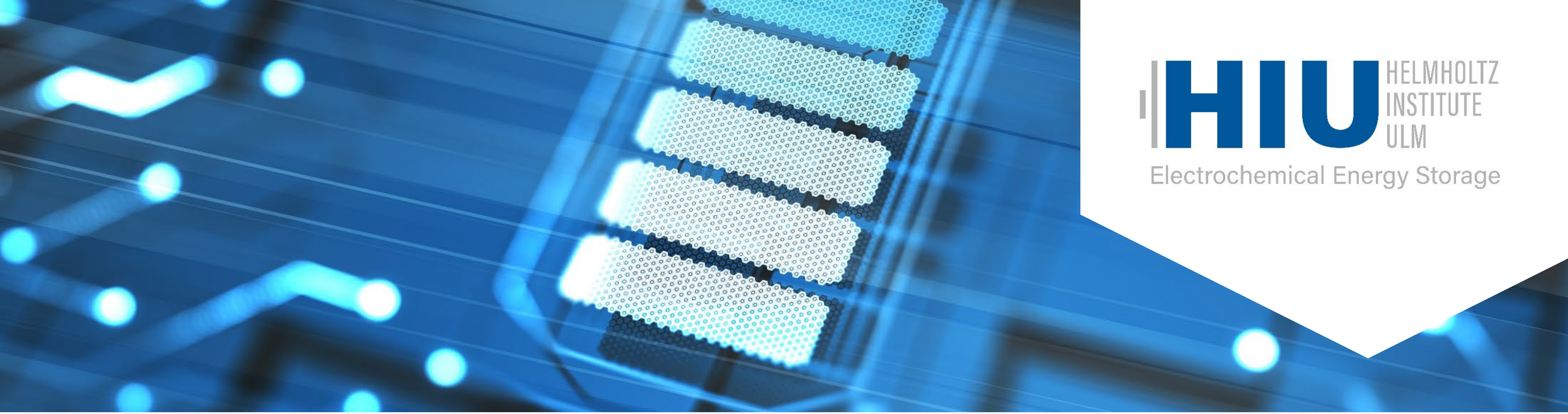


Maximilian Fichtner

The transformation of propulsion

HERAEUS Seminar Bad Honnef
19. June 2023

Storage of renewable energy with batteries

(i2.wp.com)

stationary / home

(www.bauen.de)

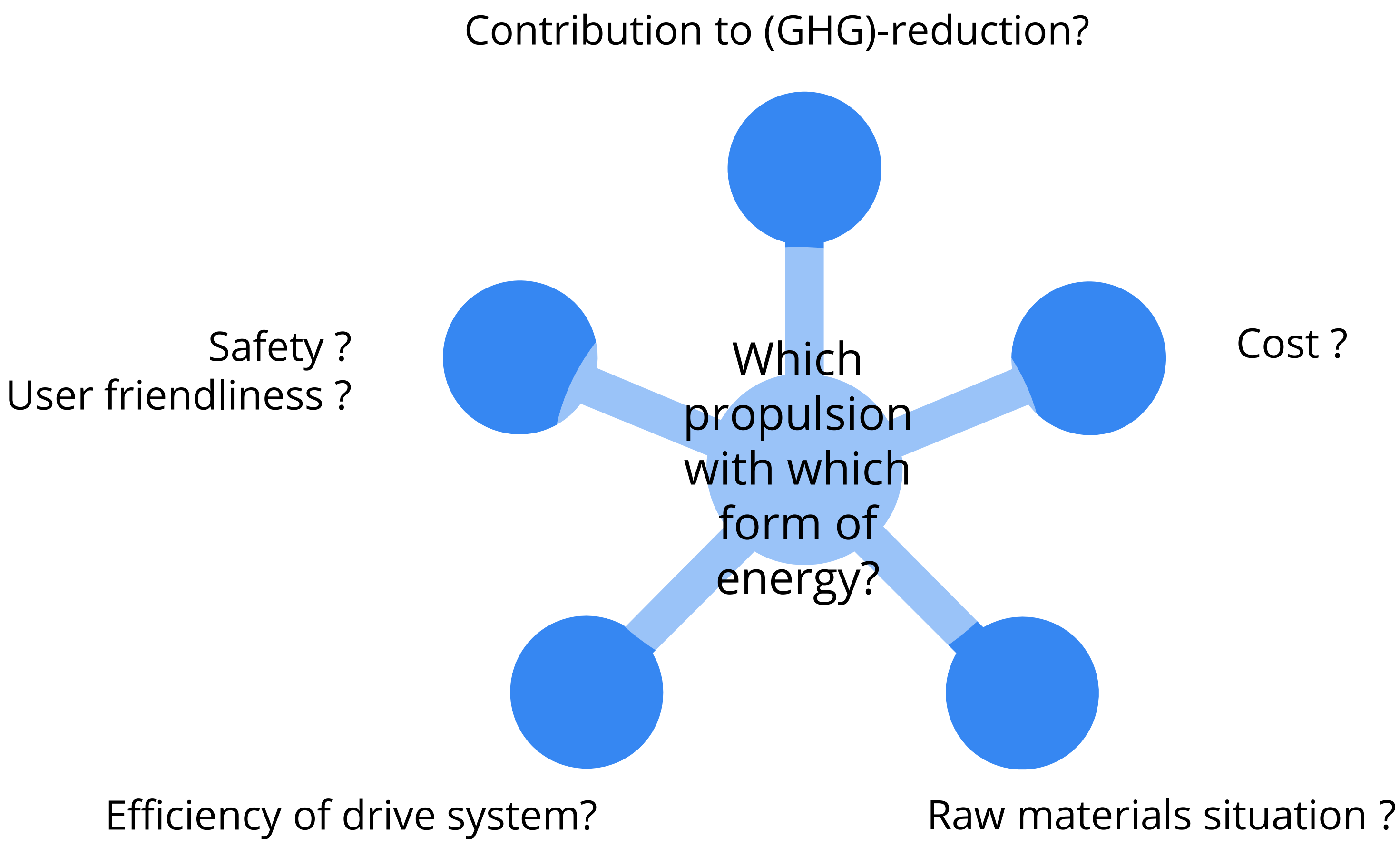
portable

(www.hp.com)

mobile

(www.catchuk.org)

Important questions when choosing the drive/storage technology



Drivetrains and their greenhouse gas emissions over life cycle

A GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF COMBUSTION ENGINE AND ELECTRIC PASSENGER CARS

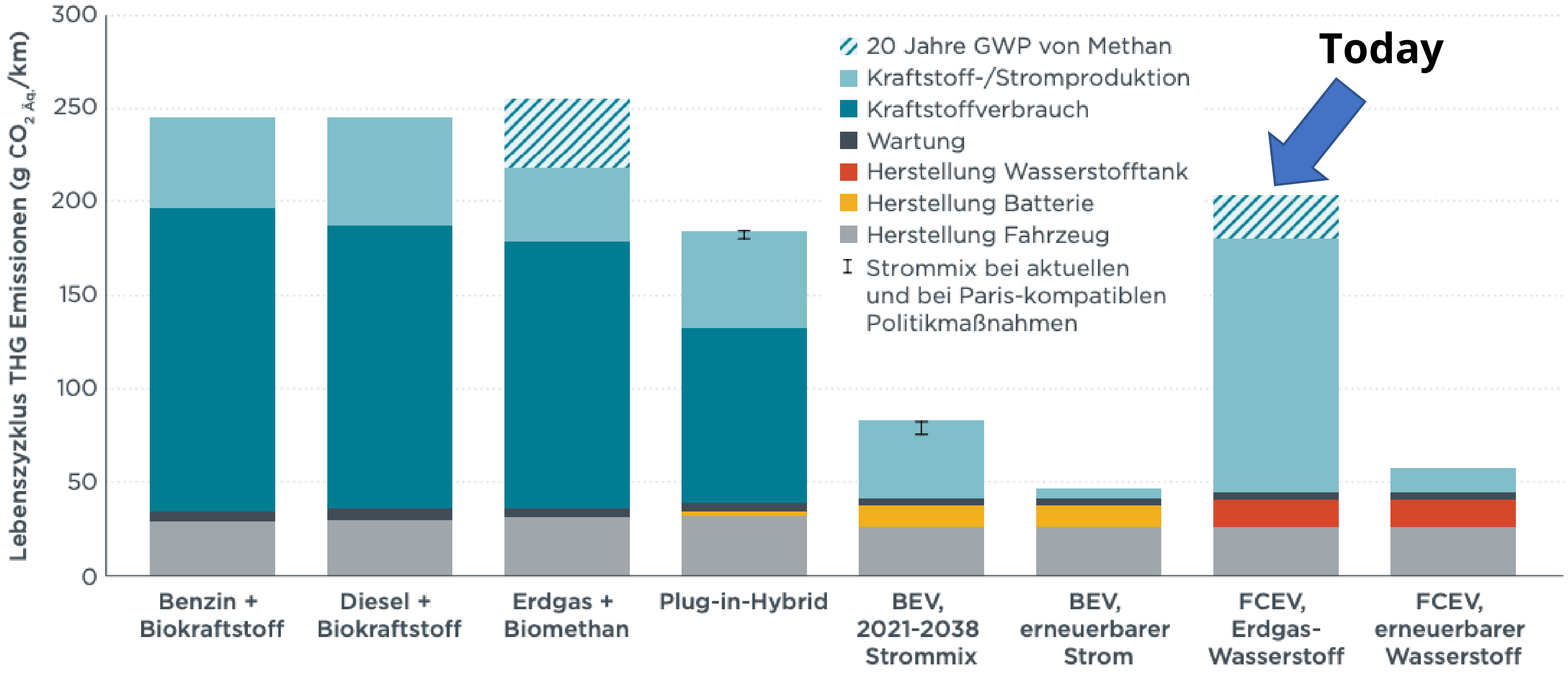


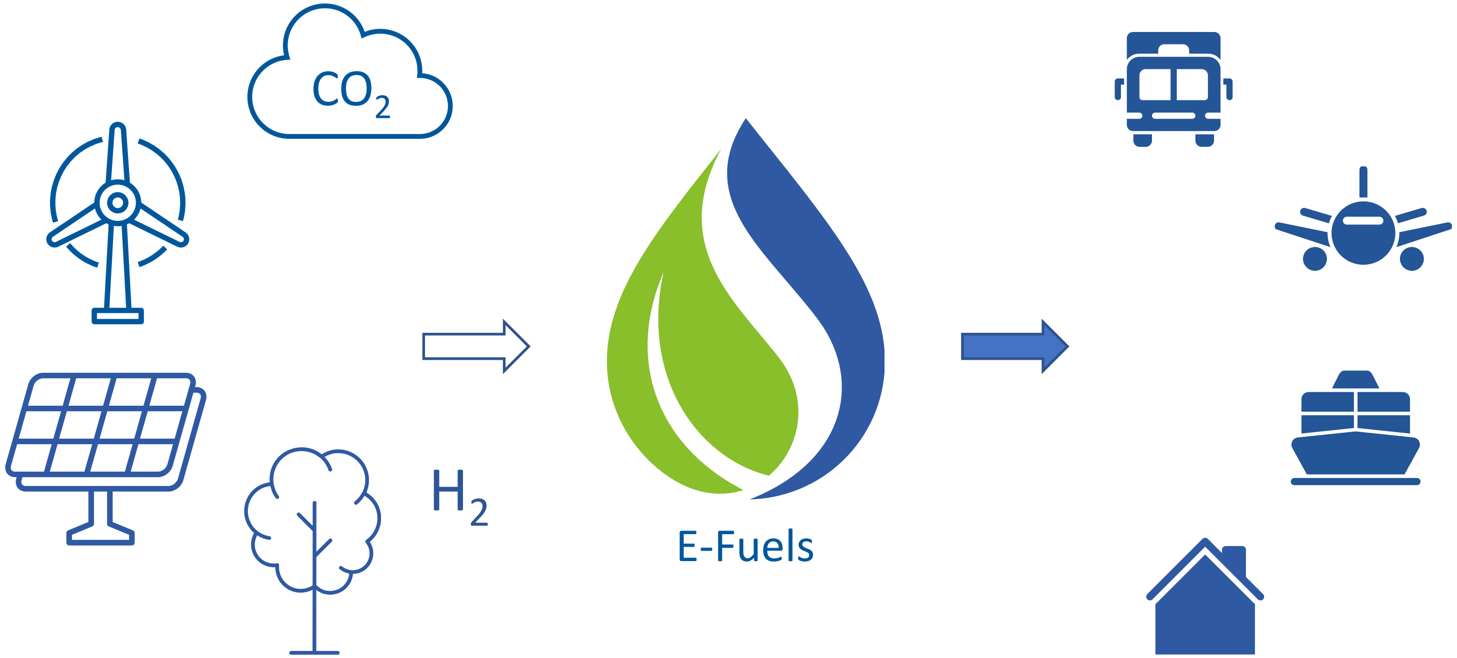
Abbildung 1. Lebenszyklus-Treibhausgas (THG)-Emissionen von durchschnittlichen neuen Benzin-, Diesel- und Erdgasfahrzeugen, Plug-in-Hybrid-Elektrofahrzeugen, Batterie-Elektrofahrzeugen (BEV) und Brennstoffzellen-Elektrofahrzeugen (FCEV) in der Kompaktklasse, die 2021 in Europa zugelassen werden. Die Fehlerbalken zeigen die Differenz zwischen der Entwicklung des Strommix gemäß der aktuellen Politikmaßnahmen (die höheren Werte) und dem, was erforderlich ist, um das Pariser Klimaabkommen zu erreichen. GWP = Treibhauspotenzial.

Quelle: ICCT, July2021

Internal combustion engine with e-Fuels

Keeping the combustion engine: E-fuels; E-Diesel

Made from CO_2, hydrogen, and electrical energy



The production of **1 Liter** e-Diesel from CO_2 and H_2 consumes 23-27 kWh electricity (LBSt, 2020)
A VW Golf Diesel consumes 6 L Diesel for 100 km → total **140-162 kWh** needed for 100 km range

- → **With that amount of energy, a battery car can drive 800-1000 km (an e-Diesel car: 100 km)**
- → **Still local emissions (soot, NOx, noise)**
- → **Very expensive (tank filling for 400 EUR w/o tax)**

E-fuels from Chile / Haru Oni

→ → → CO_2 + H_2 → → → e-Fuel

Goals:

130.000 L in 2022
55 Mio L in 2024
550 Mio L in 2026

- Wind power for electrolysis
- 9 kg purified water per 1 kg H_2
- CO_2 sequestration from air (→ 1000 kWh electric./ 1 t CO_2)
  → 1000 kWh for 720 kg Methanol (fuel)*
  → 25% of energy content **just for CO_2 collection**

* K. Madhu *et al.*, Nature Energy 6 (2021) 1035

SIEMENS energy

HIF

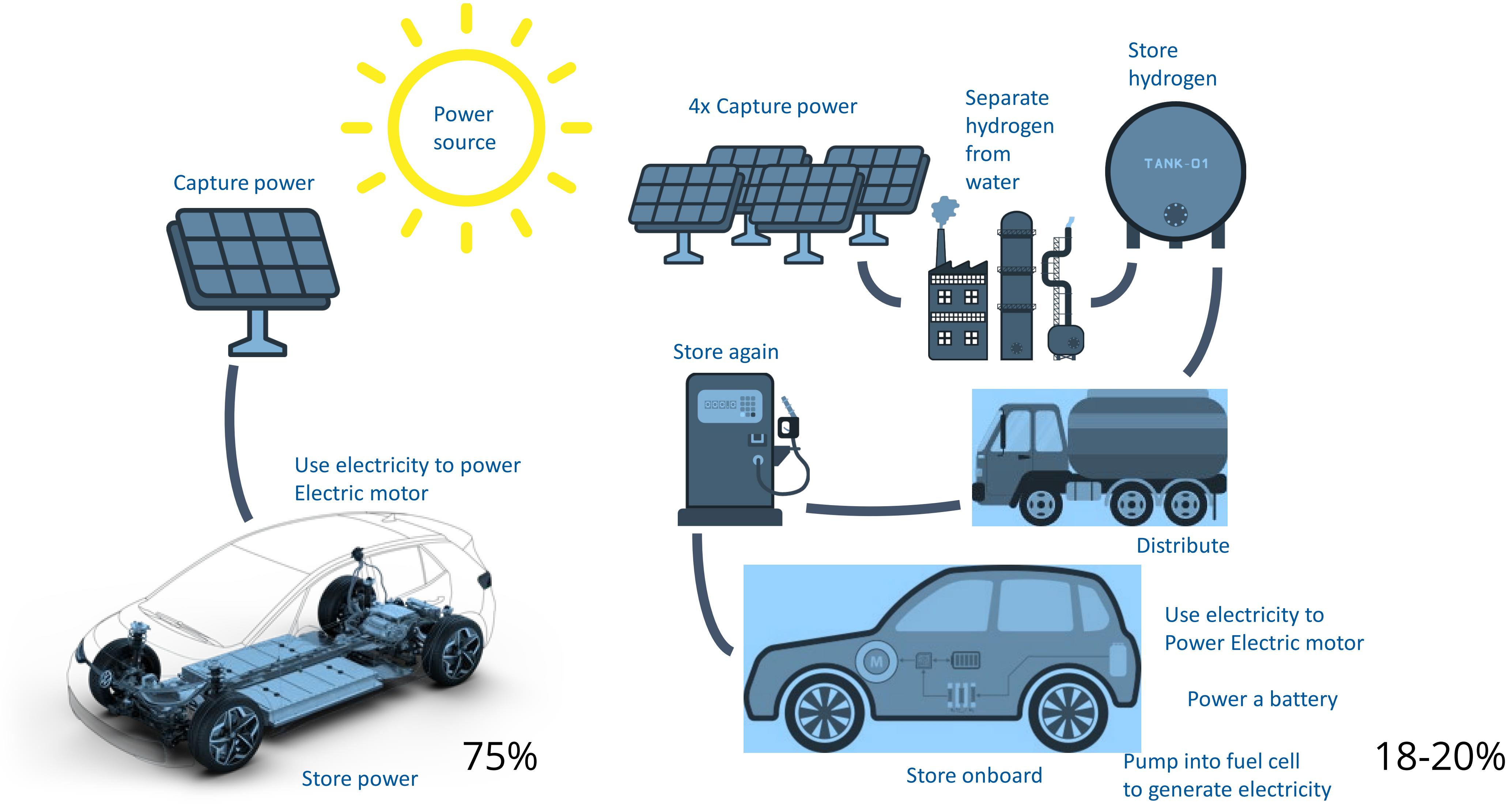
PORSCHE STUTTGART

But:
Fuel consumption in BRD: 48 Mrd. L /a
i.e. ~1% could be supplied

→ **The intention of using this to achieve climate goals is illusory for the time being**

Electric drivetrains

Electric drives as the most efficient type of drive

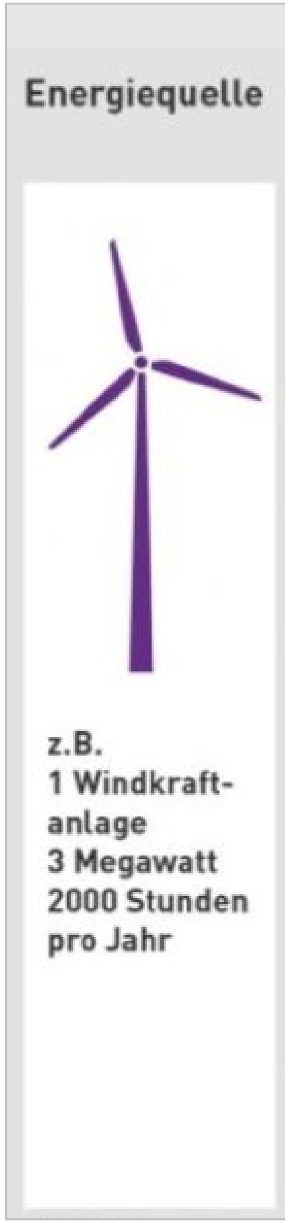


Battery electric

H_2 drive with fuel cell

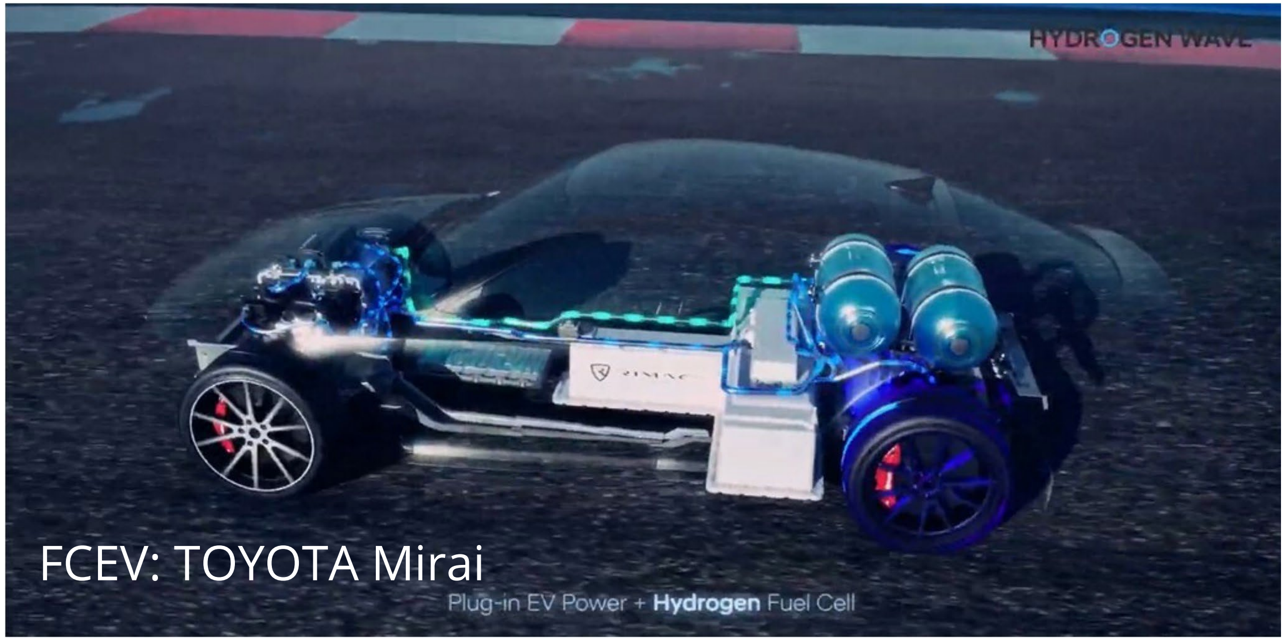
Drivetrains in comparison / energy consumption

3 MW
2000 h/a



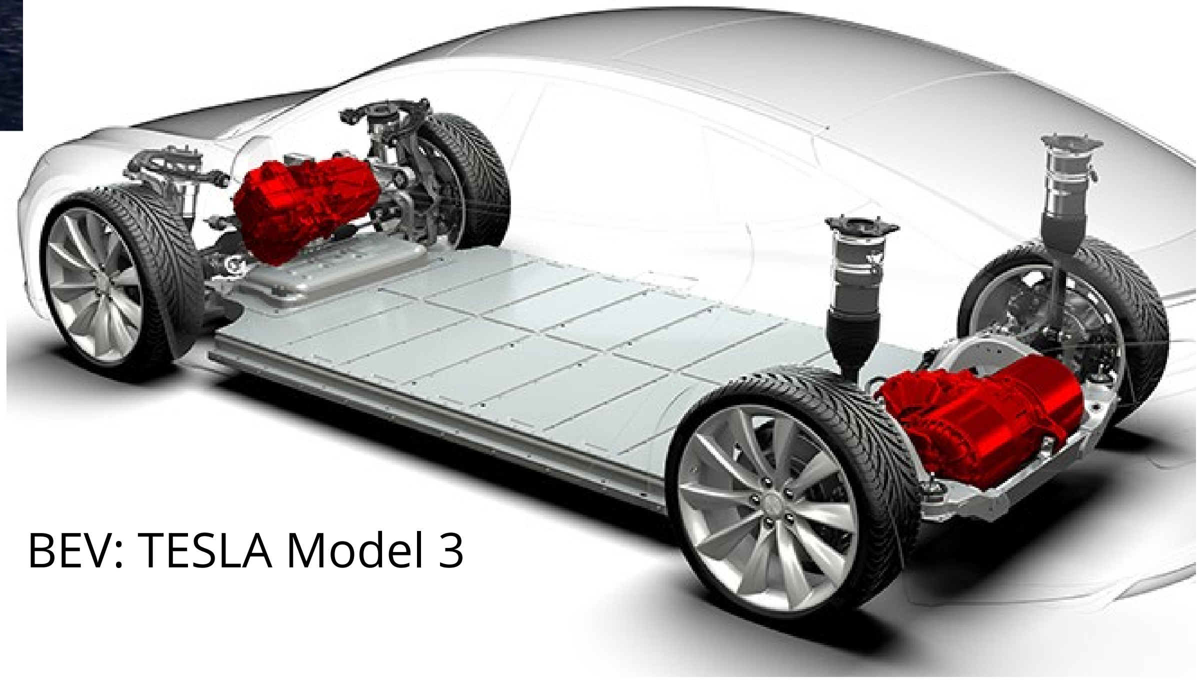
Ref: VDE

Comparison of drivetrains



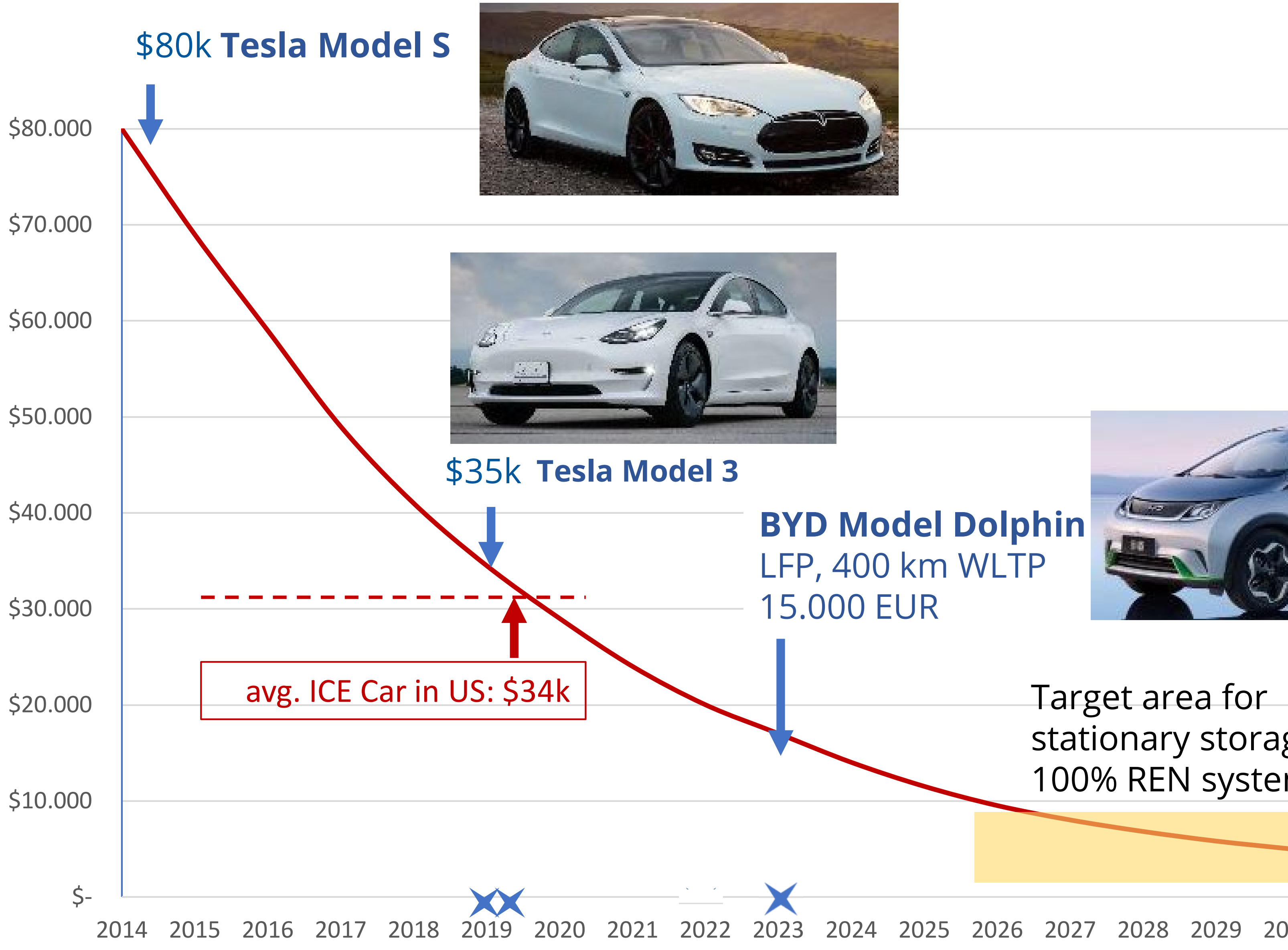
FCEV: TOYOTA Mirai

Sectional images
FCEV
BEV



BEV: TESLA Model 3

Cost curve for BEV with 350-400 km range



Comparison H_2:
Hyundai Nexo (500 km)
80 TEUR sales
120 TEUR in production

Consumption:
15 EUR/100 km in Germany
32 USD in California

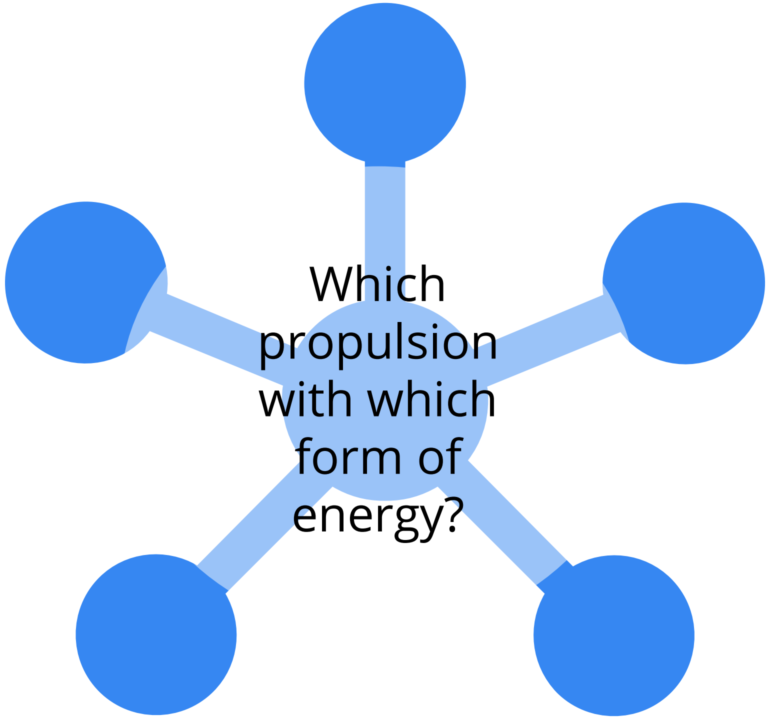
Prediction based on a simple cost-curve analysis from 2014
! Clean Disruption ©2014 Tony Seba

Important questions when choosing the drive/storage technology

Battery car

Contribution to (GHG)-reduction?

Safety ?
User friendliness ?



Cost ?

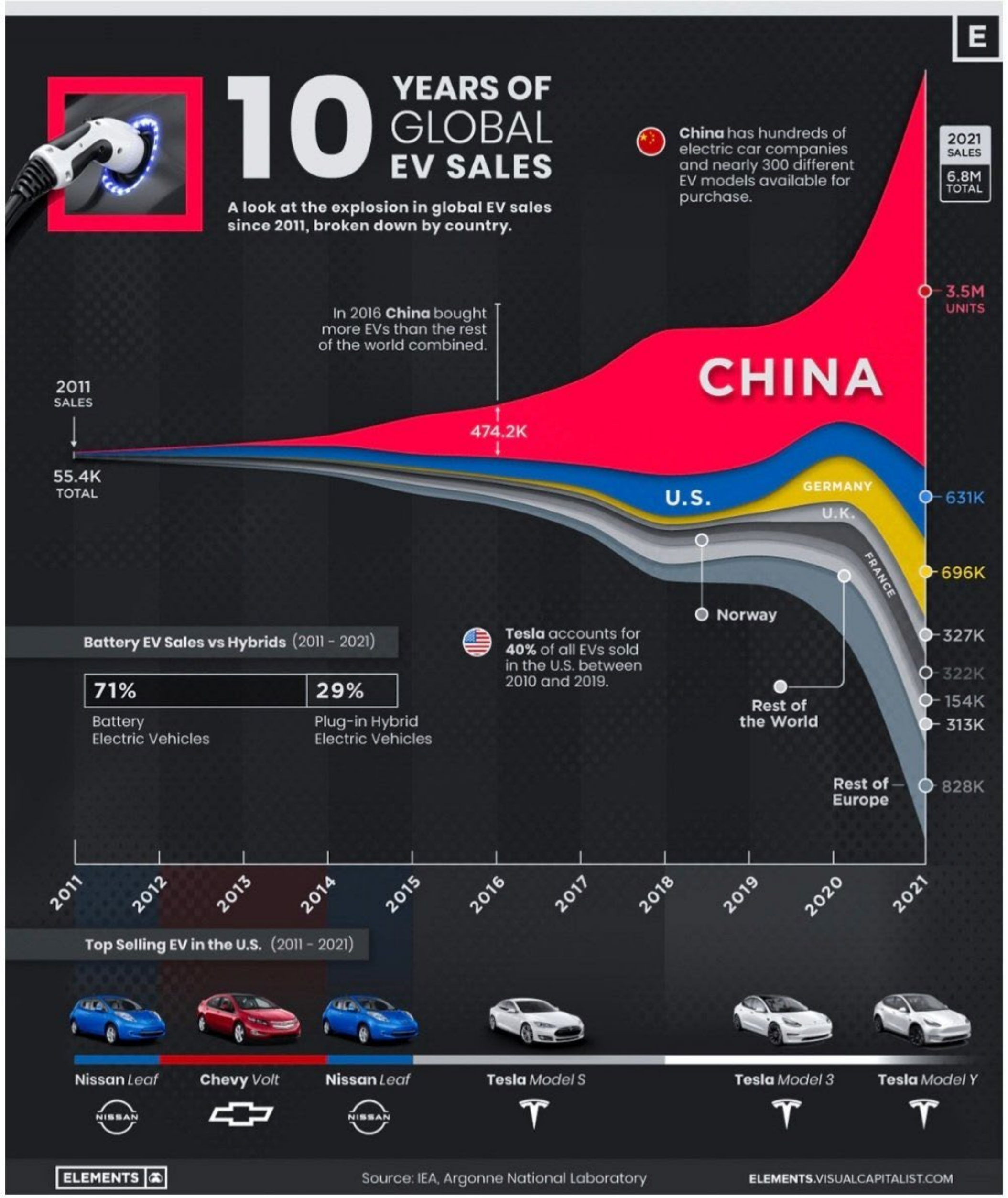
Battery car

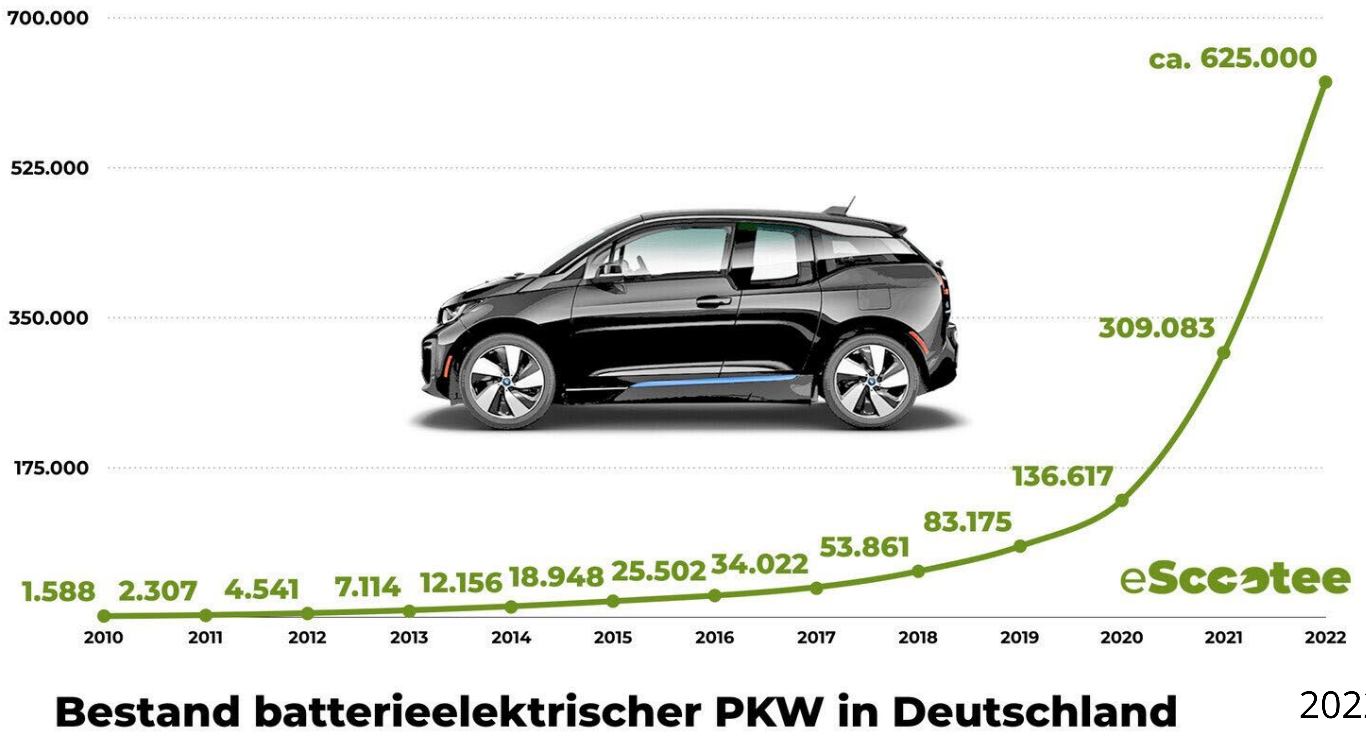
Efficiency of drive system?

Battery car

Raw materials situation ?

Development in the sale of electric vehicles (global and Germany)





2022

Electric Trucks

VOLVO already has 5 BEV trucks on sale

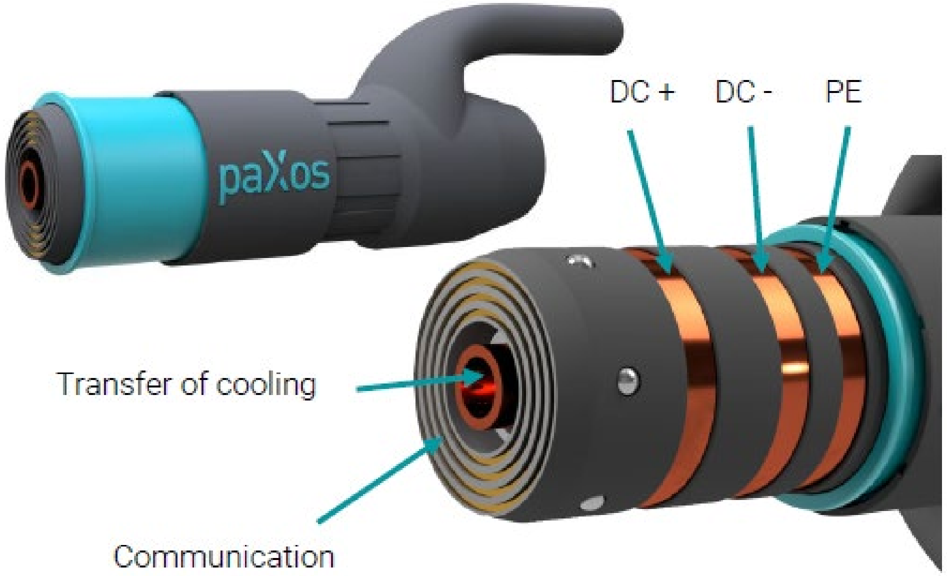
720 km without charging


Foto: Designwerk/Jens Bahrmann

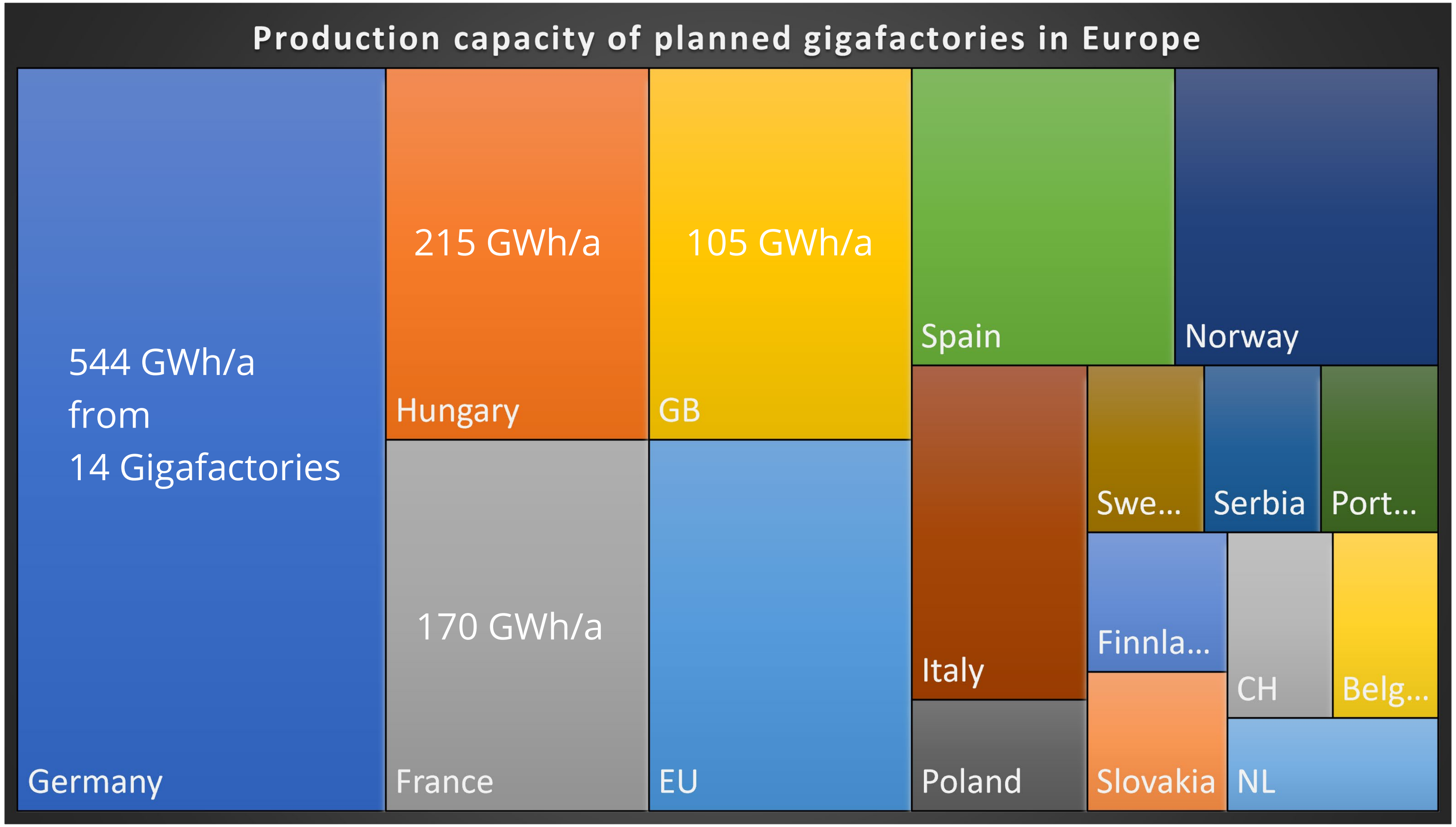
Zürich-Hannover mit dem Lkw - kein Problem. Aber mit dem Elektro-Lkw? Und ohne Zwischenladen? Designwerk-Key-Account-Manager Jens Bahrmann macht den Selbstversuch.

20.03.2023 Matthias Rathmann

Charging up to 12 MW (planned: 40 MW)

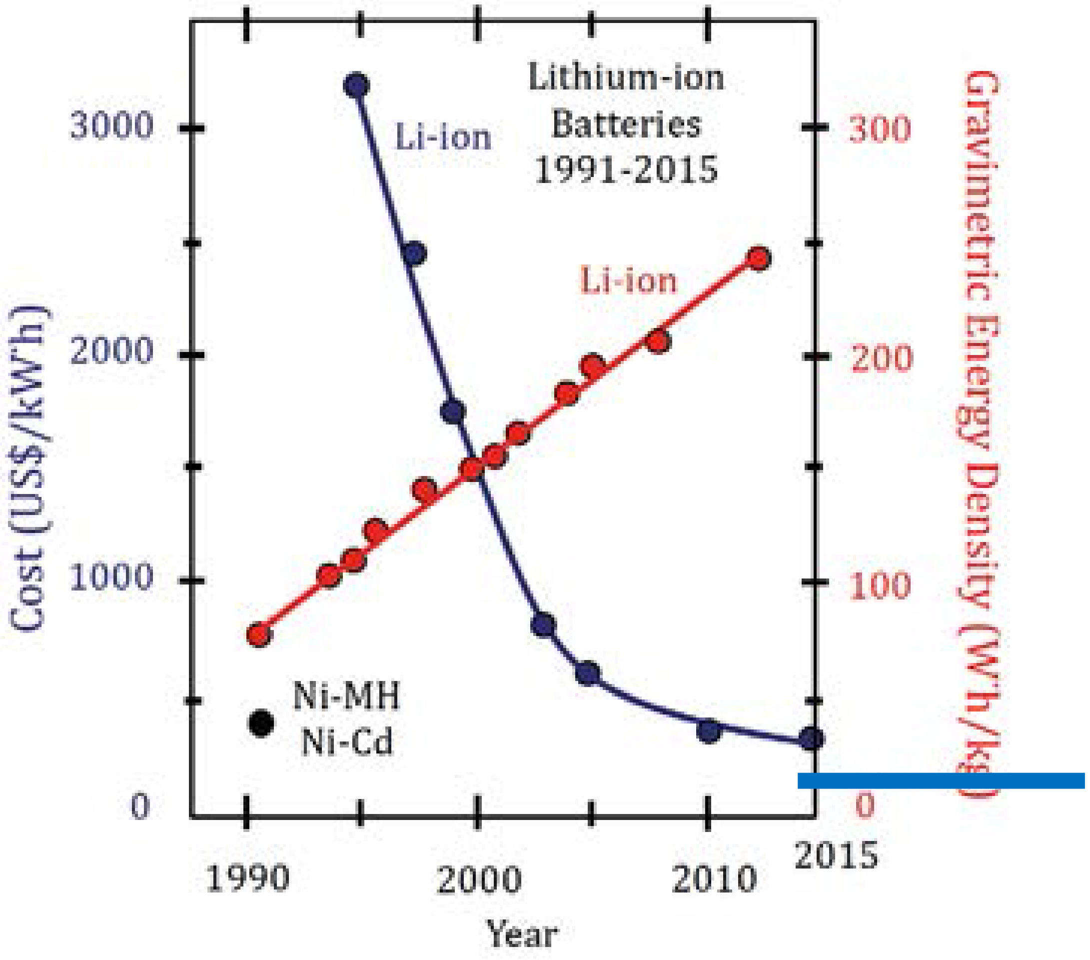


Battery production capacity in Europe is rising strongly (as of June 2023)



Total: 2 TWh/a

Why Li-Ion batteries?



cost goal
for 2022

📖 G.Crabtree, *MRS Bulletin* 40, 1067 (2015)

Since market introduction:
Energy density: x4
Cost÷18

- **90% cost reduction within the last 10 years**
- **capacity = double/tripled in the last 10 years**

Ranking of current battery storage plants (Li ion technology)

HELMHOLTZ INSTITUTE ULM
Electrochemical Energy Storage

Ranking	Plant	Location	max. Power	Capacity
1	Moss Landing Energy Storage Facility	Monterey County, USA	**400 MW (1.5 GW)**	**1.600 MWh (6 GWh)**
2	Manatee Energy Storage Center	Manatee County, FL/USA	**409 MW**	**900 MWh**
3	Alamitos Energy Center	Long Beach, USA	**100 MW**	**400 MWh**
4	Buzen Substation	Fukoka, Japan	**50 MW**	**300 MWh**
5	Gateway Energy Storage	Otay Mesa, USA	**250 MW**	**250 MWh**
6	Rokkasho Village Wind Farm	Aomori, Japan	**34 MW**	**245 MWh**
7	Hornsdale Power Reserve	Jamestown, Australien	**150 MW**	**193,5 MWh**
8	Escondido Substation	San Diego, USA	**30 MW**	**120 MWh**
9	Mira Loma Substation	Ontario, Kalifornien, USA	**20 MW**	**80 MWh**
10	Tesla Solar Plant	Kauai, Hawaii, USA	**13 MW**	**52 MWh**

#1 Moss Landing: Phase 1; installed in turbine hall of a former gas power plant
Largest in Germany: **Netzbooster Kupferzell with 250 MWh** (planned)

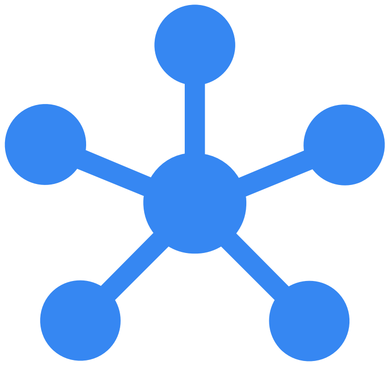
www.ingenieur.de; 2021

Goals of battery research

„Better“ Batteries

(more energy, fast charging, safe, durable)

→ „better“ materials and battery designs



Sustainable Batteries

(abundant and non-toxic raw materials, recyclable)

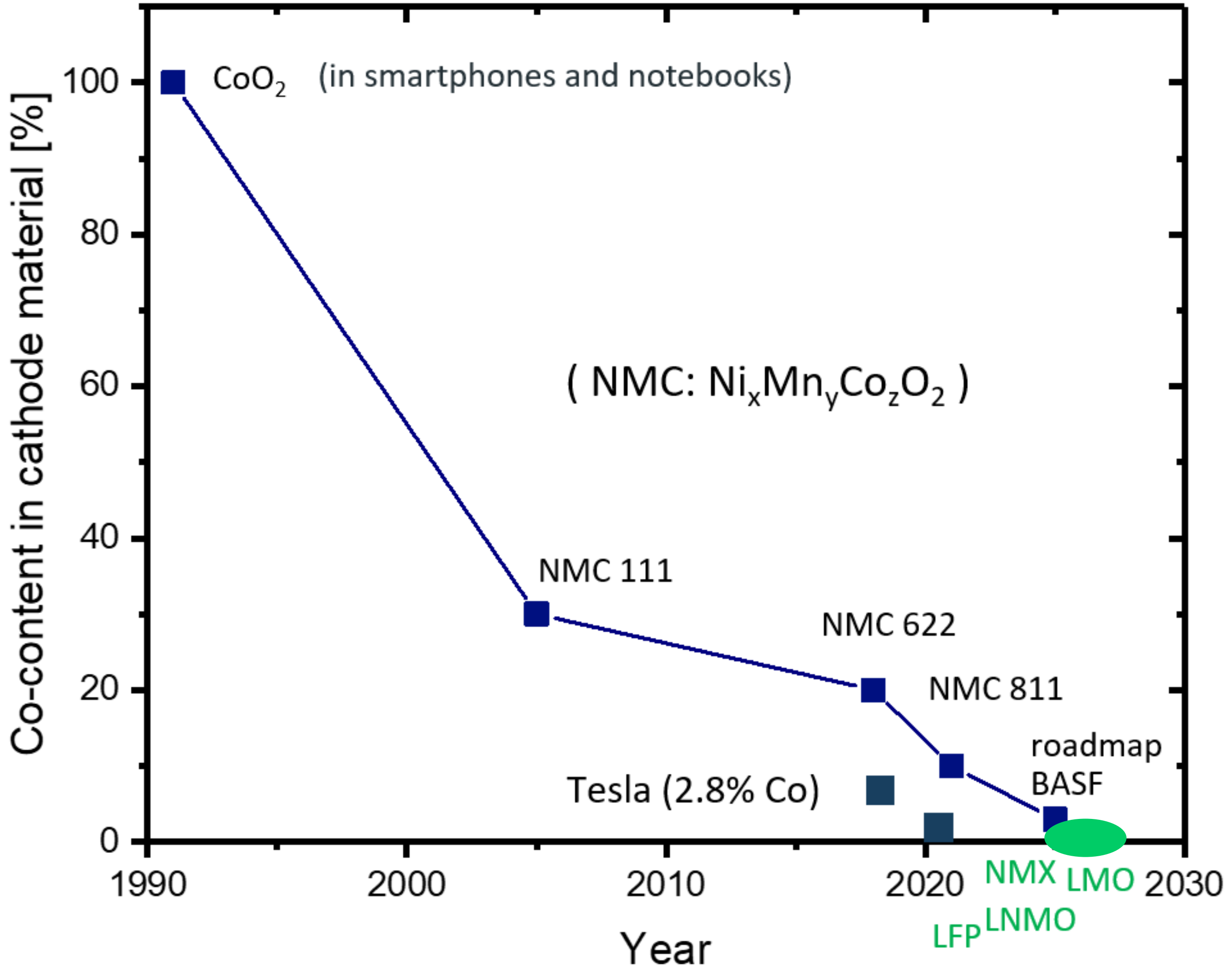
→ New battery types

On the way to more sustainability and power

Perspectives of Li- and post-Li systems

Cathode: Co content in batteries

General Trend: reduction of critical raw materials



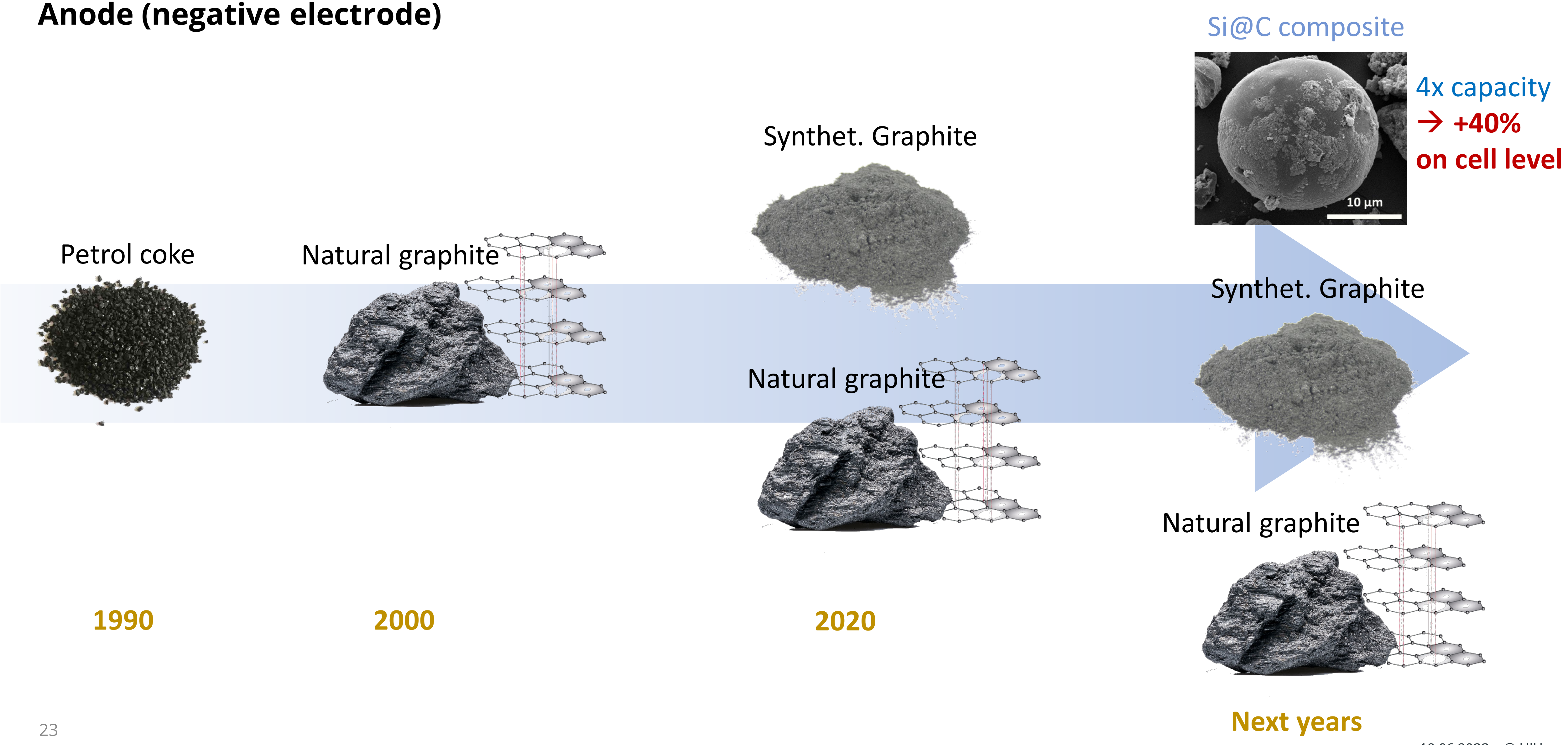
June 2022: TESLA delivers 50% of car fleet without Co

LFP: $LiFePO_4$
NMX: $LiNi_{3/4}Mn_{1/4}O_2$
LMO: $LiMnO_2$

(Materials with 0% cobalt)

Anode: new materials

Anode (negative electrode)



Interplay of Chemistry and Engineering

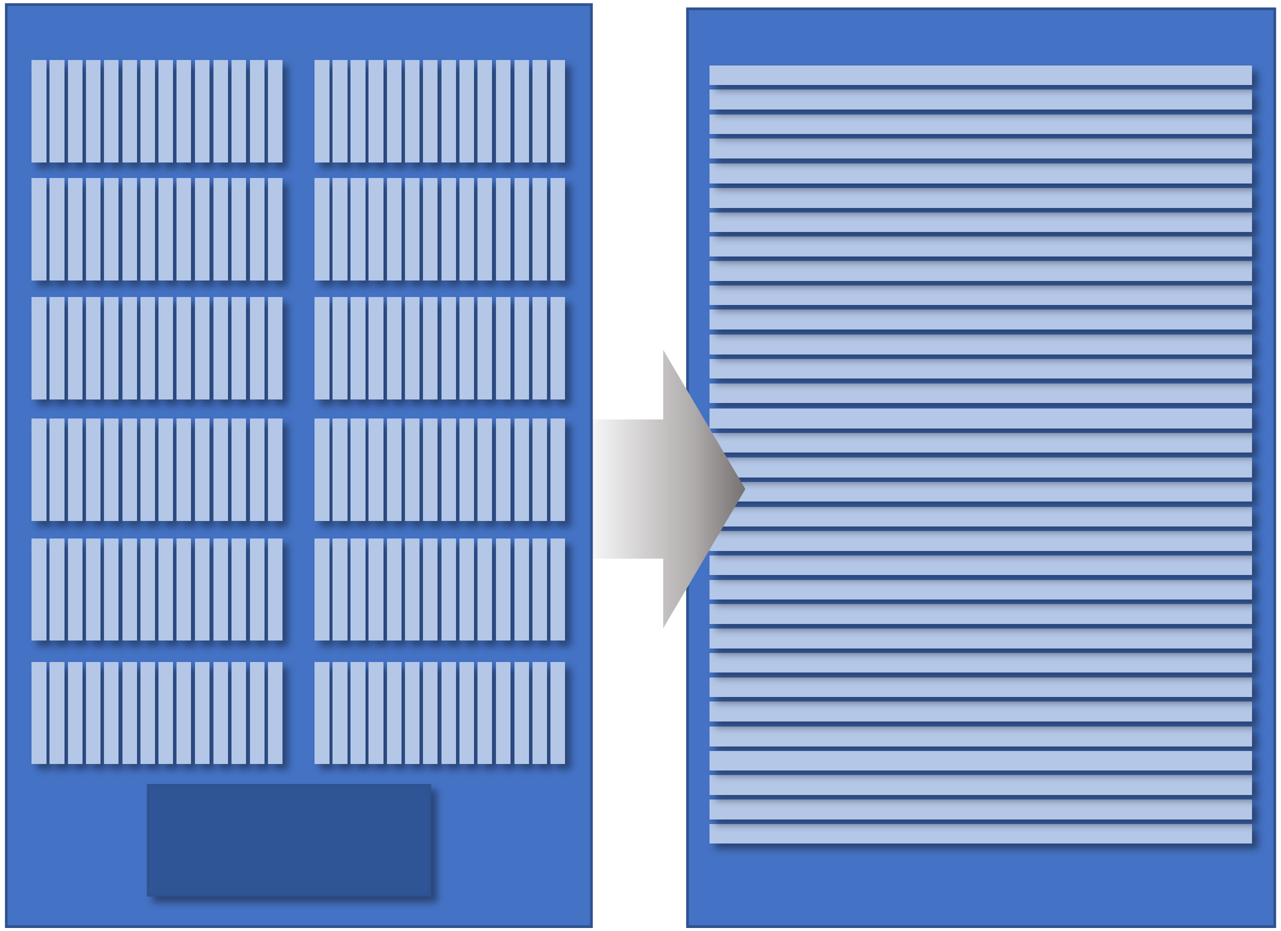
Driving range; Raw materials

The interplay of Chemistry and Engineering

POLiS Post Lithium Storage Cluster of Excellence

25% active material
Conventional design

30-35% active material
Cell-to-Pack design



CATL

Cell-to-Pack (CTP) -Technology allowed CATL to increase

- Specific energy by 10-15%, and
- energy density by 15-20%, and
- to reduce the number of parts for making the battery pack by 40% (!)

BYD: „Blade" battery

M. Fichtner, *Recent research and progress in batteries for electric vehicles*, Batteries&Supercaps (2022) e202100224

New cell and pack designs give new room for development

We recognize:
More space for active materials in the battery
→ more flexibility in the choice of materials

- Cost ✓
- Durability ✓
- Safety ✓
- Sustainability ✓
- Energy density ✗

$LiFePO_4$ + others ?

„Materialdämmerung“

2020

„**Blade Battery**“ (CTP (cell to pack) technology

LFP-cathode (LiFePO$_4$)

50% Raumgewinn für Kathode

605 km NEFZ (2020)

3.9 sec for 0 – 100 km/h

for 30,000 EUR

$$(\rho = 3{,}5\ \mathrm{g} \cdot cm^{-3})$$

vs. $5 - 6\ g \cdot cm^{-3}\ for\ NMC$

State-of-the art 2023: Batteries with 50% longer driving range

CATL launches CTP 3.0 battery "Qilin," achieves the highest integration level in the world

2022-06-23

https://www.catl.com/en/news/958.html

255 Wh/kg on pack level

BYD and CATL in 2023:

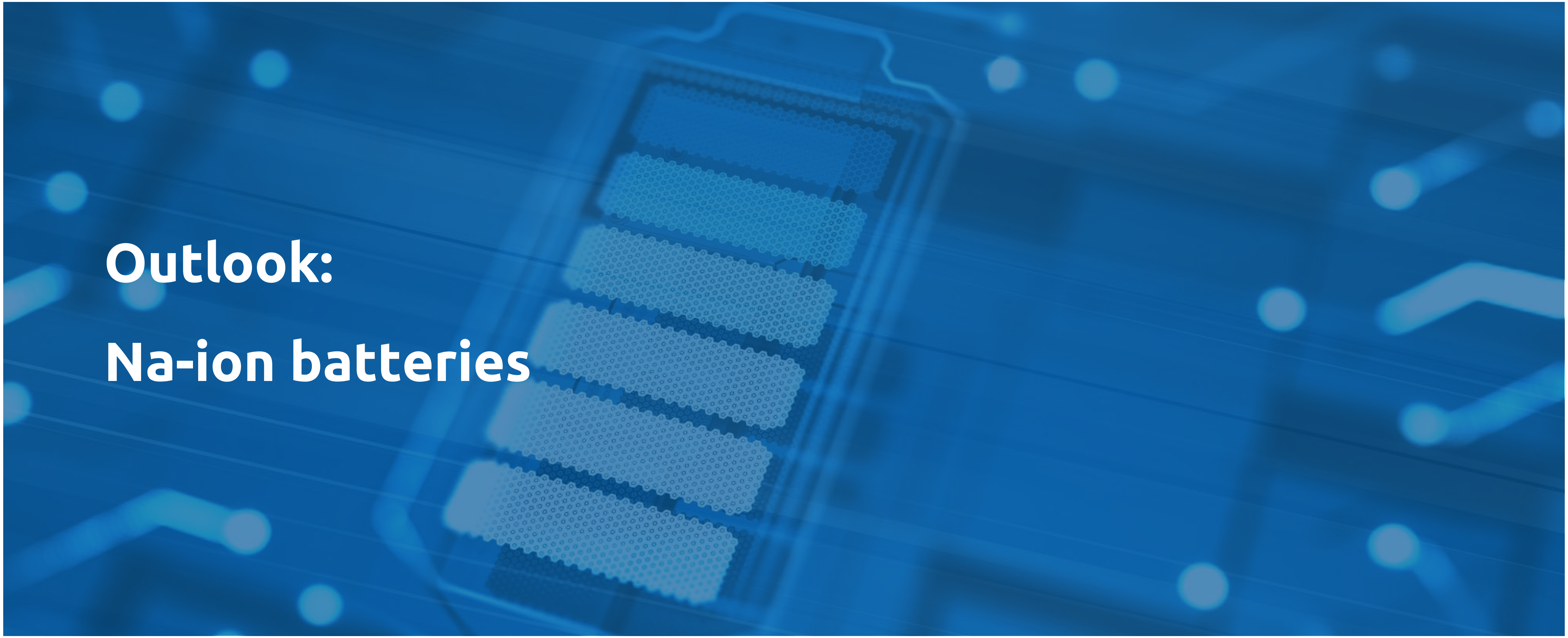
- **>1000 km range (WLTP)**
- **charging: 700 km in 10 min**

manufacturer: **Geely, Model Zeekr 001**

Geely-Group: Volvo, Lotus, Lynk, 10% of Mercedes, ….

140 kWh LFP-Akku, 3,8 sec from 0-100 km/h, 120 km charging in 5 min

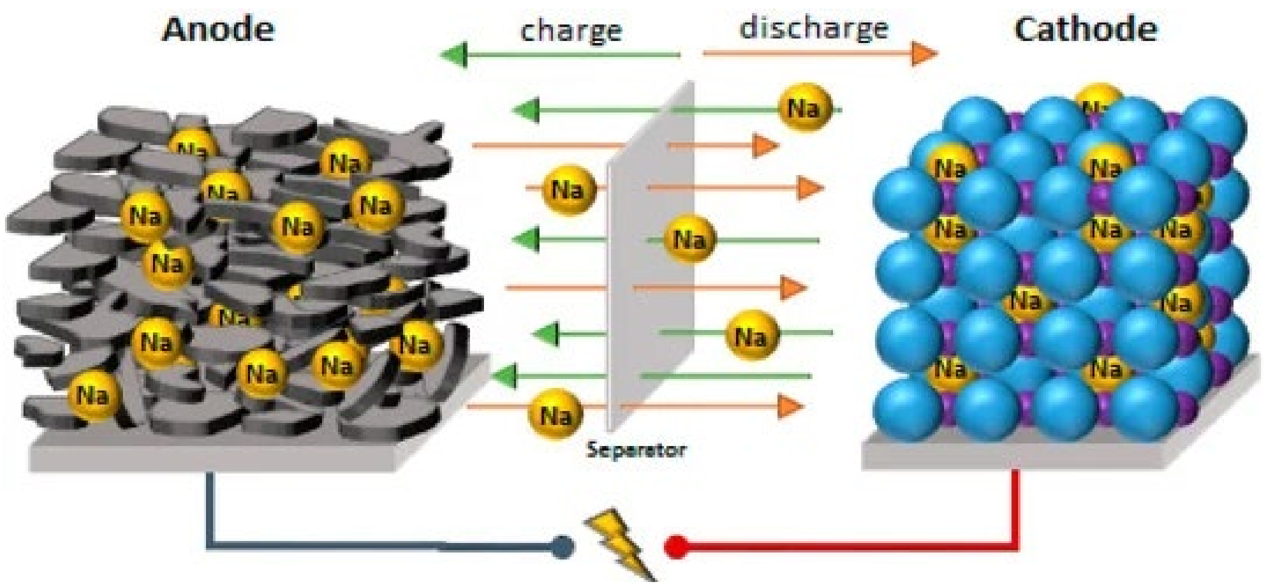
https://www.auto-motor-und-sport.de/elektroauto/geely-premium-e-autos-zeekr-001/



Outlook:

Na-ion batteries

Working principle of sodium ion battery



📖 J. Peters et al., Batteries 2019, 5 (1), 10

„Drop-in“ technology

Post Lithium Storage Cluster of Excellence

No use/dependence of critical raw materials

Li-Batteries

Al

Li
Ni
Mn
Co
Graphite

Cu

critical/expensive/toxic raw materials

Na-Batteries

Al

Na
Fe
Mg
Mn
Hard carbons

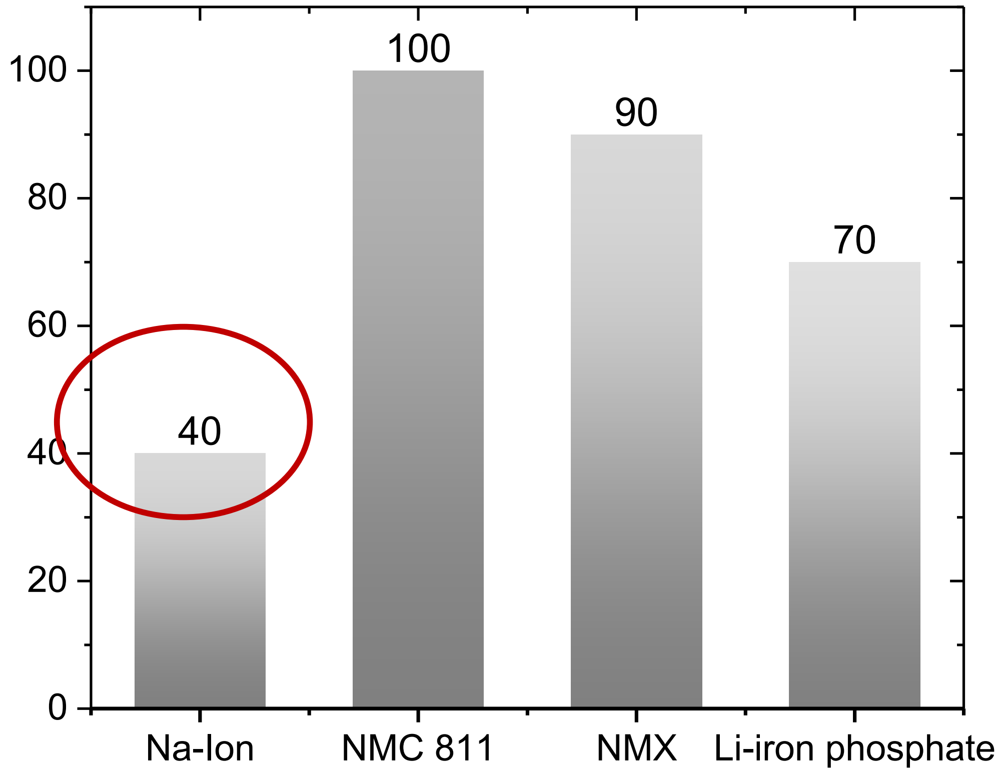
Al

sustainable/cheap/abundant raw materials

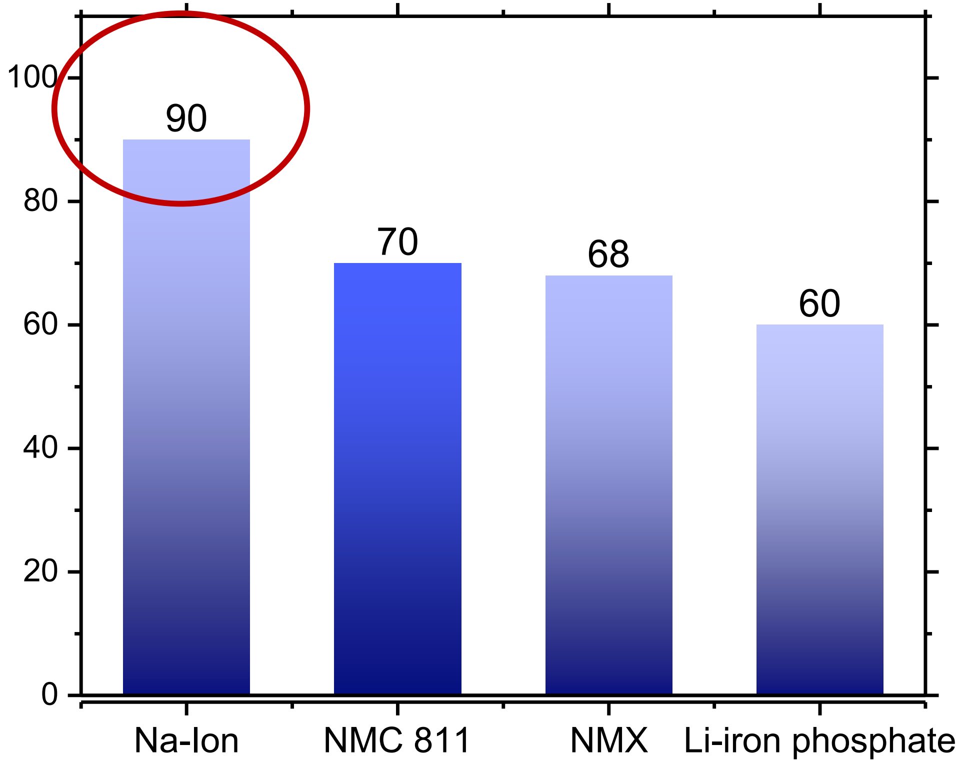
Properties of Na ion batteries / Perspectives

LIB with $LiFePO_4$: 200 Wh/kg 350 Wh/l
NIB: 160 Wh/kg (2021) 300 Wh/l
200 Wh/kg (2022)

relative costs



capacity at -20°C



Conclusion and

Perspectives

Perspectives

- **Overall:**

Battery vehicles have the lowest GHG emissions, the best energy efficiency and the lowest costs.

General trend to move away from critical raw materials and to reduce manufacturing costs

→ cheaper, more abundant materials

→ manufacturing processes with lower energy consumption

→ use of 100% RE in production

- **Chemistry**

→ Approx. 10-20% increase in capacity through better cathodes with higher voltage and capacity

→ Approx. 30-40% increase in capacity through better anodes with silicon@carbon composites

→ Batteries free of critical raw materials, e.g. the Na-ion battery

- **Engineering**

New batteries with an optimized pack design (from 2023) allow longer ranges, faster charging, greater safety

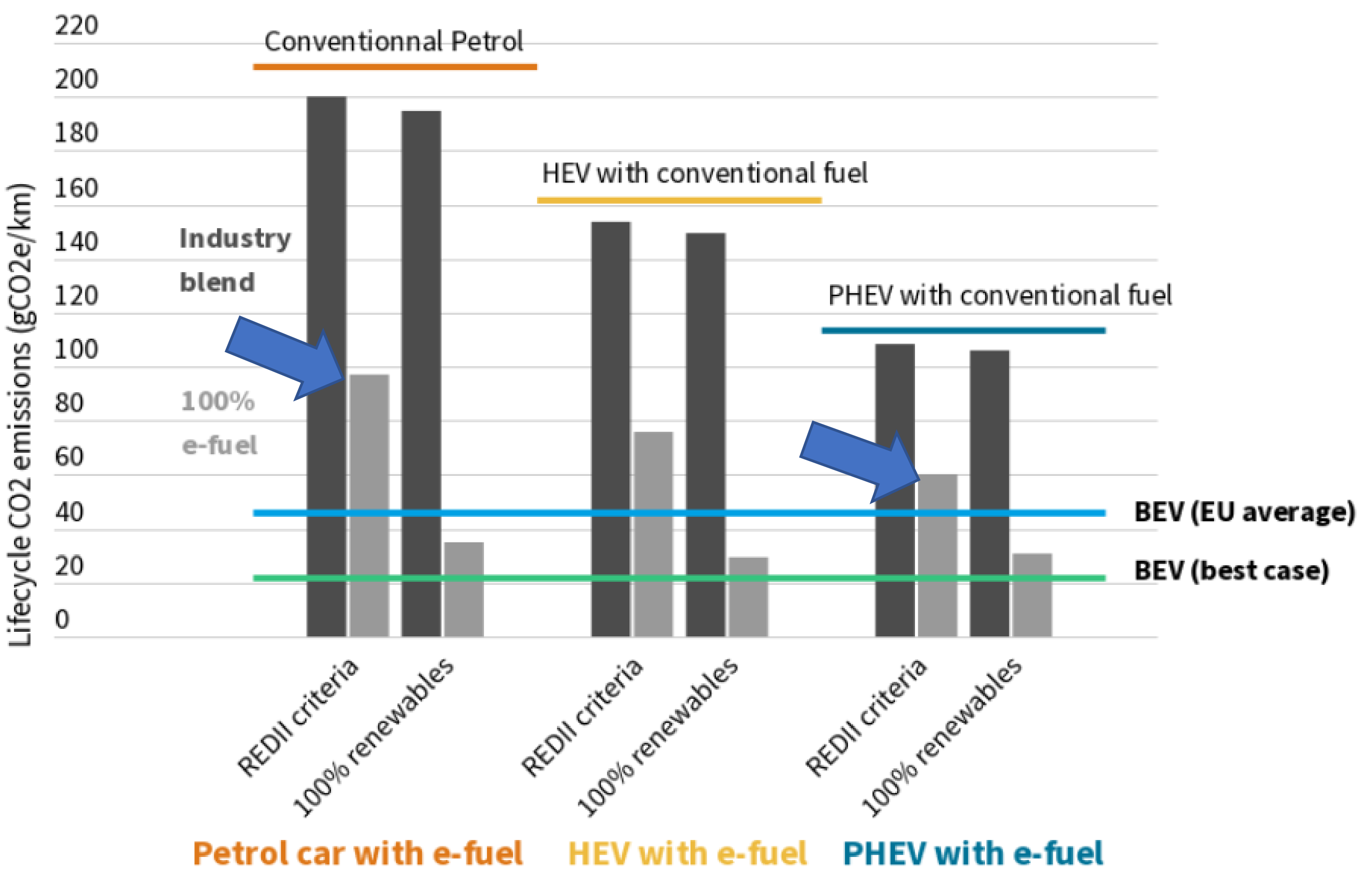
→ BYD, CATL, NIO: 1000 km WLTP; 700 km charge in 10 min.

Thank you !

www.celest.de
www.hiu-batteries.de
www.postlithiumstorage.org

Zusatzfolien

LCAs with E-Fuel and other drivetrains in comparison



REDII criteria: the electricity used to produce the e-fuel is based on a 70% CO2 reduction of the WTW fuel emissions.
100% renewables: based on the forecast of renewable energy sources used by electrolysers.
BEV (best case): Swedish electricity grid used for battery production and charging, and low supply-chain impacts.
Source: T&E LCA analysis of medium-sized car bought in 2030

Figure 5 – Lifecycle emissions of cars running on e-fuels for cars bought in 2030

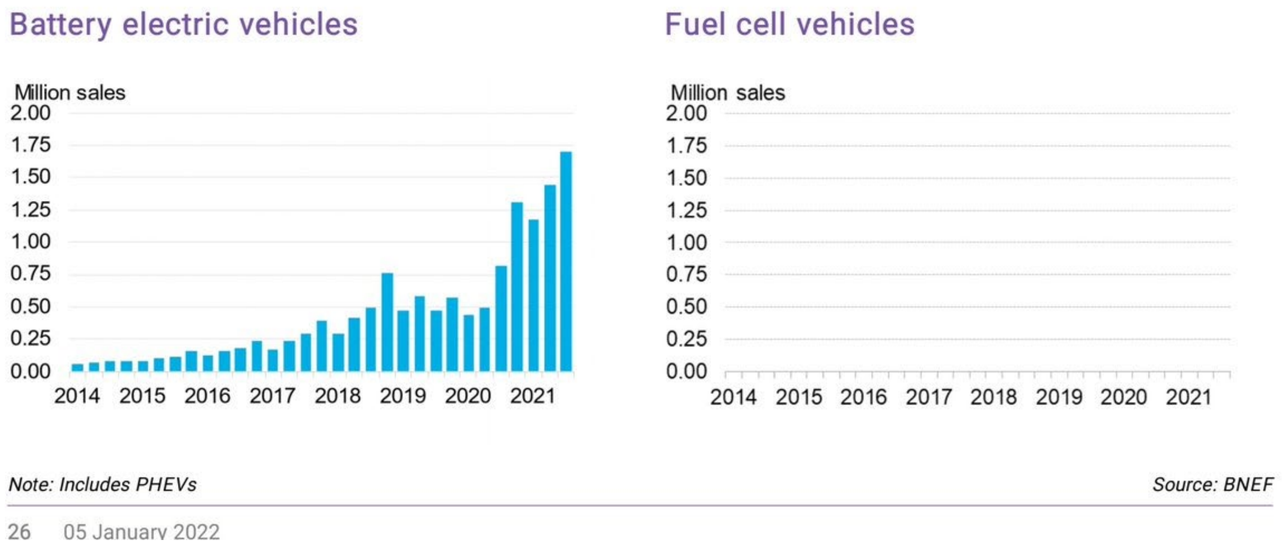
E-Fuels have a GHG reduction potential if the electricity used is coming to > 80% from renewables

(FhG-ISI, 2022)

Entwicklung der Zulassungszahlen von BEV and FCEV

Verkauf BEV und FCEV weltweit nach Quartal

Liebreich Associates

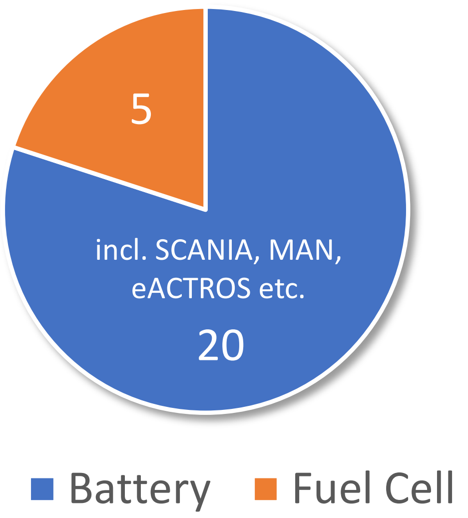


China: Jan - Mar 2021

273.000 BEV
37 FCEV

Und LKWs ?

Antriebe von Null-Emission Trucks werden derzeit von 25 Firmen weltweit entwickelt



(www.forbes.com; Jan 19, 2021)

„Tipping point“ of a new technology is reached at 10-12% market introduction

→ „Market-Trauma“ for the „old“ technologies

H_2 für Schwerlastverkehr

wird konkurrenzfähig bei Kosten < 4-5 EUR/ kg H_2
Derzeit: 9,5 EUR/ kg H_2 („grauer" H_2)

→ Faktor 1/2 für grünen H_2 wird schwierig zu erreichen, wird eher teurer.
→ Kosten für Batterien sinken stetig

Kostenanalyse mit Vorausschau für 2025+:*

0,44 €/km

0,5-0,7 €/km

Kilometerkosten 30-60% höher als bei vollelektrisch

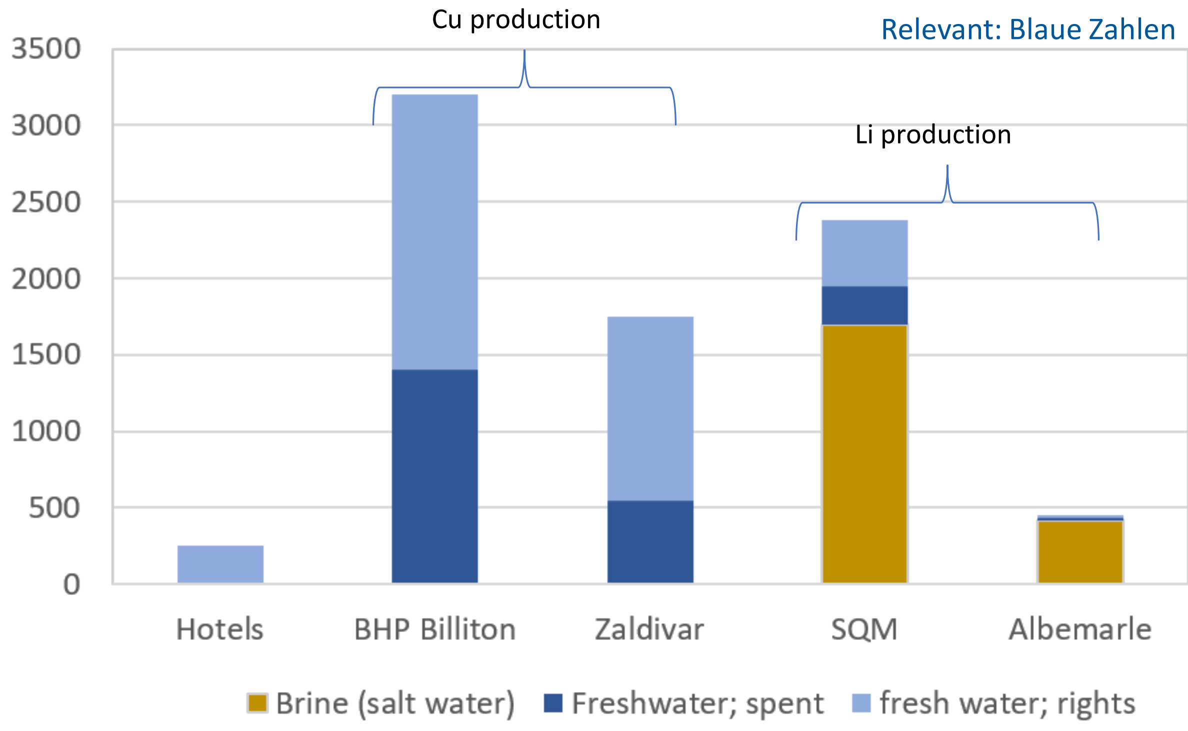
0,54 €/km


GenH2 von DAIMLER

75% der ursprünglich für BZ-H2 avisierten Anwendungen werden als vollelektrisch projektiert.

*J. Schenk, P3 automotive GmbH, UECT, 2021

Lithium Produktion und Wasserverbrauch/Wasserrechte vor Ort



data from:
Ministerio de Minería
Chile (2018)

ref.: en.mercopress.com/2011/07/22/

Süßwasserverbrauch + Wasserrechte in der Salar de Atacama Region:

710 Mio m³/a für Li (Verbrauch: **260** Mio m³/a)

4950 Mio m³/a für Cu (Verbrauch: **2000** Mio m³/a)

250 Mio m³/a für Hotels (= Verbrauch)

Grundwasser sinkt seit den 1960er Jahren

8x höherer Wasserverbrauch für die Kupferproduktion am Salar

Batterierecyclingkapazitäten in Europa

with reference to Tom Tsogt 2021
and Raphael Danino-PERRAUD 2020

northvolt
25.000 tpa
50% recycled material by 2030 (target)

saft
2.000 tpa

hydrovolt
8.000 tpa (target)
Li, Mn, Co

BatteriRetur
20,000 collection points

LITHIUM SAFETY SOLUTIONS
De specialist in lithium-ion veiligheid
LIB

STIBAT
23.907 collection points

NFM

umicore
7000 tpa
Li, Co, Ni, Cu, RE

bebat
23.908 collection points

reneos
Li

REVATECH
50.000 tpa
Zn, Pb, Cu, Ni, Sn, Co, Mo

ECOBAT
Battery collection only

H.RIPLEY&CO
WEEE, tire, cable, Ni, Co, Graphite, Cu and Al

impact solutions
Li, Co, Mn

LiBatt RECYCLING LTD
WEEE

Lincoln Storm
8000 tpa
Ni,Co,Li,Mn

RICARDO
Li, Co, R&D not industrial scale

WasteCare
Battery collection only

weee ireland
6.000 collection points

ecopilas
44.612 collection points

envirobat España
Zn, Mn

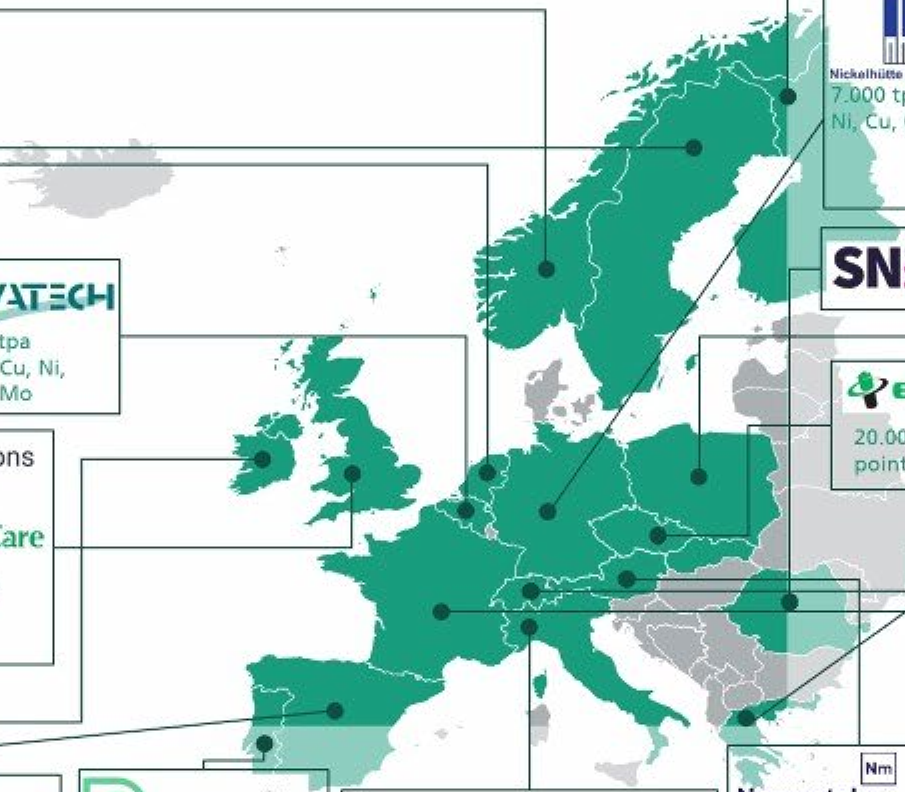
RECYPILAS
Lamps, NFM

UTE vilomara
Lamps

AKKUSER
Co, black mass

fortum
Li, Co, Ni, Mn

Recycle
Black mass



electrão
WEEE, 3.500 collection points

cobat RIPA
n.a.
Battery, WEEE, tires collection only

Neometals
Lab scale
Li, Co, Ni, Cu, Fe, Au, Graphite, Mn, plastic

ACCUREC
6.000 tpa
Li, Cu, Fe, Ni, Co, Al, plastic

BASF Chemetall
Samll scale
Cu, Co, Ni, Li

Duesenfeld
3.000 tpa
Li, Co, Ni, Fe, Cu, Al

Stiftung GRS Batterien
15.000 collection points

ERLOS
LIB, platic

WALCH
Li, Nd, Fe, magnets, RE, scrap,wind turbine

DK RECYCLING & ROHEISEN

REDUX
10.000 tpa
Fe, Al, Cu, Co, Ni, plastic

Nickelhütte Aue GmbH
7.000 tpa
Ni, Cu, Co, Zn, Mo

Primobius
Co, LIBs

reco-e
Co, Ni, Al, Fe, plastic, scrap

VOLKSWAGEN GROUP COMPONENTS
1.200 tpa
Ni, Co, Li, Mn

PROMESA
Co, Ni

SNRB
All kinds of batteries

eneris
n.a.

ROYAL BEES
WEEE

ecobat
20.000 collection points

Re-Battery
8.170 collection points

GLENCORE
Battery collection only in EU - export to Canada

BATREC
Mercury

Euro Dieuze
5.000-6.000 tpa
Li, Co, Cu NFM

eramet
10.000 tpa
Li, Co, Ni, Fe, Cu, Al

ERASTEEL
Ni, Co, Mo, Tungsten, Vanadium, NFM, other

RECUPYL
Mn, Co, Li, Ni, Al, Cu, Fe

SNAM
300 t; Co, Ni, Cu, Al, Fe +Repurposing

VEOLIA
Li, Ni, Fe

NFM – Non-Ferrous Metals
n.a. – Not available
WEEE – Waste Electrical and Electronic Equipment
LIB – Lithium-ion Battery
tpa: tonne/year

  Offen

Fraunhofer IPA

Preise für grünen Wasserstoff und Methan voraussichtlich
→ **über 100 Euro** je MWh im Jahre 2030
→ **knapp unter 100 Euro** je MWh im Jahre 2050.

Aktuell beträgt der Preis für Methan am europäischen Rohstoffmarkt **rund 30 Euro** je MWh.

»Die hohen Kosten zeigen, dass der Import von E-Fuels nach Europa kein billiges Patentrezept ist, um Engpässe beim Ausbau der erneuerbaren Energien zu umgehen oder eine Transformation auf der Angebotsseite zu erreichen«

(FhG-IEG, KIT-DVGW (2022))

https://www.ieg.fraunhofer.de/de/presse/pressemitteilungen/2022/energieimporte-gruener-wasserstoff.html

(creative commons, Wikipedia)

Bewegte Teile Verbrenner:
ca. 1300

Bewegte Teile e-Antrieb:
ca. 40

