UNIVERSITÀ DI TRENTO

DEPARTMENT OF

INDUSTRIAL ENGINEERING

Renewable Energy Conversion Systems

Lecture 23

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MSc Degree in Mechatronic Engineering,

Academic Year 2024-2025

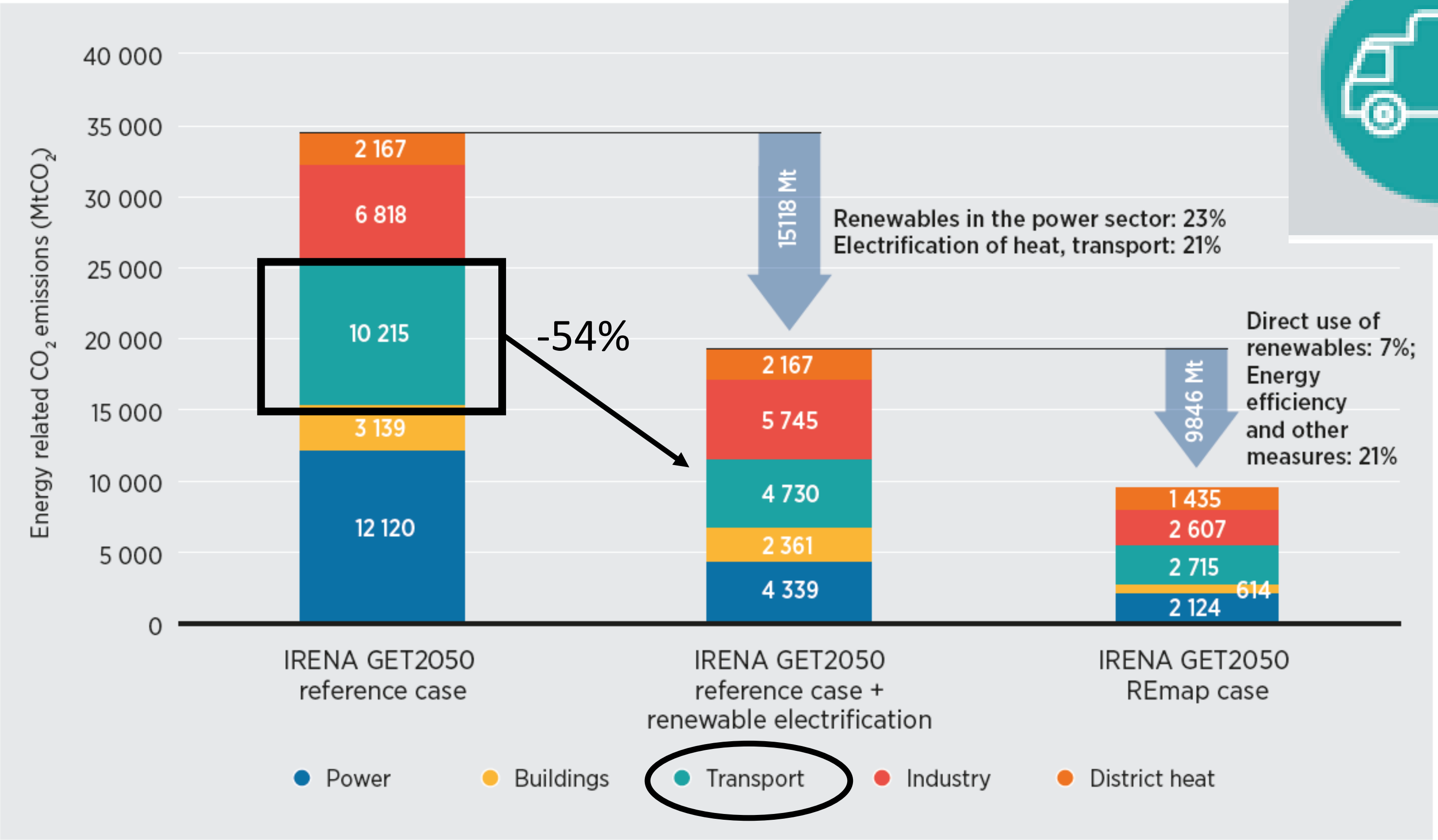
Lecture 23: Outline

Main topic:

Electric vehicles (EVs) and their impact on the electric grid

- Evolution of the market of Electric Vehicles
- Classifications of EVs
- Main components in the EV power train
- Impact of EVs on the electric grid
    - Traditional (unidirectional) charging
    - Vehicle to grid (V2G) and its coordination strategies
    - Vehicle to Home (V2H)

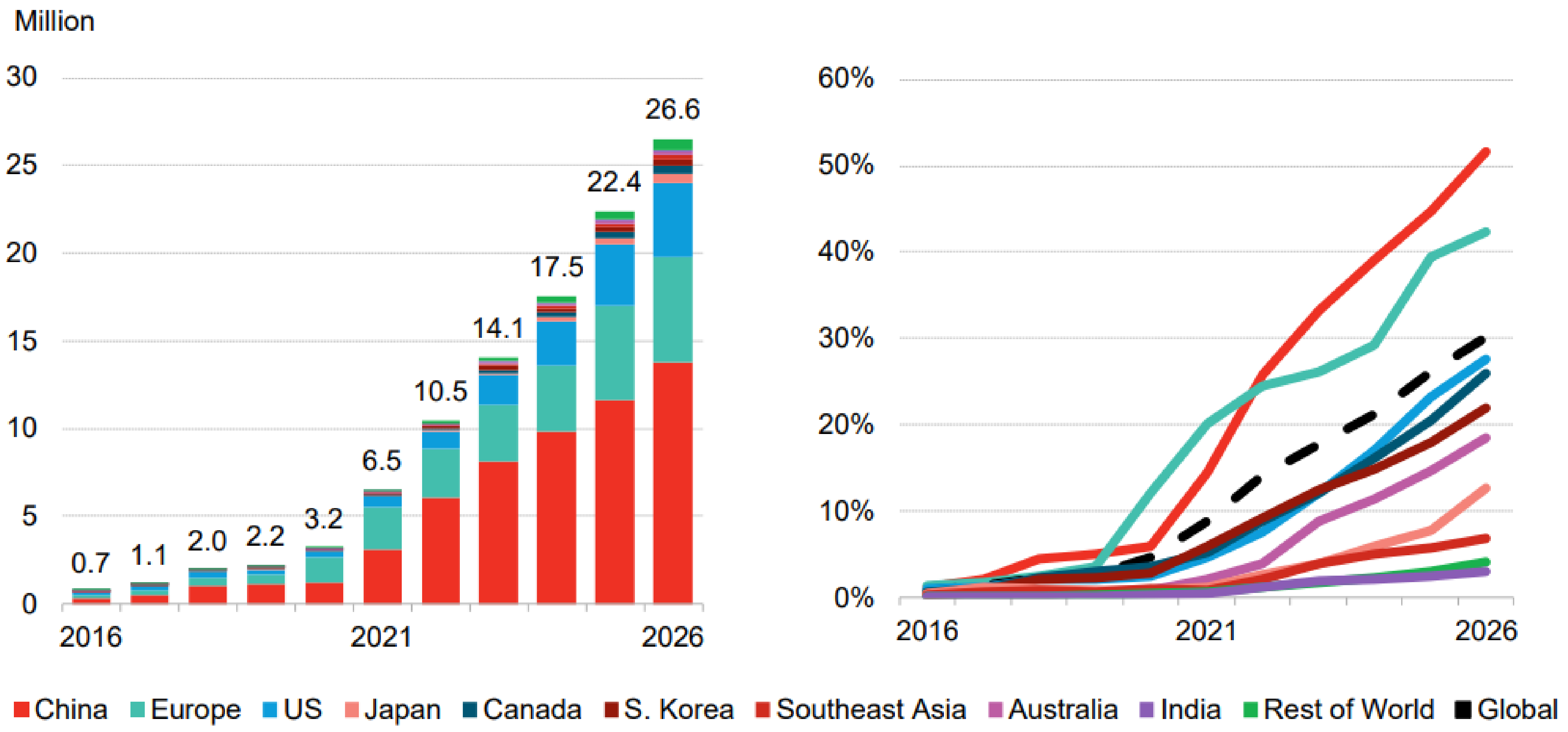
Electrification in the transport sector



Notes: CO_2 = carbon dioxide; $MtCO_2$ = million tonnes of carbon dioxide.
Source: IRENA's own analysis based on IRENA (2018a)

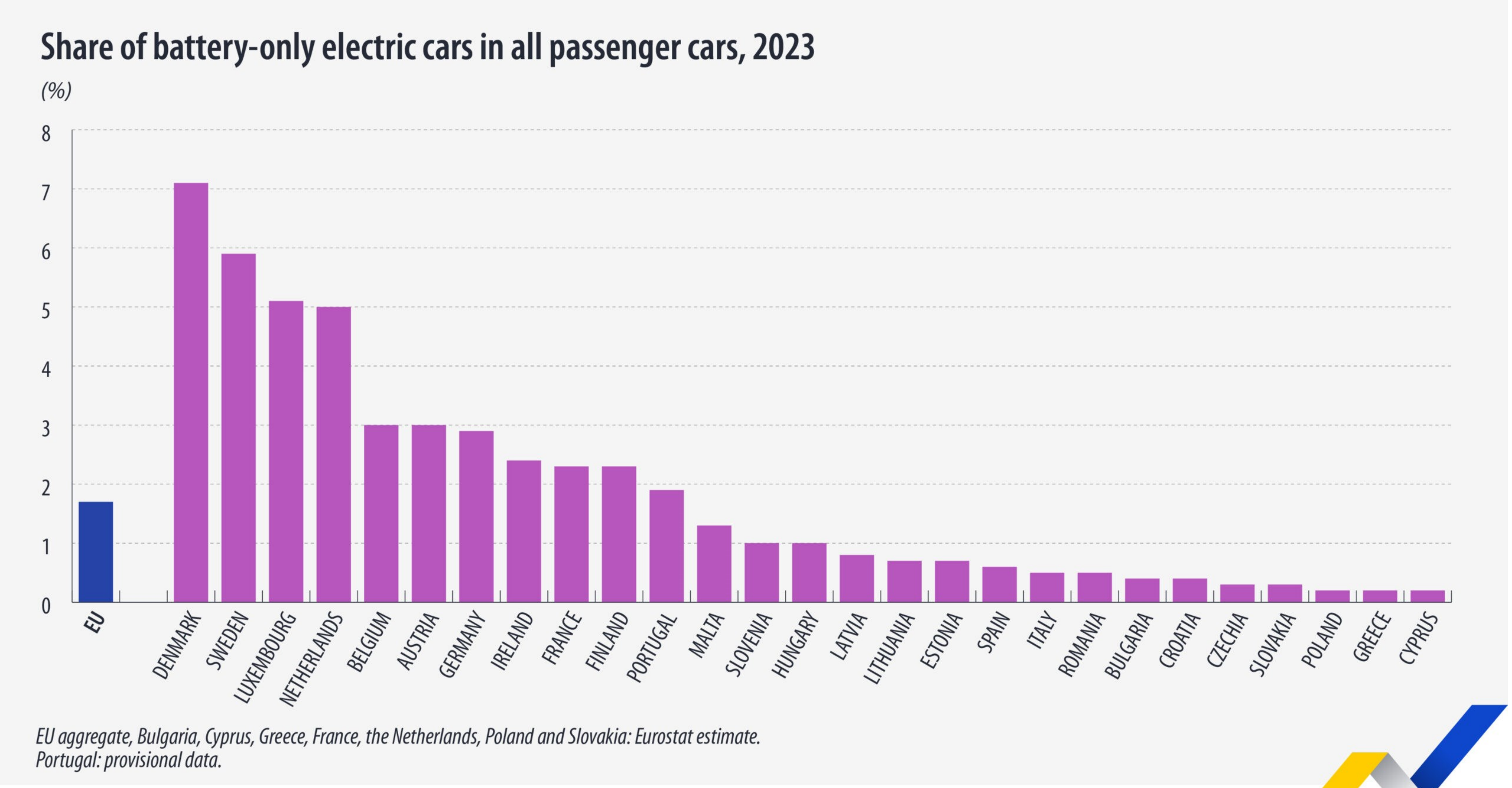
Electric mobility share in passenger cars

Figure 1: Global near-term passenger EV sales and share of new passenger vehicle sales by market



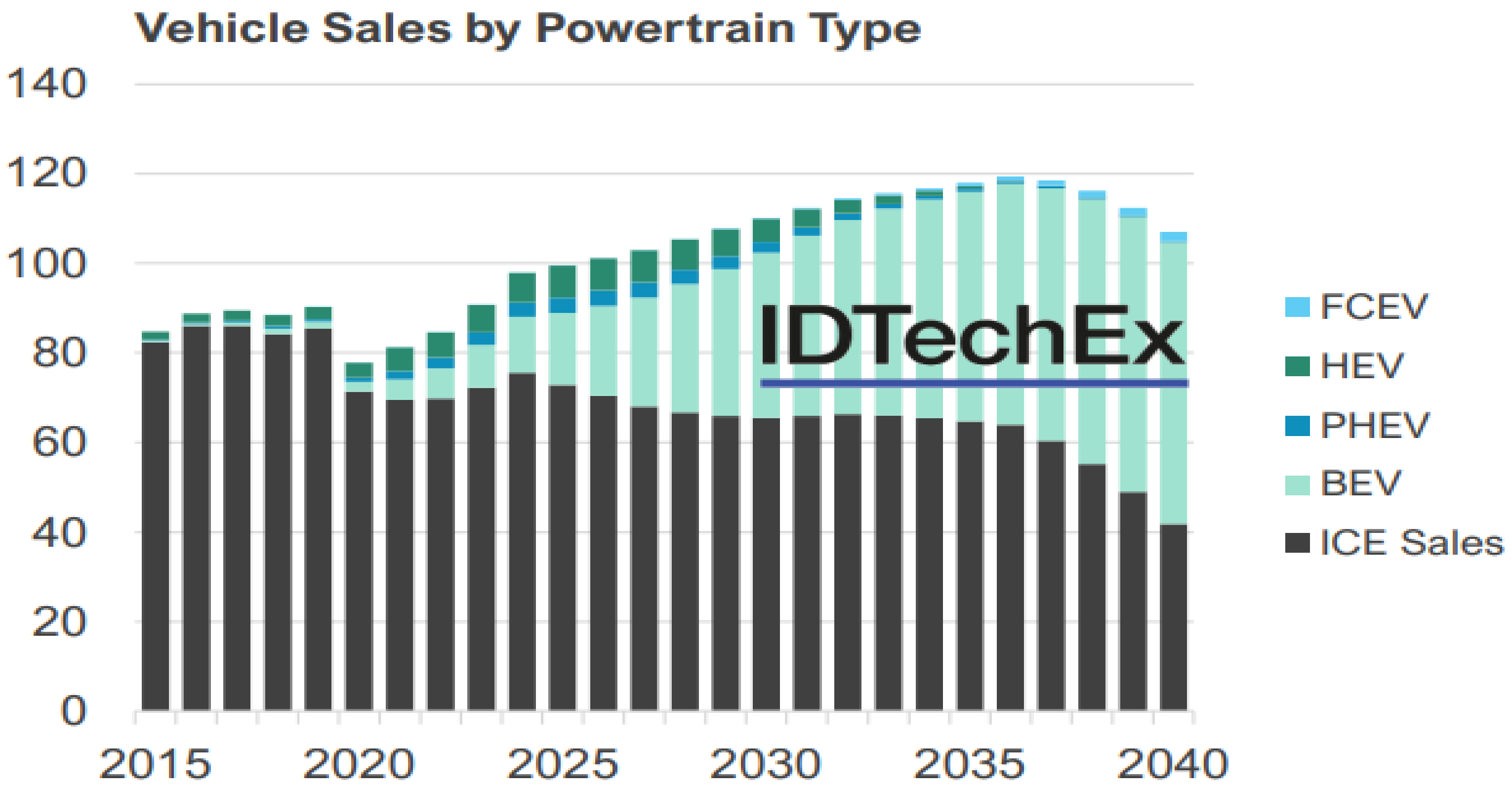
Source: BloombergNEF. Note: Europe includes the EU, the UK and EFTA countries. EV includes BEVs and PHEVs.

Electric mobility share in passenger cars



eurostat

Electric mobility share in passenger cars

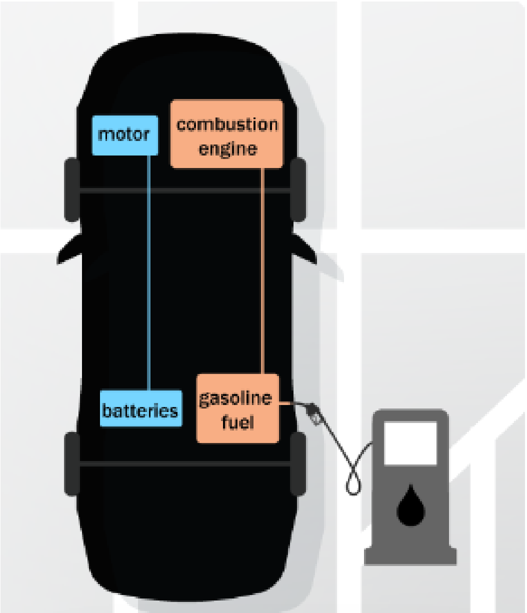


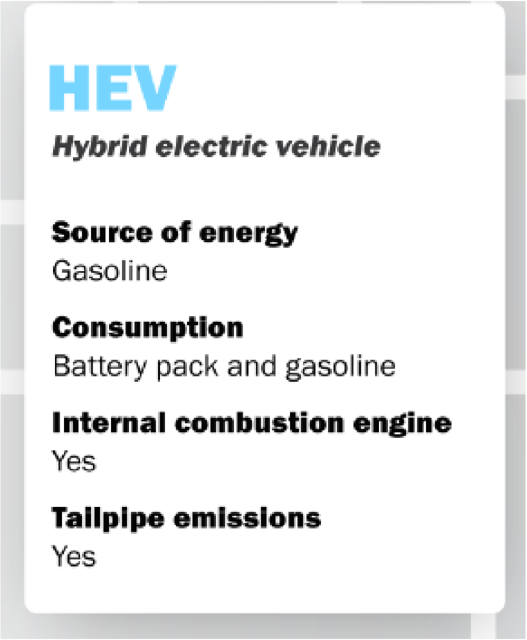
Source: IDTechEx

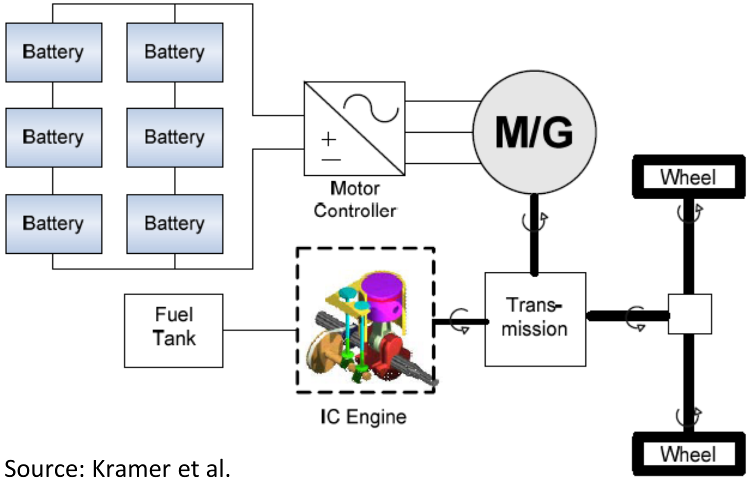
Types of electric vehicles (EVs)

- Hybrid Electric Vehicles (HEV)
- Plug-in Hybrid Electric Vehicles (PHEV)
- Battery Electric Vehicles ([B]EV)
- Fuel Cells Electric Vehicles (FCEV)

Hybrid electric vehicles (HEVs)



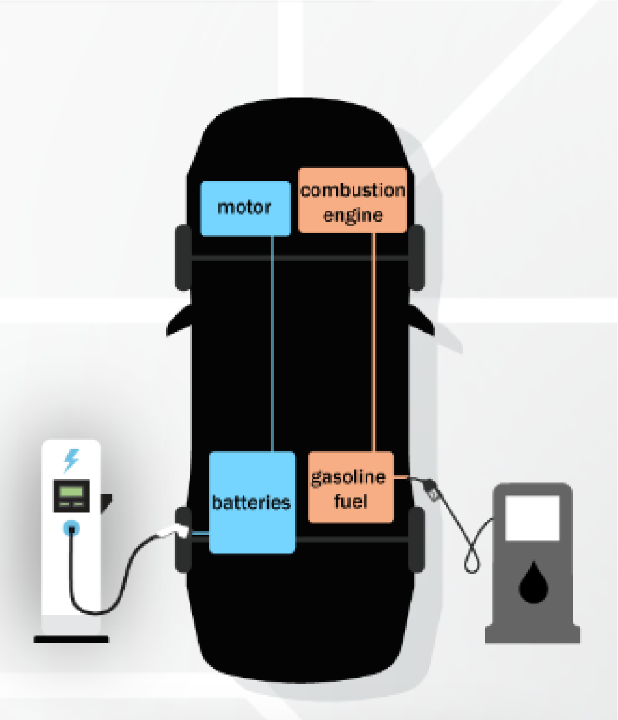


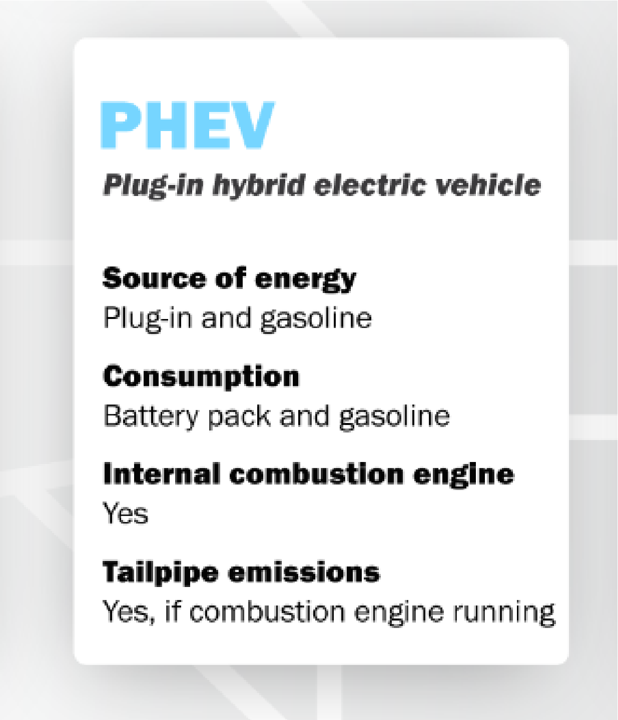


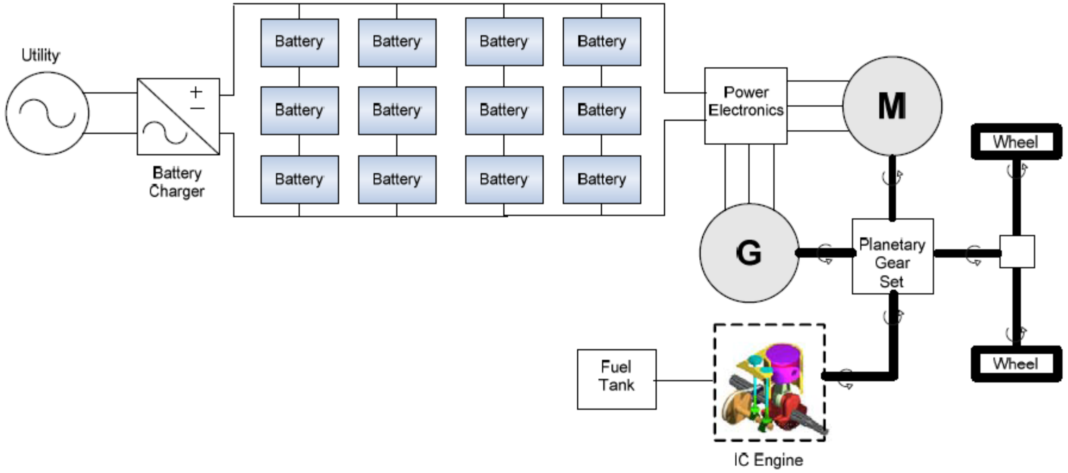
Source: Kramer et al.

Hybrid EVs combine an electric motor and an internal combustion engine (ICE)

Plug in Hybrid electric vehicles (PHEVs)

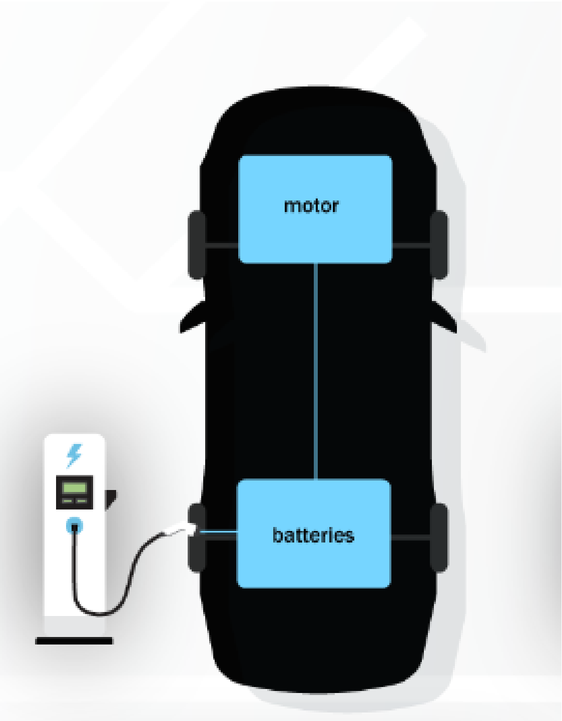






PHEVs have a battery pack of high energy density (compared to HEV) that can be externally charged and, hence, can run solely on electric power for a range longer than regular HEVs

(Battery) electric vehicles ([B]EVs)



BEV

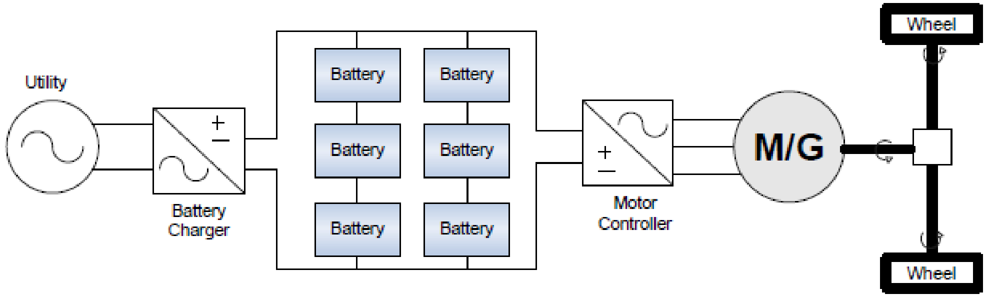
Battery electric vehicle

Source of energy
All-electric, plug-in

Consumption
Battery pack

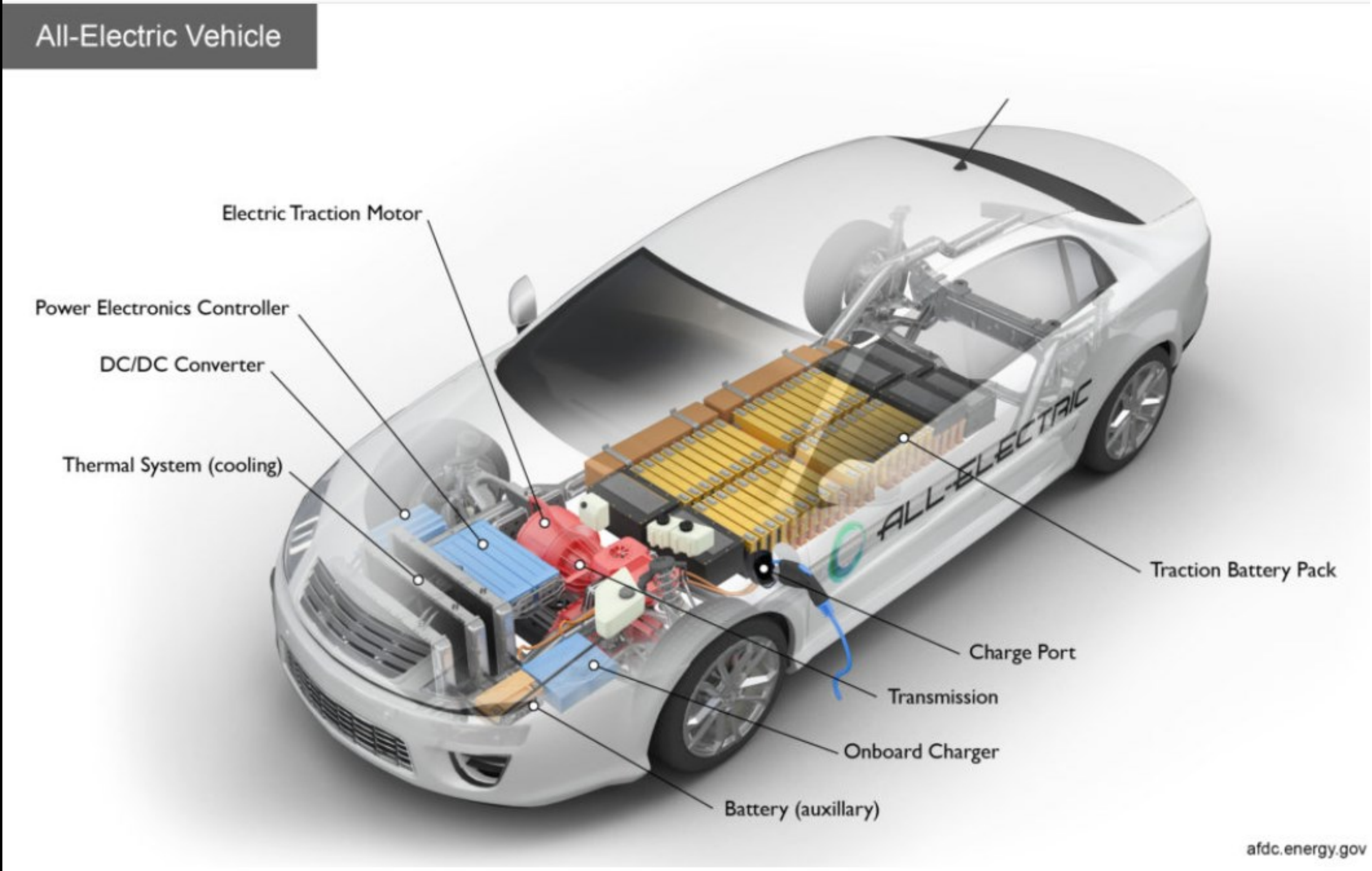
Internal combustion engine
No

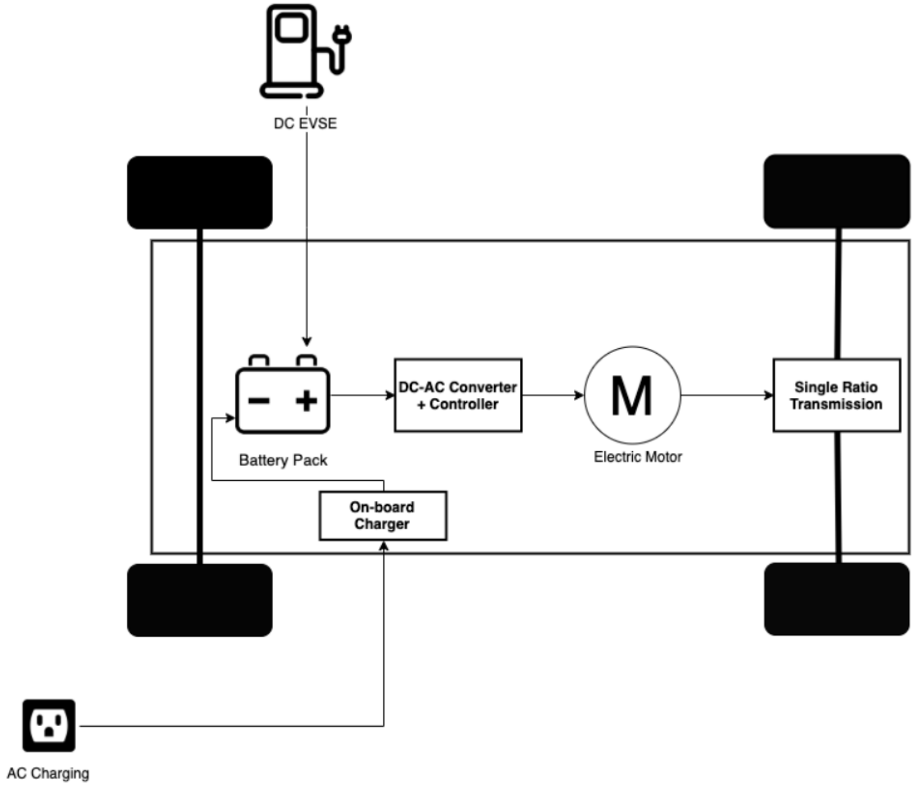
Tailpipe emissions
No



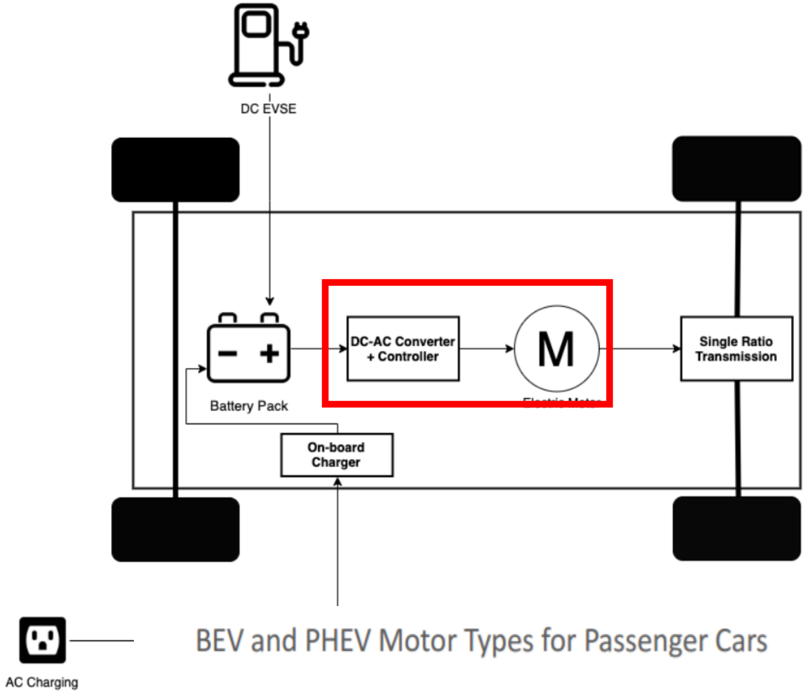
BEVs are only powered by a battery pack (i.e. they are 100% electric cars) so plug-in functionality is required

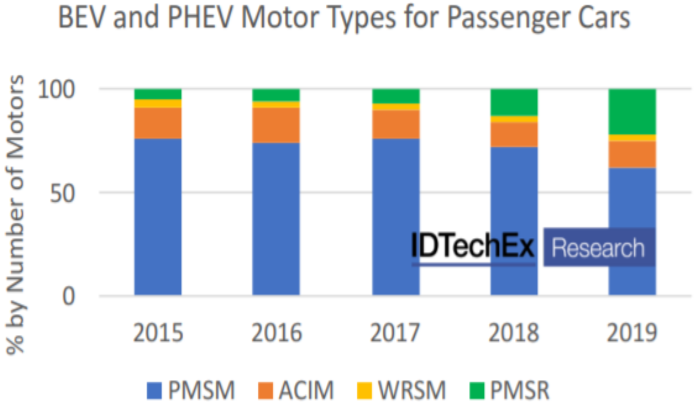
EV power-train



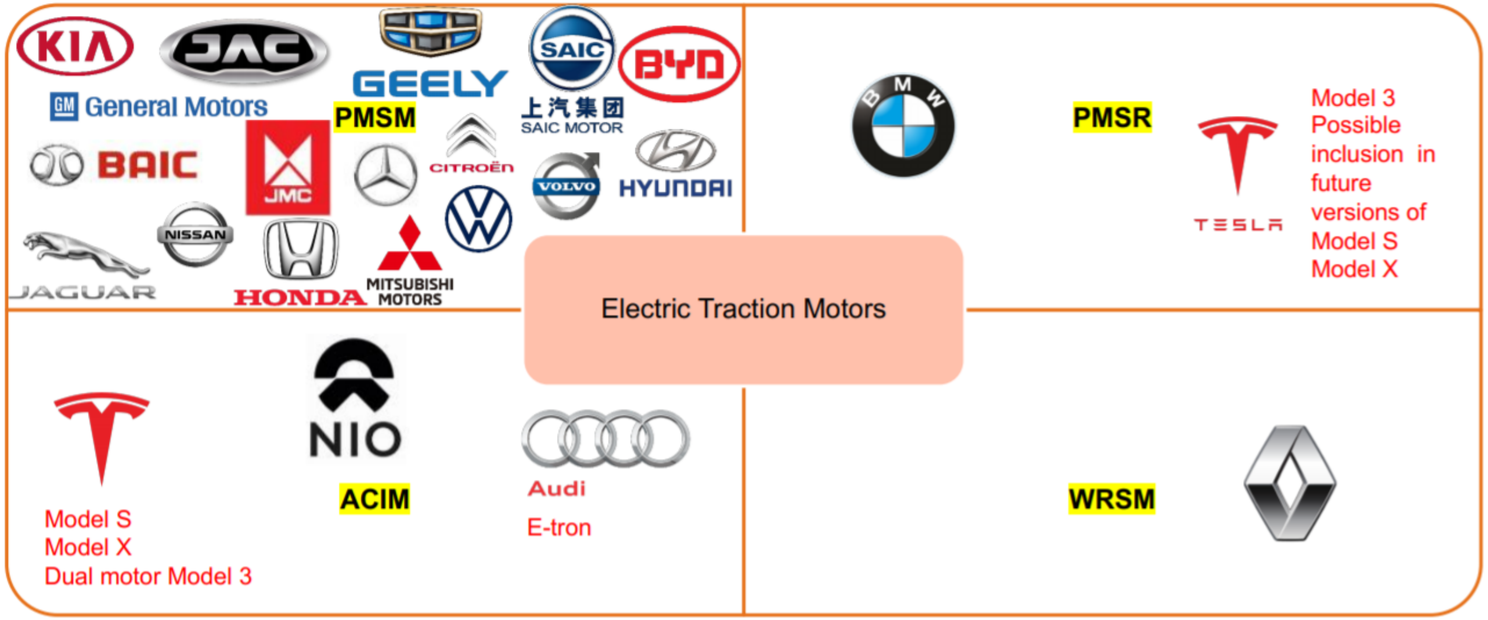


EV power-train

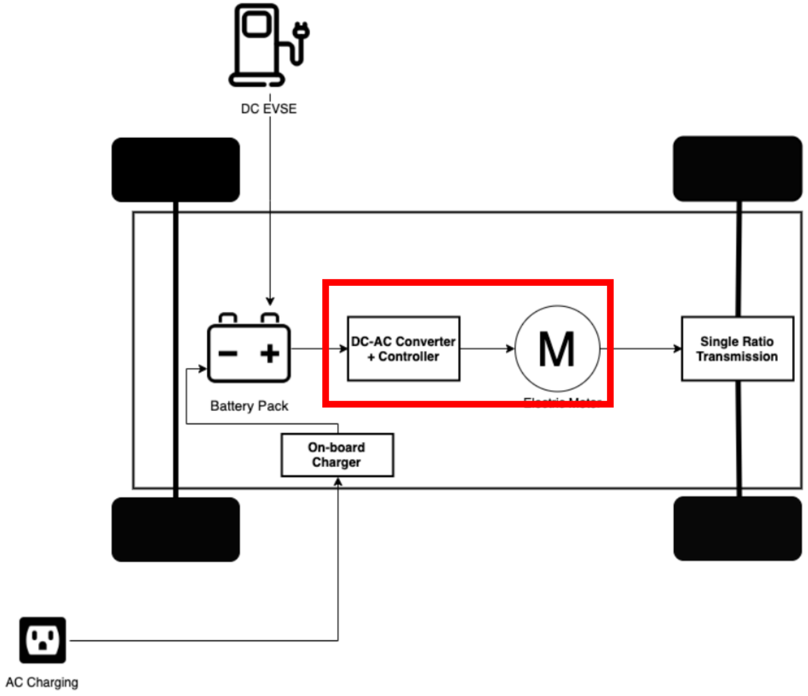




Electric machine + Power electronics

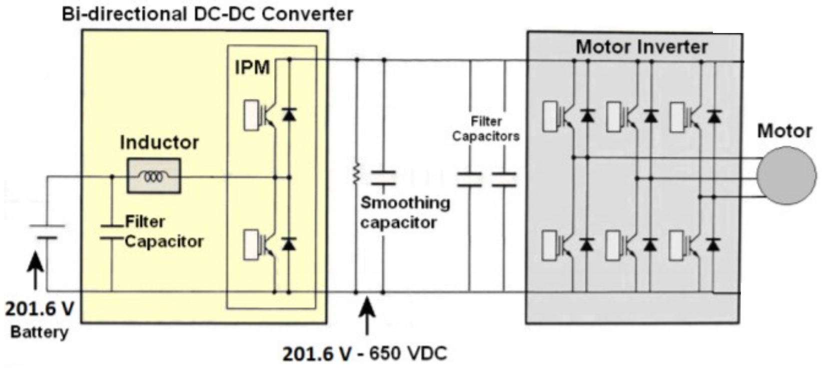


EV power-train

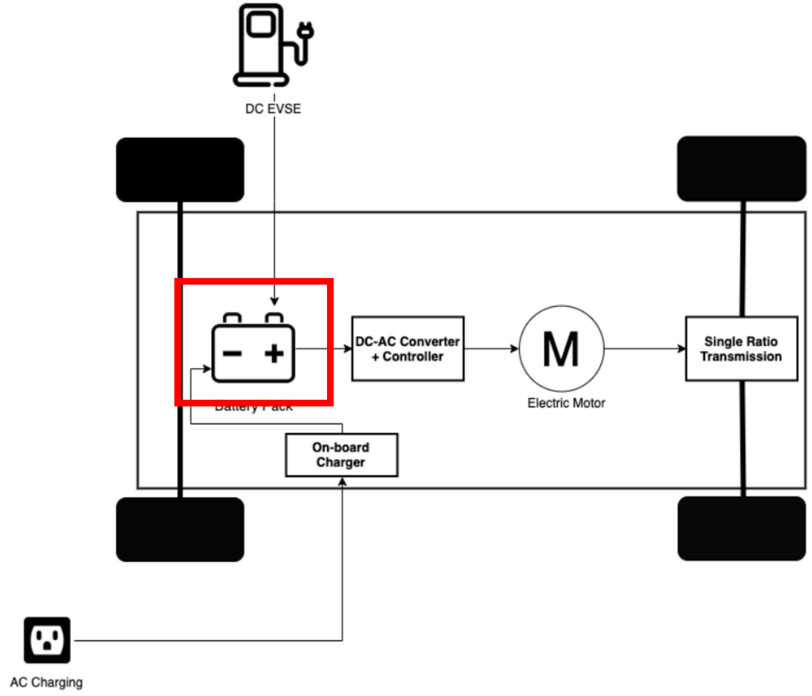


Electric machine + Power electronics

- Need to convert dc power from the batteries to ac power to supply the motor
- Onboard charger requires power converters
- Additional dc-dc for auxiliary systems



EV power-train



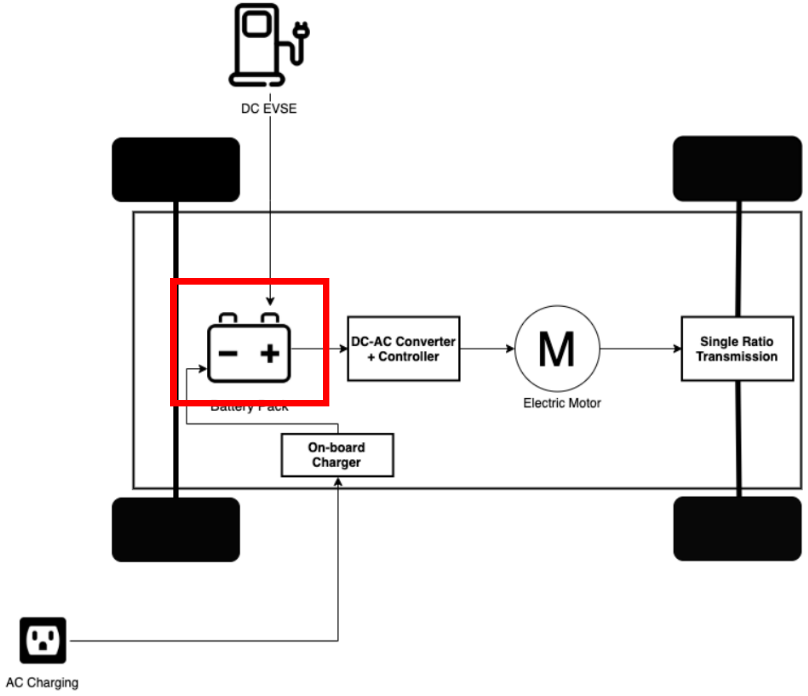
Batteries

- Multiple battery technologies used

Cathode Material Type	EVs battery packs Manufacturers	EVs developers and EV models	Battery packs usable capacity (kW h)	Approx. range under normal driving conditions (mile)
Lithium Cobalt Oxide (LCO)	Panasonic,	Tesla–Roadster	56	245
	Tesla	Daimler Benz–Smart EV	16.5	84
Lithium Manganese Oxide (LMO)	AESC, EnerDel,	Think–Think EV	23	99.4
	GS Yuasa, Hitachi, LG Chem, Toshiba	Nissan–Leaf EV	24	105
Lithium Iron Phosphate (LFP)	A123, BYD, GS	BYD–E6	57	249
	Yuasa, Lishem, Valence	Mitsubishi–iMiEV	16	99.4
Lithium Nickle–Manganese–Cobalt Oxide (NMC)	Hitachi, LG Chem, Samsung	BMW–Mini E	35	150

Source: Abbas Fotouhi et al, 2016

EV power-train



Batteries

- Significant evolution over time

Battery	Cruising distance (WLTC/JC08 mode)
24kWh	2010 (200km@JC08)
24kWh	2012 (228km@JC08)
30kWh	2015 (280km@JC08)
40kWh	2017 322km@WLTC Mode (400km@JC08 Mode)
62kWh	2019 458km@WLTC Mode (570km@JC08 Mode)

Using Nickel-Cobalt-Manganese Oxide

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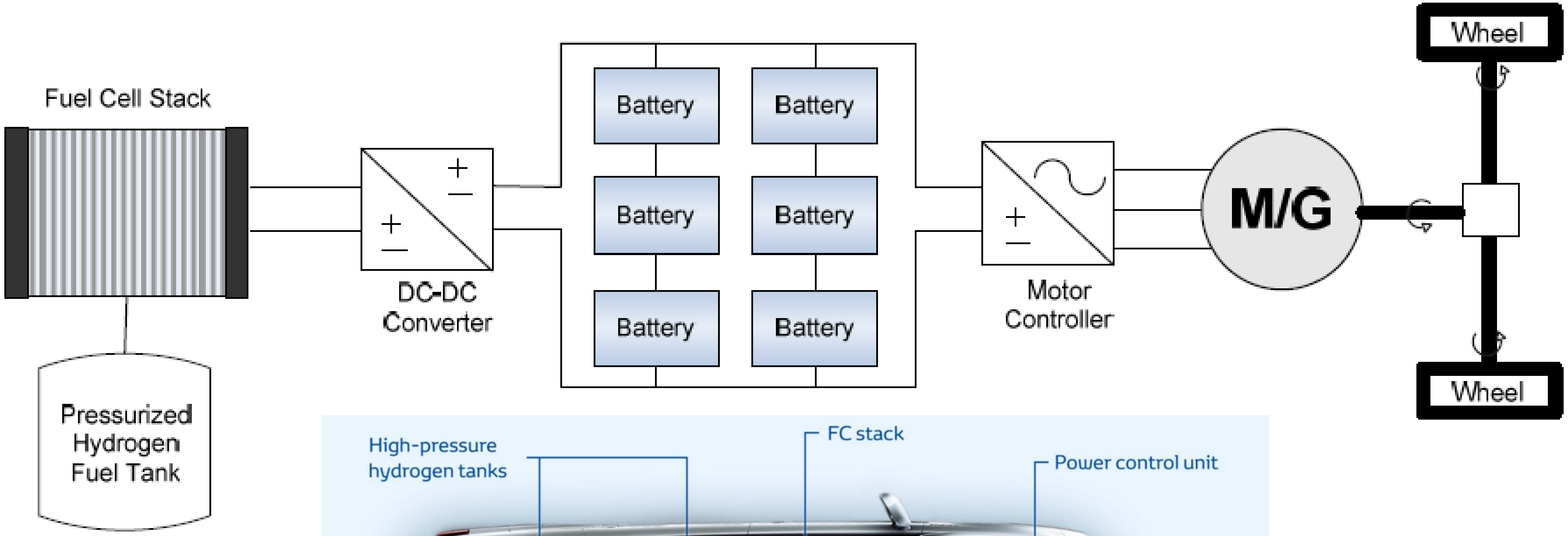
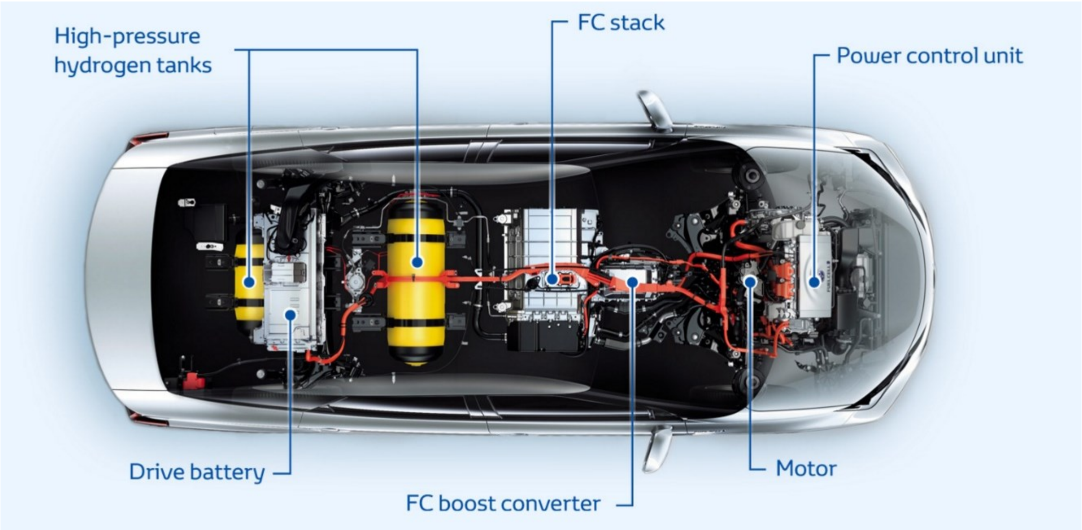
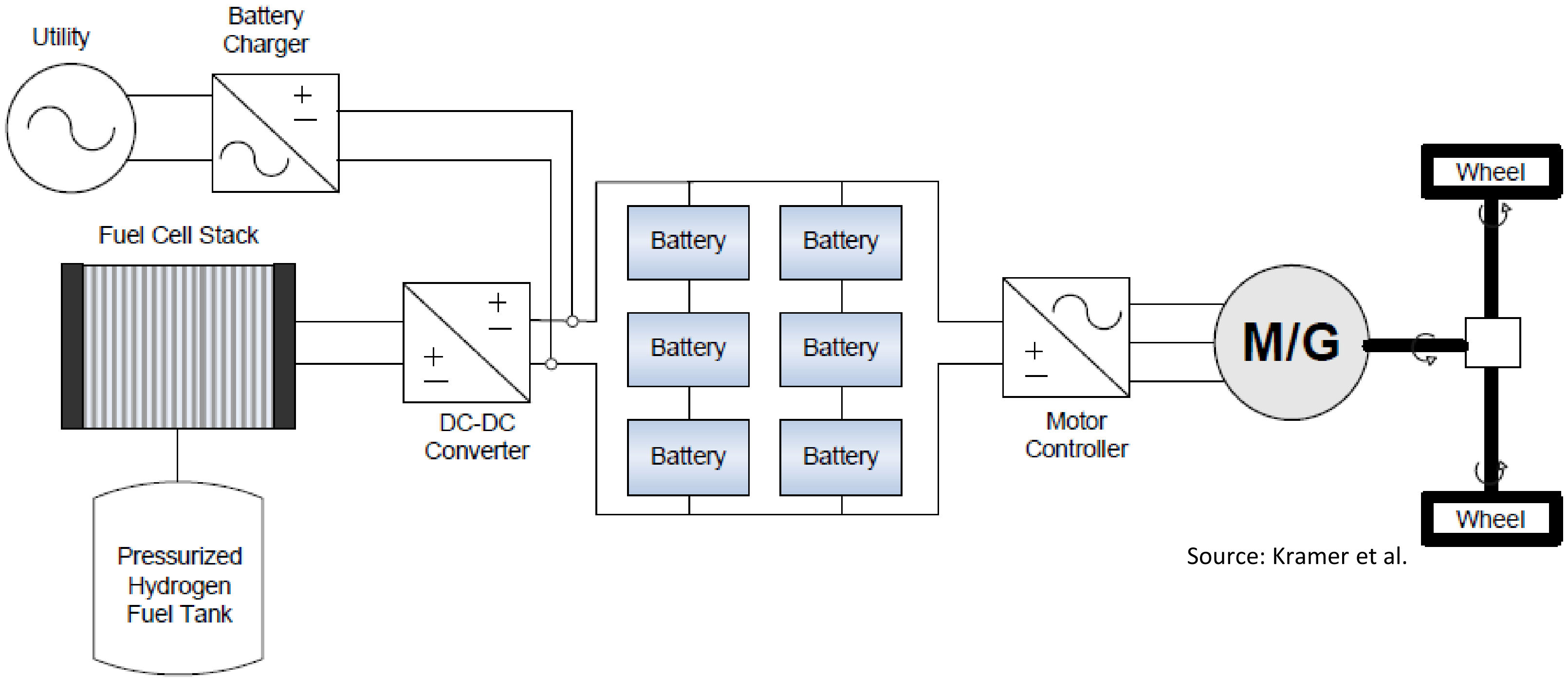
Fuel Cells (FC) electric vehicles



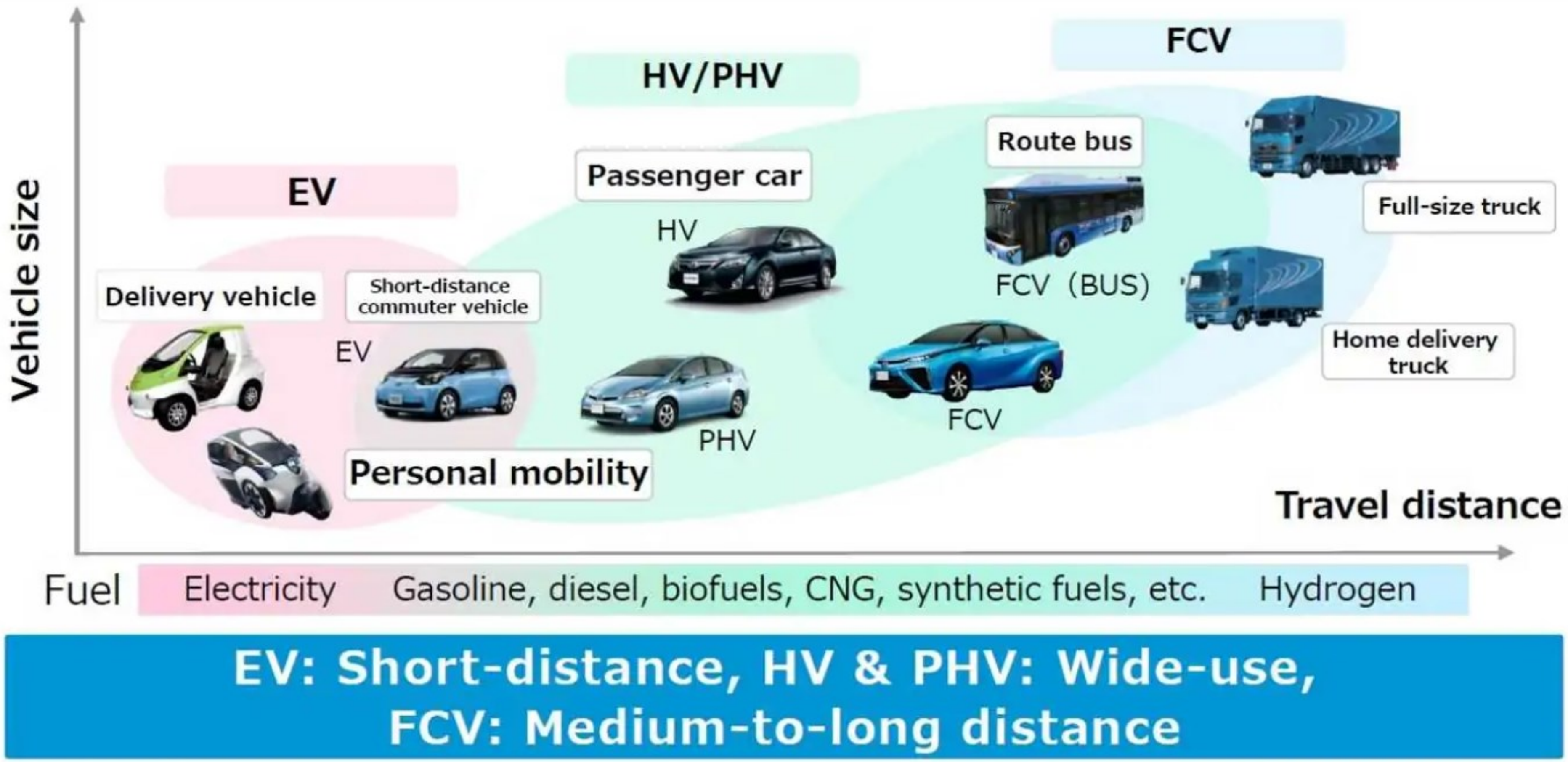


Plug-in Fuel Cells (PFC) electric vehicles



Source: Kramer et al.

Fuel Cells electric vehicles



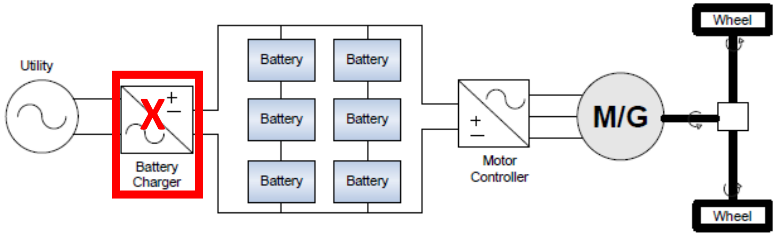
Source: Toyota

Electric vehicles’ charging infrastructure

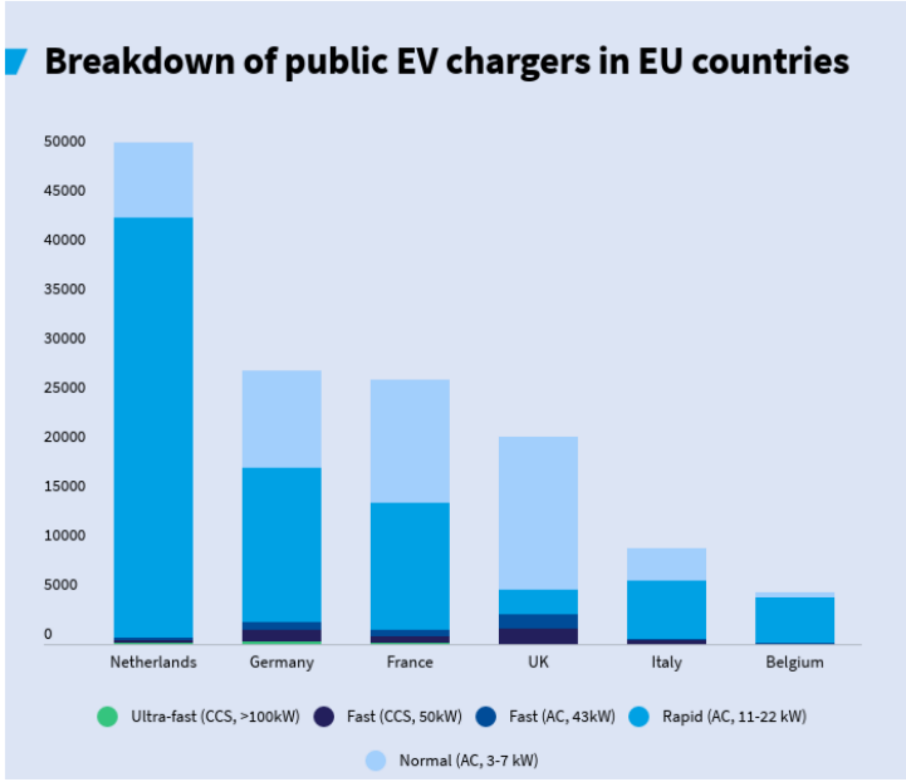
Level-1	• Supply from household outlet • Make use of EV’s on-board charger • 120V 1ph AC; 12-16A • Charging power: 1.4KW or 1.9KW
Level-2	• Supply from household outlet or EV Charge point • Make use of EV’s on-board charger • 208-240V 1ph AC ; 12 to 80A (Typ. 30A) • Charging power: 2.5KW to 19.2KW (Typ. 7KW)
Level-3	• Supply from 208-600V 3ph AC • Make use of off-board DC fast charger • 400A (Typ. 60A) • Charging power: up to 240KW (Typ. 50KW)

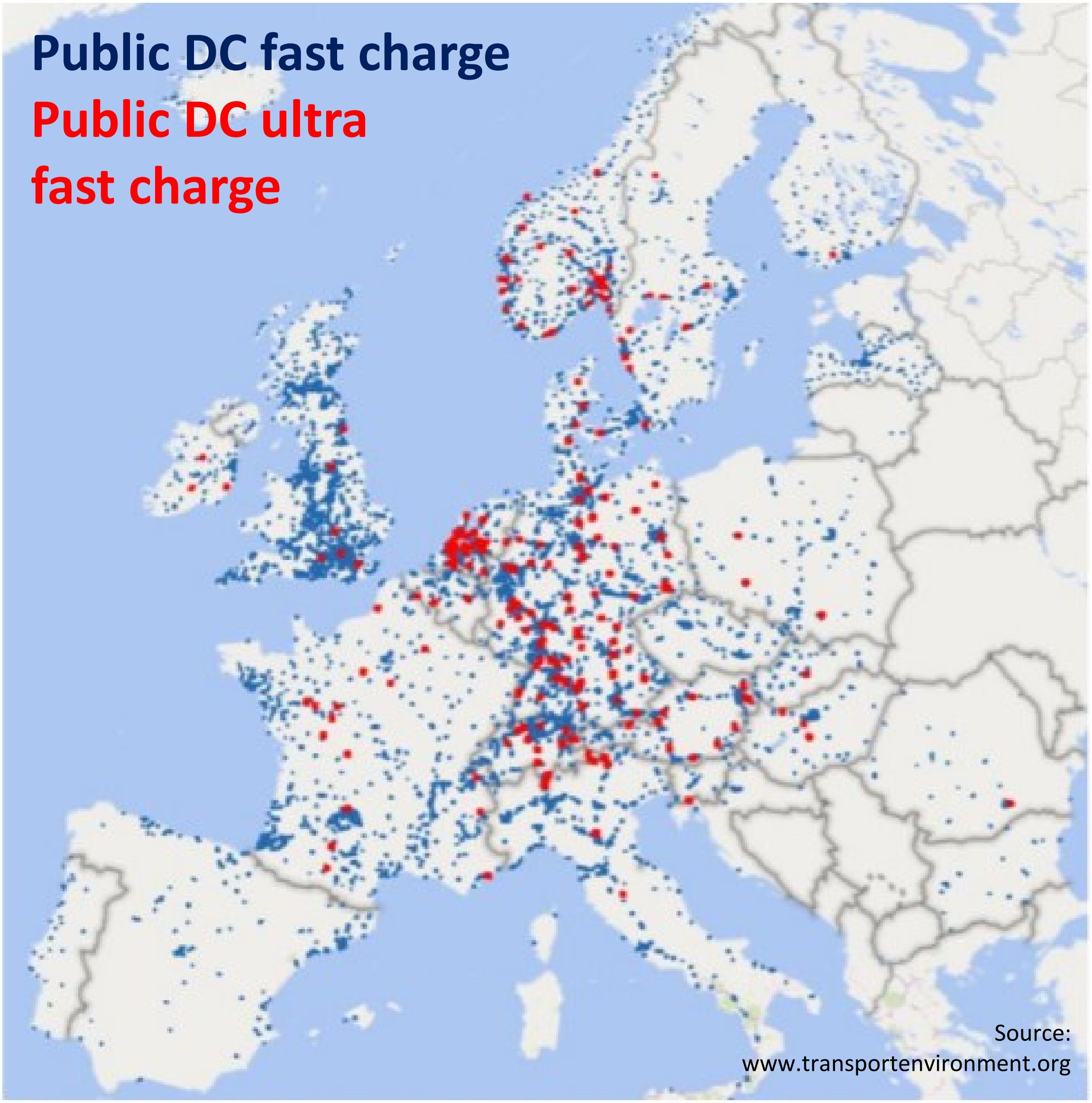
Source: ://www.emobilitysimplified.com

DC fast charge bypasses the on-board battery charges and feeds the battery pack directly with higher power



Source: Kramer et al.


Breakdown of public EV chargers in EU countries
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Netherlands
Germany
France
UK
Italy
Belgium
Ultra-fast (CCS, >100kW)
Fast (CCS, 50kW)
Fast (AC, 43kW)
Rapid (AC, 11-22 kW)
Normal (AC, 3-7 kW)


Public DC fast charge
Public DC ultra fast charge
Source:
www.transportenvironment.org

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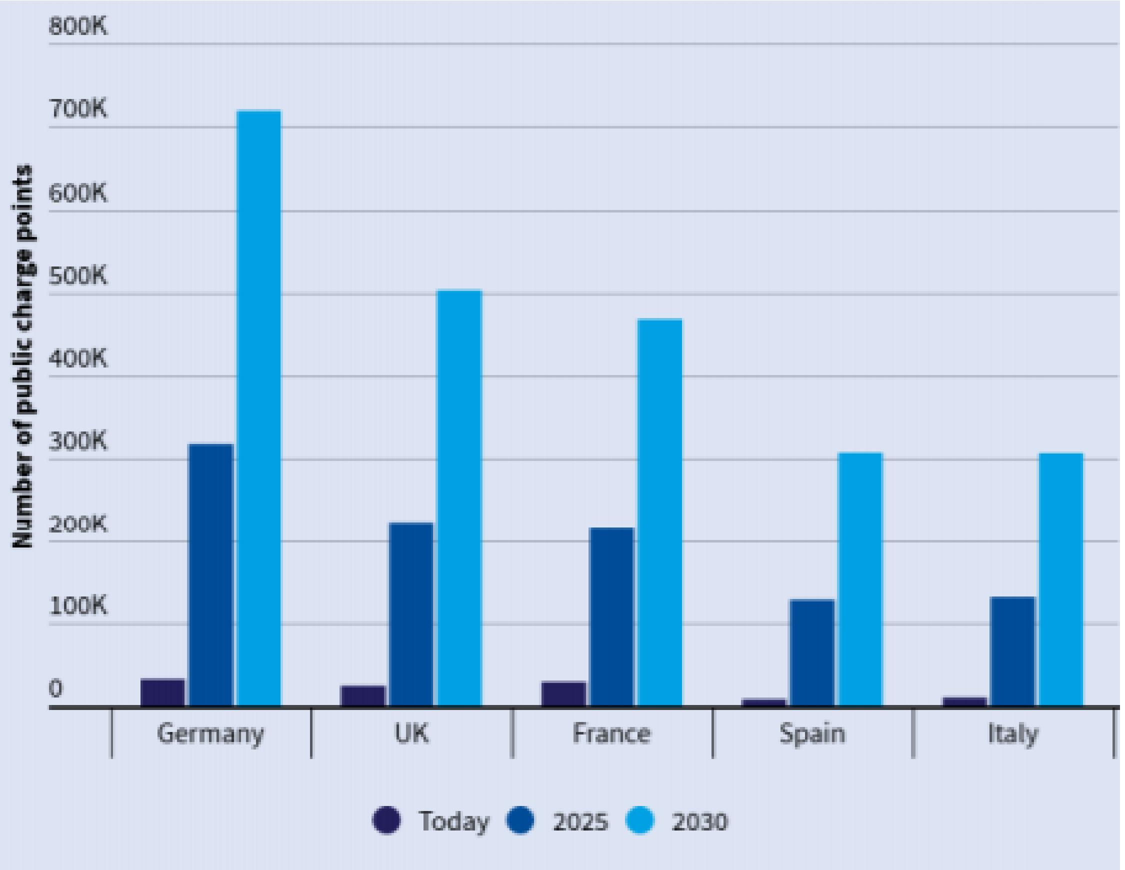
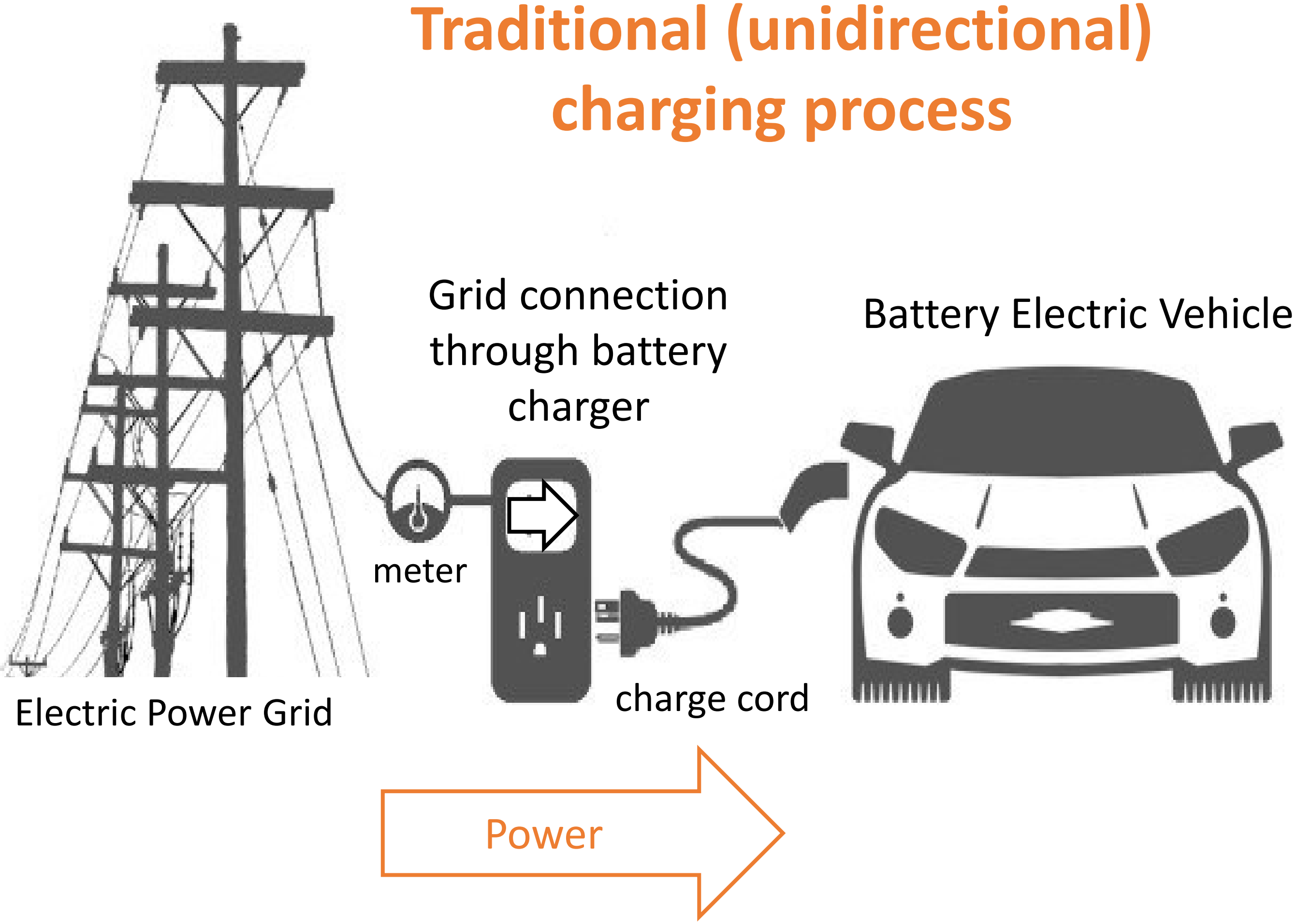
~78% of EU public charge points will be in the five biggest markets



Source: www.transportenvironment.org

Electric vehicles’ charging infrastructure

Traditional (unidirectional) charging process



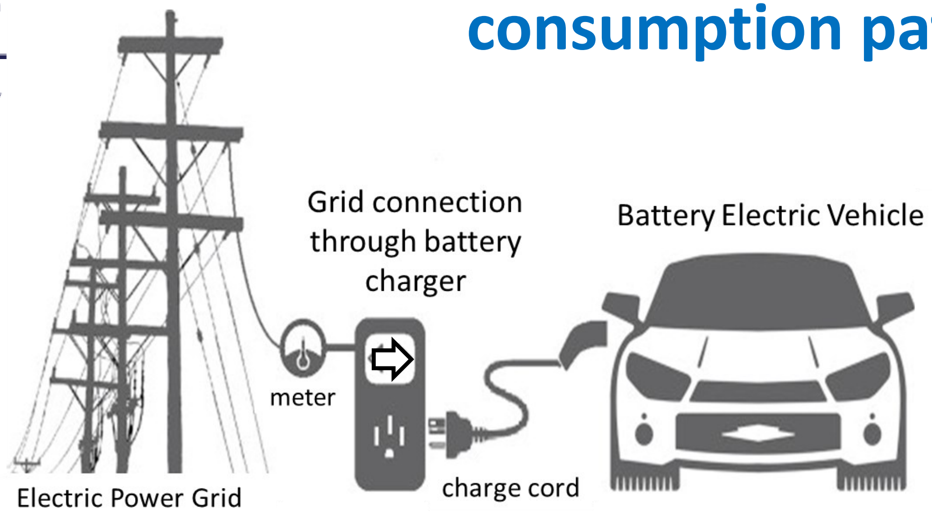
For the electrification strategy to be effective electricity should be produced by renewable sources

If a significant increase in the electric load (due to EV charging needs) occurs at the same time, congestions in the power grid may occurr

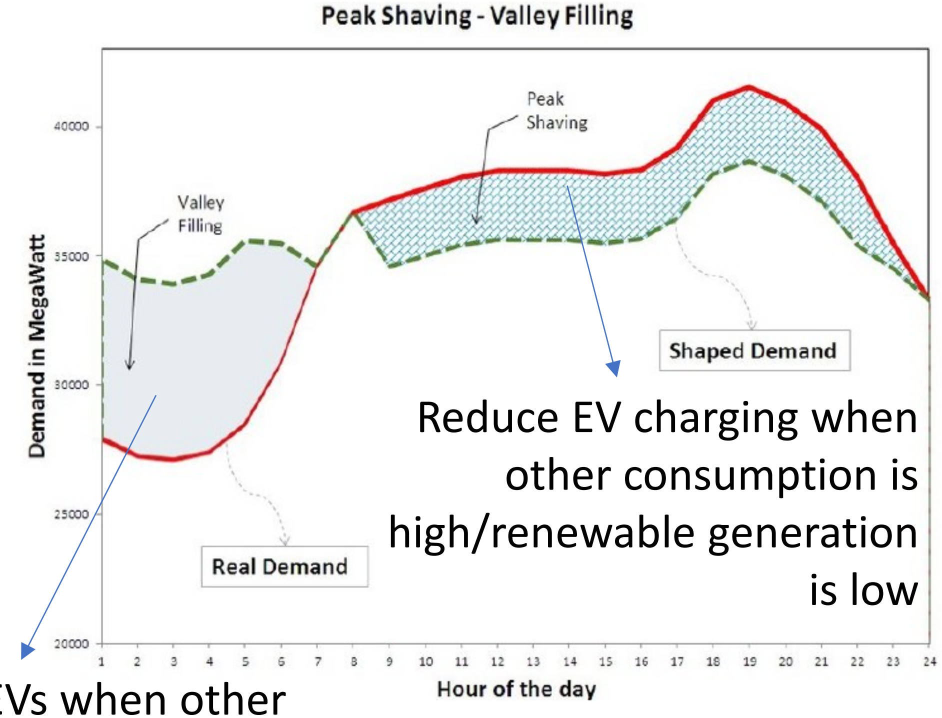
Smart charging may be applied

Unidirectional smart charging

Charging of EVs can be used to better «match» generation and consumption patterns



Power

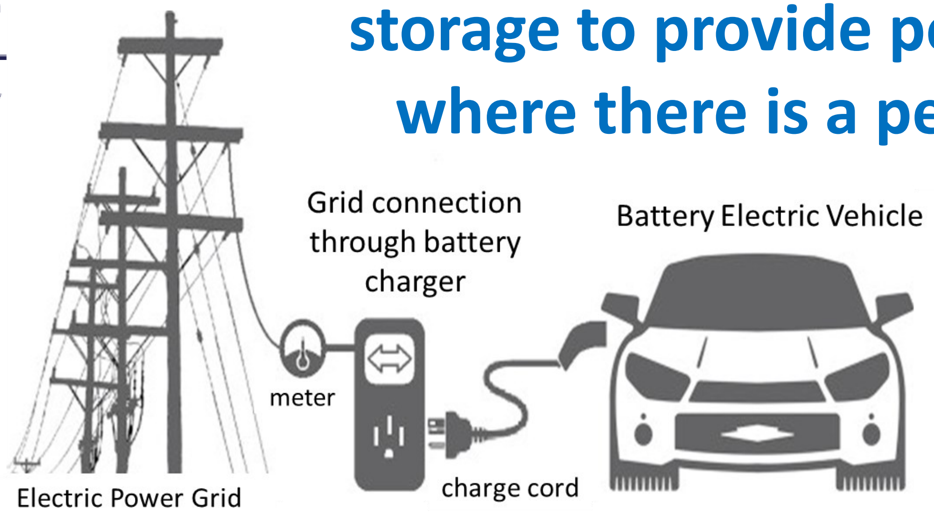


Reduce EV charging when other consumption is high/renewable generation is low

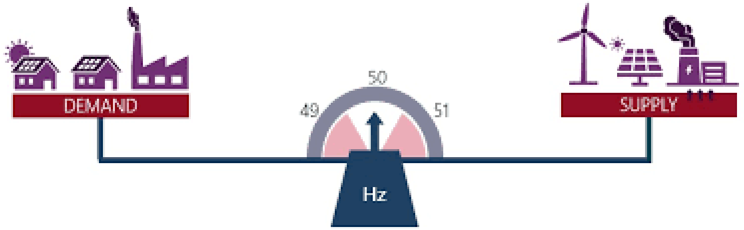
Charge more EVs when other consumption is low /excess renewable energy is available

Bidirectional smart charging: Vehicle-to-grid (V2G)

In Vehicle-to-grid (V2G), batteries of EVs can be used as distributed energy storage to provide power to the grid where there is a peak of demand



The short time of response of such battery systems would allow providing the grid frequency support services



Bidirectional smart charging: Vehicle-to-grid (V2G)

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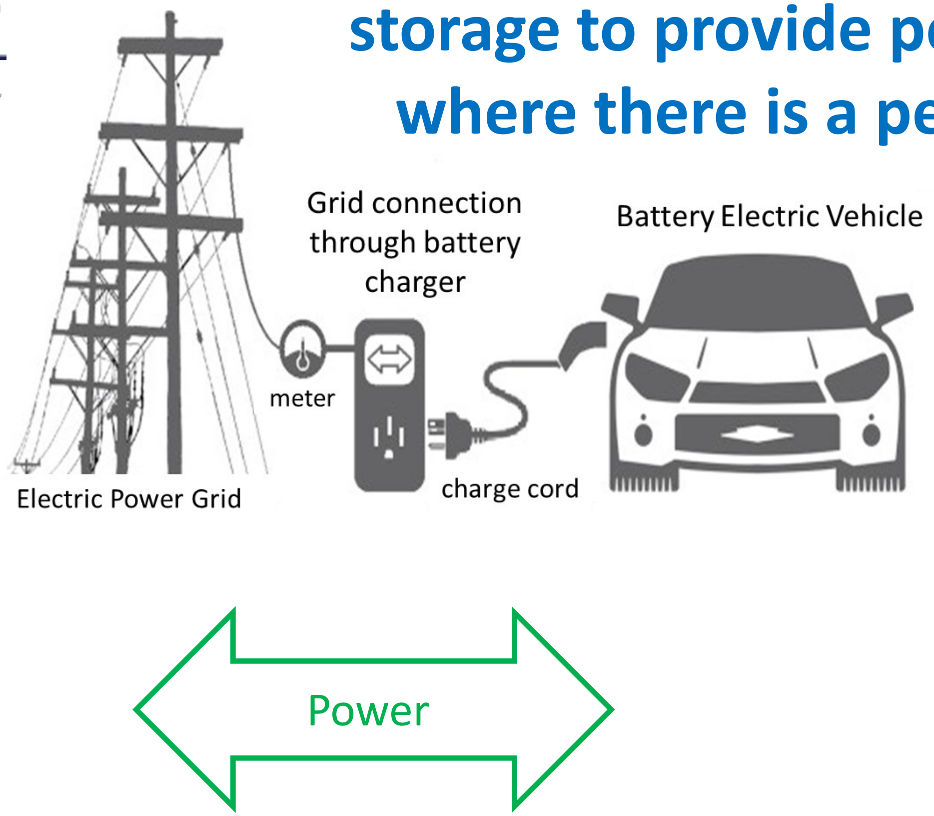
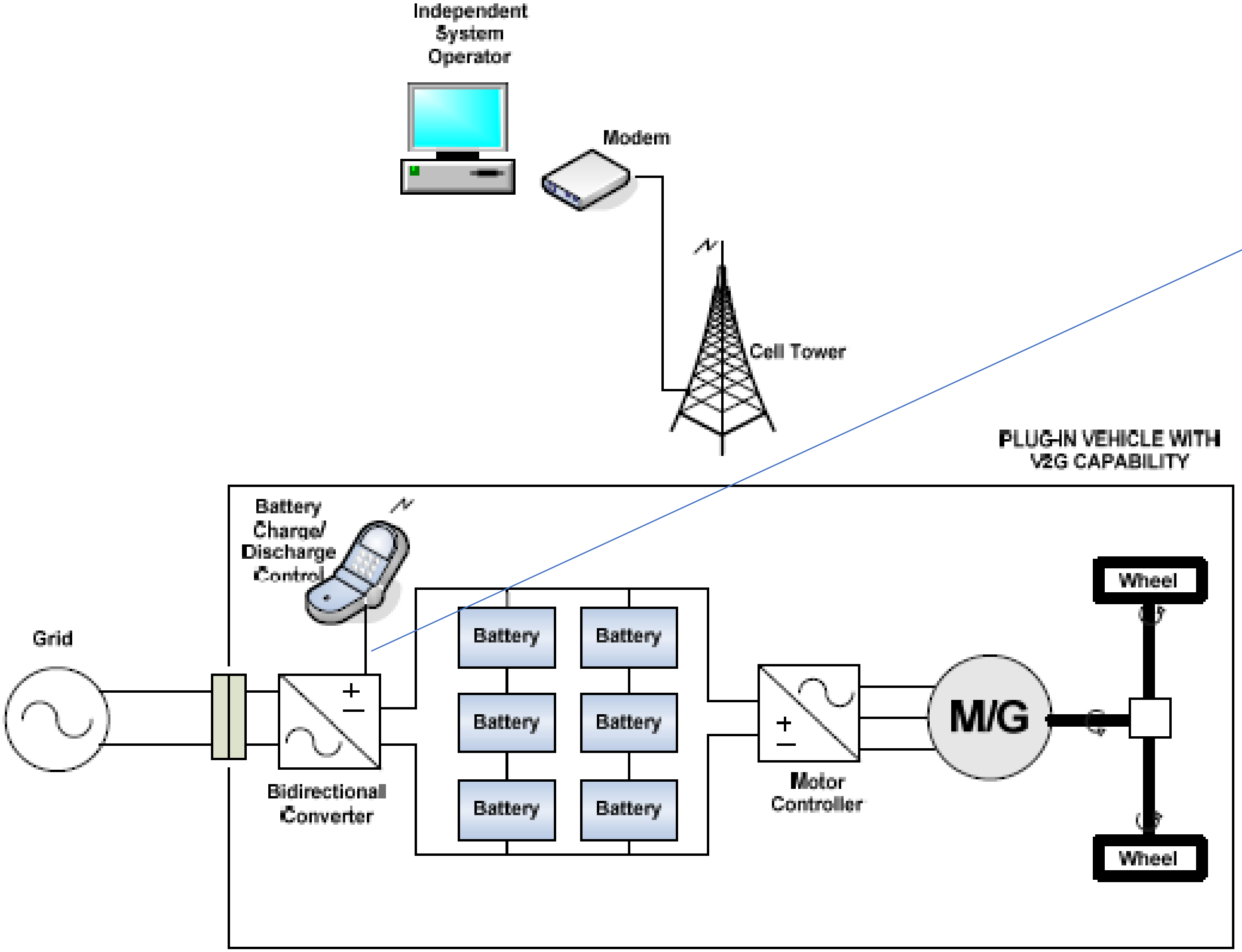
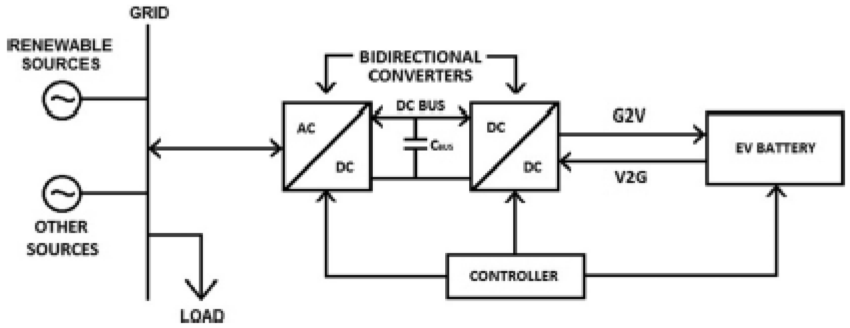


Through the grid dc-ac converter EV can also provide voltage support services (e.g. low-voltage ride through, under/over voltage regulation etc.) that require reactive power provision

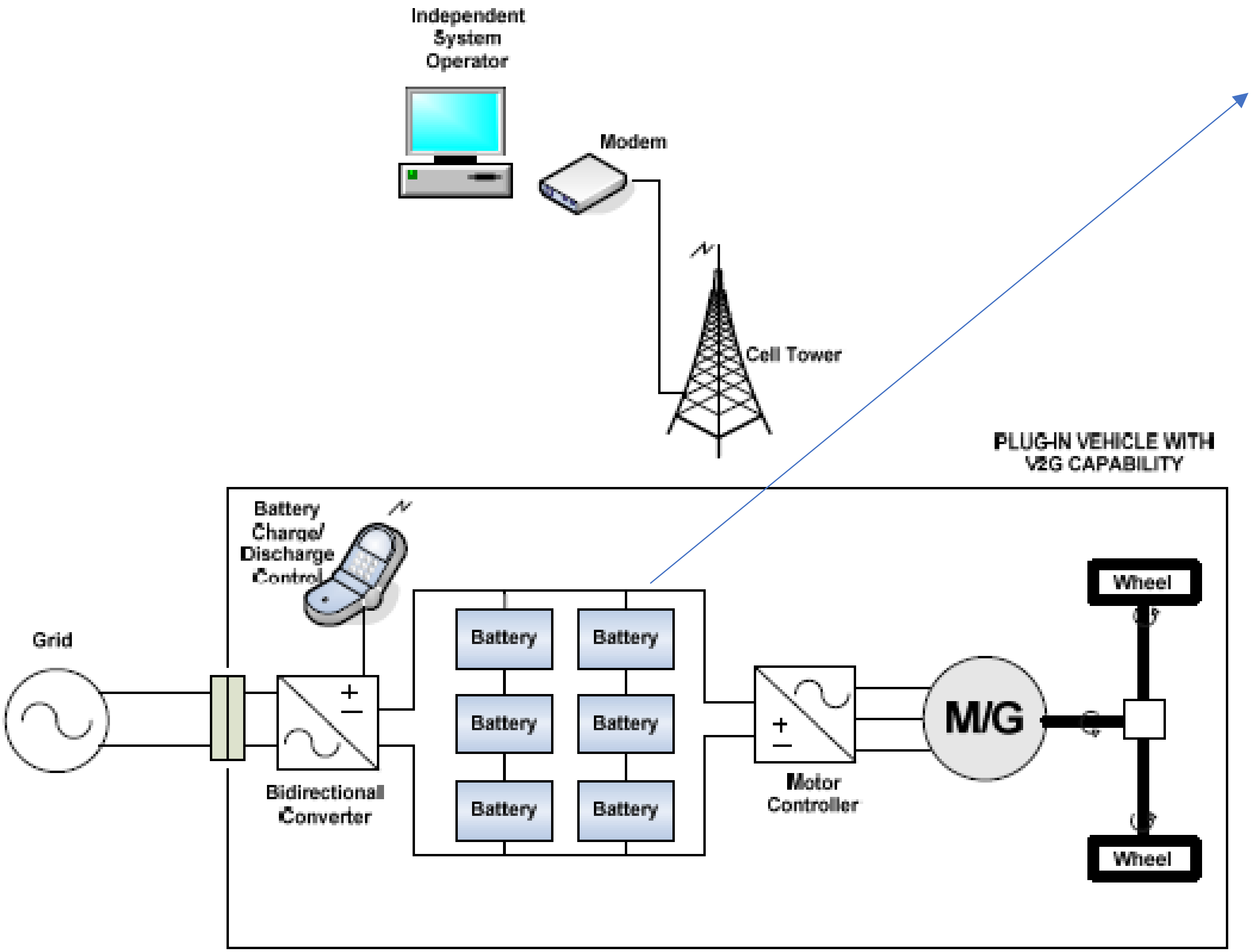
Technical requirements for V2G





To allow V2G the battery charger onboard needs to be bidirectional

Technical requirements for V2G

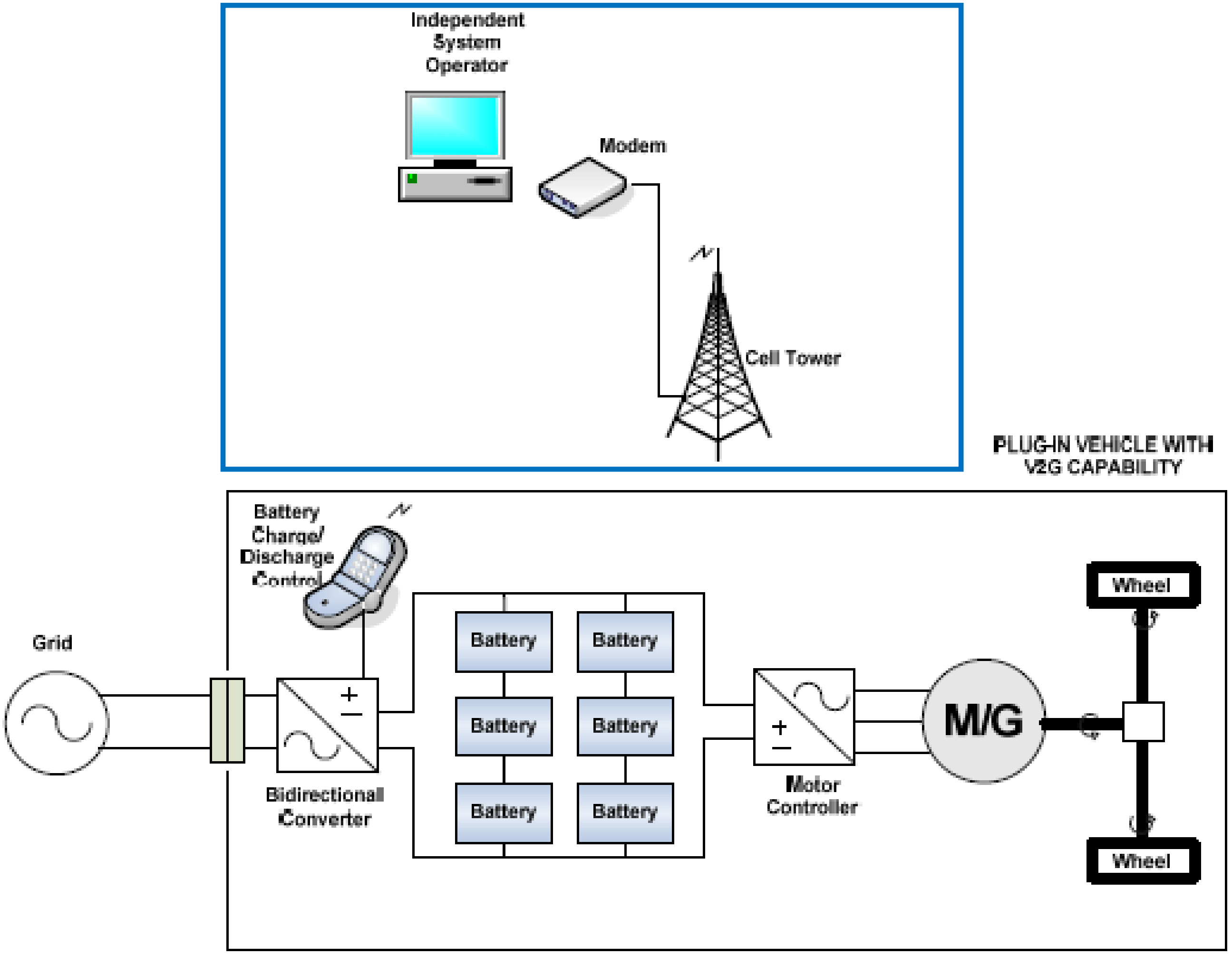


Smart meters need to be installed to monitor the power flows and the state of the battery at every instant

Functionalities:

- Real time power flow measurement
- Remote control including demand/response
- Power quality monitoring
- Communication capabilities

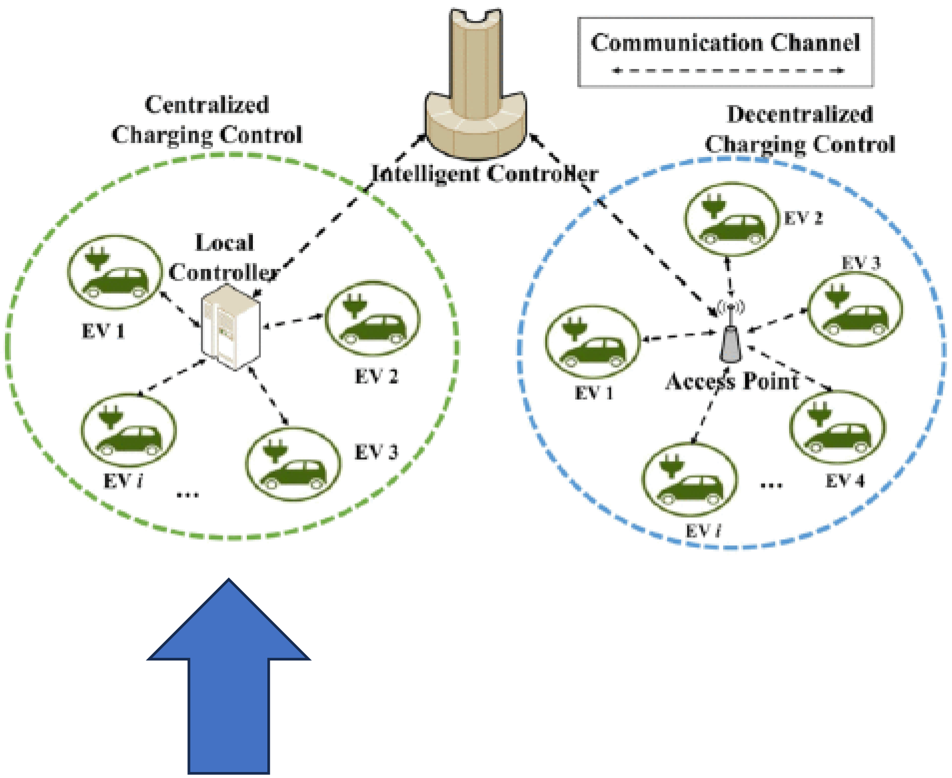
Technical requirements for V2G



Communication requirements

- between the Electric Vehicle Management System (EVMS) and the Smart Meter (SM). Based on wireless communication or power line communication
- between the SM and the data centers of the network operator. Based on mobile communication technologies

Smart charging strategies: centralized control



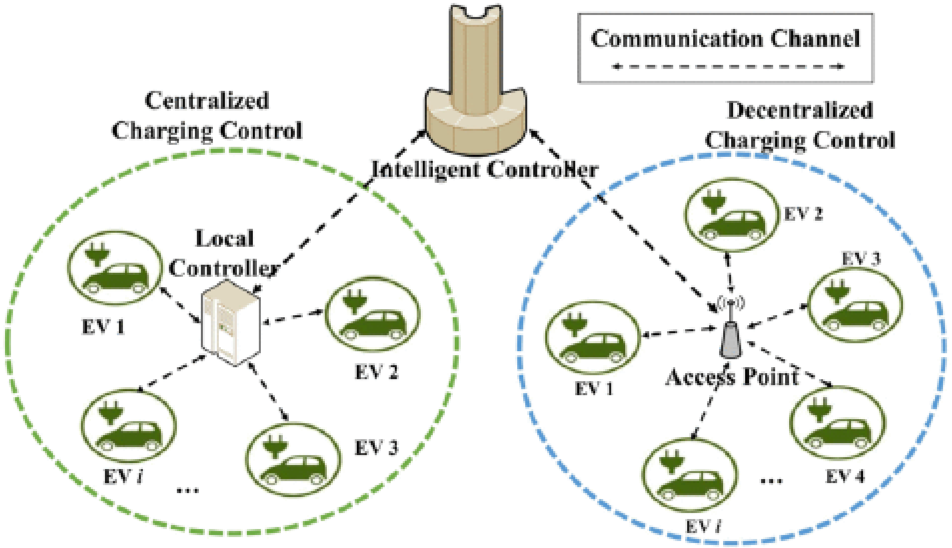
Centralized charging control

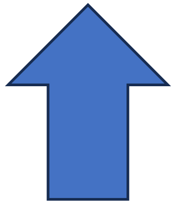
A central operator (i.e., aggregator) establishes when and at which price each EV should charge. Decisions depend on EV/system needs, and can be based on predictive algorithms

Criticalities:

- the aggregator fails to solve the optimization problem
- scalability

Smart charging strategies: decentralized control





Decentralized charging control

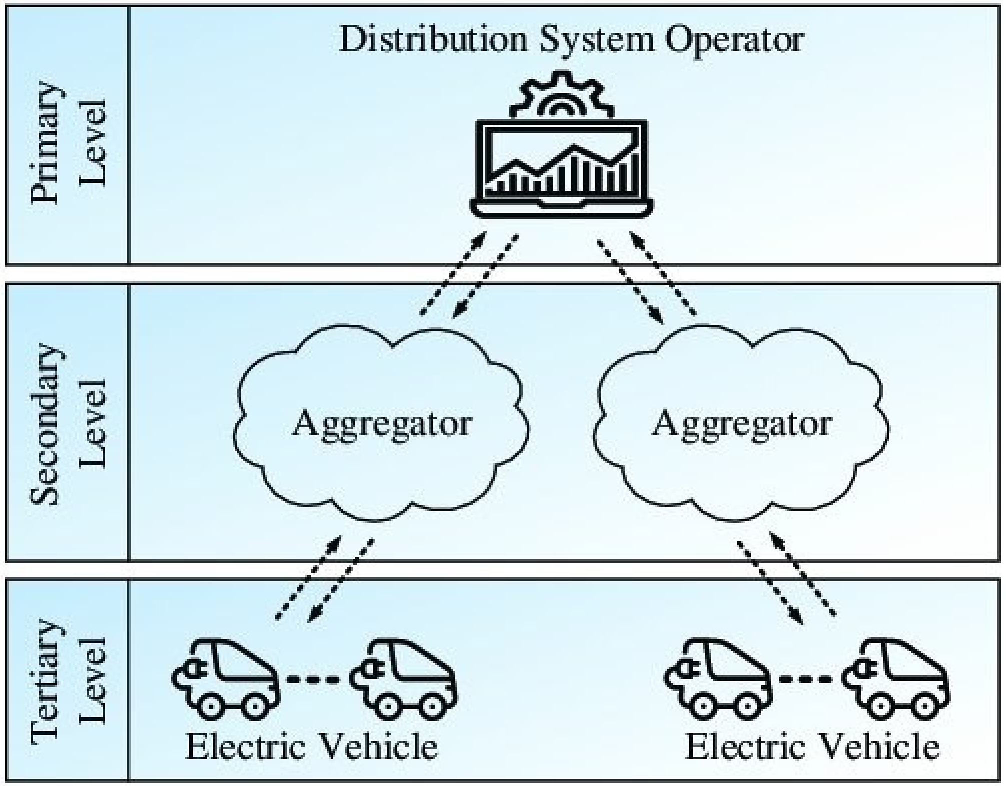
Each EV has the full freedom to decide its charging pattern. The network operator can only influence such choices indirectly, e.g., through financial incentives. Highly scalable

Criticalities:

Optimal energy usage policy cannot be guaranteed.

Ancillary services provision is more complex

Smart charging strategies: hierarchical control



Hierarchical control

Organized into 2 layers. The grid operator manages multple aggregators to achieve grid objectives. Every aggregator manages a group of loads

Criticalities:

Vulnerability to faults in the highest levels

Role of EVs users/incentives

Charging strategies need to comply with users' needs, which may be defined in a more or less specific way (also depending on the cooperation strategy).
This goes from setting:
- Hard requirements

To setting:
- Hard reqirements
- Less-critical requirements
- Other preferences

When users have full charging/discharging freedom, financial incentives may help orient their choices

Privacy aspects

The need for a communication level and the associated exchange of data, have implications on privacy policies and data security aspects

Data minimization
Data generalization
Data suppression **aimed at:**

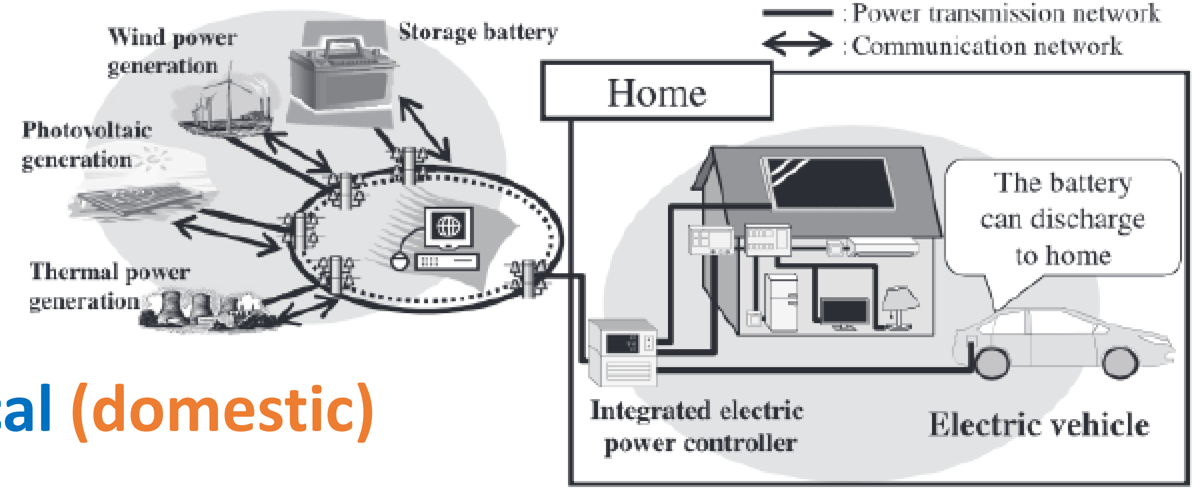
Anonimity, unlinkability, undetectability, unobservability, pseudonimity

Data	Billing relation	Reliability relation	Security relation	Privacy relation	Description
Customer ID			√	√	customer name, vehicle ID
Location data			√	√	charging location and schedule
Meter data	√				electricity consumed or supplied over a time period
Configuration data		√	√		system operational settings, thresholds for alarms, task schedules, policies, etc.
Control commands		√	√		inquiries, alarms, events, and notifications
Access control policies		√	√	√	permitted communication partners, their credentials and roles.
Time, clock setting	√	√	√		used in records and sent to other entities.
Payment and tariff data				√	informing consumers of new or temporary tariffs as a basis for purchase decisions.
Firmware, software, and drivers		√	√		software components installed and may be updated remotely.

Vehicle to Home (V2H)

Another advantage of the V2G, is the possibility to use EV batteries as domestic storage system

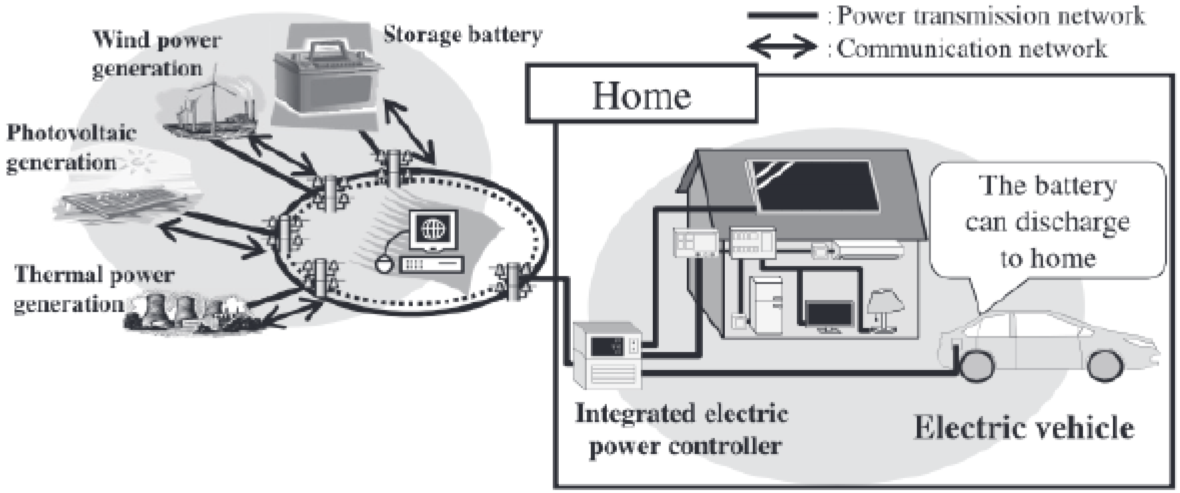
In this case, the EV is not supposed to exchange power with the main power system, neither to provide grid support services to the main grid.
It is only dedicated to optimizing the local (domestic) energy management



Home energy management systems (HEMSs) shift and reduce energy demand from the main grid based on electricity prices and user's needs

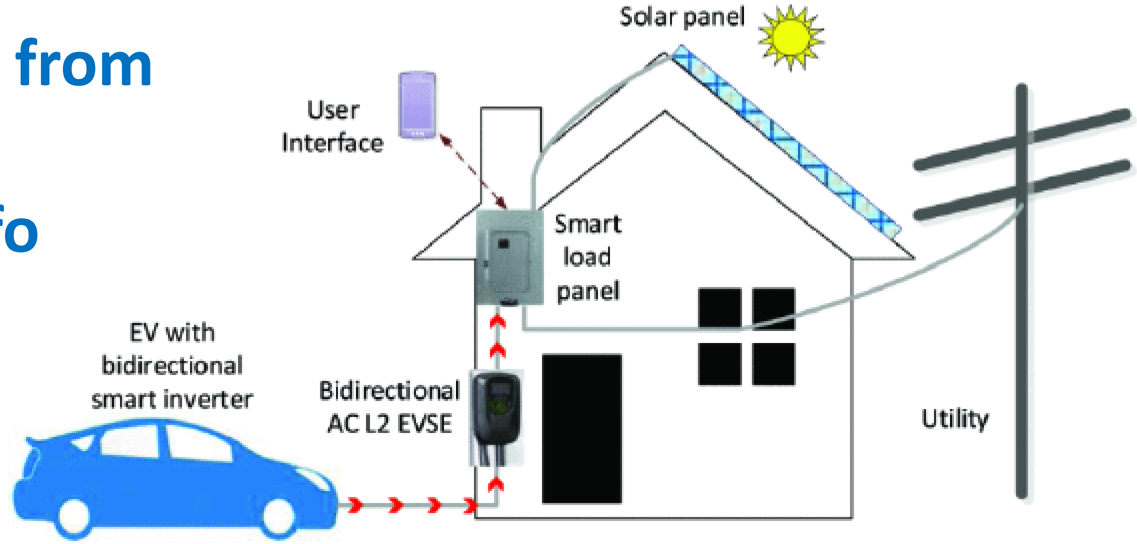
Vehicle to Home (V2H)

Home energy management systems (HEMSs) can communicate with domestic appliances and receive external information (e.g. local electricity production data, electricity prices), to optimize local consumption patterns



Vehicle to Home (V2H)

The V2H requires:
- Local generation
- Bidirectional battery charger (switching from EV charging to V2H mode)
- Smart panel, sensoring/capturing all info on local (critical) loads
- User's interface to input user's needs/preferences on both the EV and home appliances



Real use-cases

Commerical EVs with V2G capability

- Nissan Leaf ZE1
- Mitsubishi Outlander PHEV
- Volkswagen ID
- Hyundai Ioniq 5 & Ioniq 6
- Ford F-150 Lightning
- KIA EV6
- BYD Atto 3
- BYD Han EV
- MG ZS EV (2022)

Real use-cases: Utrecht mobility project

Hyundai Motors Group has partnered with mobility provider We Drive Solar and has launched a new mobility project in Utrecht. Hyundai is deploying 25 IONIQ 5 units with vehicle-to-grid (V2G) technology to lead Utrecht to become the world's first bi-directional region

Hyundai's deployment of IONIQ 5 units equipped with solar technology will be utilised in a new car-sharing service for the Cartesius district. Eventually, 150 vehicles will serve as a buffer for renewable energy on the grid, and also help reduce traffic on the streets, and emissions

Real use-cases: California E-bus mobility project

Cajon Valley Union School District in California, which has worked with its electric utility and technology partners to build out its electric school bus (ESB) fleet while participating in a vehicle-to-grid pilot program and discharging energy back to the electric grid (7 of the district's 49 school buses are V2G capable ESB).

Cajon Valley's 7 V2G-enabled ESBs can simultaneously discharge to the grid through their chargers. The original five buses are reportedly discharging 24 or 28 kW of power back to the grid, while the newer two buses are discharging 45 kW of power. To maximize benefits for the grid, the buses are engaged in managed charging and will charge outside of peak hours when not in use

Conclusions

- Electric mobility, particularly electric road transport is pivotal to the energy transition
- Transport electrification has, however, serious consequences on the electrical infrastructure, especially in case of significant uncoordinated load demand
- Vehicle-to-grid (V2G) capability can turn EV batteries in a form of distributed energy storage that can be used to support the electric grid operation and help counteract renewable energy intermittency, if properly managed
- Vehicle-to-home (V2H) and in general V2X offer further flexibility in different contexts

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