MAPNA GROUP
EVIDC
Electric Vehicle & Infrastructure Development Center

Workshop

MAPNA GROUP
MAPNA Electric & Control Engineering & Manufacturing Co. (MECO)

Title:

Electric Vehicles: Fundamentals, Structures, and Infrastructures

Presented by:

Alireza Khoshsaadat

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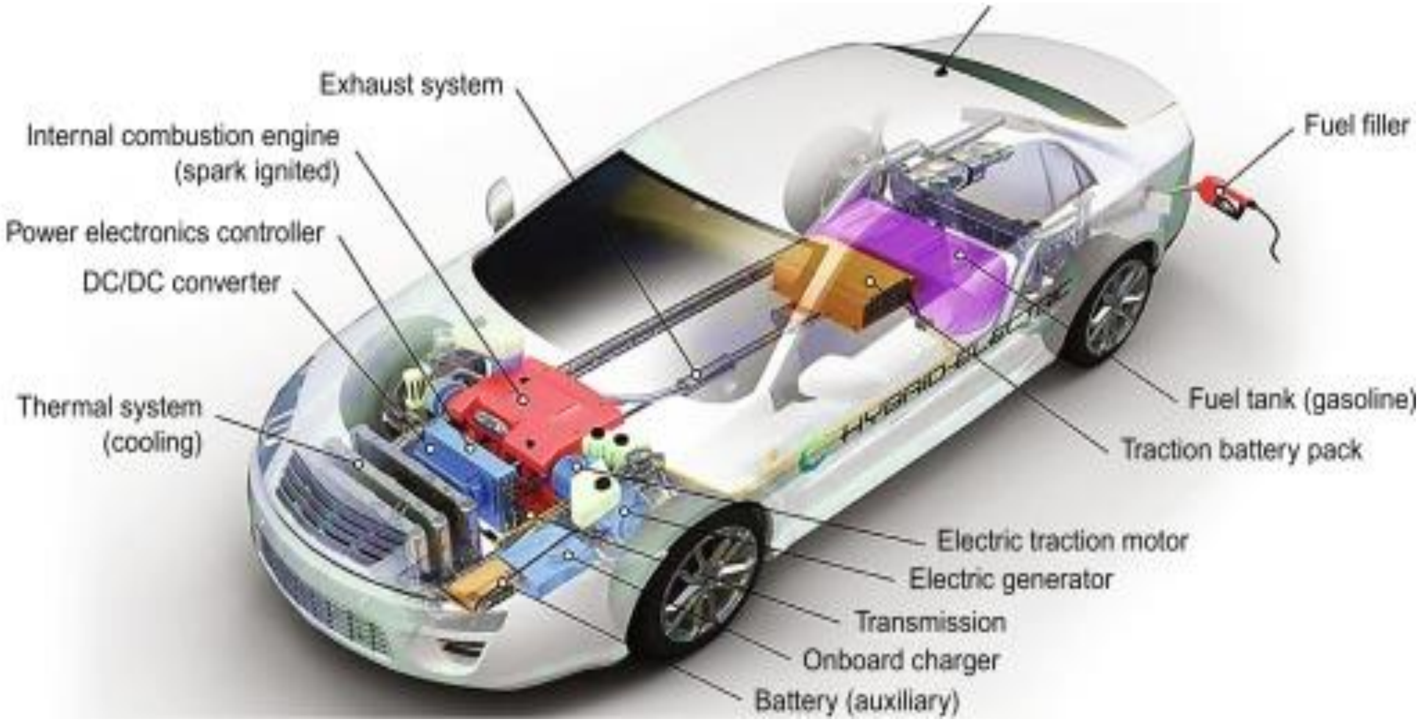

Chapter 2: Charging Infrastructures of EVs: Types, Charger Topologies, and Standards;

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3.1. EV Impacts on Our World;

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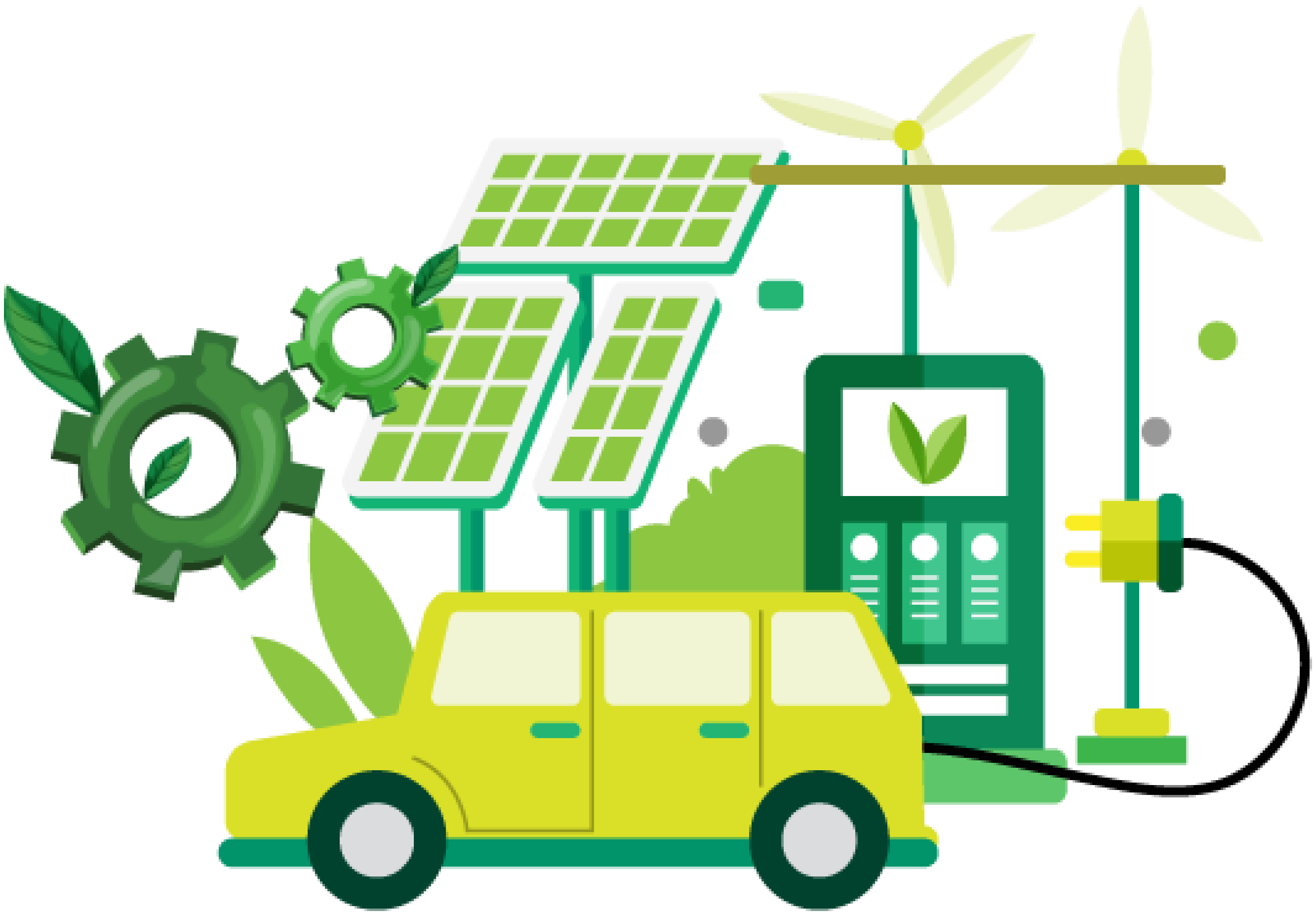

Chapter 4: MAPNA Group: Electric Vehicle Infrastructure and Development Center (EVIDC);

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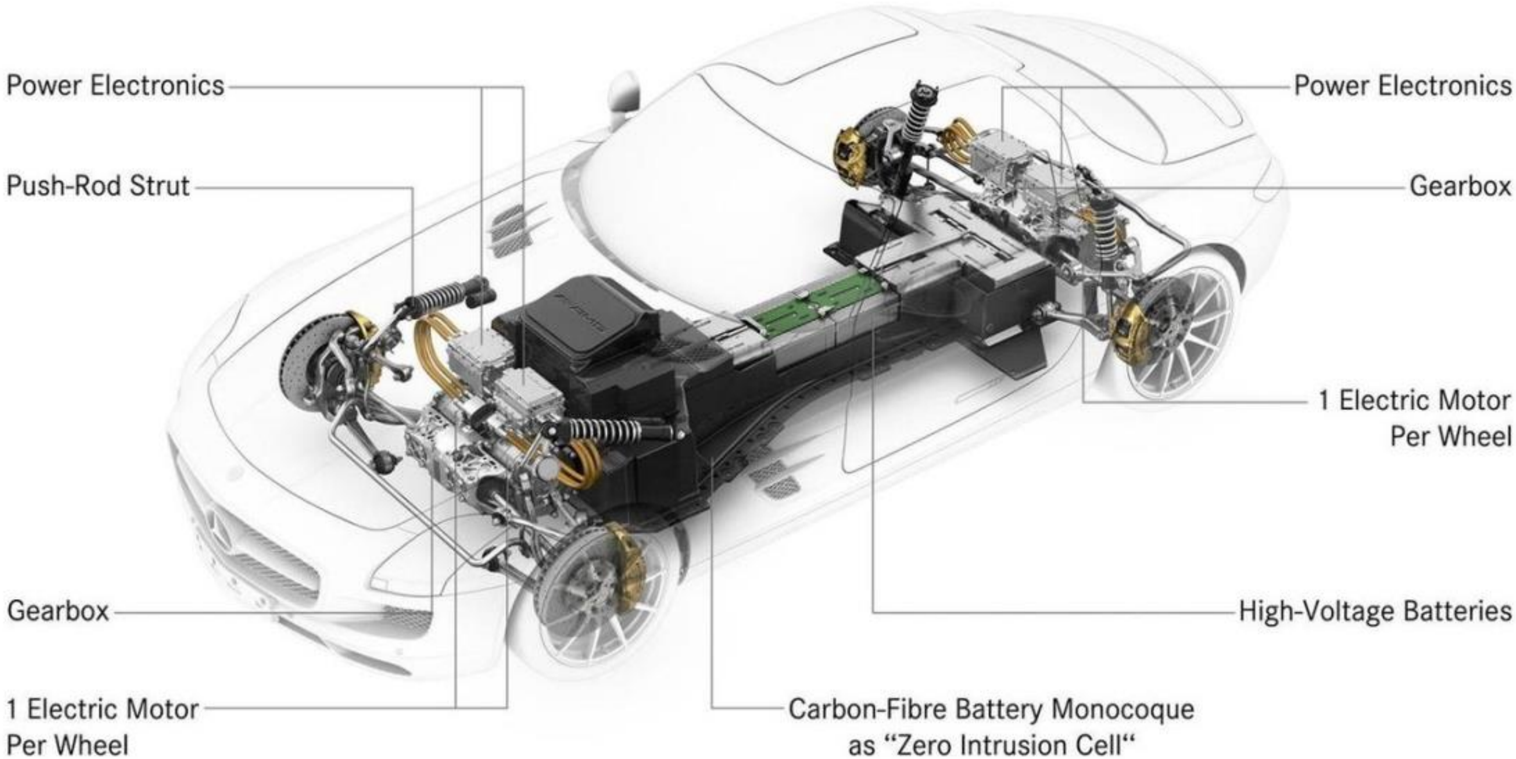
Chapter 1:

Electric Vehicle (EV): introduction, general types, structure, and subsystems



1.1. Definition, Merits and limitations

- **An Electric Vehicle (EV)** is a vehicle that is powered or propulsed, at least in part, by electricity.

- **Main merits of EV:**

✓ Contribution in reducing Green House Gas (GHG): in 2009, the transportation sector emitted 25% of the GHGs produced by energy related sectors;
✓ Quiet operation (reducing noise pollution urban);
✓ Provides the total torque from startup (high instant torque);
✓ Does not require trips to the gas station;
✓ Various onboard energy storage devices (batteries, Ultra-Capacitors (UCs), Fuel Cells (FCs));
✓ Does not use any stored energy or cause any emission while idling;
✓ Regenerative braking to recover the kinetic energy of the vehicle;

- **Main limitations of EV:**

✓ High costs (Due to high price of battery pack);
✓ Battery volume and weight;
✓ Short drive range per charge;
✓ Long charging time;
✓ Loading a high demand on power grid.

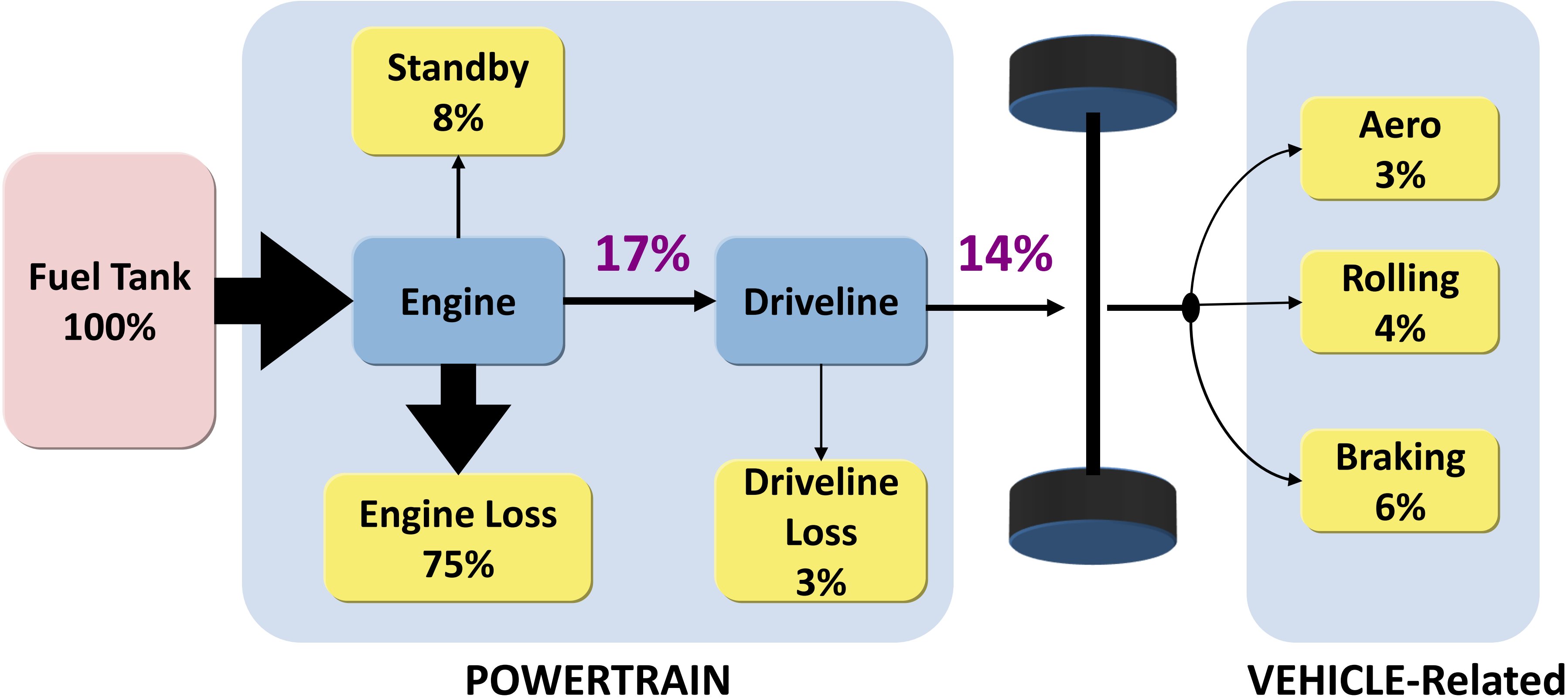


Fig. 1. Input to output (tank-to-wheel) efficiency of a typical Internal Combustion Engine (ICE) vehicle, 2005 3 L Toyota Camry, in city driving condition.

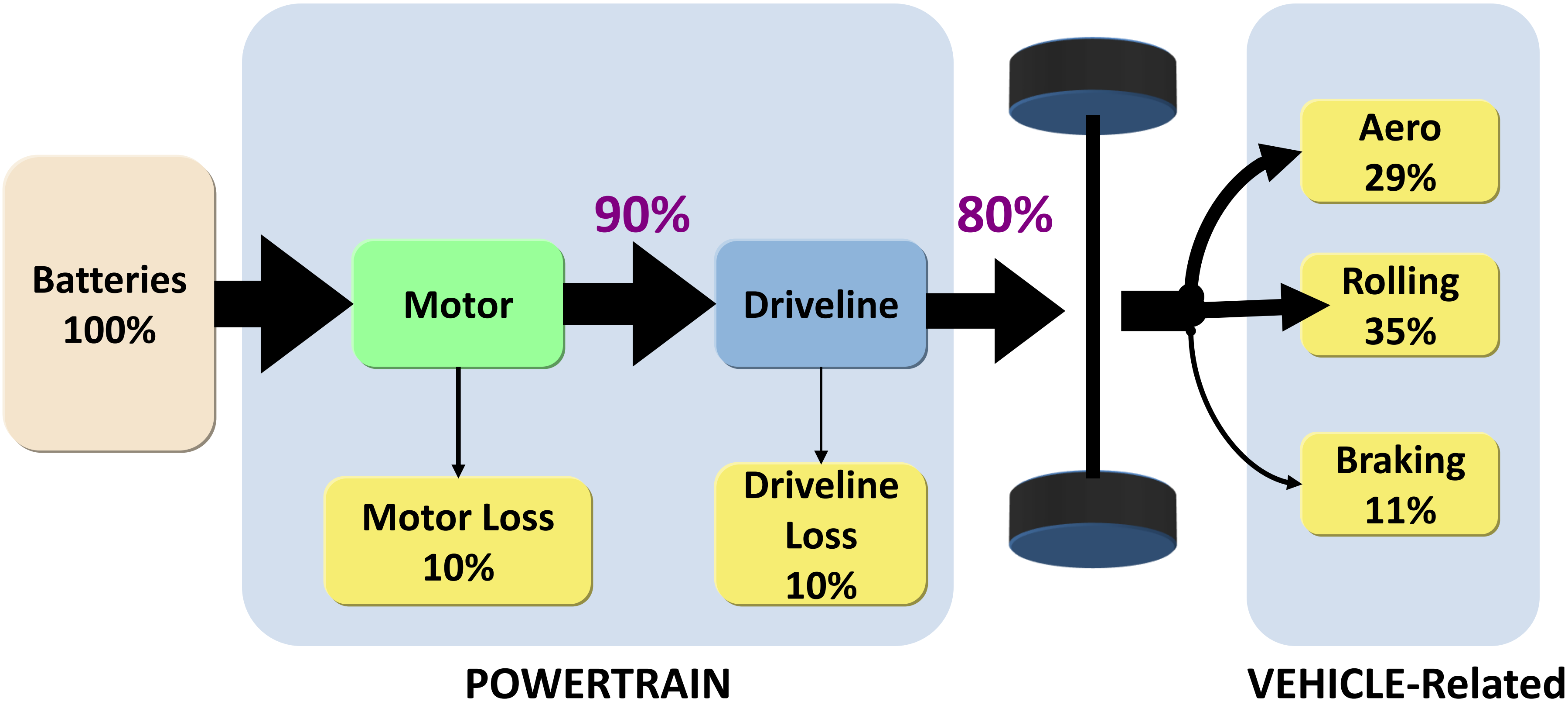


Fig. 2. Input to output (plug-to-wheel) efficiency of a typical EV in city driving condition.

- A comparison between **well-to-wheel** chain efficiency in both EVs and Internal Combustion Engine (ICE) vehicles demonstrate that an EV has higher chain efficiency.

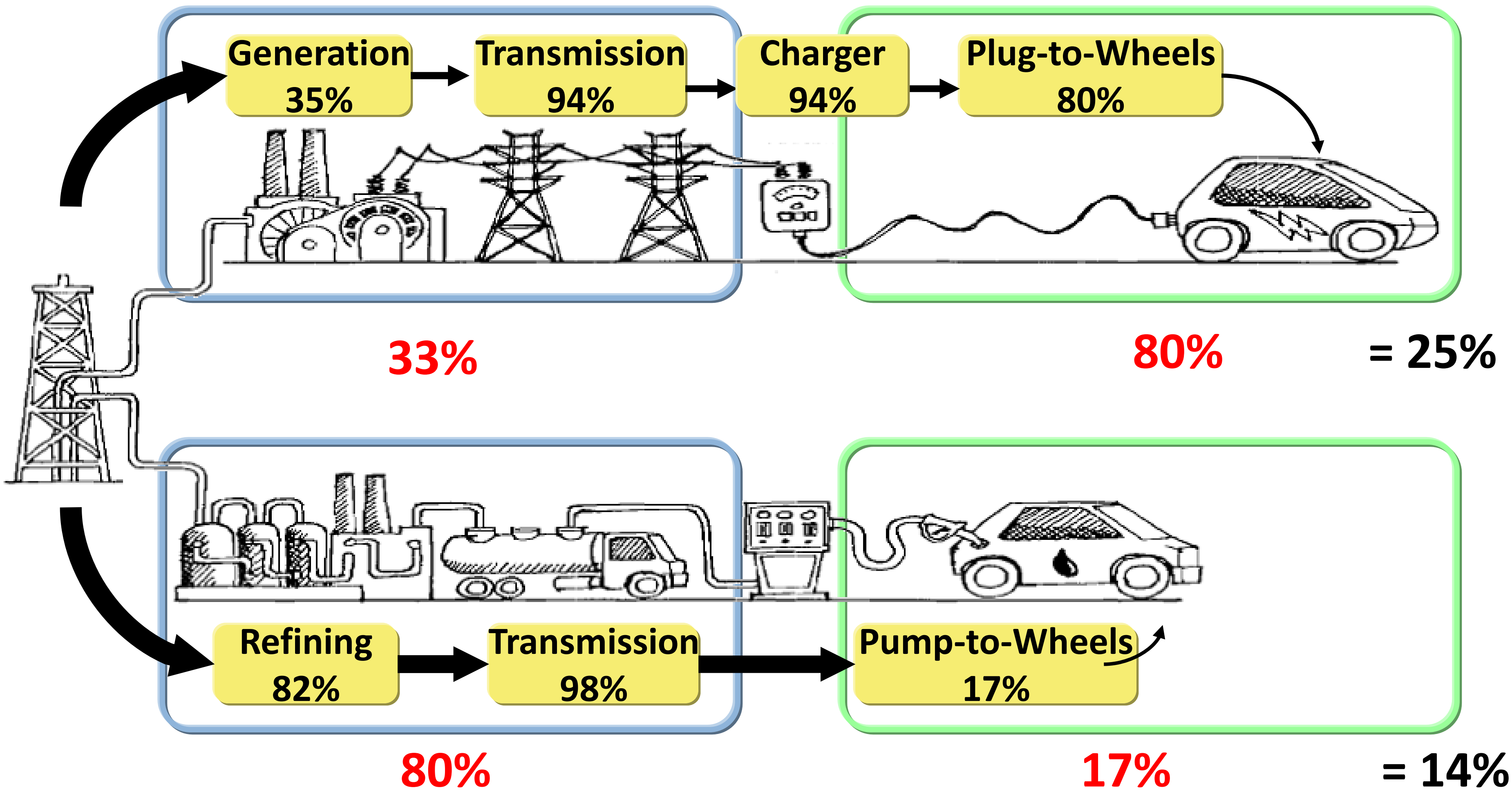


Fig. 3. Well-to-wheel efficiency comparison between the EVs and ICE vehicles.

1.2. EV history

- By the 1900s, EVs had captured a notable share of the leisure car market. Among the 4200 automobiles sold in the United States in 1900, **38% were electric** and only **22% were gasoline**, while another **40% were still steam driven**. Why ICE conquered the market and EVs got lost into oblivion?

- ✓ Very low oil price;
- ✓ Simple operation of Vehicle starter;
- ✓ Problems in battery technology (low energy density cause to Short driving range; and low life cycle);
- ✓ Weak chargers technology;

A few decades stagnation of EVs

$$\eta_{W-W} = \eta_{W-T} \times \eta_{T-W}$$

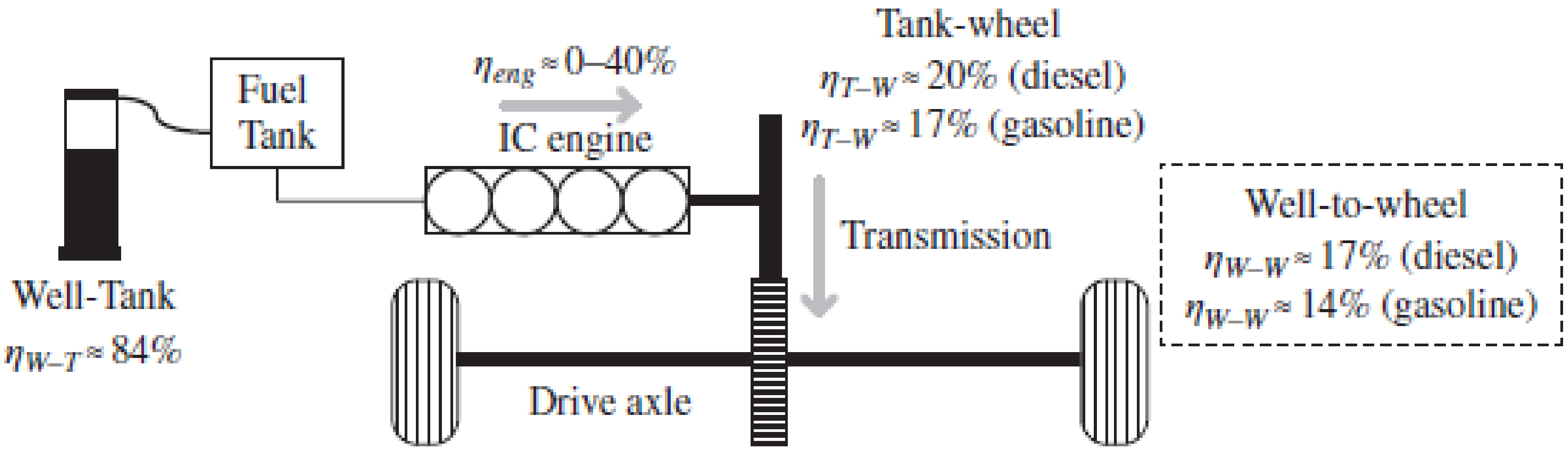


Fig. 4. Conventional vehicle architecture and energy flow.

- EV resurrection began with **General Motors EV1** production in 1996 and quickly became very popular. Other carmakers, **Ford**, **Toyota**, and **Honda** presented their own EVs as well. **Toyota Prius**, was the first commercial Hybrid Electric Vehicle (HEV), launched in Japan in 1997, with **18,000** units sold in the first year of production.
- Nowadays, the market is dominated by **Nissan Leaf**, **Chevrolet Volt**, and **Tesla Model S**, and **BYD** (mostly in Chinese market).

Nissan Leaf

Chevrolet Volt

General Motors EV1

Tesla Model S

BYD Tang

1.3. Statistic of EV trend in the world;

- Some of most **famous EV manufacturers** are: Nissan, Mitsubishi, Chevrolet, Tesla, BYD.

Table 1. Some of first mass produced highway-Capable and Light Utility. EVs.

Model	Market Launch	Global Sales	Sales Through
Nissan Leaf	December 2010	83,000	September 2013
Mitsubishi i-MiEV family	July 2009	>26,000	September 2013
Tesla Model S	June 2012	18,200	September 2013
Renault Kangoo Z.E.	October 2011	11,069	September 2013
Chery QQ3 EV	March 2010	9512	October 2013
Renault Zoe	December 2012	6605	September 2013
Mitsubishi Minicab MiEV	December 2011	4972	September 2013
BYD e6	May 2010	3220	October 2013
Tesla Roadster	March 2008	~2500	December 2012
Bolloré Bluecar	December 2011	2300	September 2013
Ford Focus Electric	December 2011	2167	September 2013

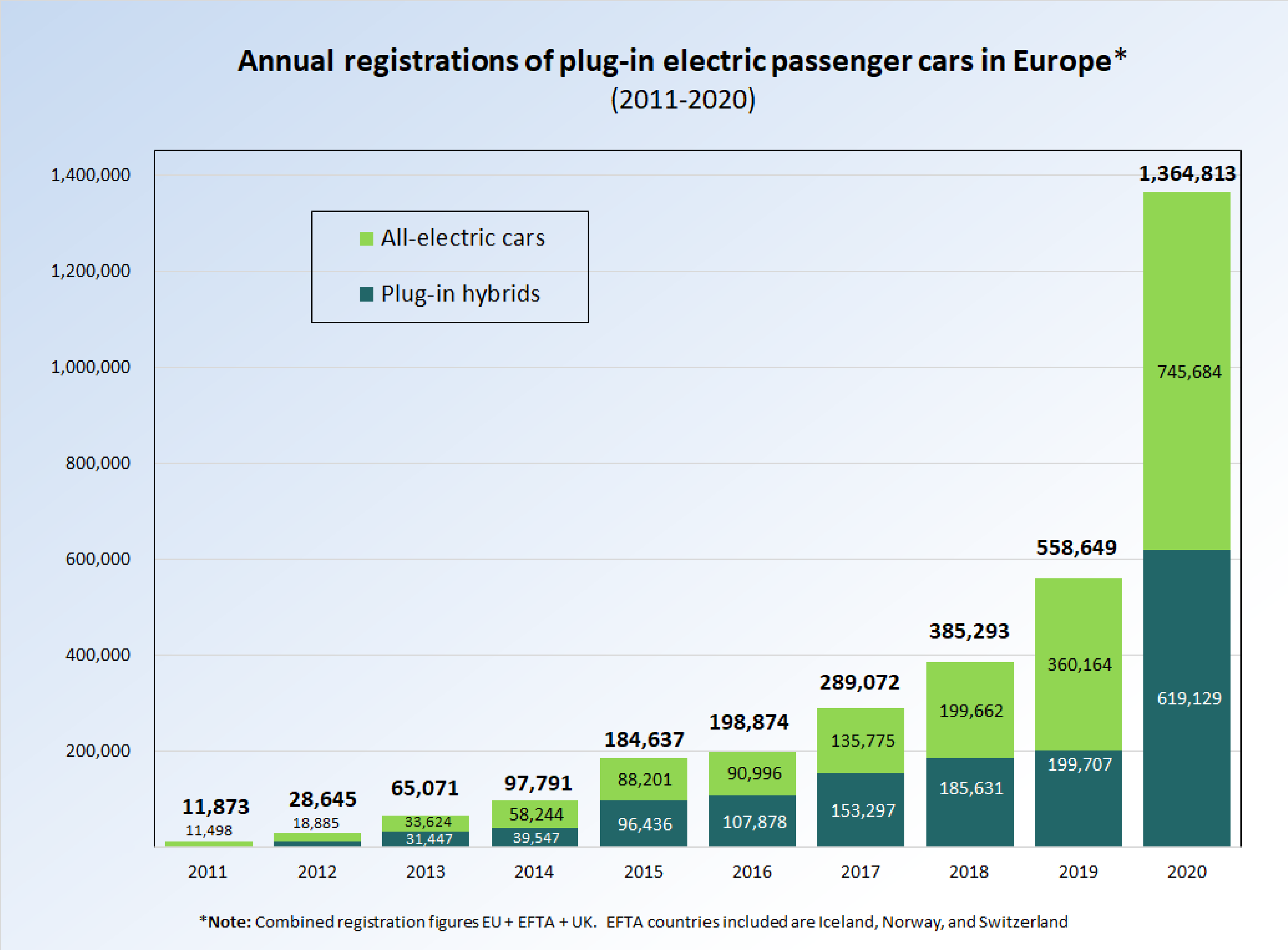


Fig. 5. Annual registration statistics of plug-in passenger EVs in Europe from 2011 to 2020.

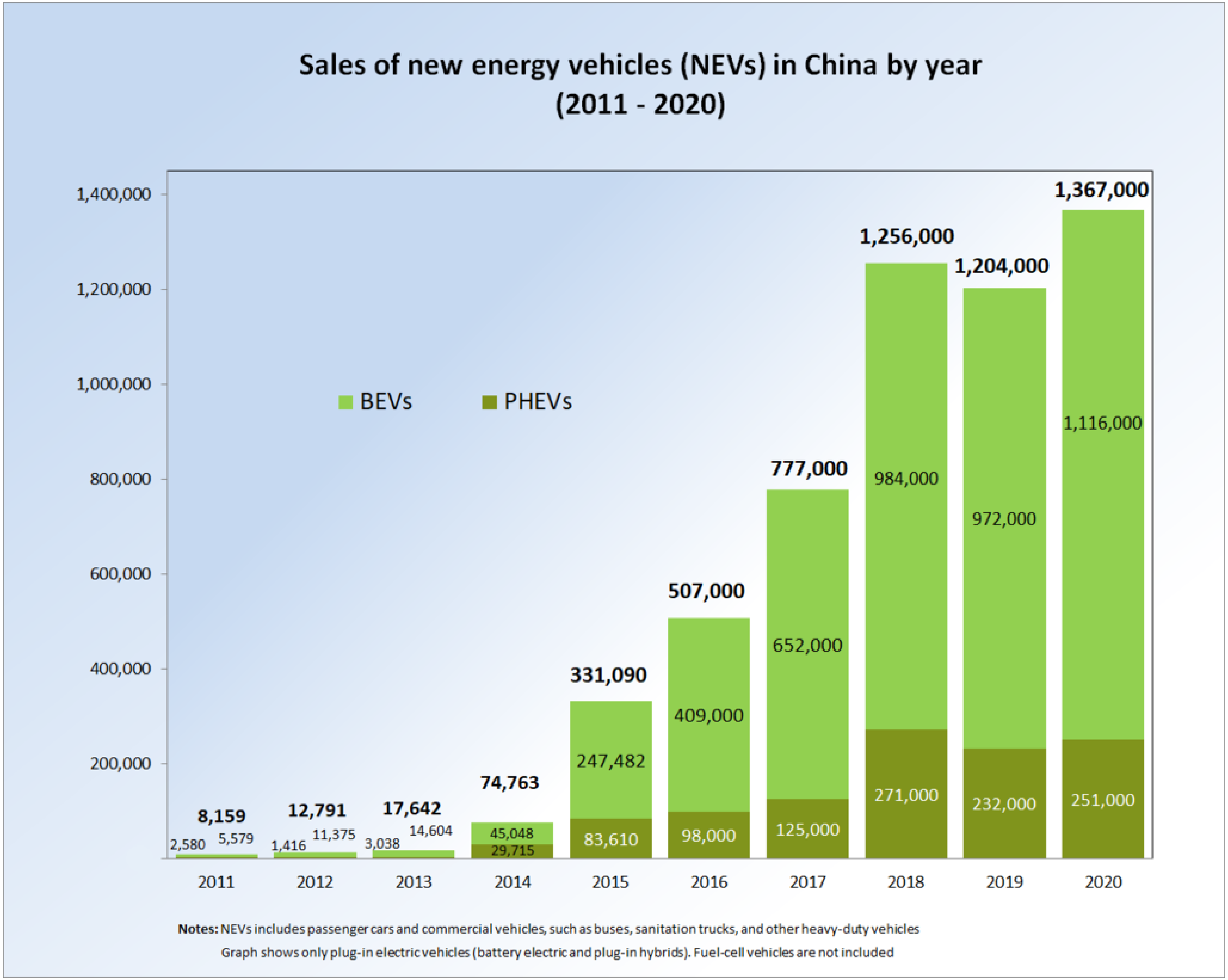


Fig. 6. Annual sales statistics of EVs in China from 2011 to 2020.

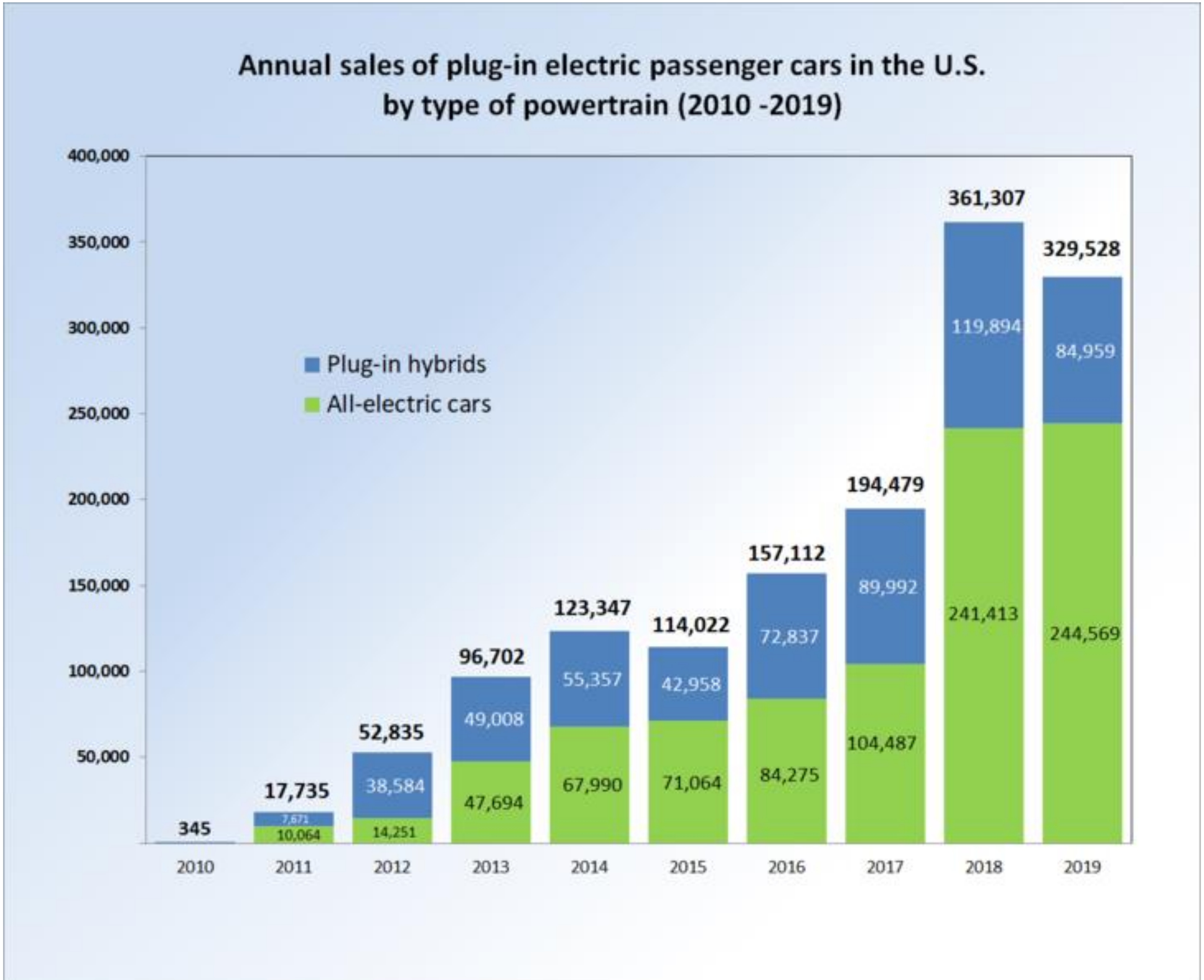


Fig. 7. Annual sales statistics of EVs in the U.S. from 2011 to 2019.

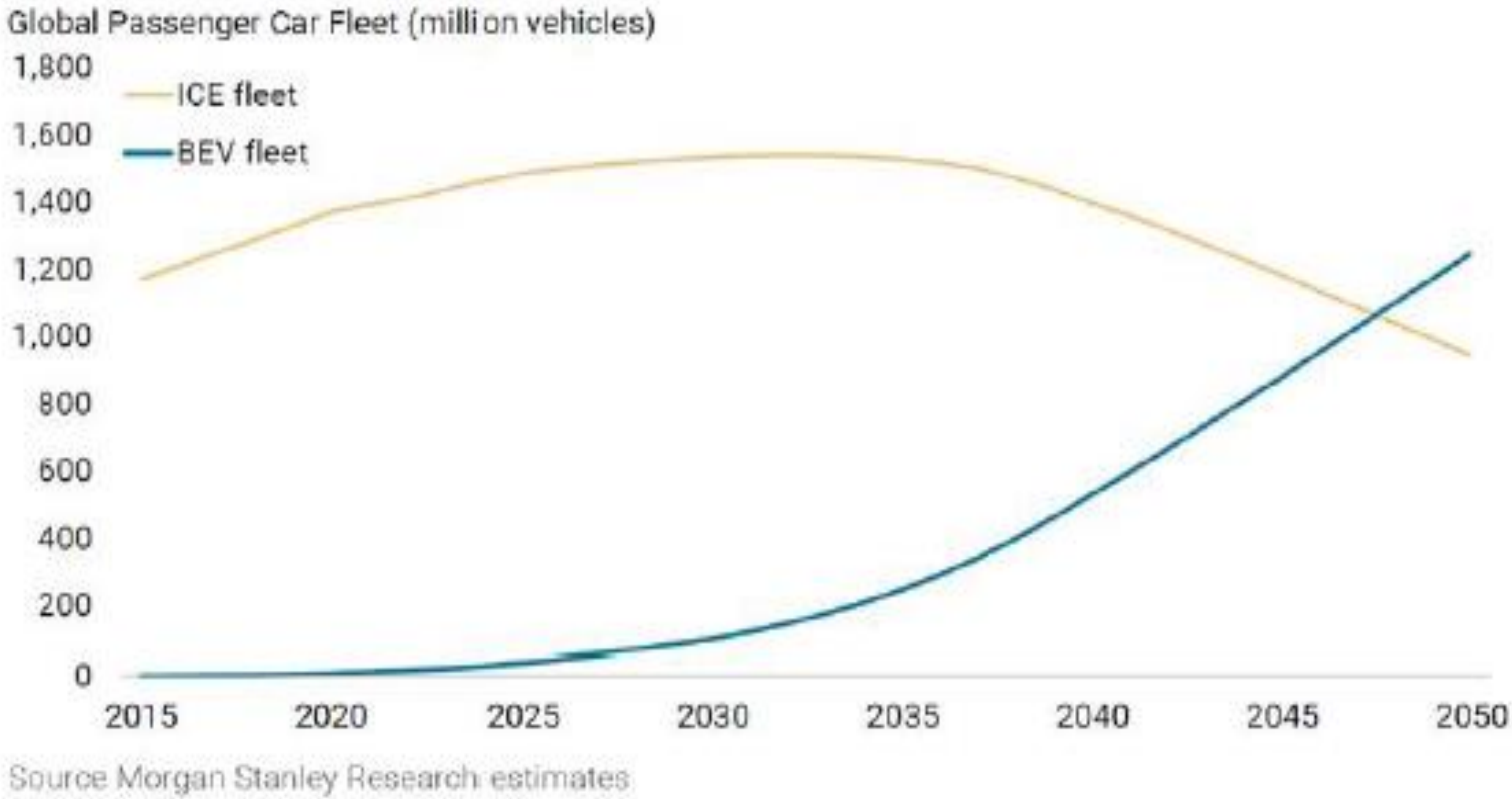


Fig. 8. Number of EVs and ICE Vehicles in a trend to 2050.

1.4. EV general subsystems

❑ An EV, unlike its counterparts ICE vehicle, **is quit flexible** because of the **absence of intricate mechanical arrangements** that applied in conventional vehicles (only controlled EM and a power supply in different arrangements).

✓ For the HEV, the ICE and EM can work in conjunction to turn the wheel.

❑ The three main subsystems of an EV are: **energy source**, **propulsion**, and **auxiliary**:

a) Energy source subsystems:

✓ Energy source;

✓ Refueling system;

✓ Energy management.

b) Propulsion subsystems:

✓ EM;

✓ Power converter;

✓ Controller;

✓ Transmission;

✓ Driving wheels.

c) Auxiliary subsystems:

✓ Auxiliary power supply;

✓ Temperature controller;

✓ Power steering unit.

❑ **A backward flow of power can be created by regenerative actions like regenerative braking.**

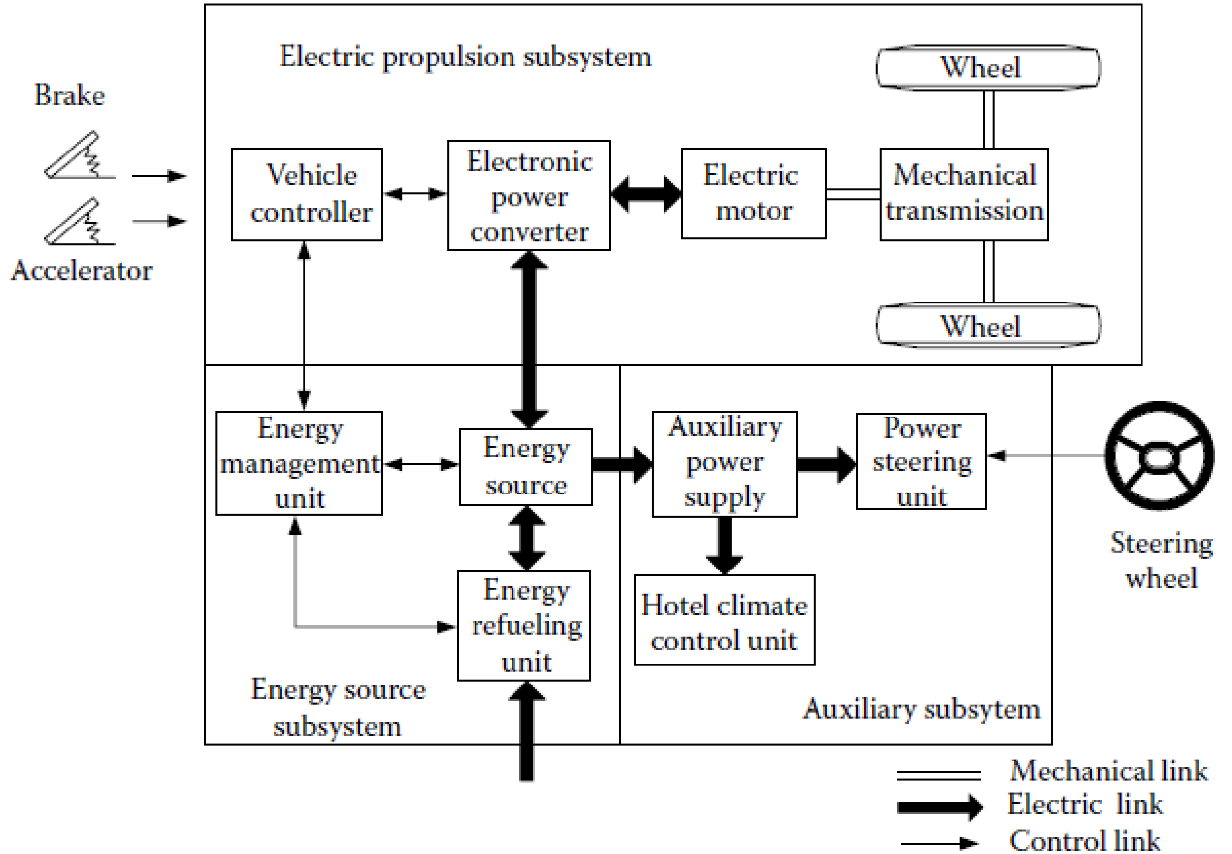


Fig. 9. An EV general subsystem.

1.5. General Types of EVs

- EVs can run **solely on electric propulsion** (Electrical Motor (EM), battery, and converter). They can have **an ICE working alongside it** named as Hybrid EV (HEV), and the **ones with Fuel Cell (FC)** named as FCEVs. Therefore, common types of EVs are:

a) Battery Electric Vehicle (BEV);
b) Hybrid Electric Vehicle (HEV);
c) Plug-in Hybrid Electric Vehicle (PHEV);
d) Fuel Cell Electric Vehicle (FCEV);

1.5.1. Battery Electric Vehicle (BEV);

- **EVs with only batteries to provide power** to the drive train are known as **BEVs**. Therefore, the **range** of such vehicles **depends directly on the battery capacity**.
- Typically a BEV can cover 150–400 km on one charge. These ranges depend on **driving style, vehicle configuration, road condition, climate, battery type and age**.

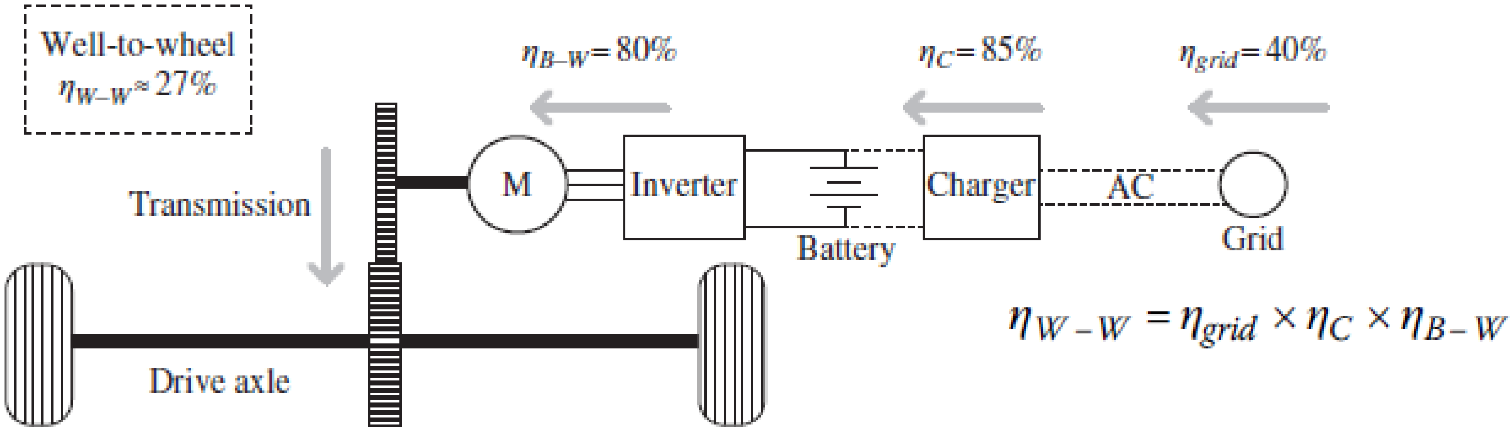


Fig. 10. Conceptual process for power conversion in a BEV.

- Most famous **BEV productions** are: **Nissan Leaf** (40kWh battery) and **Tesla Model S** (85kWh battery).

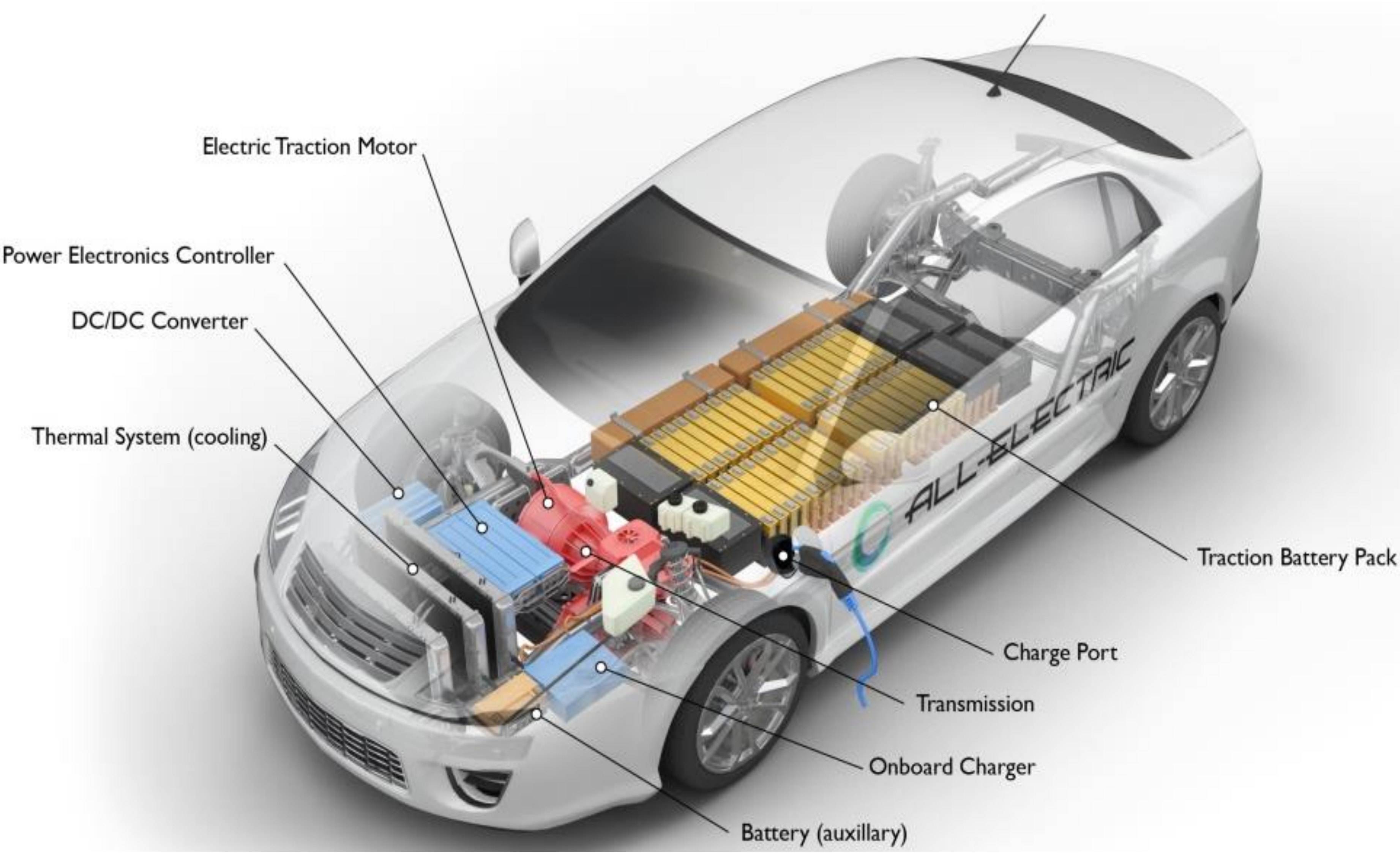


Fig. 11. Conceptual presentation of a typical BEV instruments.

1.5.2. Hybrid Electric Vehicle (HEV)

- **HEVs** Employ both **ICE** and an **Electric Power Train** as the propulsion system of the vehicle. These two are combined in different forms (for mileage improving or performance enhancing):

✓ An HEV **uses the electric propulsion** system when the **power demand is low** (urban environment); Also, in **idling periods**, for example traffic jams, the fuel consumption as the engine stays totally off (reducing GHG). When **higher speed is needed**, the HEV switches to the **ICE**. The two drive trains can also work together to improve the performance.

✓ The **power has been splatted between the ICE and the EM** by considering the vehicle speed, driver input, State Of Charge (SOC) of battery, and the motor speed to attain maximum fuel efficiency.

- Hybrid power systems are used to reduce or to remove turbo lag in turbocharged cars, like the Acura NSX.

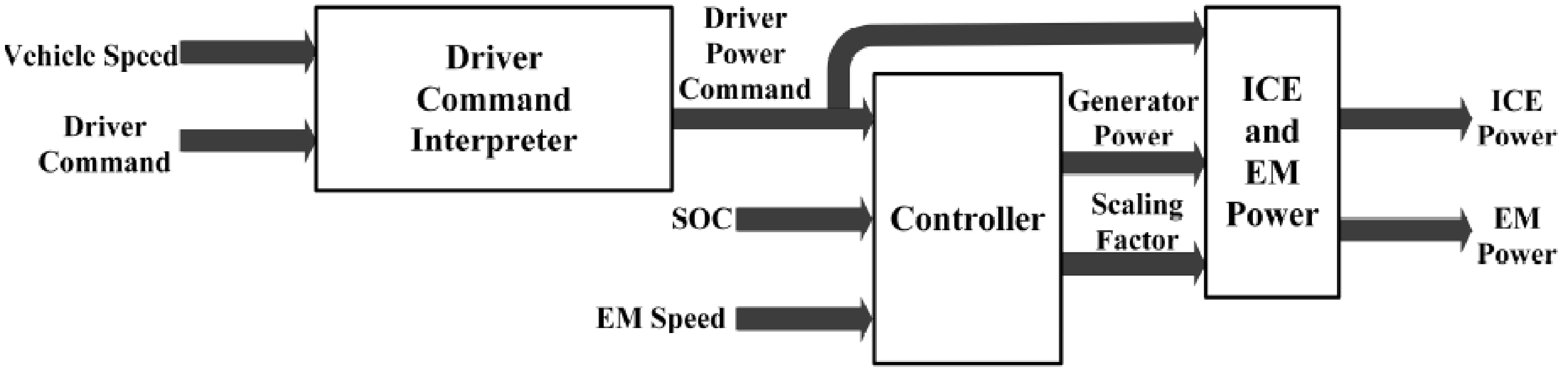


Fig. 12. An example of Vehicle Control Unit (VCU) structure of a typical HEV.

- Hybrid vehicles are divided into **micro hybrids**, **mild hybrids**, **power (full) hybrids**, and **energy hybrids**, based on the relative size of the electric propulsion system with respect to the ICE and the role and functions performed by the electrical and mechanical propulsion systems.

✓ **Hybridization Factor (HF)**, in its simplest form, is defined as the ratio between the peak electrical propulsion power and the peak total electrical + mechanical propulsion power:

$$\mathrm{HF} = \frac{P_{EM}}{P_{EM} + P_{ICE}}$$

a) **Micro hybrids:** HF is in the range of **5%–10%** (benefit from the start/stop technology).
b) **Mild hybrids:** HF is usually in the range of **10%–25%**.
c) **Power (full) hybrids:** have higher HFs than **25%**.
d) **Energy hybrids:** have higher HFs than **25% with plug in capability**.

- **HEVs** use both an electrical propulsion system and an ICE. Various ways in which these two can be set up to spin the wheels creates different configurations as:

a) **Series Hybrid;**
b) **Parallel Hybrid;**
c) **Series-Parallel Hybrid;**

- **Degree of hybridization** can be classified according to some capabilities as:

The vehicle is a....

If it...	Micro Hybrid	Mild Hybrid	Full Hybrid	Energy Hybrid
Automatically stops/starts the engine in stop-and-go traffic				
Uses regenerative braking and operates above 60 volts				
Uses an electric motor to assist a combustion engine				
Can drive at times using only the electric motor				
Recharges batteries from a wall outlet for extended all-electric range				

Fig. 13. EVs capability in various degree of hybridization.

a) Series HEVs

- ✓ combines the best attributes of the ICE (high-energy-density fuel) and the BEV (powertrain efficiency).
- ✓ Only the motor is connected to the wheels;
- ✓ The engine is used to run a generator which provides the electrical power;
- ✓ It can be put as an EV that is assisted by an ICE generator.

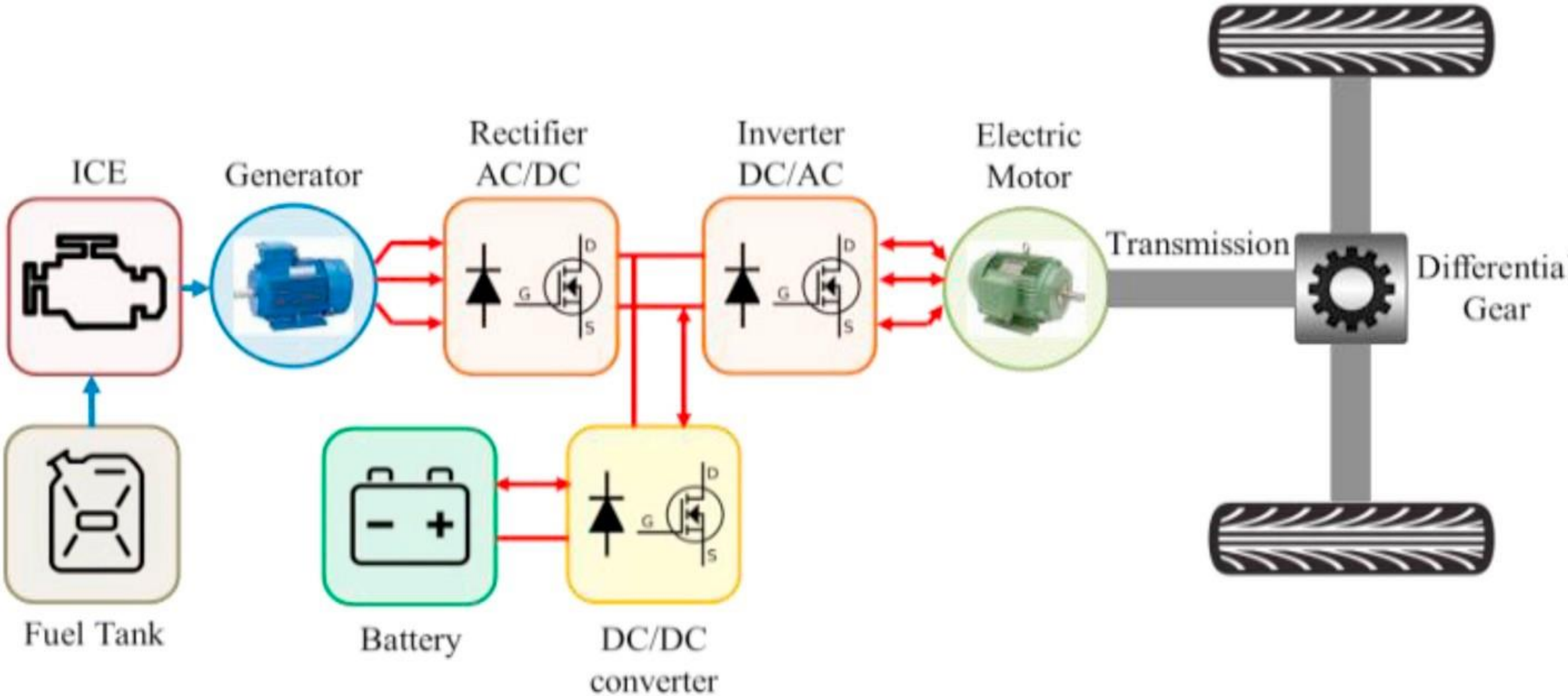


Fig. 14. Configuration of a series HEV.

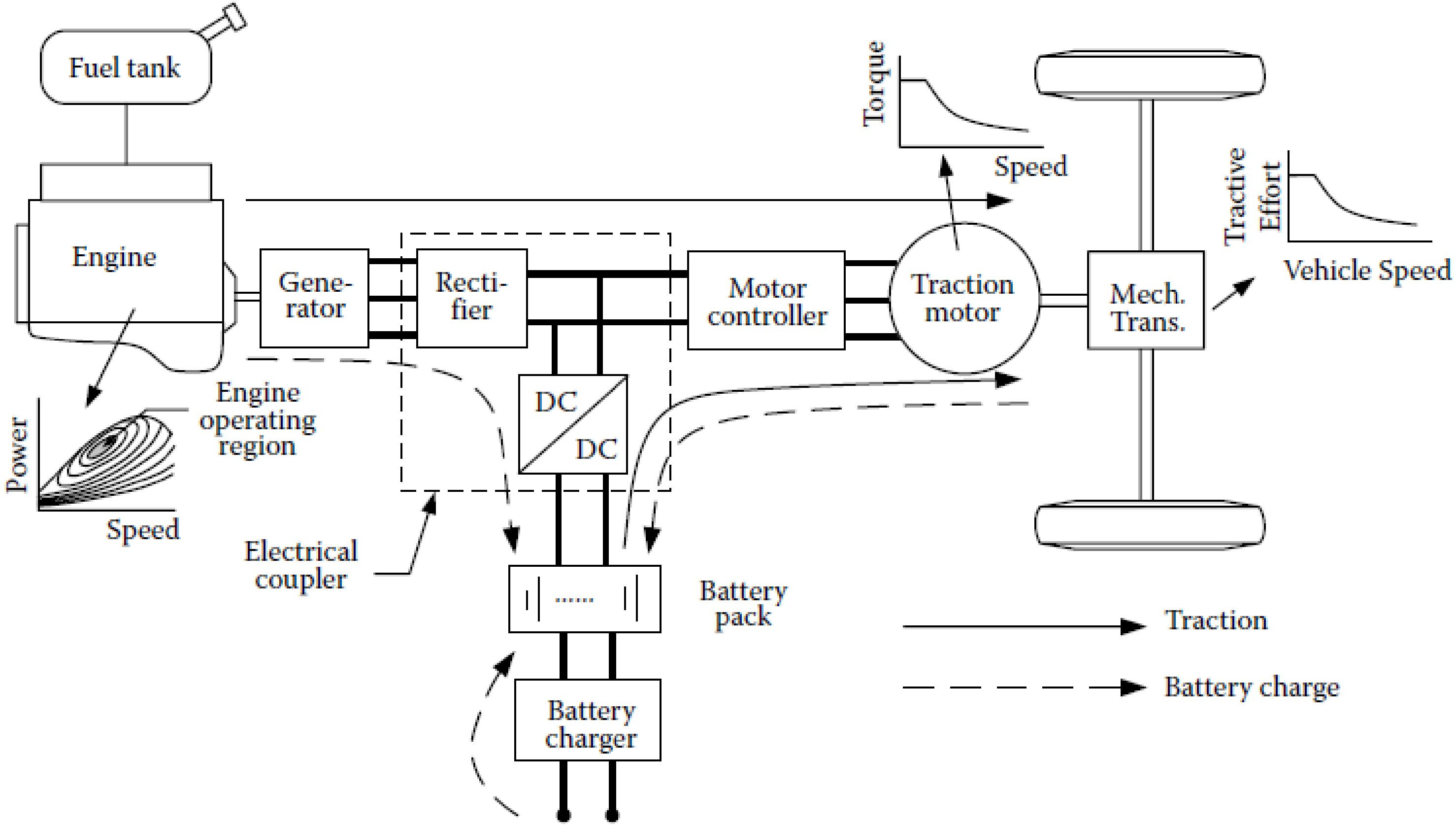


Fig. 15. Configuration of a series HEVs with powers flow directions.

❑ **Also named as: Extended Range Electric Vehicle (EREV).**

❑ **Application:** Passenger cars, Large vehicles such as E-buses, trucks and locomotives.

❑ Two famous series HEVs are: **Chevrolet Volt** (35.000 $ price) and **BMW i3** (45.000 $ price).

b) Parallel Hybrid

- ✓ both the ICE and the EM are connected in parallel to the wheels;
- ✓ Either or both of (ICE and EM) take part in delivering the power;
- ✓ Can be considered as an ICE vehicle with EM assistance;
- ✓ The energy storages can be charged by the EM by means of regenerative braking or by the ICE when it produces more than the power required to drive the wheels.
- ✓ Has been implemented using a **Dual-Clutch Transmission** (**DCT**) on vehicles such as the **Honda Fit** and the **Hyundai Ioniq**.

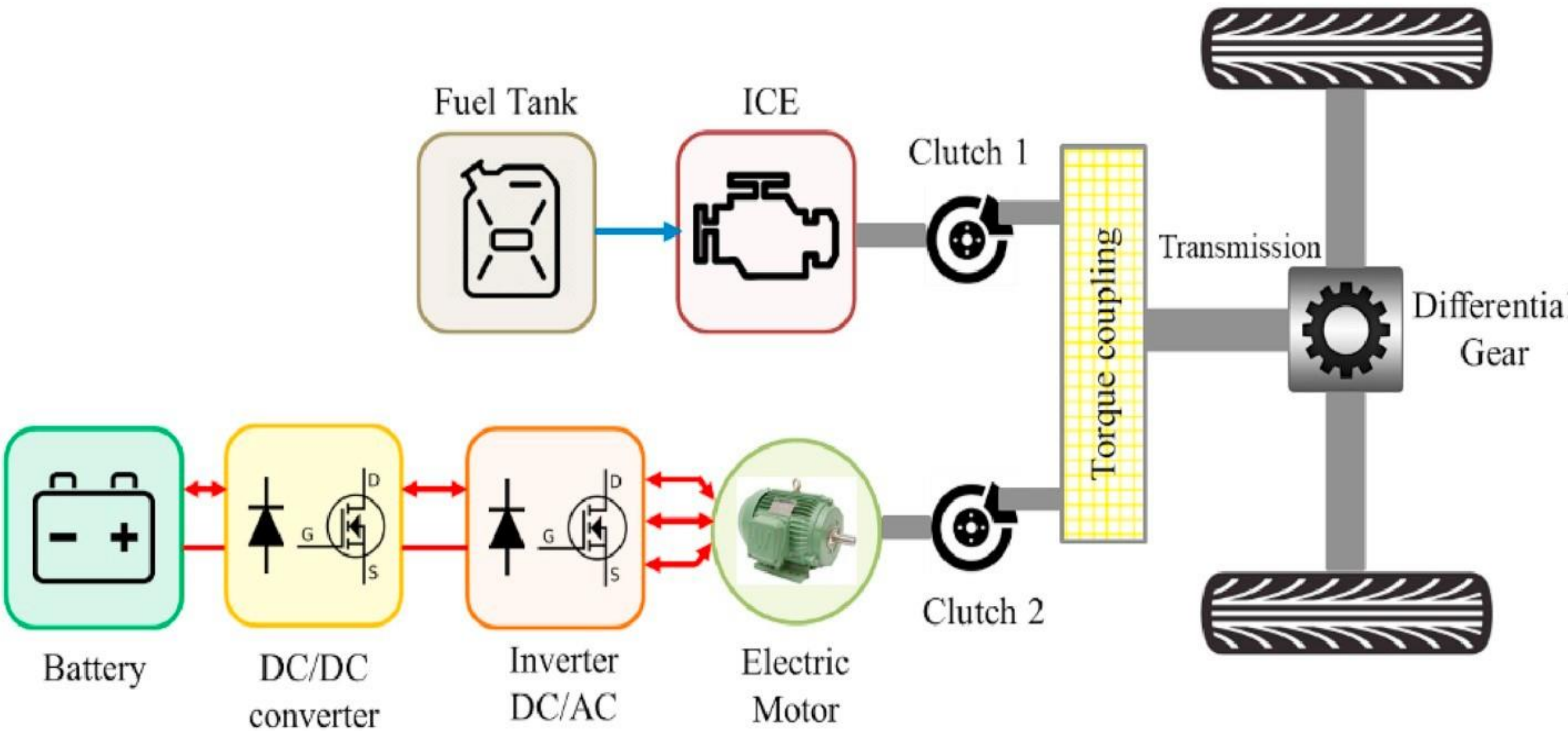


Fig. 16. Configuration of a parallel HEV.

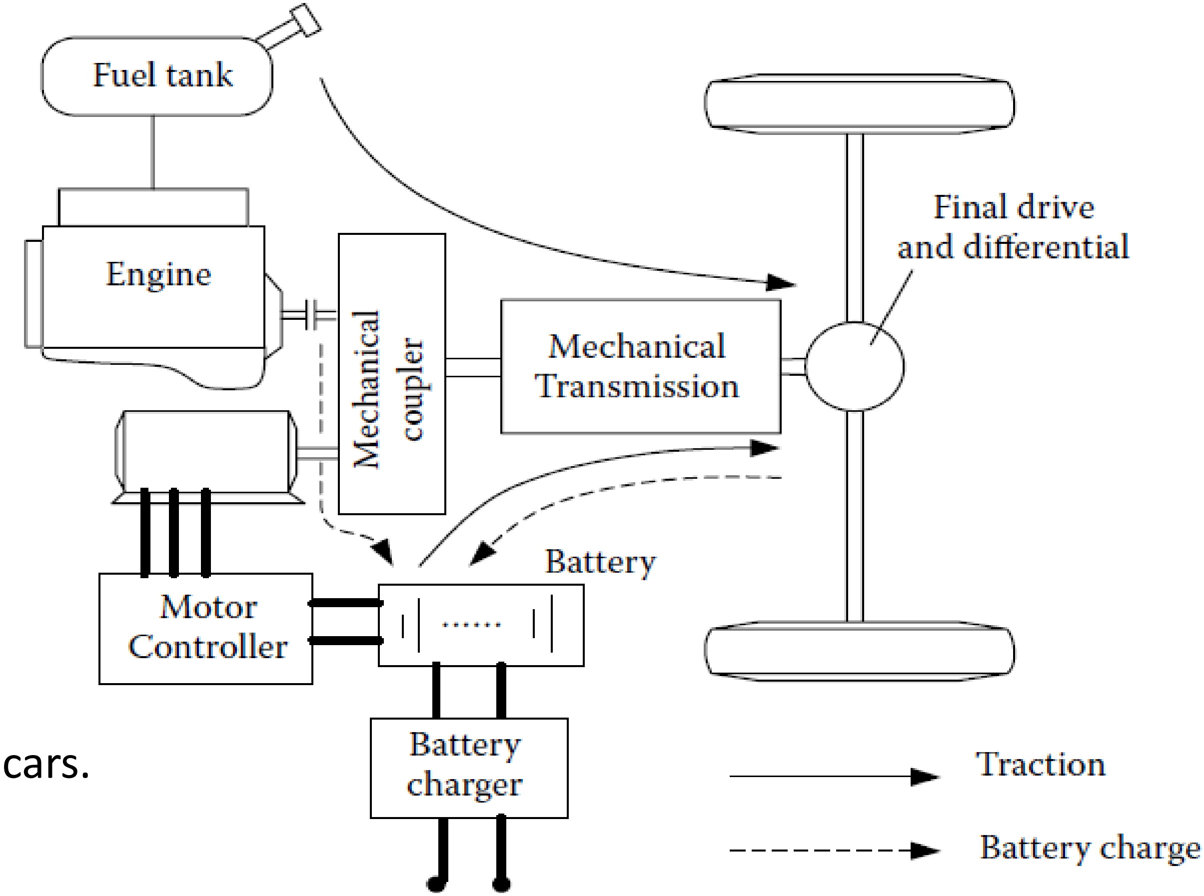


Fig. 17. Configuration of a parallel HEV with powers flow directions

- **Application:** urban passenger cars.

- Two famous parallel HEVs are: **Honda Fit** (17.000 $ price) and **Hyundai Ioniq** (26.000 $ price).

c) Series-Parallel Hybrid

- ✓ Has an **additional mechanical link** compared to the **series** type, or an **extra generator** when compared to the **parallel** type;
- ✓ Has the advantages of both the systems but is more costly and complicated nonetheless;

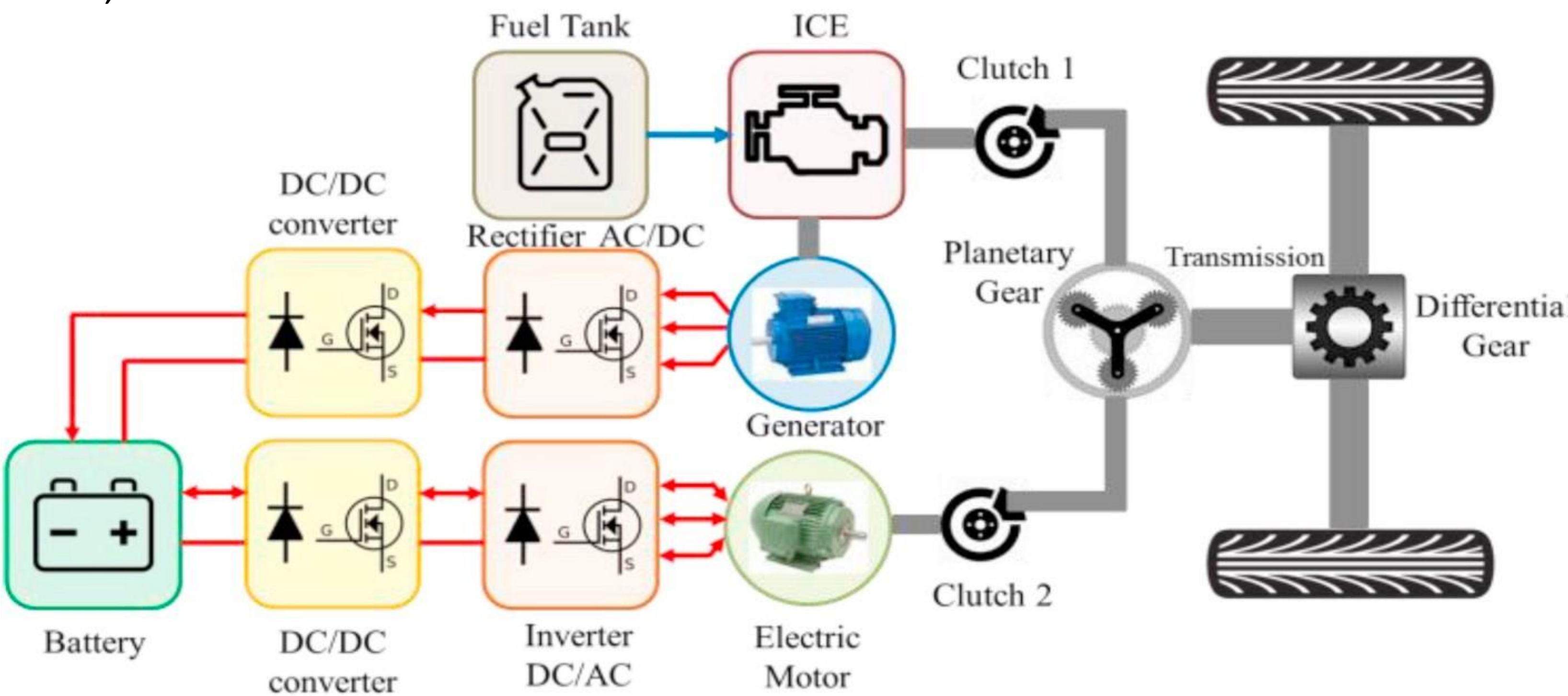


Fig. 18. Configuration of a series-parallel HEV.

- ❑ Two famous parallel HEVs are: **Toyota Prius** (25.000 $ price) and **Ford Escape** (36.000 $ price).

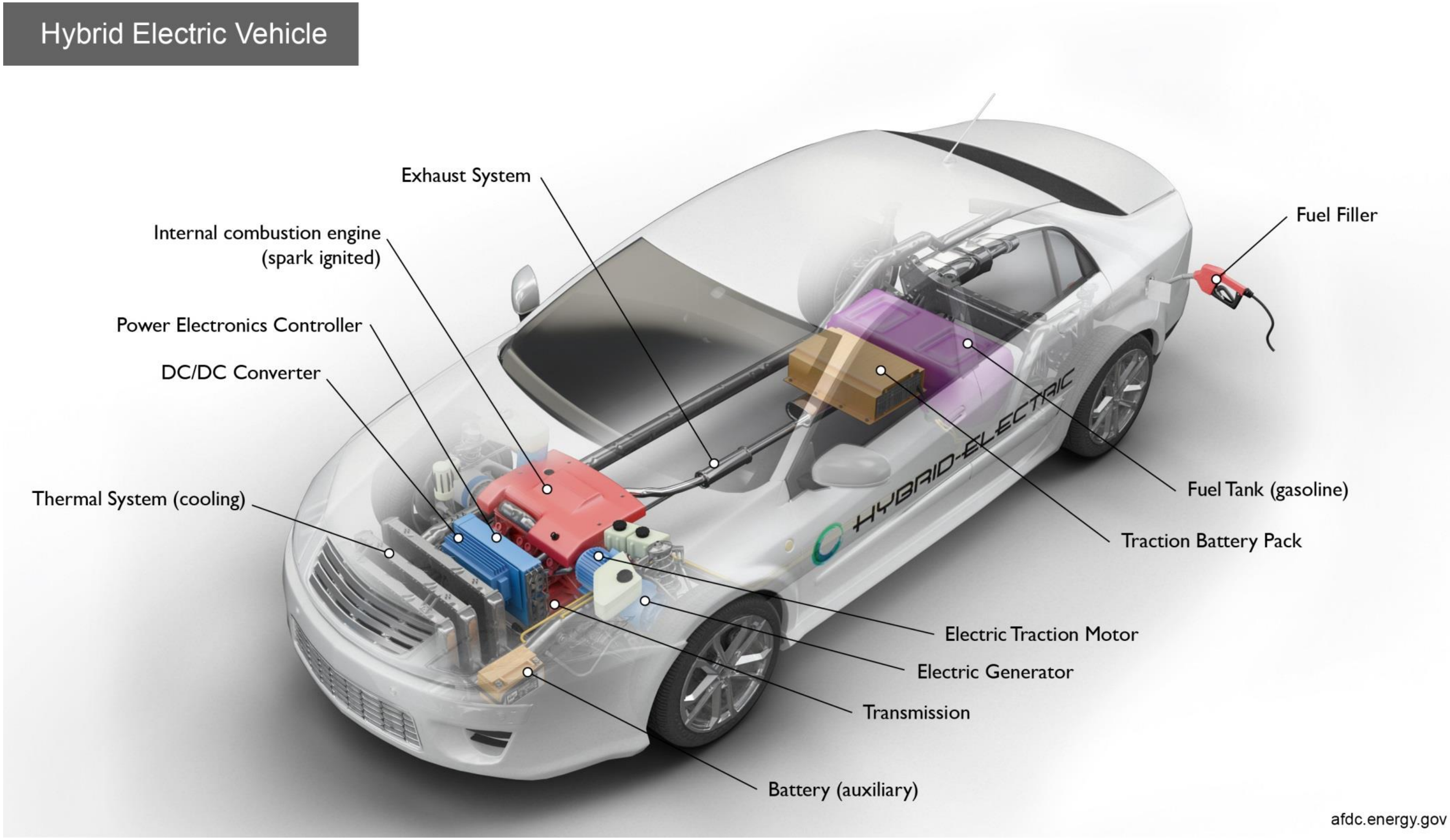


Fig. 19. Conceptual presentation of a typical HEV instruments.

1.5.3. Plug-in Hybrid Electric Vehicle (PHEV);

- ❑ The PHEV concept arose **to extend the all-electric range of HEVs**. It like an HEV, but the difference between them is that the PHEV uses **electric propulsion** as the **main driving force**, so these vehicles require **a bigger battery capacity than HEVs**.
- ✓ When the PHEV battery is low in charge, it calls on the ICE to provide a boost or to charge up the battery pack. The ICE is used here to extend the range.
- ✓ PHEVs can charge their batteries directly from the grid (which HEVs cannot) and have the facility to utilize regenerative braking.
- ✓ PHEV has ability **to run solely on electricity for most of the time**, makes its carbon footprint smaller than the HEVs. They consume **less fuel** as well and thus **reduce the associated cost**.

- ❑ A PHEV run in BEV mode for a significant distance. A PHEV running as a BEV is operating in **Charge Depleting** (**CD**) mode. A PHEV running as a HEV and maintaining the battery at an average State Of Charge (SOC) is operating in **Charge-Sustaining** (**CS**) mode.

- ❑ The vehicle market is populated with these PHEVs: **Chevrolet Volt** (35.000 $ price), **Toyota Prius Prime** (28.000 $ price)**, and Mitsubishi Outlander** (25.000 $ price).

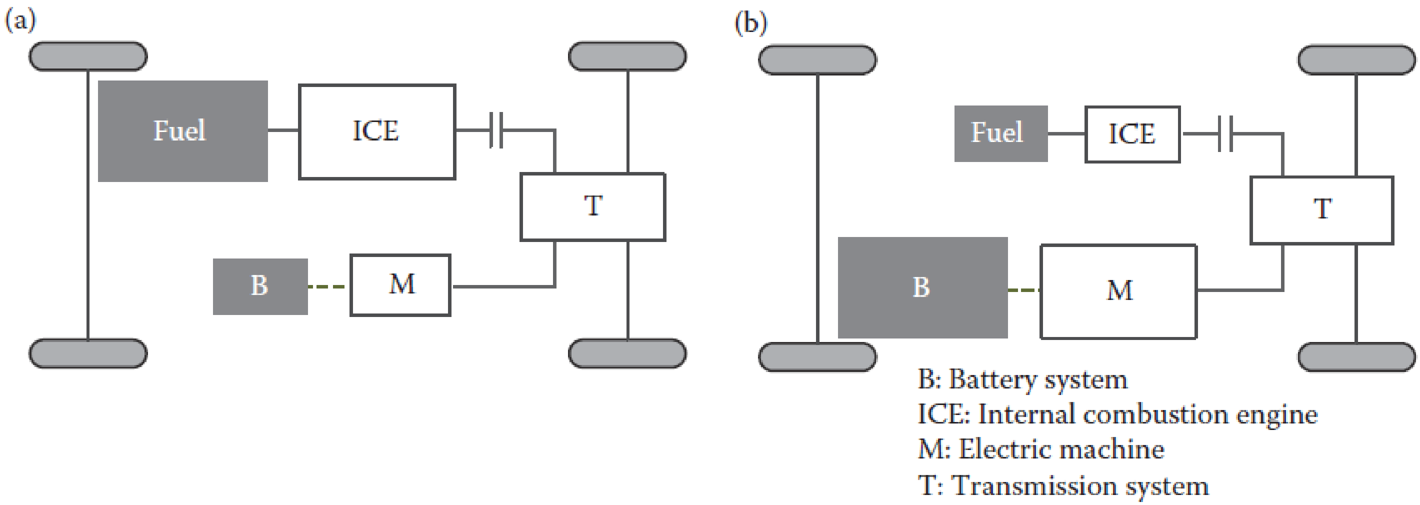


Fig. 20. Difference between a parallel HEV and a parallel PHEV: (a) parallel HEV, (b) parallel PHEV.

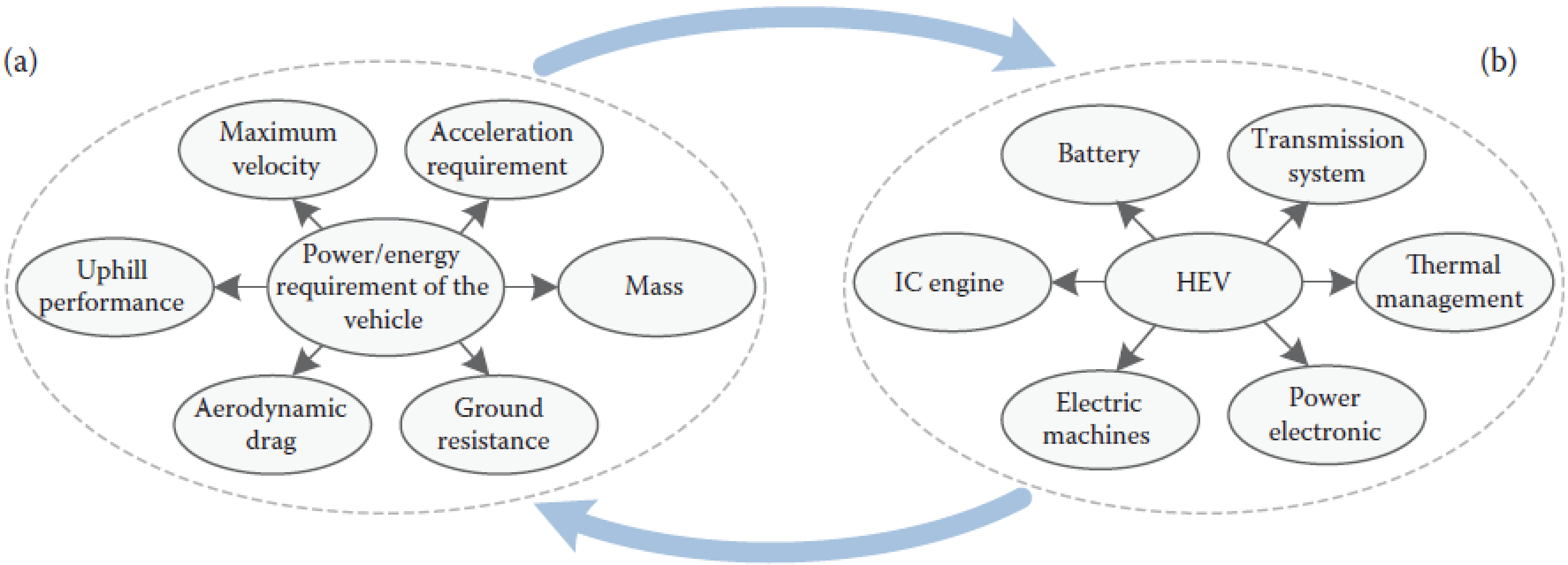


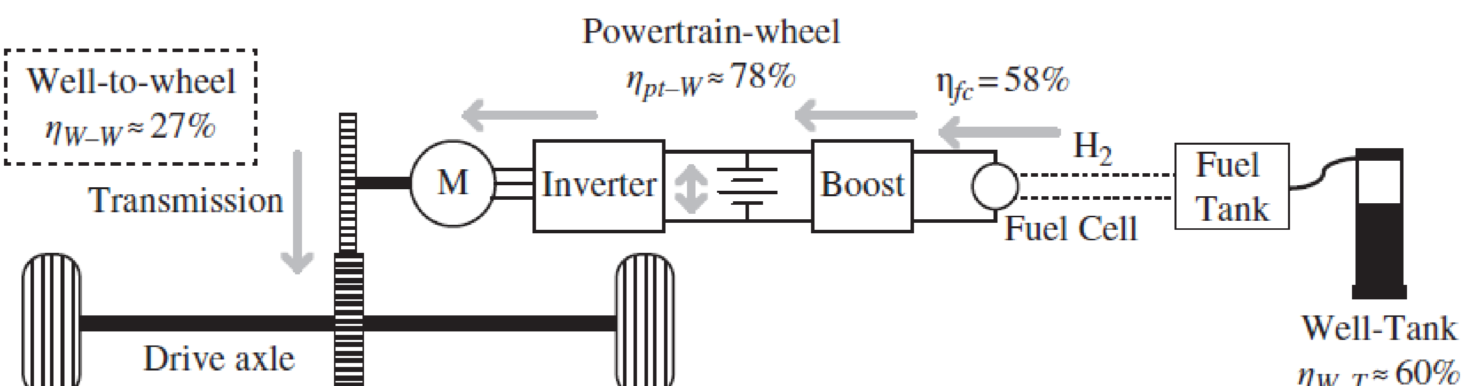
Fig. 21. Power and energy requirement of the vehicle and their effect on HEV design. (a) Key design parameters to define the power and energy requirements of the vehicle. (b) Power and energy supplying components of the powertrain.

1.5.4. Fuel Cell Electric Vehicle (FCEV);

- **FCEVs or FCVs** got the name because the heart of such vehicles is FC that uses chemical reactions to produce electricity.
- ✓ FCEVs carry the **hydrogen** in special **high pressure tanks**. Another ingredient for the power generating process is **oxygen**, which it acquires from the air sucked in from the environment. Electricity generated from the FCs goes to an EM which drives the wheels.
- ✓ **Excess energy** is stored in storage systems like **batteries** or **UCs**.
- ✓ FCVs only produce water as a byproduct of its power generating process which is ejected out of the car through the tailpipes (produced GHG is zero).
- ✓ Commercially available FCEVs that use the battery are: **Toyota Mirai** (20.000 $ price), and **Honda Clarity** (17.000 $ price)..

Fig. 22. A FCEV block diagram configuration.

$$\eta_{W-W} = \eta_{W-T} \times \eta_{fc} \times \eta_{pt-W}$$



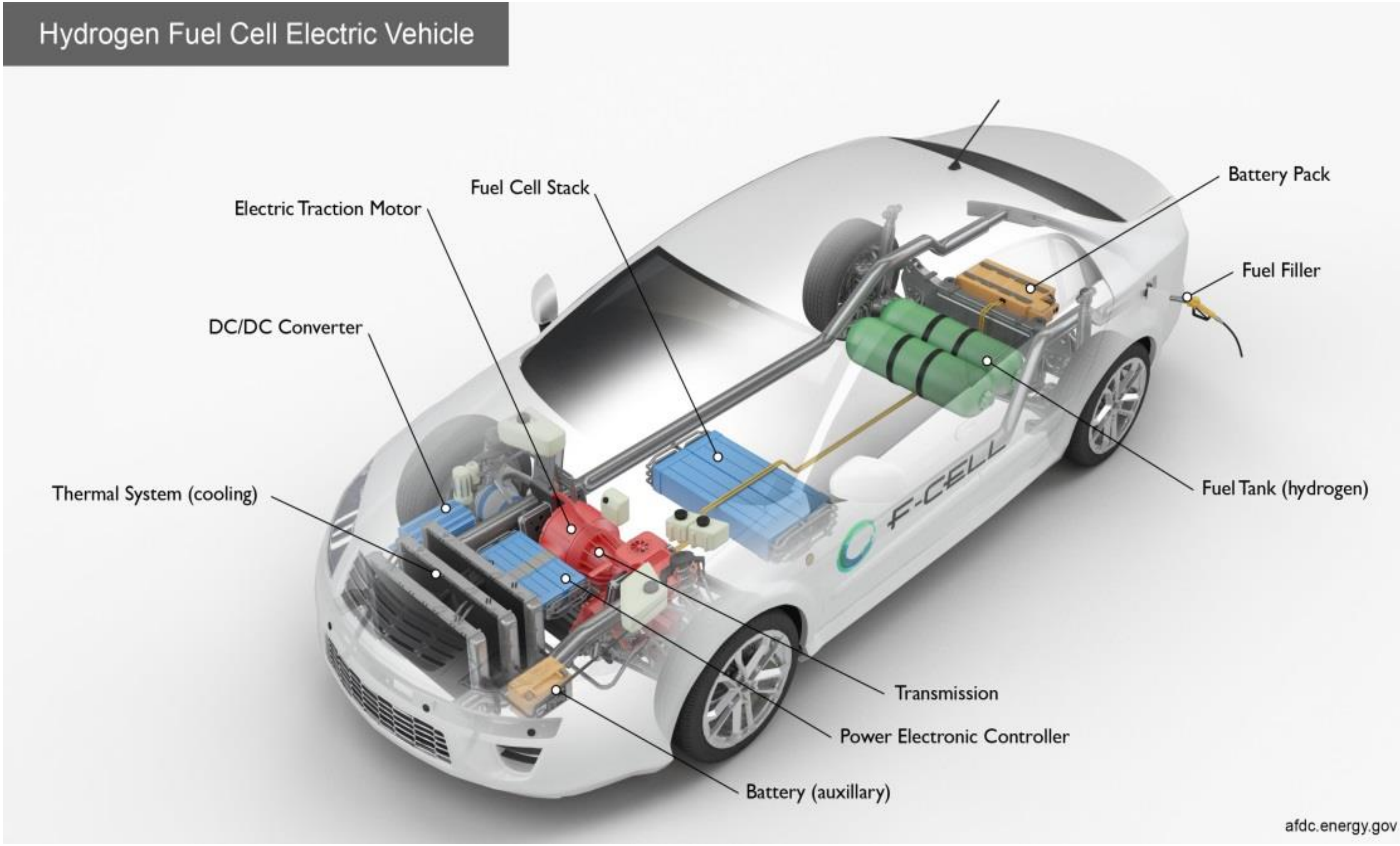


Fig. 23. Conceptual presentation of a typical FCEV instruments.

- **In plug-in FCEVs (PFCEVs),** with a **larger battery and smaller FC (battery-dominant car)**, if hydrogen can be made from the renewable sources, to run the FC, and the energy to charge the battery come from green sources, this **PFCEV** will be the vehicle future.

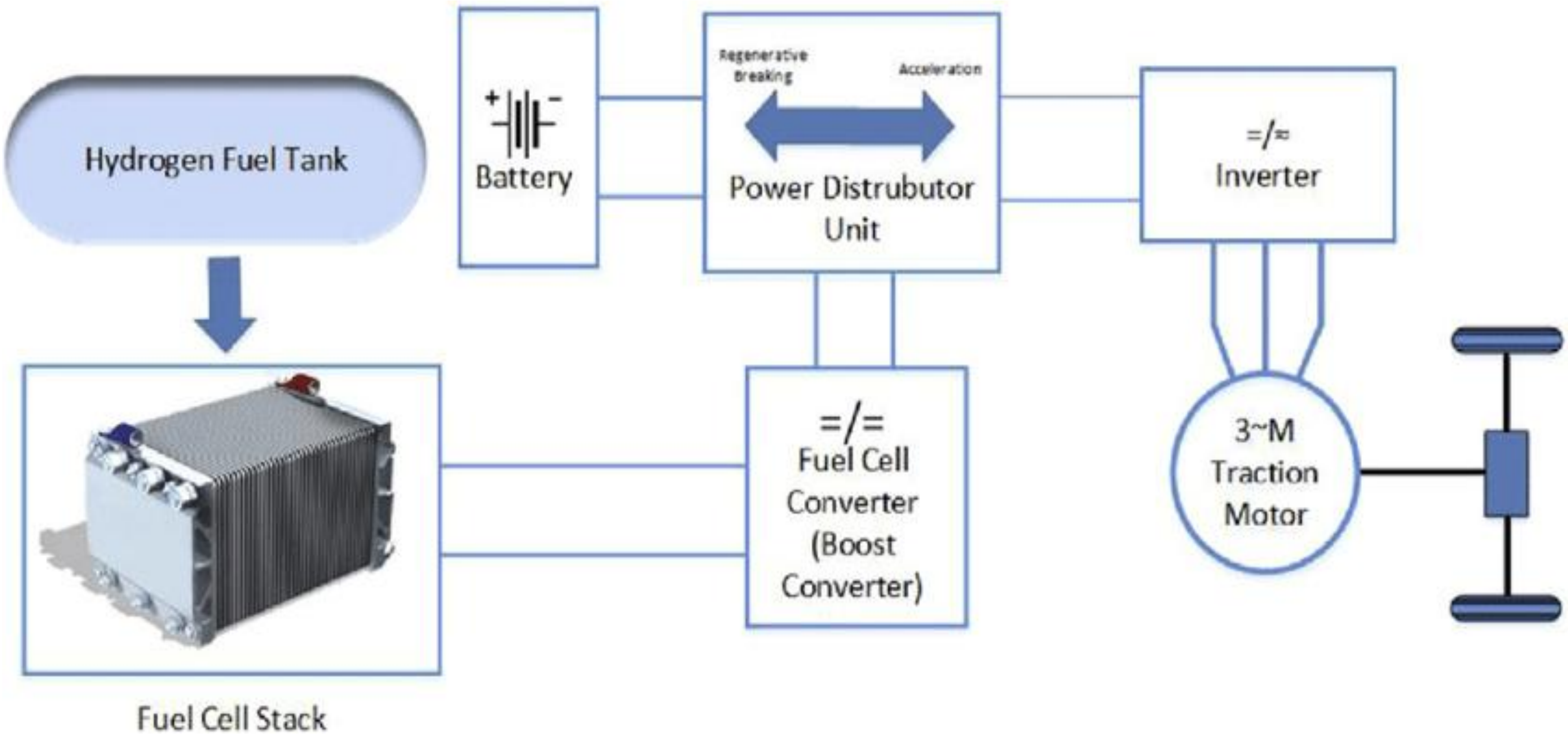


Fig. 24. Power train architecture of a FCEV.

1.6. Wheels drive configurations;

- Motor, mechanical transmission, and wheel configuration in an EV has different types as:

a) front-wheel drive with just an ICE replaced by an EM. The wheels rotate at different speeds by differential.
b) a clutch omitted configuration. It has a FG in place of the GB which removes the chance of getting the desired torque-speed characteristics (reducing weight and size).
c) the motor, gear and differential as a single unit that drives both the wheels. (Nissan Leaf, and the Chevrolet Spark).
d) obtaining differential action by two EMs for two wheels.
e) mechanical interaction is further reduced by placing the motors inside the wheels (in-wheel drive). A planetary gear system is employed because advantages like high speed reduction ratio and inline arrangement of input and output shafts.
f) System is gearless by mounting a low-speed motor with an outer rotor configuration on the wheel rim. Controlling the motor speed thus controls the wheel speed and the vehicle speed.

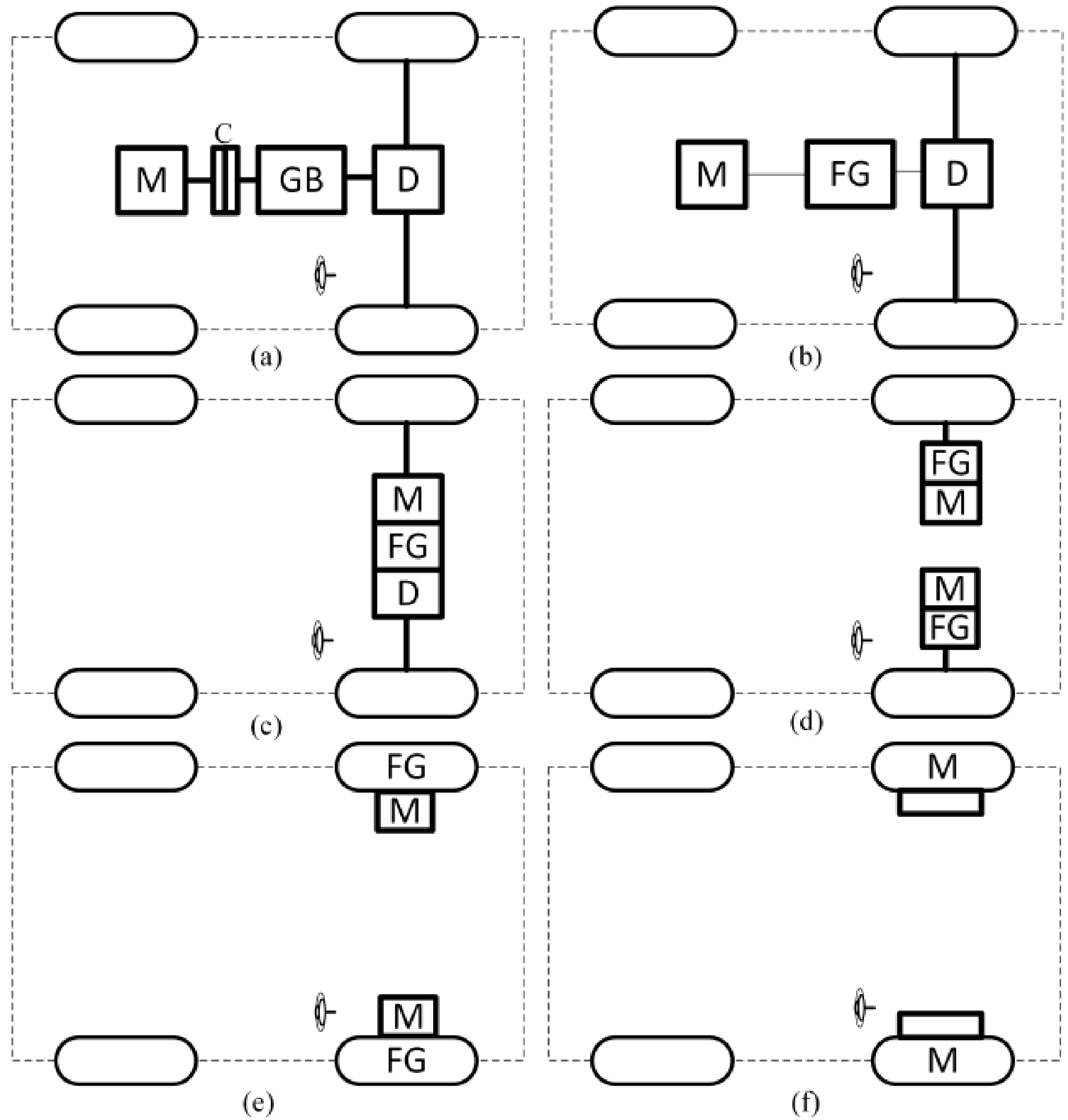


Fig. 25. Different front wheel drive EV configurations.

Table 2. Some of Famous EVs specifications.

INSIDEEVs

All-Electric Car Comparisons - US

Estimated/Unofficial

Updated 2020-08-12

Brand	Model		Base Price (MSRP)	Dest. Charge	Tax Credit	Price After Tax Credit	Battery Size (kWh)	EPA EV Range (mi)	0-60 mph (sec)	Top Speed (mph)	Peak Power (kW)	EPA Energy consumption combined (Wh/mi)	city (Wh/mi)	highway (Wh/mi)	Weight (lbs)
Audi	e-tron (2021)	AWD	$ 65 900	$1 095	$ 7 500	$ 59 495	95	222	5.5	124	300	432	432	432	
Audi	e-tron Sportback (2021)	AWD	$ 69 100	$1 095	$ 7 500	$ 62 695	95	218	5.5	124	300	438	443	432	
BMW	i3 (2020)	RWD	$ 44 450	$ 995	$ 7 500	$ 37 945	42.2	153	7.2	93	125	298	272	330	2 965
BMW	i3s (2020)	RWD	$ 47 650	$ 995	$ 7 500	$ 41 145	42.2	153	6.8	100	135	298	272	330	3 034
Chevrolet	Bolt EV (2020)	FWD	$ 36 620	$ 875	N/A	$ 37 495	66	259	6.5	90	150	286	265	312	3 563
Fiat	500e (2019)	FWD	$ 33 460	$1 495	$ 7 500	$ 27 455	24	84	8.9	85	83	301	279	327	2 980
Hyundai	IONIQ Electric (2020)	FWD	$ 33 045	$ 975	$ 7 500	$ 26 520	38.3	170	10,0	102	100	253	232	279	3 371
Hyundai	Kona Electric (2020)	FWD	$ 37 190	$1 140	$ 7 500	$ 30 830	64	258	7.6	104	150	281	255	312	3 715
Jaguar	I-PACE (2020)	AWD	$ 69 850	$1 025	$ 7 500	$ 63 375	90	234	4.5	124	294	443	421	468	4 784
Kia	Niro EV (e-Niro) (2020)	FWD	$ 39 090	$1 120	$ 7 500	$ 32 710	64	239	7.5	104	150	301	274	330	3 854
MINI	Cooper SE	FWD	$ 29 900	$ 850	$ 7 500	$ 23 250	32.6	110	6.9	93	135	312	293	337	
Nissan	LEAF (40 kWh) (2020)	FWD	$ 31 600	$ 925	$ 7 500	$ 25 025	40	149	7.4	90	110	304	274	340	3 433
Nissan	LEAF e+ S (62 kWh) (2020)	FWD	$ 38 200	$ 925	$ 7 500	$ 31 625	62	226	6.5		160	312	286	347	3 780
Nissan	LEAF e+ SV/SL (62 kWh) (2020)	FWD	$ 39 750	$ 925	$ 7 500	$ 33 175	62	215	6.5		160	324	296	359	3 811
Polestar	2 (2020)	AWD	$ 59 900	$1 300	$ 7 500	$ 53 700	78	275	4.7		300				
Porsche	Taycan 4S Perf Battery Plus (2020)	AWD	$112 990	$1 350	$ 7 500	$ 106 840	93.4	203	3.8	155	420	488	496	475	4 953
Porsche	Taycan Turbo (2020)	AWD	$153 510	$1 350	$ 7 500	$ 147 360	93.4	201	3.0	161	500	488	496	475	5 132
Porsche	Taycan Turbo S (2020)	AWD	$187 610	$1 350	$ 7 500	$ 181 460	93.4	192	2.6	161	560	496	503	496	5 121
Tesla	Model 3 Standard Range Plus (2020)	RWD	$ 37 990	$1 200	N/A	$ 39 190	59.5	250	5.3	140		239	228	255	3 627
Tesla	Model 3 Long Range AWD (2020)	AWD	$ 46 990	$1 200	N/A	$ 48 190	80.5	322	4.4	145		279	272	291	4 072
Tesla	Model 3 Perf. LR AWD (2020) 20"	AWD	$ 54 990	$1 200	N/A	$ 56 190	80.5	299	3.2	162		298	286	315	4 072
Tesla	Model S Long Range Plus (2020)	AWD	$ 74 990	$1 200	N/A	$ 76 190	100	402	3.7	155		288	279	301	4 883
Tesla	Model S Performance LM (2020) 19"	AWD	$ 94 990	$1 200	N/A	$ 96 190	100	348	2.3	163		324	324	324	4 941
Tesla	Model X Long Range Plus (2020)	AWD	$ 79 990	$1 200	N/A	$ 81 190	100	351	4.4	155		351	340	362	5 421
Tesla	Model X Performance LM (2020) 20"	AWD	$ 99 990	$1 200	N/A	$ 101 190	100	305	2.6	163		374	374	379	5 531
Tesla	Model Y Long Range AWD (2020) 19"	AWD	$ 49 990	$1 200	N/A	$ 51 190	80.5	316	4.8	135		279	265	296	4 416
Tesla	Model Y Perf. LR AWD (2020) 21"	AWD	$ 59 990	$1 200	N/A	$ 61 190	80.5	291	3.5	155		304	291	318	4 416

1.7. General features of an ESS

❑ Critical measures of an ESS performance are:

a) **Cycle life:** The number of full charge/discharge cycles until the ESS reaches **End Of Life (EOL)** condition; the definition of EOL condition varies with the usage of the ESS. A typical EOL criterion is for the battery energy storage capacity to drop to 80% of the BOL value, or for the internal resistance to increase by 50%.

b) **Energy density:** The amount of energy each kilogram or liter of ESS contains (Wh/kg and Wh/L). **Specific energy** is the amount of energy stored per unit mass.

c) **Power density:** The amount of power each kilogram or liter of ESS delivers per second (W/kg and W/L). **Specific power** is the amount of power stored per unit mass.

d) **Charge acceptance capacity:** The amount of energy the ESS absorbs per second (W/kg and W/L).

e) **State Of Charge** (**SOC**): is the portion of the total battery capacity that is available for discharge. It is often expressed as a percentage, and can be seen as a measure of how much energy remains in the battery.

f) **depth of discharge** (**DOD**): is the portion of electrical energy stored in a battery that has been discharged. It is often expressed as a percentage.

g) **Self-discharge**: is the energy loss per unit time, typically %/day.

h) **C-rate:** is a measure of how quickly the battery is charged or discharged relative to its maximum capacity.

i) **Cost:** $ per kWh.

❑ Main features of an EV Energy Storage System (ESS):

- ✓ High energy density (to provide a long driving range);
- ✓ High power density (to increase the acceleration);
- ✓ Long service cycle life;
- ✓ Easy maintenance;
- ✓ Fast charging;
- ✓ Low cost;

❑ ESSs can be used in different combinations to provide desired power and energy requirements.

❑ Because of the diverse characteristics that are required for the perfect source, quite a few sources or ESSs come into discussion as:

a) Battery;

b) Ultra-Capacitor (UC);

c) Fuel Cell (FC);

1.7.1. Batteries

- Has been a major energy source for EVs for a long time. More prominent battery types are: **Lead-Acid**, Nickel-Cadmium **(Ni-Cd)**, **Ni-Zn**, Nickel–Metal Hydride **(Ni-MH)**, Sodium Nickel Chloride **(Na-Ni-Cl)**, **Li-Polymer**, and Lithium-Ion **(Li-Ion)** batteries.

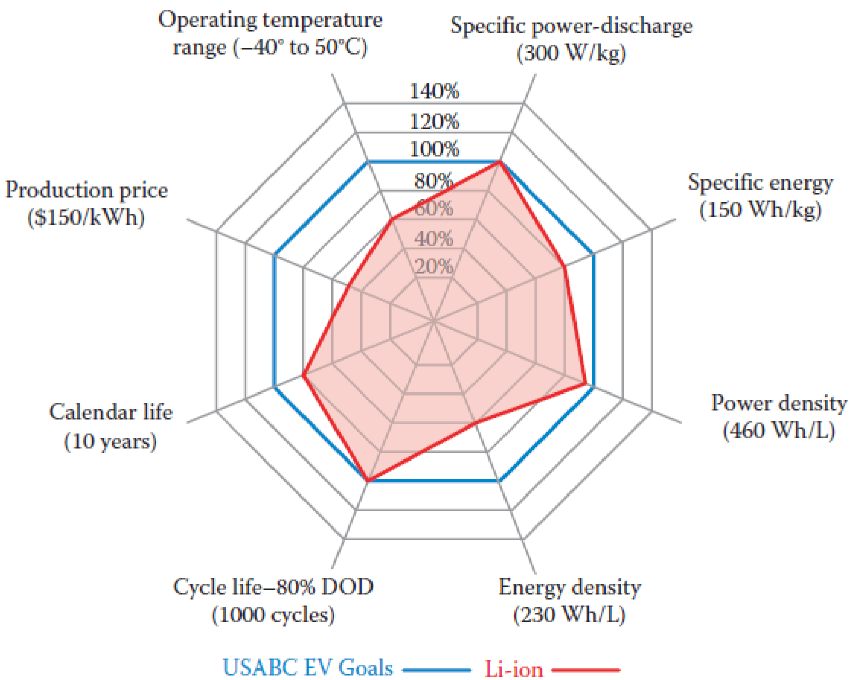


Fig. 26. Performance comparison of current Li-Ion batteries with the defined goal in U.S. Advanced Battery Consortium (USABC).

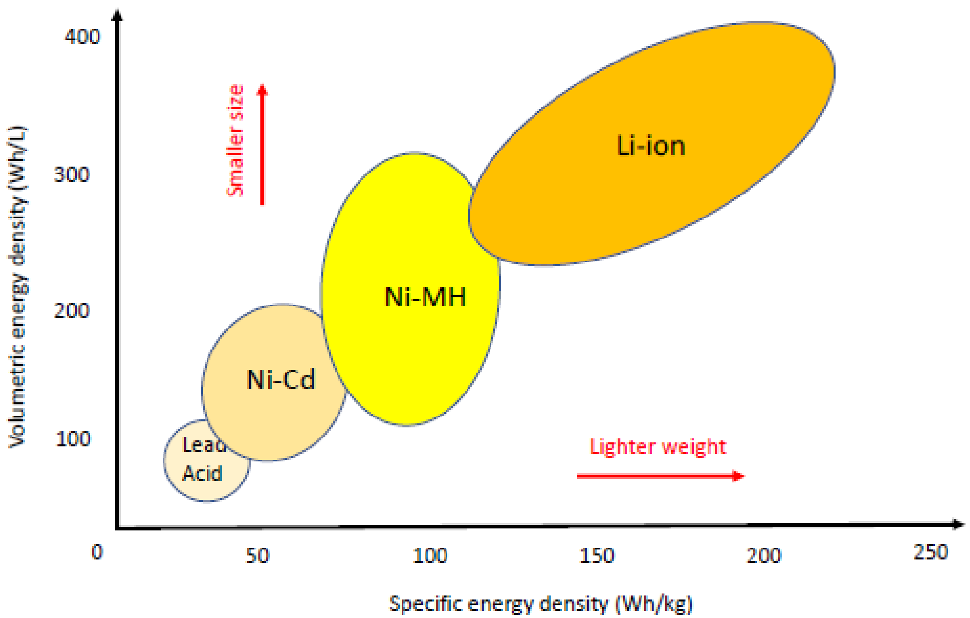


Fig. 27. Energy density comparison of size and weight of the main types of battery chemistries in automotive applications.

1.7.1.1. A battery pack parts;

- ❑ Three main parts of a battery pack are: **Cell**, **Module** (number of cells), and **pack** (number of modules).

- ✓ There are three different **cell designs** that are used in lithium-ion battery manufacturing: **cylindrical cells**, **prismatic cells**, and **pouch cells**.

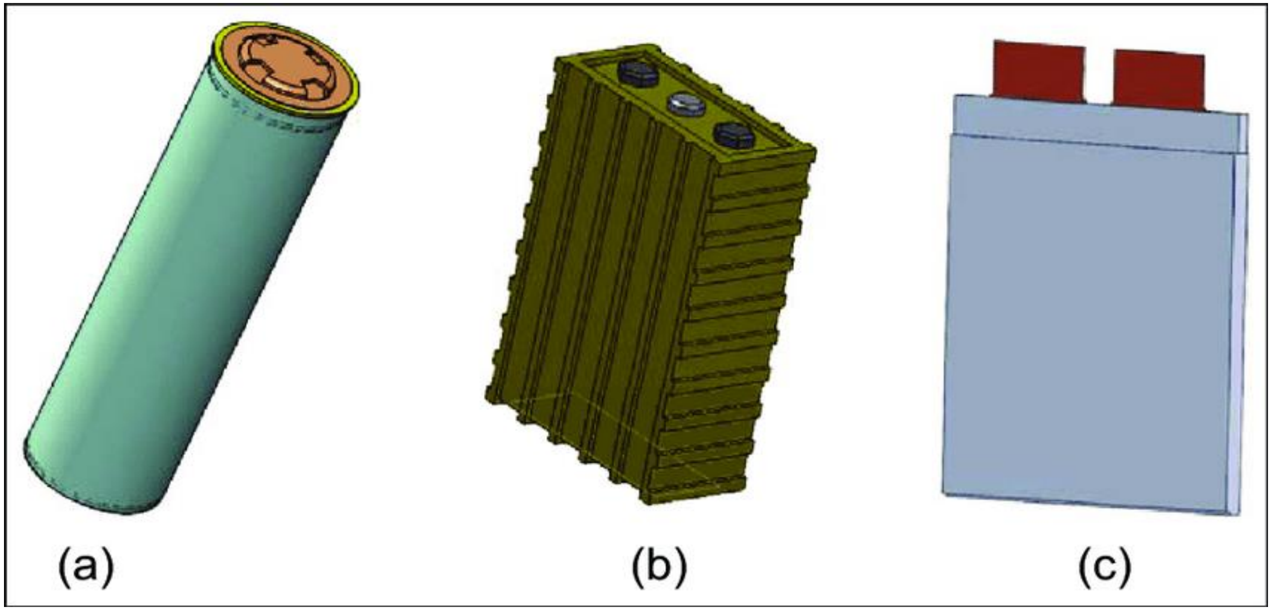


Fig. 28. Three major types of battery cells: a) Cylindrical; b) prismatic; c) pouch.

❑ Arrangements of battery cells are as:

- ✓ to increase output voltage, cells are connected in **series**. Strings that are connected in series can be **prone to failure/showdown** by the weakest cell in the chain. For a series-only configuration, **open-circuit failures** will cause total failure of the pack; complete pack shutdown will also occur if the weakest cell needs to be shut down for safety reasons.
- ✓ to increase current, **parallelization** is employed.
- ✓ **Series–parallel** topology, are somewhat less prone to this since other parallel cell strings can meet the power/energy requirements, if only at least for some time duration.
- ✓ The most complex arrangement is a **matrix topology**, where **parallel cell groups are placed in series**. This topology can, in principle, **bypass a single open circuit cell failure** and utilize the remaining working cells. The manufacture of this topology can be **prohibitive** due to the extra wiring involved. Moreover, uneven current circulations can arise when parallel cell arrangement is employed.

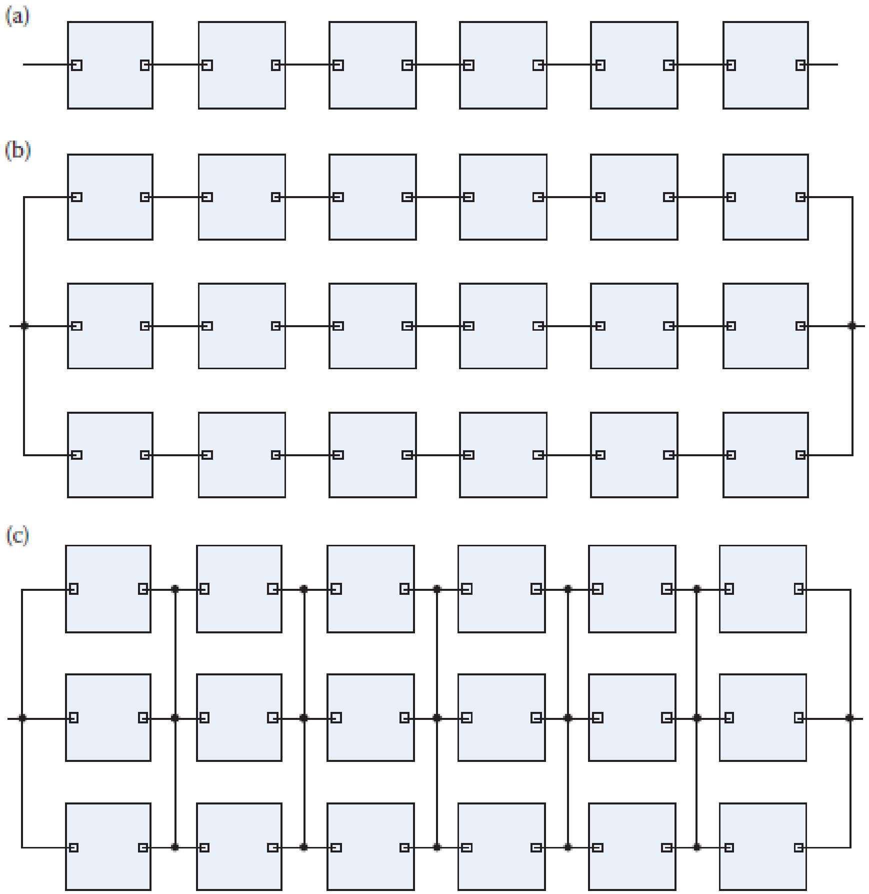
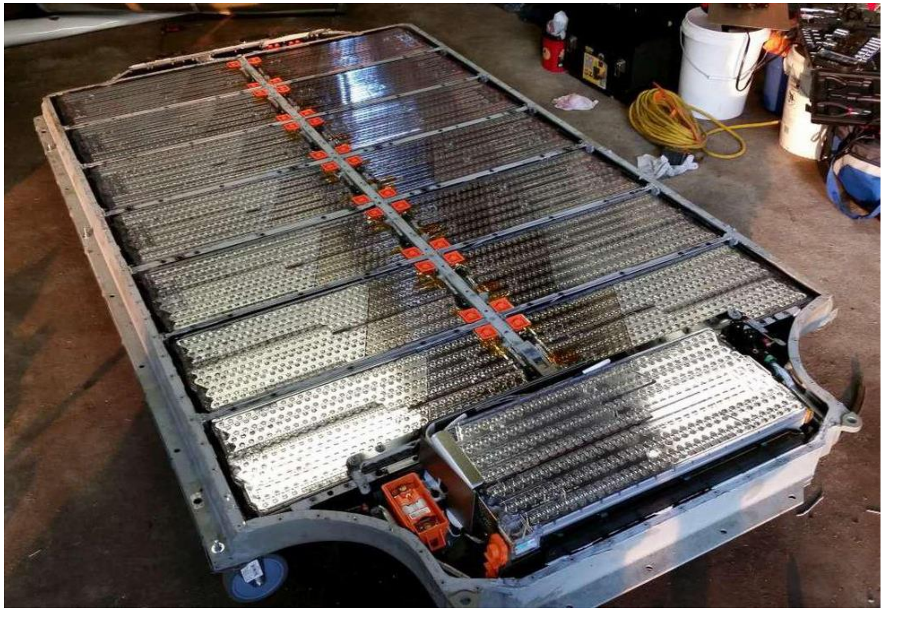


Fig. 29. Possible cell arrangement for a battery pack/module: (a) series configuration, (b) series–parallel configuration, and (c) matrix configuration.

Table 3. Battery characteristics of some famous EVs.

Vehicle	Vehicle weight (kg)	Battery weight (kg)	Battery manufacturer	Chemistry	Rated energy (kWh)	Specific energy (Wh/kg)	Cell/pack nominal Voltage (V)	Rated power (kW)	Specific Power (W/kg)	P/E
1996 GM EV1	1400	500	Delphi	PbA	17	34	2/312	100	200	6
1999 GM EV1	1290	480	Ovonics	NiMH	29	60	1.2/343	100	208	3
1997 Toyota Prius	1240	53	Panasonic	NiMH	1.8	34	1.2/274	20	377	11
2008 Tesla Roadster	1300	450	Panasonic	Li-ion	53	118		185	411	3
2011 Nissan Leaf	1520	294	AESC	Li-ion	24	82	3.75/360	80	272	3
2011 ChevyVolt	1720	196	LG Chem	Li-ion	17	87	3.75/360	110	560	6
2012 Tesla Model S	2100	540	Panasonic	Li-ion	85	157		270	500	3
2017 Chevy Bolt	1624	440	LG Chem	Li-ion	60	136	3.75/360	150	341	3

- The battery packs used in EVs are **made of numerous battery cells**. The **Tesla Model S**, for example, has **7104 Li-Ion cells** in the **85 kWh** pack.



1.7.1.2. Battery Management System (BMS)

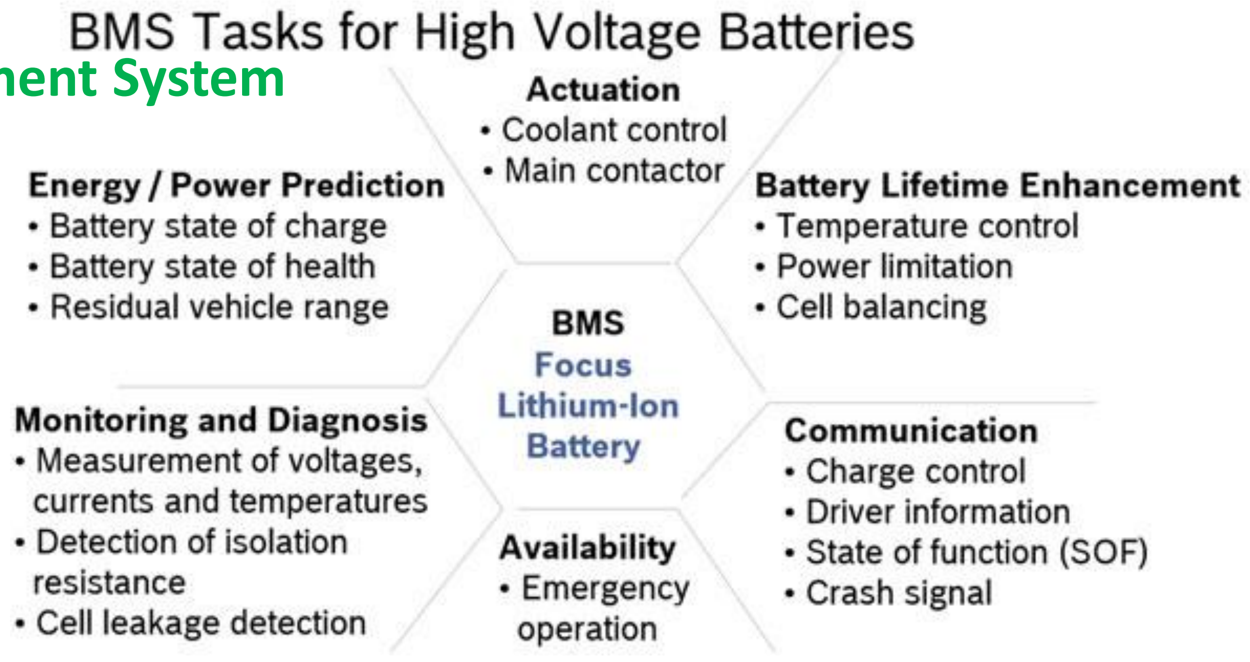


Fig. 30. BMS-tasks for high voltage batteries

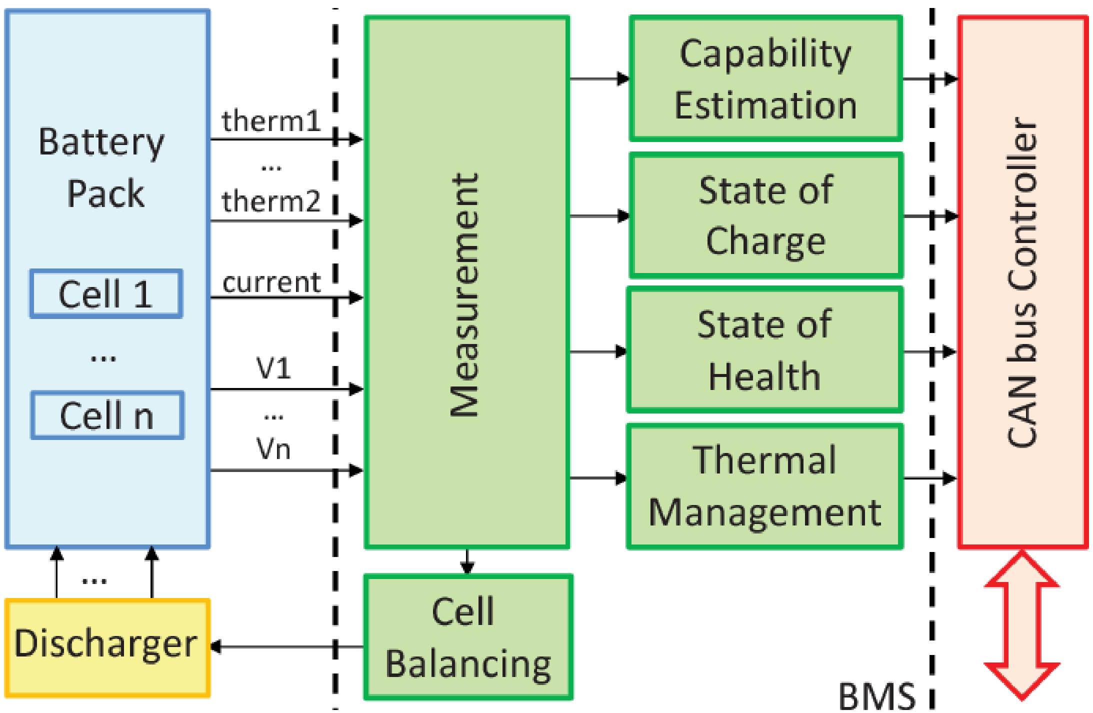


Fig. 31. Conceptual scheme of a BMS applied in battery pack.

1.7.1.3. Battery pack cooling system

- A controlled **thermal management system** (usually liquid cooling based) for a battery pack should be applied to prevent extra-heating of the battery cells and their life time degradation.

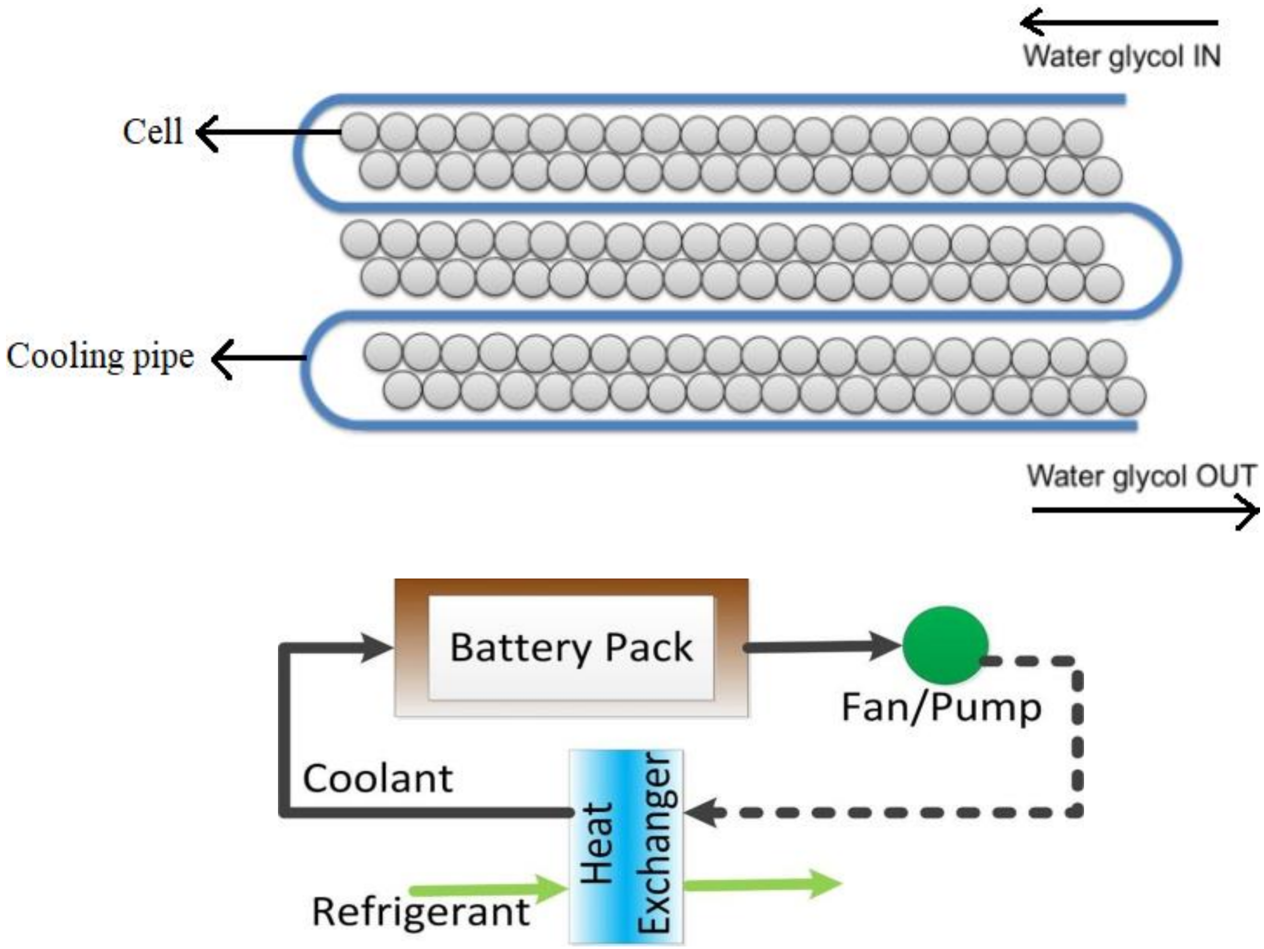


Fig. 32. Battery cell arrangement in a battery pack. Cooling tubes are used to dissipate the heat generated in the battery cells.

1.7.2. Ultra-Capacitors (UCs)

❑ **The main features of UC:**

a) **Long cycle life,** because no chemical reactions take place on the electrodes;
b) **Low energy density** due to the absence of any chemical reaction;
c) **Low internal resistance,** making it highly efficient, but it also causes high output current if charged at a state of extremely low SOC;
d) **Directly proportional terminal voltage to SOC** (load leveling capability), so it can also operate all through its voltage range;
e) **capability in high power providing for short durations,** make them suitable for EVs because they go through start/stop conditions quite a lot (especially in urban driving situations). Also, during acceleration or conditions like hill-climb a high power is required in a short duration of time. This makes the battery discharge rate highly changeable;
f) **fast in capturing the energy** generated by regenerative braking;
g) **temperature adaptability;**

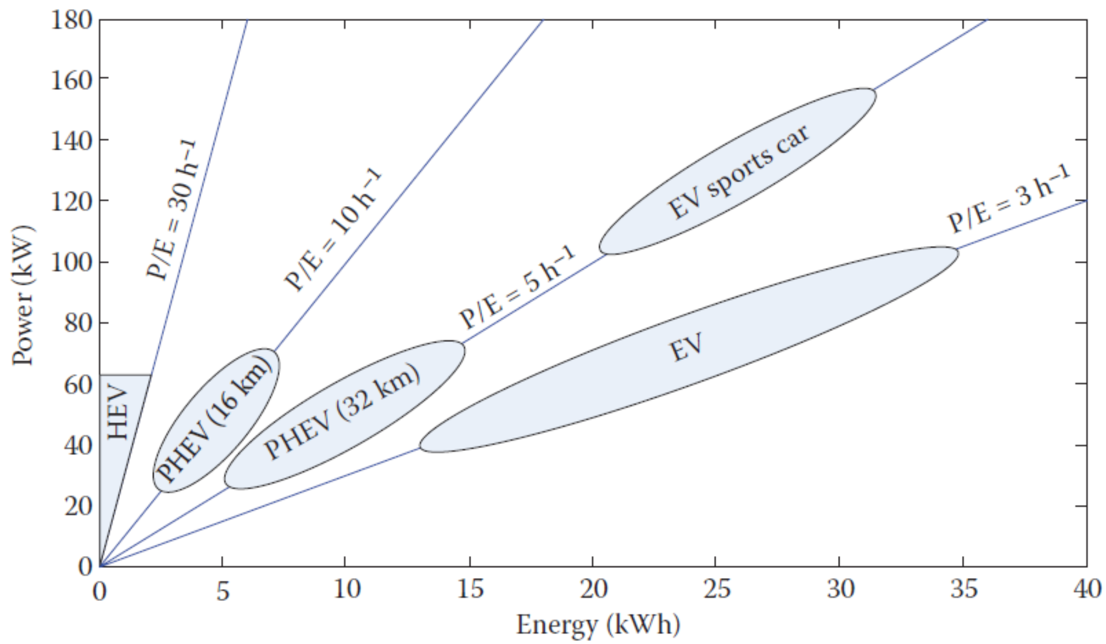


Fig. 33. Requirements for automotive ESSs.

Table 4. Comparison of ESS technologies.

	Lead Acid	NiMH	Li-ion	Na–Ni–Cl	EDLC	Hybrid UC
Specific energy (Wh/kg)	30–50	60–120	100–265	100–120	2.5–15	2.84–120
Energy density (Wh/L)	50–80	140–300	250–730	150–180	10–30	5.6–140
Specific power (W/kg)	75–300	250–1000	250–340	150–200	500–5000	2300–14,000
Power density (W/L)	10–400	80–300	100–210	220–300	100,000	2500–27,000
Round-trip efficiency (%)	70–80	60–70	85–98	85–90	90–98	95–99
Self-discharge (%/day)	0.033–0.3	25–30	0.1–0.3	15	20–40	0.1–12.5
Cycle lifetime (cycles)	100–2000	500–1000	400–1200	2500	10,000–100,000	5000–200,000
Power capacity Cost ($/kW)	175–600	150–1500	175–4000	150–300	100–360	50–320
Energy capacity Cost ($/ kWh)	150–400	150–1500	500–2500	100–200	300–94,000	600–50,000

Source: Augmented from Bradbury, K. *Energy Storage Technology Review*. Duke University, Durham, NC, 2010: 1–34.

- ❑ Also a pack of UC cells should include **protective devices** to avoid:
- ✓ Application of too high charge or discharge rates;
- ✓ Improper charge or discharge voltage or voltage reversal;
- ✓ Short circuiting;
- ✓ Charging or discharging at too high or too low temperatures.

- A combined battery-UC system negates each other shortcomings and provides an efficient and reliable energy system.

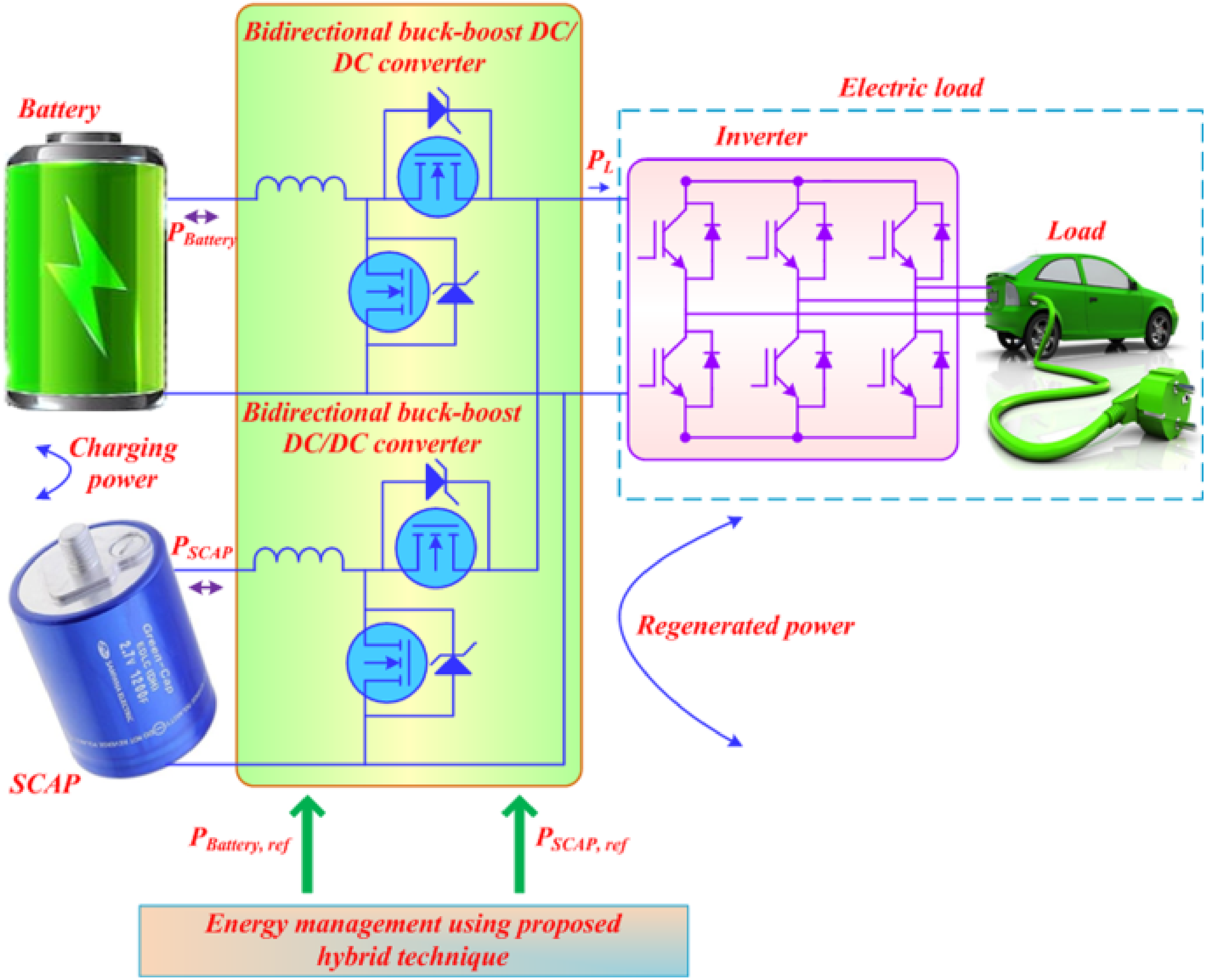


Fig. 34. Combination of a battery and an UC to complement each-other shortcomings.

1.7.3. Fuel Cells (FCs)

- According to the material used, FCs can be classified into different types as:
  - ✓ **PEMFC:** Proton exchange membrane FC. Also named as Solid polymer FC (SPFC);
  - ✓ **DMFC:** Direct Methanol FC;
  - ✓ **AFC:** Alkaline FC;
  - ✓ **PAFC:** Phosphoric acid FC;
  - ✓ **MCFC:** Molten Carbonate FC;
  - ✓ **SOFC:** Solid oxide FC;

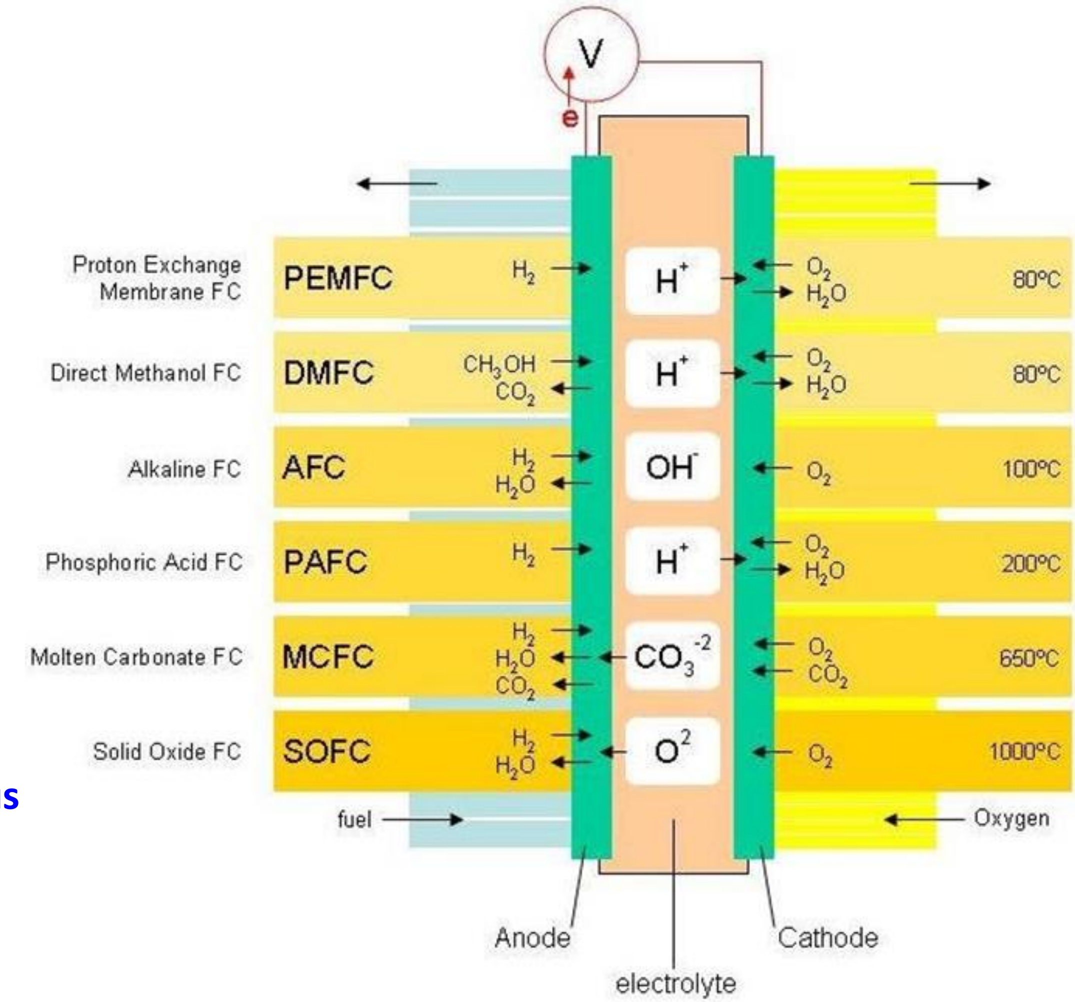


Fig. 35. Graphical presentation of various types of fuel cells

Table 5. Comparison of different FC configurations

	PAFC	AFC	MCFC	SOFC	SPFC	DMFC
Working temp. (°C)	150–210	60–100	600–700	900–1000	50–100	50–100
Power density (W/cm^2)	0.2–0.25	0.2–0.3	0.1–0.2	0.24–0.3	0.35–0.6	0.04–0.25
Estimated life (kh)	40	10	40	40	40	10
Estimated cost (USD/kW)	1000	200	1000	1500	200	200

❑ FC merits for EV utilizations:

- ✓ efficient production of electricity from fuel;
- ✓ noiseless operation;
- ✓ fast refueling;
- ✓ no or low emissions;
- ✓ durability;
- ✓ ability to provide high density current output.

❑ FC limitations for EV utilizations, which cause sources like batteries or UCs are used alongside it:

- ✓ high price;
- ✓ lower energy density compared to petroleum fuel (larger fuel tanks are required for FCEVs;
- ✓ explosion danger in case of an accident (need for big and special tank);
- ✓ efficiency reduction if high power is drawn. Voltage drop in the internal resistances cause most of the losses;
- ✓ Higher response time in comparison with UCs or batteries.

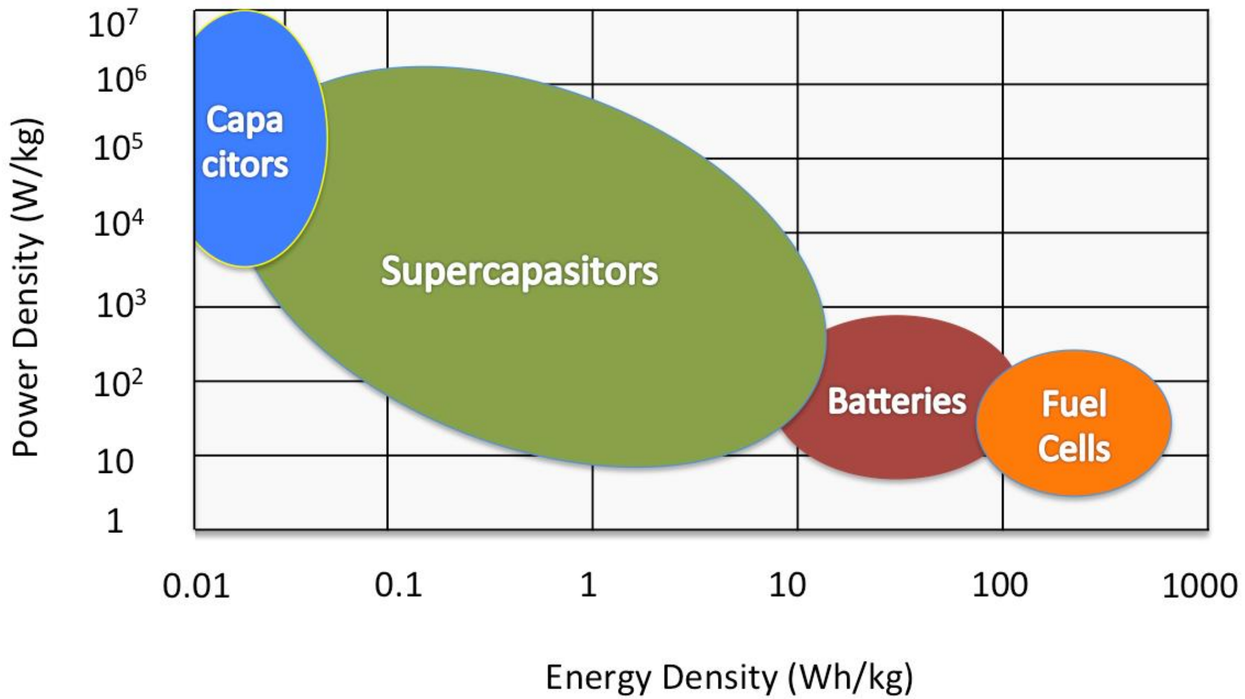


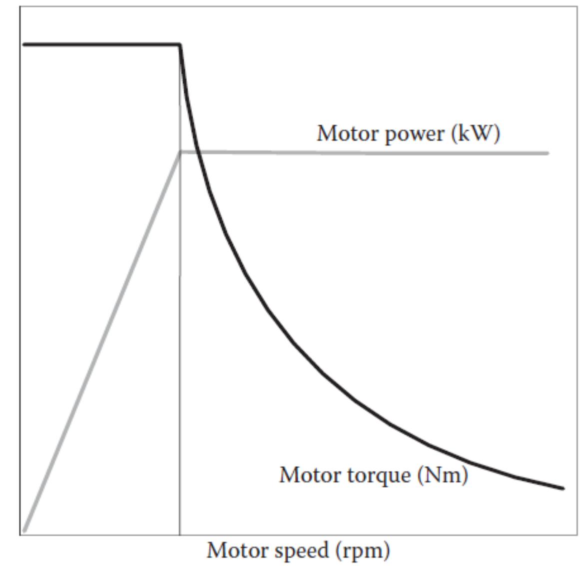
Fig. 36. Energy density vs. power density for various energy-storing devices (Capacitors, UCs, Batteries, FCs).

Table 6. Relative energy and power densities of different energy storage systems

Storage	Energy Density	Power Density
Battery	High	Low
Ultracapacitor	Low	High
Fuel cell	High	Low
Flywheel	Low	High

1.8. Applied Ems as the Propulsion System in EVs;

- ❑ An **Electric Motor (EM)** converts **electrical energy** that it gets from the battery into **mechanical energy** which enables the vehicle to move. It also acts as a **generator** during **regenerative action** which sends energy back to the ESS.
- ❑ requirements of an EM for an EV:
  - ✓ high power and small size;
  - ✓ high torque;
  - ✓ wide speed range;
  - ✓ high efficiency;
  - ✓ Reliability;
  - ✓ reasonable cost;
  - ✓ low noise;
  - ✓ frequent starts and stops capability;
  - ✓ high rates of acceleration/deceleration;
  - ✓ high torque and low-speed ability in hill climbing;
  - ✓ low torque and high-speed ability in cruising,
- ❑ **Various candidates of EMs for EV application are:**
  - ✓ Brushed DC motor;
  - ✓ Brushless DC motor (BLDC);
  - ✓ Permanent Magnet Synchronous Motor (PMSM);
  - ✓ Induction Motor (IM);
  - ✓ Switched Reluctance Motor (SRM);
  - ✓ Synchronous Reluctance Motors (SynRM);



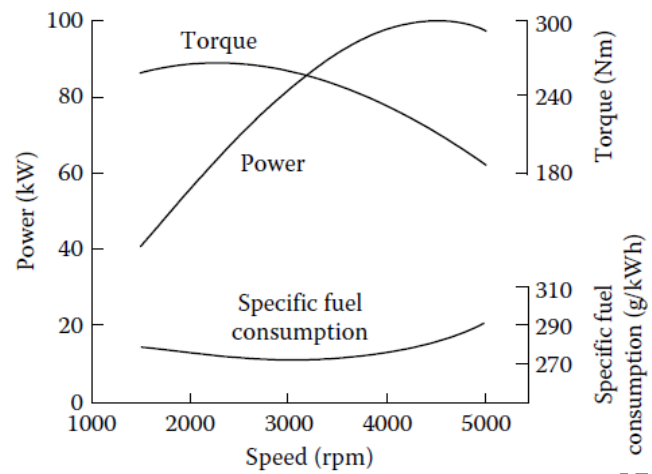


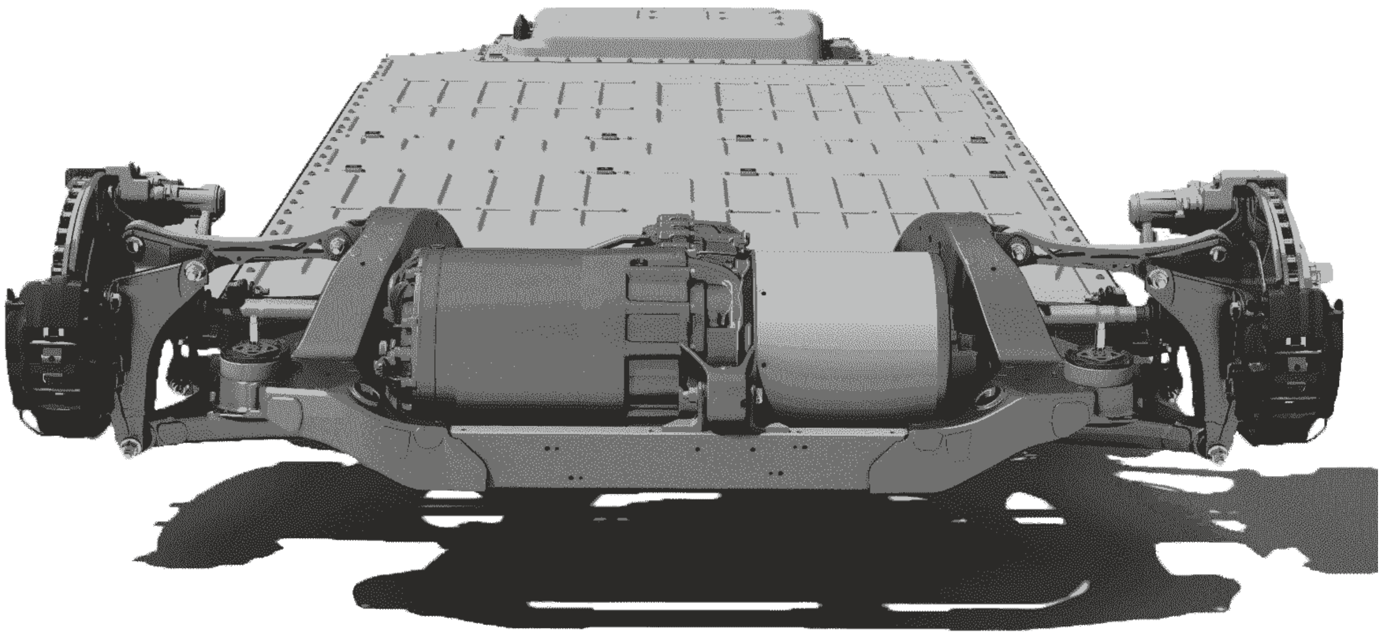
Fig. 37. An EM and an ICE torque-speed characteristic.

Table 7. Advantages, disadvantages and usage of different EM types and their usage cases. Con.

Motor Type	Advantage	Disadvantage	Vehicles Used In
Brushed DC Motor	• Maximum torque at low speed	• Bulky structure • Low efficiency • Heat generation at brushes	Fiat Panda Elettra (Series DC motor), Conceptor G-Van (Separately excited DC motor)
Permanent Magnet Brushless DC Motor (BLDC)	• No rotor copper loss • More efficiency than induction motors • Lighter • Smaller • Better heat dissipation • More reliability • More torque density • More specific power	• Short constant power range • Decreased torque with increase in speed • High cost because of PM	Toyota Prius (2005)
Permanent Magnet Synchronous Motor (PMSM)	• Operable in different speed ranges without using gear systems • Efficient • Compact • Suitable for in-wheel application • High torque even at very low speeds	• Huge iron loss at high speeds during in-wheel operation	Toyota Prius, Nissan Leaf, Soul EV
Induction Motor (IM)	• The most mature commutatorless motor drive system • Can be operated like a separately excited DC motor by employing field orientation control		Tesla Model S, Tesla Model X, Toyota RAV4, GM EV1

Table 7. Advantages, disadvantages and usage of different EM types and their usage cases.

Motor Type	Advantage	Disadvantage	Vehicles Used In
Switched Reluctance Motor (SRM)	• Simple and robust construction • Low cost • High speed • Less chance of hazard • Long constant power range • High power density	• Very noisy • Low efficiency • Larger and heavier than PM machines • Complex design and control	Chloride Lucas
Synchronous Reluctance Motor (SynRM)	• Robust • Fault tolerant • Efficient • Small	• Problems in controllability and manufacturing • Low power factor	



Chapter 2:

Charging Infrastructures of EVs:

Types, Charger Topologies, and Standards

2.1. General features and structures of EV chargers

- Basic structure for all of the EV chargers contains two major parts for power converting as:

1) **AC/DC converter with PFC;**
2) **DC/DC converter;**

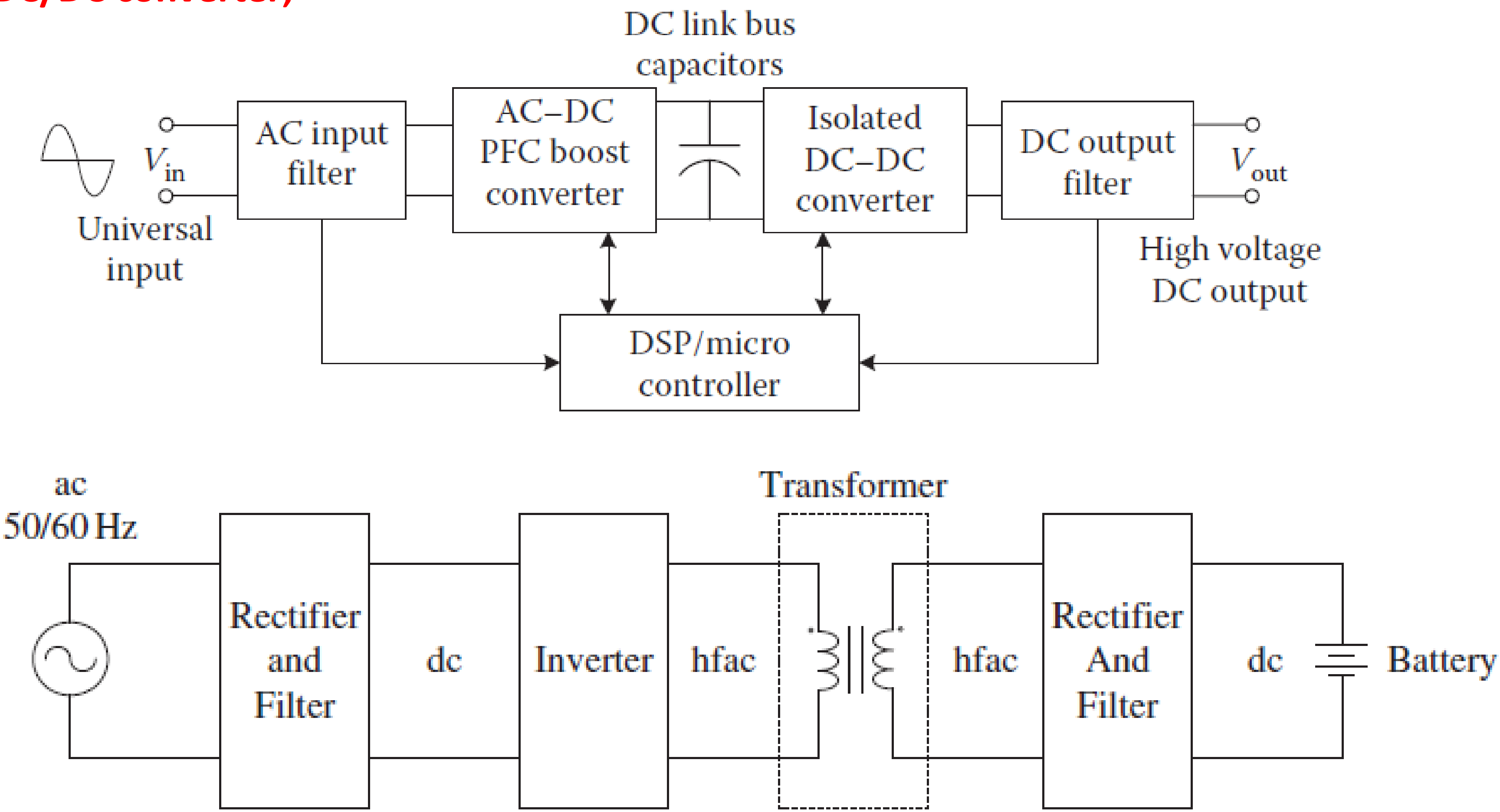


Fig. 39. Basic block diagram of a battery charger in two presentation aspects.

- ❑ Based on the **power level** of the chargers and also **location of the AC/DC/DC power conversion unit** (internal/external of the EV) , they can be in two categories as:

1) **On-board charger:** AC/DC/DC power conversion take place in the EV with relative lower power;
2) **Off-board charger:** AC/DC/DC power conversion take place out of the EV with relative higher power;
3) **Wireless charging:** some part of AC/DC/DC power conversion take place out of the EV and some take place in the EV, with relative lower power;;

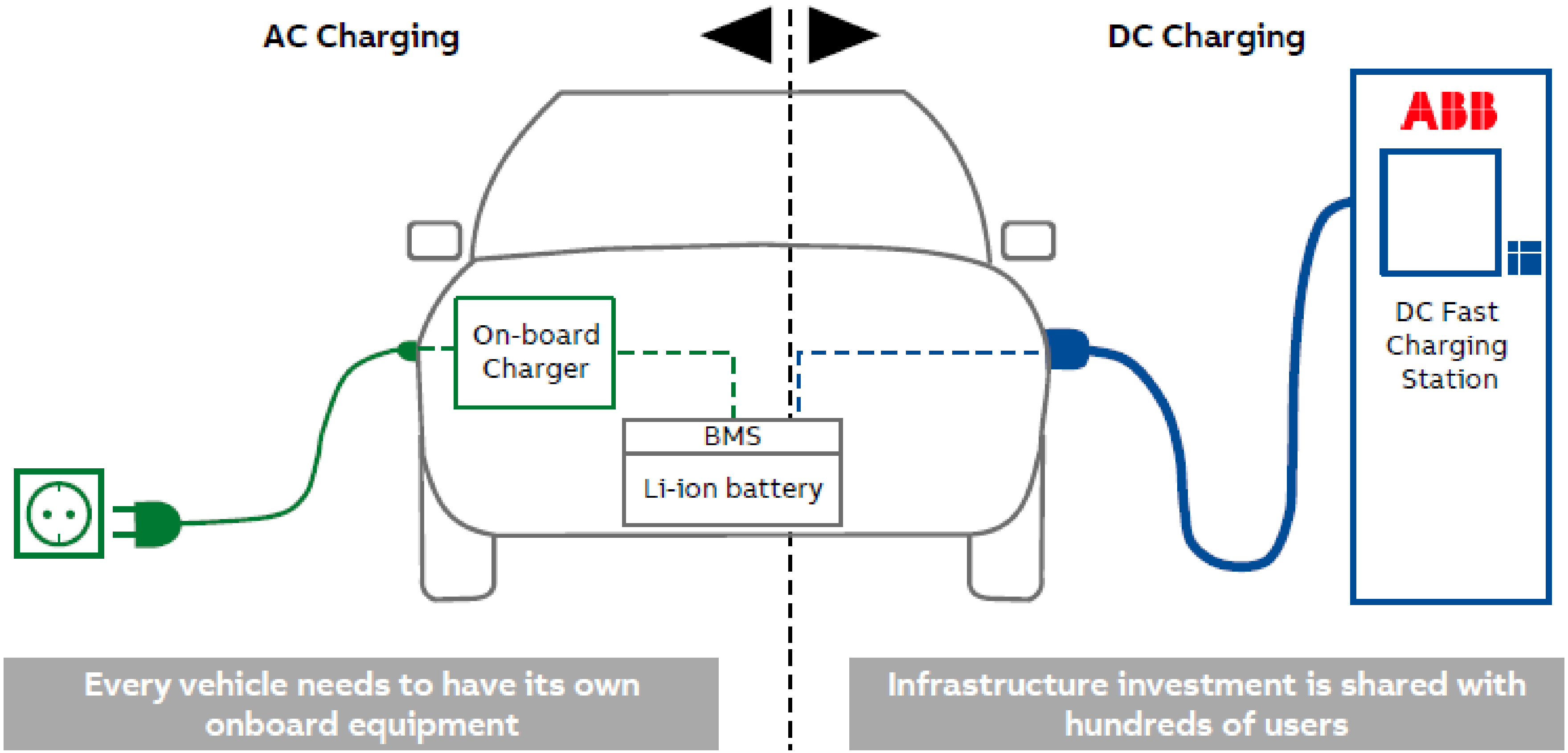


Fig. 40. AC charging versus DC charging (on-board versus off-board charging).

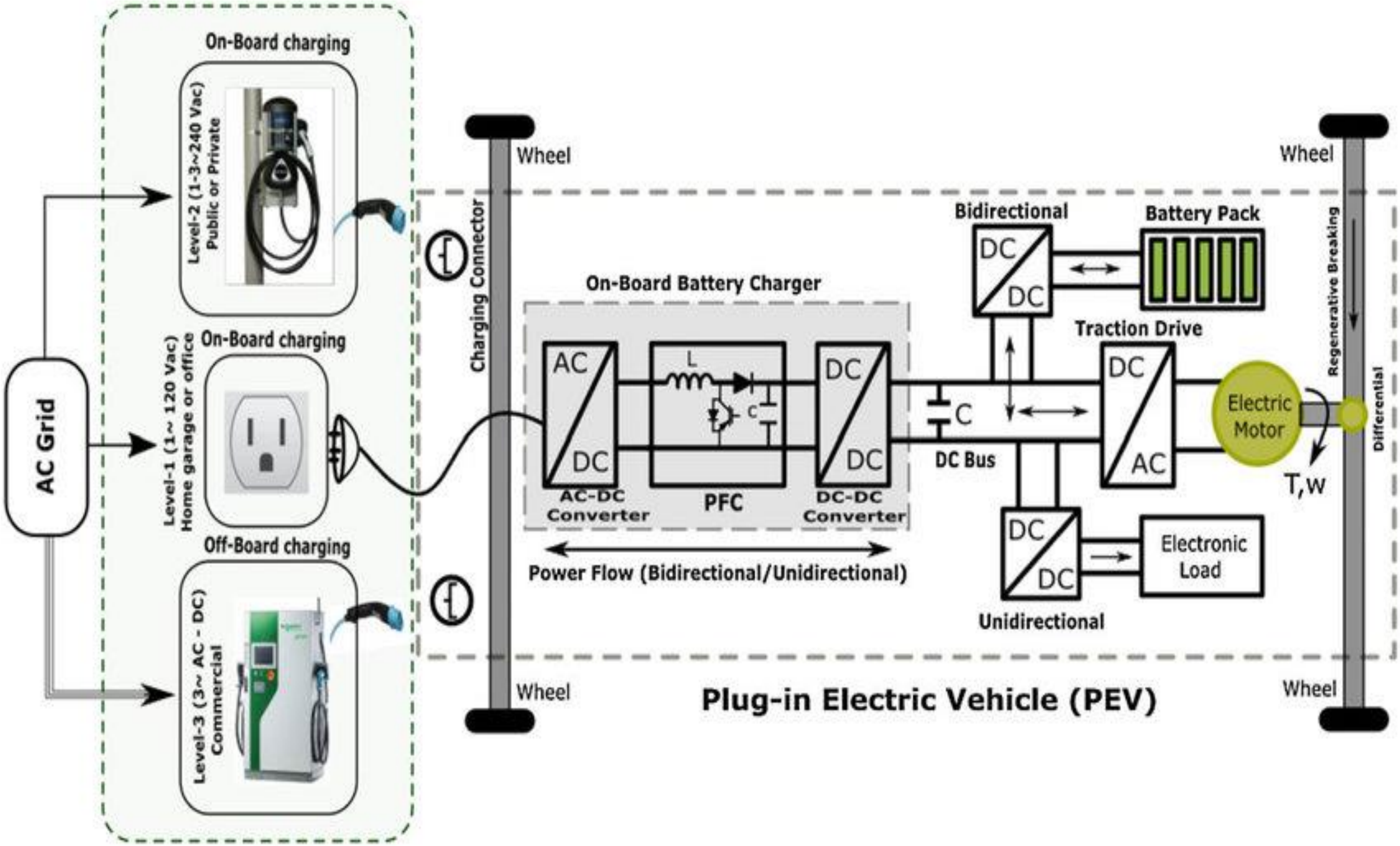


Fig. 41. Conceptual presentation of the conductive charging systems for EVs: on-board and off-board.

2.1.1. AC chargers

Table 8. AC charging characteristics according to Society of Automotive Engineers (SAE).

AC Charging System	Supply Voltage (V)	Maximum Current (A)	Branch Circuit Breaker Rating (A)	Output Power Level (kW)
Level 1	120 V, 1-phase	12	15	1.08
	120 V, 1-phase	16	20	1.44
Level 2	208 to 240 V, 1-phase	16	20	3.3
	208 to 240 V, 1-phase	32	40	6.6
	208 to 240 V, 1-phase	≤80	Per NEC 635	≤14.4
Level 3	208/480/600 V	150–400	150	3

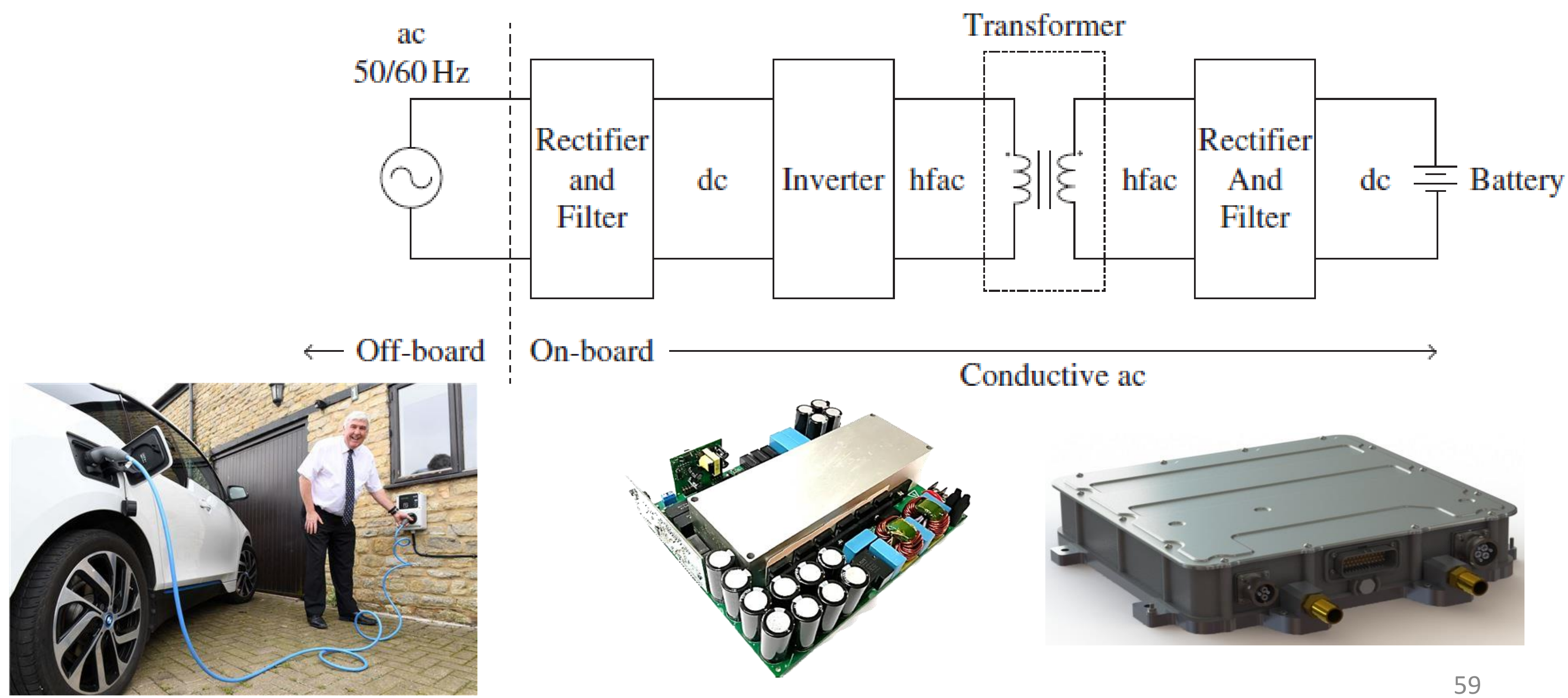
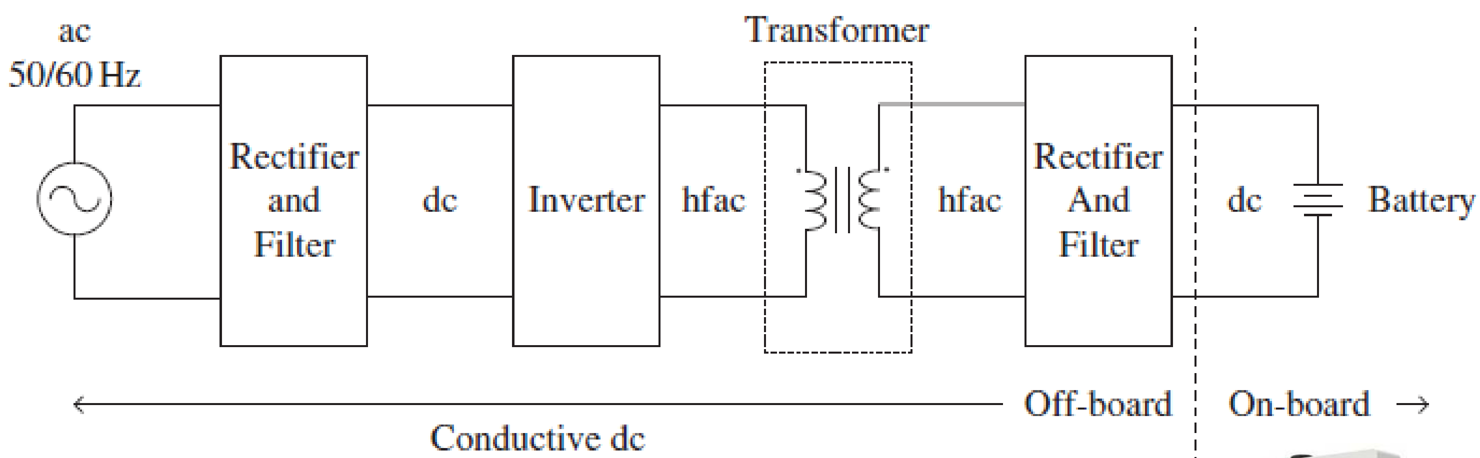


Fig. 42. Conductive AC charger block diagram and a sample.

2.1.2. DC chargers

Table 9. DC charging characteristics according to SAE.

DC Charging System	DC Voltage Range (V)	Maximum Current (A)	Power (kW)
Level 1	200–450	$\lesssim 80$	$\lesssim 36$
Level 2	200–450	$\lesssim 200$	$\lesssim 90$
Level 3	200–600	$\lesssim 400$	$\lesssim 240$



- ❑ DC systems currently have three existing standards/protocol:
- ✓ **Combined Charging System (CCS):** applied for European EVs;
- ✓ **CHAdeMO:** applied for Japanese EVs;
- ✓ **GB/T:** applied for Chinese EVs;
- ✓ **Supercharger:** only for Tesla EVs;

Fig. 43. Conductive DC charger block diagram and two samples.

- ❑ AC systems currently have three main types as:
- ✓ **Type 1:** Low power level for household sockets;
- ✓ **Type 2:** Most applicable;
- ✓ **Type 3:** is not applied yet;
- ❑ DC systems currently have three existing standards/protocol:
- ✓ **Combined Charging System (CCS):** applied for European EVs (Volkswagen, BMW, General Motors and Ford). It has to types as: **CCS1** and **CCS2**;
- ✓ **CHAdeMO:** applied for Japanese EVs (like Nissan, Toyota and Honda);
- ✓ **GB/T:** applied for Chinese EVs;
- ✓ **Supercharger:** only for Tesla EVs;

Current type	Region			
	Japan	America	Europe, rest of world	China
AC				
Plug name:	J1772 (or Type 1)	J1772 (or Type 1)	Mennekes (or Type 2)	GB/T
DC				
Plug name:	CHAdeMO	CCS1	CCS2	GB/T

Fig. 44. AC and DC plugs standard in Japan, America, Europe, and China.

2.1.3. Wireless chargers

- In **wireless charging of Wireless Power Transfer (WPT)**, the power transfer is performed without any direct contact between the EV and the charger. Power level in WPT usually is lower that 10kW right now due to technological problems.

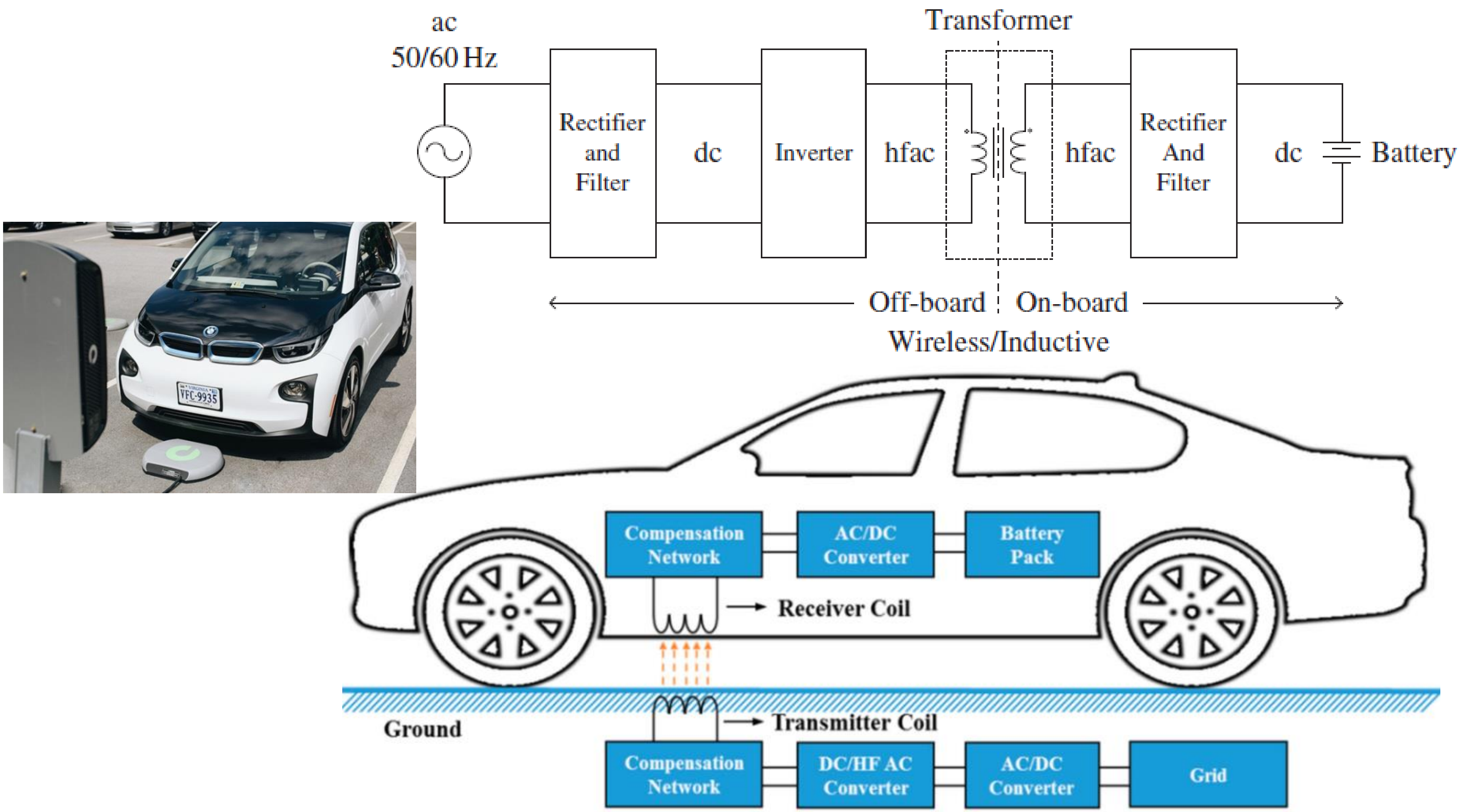


Fig. 45. Wireless charging conceptual block diagrams and a sample.

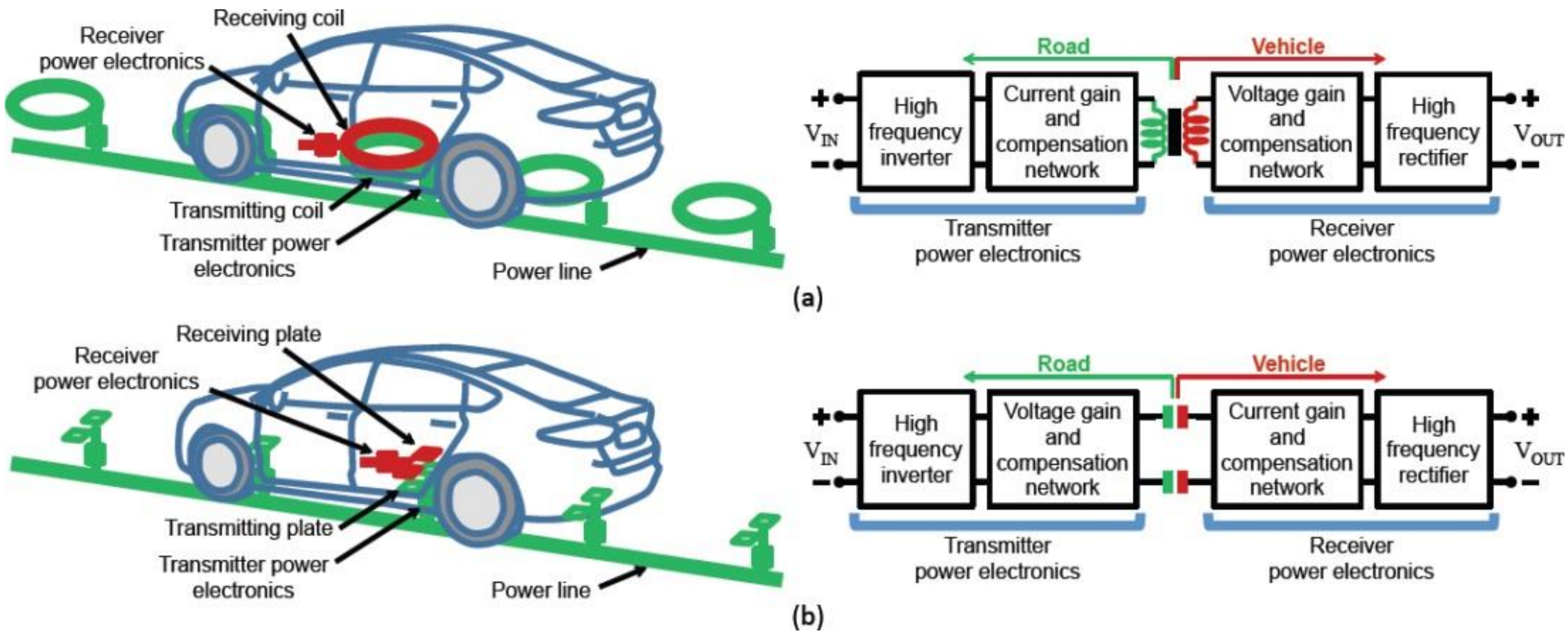


Fig. 46. Two main scenario for wireless power transferring in EV charging: inductive power transfer (high), capacitive power transfer (low).

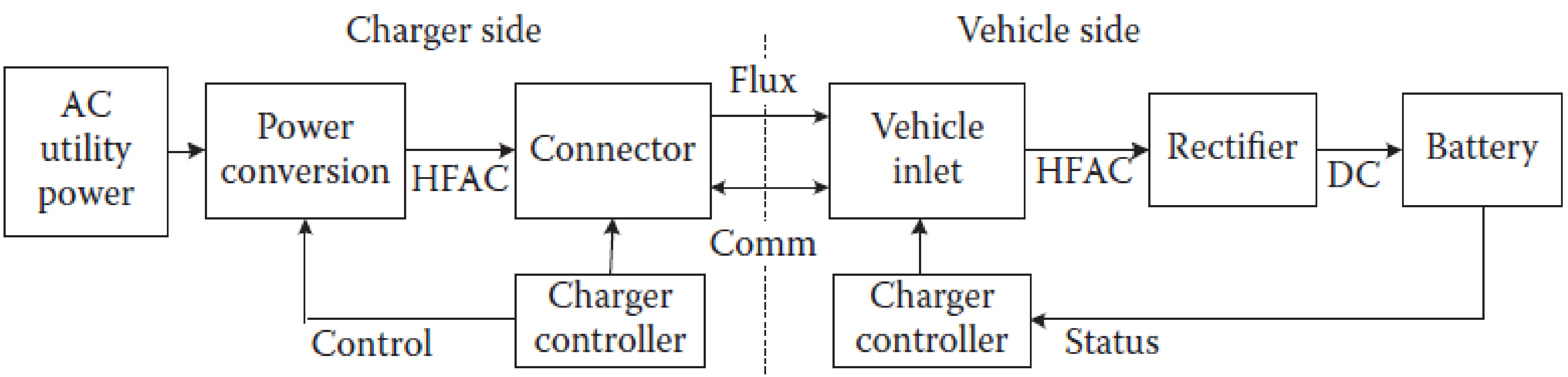


Fig. 47. Typical closed-loop WPT charging systems.

2.2. Standards for charger design

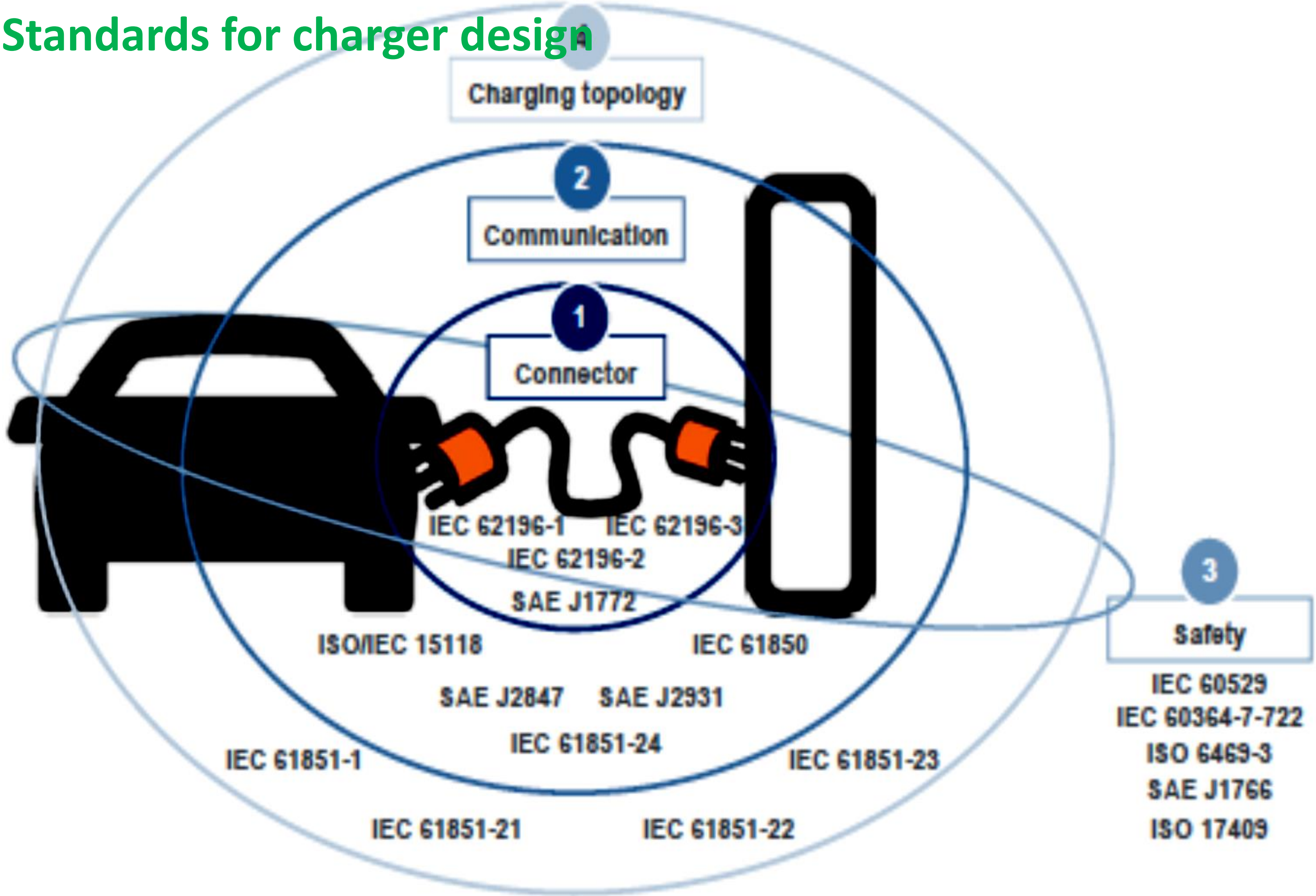


Fig. 48. Applied standards for EV charging design in various levels.

- **IEEE-1547**, **SAE-J2894**, **IEC1000-3-2**, and the U.S. **National Electric Code (NEC) 690** standards limit the **allowable harmonic** and **dc current injection** into the grid, and EV chargers are usually designed to comply.

2.3. Communication protocols for chargers

- ✓ **EVSE:** Electric Vehicle Supply Equipment;
- ✓ **CPO:** Charging Point Operator;
- ✓ **eMSP:** E-Mobilty Service Provider;
- ✓ **DSO:** Distribution system operators;

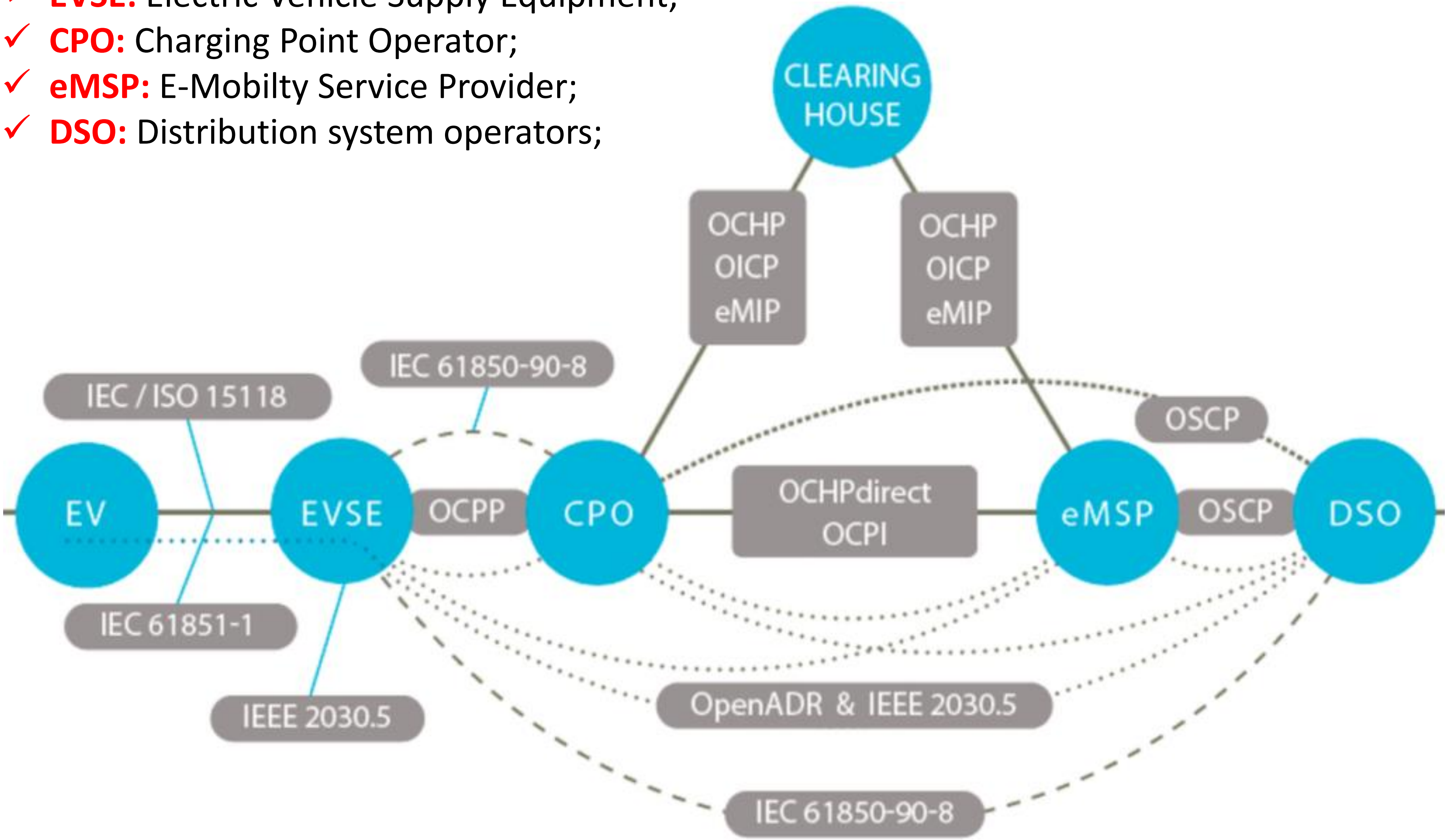


Fig. 49. Conceptual presentation of communication protocols among EVSE and power grid and upstream systems.

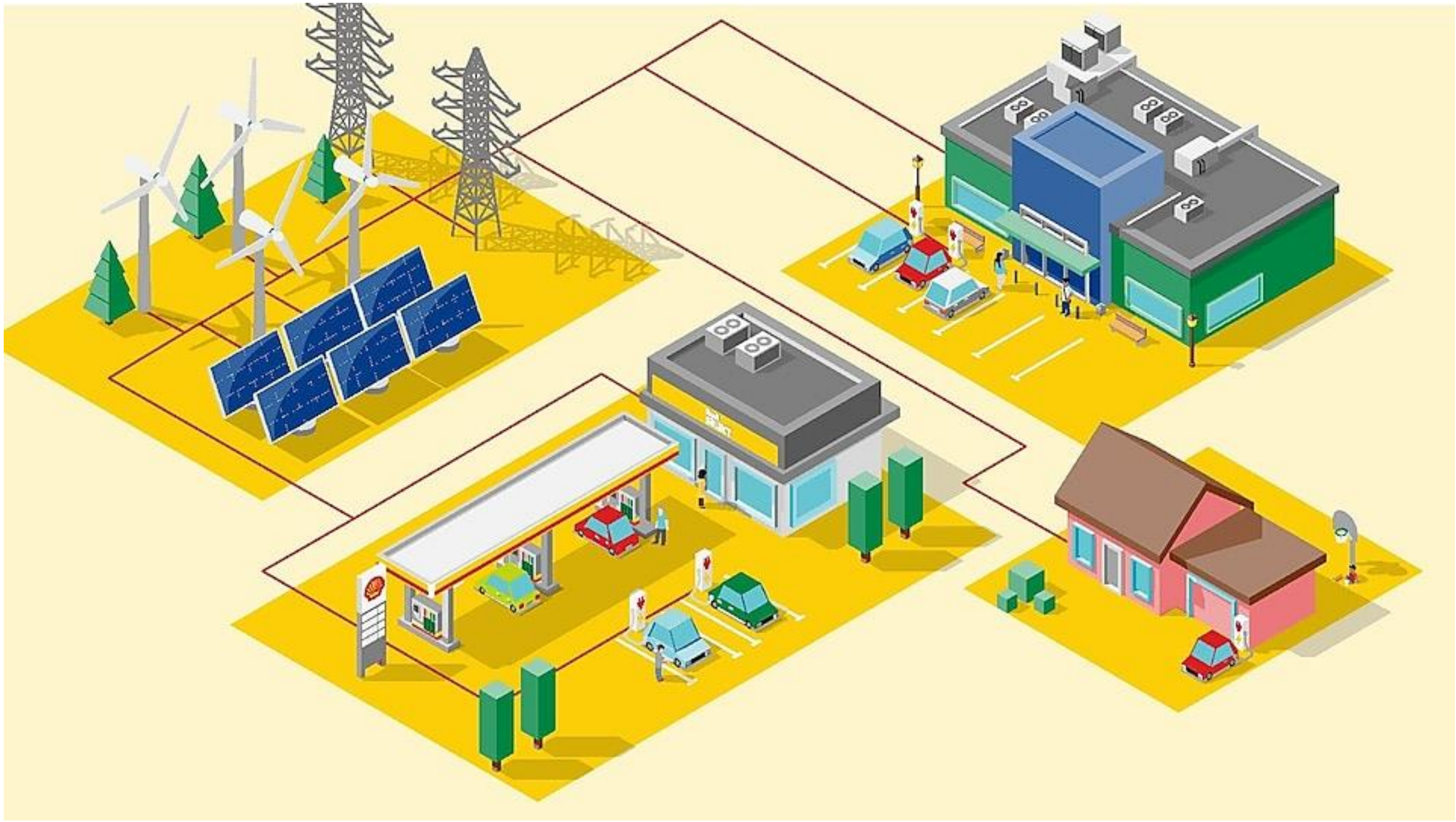
2.4. Electric bus chargers

- There are four main charging methods for E-buses charging as:

1) plug-based charging: for depot locations of E-buses, up to 350kW;
2) Flash charging: for bus stations in the various stations, lower that 100kW;
3) Opportunity charging based on pantograph: usually for first and final station in a line or in the depot locations, up to 600kW;
4) Trolley charging: using a continues power line in the rout (out of date nowadays);

Chapter 3:

EV Development Dimensions: Impacts on Our World, Development Barriers and Solutions, and Market



3.1. EV Impacts on Our World

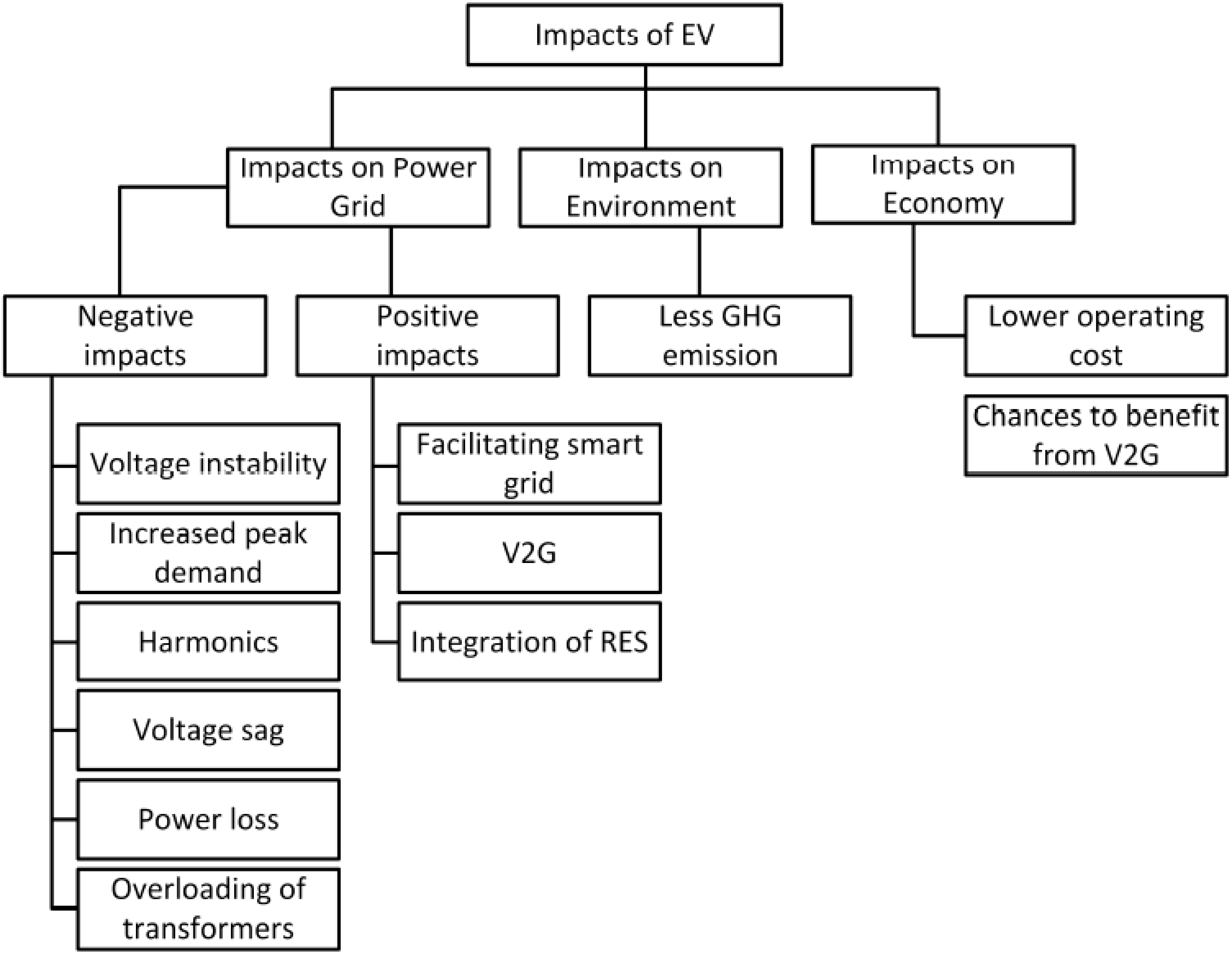


Fig. 50. A short list of the impacts of EVs on the power grid, environment and economy.

3.2. EV Public Adoption

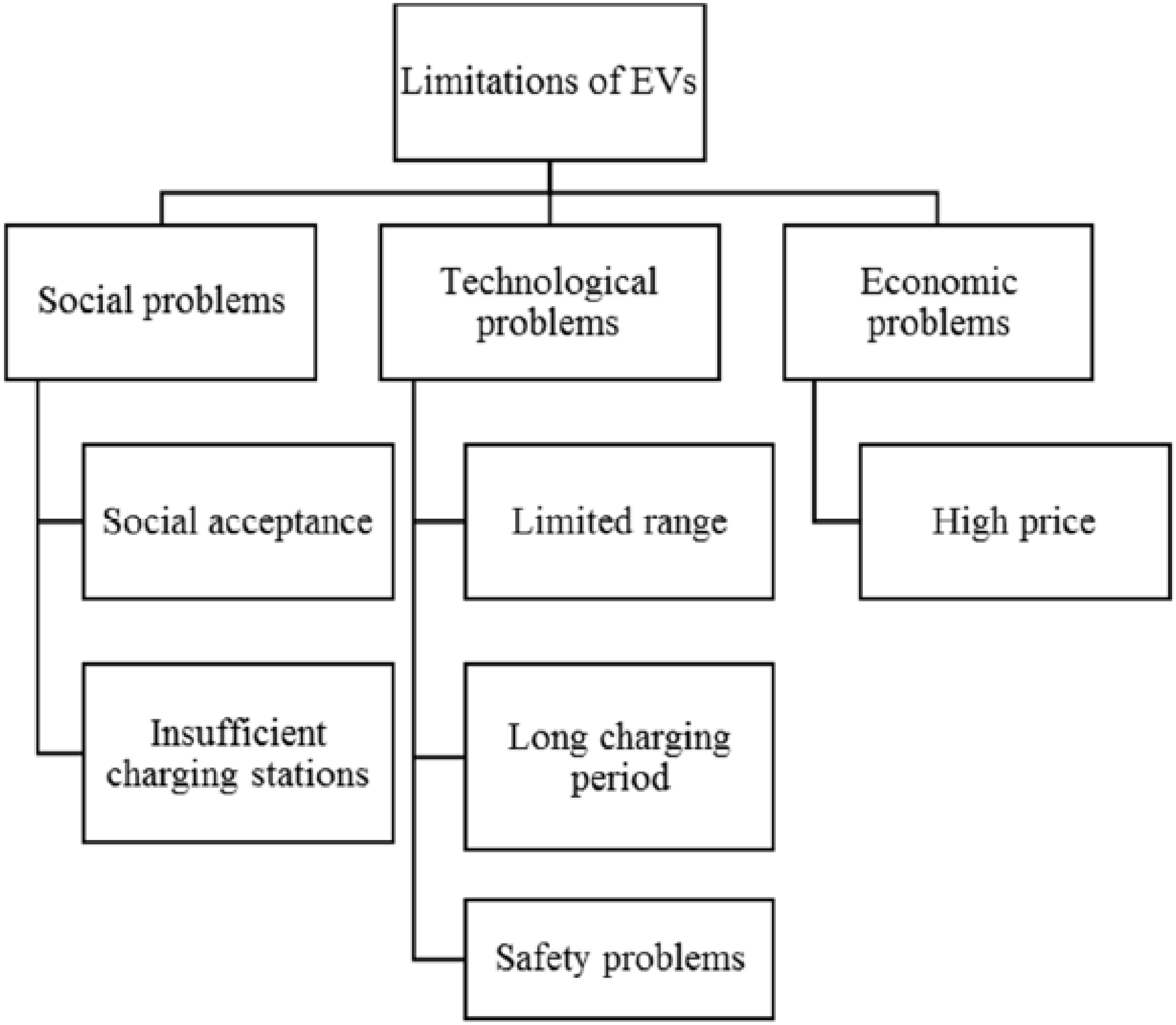
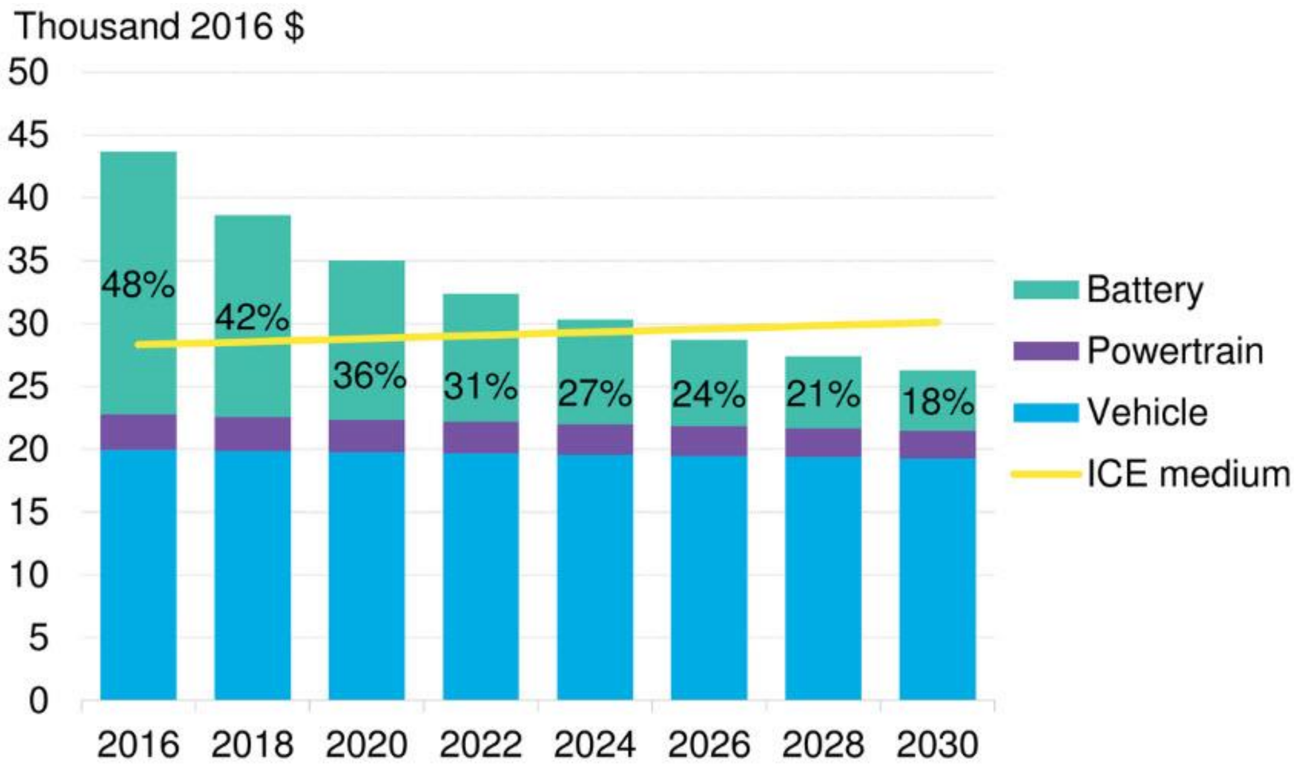


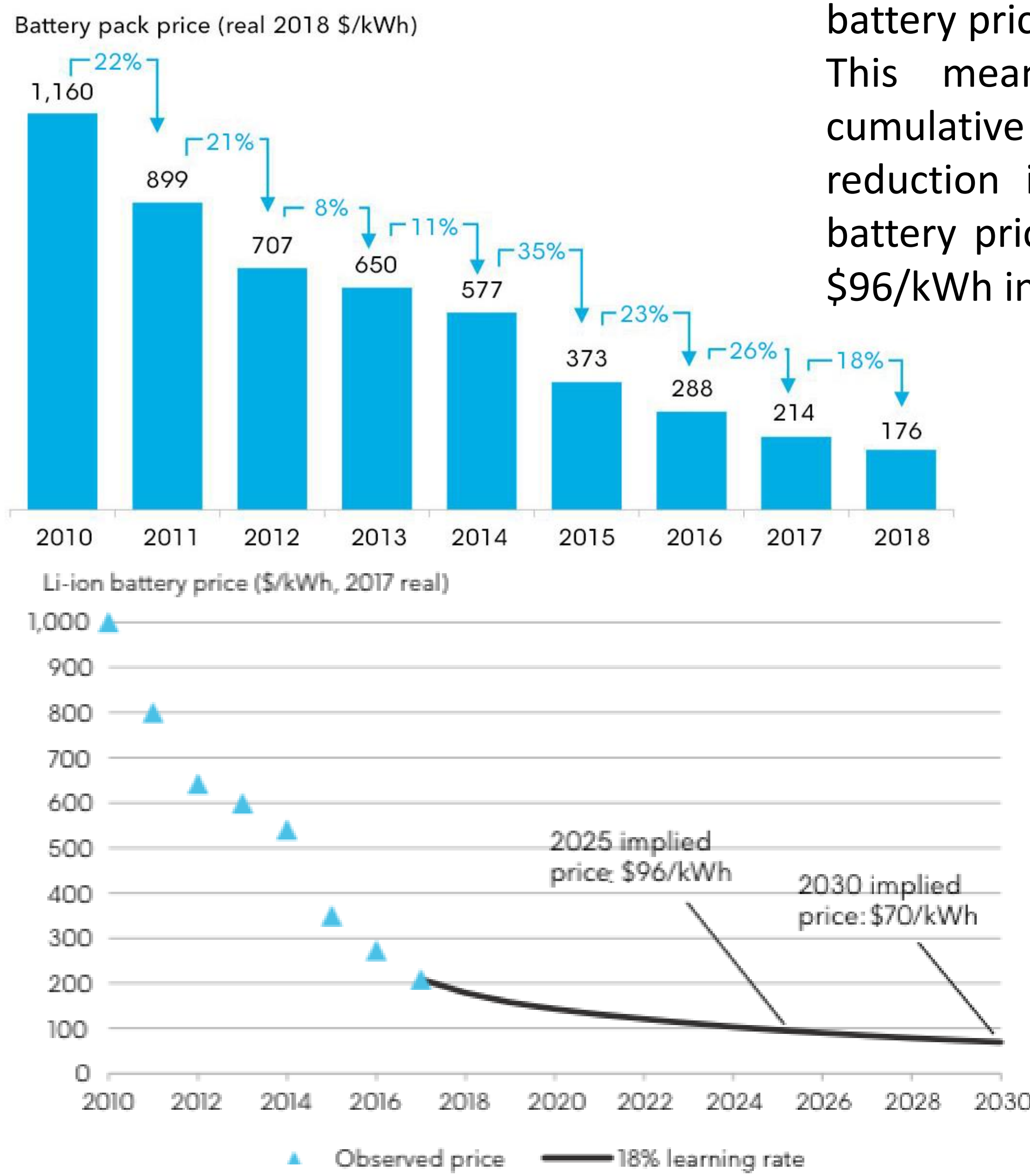
Fig. 51. Social, technological, and economic problems faced by EVs.

3.3. EV Market trend

- The **location of battery manufacturing** also plays an important role in determining costs. Factors such as local electricity costs, labor and financing will also affect the cost of manufacturing. Battery prices in China are currently the lowest at **both pack and cell level**, due to a **combination of scale of manufacturing**, **labor costs**, **electricity prices** and **favorable local conditions**. This in turn allows e-buses made in China to be considerably cheaper than in the rest of the world. We estimated the manufacturer's price for the electric BYD K9 at around 1.75 million Yuan ($264,000) – significantly less than e-buses on offer in Europe or the U.S.

Fig. 52. EV parts price trend in the future.





- ❑ The historic learning rate for EV lithium-ion battery prices from 2010-2017 was around 18%. This means that for every doubling of cumulative volume, we observe an 18% reduction in cost. Based on this, we expect battery prices to continue to decline, reaching $96/kWh in 2025 and $70/kWh in 2030

Fig. 53. Li-ion battery price trend till now (upper) and in the future (lower).

- ❑ The price for lithium-ion battery packs has fallen by 24% since 2016 and 79% since 2010.

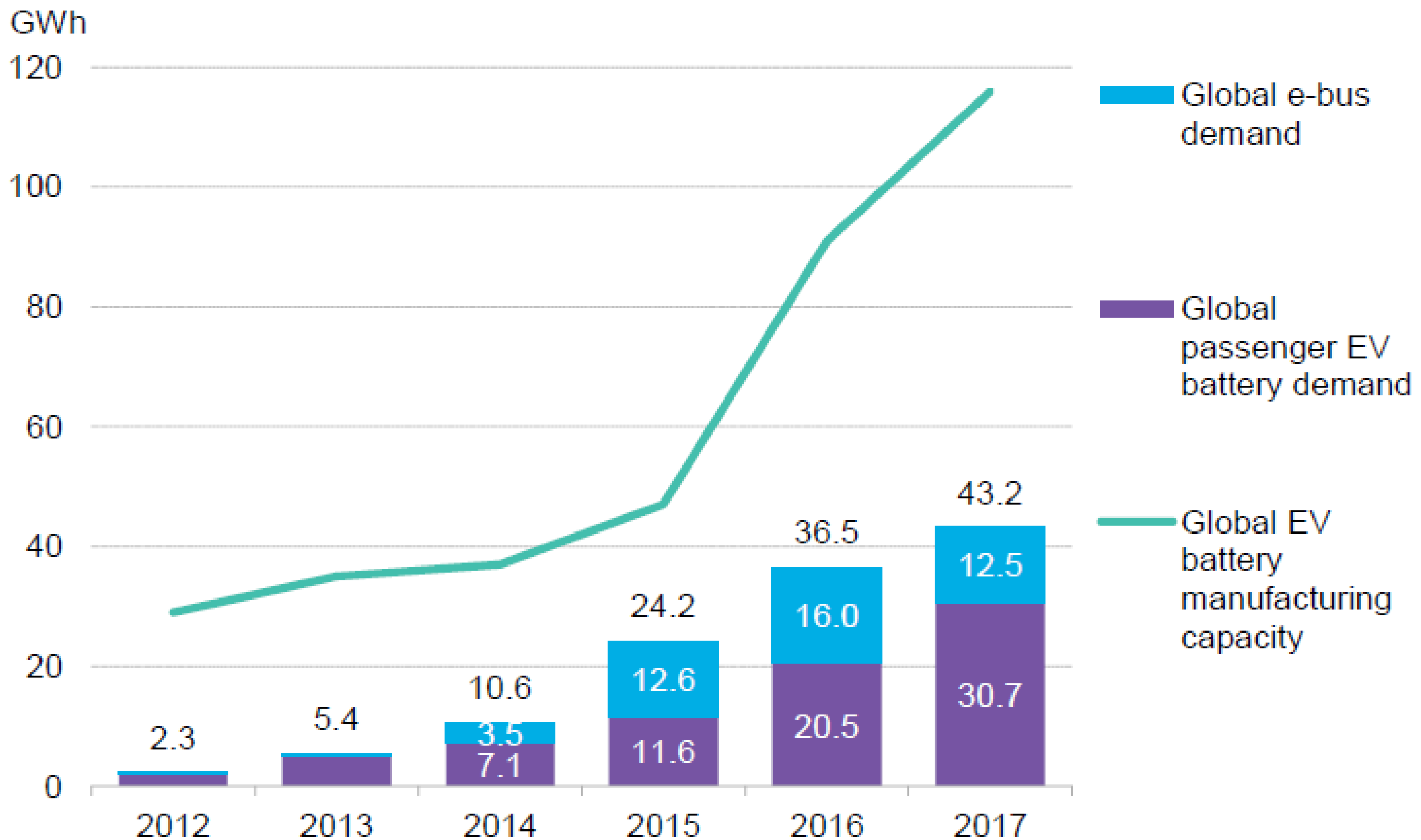


Fig. 54. Global li-ion battery demand for EVs and global EV lithium-ion battery manufacturing capacity.

- In 2017 battery demand from e-buses was slightly lower than in 2016, as a result of the drop in e-bus sales in China. The majority of lithium-ion battery manufacturing capacity is located in China.

Chapter 4:

MAPNA Group

Electric Vehicle Infrastructure and Development Center (EVIDC)

www.mapev.ir

4.1. MAPNA EV chargers

Slow Portable Charger

Fast Wall-box Charger

Fast Charger Station

Slow Wall-box Charger

Slow Charger Station

Slow Street Charger

- Ethernet
- WIFI
- RFID Reader
- Multi Protocol
- OCPP 1.6
- LCD Display

Product highlight:

- Support Standards (Optional): CCS, CHAdeMO, GB and AC
- Nominal output power: 30 kW
- 94% efficiency
- Network connectivity (OCPP 1.6)
- Application and website
- Remote update
- Graphic visualization of charging progress
- RFID card and QR Code for user authentication

Output	Connectors (Optional)	CCS or CHAdeMO or GB or AC type 2.0
	Nominal power	30 kW
	Nominal Voltage	150-500 Vdc
	Max. current	60 A
Environmental	Operating Temperature	-25°C - 50°C
	Protection	IP55
	Application	Indoor / Outdoor

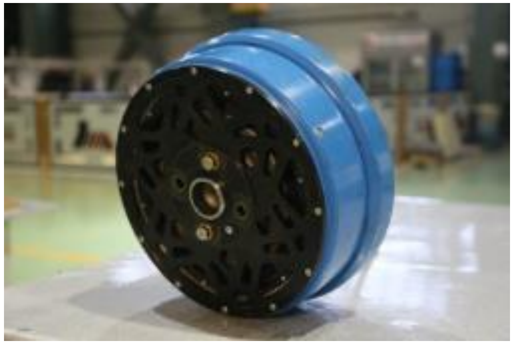
4.2. MAPNA EV charging stations


EV FAST CHARGER


معاونت عمران، حمل و نقل و ترافیک
اولین ایستگاه شارژ برقی مشهد مقدس
Electric
Vehicle
MAPEV


MAPEV

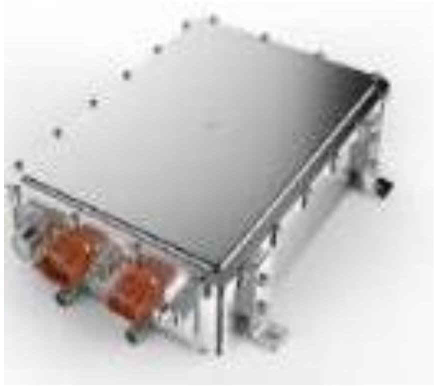
4.3. MAPNA Electrified vehicles



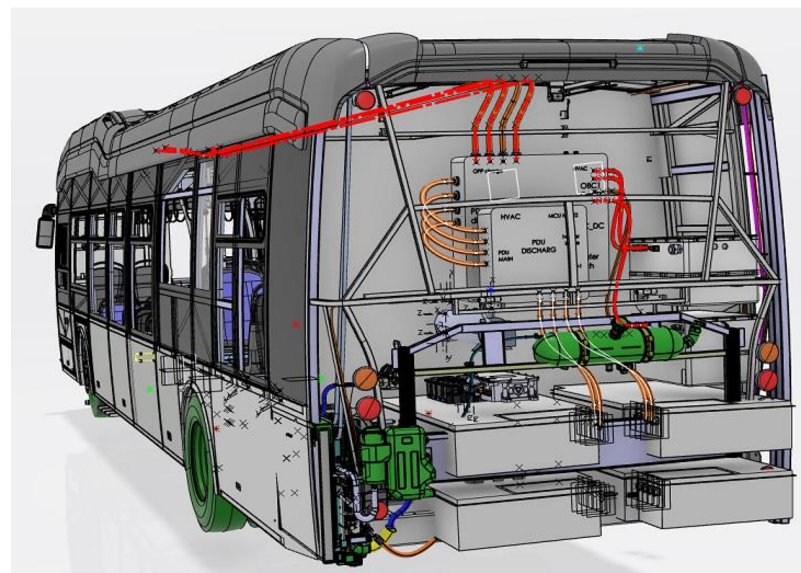
Motor	60 kW×2 PMSM
Max Power	100 hp×2
Max Speed	160 km/h
Range	City: 100 km Highway: 150 km
Battery Pack	NMC, Lithium-ion battery 28kW
Display	10" information display
Lock of Gear	Automatic
Portable Charge Cable	120 V/240 V

Motor Type	Permanent Magnet Synchronous Motor	
Power	70/ 120 kW	
Torque	335/1100 N.m	
Motor RPM	4500 rpm	
Battery Pack		
Cell Capacity	13.5	Ah
Cell type	NMC Li-ion	
Cell Voltage	3.6	V
Pack Voltage	420/ 360	V
Topology	100S10P	
Energy Density	178	Wh/kg
Charge C-Rate	4/ 6	
Discharge C-Rate	5/ 8	
Pack Capacity	48.6	kWh
Weight	≈ 400	kg
On-board Charger	✓	
AC Charging Standard	J1772	
DC Charging Standard	CHAdeMO (Up to 300 kW)	

Parameters		Value
Mass		1645
Acceleration	Pure electric	12 s
	ICE	12 s
	Dual	6 s
Mileage in NEDC		114 km
Maximum velocity		160 km/h
Maximum gradeability		45 %
Motors		PMSM
Battery		Li ion
Nominal voltage		302 V
Battery capacity		20 kW
Onboard charger		6.6 kW
Fast charger		Chademo 50kW



Parameter	Unit	New
Model	-	Shetab 01
Size	mm	12947*2550*3215
Total Weight	kg	20500
Top Speed	km/h	80
Tire	-	275/70R22.5
Gradeability	%	20
Battery Pack	kWh	341
Charger	kW	50*2
HVAC	kW	37
Pantograph System	-	Yes
Regenerative Brake	-	Yes
IOT base design	-	Yes
Kneeling	-	Yes
EBS	-	Yes
ABS	-	Yes
TC	-	Yes
OBD		Yes



Drivetrain		
Motor Max power	kW	80/125
Motor Max torque	Nm	280
Electric motor type		PMSM
Maximum speed	RPM	12000

Battery Pack Spec.		
Battery capacity	kWh	41
Type		Lithium-ion
Voltage	VDC	345.6
Number of cells	-	96

Charger		
On-board charger	kW	6.6
Portable charger	kW	5.5
Quick Charge port	kW	50

Performance		
Motor Max speed	RPM	12000
Maximum Mileage @ NEDC	km	>300
Maximum Mileage @ 80km/h	km	385
Maximum gradeability @ 20s	%	45
Maximum Continuous gradeability	%	37
Maximum Speed @ 35 % grade	km/h	35
Acceleration time (0 -100)	s	9.8
Top speed	km/h	155

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