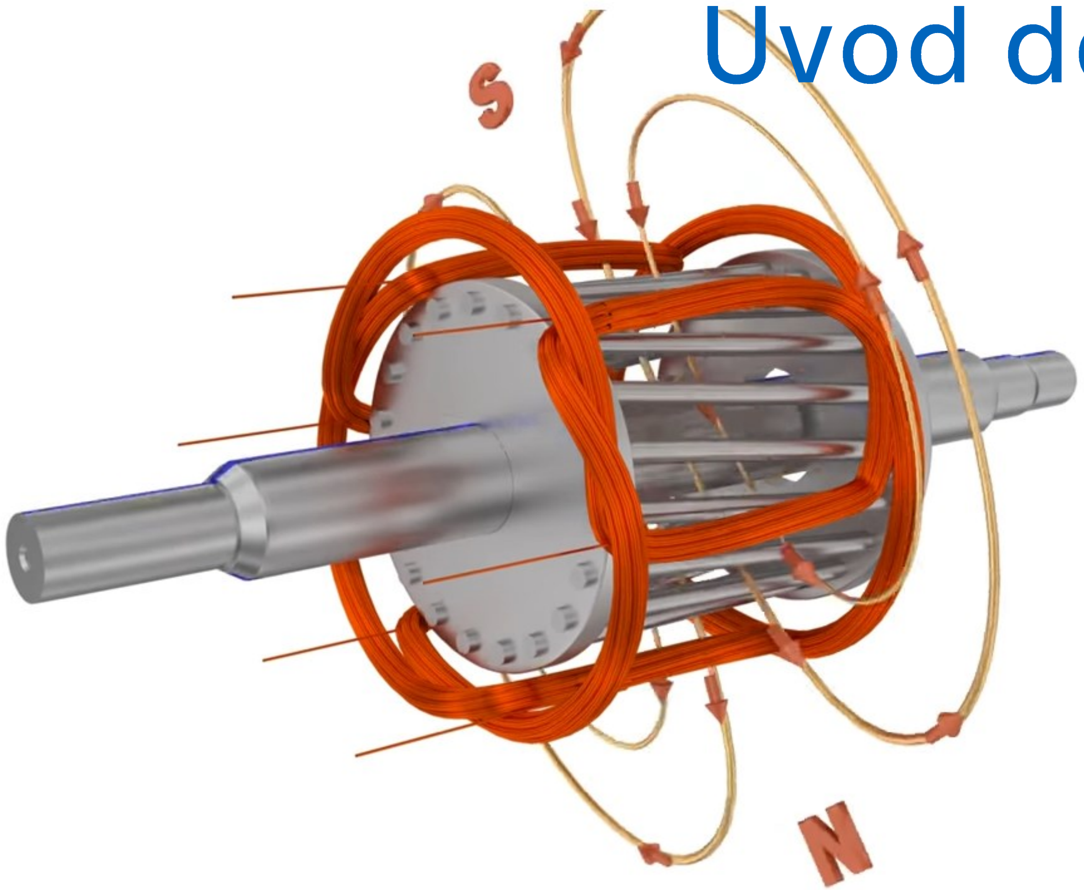


Úvod do elektrotechniky

Doprovodný materiál k přednáškám

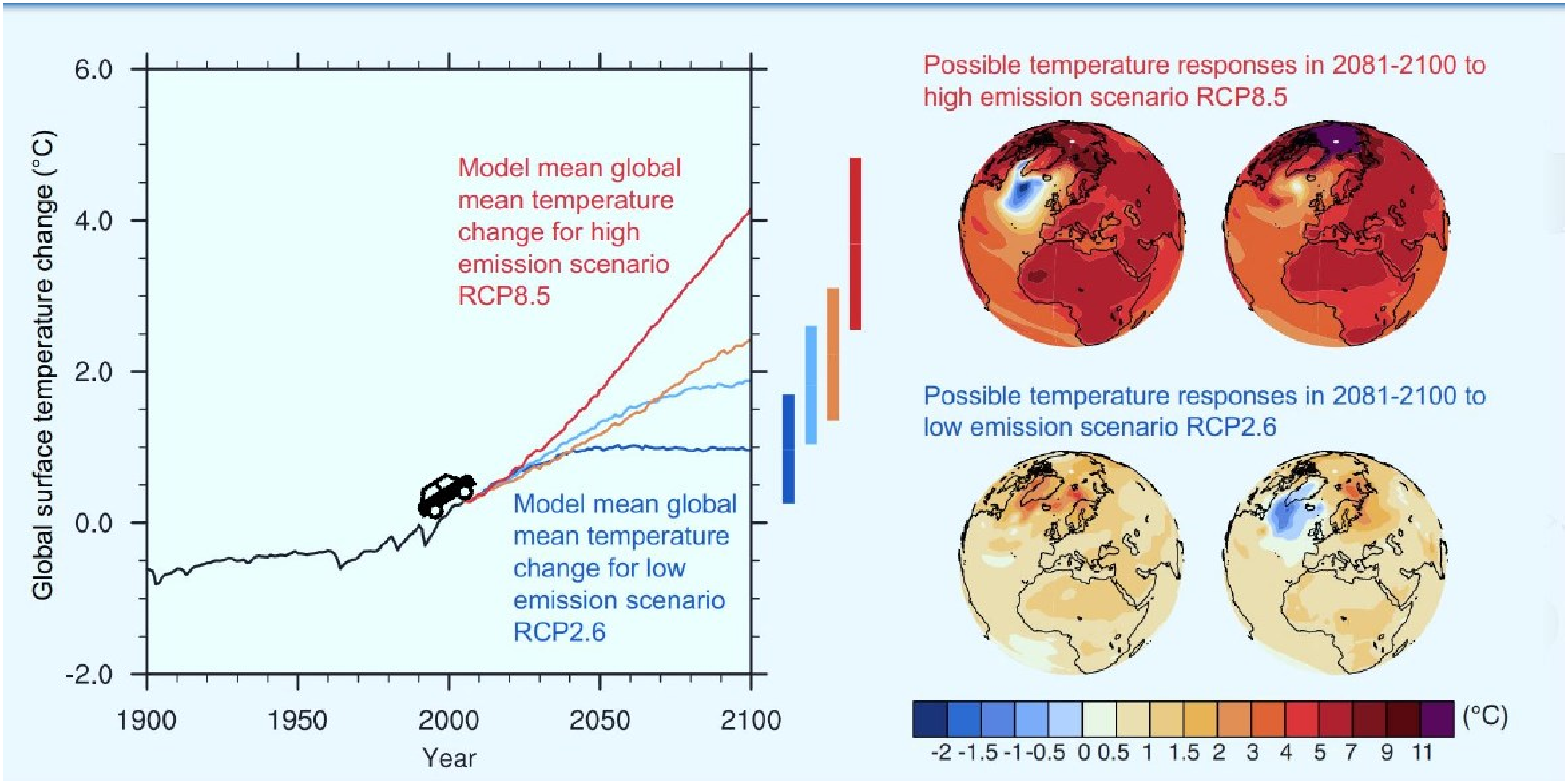
Autoři:

Jan Bauer – bauerja2@fel.cvut.cz

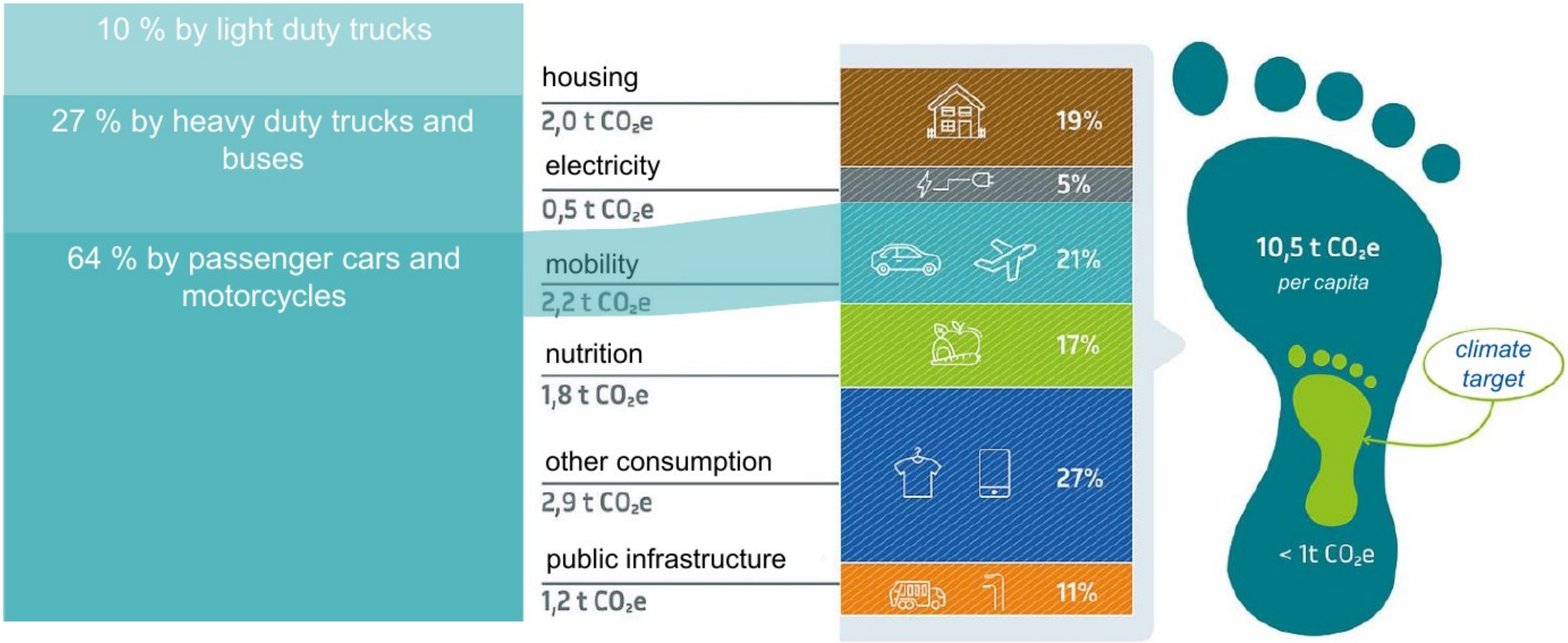
Zimní semestr 2021/2022

.

Motivace


6.0
4.0
2.0
0.0
-2.0
Global surface temperature change (°C)
1900
1950
2000
2050
2100
Year
Model mean global mean temperature change for high emission scenario RCP8.5
Model mean global mean temperature change for low emission scenario RCP2.6
Possible temperature responses in 2081-2100 to high emission scenario RCP8.5
Possible temperature responses in 2081-2100 to low emission scenario RCP2.6
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)

Uhlíková stopa - Německo



Fakta

How many cars per capita in:
Europe
North-America
Asia
Africa
Which country is the highest in the world?
Which country the lowest?

How much is the average expenditure per capita in Germany for mobility per year?

Daily mobility in Germany:

How many trips?
How many kilometers?
How much time?

(average per person)

Europe 0,51
North America 0,71
Asia 0,14
Africa 0,06

Highest, New Zealand 0,9
Lowest, Congo 0,004

2.600 €

3.1 trips

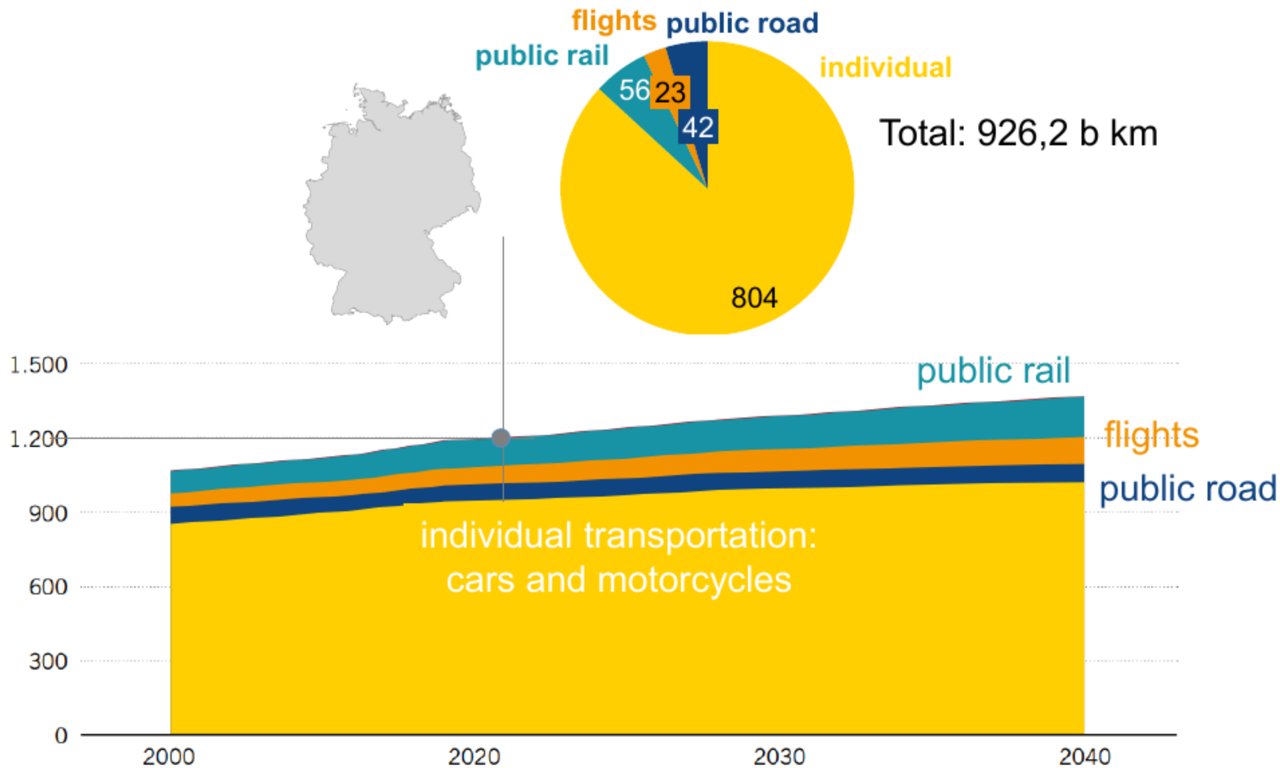
85 minutes

39 kilometers

Uplatnění


vehicle energy and power density/demand
distance to charging infrastructure

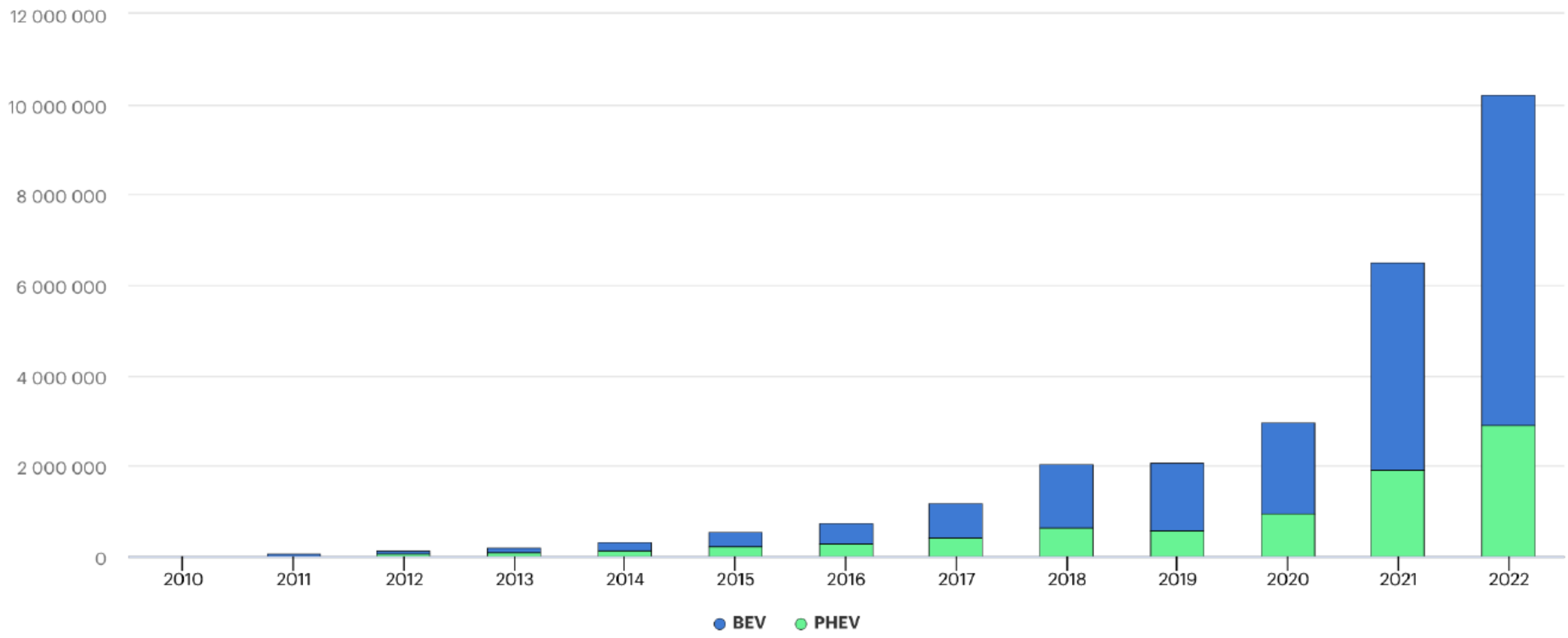
Způsoby cestování



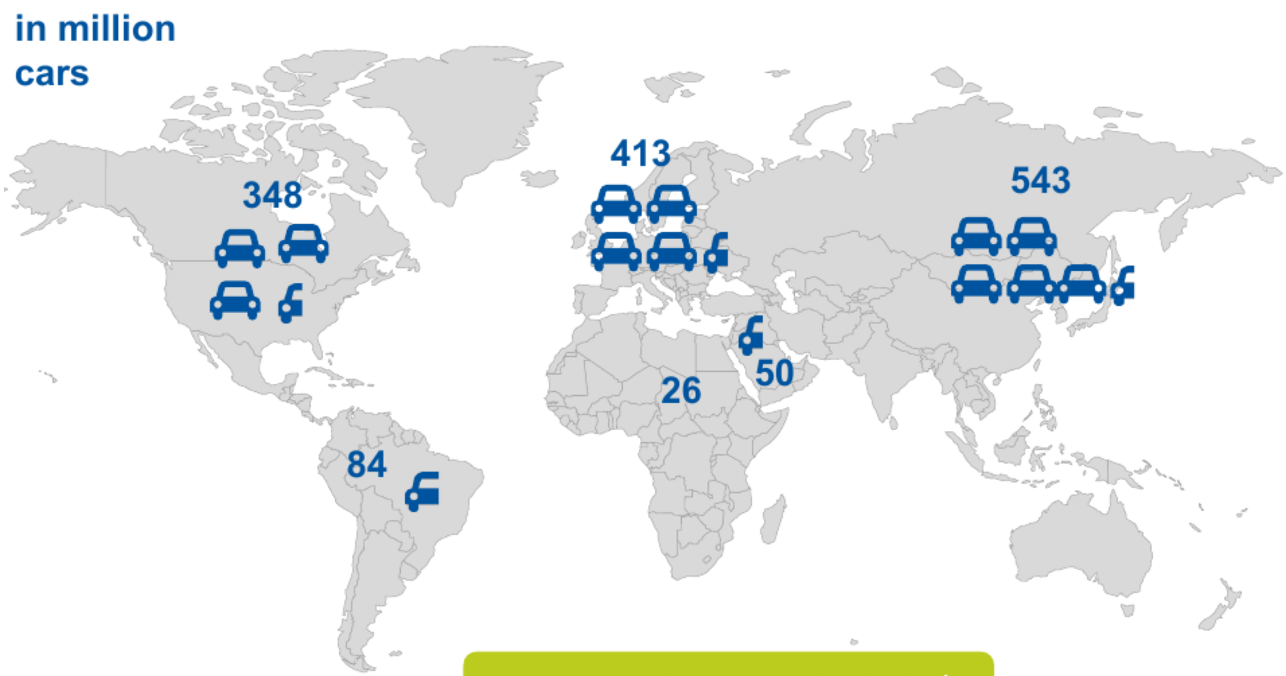
GLOBAL
in 2016

- **Individual** (cars and motorcycles) 25 trillion passenger kilometers
- **Public land** 10 tr. passenger km public
- **Flights** 5 tr. passenger km

Prodeje aut


12 000 000
10 000 000
8 000 000
6 000 000
4 000 000
2 000 000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
BEV
PHEV

Auta ve světě



1.474 billion cars in 2023[1]

+ about 50 cars in Antarctica

~ 14 % of new cars sold in 2023 are hybrid or electric[2]

Of Total car sales (~ 100 million):

- In 2025: 30 million are EV (30 %) in 2025 and
- In 2030: 70 million EV (60 %)

For full electrification we need 100 % EV sales! And the phaseout of still sold combustion engine vehicles.

With a lifetime of 12 years per car and combustion engines still being sold, full electrification will take likely > 30 years.

Opatření v EU

Political incentives for establishing Germany and Europe as a lead market for electromobility

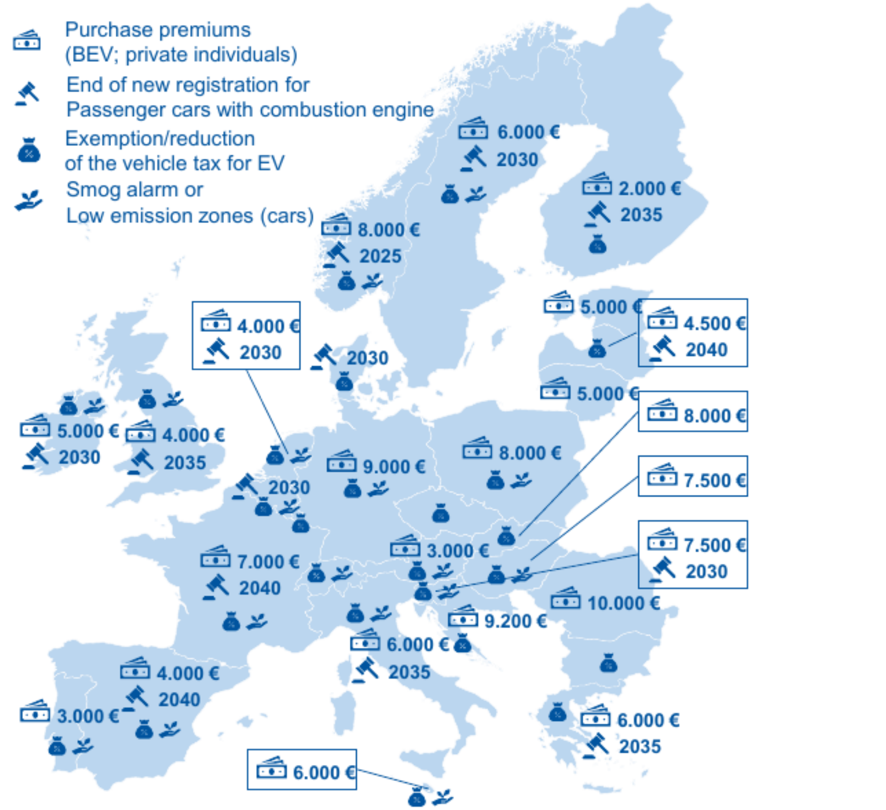
- Climate protection
- Purchase premiums
- Vehicle tax
- Charging station infrastructure

Political incentives to establish Germany and Europe as a lead provider for electromobility

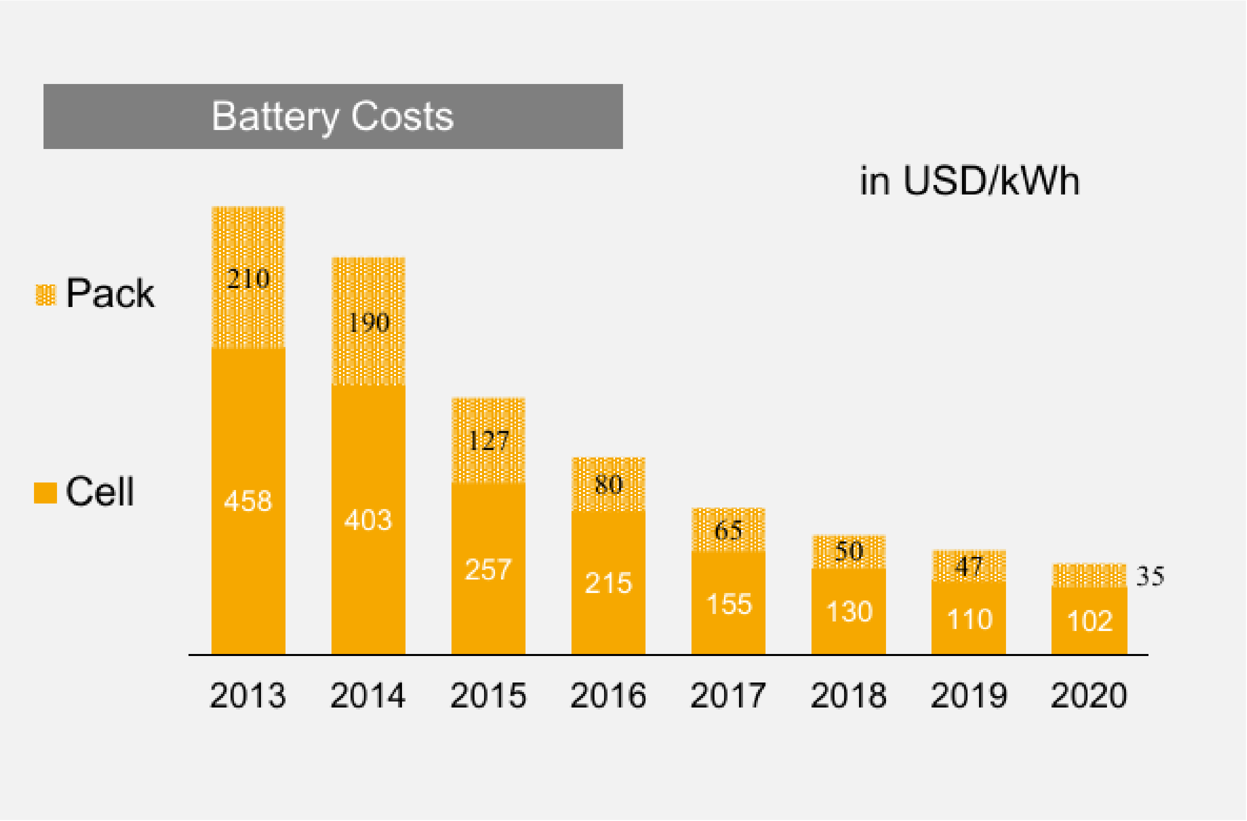
- CoPa 35c
- IPCEIs
- Fraunhofer facility Research Manufacturing Battery cell (FFB)

International political framework for electromobility

- Purchase premiums
- European Green Deal
- IRA (USA)
- Country-specific ambitions
- End of new registrations for Internal combustion engines



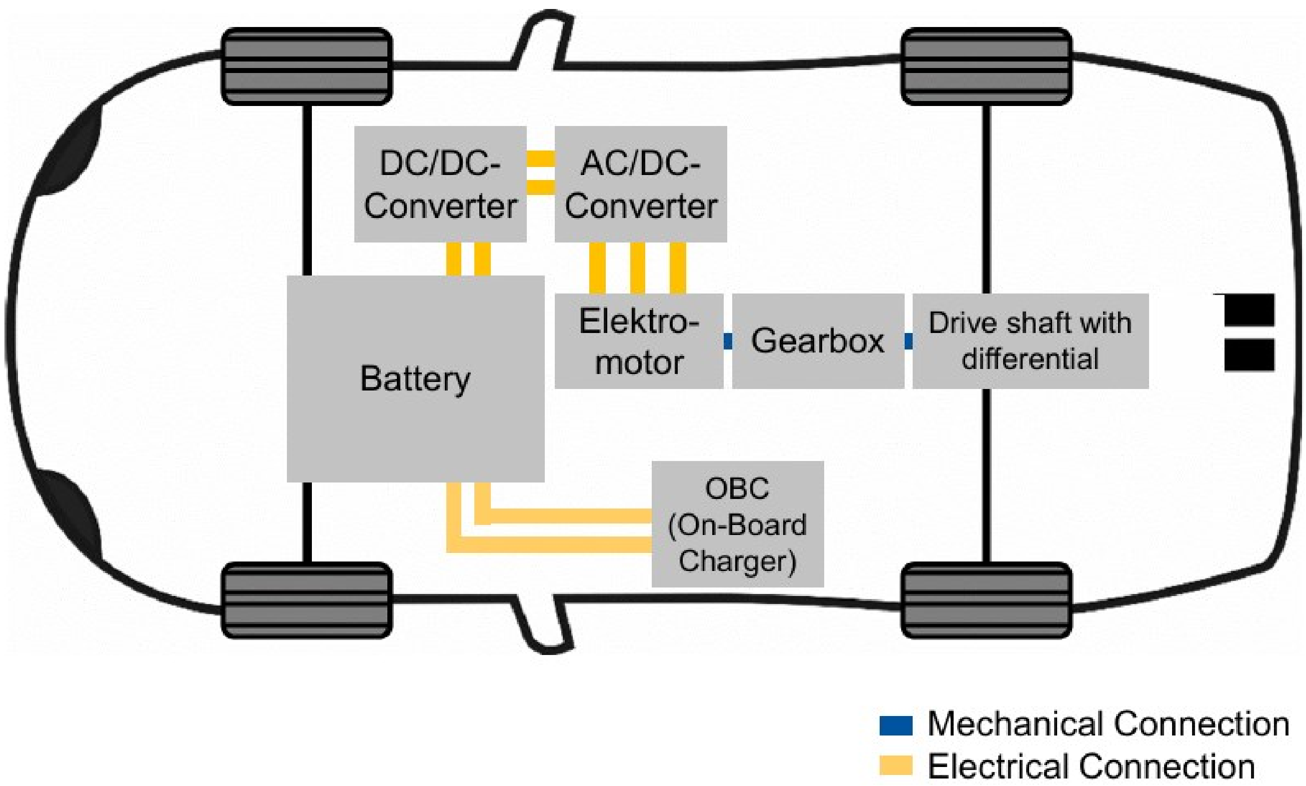
Cena baterie



Definition: Electric Vehicle

Any vehicle propelled by an electric drivetrain taking power from a rechargeable battery or from a portable, refillable, electrical energy source (like fuel cell, solar panels, etc.), which is manufactured for use on public roads

Elektromobil



Where is the Car, where is the Horse? (Tony Seba)

Photo: Fifth Ave NYC on Easter Morning 1900 Source: US National Archives from (Wikipedia)

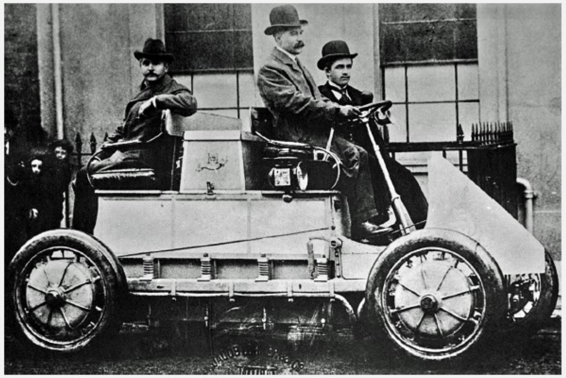
2001-2014 by Tony Seba

Photo: Easter 1913, New York. Fifth Avenue looking north. George Grantham Bain Collection

Source: shorpy.com

Source : Tony Seba

Ludwig Lohner and Ferdinand Porsche (1858 & 1875)

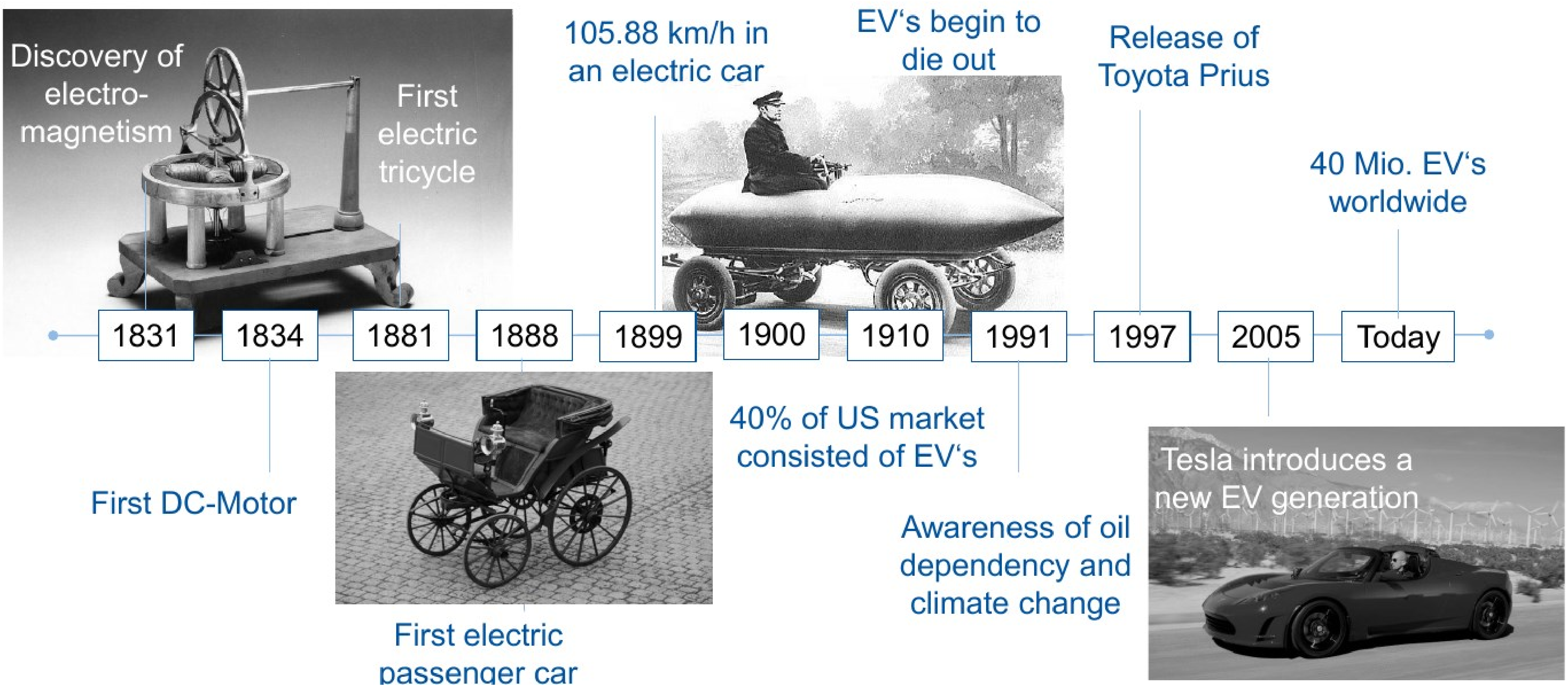


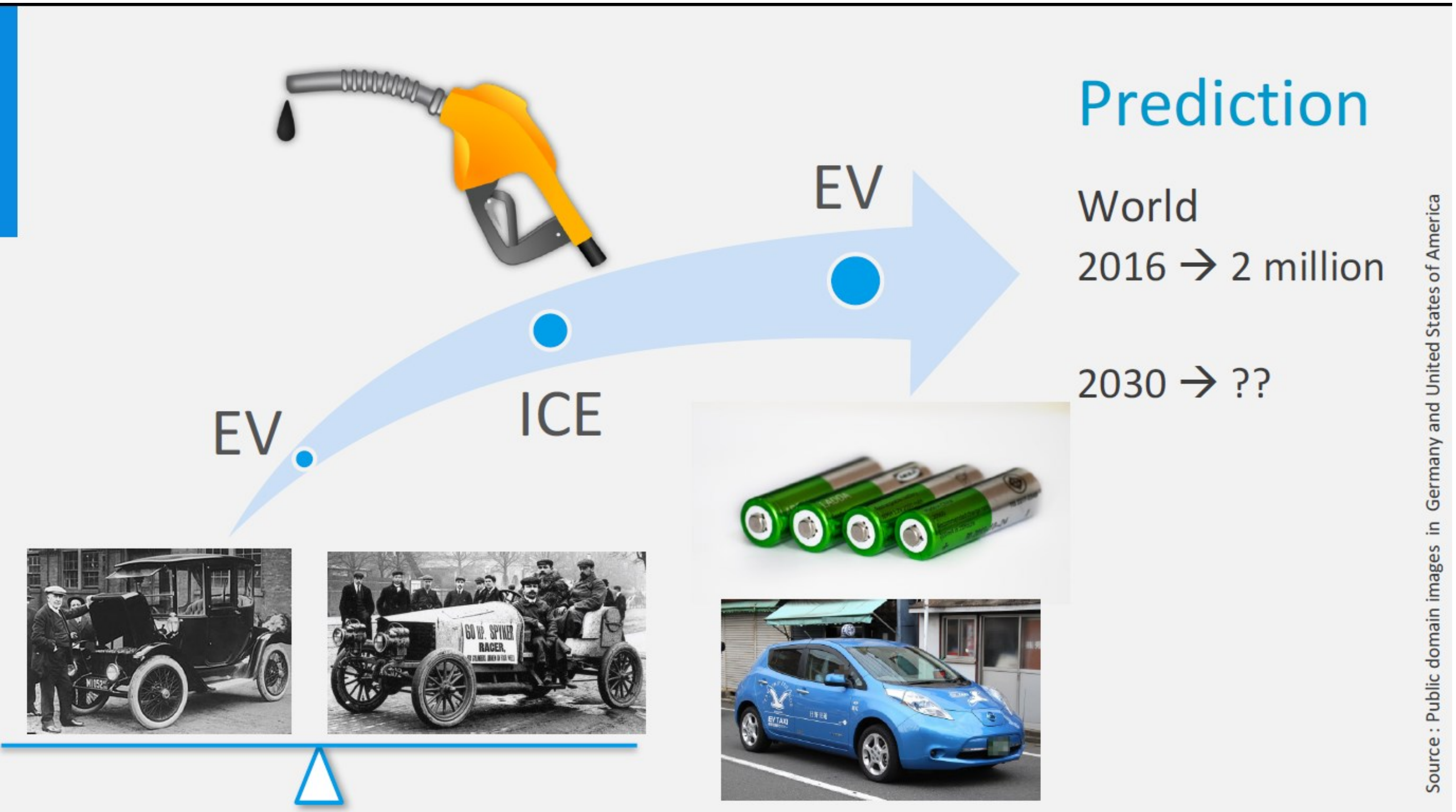
First in-wheel motor electric & hybrid car in the World (1900)

Source: http://www.germannotes.com/archive/article.php?cPath=49_52&products_id=791, Ludwig Lohner, : Jacob Lohner & Co

Ferdinand Porsche started his career with an EV built by Ludwig Lohner in Austria.
In 1900, they engineered an in-wheel electric motor
The full electric version, powered by lead acid batteries, has already four-wheel drive.
In another hybrid version, the rear wheels were driven by a combustion engine.

Časová osa


Discovery of electro-magnetism
First electric tricycle
105.88 km/h in an electric car
EV's begin to die out
Release of Toyota Prius
40 Mio. EV's worldwide
1831
1834
1881
1888
1899
1900
1910
1991
1997
2005
Today
First DC-Motor
First electric passenger car
40% of US market consisted of EV's
Awareness of oil dependency and climate change
Tesla introduces a new EV generation



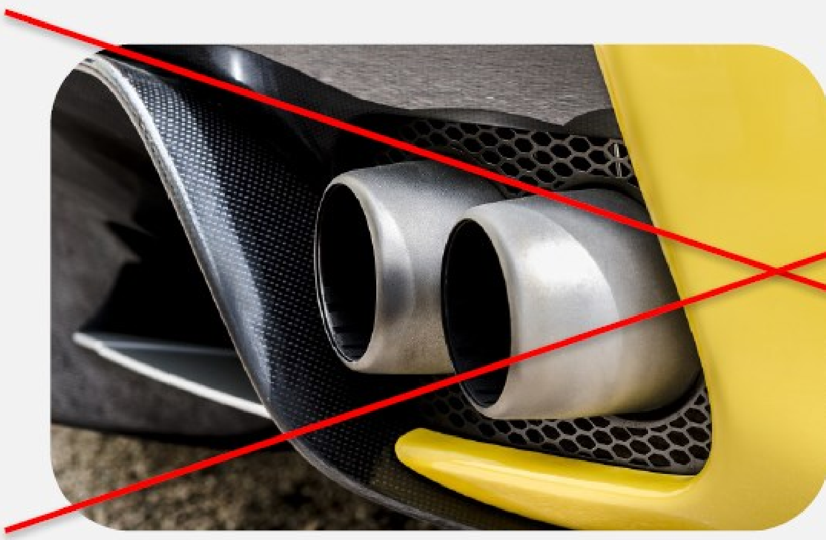
- Due to poor battery technology, electric vehicles had a low range in those days and could never travel the long distances reached by a gasoline powered car.
- Further, charging them took much longer than refueling gasoline.
- The mass production of cars like the Ford Model-T made gasoline cars affordable.
- With abundantly available and cheap fuel, fossil fuel powered cars became the clear winner over electric cars.
- As a result, the internal combustion engine car has gradually dominated the market since then, until this day.

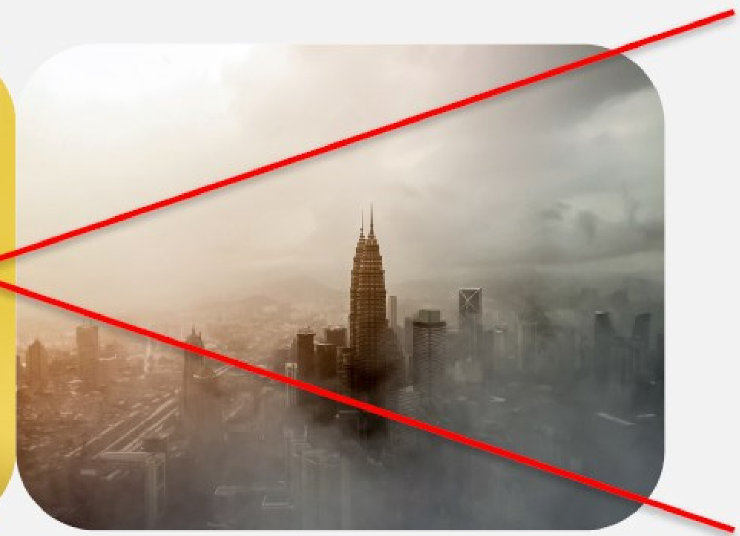
Benefits of EVs

- Sustainability
- Efficiency
- Convenience
- Economy

Sustainability: No tail-pipe emissions

- EVs have no tail-pipe emission
- Reduced air pollution in cities due to CO_2, SOx, NOx, particulate matter





The main drivers for urban mobility

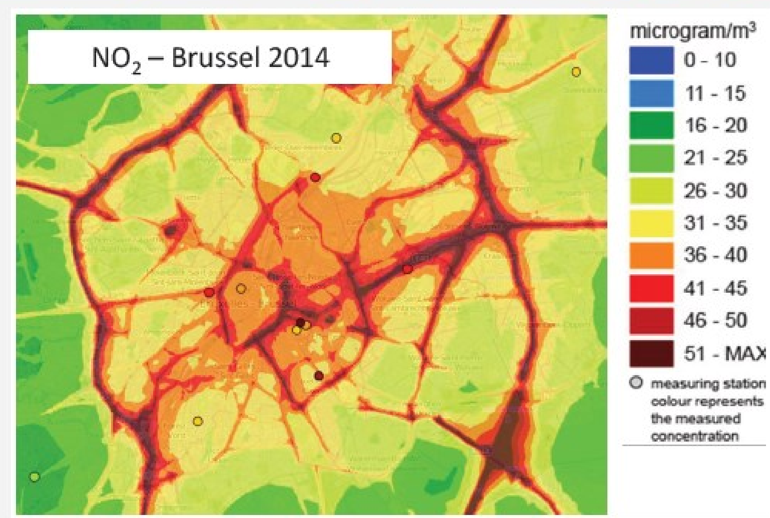
Today: Air quality / Fine dust

Today: Smart Logistics

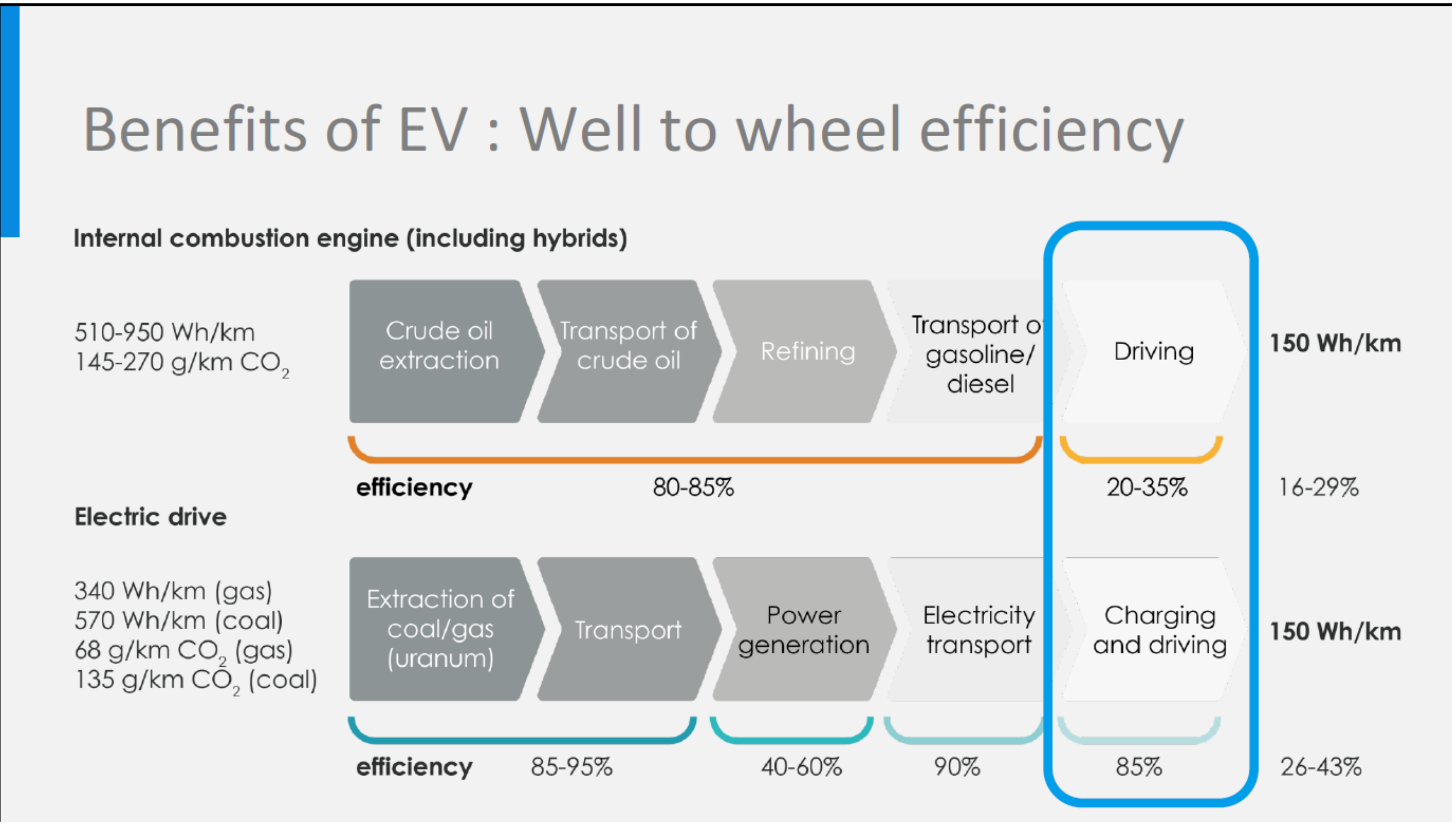
Today: Noise / Quality of live

Tomorrow: Energy / CO2

Always: €€€€€€€



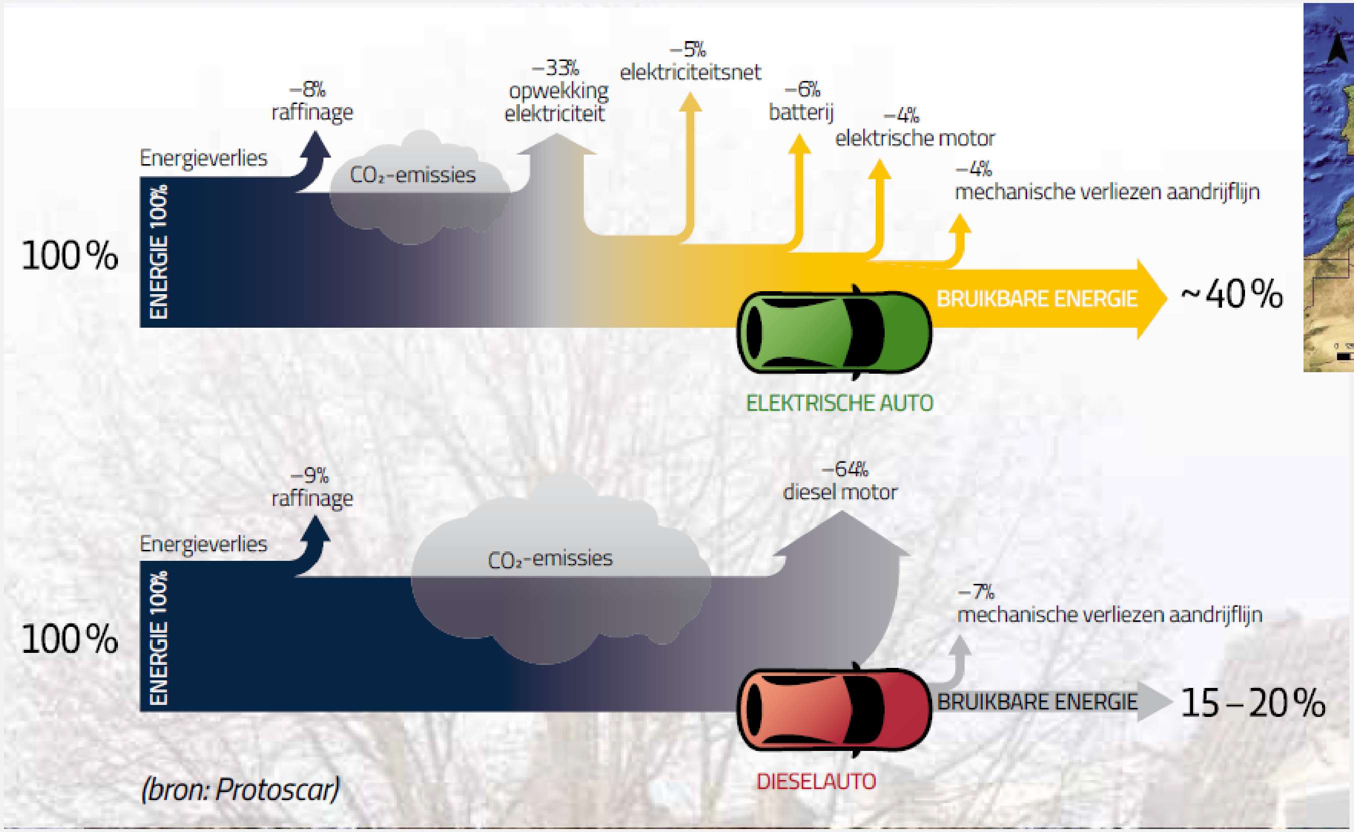
Source : Pixabay

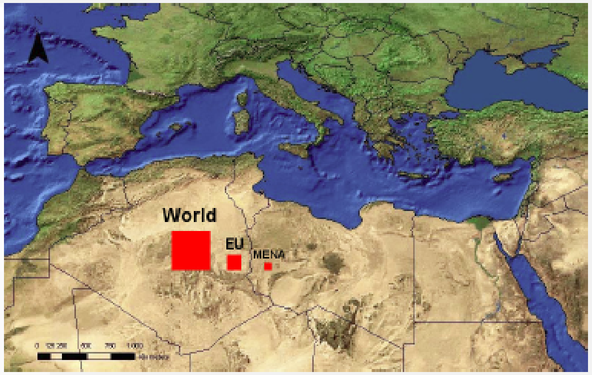


- The term "**well-to-wheel**" refers to the entire process of energy flow, from the mining of the energy source to a vehicle being driven.
- The efficiency of the vehicle from the fuel tank to the wheel, the efficiency of the EV drivetrain is around 85%, which is much higher than the 25% efficiency of the ICE vehicles.

- The EV has a well-to-wheel efficiency of 35% which is around 50% higher than the ICE vehicle well-to-wheel efficiency of close to 22%.

Already today EV's are 2 to 3 three times less energy consuming from Well to Wheel



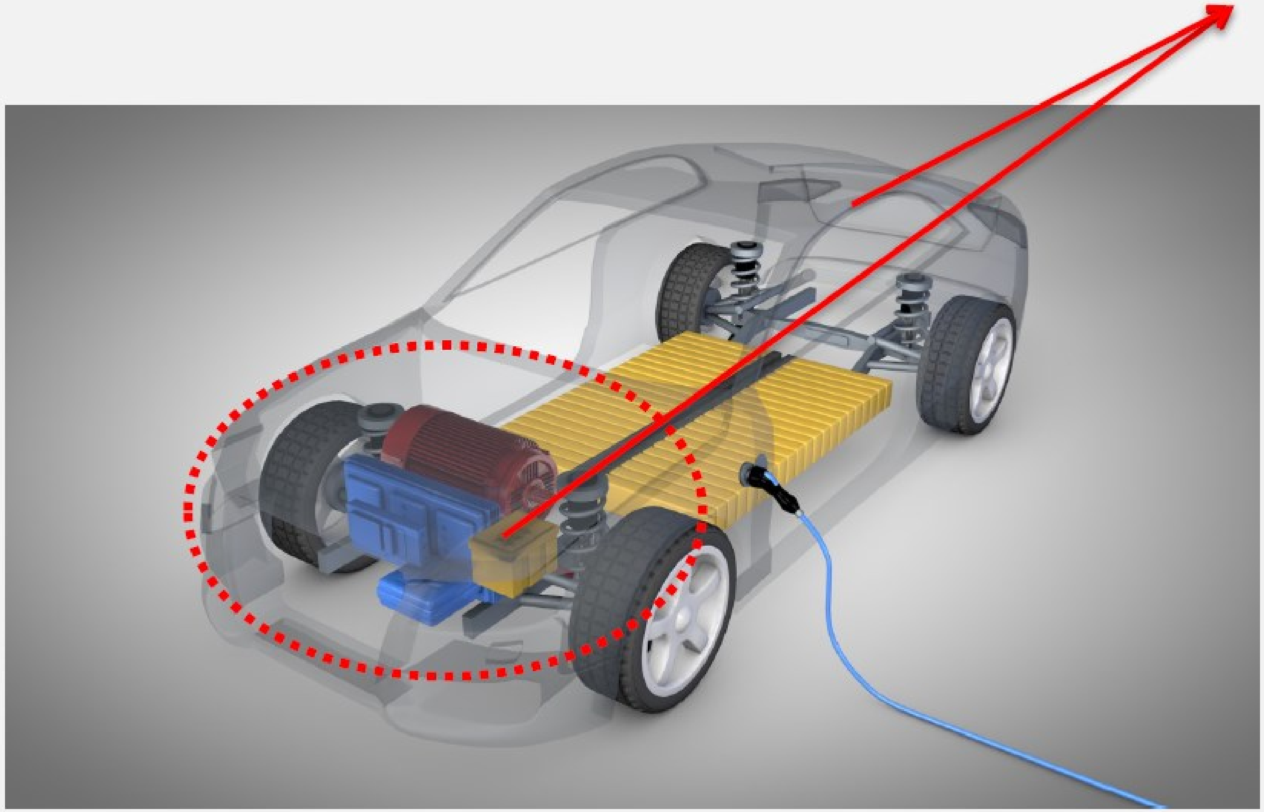


Source: Protoscar, cleantechnica.com

Benefits of EV : Convenience

Large storage place

Quieter



No gear change

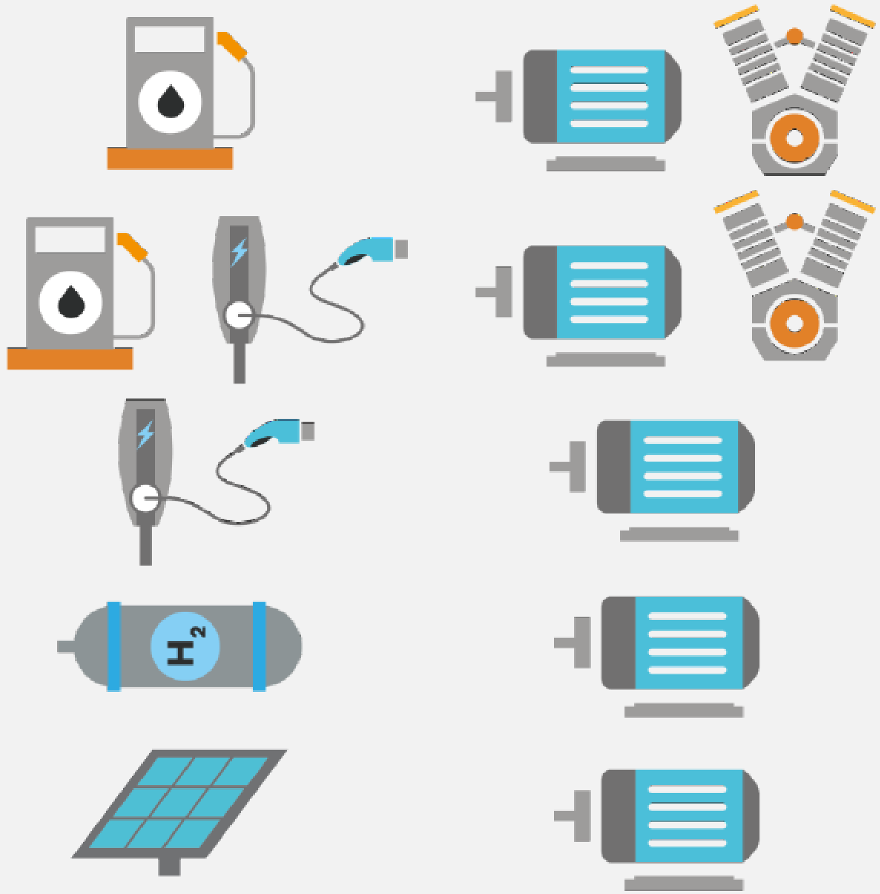
Self driving!

Charge @ Home

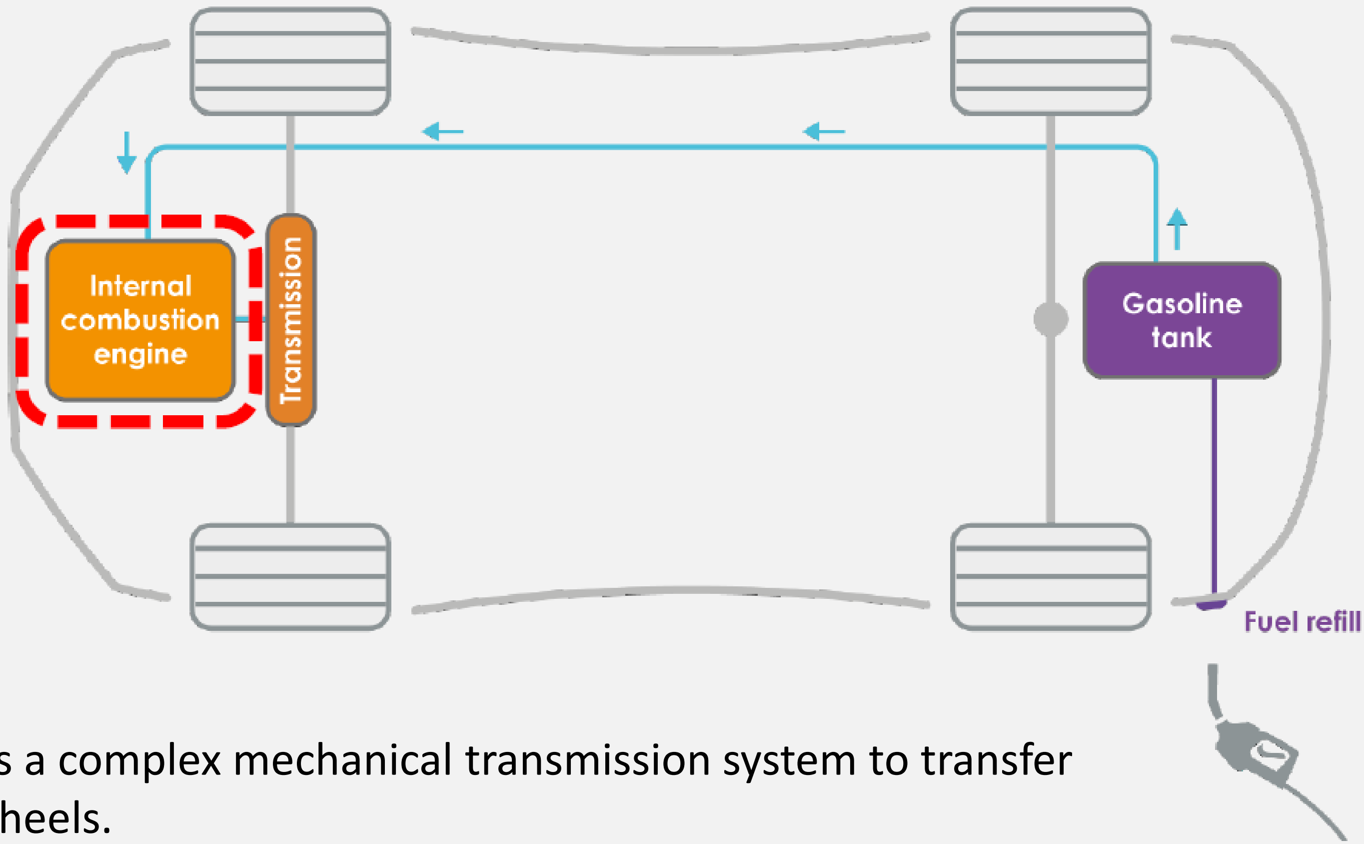
Types of EV

Energy Source | Propulsion

1. **Hybrid electric vehicle, HEV**
   (Series, parallel, series-parallel)
2. **Plug-in hybrid electric vehicle, PHEV**
3. **Battery electric vehicle, BEV**
4. **Fuel cell electric vehicle, FCEV**
5. **In future, Solar electric vehicle**

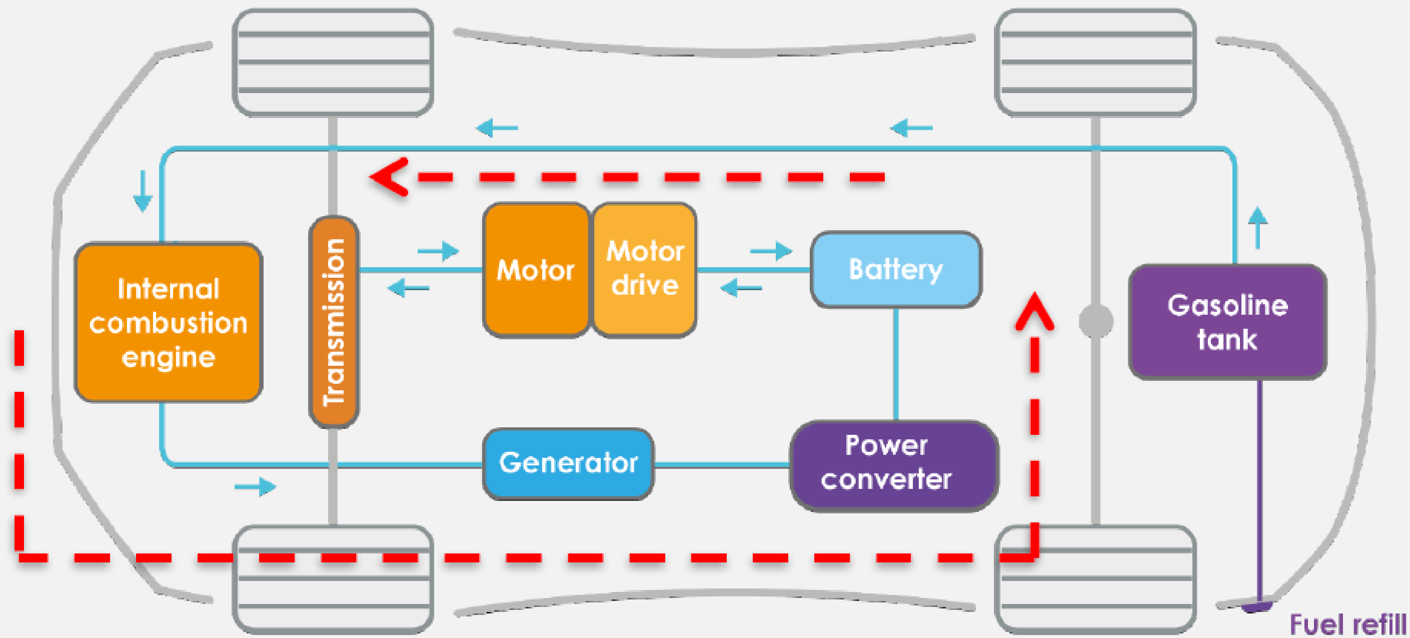


Gasoline/Diesel vehicle



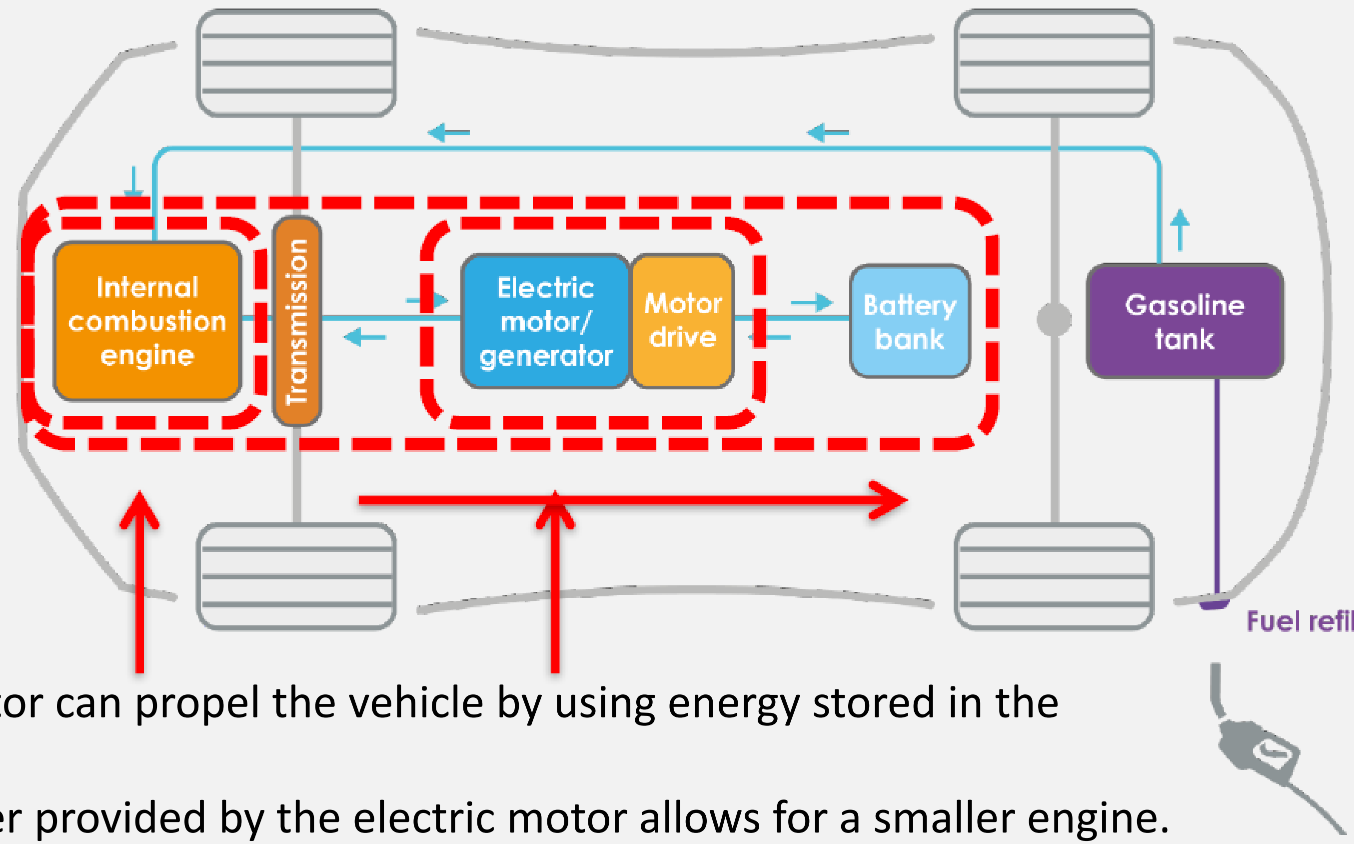
- The engine uses a complex mechanical transmission system to transfer power to the wheels.

Hybrid electric vehicles (HEV): Series



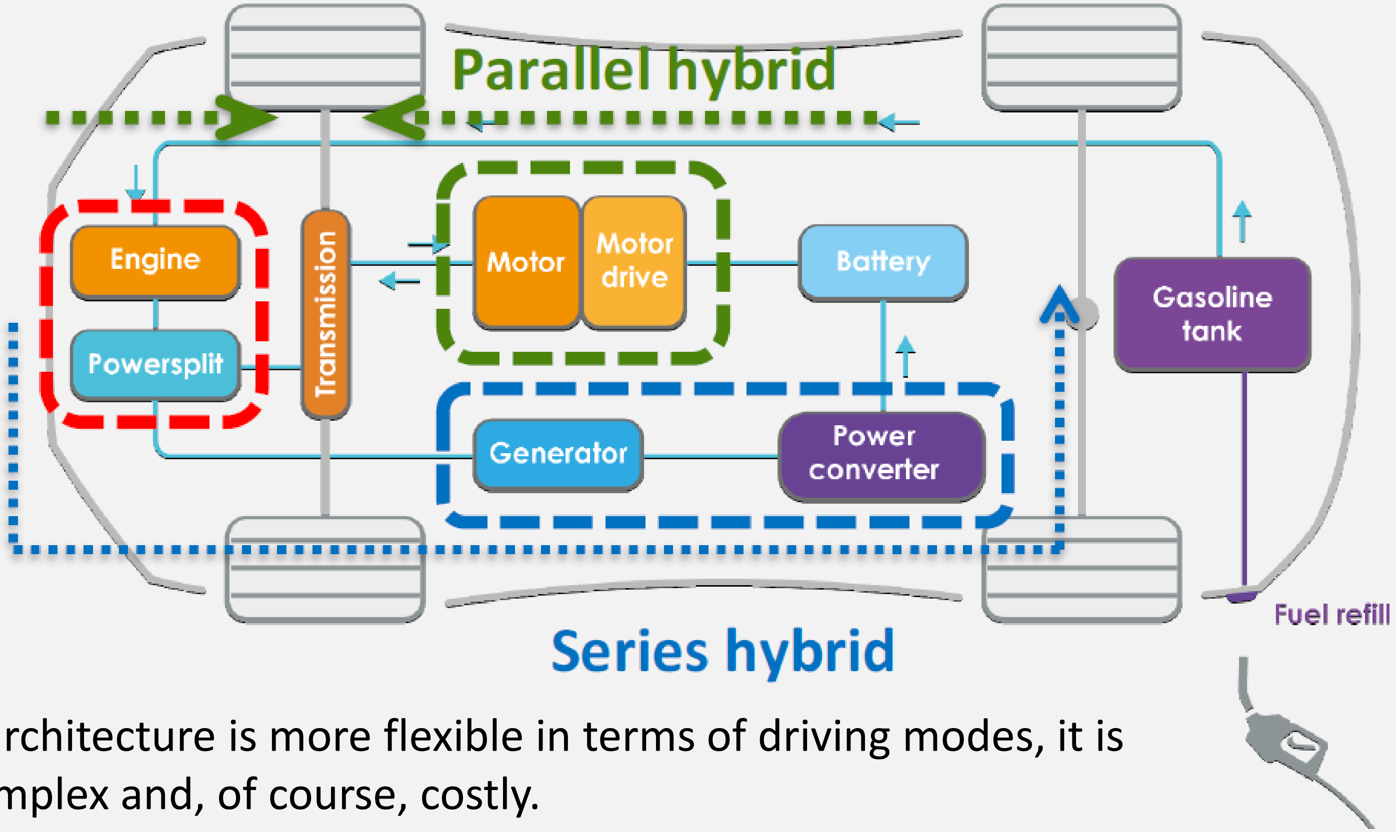
- The internal combustion engine is used to drive a generator and provide electrical power for the traction motors and to charge the battery.
- The advantage is that the internal combustion engine can be operated at its most efficient point to generate the necessary current

Hybrid electric vehicles (HEV): Parallel



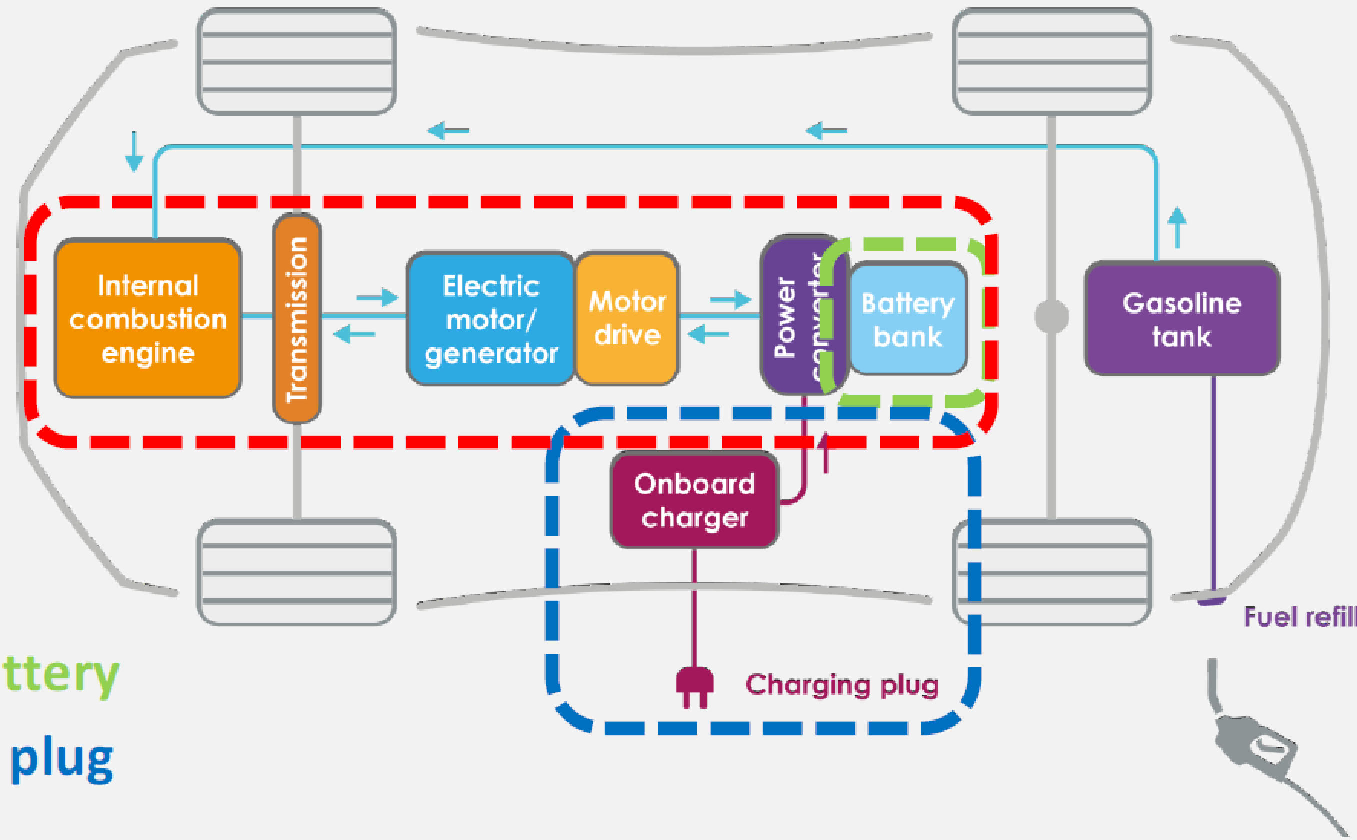
- An electric motor can propel the vehicle by using energy stored in the batteries.
- The extra power provided by the electric motor allows for a smaller engine.
- Further, the motor allows the engine to be operated in its optimal efficiency point, resulting in better fuel economy.

Hybrid electric vehicles: Series-Parallel



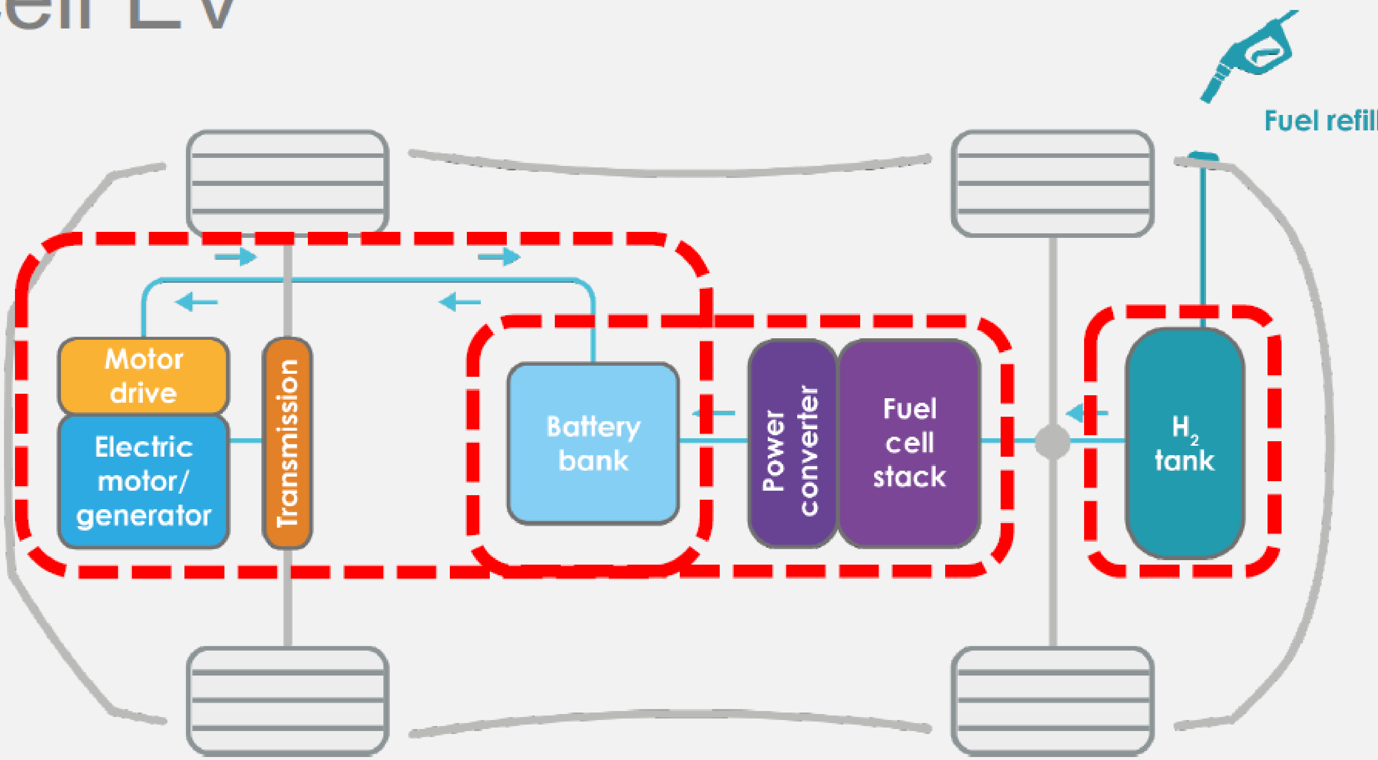
- This type of architecture is more flexible in terms of driving modes, it is also more complex and, of course, costly.

Plug-in hybrid electric vehicles (PHEV)



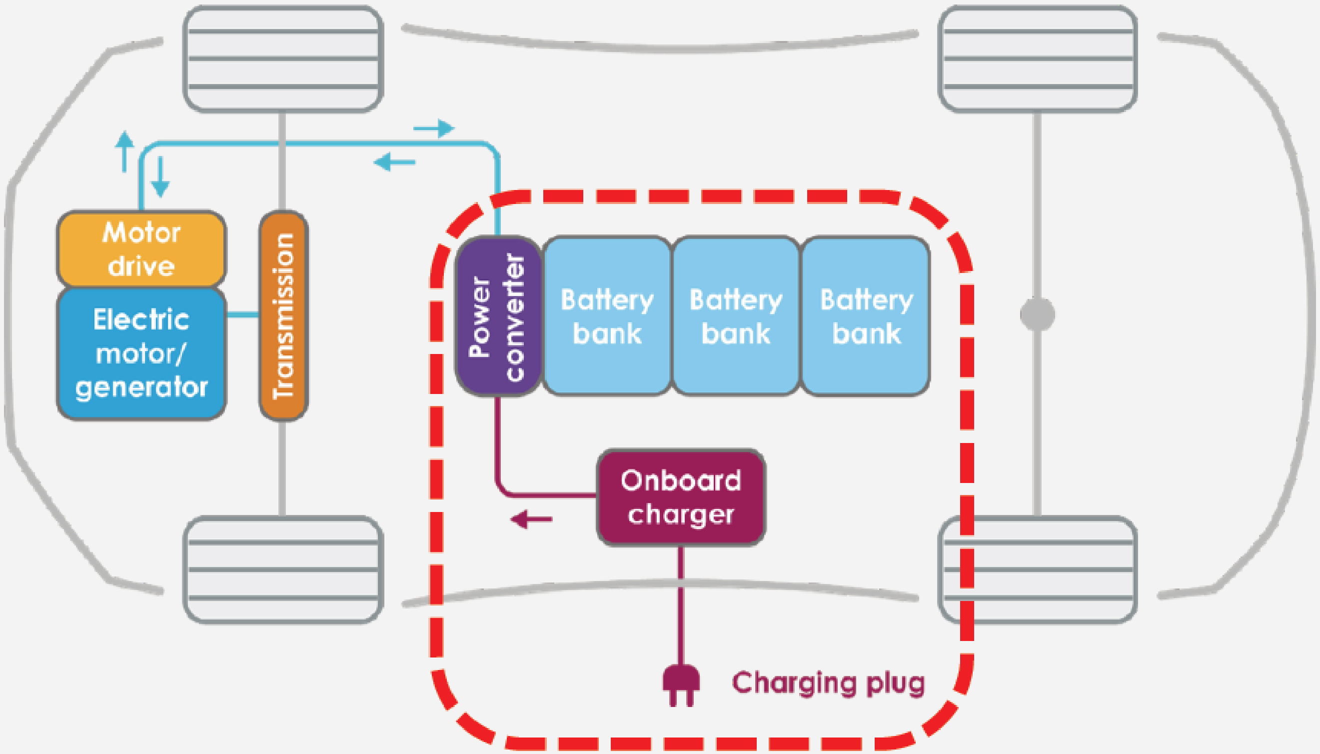
1. Larger Battery
2. Charging plug

Fuel cell EV



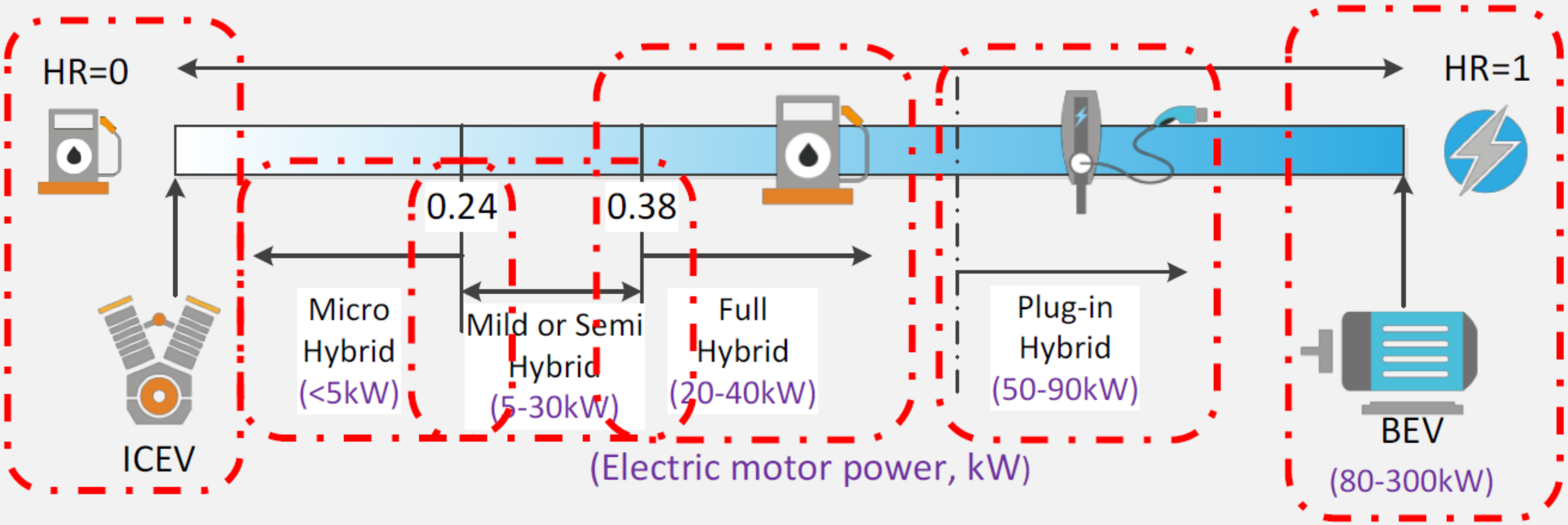
- A fuel cell electric vehicle substitutes the large battery of a battery electric vehicle for a fuel cell stack to generate electricity from the hydrogen fuel.
- Unlike a battery, a fuel cell is not a storage device, but a component that produces direct current from a chemical reaction.

Battery electric vehicles (BEV)



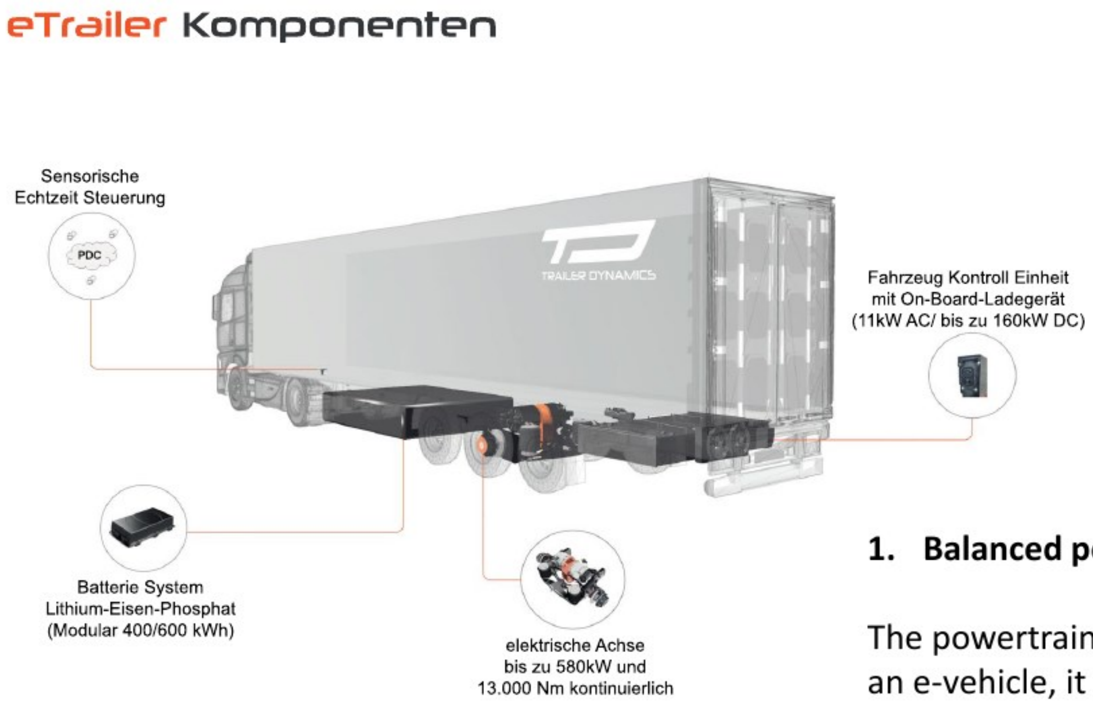
Hybridization rate (HR)

$$HR = \frac{P_{em}}{P_{em} + P_{ice}} \times 100$$



- Level is determined by the role that the electric motor has in the performance of the car.
- It is defined as the ratio of electric power to total power and is described by this equation where P-em is the power provided by the electric machine and P-ice is the power provided by the internal combustion engine.

E-truck



1. **Balanced powertrain design:**

The powertrain is the heart of any vehicle. For the success of an e-vehicle, it is essential that the powertrain functions reliably under all normal circumstances. It must be robust and resistant to external influences while not being oversized to avoid unnecessary costs and weight.

Elektrický pohon

When did scientists discover that electromagnetism could cause a permanent rotation?

When was the first official electric passenger car released?

What is the efficiency of a powertrain with combustion engine?

What about an electric powertrain?

Which component has the lowest efficiency in an electric powertrain and how much is it?

1831, by Michael Faraday

1888, by the Maschinenfabrik Flocken

25%

65%-70%

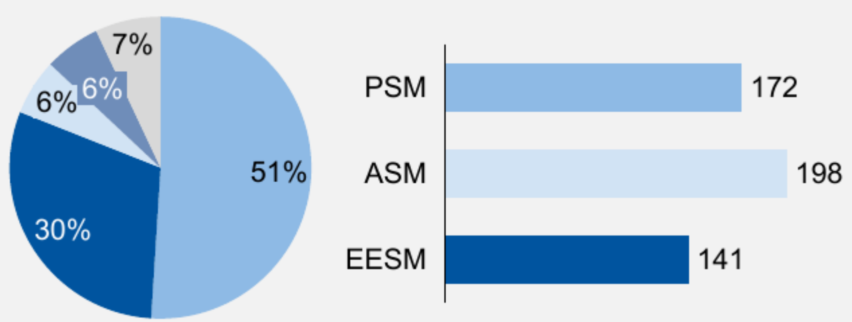
DC/AC-Inverter

90%

Typy motorů

*E-motors in use in 2022 (Germany)**

Distribution of the types of construction | **Average power (in kW)**



PSM | ASM | N/A
EESM | ASM/PSM

PSM: Permanently excited synchronous motor
EESM: Electric excited synchronous motor
IM: Induction motor

*Only purely battery-powered electric vehicles as of Aug. 31, 2022 (n=142).

Change in the types of electric motors at OEMs

Model S (2012): **IM**

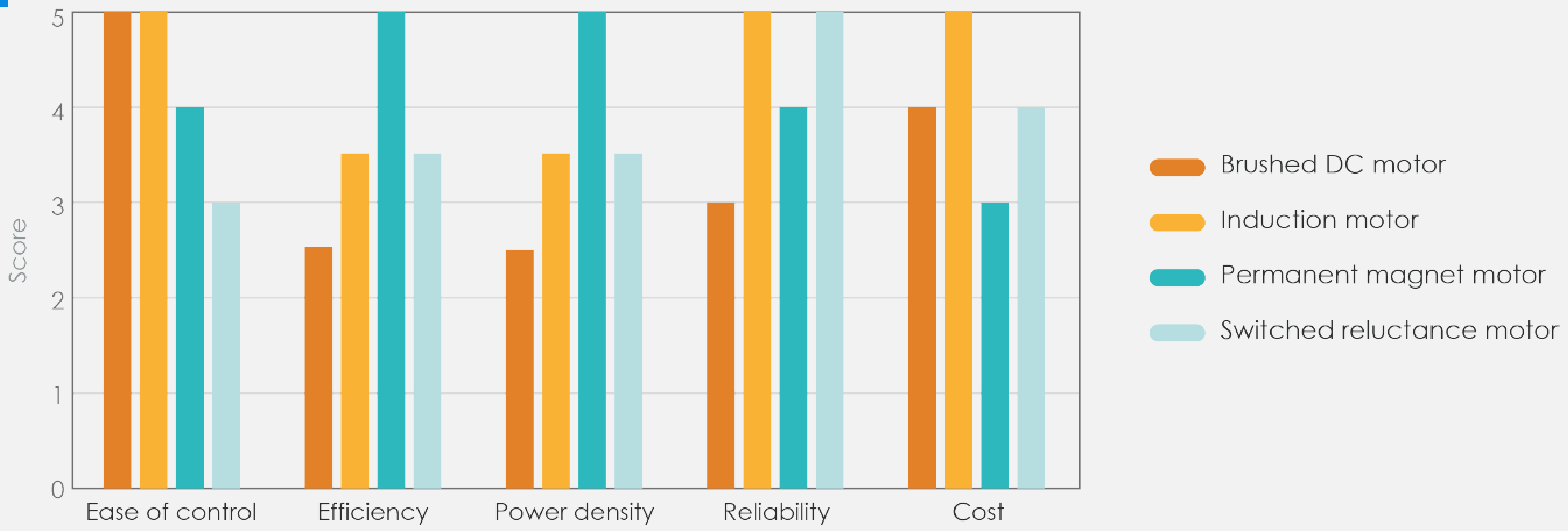
Model 3 (2017): **PSM**

BMW i3 S (2013): **PSM**

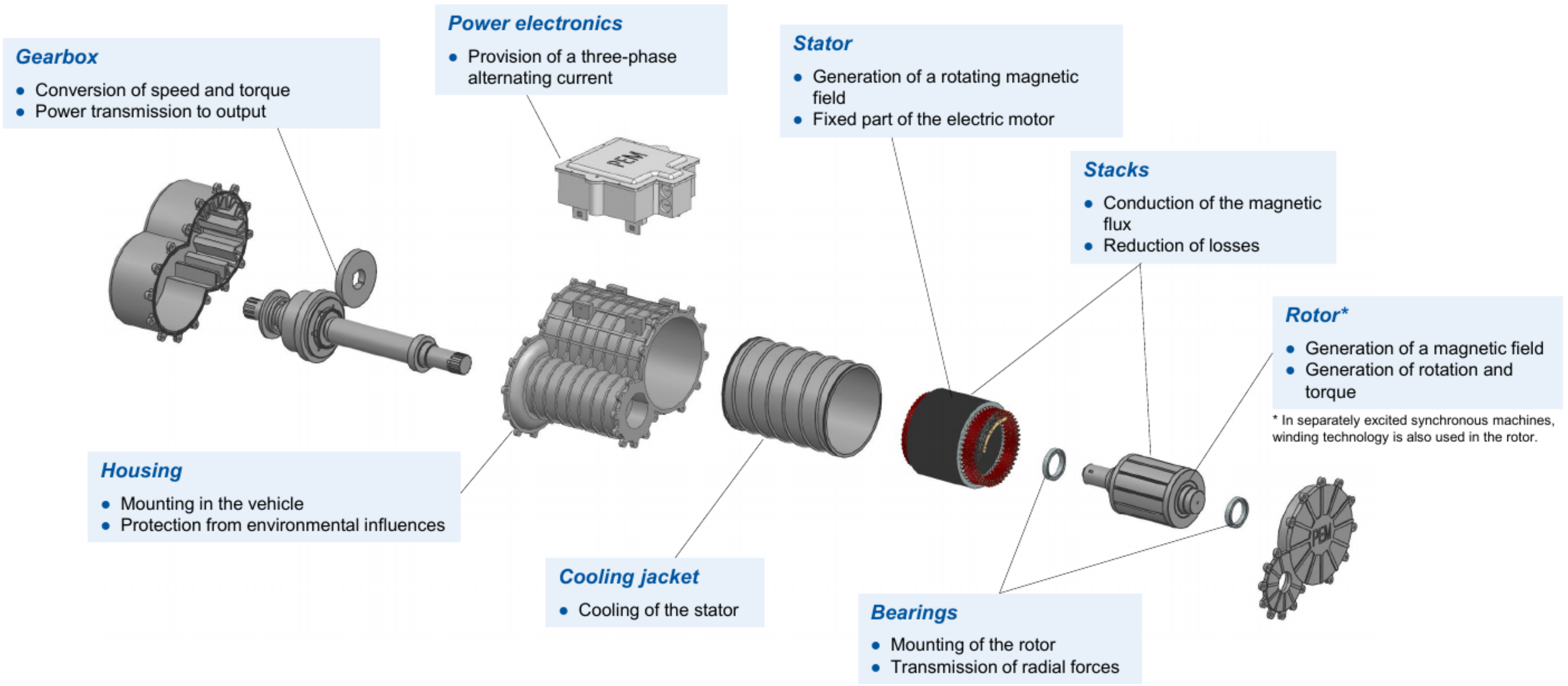
BMW iX3 (2021): **EESM**

Image sources: Tesla, BMW

Commonly used electric motor types



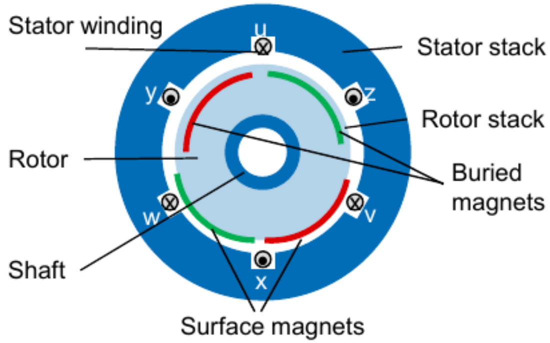
Stavba elektromotoru



PMSM

Functional principle

- Stator windings are fed with three-phase current and cause a rotating magnetic field.
- Rotor follows the magnetic field of the stator due to its permanently excited magnetic field (without slip).
- Speed of the rotor is proportional to the speed of the magnetic field and is therefore called synchronous speed.



Internal permanent magnet rotor

Rotor with surface magnets

Automotive relevance

- Most widespread variant (Toyota, Honda, BMW (i3), VW, Tesla (Model 3), Audi)

Benefits

- Low weight
- Compact design
- High power density
- High efficiency

Disadvantages

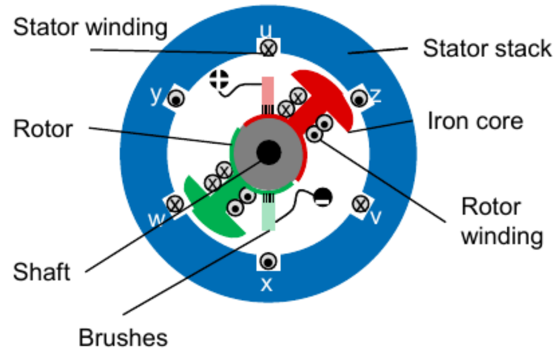
- Required magnet materials are finite → resources higher costs
- Assembly of the magnets is time-consuming

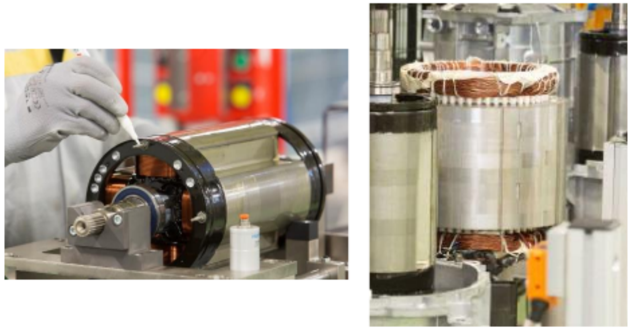
Source: Karle, A.: Elektromobilität, Grundlagen und Praxis, 2015 Bilder: elektronikpraxis, Aliexpress

EESM

Functional principle

- Stator windings are fed with three-phase current and cause a rotating magnetic field.
- Rotor contains a coil. Slip rings provide direct current for the excitation winding of the rotor.
- An electromagnetic field is created in the rotor, which synchronously follows the rotating field formed by the stator.





Renault Zoe: Rotor (right), Stator (left)

Source: Karle, A.: Elektromobilität, Grundlagen und Praxis, 2015   Bilder: InsideEVs

Automotive relevance

- BMW (HEAT), Renault Zoe, Nissan Leaf, Smart, Zhidou EV2

Benefits

- No permanent magnets required
- Simple construction
- Lower costs

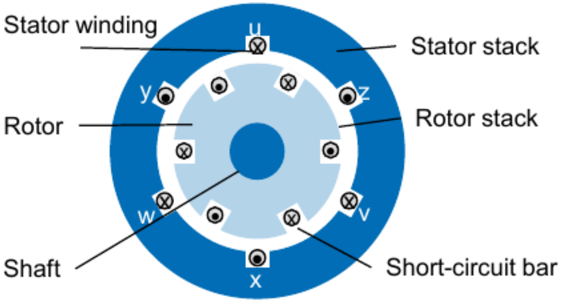
Disadvantages

- Mechanical wear of the abrasive brushes→ maintenance necessary

IM

Functional principle

- Stator windings are fed with three-phase current and cause a rotating magnetic field.
- Rotating magnetic field induces current in short-circuit bars of the rotor. This generates counter field.
- Interaction between stator and rotor field generates torque.
- Rotor is always slower than stator (slip). The greater the torque required, the greater the slip.



Tesla ASM Motor

Automotive relevance

- Preferred in some cases due to cost advantages (Tesla Model S and X, GM, BAIC, Audi)
- Highly integrated eDrive systems from Magna for passenger car applications

Benefits

- Low cost
- Higher torque than DC motors
- No permanent magnets required

Disadvantages

- Lower power density than PSM
- Lower efficiency than PSM
- High demands on the thermal management system

Source: Karle, A.: Elektromobilität, Grundlagen und Praxis, 2015 Bilder: VAC, Toyota

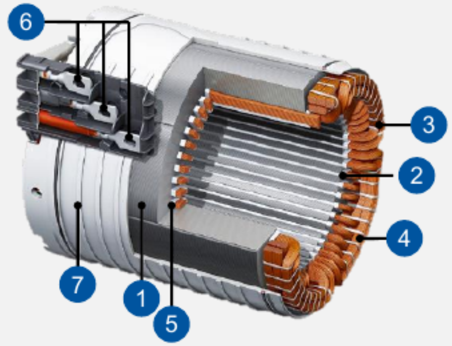
Stavba statoru

Generic product architecture

Practical examples:

Components:

1. Laminated core
2. Slot insulation (coil and phase insulation)
3. Moldings / Bandaging
4. Winding / enamelled copper wire
5. Impregnation
6. Interconnection
7. Stator carrier



Materials used:

- Laminated core (assembled from electrical sheets)
- Copper wire with enamel insulation
- Insulation paper
- Resin for impregnation / potting
- Various metals and plastics for housings, molded parts and connection assemblies

Function and principles of action:

Winding: Generation of a rotating magnetic field

Slot insulation: avoidance of short circuits

Impregnation: heat dissipation, protection against mechanical damage, electrical insulation

→ The coil windings are combined into phases applied on the stator circumference

→ The windings are supplied with a three-phase current; induction creates a magnetic rotating field

Stavba rotoru

Externally excited synchronous motor (ESM)

- Rotor magnetic field flexibly controllable
- Particularly suitable for use in cost-sensitive vehicle classes due to low cost

Permanently excited synchronous motor (PSM)

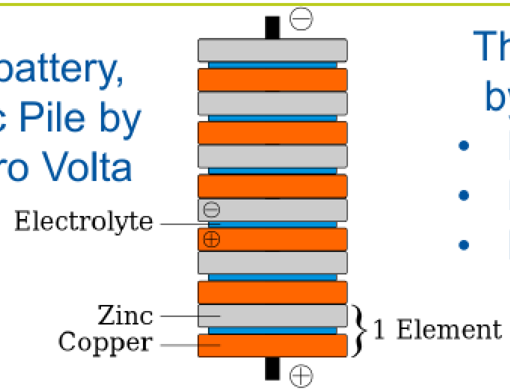
- Advantages in efficiency and power density compared to IM and ESM motivate over the increased cost
- Small installation space enables application in hybrid vehicles

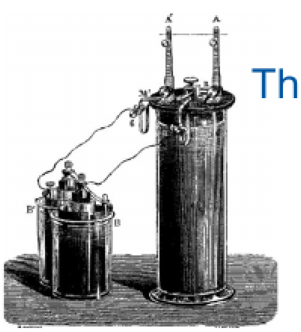
Induction motor (IM)

- Can be switched off completely (unlike PSM) makes "sailing" possible in an energy-efficient manner, as drag losses are eliminated
- Lower unit costs than PSM/ESM

Baterie

1799 – The first battery, the Voltaic Pile by Alessandro Volta



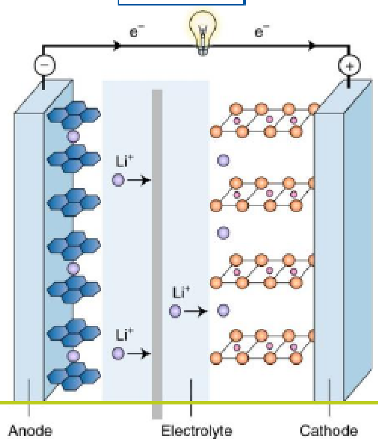


1859 – The first lead acid battery, by Gaston Planté
- rechargeable
- suitable for the mass

1979 – The first lithium battery by John Goodenough
- higher energy density
- higher charging speed
- longer lifetime

1985 – The first rechargeable lithium battery by Moli Energy

1991 – Sony produced the first lithium-ion battery



Baterie fakta

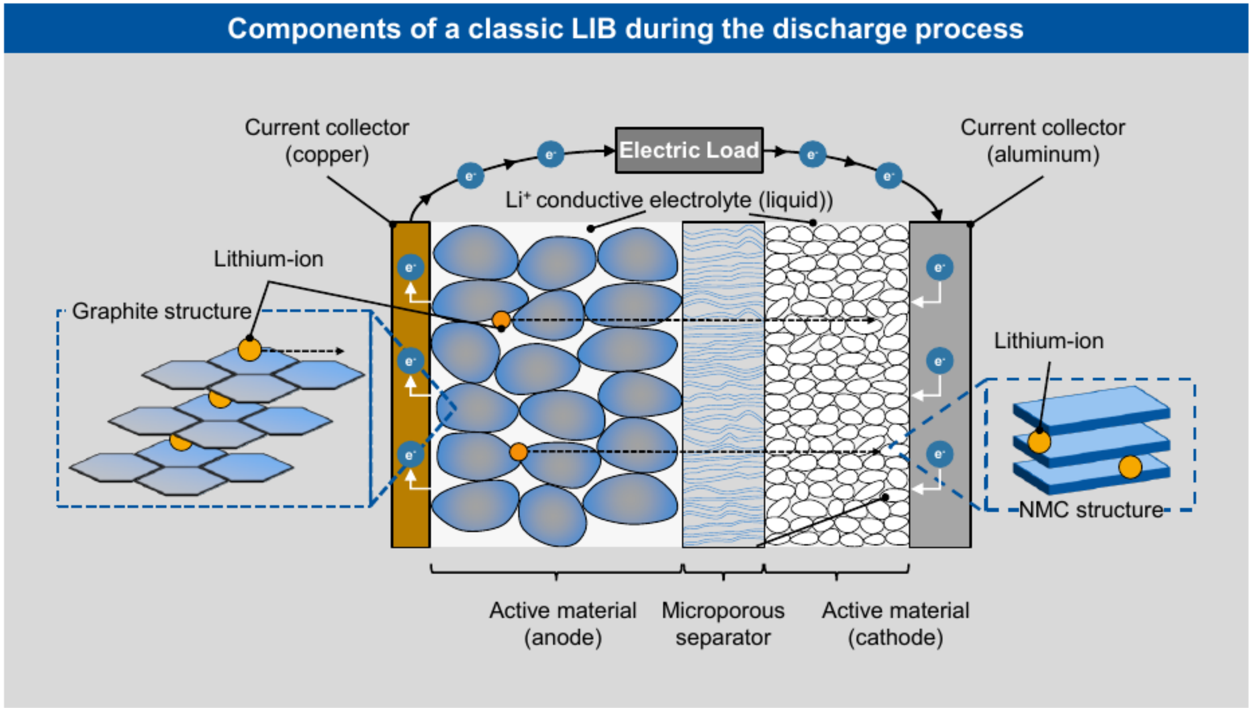
Which component of a battery cell has the highest percentage of the total costs?	How many kg lithium is used in one EV battery in average?	How many years does it take to build up a gigafactory for batteries?
Cathode With 44% of the price	15 kg or 150 g/kWh	Up to 6 years

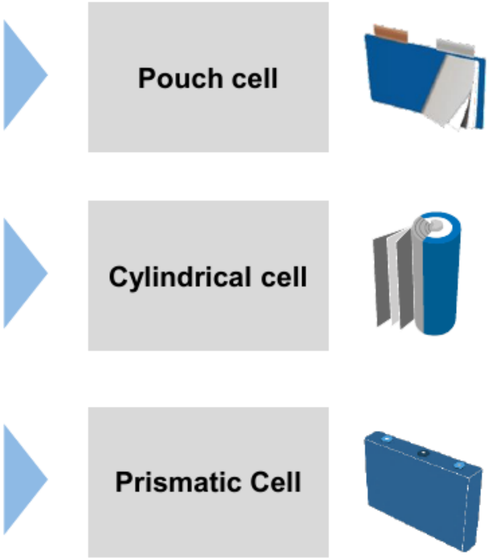
Battery types

- Lead acid
- Nickel based: NiMH, NiCd
- Lithium based :
    - Lithium-ion (Li-ion) and
    - Lithium-polymer (Li-poly)

Weight of 20kWh battery	
Lead acid	550 kg
Nickel Cadmium	500 kg
Nickel Metal Hydride	350 kg
Lithium Ion	180 kg

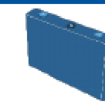
Typy baterií





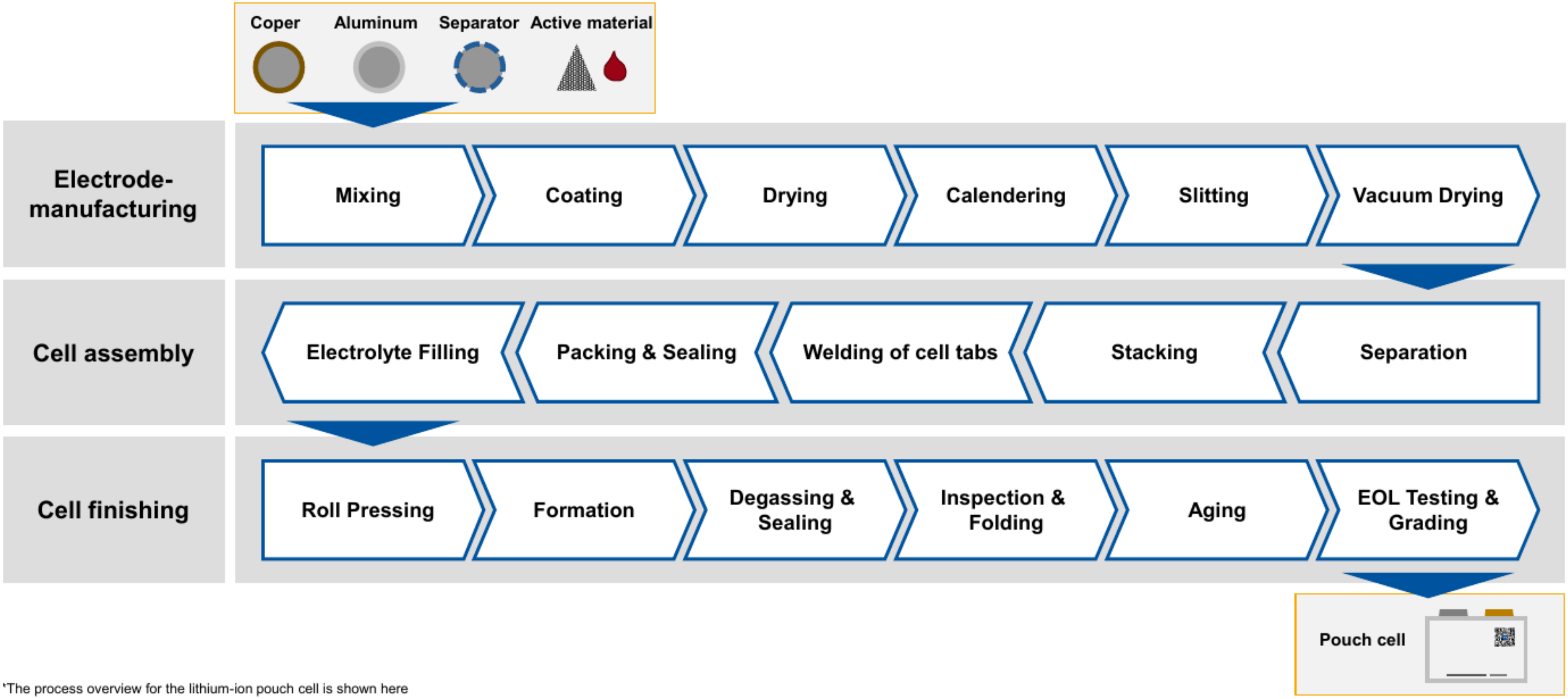
Three main battery cell formats have become established in the production of electrical storage systems for automotive applications.

Typy baterií

	Pouch cell	Round cell	Prismatic cell
			
Vol. energy density	Average energy density at cell level	Currently highest energy density at cell level	Lowest energy density of the three cell formats
Lifetime	Format-independent	Format-independent	Format-independent
Enclosure	Aluminium-plastic composite foil	Mainly nickel-plated steel	Predominantly aluminium
Dimensions	- Changeable design / Variant formats - Efficient use of space due to rectangular shape - Opposite or adjacent cell contacts	- D x L (mm): 18 x 65; 21 x 70; 46 x 80 - Inefficient use of space at module level - Low packing density at module level	- Less diversity than with the pouch cell - Efficient packing of the cell compound - Tendency towards elongated casings
Strength	- Unstable housing - Swelling under pressure - Sealing very complex	- High tightness - High stiffness - Mechanically robust - Robust under internal pressure due to degassing	- High tightness - High stiffness - Lower mechanical stability than round cell
Thermal regulation	- Good surface-to-volume ratio - Efficient temperature control	- Low heat dissipation / Complex cooling channels - Heat conducting surface	- A lot of volume compared to the surface - Heat conducting surface
Special features in the production process	- Stacking challenging	- Extensive experience in the production process - Low manufacturing costs	- Pressure on cells necessary for joining
Example application	Nissan Leaf 	Tesla Model S 	BMW i3 
Typical energy content	65 - 300 Wh (depending on format)	10 - 12 Wh (1865 cells) / 18 - 21 Wh (2170 cells) Upcoming: x Wh (4680 cells)	80 - 450 Wh (depending on format)

Currently, all three cell formats are used in electric vehicles. A trend is not yet foreseeable.

Postup výroby



'The process overview for the lithium-ion pouch cell is shown here

Postup výroby

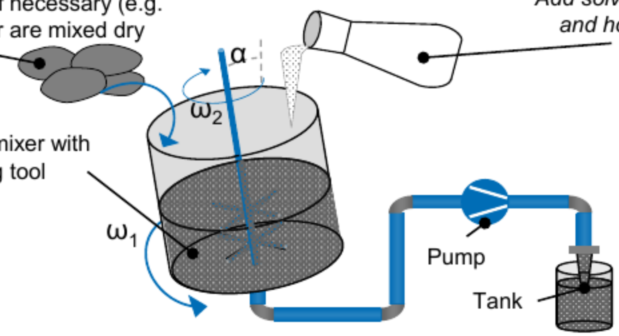
Cell assembly | Cell finishing

Anode formulation*

Active material: graphite (90 wt.%)
Conductive carbon black: Nano microscopic carbon, e.g. Super P® (5 wt.%)
Solvent: Deionized water
Binder: CMC (3 wt.%)
Additive: SBR (2 wt.%)

Step I: Mixing (dry)
Active material, additives if necessary (e.g. carbon black) and binder are mixed dry

Step II: Dispersing (wet)
Add solvent, disperse and homogenize



Cathode formulation*

Active material: $Li(NiMnCo)O_2$ (90 wt.%).
Conductive carbon black: Nano microscopic carbon, e.g. Super P® (5 wt.%)
Solvent: N-methyl-2-Pyrrolidone (NMP)
Binder: PVDF (5 wt.%)

Process description

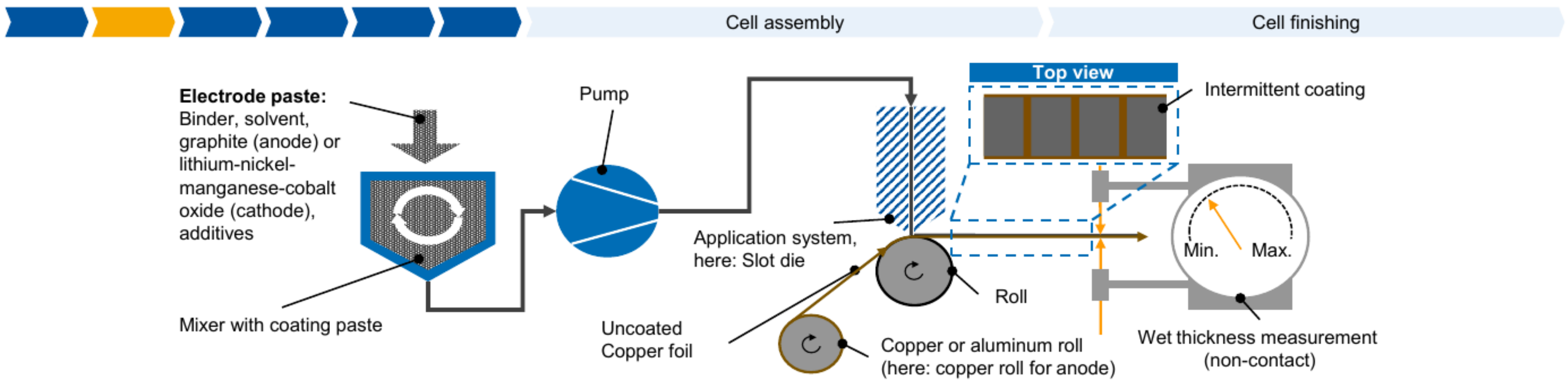
- By **applying energy**, the starting materials are combined via a rotating tool (electrode slurry).
- **Process control**: Either one or more container are used for mixing and dispersing
  - Mixing (dry mixing): The aim is to achieve a good coating of the active materials with conductive carbon black, binder and additives.
  - Dispersing (wet mixing): solids are homogeneously distributed in the solvent and agglomerates are broken up

Additional information & technological alternatives

- Rotary mixer
- Planetary mixer
- Centrifugal mixer
- Extruder mixers (development status)

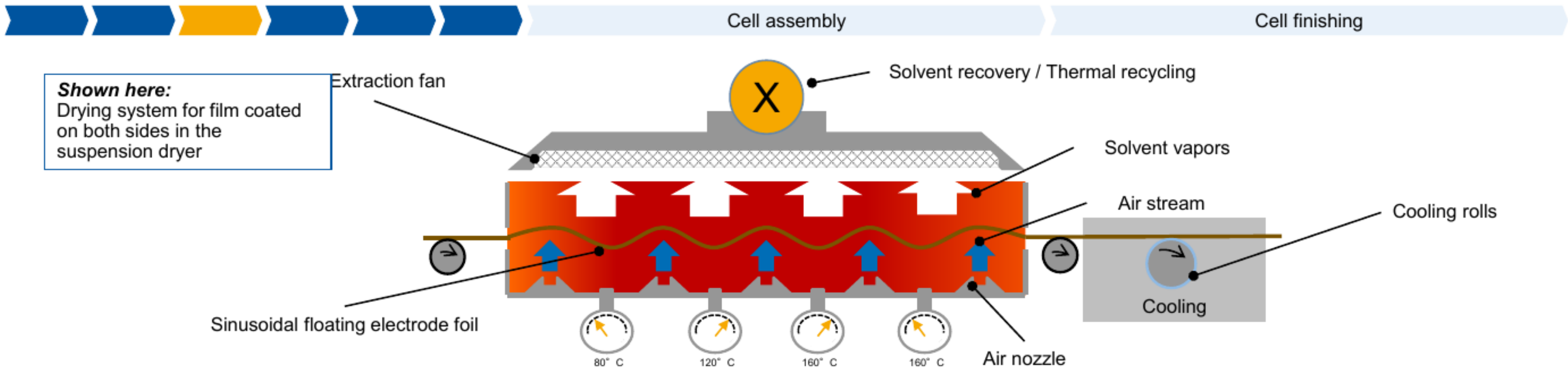
*Example formulation

Postup výroby



Process description	Additional information & technological alternatives
• **Unwinding** of the carrier foil and coating with the electrode paste. • Optional cleaning and **activation** of the film (e.g. corona treatment) • Application control via pump system (e.g. for intermittent coating): Example screw pump • Usually, the electrodes are coated on both sides (**tandem coating**) • **Wet thickness measurement** to check the coating thickness	Possible application tools: • **Doctor blade:** The coating paste is spread onto the substrate with a doctor blade. • **Slot die:** Protection against impurities from the environment • **Cascade nozzle**: Multi-stage (cascaded) application system in the manner of the slot die, more homogeneous distribution • **Anilox roller application system:** The coating roller transfers the paste from a dip tank to the film

Postup výroby



Process description

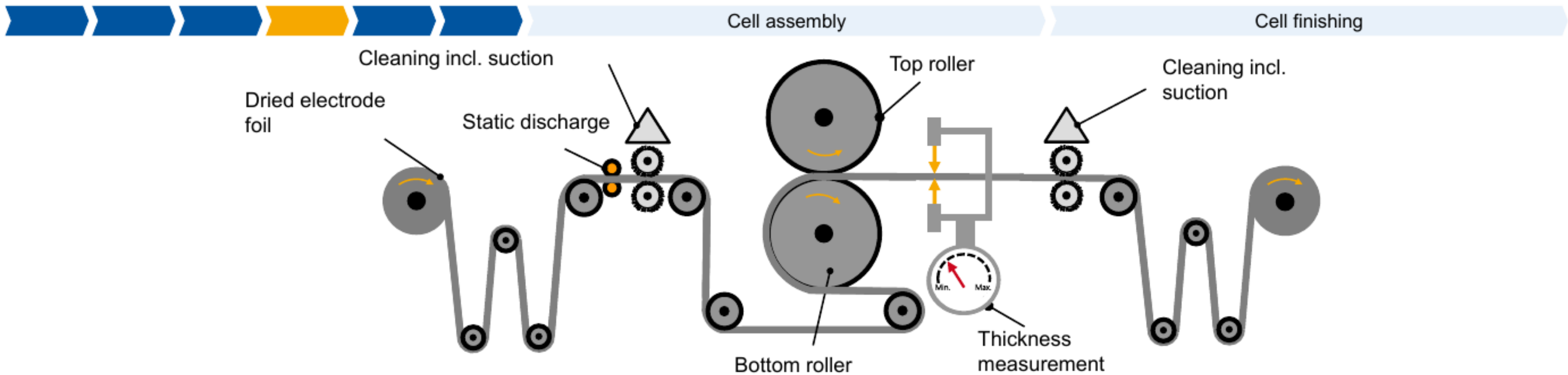
After coating, the applied active material is dried in a continuous process:

- The solvent is removed from the material by adding heat
- The highly flammable solvent (hazardous material) contained in the cathode coating is recovered (solvent recovery) or sent for thermal recycling (post-combustion)
- The combustion heat is used to preheat the fresh air stream
- After the dryer, the film is cooled down to room temperature

Technological alternatives

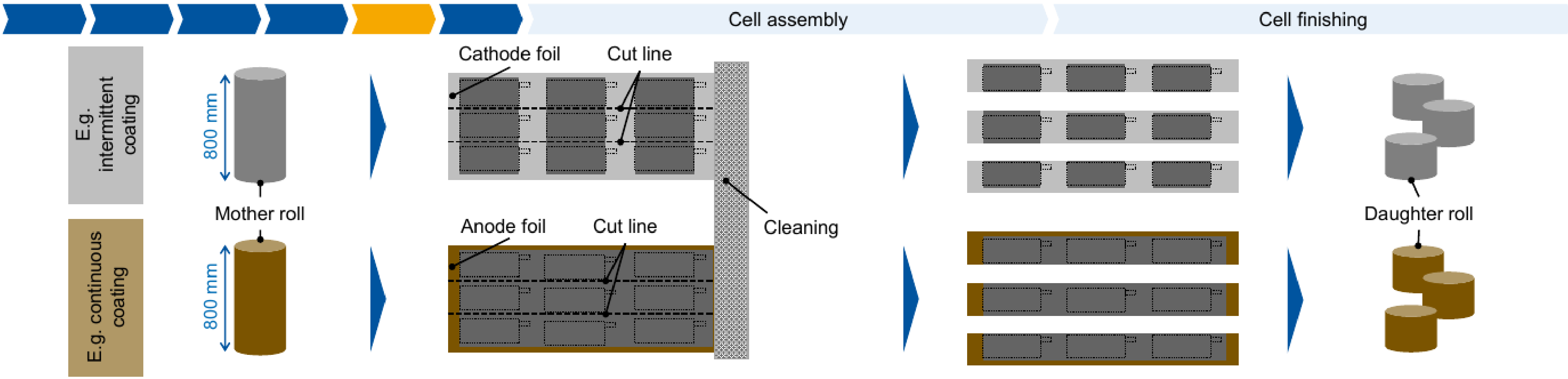
- Convection dryer (Conventional dryer)
- Infrared drying (efficient supplement to convection dryers)
- Suction jet dryer
- Roller conveyor dryer
- Laser drying (development phase)
- Microwave drying (development phase)

Postup výroby



Process description	Additional information & technological alternatives
• Dried porous electrode foil is statically discharged and cleaned by a brush or an air stream • The copper or aluminum foil coated on both sides is then compacted by a rotating pair of rollers and cleaned again • Thickness reduction for improved contacting of particles and higher volumetric **energy densities** (if necessary, over several rolls: advantage of better control during compaction, but increased risk of damage) Target porosity (after calendering): **20 – 40%.**	• **Hot rolling:** Depending on the plant concept, the top and bottom rolls can be heated. In this way, the ductility of the active material can be brought to a defined value. As a rule, water or oil is used as the heating medium. • **Integrated film smoothing** (e.g. inductive): In some cases, the electrodes are post treated to compensate for stress wrinkles occurring at the coating edges after calendering.

Postup výroby

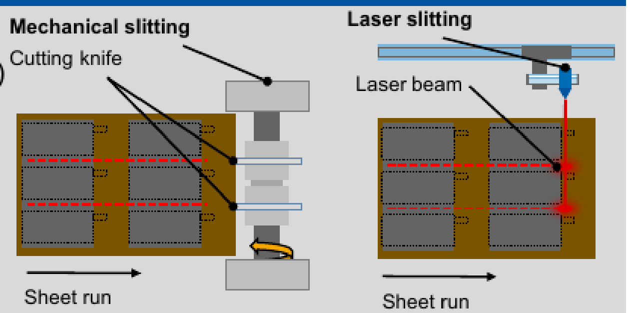


Process description

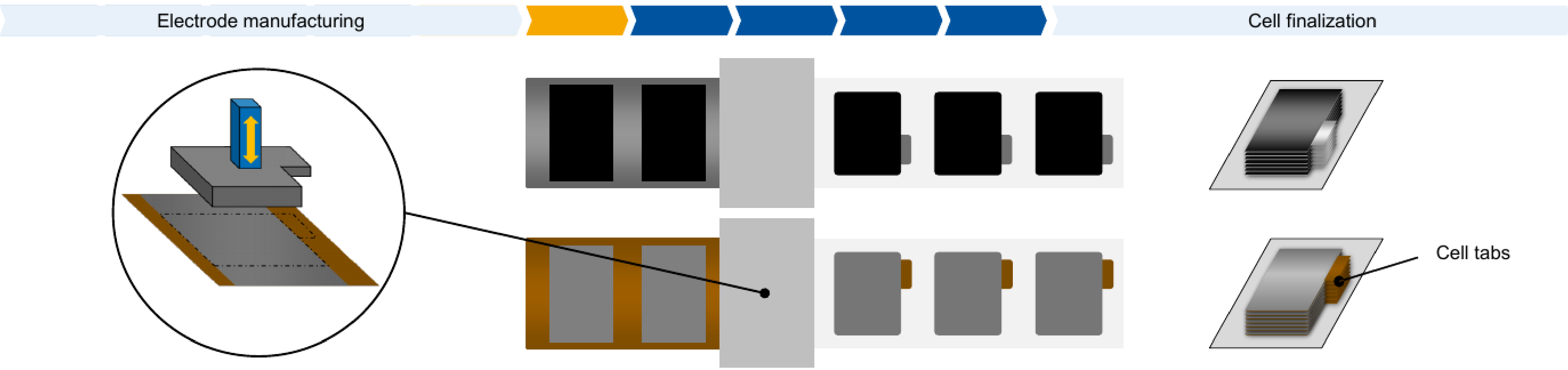
- The calendered cathode and anode coils are fed into the slitting machine for separation
- Slitting is a separation process in which a wide electrode strip (mother coil) is divided into several, smaller electrode strips (daughter coils)
- **Cleaning**: cutting particles are extracted
- The separated coils are rolled up and transported to the subsequent process step in vacuum boxes

Additional information & technological alternatives

- Mechanical slitting (High strength cutting blades)
- Laser slitting



Postup výroby



Process description

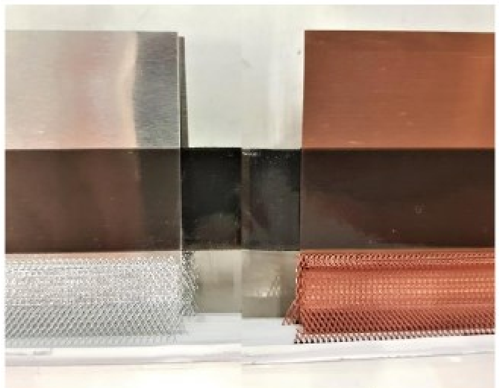
1. The dried daughter rolls are unwound and fed to the separation station.
2. This is followed by continuous separation of anode, cathode and separator sheets from the roll stock.
3. Depending on the system concept, the individual sheets are stored in a magazine or transferred directly to the next process step.

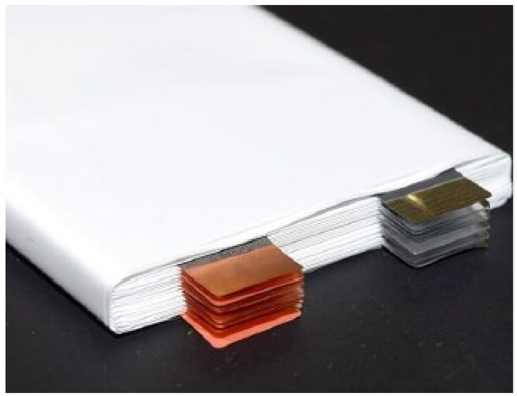
Additional information and technological alternatives

- The uncoated edge areas of the electrode foil are used in a later process step for welding on the so-called cell tab.
- As a rule, the separation process is carried out by a shear cut (punching tool).
- Alternatively, the sheets can also be separated by laser cutting. This has the advantage of higher flexibility and lower tool wear. However, the process speeds are lower.

Postup výroby

Electrode manufacturing → → → → → → Cell finalization





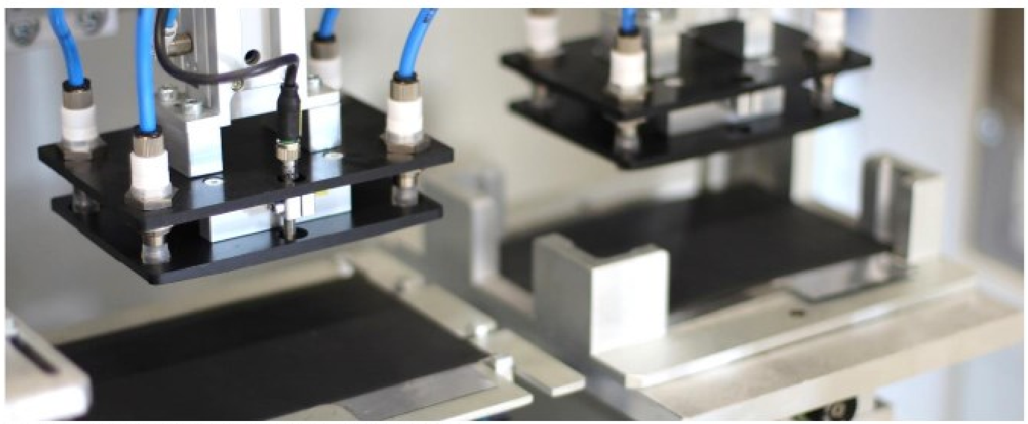


Image source: RIT Rochester, PEM der RWTH Aachen

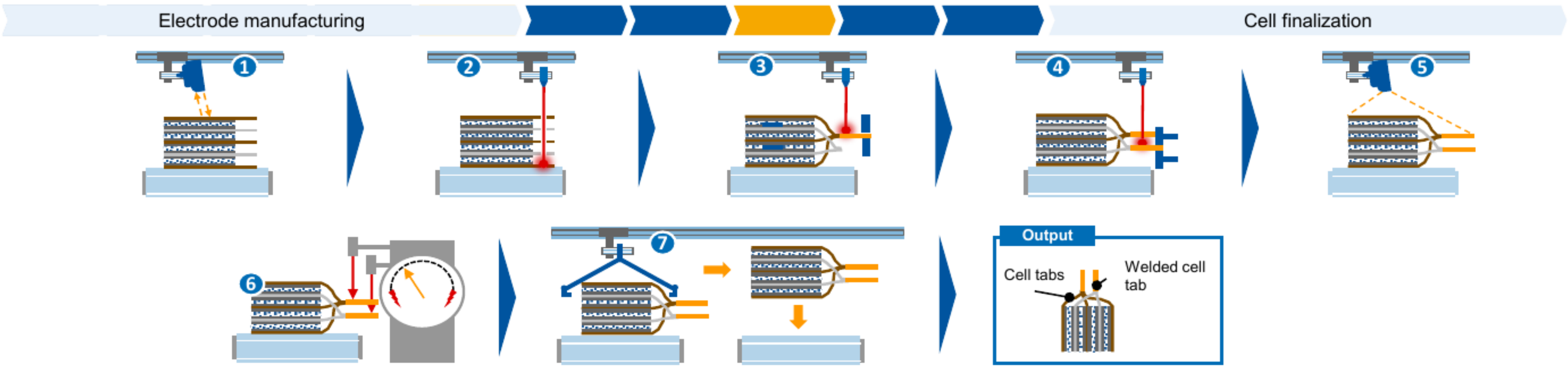
Process parameters

- Cycle times: approx. 1s/sheet, up to 1 minute per cell
- Stacking accuracy: approx. ± 200 µm – 300 µm

Requirements and quality characteristics

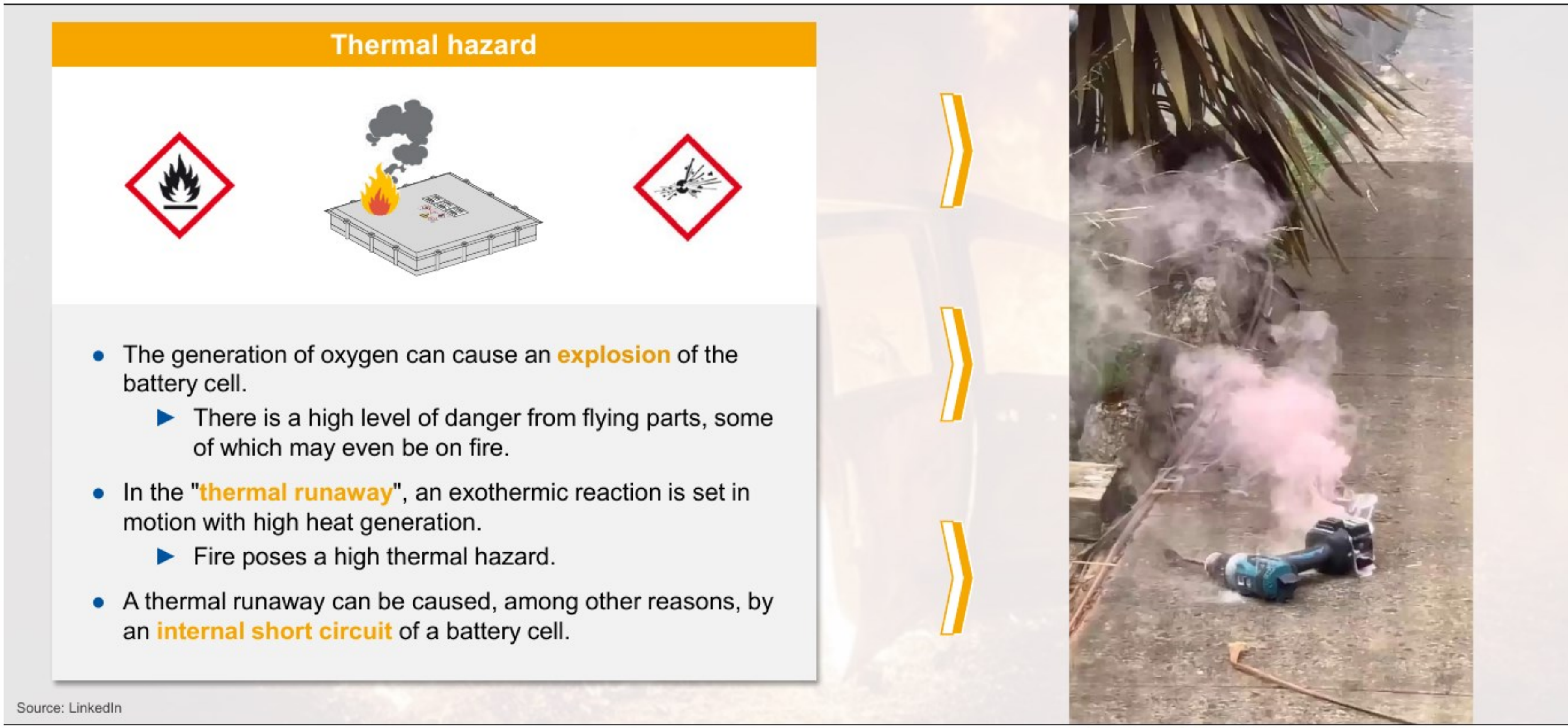
- High positioning accuracy of the individual anode and cathode sheets relative to each other to avoid internal short circuits and performance losses
- Damage-free handling of the electrode sheets (Pick&Place)
- Optical position control
- Accurate calibration of the separator bias voltage

Postup výroby

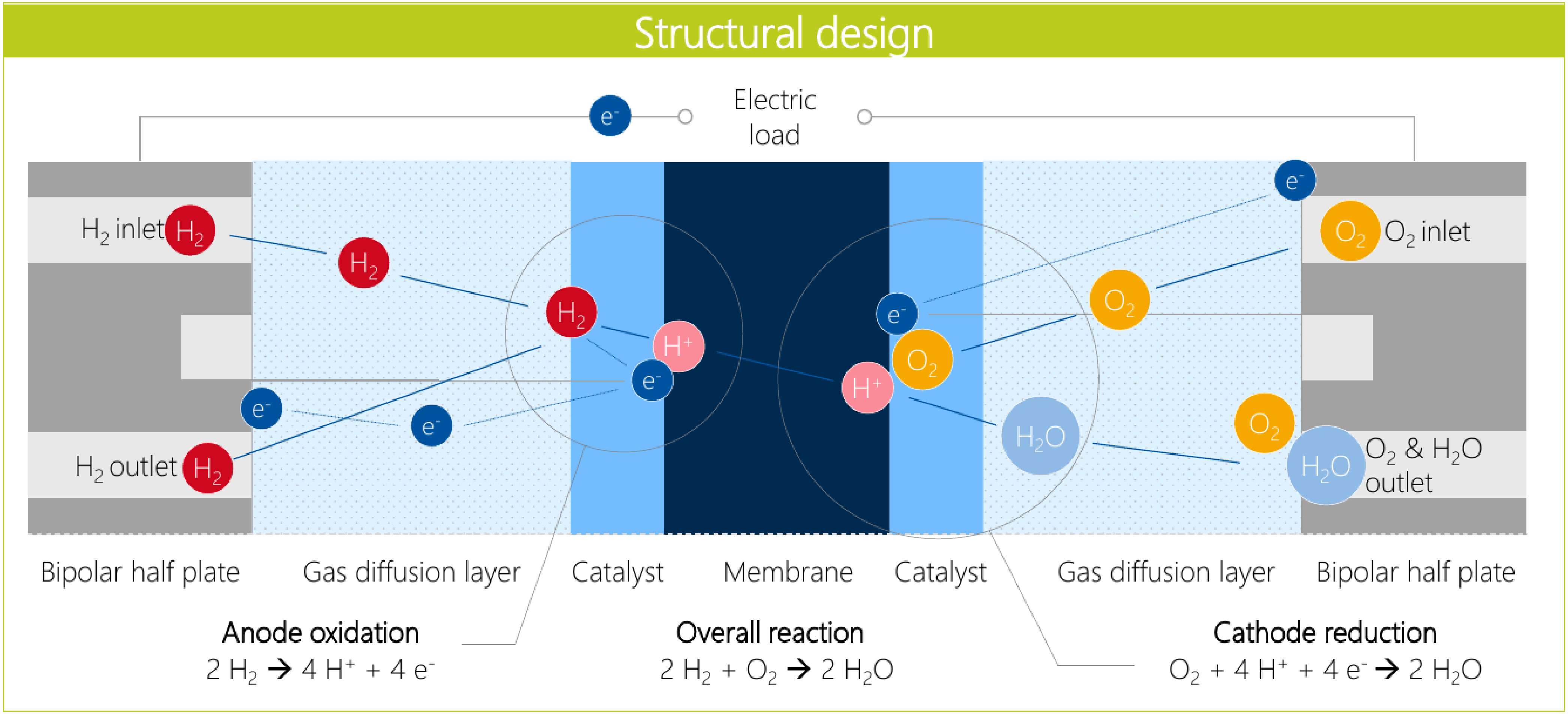


Process description	Additional information and technological alternatives
1. In this process step, the current lugs of the electrode stack are welded to the contact lugs (cell tabs). 2. For this purpose, the cell tabs are placed on the current lugs and fixed in place by a vacuum suction cup. 3. Optionally, the current lugs are shortened by a knife cut before the welding process. 4. After the welding process, the cell is measured to exclude internal short circuits.	• Usually, an ultrasonic welding process is used. • Laser welding can also be used as an alternative. • The cell tabs on the anode side are typically made of copper or nickel, on the cathode side of aluminum • In high-volume production, welding of the contact tabs is often performed on a rotary table. • In some cases, the welding point is covered with a protective tape after the welding process

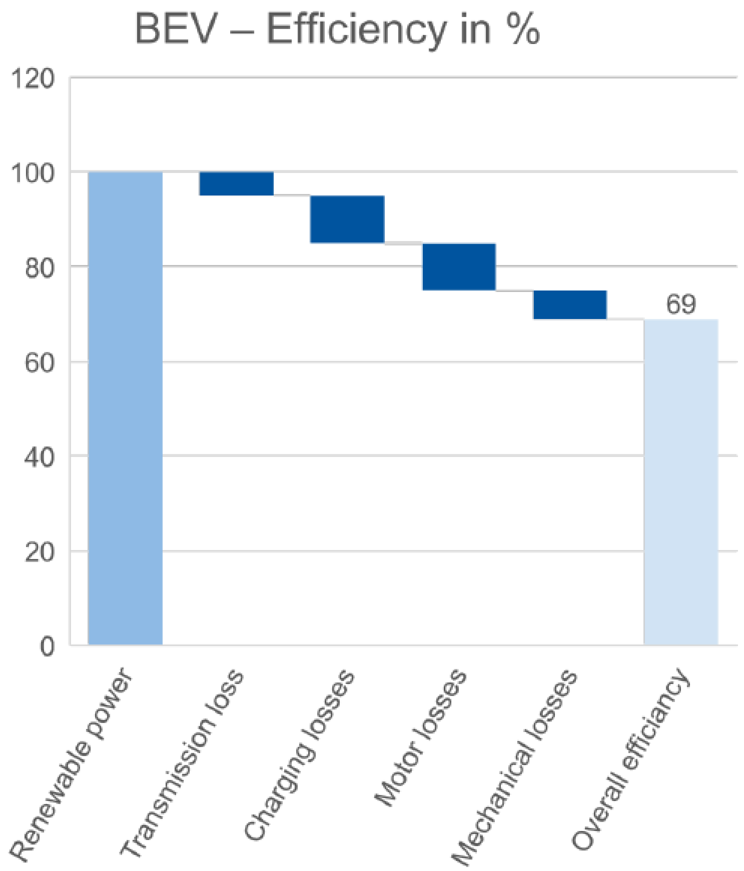
Baterie - nebezpečí

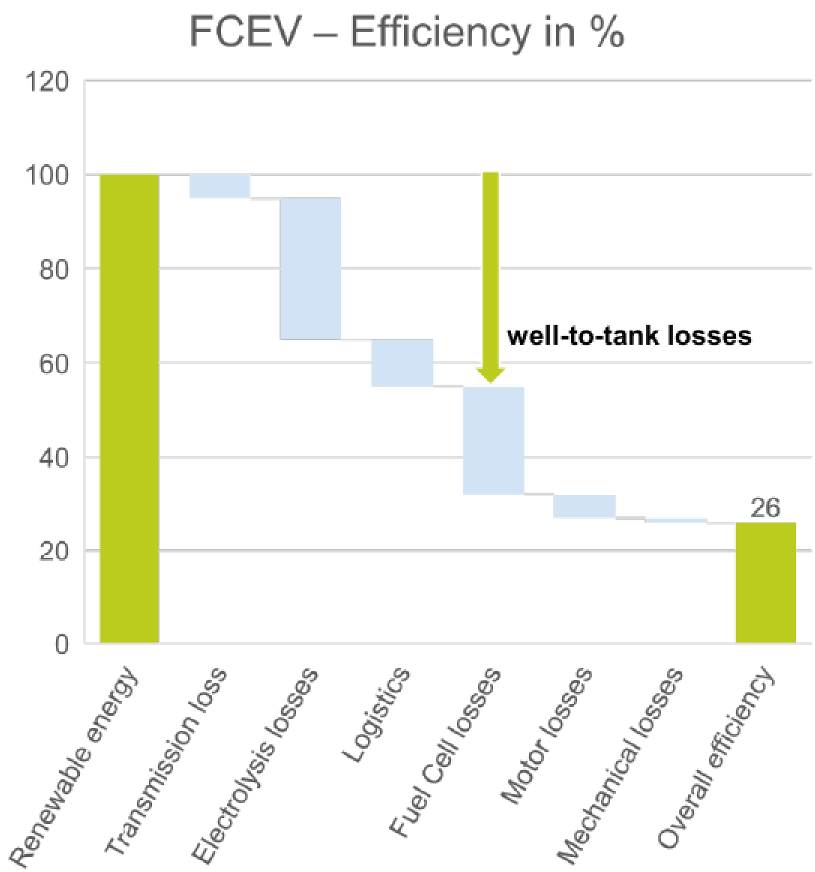


Palivový článek

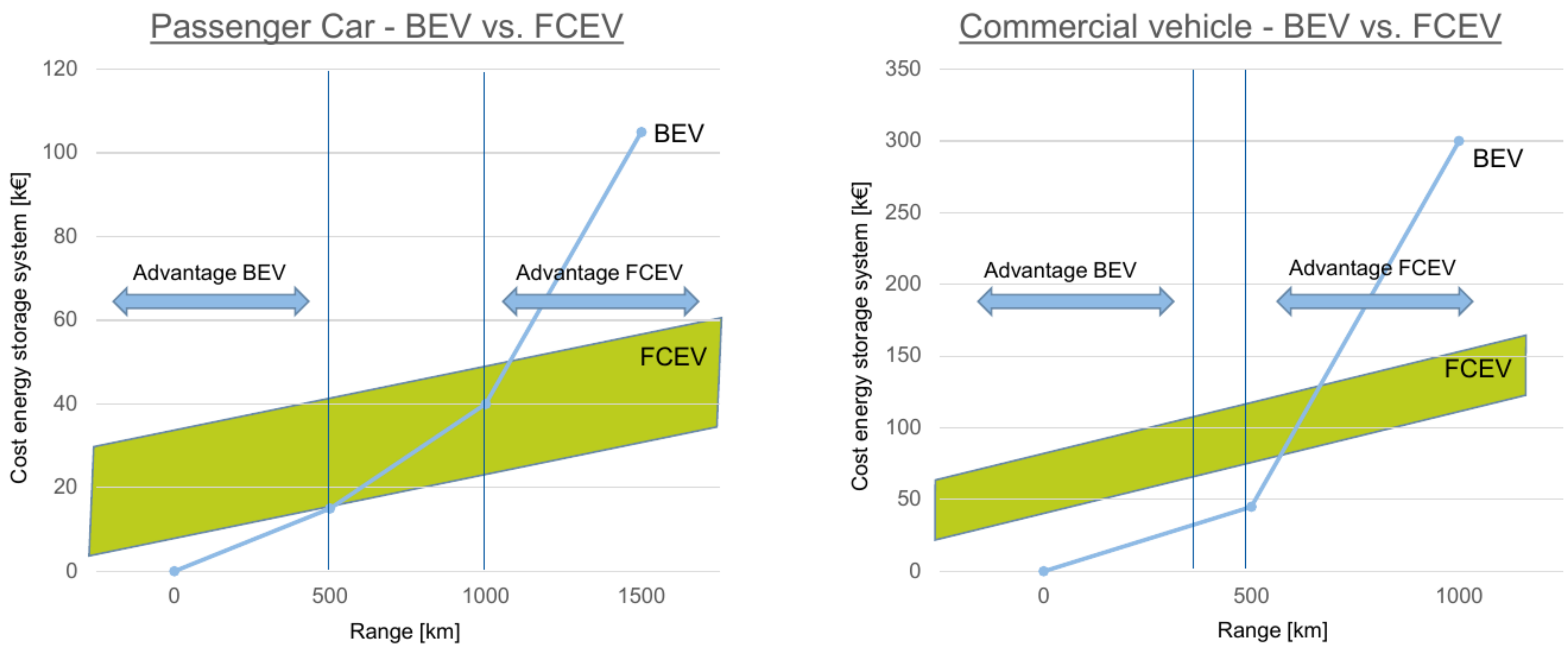


FCEV – BEV Well to wheel

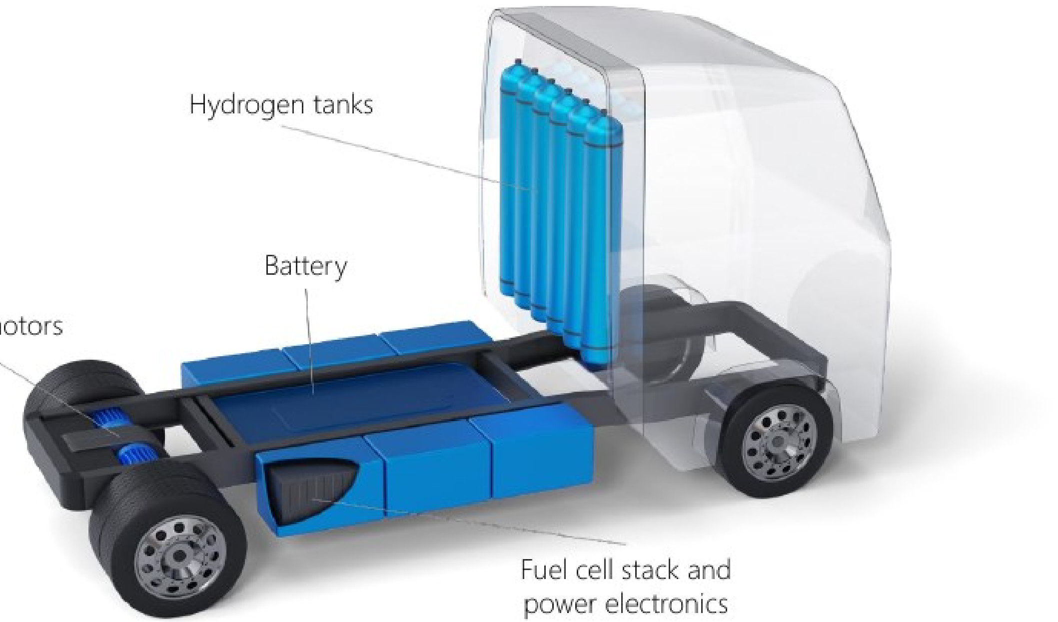




Výhody FCEV


Passenger Car - BEV vs. FCEV
Cost energy storage system [k€]
120
100
80
60
40
20
0
BEV
Advantage BEV
Advantage FCEV
FCEV
0
500
1000
1500
Range [km]
Commercial vehicle - BEV vs. FCEV
Cost energy storage system [k€]
350
300
250
200
150
100
50
0
BEV
Advantage BEV
Advantage FCEV
FCEV
0
500
1000
Range [km]

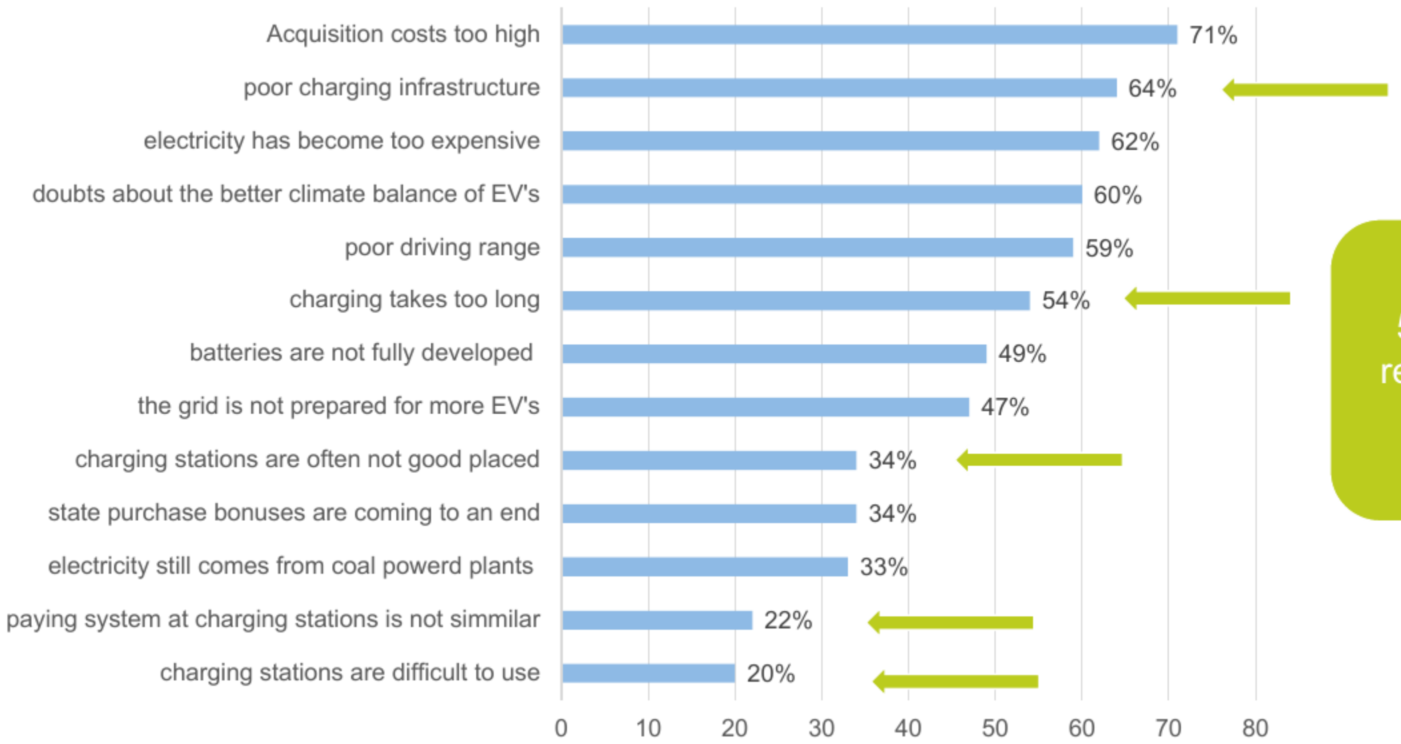
FCEV Truck



FC-Vehicle architecture can be divided into five subsystems:

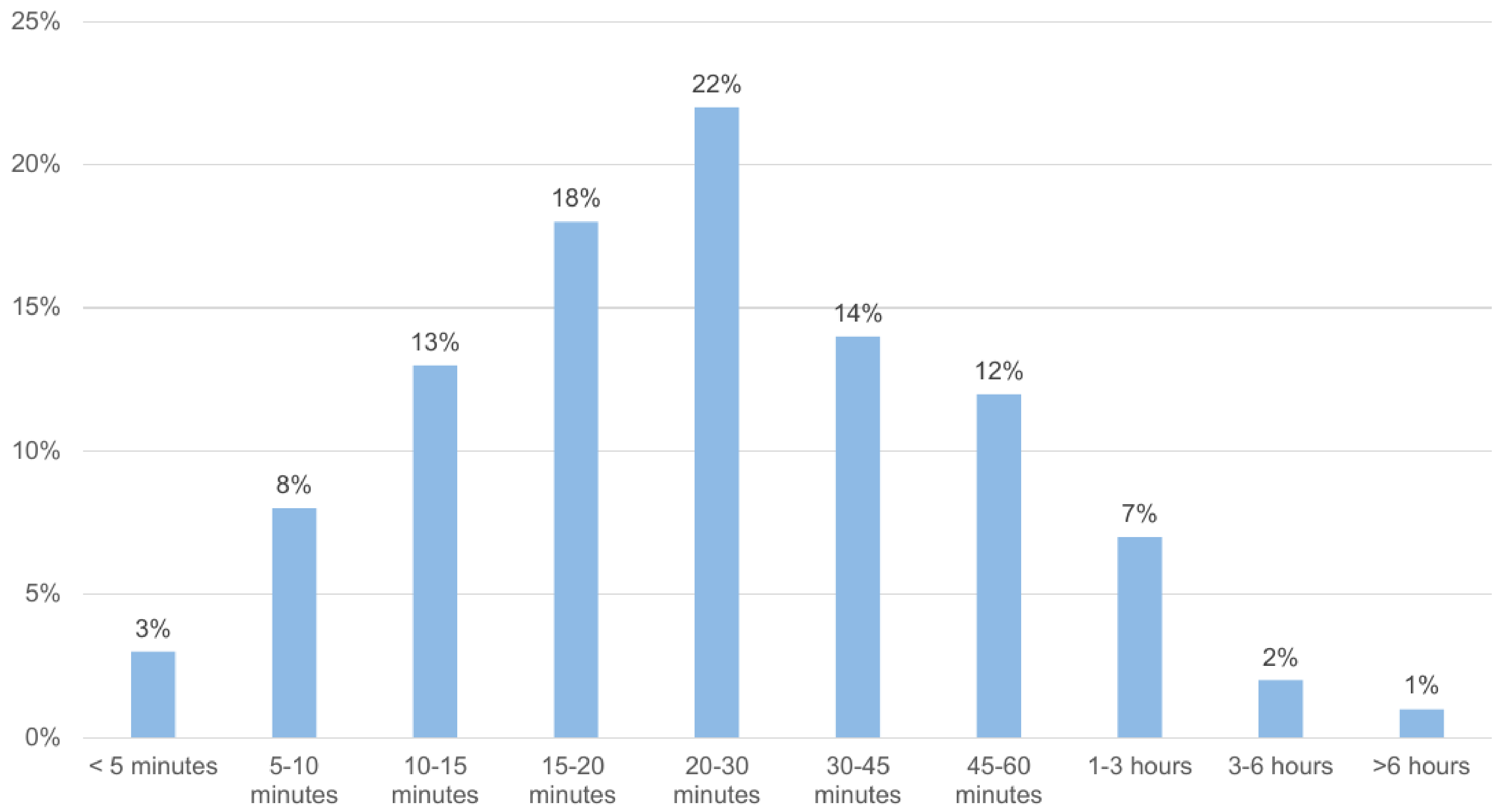
- Fuel cell system
- Hydrogen tanks
- Lithium-Ion battery
- Electric motor
- Power electronics

Důvody proč ne EV



5 of the 13 most named reasons are related to the charging infrastructure

Akceptovatelná doba nabíjení



Standardy

ISO 15118-20 (04.2022)

- Definition of communication interface between vehicle and charging station
- Prerequisite for intelligent and bidirectional charging
- Communication of charging schedules, charging status, etc.
- Necessary for Plug&Charge with more than one contract

Charging Column Ordinance and AFIR

- Rules Minimum requirements for public charging infrastructure
- Card payment terminals are required in both, but to different extents
- AFIR calls for a charging station with at least one 150 kW charging point every 60 km from 2025 onwards

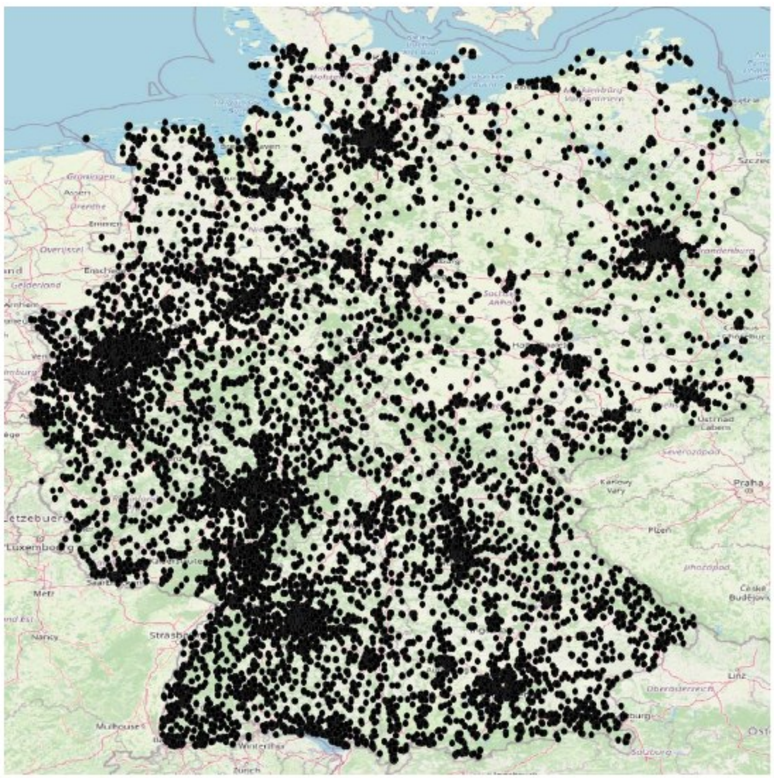
Energy Performance of Buildings Directive (12.2021)

- For new buildings/renovation: Pre-cabling of all parking spaces of car parks with more than 3 parking spaces as well as 1 installed intelligent charging-point for more than 5 parking spaces
- Existing buildings: 1 smart charging point per 10 parking spaces for more than 20 parking spaces from 2027 on.

MCS and heavy goods traffic

- Charging plugs with up to 1250 V and 3000 A (and thus up to 3.75 MW)
- Target: reload a truck in under 45 minutes
- Enables heavy-duty electric transport
- Tender initial network until Q4/2023

Nabíjecí stanice



- Charging infrastructure is necessary for EV operation
- Several ways to distinguish:
  - AC vs DC
  - Mode 1, 2, 3, 4
  - Standard, High Power, Ultra High Power
- Different modes for different situations:
  - At home
  - Workplace
  - Destination
  - On-Road

Konektory

- Type 2 most frequent in Europe with 2 signal cables, 1 ground, 1 neutral, and 3 phases
- Type 1 practically non-existent in Europe
- CCS is a Type 1 or 2 with DC extension obligatory at fast-chargers in Europe
- CHAdeMO is DC only and popular in Japan, but loosing relevance in Europe and US
- Not shown:
  - MCS for trucks
  - Tesla‘s NACS relevant in the US
  - GB/T in DC and AC variant relevant in China

Nabíječky

- Can be plugged into a household socket
- Very low power limited by socket (2 kW for Schuko)
- Low efficiency due to low power inside the vehicle
- Single-phase charging

Nabíječky - wallbox

- Typically 11 kW power
- Fixed wall-mounted installation
- Can include metering and authentication equipment
- Typically equipped with a Type 2 charger
- Bidirectional versions available

Nabíječky- stanice

Sources (left to right)
https://commons.wikimedia.org/wiki/File:Electric_vehicle_charging_station_Ladestasjon_for_elbil_Storgaten_T%C3%B8nsberg_kommune_Norway_2017-09-20_06.jpg,
https://commons.wikimedia.org/wiki/File:Charging_station_hydropower.jpg,
https://commons.wikimedia.org/wiki/File:Lades%C3%A4ule_f%C3%BCr_E-Autos_in_Spremberg_(2).jpg

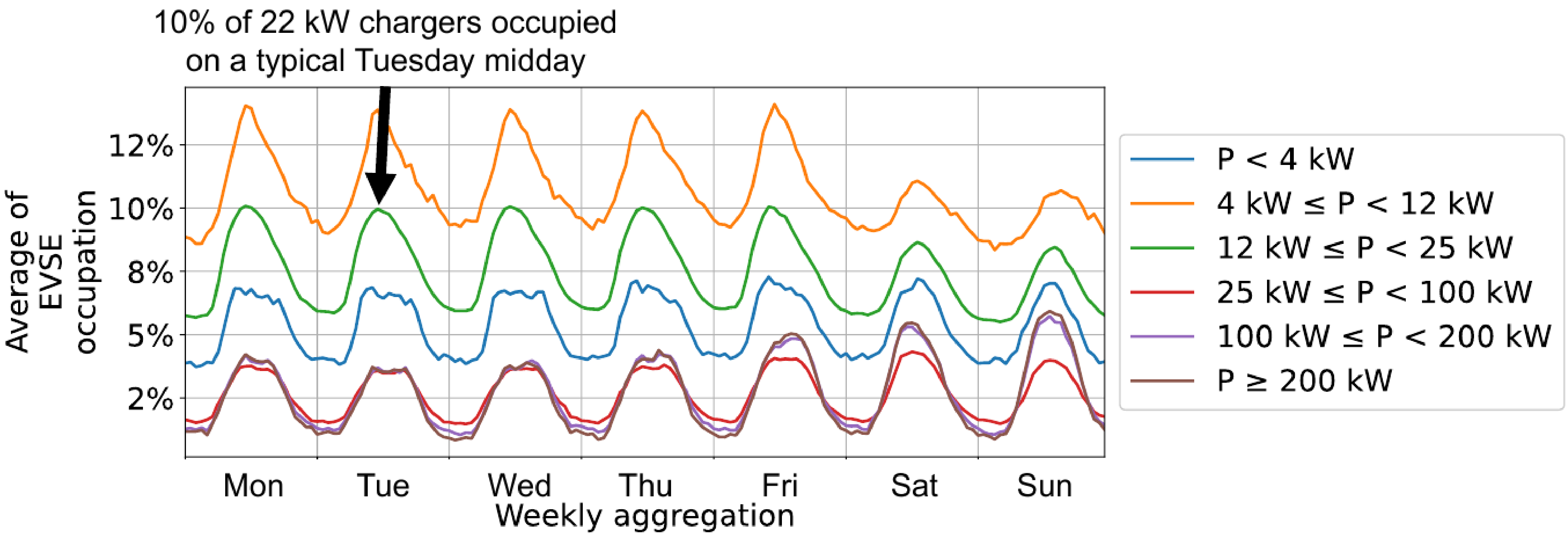
- Most frequently encountered type of charging station
- Predominantly used in the public space
- Consists of pole(s) with two connectors
- Typically metering and authentication/payment hardware installed
- Delivers 11 or 22 kW per connector
- Offers either Type 2 socket or cable. Few exceptions still exist, but disappearing.

Charging Power Level

1 kWh = 5

Charging level	AC / DC	Power	km added hour of cha
Level 1	AC and DC	0-10 kW	50 km
Level 2	AC and DC	10-50 kW	50 – 250
Level 3 (Fast charging)	Only DC	> 50 kW (up to 350 kW)	250 – 1750

Využití nabíječek



Charging calculation

Charging power and current:

$$P_{ch} = V_{batt} I_{ch}$$

where

P_{ch} is the charging power, in W

V_{batt} is voltage of the EV battery, in V

I_{ch} is the charging current, in A

Charging calculation

Charging power and energy:

$$E_{ch} = \int P_{ch}\, dt$$

where

P_{ch}	is the charging power, in kW
E_{ch}	is the energy delivered during charging, in kWh
t	is the time period, in hours

Charging calculation

$$20\ kWh = 10kW\,(2h)$$

Charging power and energy:

$$E_{ch} = P_{ch} t_{ch}$$

where

P_{ch} is the charging power, in kW

E_{ch} is the energy delivered during charging, in kWh

t_{ch} is the charging time, in hours

Charging calculation

C-rate

$$C\text{-}rate = \frac{P_{ch}}{E_{nom}}$$

where

P_{ch} is the charging power, in kW

E_{nom} is the nominal energy capacity of the battery, in kWh

Higher C-rate ←→ Higher battery losses ←→ Lower lifetime

E-truck

Depot	On-road

Depot

- Recharging happens over night or if vehicles are stationed anyways
- Many connectors required to service all vehicles
- Energy management system required to distribute energy between vehicles
- CCS connector

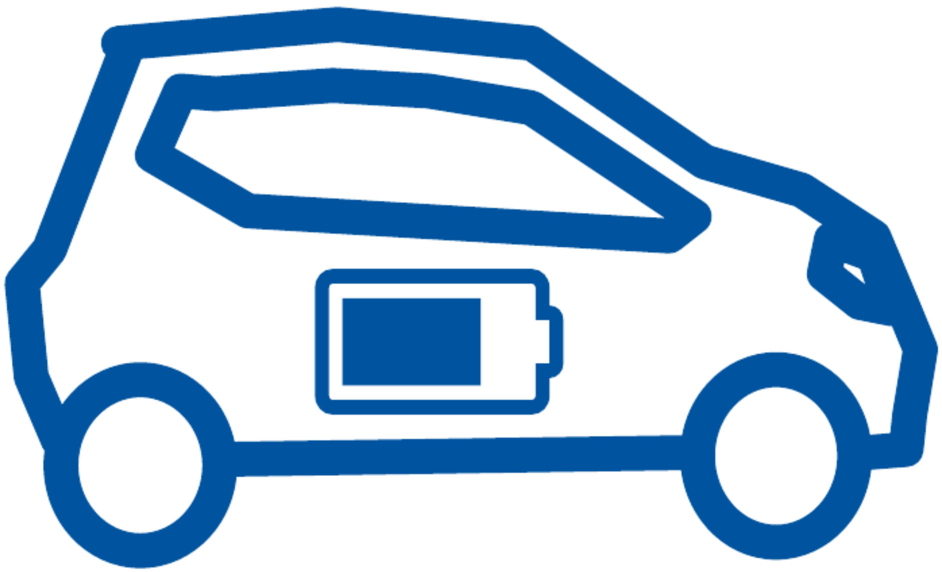
On-road

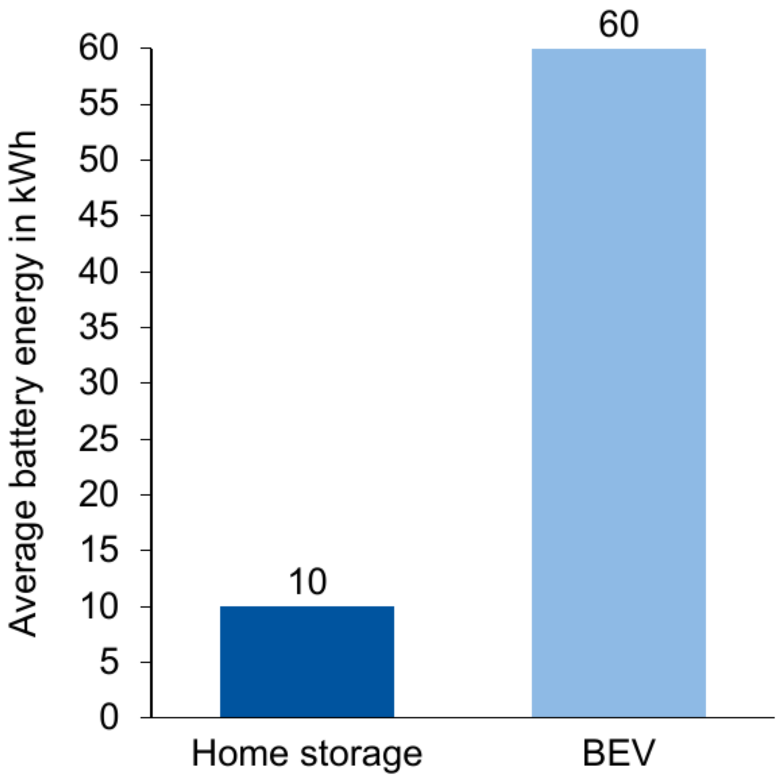
- Recharging in the mandatory 45 minute break
- With 4.5 h driving at 100 km/h and 1.2 kWh/km consumption, 540 kWh need to be recharged
- Including a buffer, appr. 1 MW charging power is required per connector
- MCS connector

Vehicle to grid

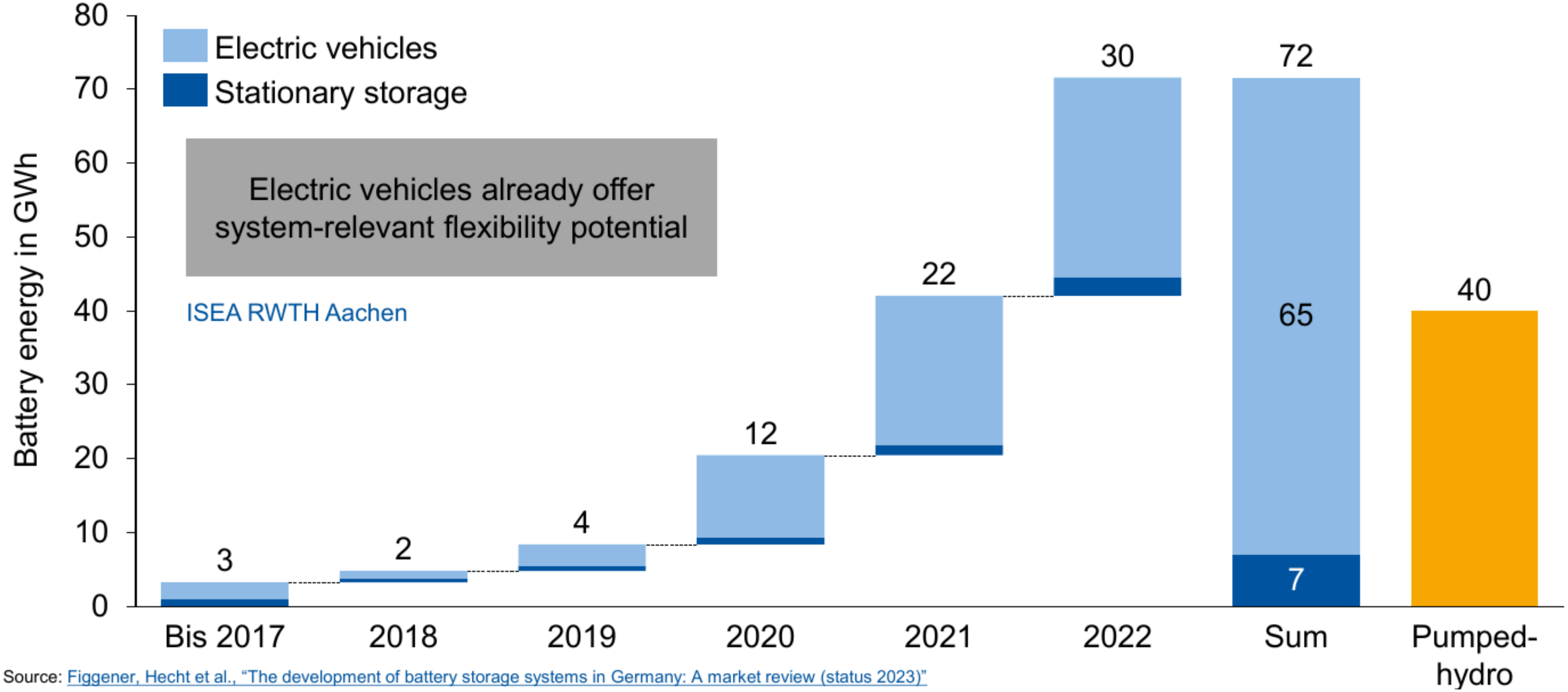
Vehicle to grid

Vehicle to grid



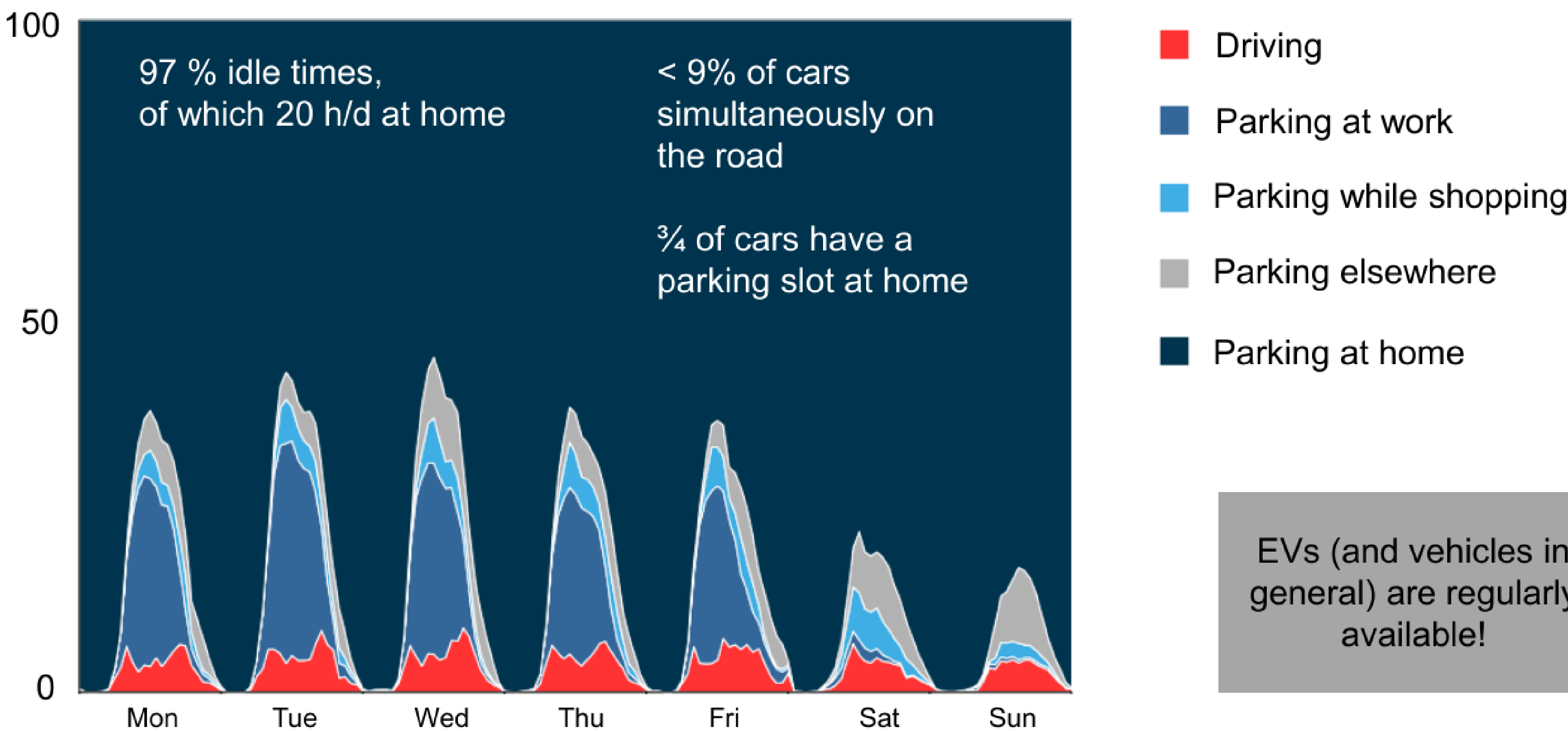


Kapacita úložiště



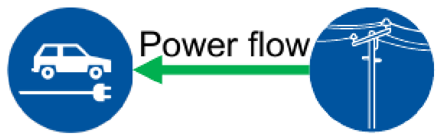
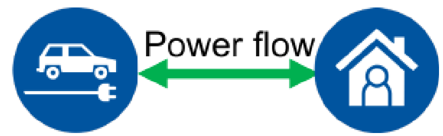
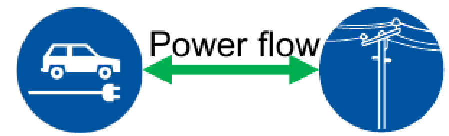
Source: Figgener, Hecht et al., "The development of battery storage systems in Germany: A market review (status 2023)"

Dostupnost baterie



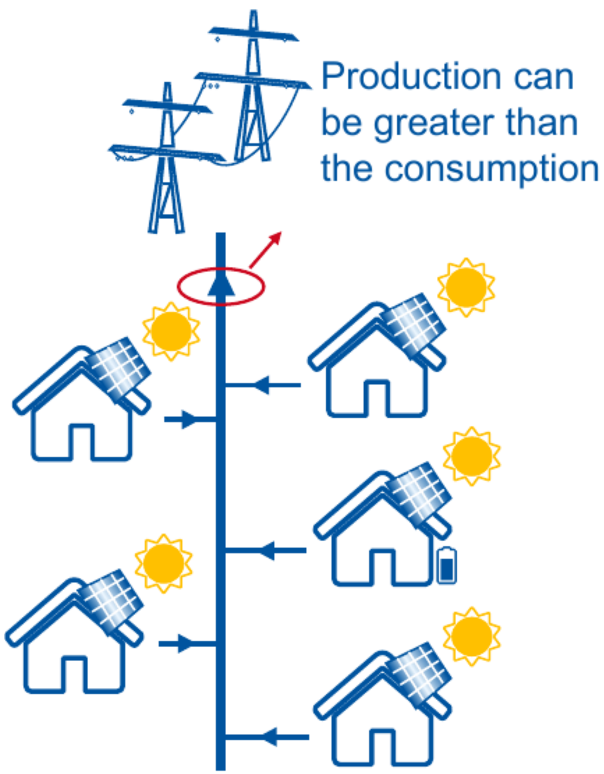
EVs (and vehicles in general) are regularly available!

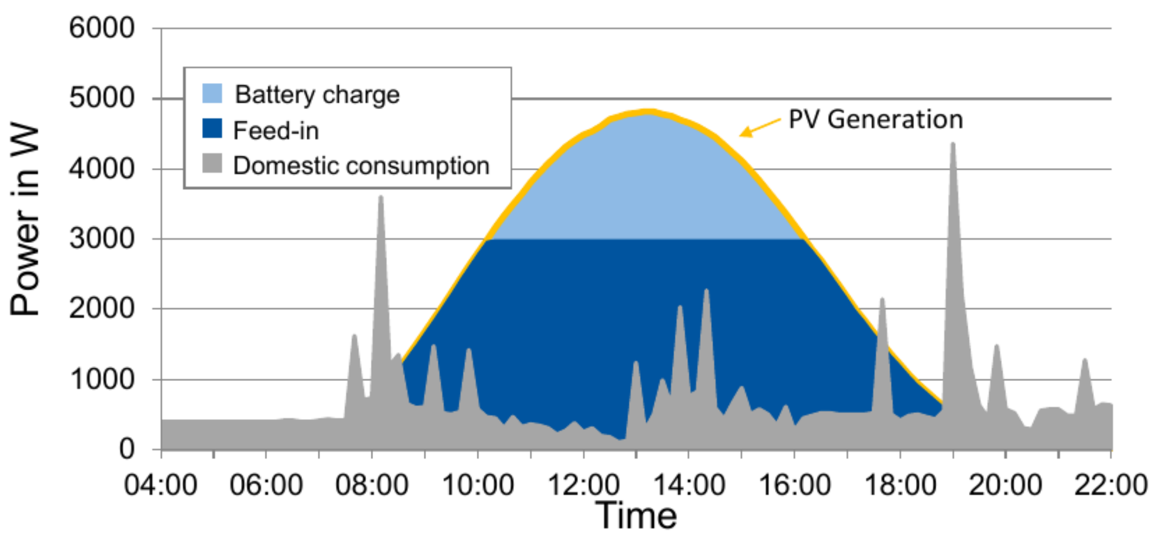
Vehicle to X

	Smart Charging	Vehicle-to-home	Vehicle-to-grid
			
Market readiness	▪ Is reached	▪ In one to two years	▪ After vehicle-to-home, depending on regulation
Estimated revenue potential*	▪ Up to € 300 per vehicle and year **	▪ 200 to 500 € per vehicle and year ***	▪ 200 to 800 € per vehicle and year ****
Battery aging	▪ Strongly reduced relative to full charge	▪ Reduced relative to full charge	▪ Reduced relative to full charge

Vehicle to home

- **Problem**: Possible grid overload due to increased integration of PV systems
- **Solution**: Limiting the feed-in power through storage





Vehicle to home

Vehicle-to-Home: Use of the vehicle as a home storage system

- Motivation
  - Feed-in tariff much lower than electricity prices. Self-consumption becomes attractive
  - Additional cycles put little strain on the battery
- Operation
  - Charging of the vehicle at times of high PV generation
  - Discharging of the vehicle in the evening and night
- Challenge
  - Vehicle not always on available
  - Losses at low powers
  - Interfaces