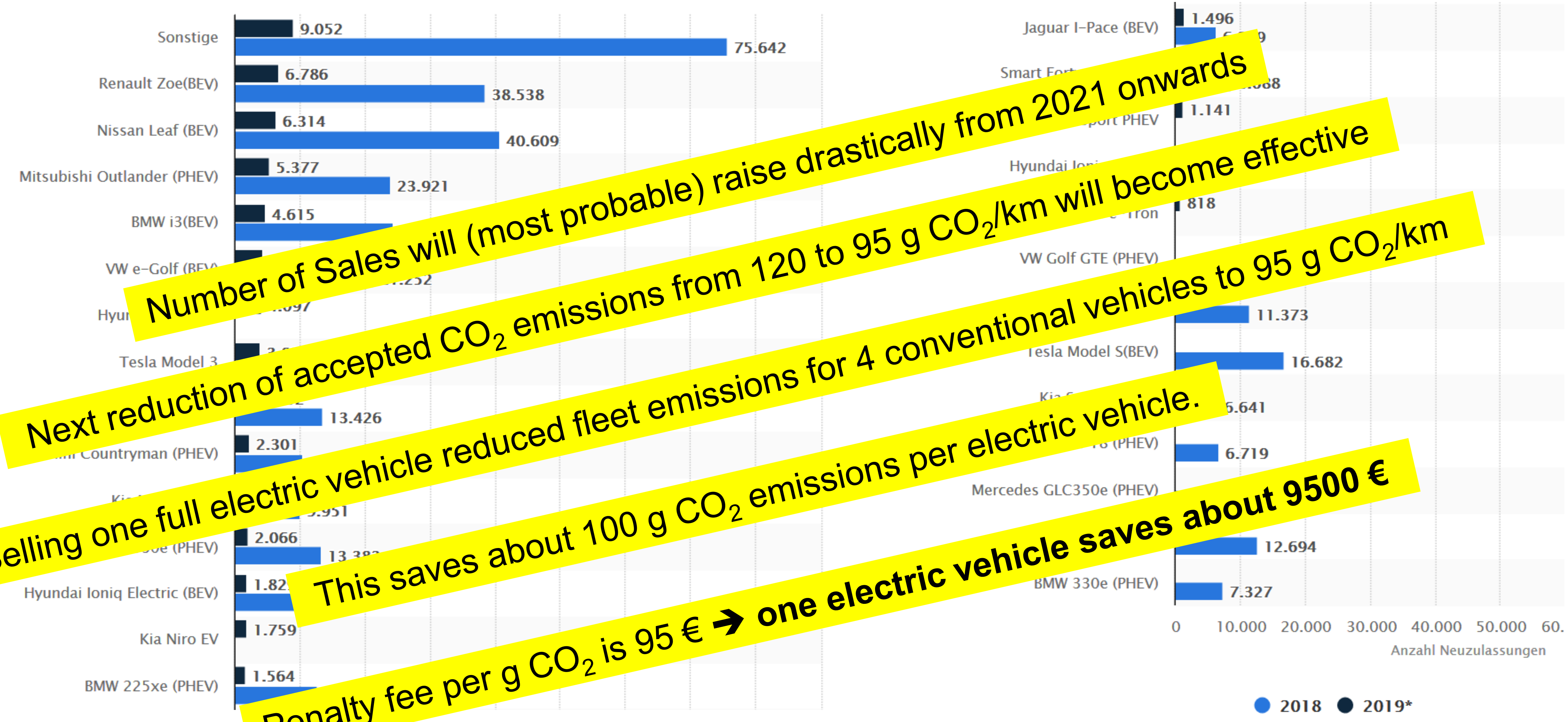
Sales of electric vehicles in Europe in 2018 and beginning of 2019



Number of Sales will (most probable) raise drastically from 2021 onwards

Next reduction of accepted CO_2 emissions from 120 to 95 g CO_2/km will become effective

Selling one full electric vehicle reduced fleet emissions for 4 conventional vehicles to 95 g CO_2/km

This saves about 100 g CO_2 emissions per electric vehicle.

Penalty fee per g CO_2 is 95 € ➔ **one electric vehicle saves about 9500 €**

Challenges and advancements in battery pack design

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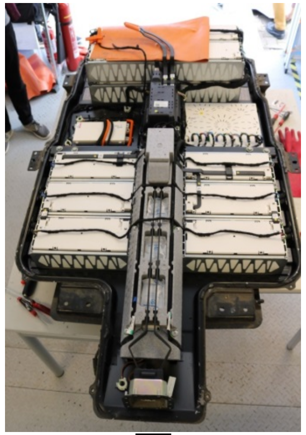
Energy and power density – Analysis of fleet vehicles from 2013/14

- Energy density
  - Wh/kg
  - Wh/l
- Power density
  - Power per kg or litre
- Values to distinguish:
  - Theoretical energy density
  - Numbers based on cells
  - Numbers based on battery packs
- High power and high energy density are not possible at a time

Source: www.mirror.co.uk

Volkswagen e-up!

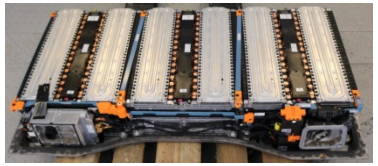
18.7 kWh, 60 kW
passive air-cooling



Source: www.insideevs.com

Smart Electric Drive

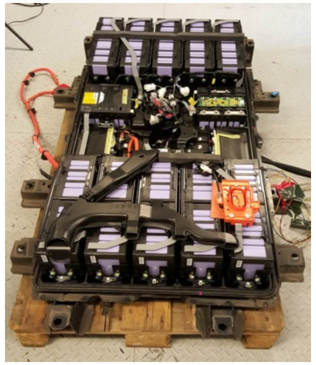
17.6 kWh, 55 kW
liquid-cooling



Source: www.autoevolution.com

Mitsubishi i-MiEV

16.3 kWh, 49 kW
active air-cooling



Source: www.carbyer.co.uk

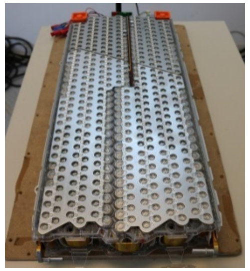
Nissan Leaf*

24 kWh, 80 kW
passive air-cooling

Source: www.autoblog.com

Tesla Model S*

85 kWh, 270 kW
liquid-cooling



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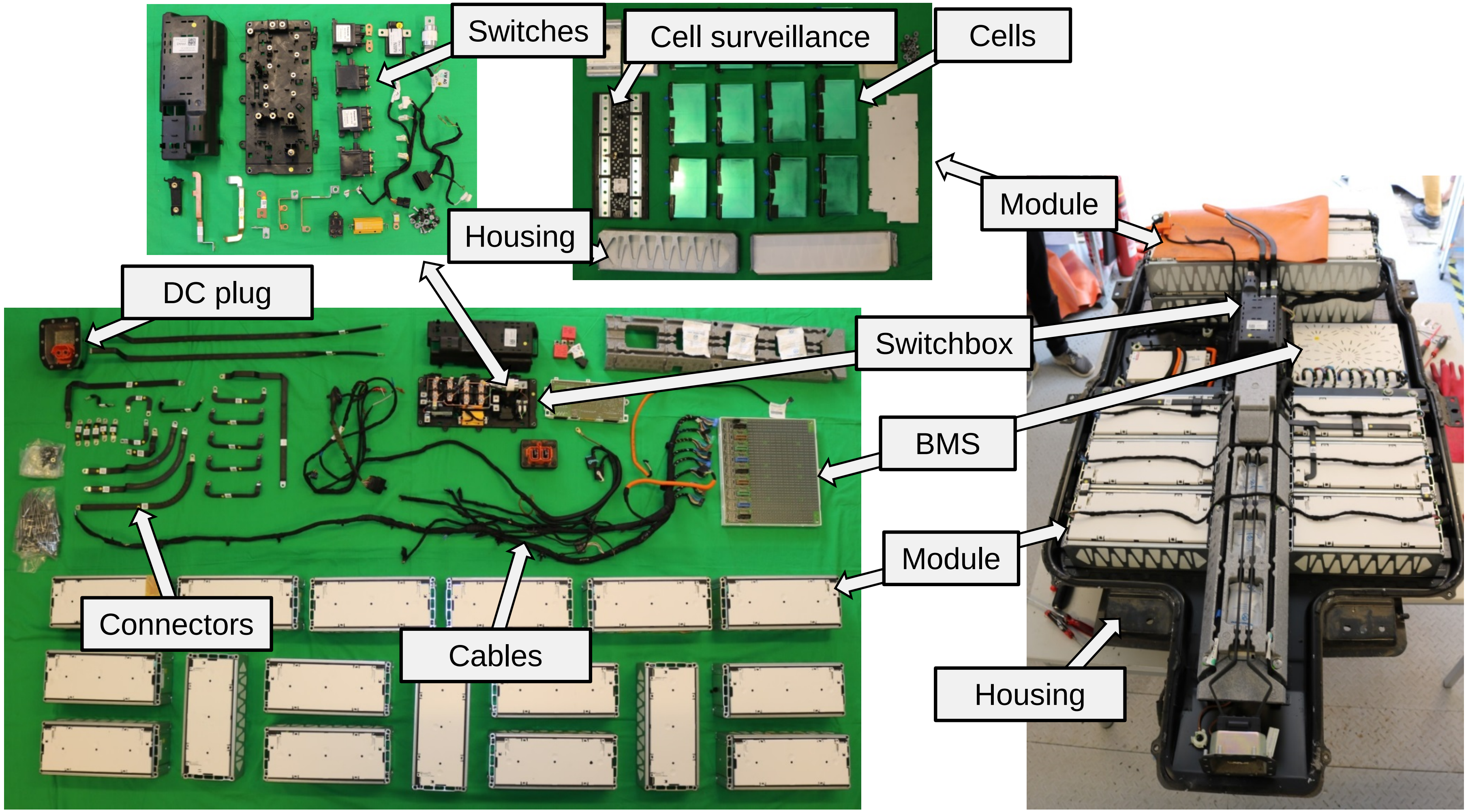
Volkswagen e-up! Battery Pack Components



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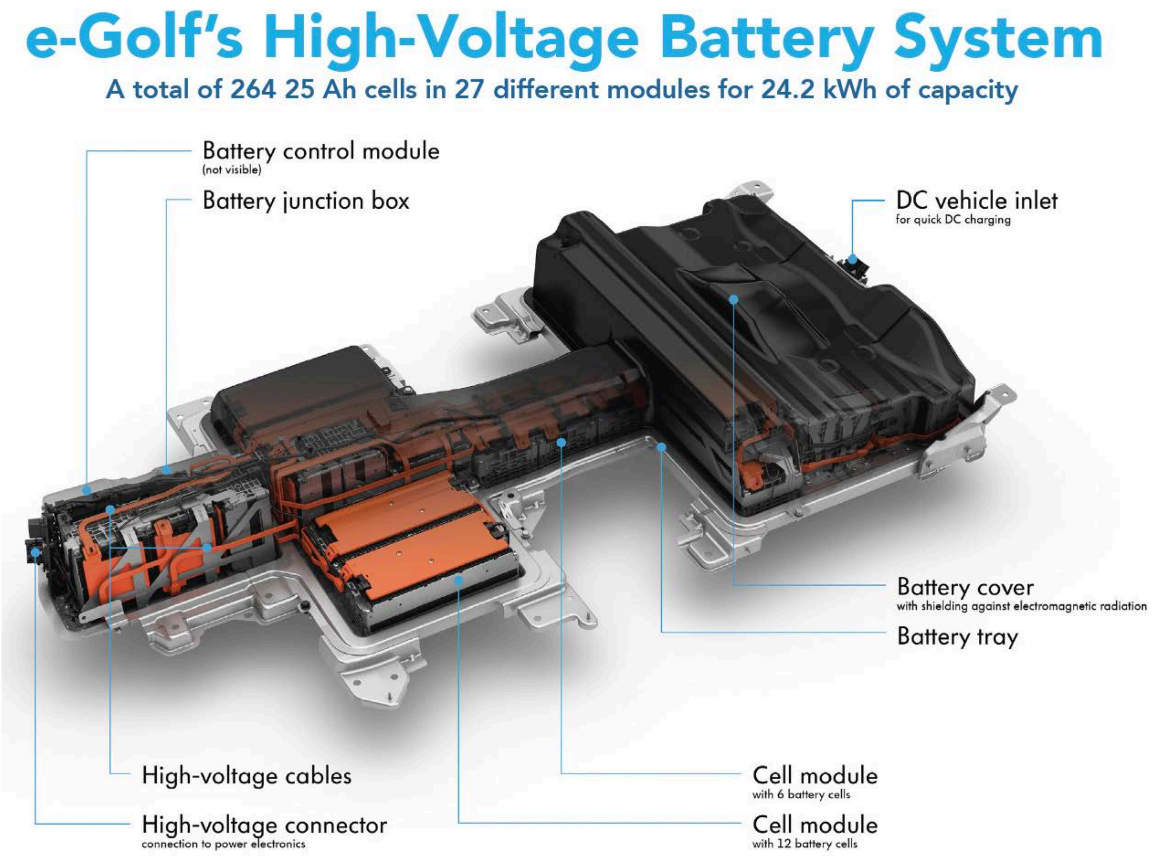
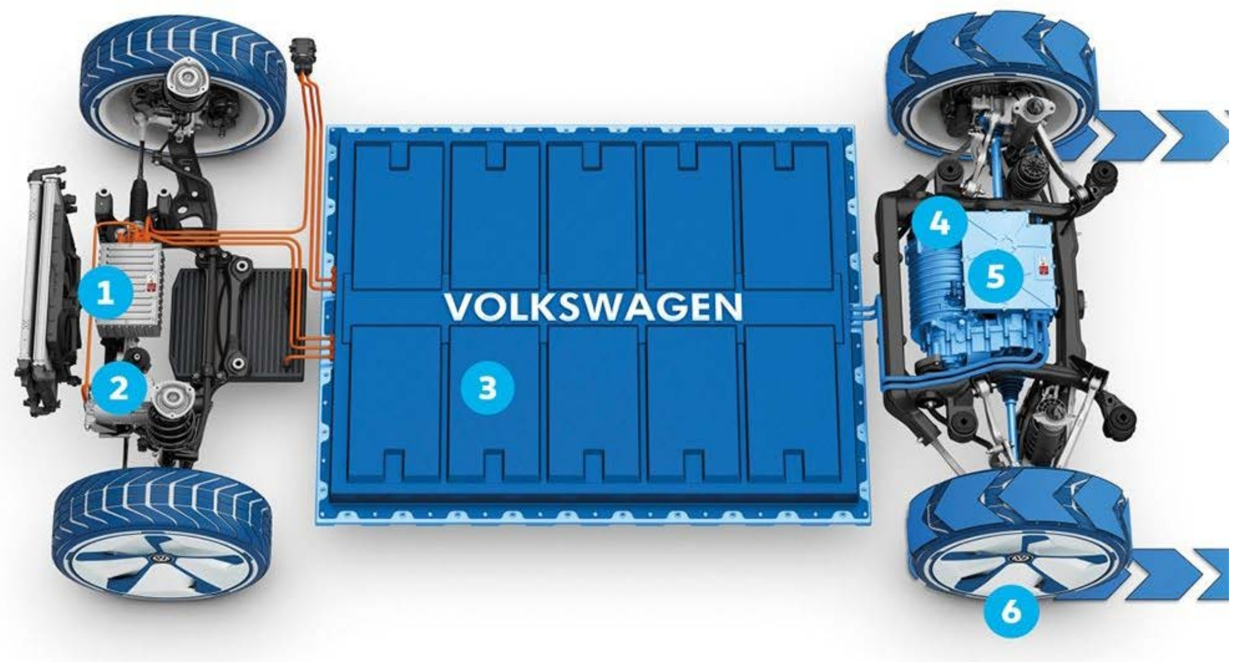
From conversion design to purpose design

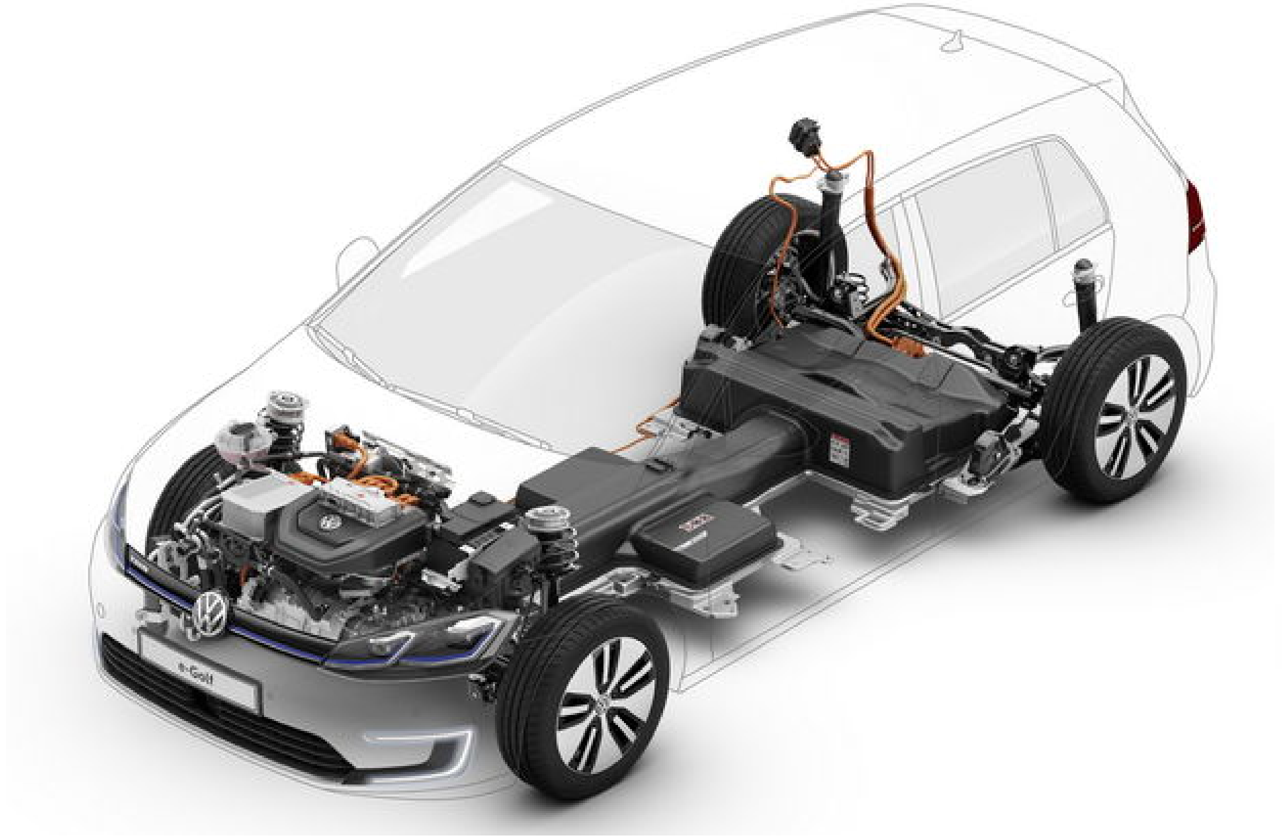


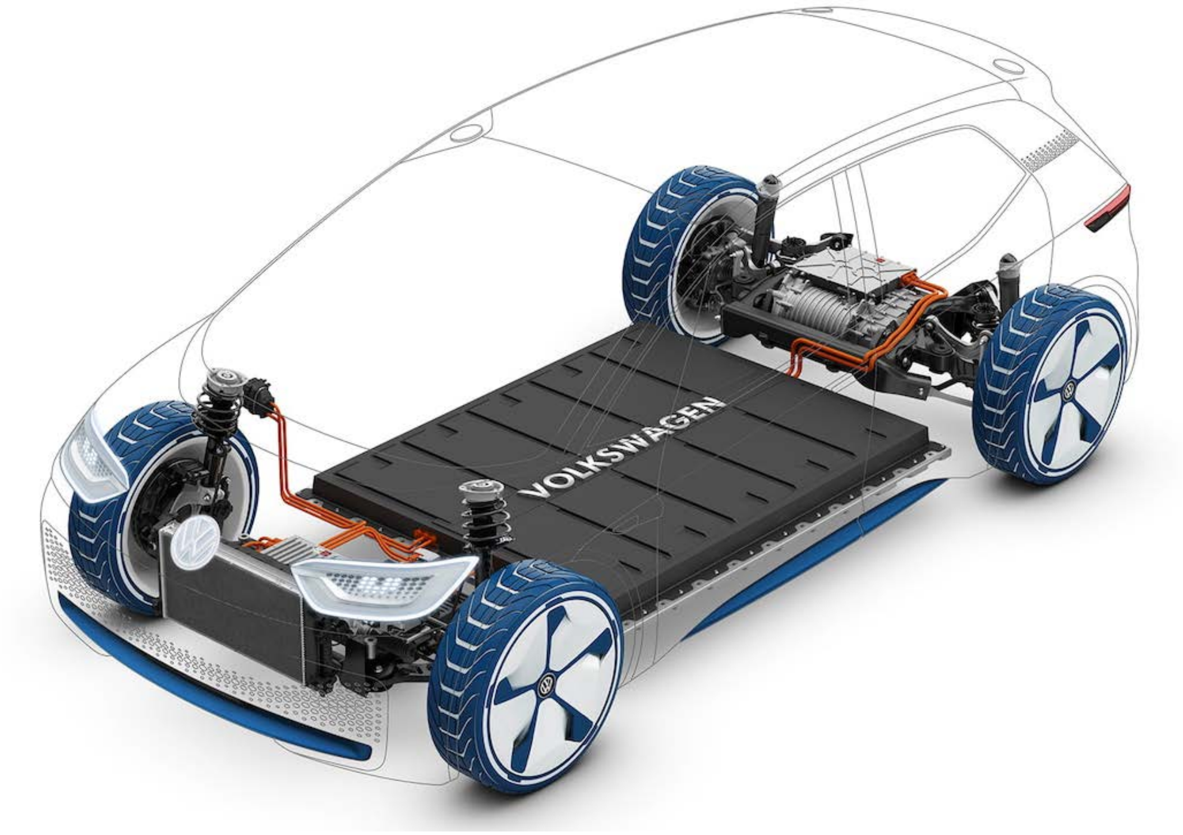
Modular Electric Building Block (MEB) e.g. for VW I.D.



Bilder: Volkswagen AG

From conversion design to purpose design



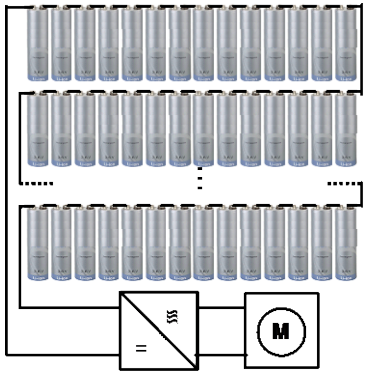


Bilder: Volkswagen AG

Challenges on battery system design

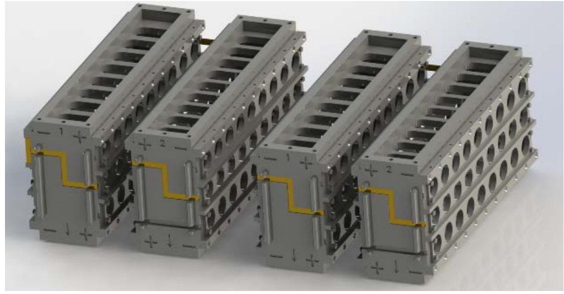
Design of architecture

- Estimation of required battery size
- Selection of a cell chemistry
- Selection of cell type
- Wiring concept



System configuration

- Cell connectors / electrical connections
- Switchbox (switches, pre-charge and fuses)
- Cooling and heating
- Battery management system



Realisation

- Structure
- Testing
- Safety – cell level
- Safety – system level
- Crash resistance

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European lithium-ion battery cell manufacturers?!

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Chair for Electrochemical Energy Conversion and Storage Systems

Europe to spend billions on lithium-ion battery plants

Cecilia Jamasmie | Oct. 15, 2018, 9:43 AM |

PEOPLEMINE FACEBOOK LINKEDIN TWITTER EMAIL PRINT

The eRuf Model A, an all-electric sports car made by German carmaker Ruf Automobile GmbH. (Image courtesy of Tom Wolf | Flickr.)

One in every twenty Europeans works in the automotive industry and the European Union believes that unless it catches up on battery technology, those jobs are at risk.

EU Battery Alliance launches Airbus-style consortium to make Europe a force in batteries

Major automotive, chemicals, raw materials, engineering and energy companies are joining forces to overcome the EU's competitive disadvantage in next-generation battery technologies and build a European battery manufacturing base

By Jayson Dong

Photo: Ludovic Hirlimann

Energy storage has emerged as a central building block of the EU's objectives in low emission electric transport and replacing electricity generated by fossil fuels with renewables.

ery

Arguments for large-scale investments in European battery manufacturers

Almost endless arguments have been used to explain, why it is not necessary or not possible to establish European cell manufacturers

Here are at least some arguments for establishing European cell manufacturers with large scale production

- Batteries may make up to one third of the total value of electric vehicles
  - Battery cell costs are decisive for the price of electric vehicles
  - Cell manufacturers will integrate themselves vertically from raw materials to battery packs, maybe even power electronics and electric drive trains

➔ Dependency on Asian cell manufacturers could be dangerous for the European can manufacturers

- (Some) German industry repeatedly argues against production in Germany by high electricity prices, labor costs, environmental regulations, etc.

➔ But why **can** Samsung, LG, or CATL build factories in Europe and even in Germany?

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Arguments for large-scale investments in … manufacturers

CATL designs the battery factory in Erfurt (Germany) for up to 100 GWh/year

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electrive.net
Branchendienst für Elektromobilität

Speichertechnik >

04.02.2019 - 16:35

CATL legt Erfurter Batteriewerk für bis zu 100 GWh aus

Die CATL-Fabrik könnte die Ausmaße der Gigafactory von Tesla schnell übertreffen

Batterie | Batterieproduktion | Batteriezellen | CATL | Erfurt | Thüringen | Zulieferer

Der chinesische Batteriezellhersteller CATL korrigiert die Pläne für seine Fabrik in Erfurt nach oben. Grund sind die strengeren CO_2-Vorgaben für Fahrzeuge in Europa. CATL hält in Thüringen eine Kapazität von bis zu 100 GWh für realistisch. Wir haben mit Europachef Matthias Zentgraf darüber gesprochen.

Zu Beginn ein kurzer Blick zurück: Als die Pläne für Erfurt im Sommer durchgesickert waren – der Branchendienst electrive.net hatte über den genauen Standort als erstes berichtet – war von einer Kapazität in Höhe von 14 GWh pro Jahr in der ersten Ausbaustufe die Rede. Die Produktion soll bereits 2021 starten. Bis 2022, so die Planung damals, wollte CATL rund 240 Millionen Euro in den Standort investieren. Nun jedoch zeichnet sich ab, dass die Batteriezellfabrik im Industriegebiet Erfurter Kreuz deutlich größer werden könnte als anfänglich gedacht.

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What are the challenges for power generation and grids

Dirk Uwe Sauer
Chair for Electrochemical Energy Conversion and Storage Systems

Handelsblatt DIGITALPASS 4 WOCHEN GRATIS TESTEN

Danger of blackouts caused by electric vehicles

PREMIUM BOOM BELASTET STROMNETZ

Blackout-Gefahr durch Elektroautos

Die Netzbetreiber schlagen Alarm: Das Stromnetz ist auf den Boom von Elektroautos nicht vorbereitet. Um Engpässe, Überlastungen und Totalausfälle zu vermeiden, muss das Netz jetzt mit Milliardensummen ertüchtigt werden.

Jürgen Flauger   Franz Hubik

21.01.2018 - 19:50 Uhr • 3 Kommentare • 17 x geteilt

Ladestation für Elektrofahrzeuge

Some numbers on power and electric vehicles

Power demand of electric vehicles

- 37 km average daily mileage in Europe
- 42 Millionen passenger vehicles in Germany
- 12 – 20 kWh / 100 km energy demand

➔ **68 – 113 TWh additional power demand out of approx. 600 TWh power production in Germany today – less than 20% !**

Grid load caused by electric vehicles assuming intelligent power management

- 7.4 kWh / day (20 kWh / 100 km)
- 22 hours/day stand-still of vehicles (average), typically more than 12 hours at home

➔ **0.62 kW average power consumption at home**
(100% recharging at home within 12 hours)

Some numbers on power and electric vehicles

Grid overload in distribution grids caused by electric vehicles?

- □ 7.4 kWh / day (20 kWh / 100 km)

➔ Charging with 3.7 kW (240 V, 16 A, single phase) charging takes 2 hours per vehicles

➔ Charging with 22 kW takes 20 min

Grid operation is a matter of statistics – If a specific car needs more power, others will need less.

Horror scenarios such as „All cars will charge at the same point in time“ are nonsense.

Communication and artificial intelligence can distribute charging efficiently.

Just recently published study by E.ON – largest utility in Germany

E.ON invests 2.5 Billion Euro for electromobility into the grid

Costs for grid extensions in the distribution grid (according to E.ON):

- 2.5 billion Euro
- Until 2045
- For an area with 6.5 Million vehicles

- Today annual spendings for the same grid area of about 1 Billion Euro

➔ **~400 € / electric vehicle**

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Challenges arising from ultra-fast charging (> 350 kW)

Dirk Uwe Sauer
Chair for Electrochemical Energy Conversion and Storage Systems

What has been discussed as high power charging few years ago until now …

- 22 to 44 kW AC charging
- 50 kW DC charging

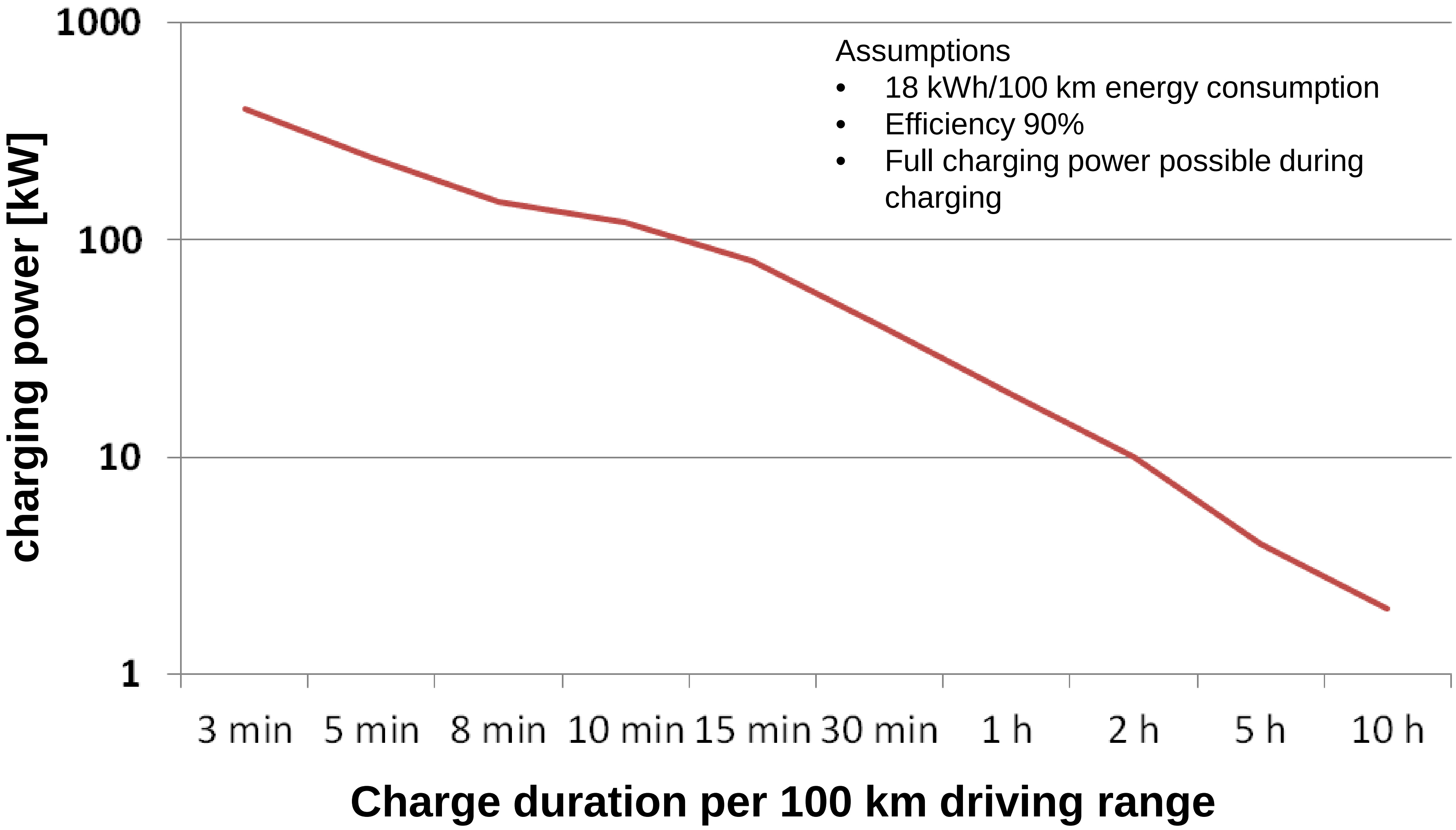
- Teslas‘ Superchargers: 120 kW DC

- Specific charging current:

$$C_{rate} = \frac{charging\ power\ [kW]}{battery\ capacity\ [kWh]}$$

- 50 kW power on 25 kWh battery ➔ 2 C
- 120 kW power on 90 kWh battery ➔ 1.3 C

Charging power vs. charging time



Now under discussion: Ultra charging with 350 to 400 kW

$$C_{rate} = \frac{charging\ power\ [kW]}{battery\ capacity\ [kWh]}$$

- 350 kW power on 30 kWh battery ➔ ~12 C
- 350 kW power on 60 kWh battery ➔ ~ 6 C
- 350 kW power on 100 kWh battery ➔ ~3.5 C
  ➔ 3x and more higher than Tesla does today

- The battery used by Tesla would die within few cycles at a C rate of 2 C at around 30°C

- For comparison average discharge rates are in the range of 0.1 to 0.8 C!

Pilotprojekt Ultra-Schnellladung für Elektroautos gestartet

G+1 0 Tweet Gefällt mir

Am 18. Oktober 2016 startete das Projekt „Ultra-E". Es soll einen wichtigen Meilenstein für die Elektromobilität und die damit verbundene umweltfreundliche Zukunft des Verkehrssektors setzen.

Die Projektpartner haben sich zum Ziel gesetzt, ein Netzwerk von 25 Ultra-Schnellladestationen mit CCS-Stecker und einer Ladeleistung von bis zu 350 kW an TEN-T Netzwerk-Korridoren zu errichten. Das Ultra-Schnellladenetzwerk wird die Niederlande, Belgien, Deutschland und Österreich verbinden.

Ein weiteres Ziel ist es, die Ultra-Schnellladetechnologie für Pkw, Busse und Nutzfahrzeuge zu testen.

Challenges for Lithium-ion batteries at high charging rates

- Power oriented design

- Cooling systems

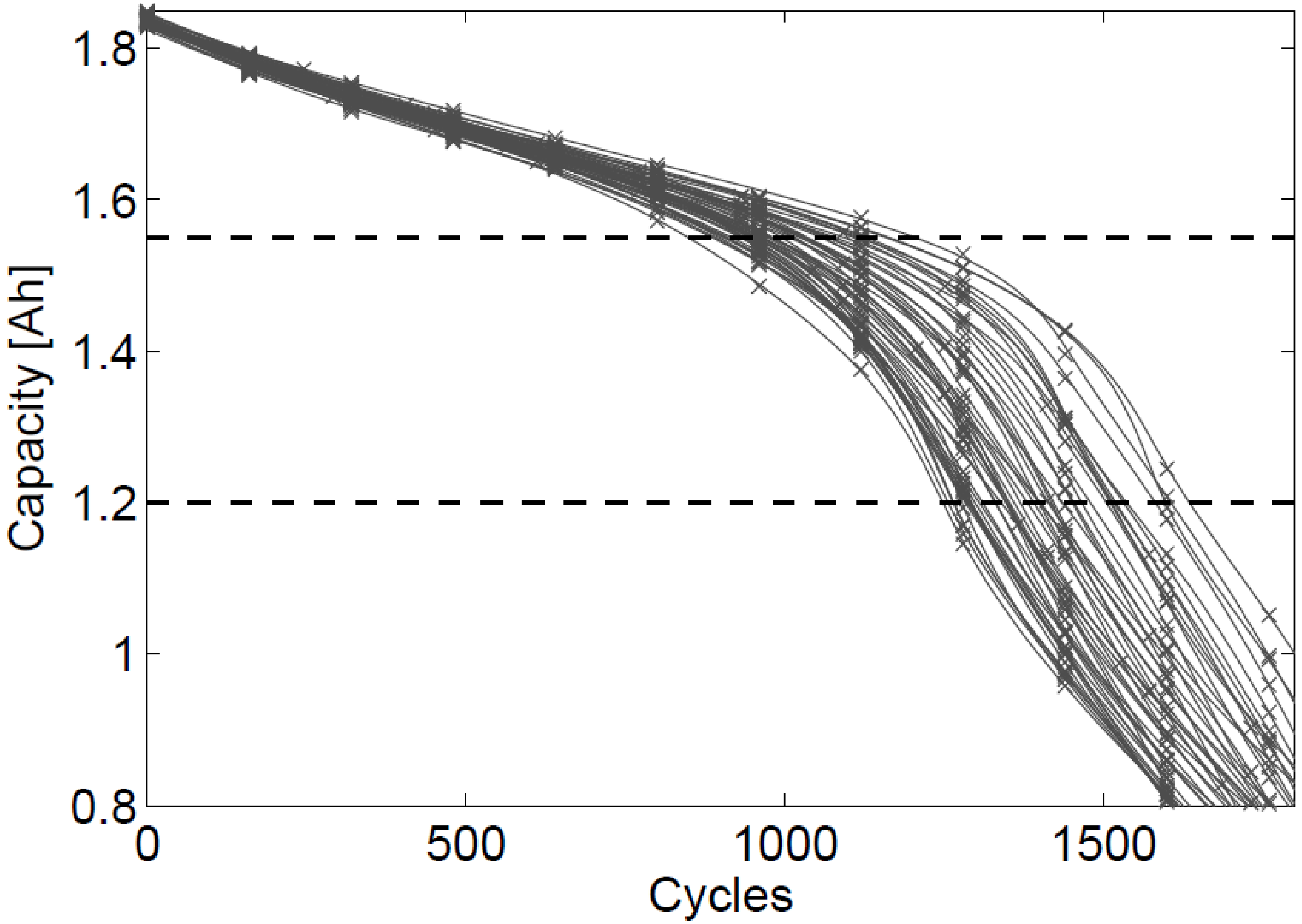
- Increased battery voltage

- Risk of accelerated ageing due to lithium plating

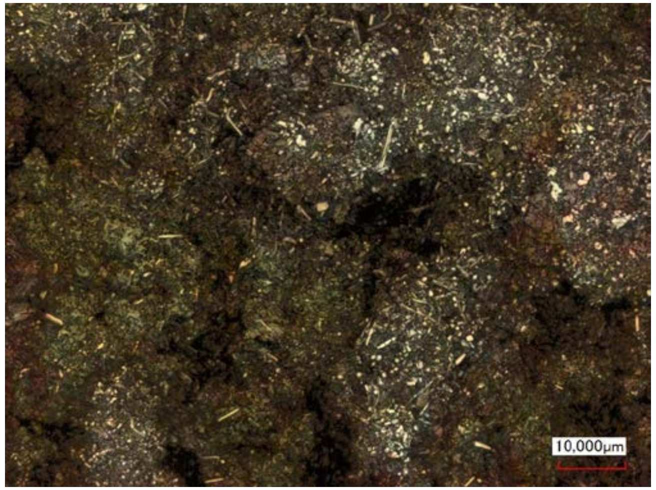
High power charging requires high battery voltage: 800 to 1000 V → ~ 400 A

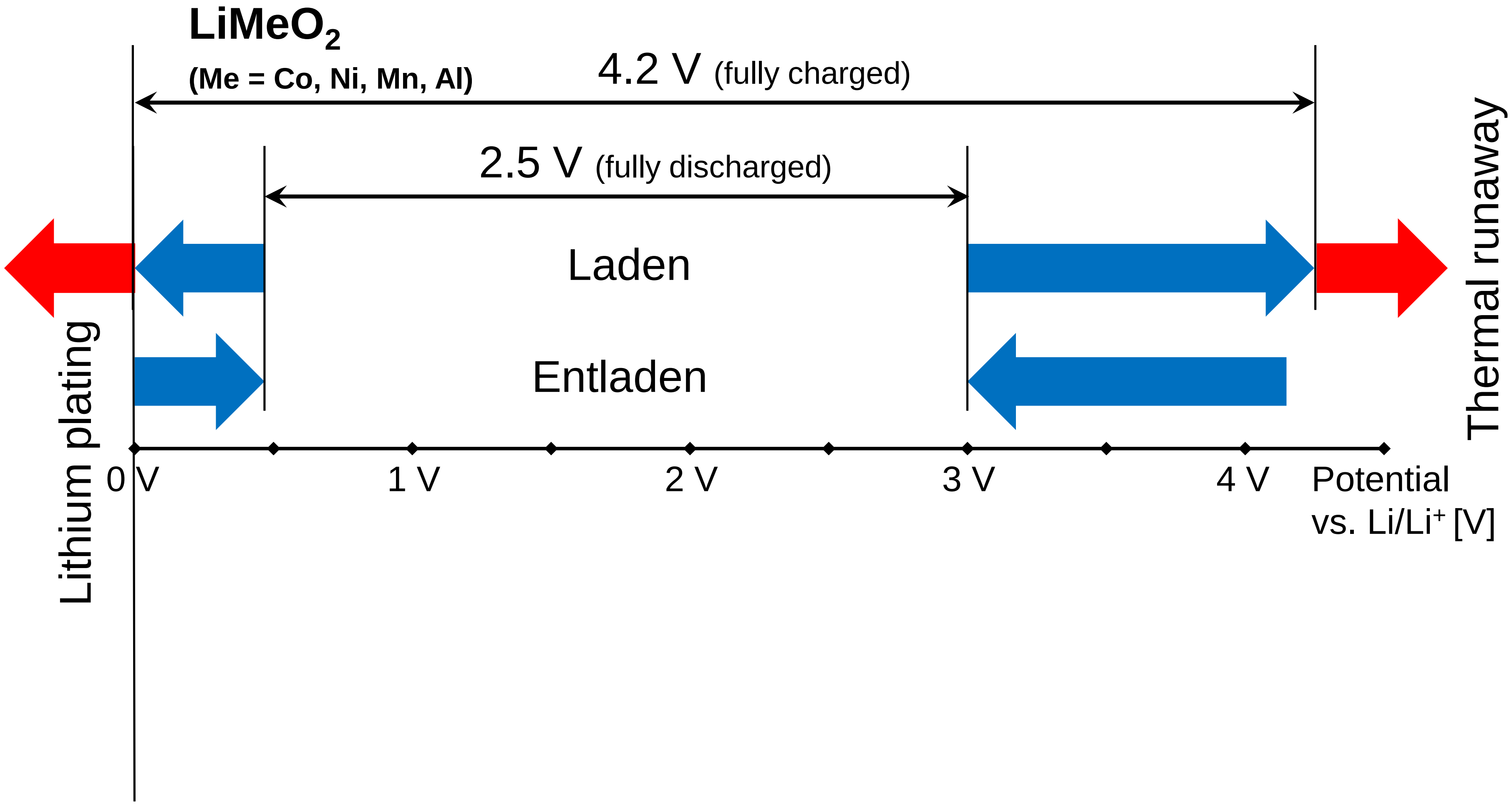
High voltage means large number of series connected cells

- Lifetime is limited by the worst cell in series connection
- Reliability decreases



Charging of Lithium-ion batteries is limited by the negative electrode potential

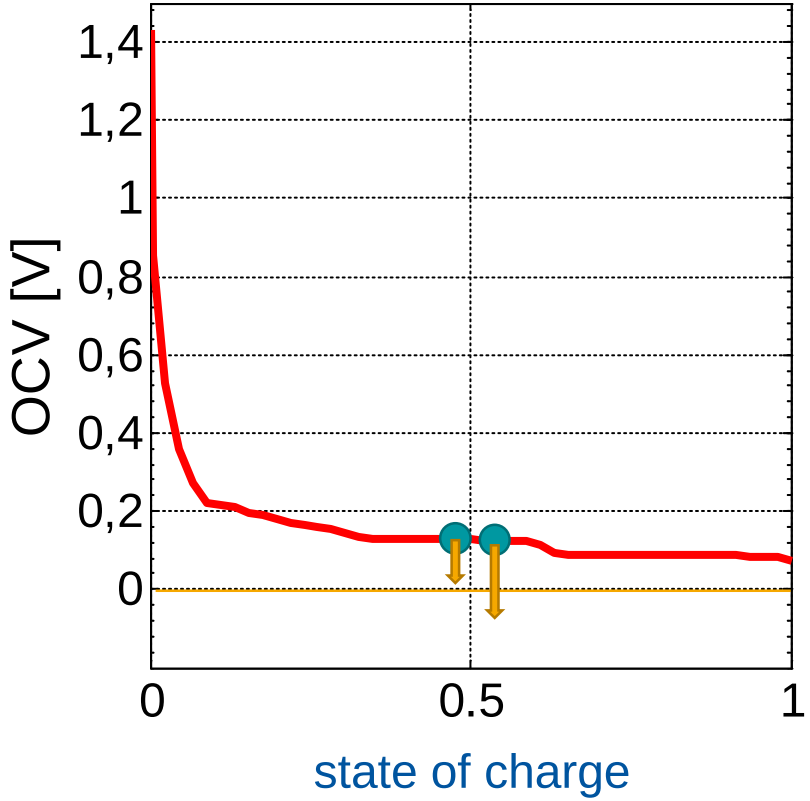




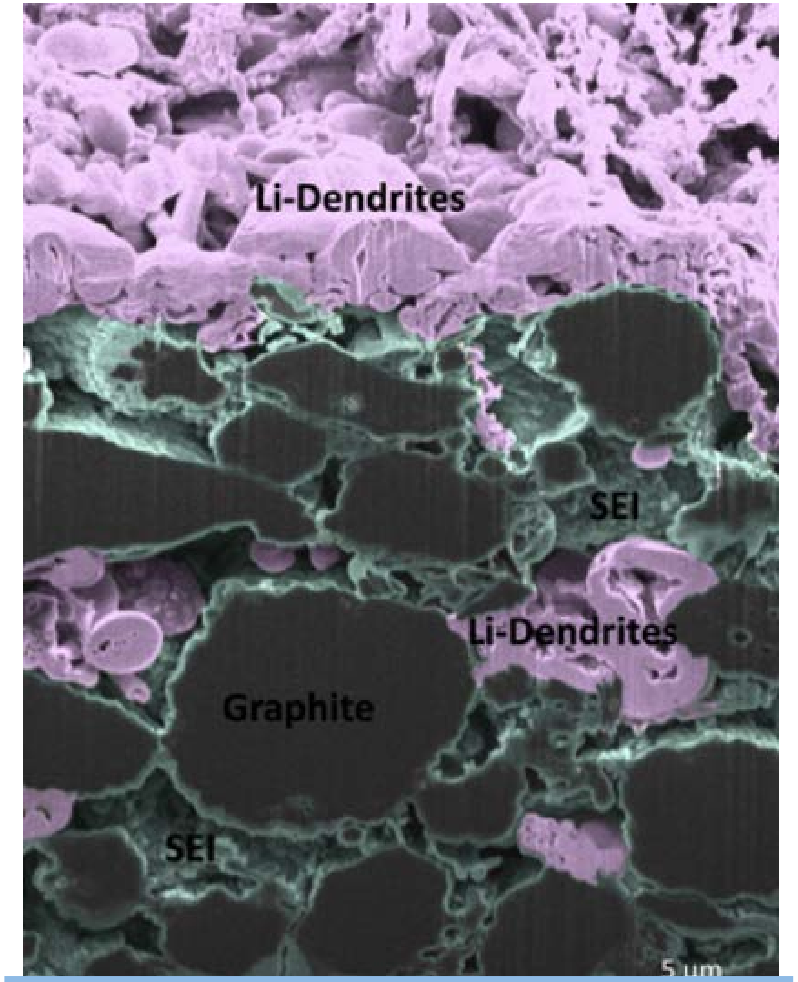
Plating depends on many parameters

- Depends on the local anode potential

- Anode potential depends on
  - Current rate
  - Temperature
  - Material
  - Internal cell design
  - State of charge
  - State of health



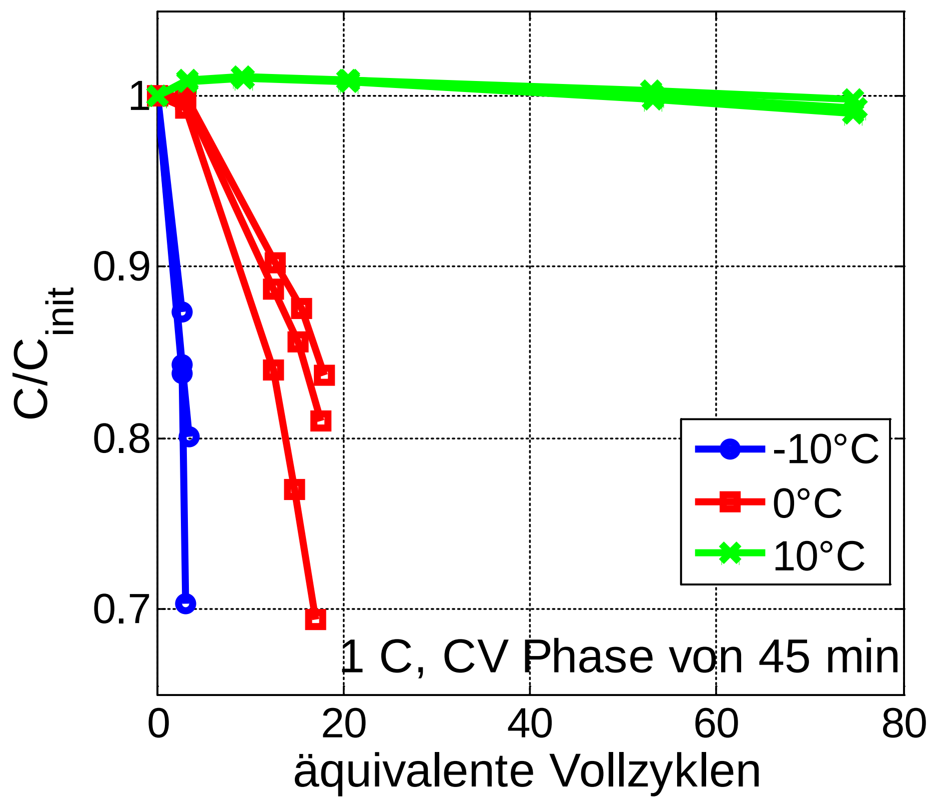
- Plating causes
  - Rapid loss of capacity
  - Risk for short circuits

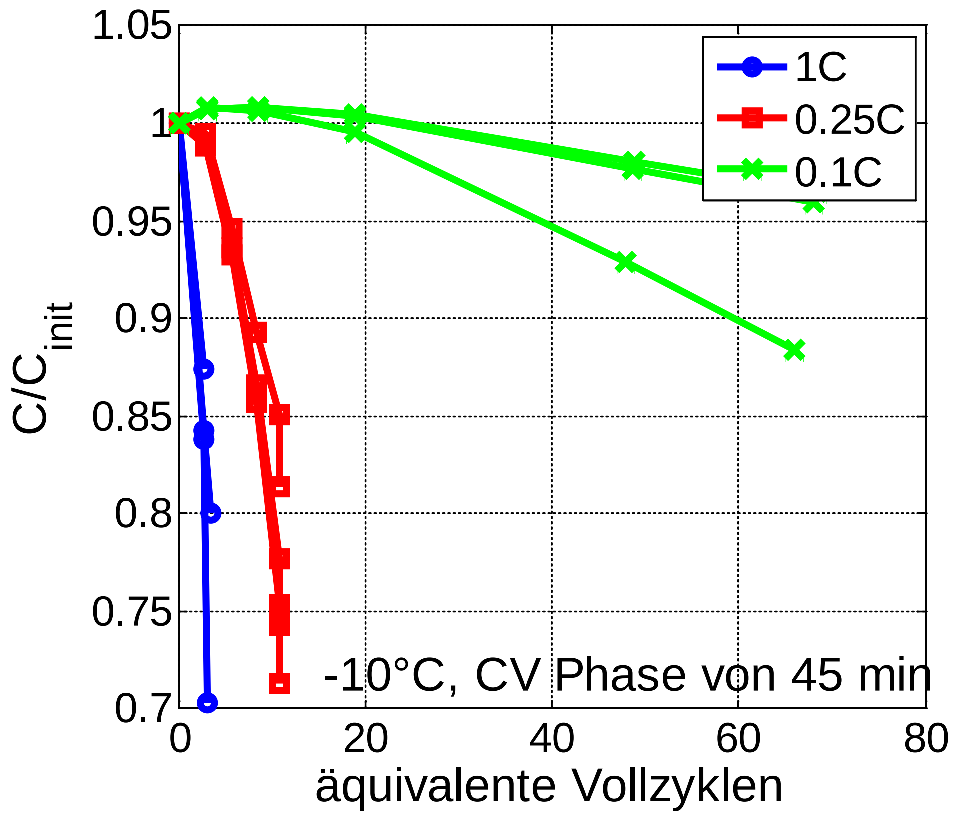


Side to current collector

Zier et al. 2014

Ageing by plating of a Kokam 40 Ah cell at different temperatures and current rates

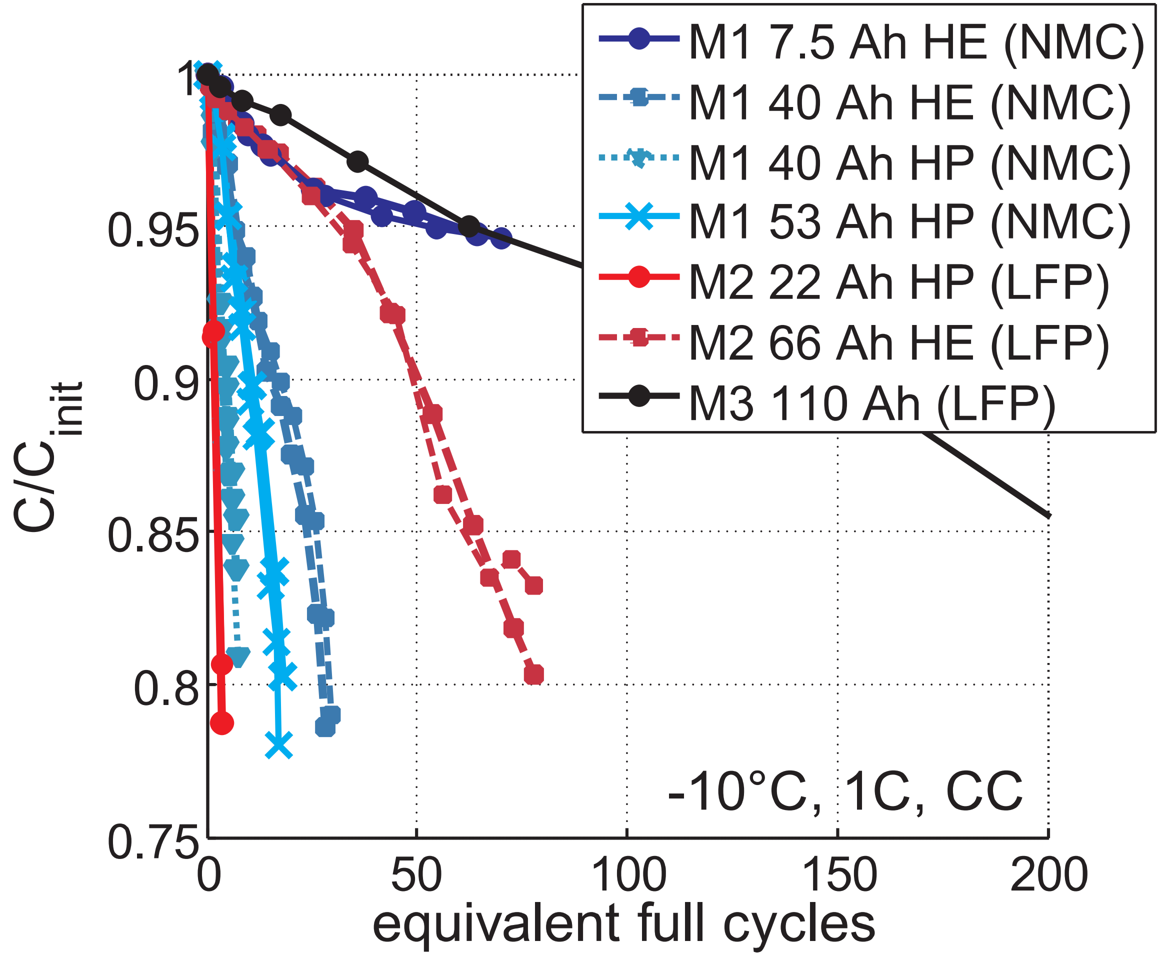




Plating for different manufacturers, sizes, chemistries

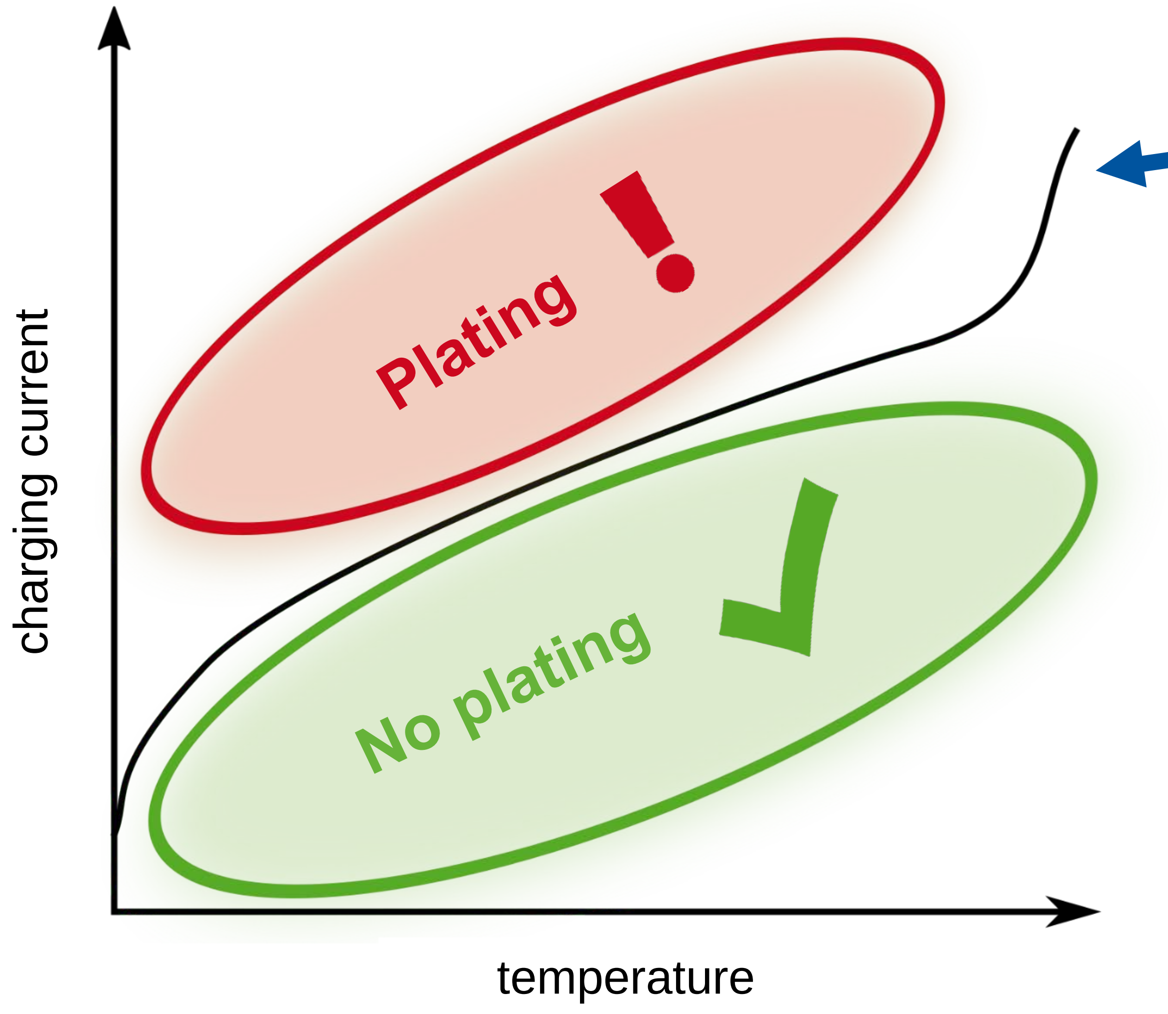
- Different manufacturers
- Different capacities
- Different designs
  (High Power HP und
  High Energy HE)

- HP cells here even age faster than HE cells



M. Ecker et al., Applied Energy, vol. 206, 934-946, 2017

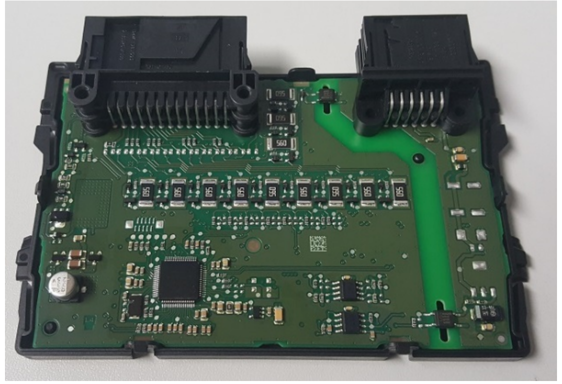
Determining max. charge current



f(T) = ?

Function is non-linear and depends on:

- Battery type
- State of health
- State of charge



Challenges in battery modelling, battery diagnostics, and lifetime prediction?

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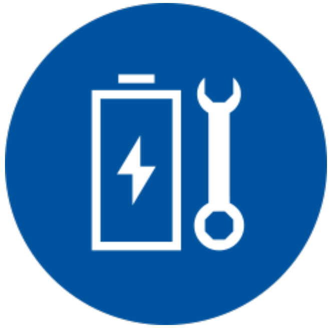
Chair for Electrochemical Energy Conversion and Storage Systems

Applications of Battery Models in BMS

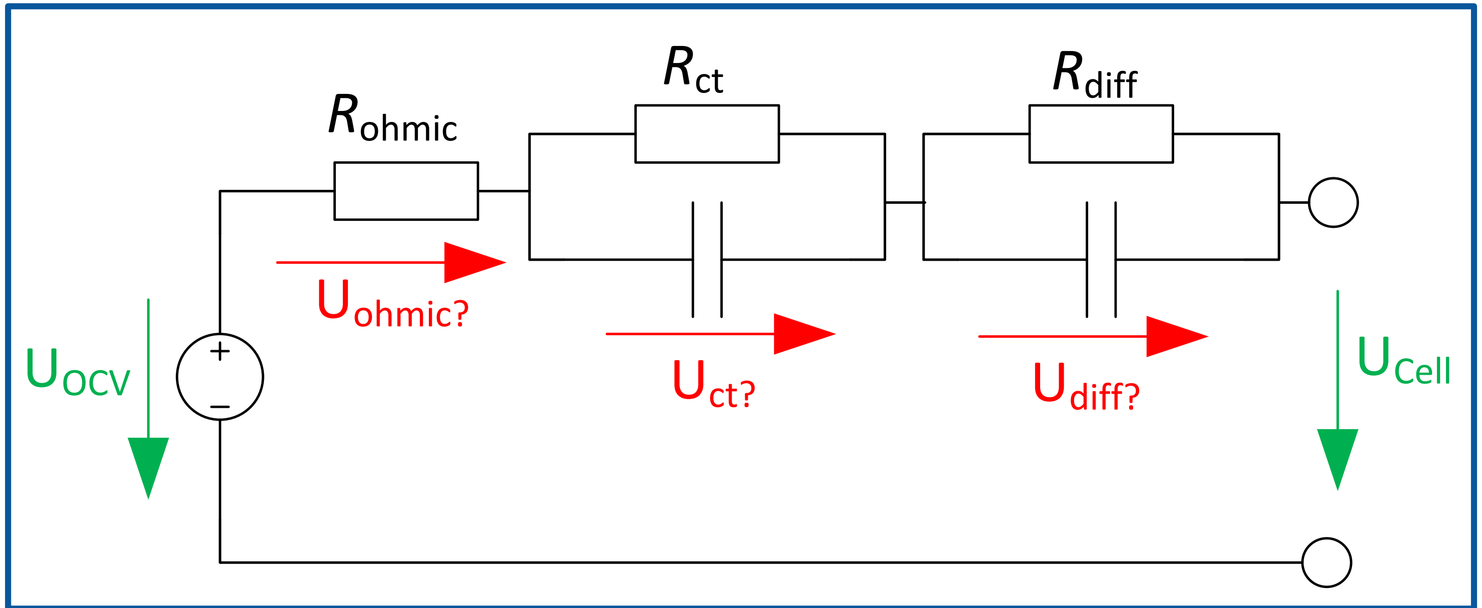
- Battery Models in BMS are used to
  - Observe non-measurable battery states
  - Predict battery states



- State Estimation
  - OCV Estimation during operation→ SOC Estimation

- Behavior Prediction
  - Power Prediction
    - How long can I keep the current power?
    - What is the maximum power for the next x seconds?
  - (Aging Prediction)
    - How will the current operation damage my battery?

State of the Art Impedance Models



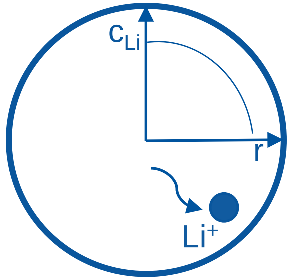
Benefits

- Easy to parameterize
- Fast
- Some states do have a physical meaning

Drawbacks

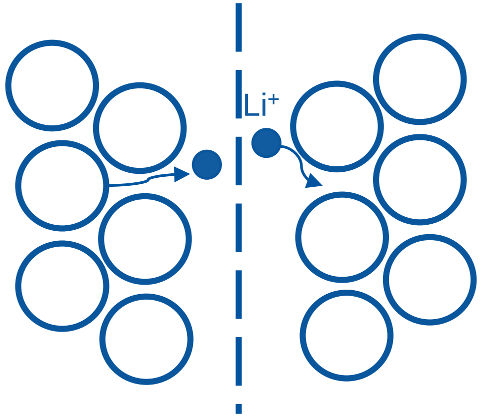
- Some states don’t have a physical meaning
- No single electrode potentials

Electrochemical Models



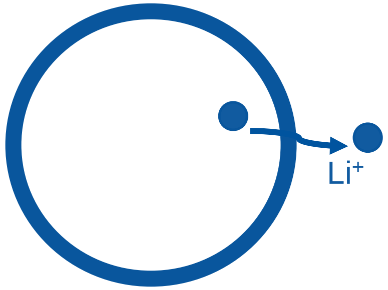
Solid State Diffusion

$$\frac{\partial c_{Li}}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(D_s r^2 \frac{\partial c_{Li}}{\partial r}\right)$$



Electrolyte Diffusion and Migration

$$\varepsilon\frac{\partial c_{Li}}{\partial t} = \nabla\left(D_{e,eff}\nabla c_{Li}\right) + \frac{1-t_+}{zF}\nabla I$$

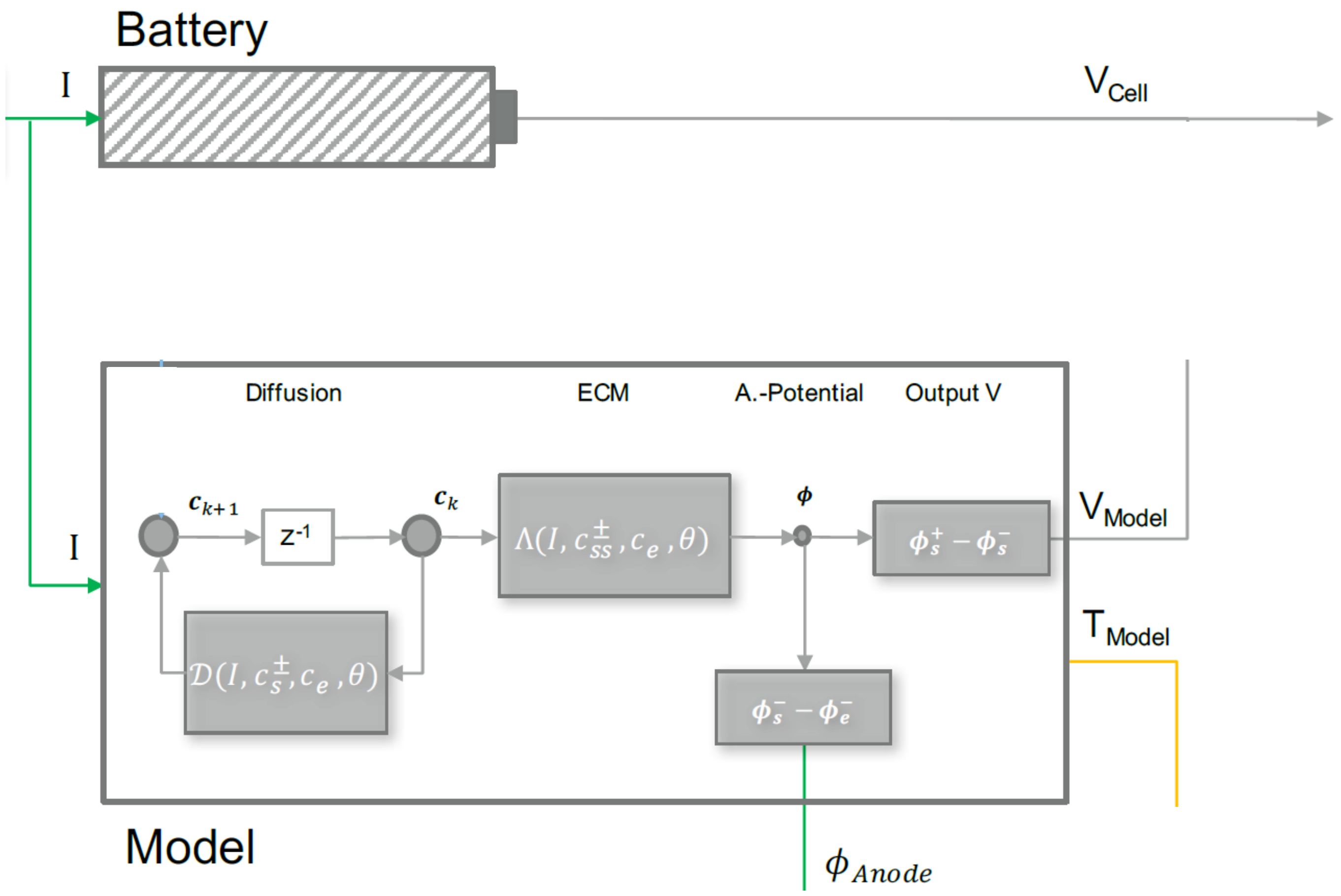


Charge Transfer

$$I_{ct} = i_0 A\left(e^{\frac{\alpha zF}{RT}\eta} - e^{1\frac{(1-\alpha)zF}{RT}\eta}\right)$$

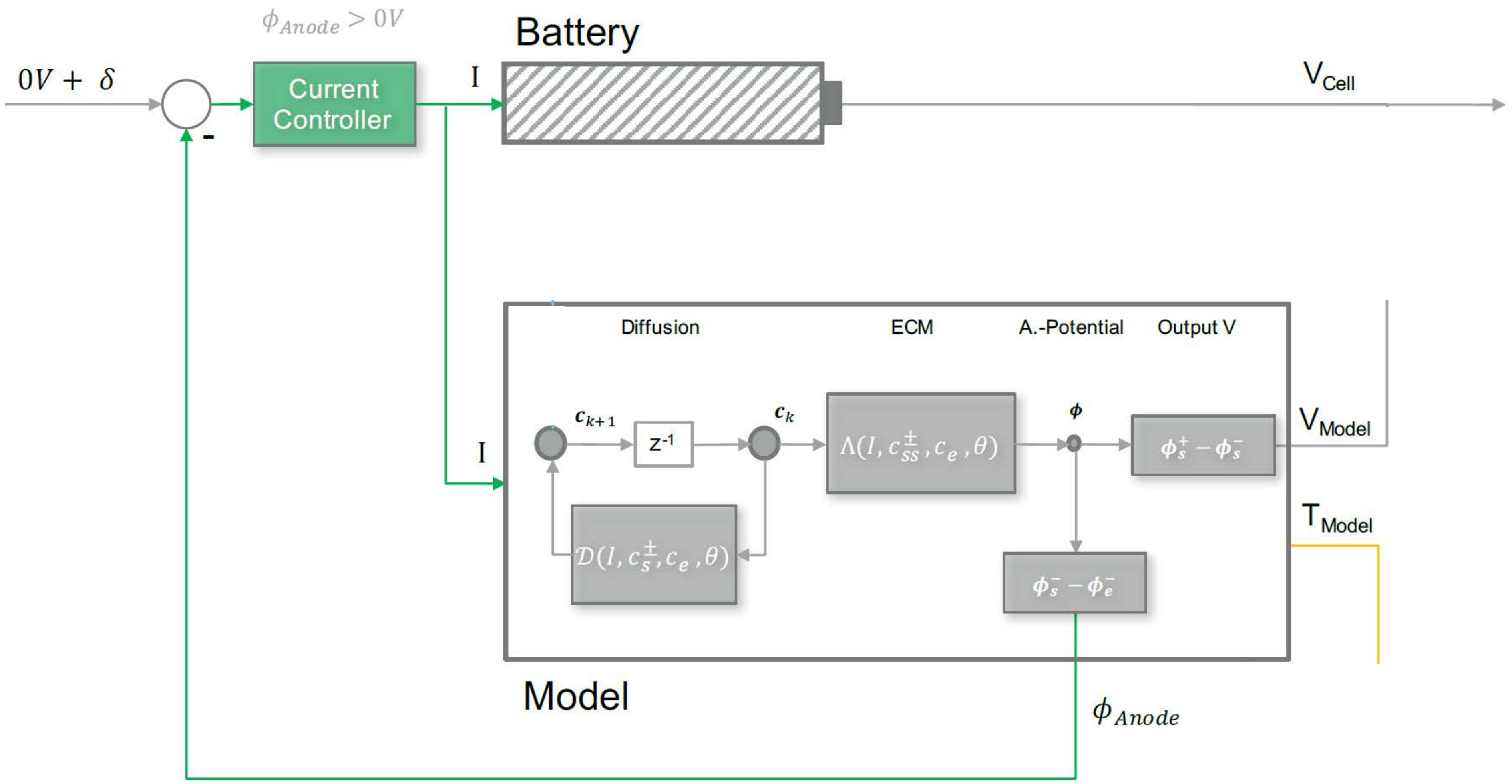
- **Benefits**
  - All states are physically meaningful
    →More battery states can be estimated
  - Predictive capabilities
    - Non parameterized operating conditions
    - Nonexistent battery cells
- **Challenges**
  - High computational load due to partial differential equations
  - High parameterization effort due to large number of parameters
  - Online adaptation of complex models with a large number of parameters

Model Structure



Electrochemical Models for Fast Charging Algorithms in Battery Management Systems, Florian Ringbeck, Marvin Garbade, Dirk Uwe Sauer, Battery Modelling Symposium 2019, Oxford

Closed Loop Current Control for optimization of charging procedure



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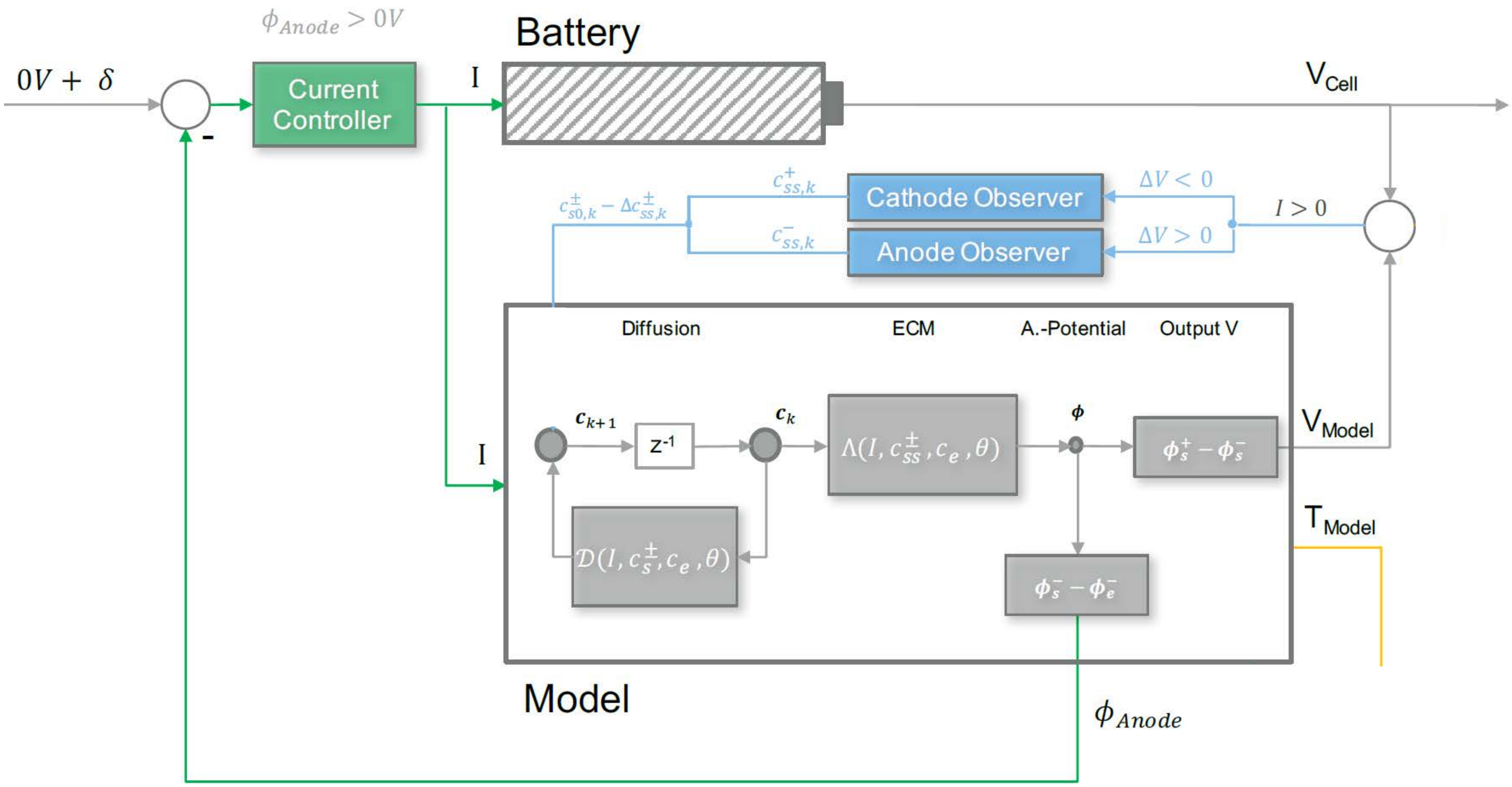

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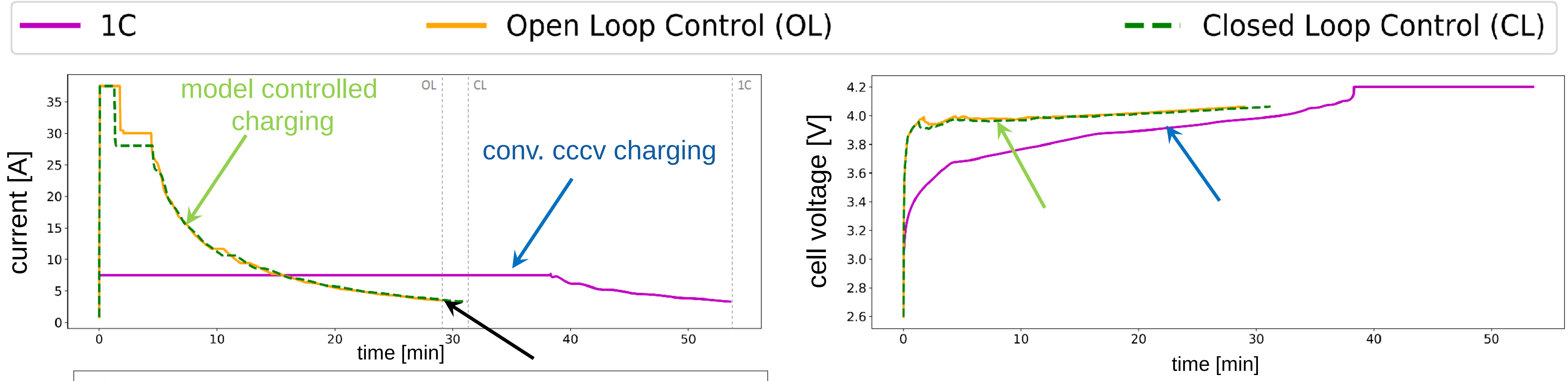
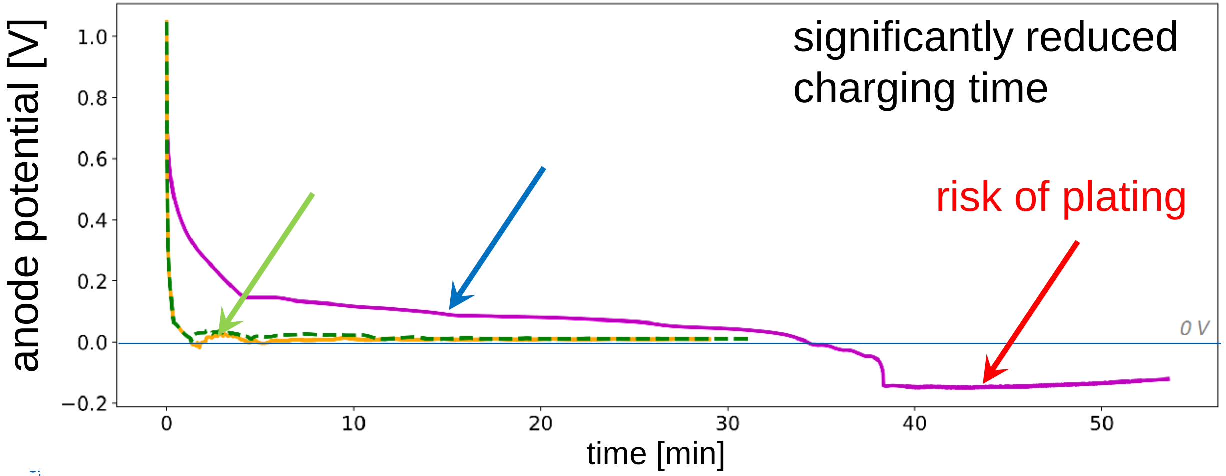
Simulation Result





- Model-based charging control allows for
  - Faster charging
  - Avoiding accelerated ageing by plating
  - On-board model adaptation to temperature and ageing

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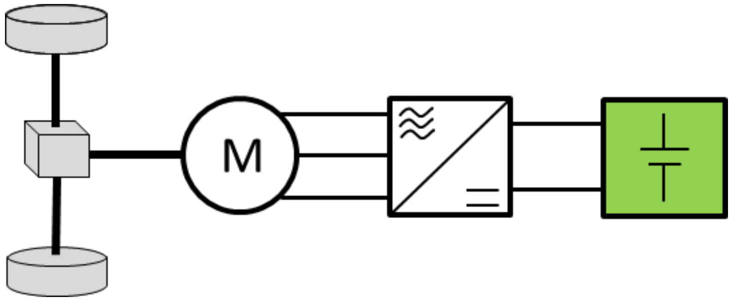
What about alternatives to battery electric vehicles?

What about other applications such as buses and trucks?

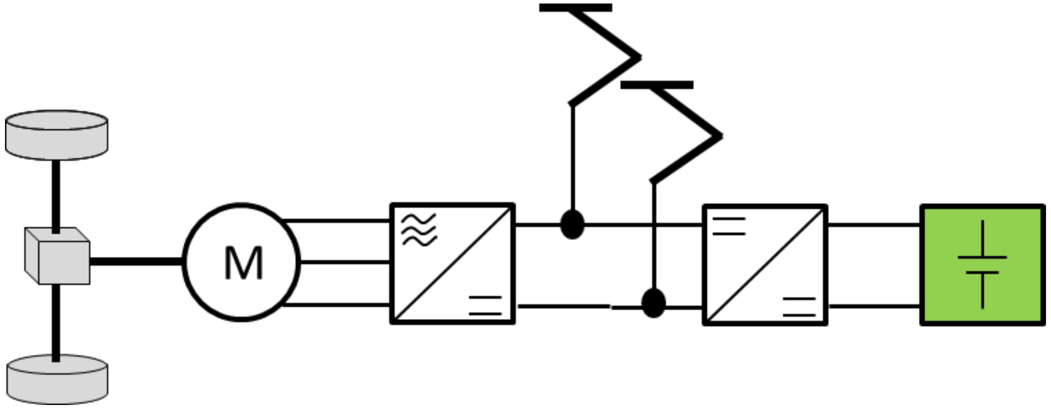
Dirk Uwe Sauer
Chair for Electrochemical Energy Conversion and Storage Systems

Topologies for emission-free drive trains for trucks

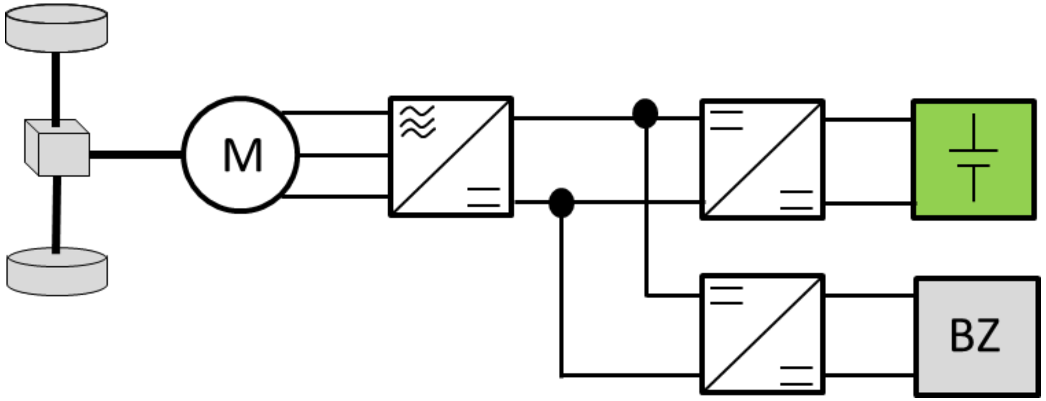
- Electric drive train with **battery**



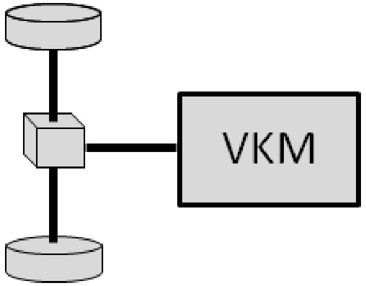
- Electric drive train with **catenary** supply



- Electric drive train with **fuel cell/hydrogen** supply



- Truck with internal combustion engine and **efuel**



Emission-free heavy trucks

4 options for 40 tons trucks

1. Catenary on highways combined with batteries for the „off-highway“ operation for a maximum of 50 to 100 km

   ➔ Realisation depends on governmental decisions; concept will work only in countries with high population density

2. Battery electric with high power charging stations alongside highways

   ➔ Recharging after 4.5 hours; weight of the battery about 6 tons; power demand for recharging about 700 to 800 kW/truck

3. Fuel cells with hydrogen infrastructure alongside highways

   ➔ primary energy demand at least 2 times higher, significant less weight, and approx. same volume compared with battery electric

4. Synthetic fuels (efuel) with combustion engine

   ➔ Total efficiency less than 20%; easy to import from third countries, lowest additional infrastructure demand

Quelle: focus.de

Quelle: eJIT

Hydrogen, biofuels or efuels will be needed definitely in sectors such as cargo chips or long-distance air planes.

Applications such as buses or trucks are more questionable.
Efficiency will matter, because wind turbines and PV generators must be placed somewhere → public acceptance

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Summary

- Car manufacturers actively re-allocating resources to electro mobility

- Major increase in EV sales is expected in 2021 due to the CO_2 regulation

- Ramping-up battery production towards 2025 will be extremely demanding

- European cell manufacturers are key for a sustainable automotive industry – Governments and EU are willing to support this substantially

- Ultra-fast charging (> 350 kW) for passenger vehicles is a key challenge for the batteries and most probably a technology only for upper class cars with very large batteries

- Other technologies such as fuel cells/hydrogen or efuels are useful complements e.g. for ships and planes, but efficiency remains an issue

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Thank you for your attention

Battery-electric vehicles at the eve to make the major breakthrough – Upcoming challenges on materials, batteries, and the energy system

Dirk Uwe Sauer, Florian RIngbeck

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