Energy Storage

4. Electric Vehicles as Energy Storage Providers

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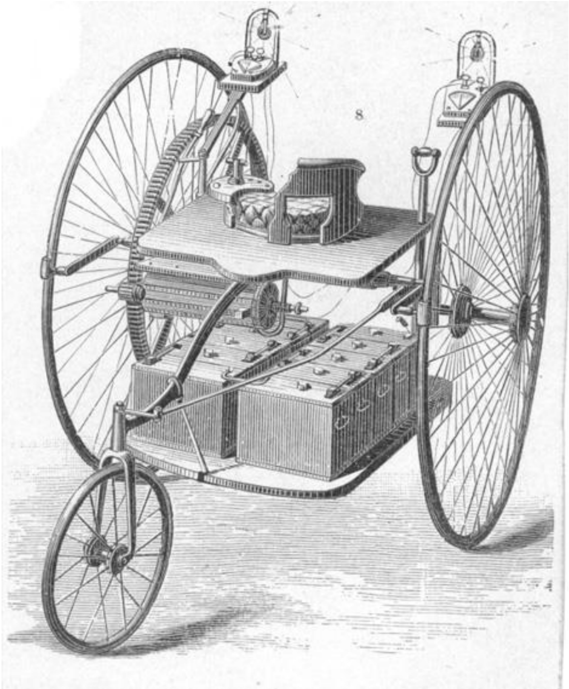
EV History

- In 1828 Hungarian inventor Ányos Jedlik invented one of the first electric motors and constructs a model car supplied by this motor
- In 1835 prof. Sibrandus Stratingh from Groningena and his assistant Christopher Becker construct a small EV supplied by primary batteries
- In 1881 William Ayrton and John Perry construct the first EV in order to advertise their inventions



EV History

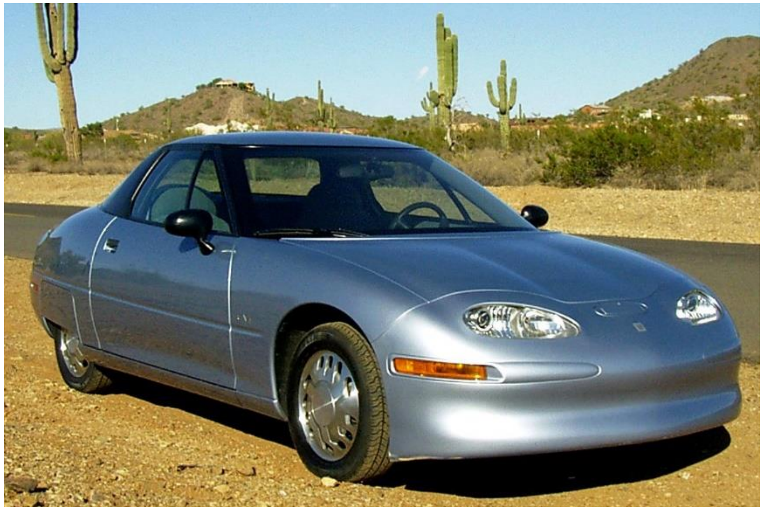
- The concept of EV battery swap was already suggested in 1896
- Delivery vehicle (furgon) was purchased without the battery
- An owner would pay a monthly fee and per mile fee
- This was in business in period 1910-1924

Fall and Rise of EVs

- Modern, quick highways, along with the development of electric starter, problems with large distances and long charging times resulted in bust of the EV industry
- Years later, the oil crisis during the 1970 and 1980 spur a new interest in EVs
- During 1990 and 2000, due to the acceptance of responsibility for our planet, this interest has further increased

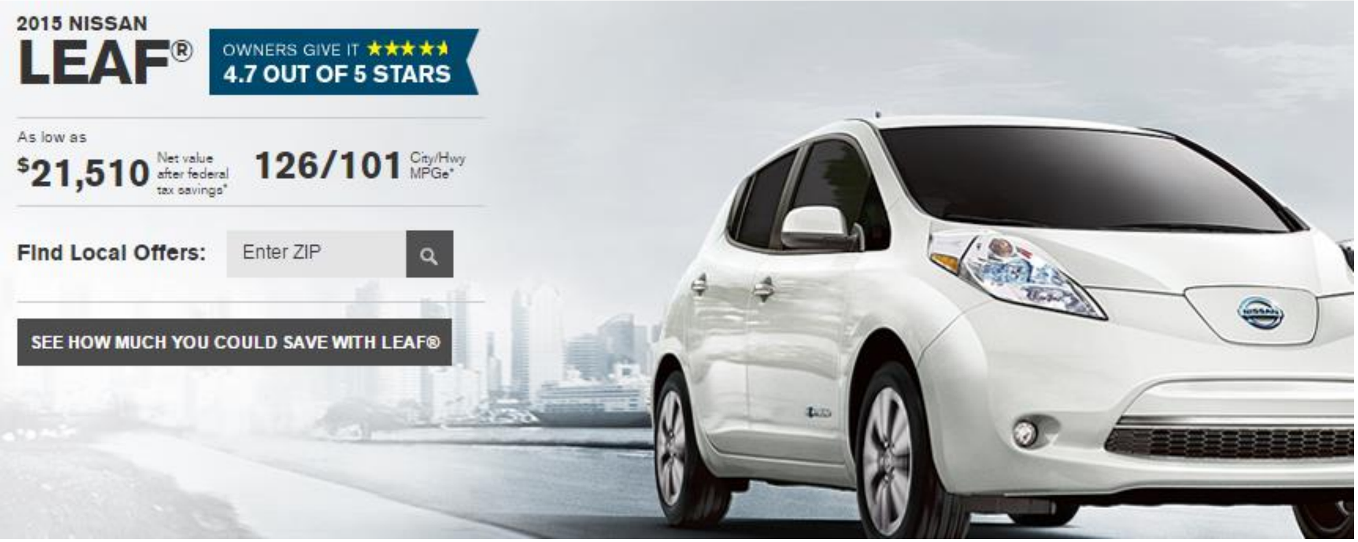
First Modern EV

- General Motors EV1
- First modern BEV from a major automaker
- Battery
  - Early versions: lead-acid, 16.5–18.7 kWh
  - Later versions: NiMH, 26.4 kWh
- Range: 70 miles (110 km)
- Almost all vehicles ultimately withdrawn and destroyed



Battery EVs Today

- They use exclusively chemical energy stored in rechargeable batteries
- Number one most selling EV is Nissan Leaf with over 370 000 sales



Battery EVs Today

EV model	Battery Capacity (kWh)	Range (km)	OBC Max Power (kW)	OBC Type	DC Max Power (kW)	FC Type
Mitsubishi i-MiEV	16	160	3,7	T1	50	CDM
Citroen C Zero	16	88	3,7	T1	40	CDM
Peugeot iOn	16	88	3,7	T1	40	CDM
Smart ED	17,6	161	7	T2	-	-
Chevrolet Volt	18,4	85	7,2	T2	50	CCS
VW e-up	18,7	159	3,7	T2	50	CCS
Fiat 500e	24	135	6,6	T2	-	-
Honda Clarity	25,5	143	7,2	T2	50	CCS
Hyundai Ioniq Electric	28	200	6,6	T2	70	CCS
Kia Soul EV	33	179	6,6	T2	100	CDM
BMW i3	33	183	11	T2	50	CCS
Ford Focus Electric	33,5	185	6,6	T2	50	CCS
VW e-golf	35,8	192	7,2	T2	40	CCS
Nissan Leaf	40	243	6,6	T2	50	CDM
Renault Zoe	41	299	22	T2	43	T2
BMW i3 (120 Ah)	42,2	233	11	T2	50	CCS
Tesla Model 3	60	370	11	T2	70	SC
Chevrolet Bolt	60	383	7,2	T2	50	CCS
Hyundai Kona E	64	415	7,2	T2	80	CCS
Tesla Model 3 (LR)	75	499	11	T2	110	SC
Tesla Model S 75D	75	417	17	T2	120	SC
Tesla Model X 75D	75	381	17	T2	120	SC
Jaguar I-Pace	90	37,5	7,4	T2	100	CCS
Tesla Model X 100D	100	475	17	T2	120	SC
Tesla Model X P100D	100	465	17	T2	120	SC
Tesla Model S 100D	100	539	17	T2	120	SC
Tesla Model S P100D	100	507	17	T2	120	SC

Croatian EV Industry

- Croatian industry has its EVs:
  - Loox by Dok-Ing
  - Concept One and Two by Rimac

Battery EVs Today

- Tesla Motors is the only car producer investing in infrastructure as well
- 1,229 supercharger stations with 9,623 superchargers worldwide

Types of electric vehicles

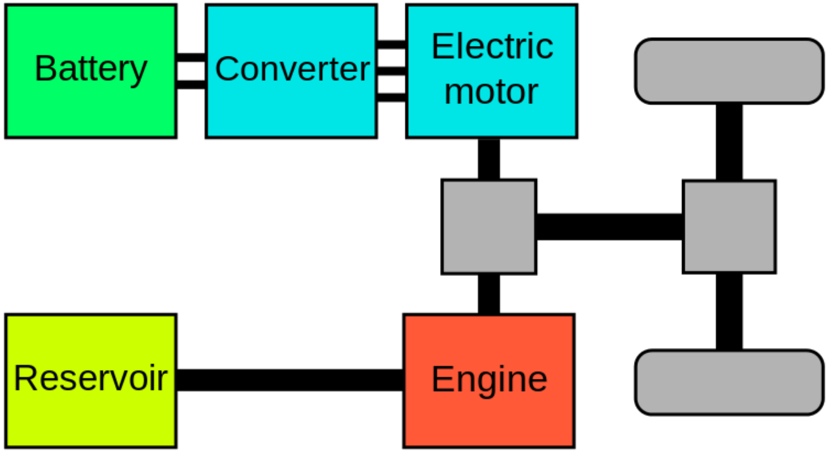
- HEV
  - Hybrid Electric Vehicle
  - Combine traditional ICE (Internal Combustion Engine) with battery driven electric motor
- PHEV
  - Plug-in Hybrid Electric Vehicle
  - Can be plugged-in to recharge battery
  - Typically has higher electric autonomy than HEVs
- BEV
  - Battery Electric Vehicle
  - No ICE
  - Often referred to simply as EV

Hybrid vehicle drivetrain

- Main types of drivetrains
  - Parallel hybrid
  - Series hybrid
  - Series-parallel (power-split) hybrid
- Regenerative breaking – all hybrid configurations including BEVs make use of regenerative breaking

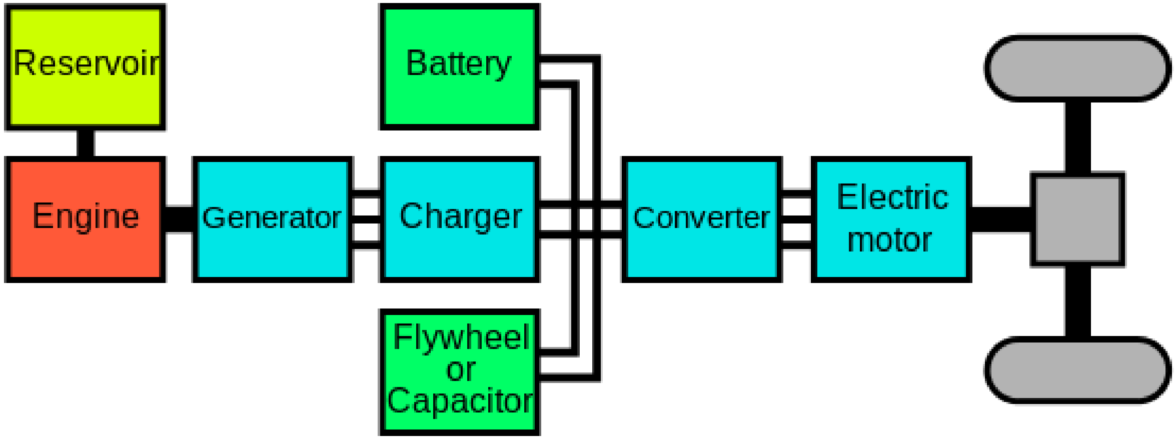
Parallel hybrid

- Typically used by HEVs
- Relies mostly on ICE
- Typically has relatively small battery
- ICE and electric motor act simultaneously – they are connected to the same shaft and their torques act togehter
- ICE may also be used for recharging battery



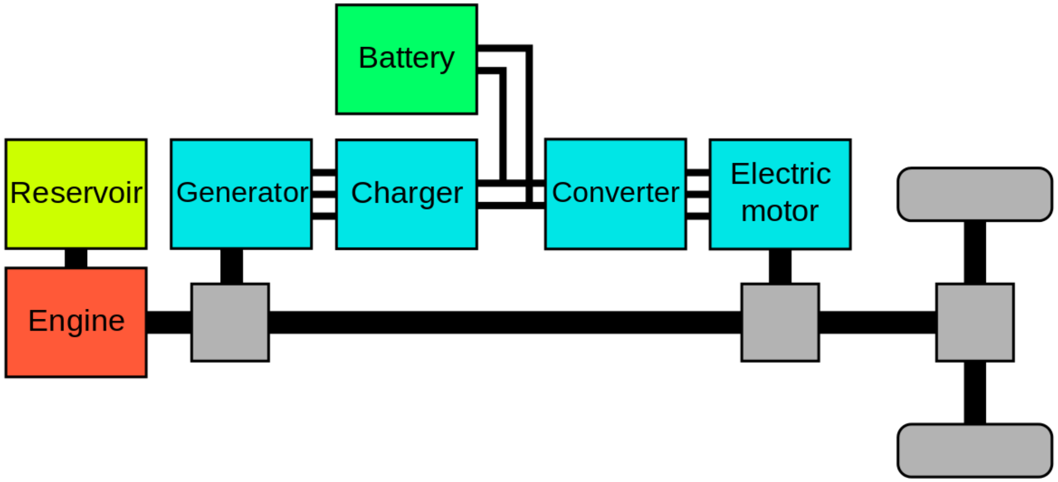
Series hybrid

- Typically used by PHEVs
- Larger battery than parallel hybrid – higher cost
- Smaller ICE
  - Often referred to as ”range extender”
  - Drives the generator
  - Not mechanically connected to the wheels



Series-parallel (power-split) hybrid

- ICE drive and electrical drivetrain can be decoupled allowing for ICE-only or electric-only drive
- Combines favorable characteristics
  - Series – more efficient at lower speeds
  - Parallel – more efficient at higher speeds
- Higher cost

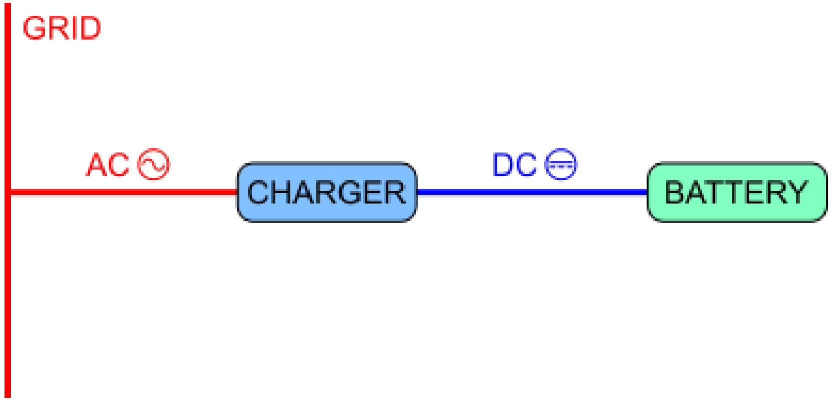


EV Charging

Introduction

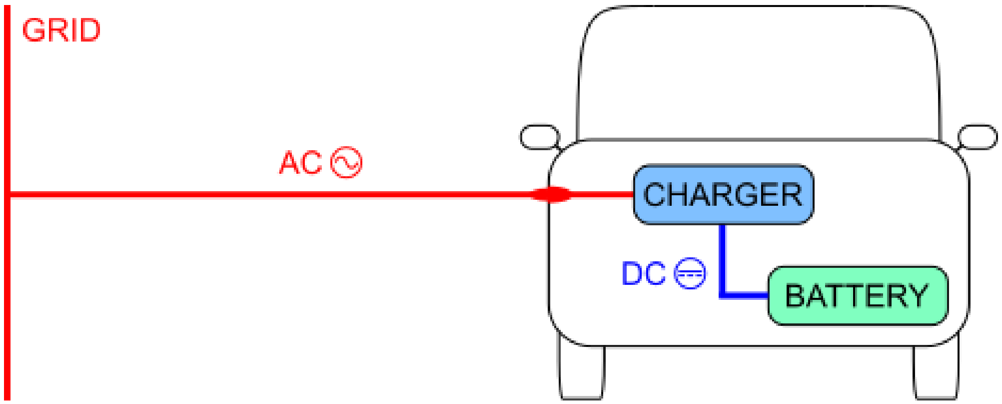
- Charging is required by:
  - Battery Electric Vehicles (BEV)
  - Plug-in Hybrid Electric Vehicles (PHEV)
- In the following slides term Electric Vehicles (EV) implies both BEV and PHEV

- AC grid vs. DC battery
- Charger
  - AC/DC converter
  - Unidirectional
  - Bidirectional

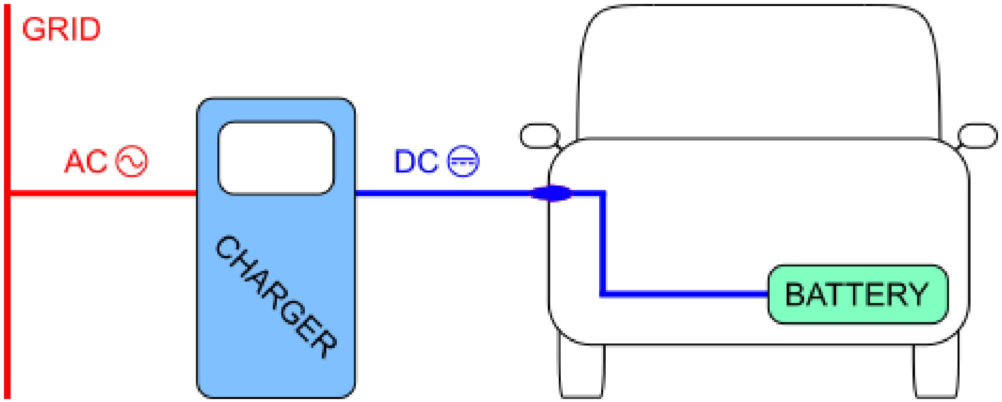


Types of EV Charging

- AC Charging
  - On-board charger
  - ”Slow” charging

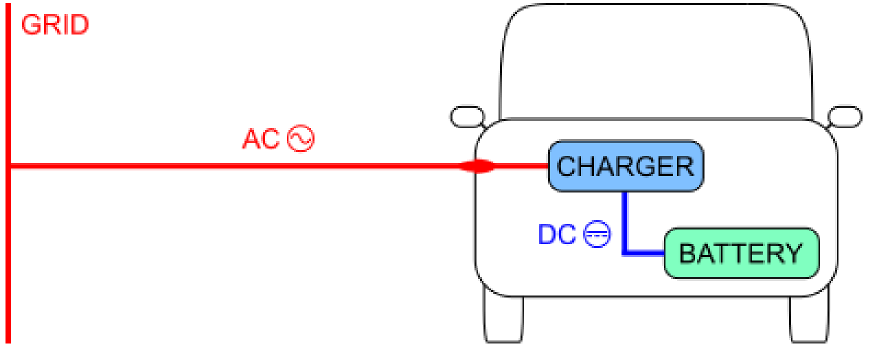


- DC Charging
  - Off-board charger
  - ”Fast” charging



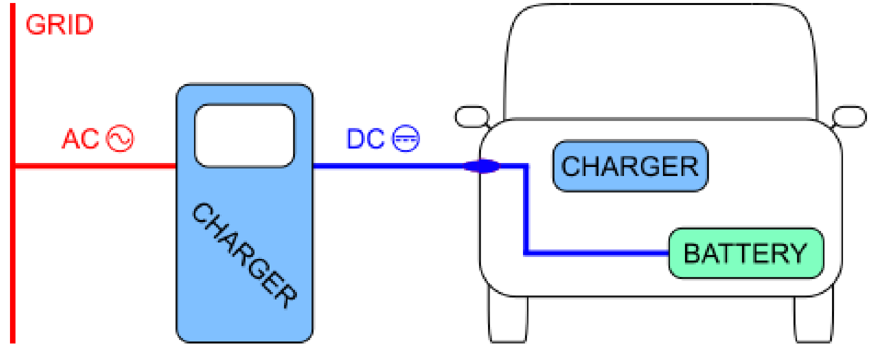
AC Charging

- On-board chargers usually have lower power:
  - Lower than 20 kW
  - Typically 3.3 – 6.6 kW
- High power on-board chargers are feasible, but have several downsides:
  - Bulkier than low power chargers thus taking more space and adding weight to an EV
  - Higher price of power electronics



DC Charging

- Off-board chargers usually have higher power:
  - Higher than 20 kW
  - Typically 20 – 100 kW
- Off-board placement allows for increased charger dimensions and weight
- DC charging stations are much more expensive compared to AC charging stations



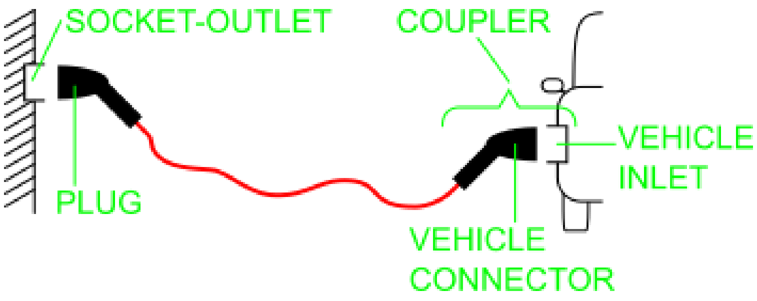
Typical Charging Times

107 miles = 172 km

Charger power	Type of charging	Charging time (cca.)	State-of-charge (SOC)
3.6 kW	AC (on-board charger)	9 hours	0-100 %
6.6 kW	AC (on-board charger)	5 hours	0-100 %
40kW	DC (off-board charger)	30 minutes	0-80 %

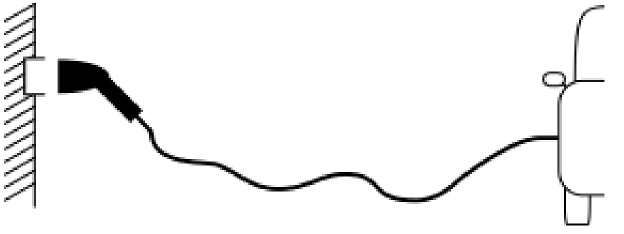
Standards

- Standards
  - IEC 61851 *Electric vehicle conductive charging system*
  - IEC 62196 *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles*
- IEC 61851 prescribes:
  - 3 EV connection cases (using cables and plugs)
  - 4 EV charging modes
- Terminology:

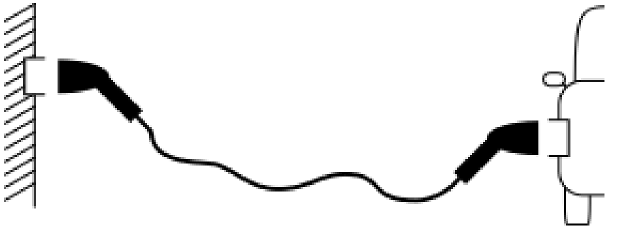


EV Connection Cases

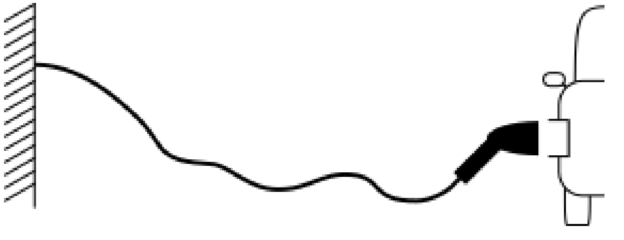
- Case A
  - Cable permanently attached to the vehicle
  - Not very common



- Case B
  - Both sides of cable are detachable

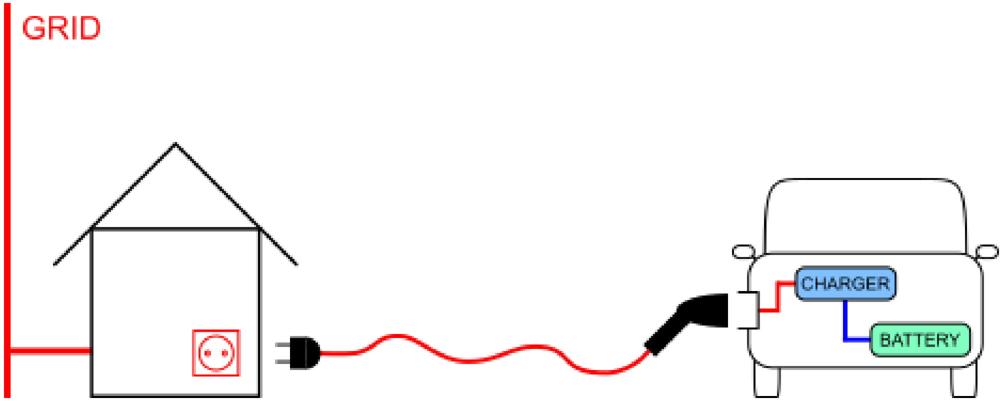


- Case C
  - Cable permanently attached to the EVSE (Electric Vehicle Supply Equipment)



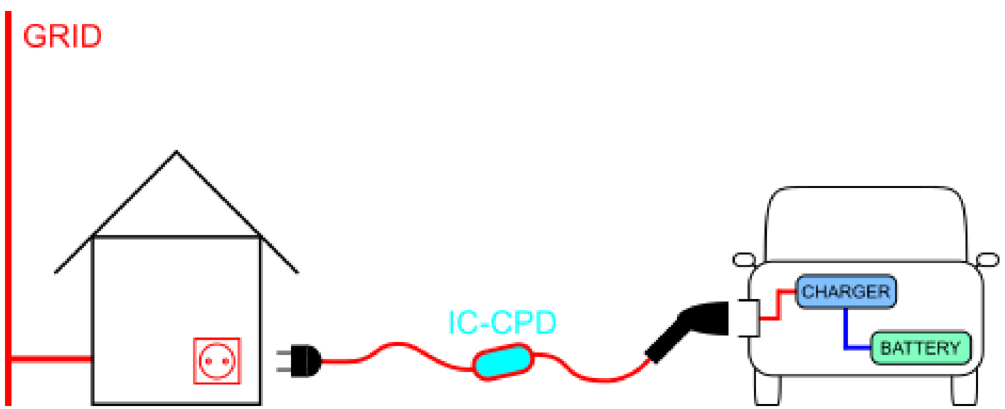
EV Charging Modes

- Mode 1
  - Direct connection to standardized residential socket-outlets
  - Electrical installation must have an earthing system, circuit breaker etc.
  - Prohibited in some countries, e.g. USA (due to lack of earthing in some residences)
  - Voltage limits (AC): 250 V (1-phase), 480 V (3-phase)
  - Current limit: 16 A



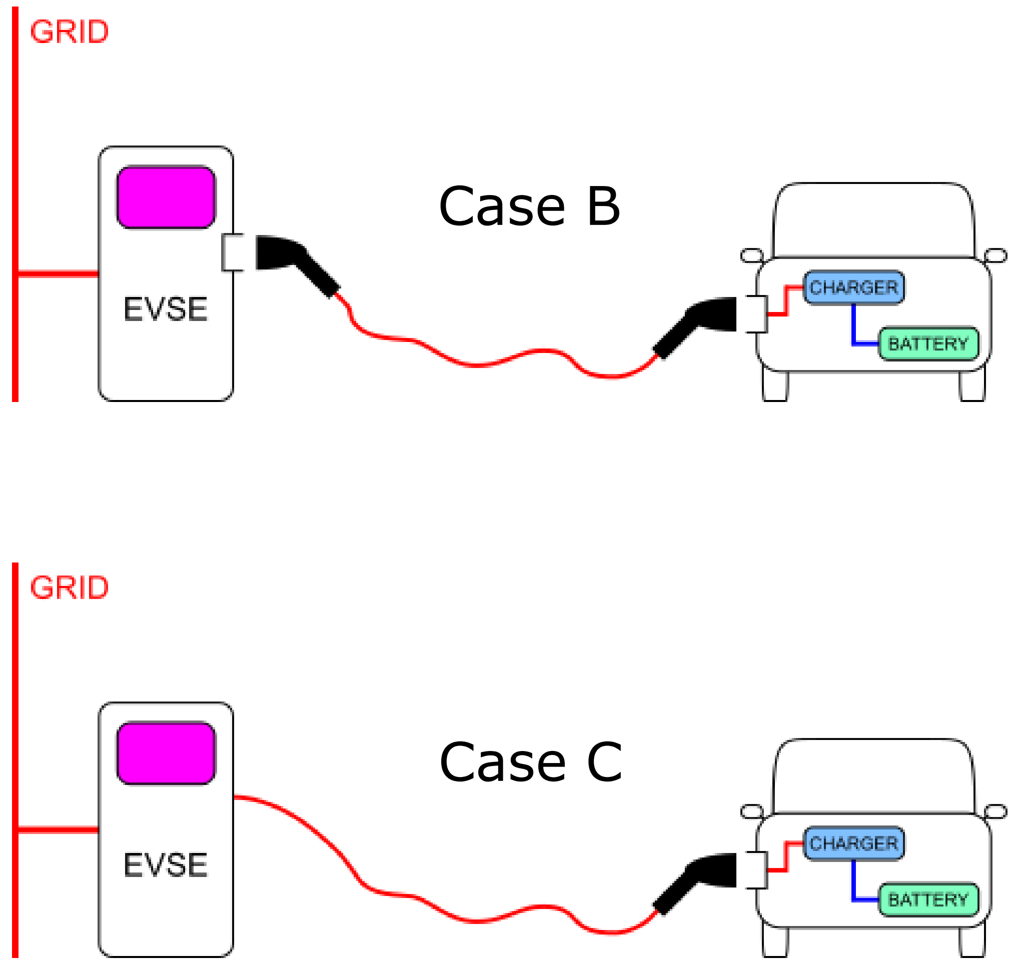
EV Charging Modes

- Mode 2
  - Connection to standardized residential socket-outlets
  - In-cable Control and Protective Device (IC-CPD) – performs control and safety functions
  - Voltage limits (AC): 250 V (1-phase), 480 V (3-phase)
  - Current limit: 32 A



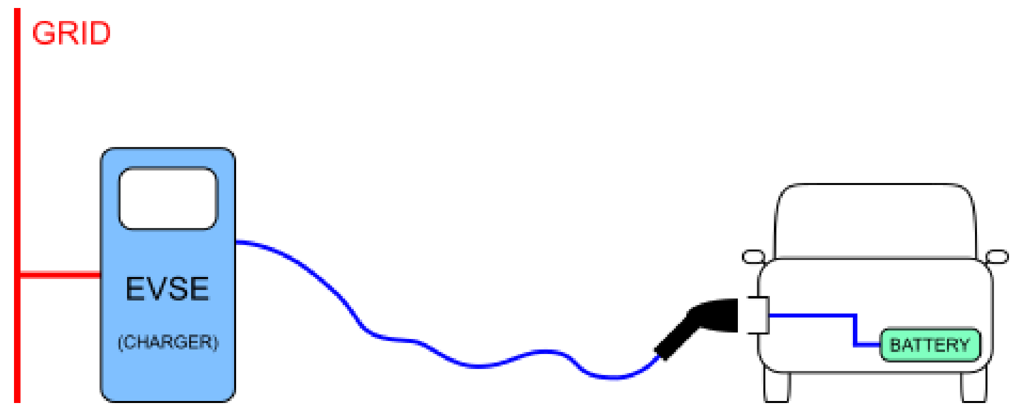
EV Charging Modes

- Mode 3
  - Connection to dedicated EVSE
  - EVSE (Electric Vehicle Supply Equipment)
    - Permanently connected to the AC supply network
    - Incorporates control and safety functions
  - On-board charger is used (AC charging)



EV Charging Modes

- Mode 4
  - Connection to dedicated EVSE
  - EVSE (Electric Vehicle Supply Equipment)
    - Permanently connected to the AC supply network
    - Incorporates control and safety functions
    - Incorporates an off-board charger (DC charging)
  - Only case C connection is allowed

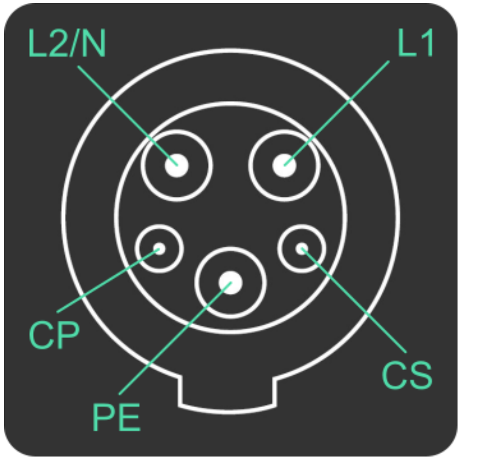


Control and Safety Functions (Pilot Functions)

- Mandatory functions for modes 2, 3 and 4
  - Verification that the vehicle is properly connected
  - Continuous protective earth conductor continuity checking
  - Energization of the system
  - De-energization of the system
- Optional functions for modes 2, 3 and 4
  - Selection of charging rate
  - Determination of ventilation requirements
  - Mechanical retaining/releasing of the coupler
  - Control of bi-directional power flow
  - Other

Pilot functions – example

- This example refers to Mode 2 and Mode 3 charging according to the SAE J1772 standard
- Pins:
  - L1 – Mains 1
  - L2/N – Mains 2 / Neutral
  - PE – Protective Earth
  - CP – Control Pilot
  - CS – Connection Switch

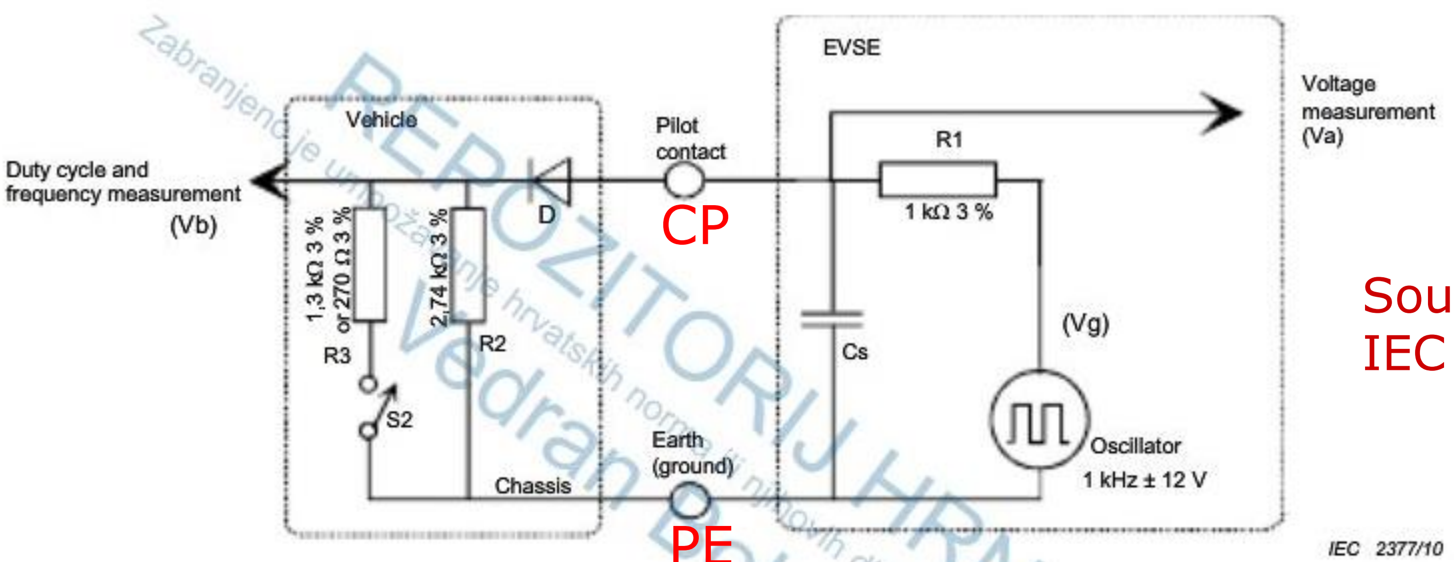


Inlet SAE J1772

- CS – ”proximity detection” function – used to signal correct insertion of the connector to the inlet
- CP – see next slide

Pilot functions – example

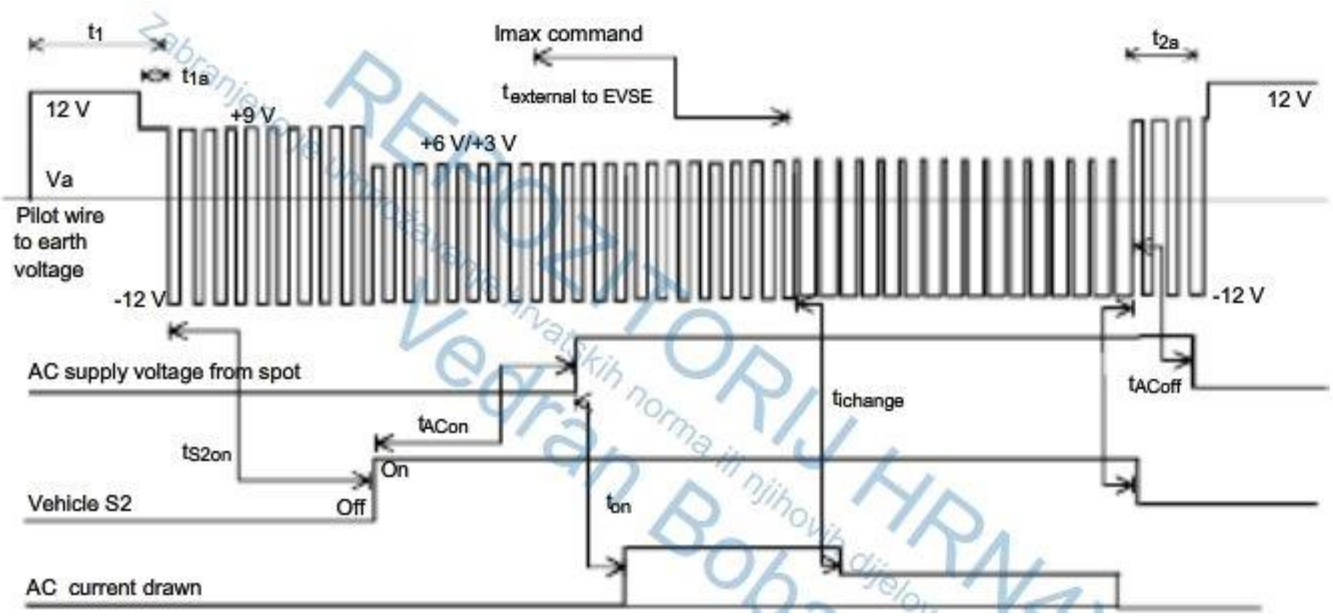
EV state	Va	S2	EV resistance	Description
A	12 V	open	-	EV not connected
B	9 V	open	2.74 kΩ	EV connected
C	6 V	closed	2.74 kΩ || 1.3 kΩ	EV ready, charging possible
D	3 V	closed	2.74 kΩ || 270 Ω	EV ready, charging possible, ventilation required
E	0 V	open	-	Error
F	- 12 V	open	-	EVSE not available



Source:
IEC 61851-1:2012

Pilot functions – example

- EVSE signal generator gives either steady state 12 V DC or a PWM signal
- EVSE indicates maximum available current by varying PWM duty cycle
- Current profile is determined by the vehicle



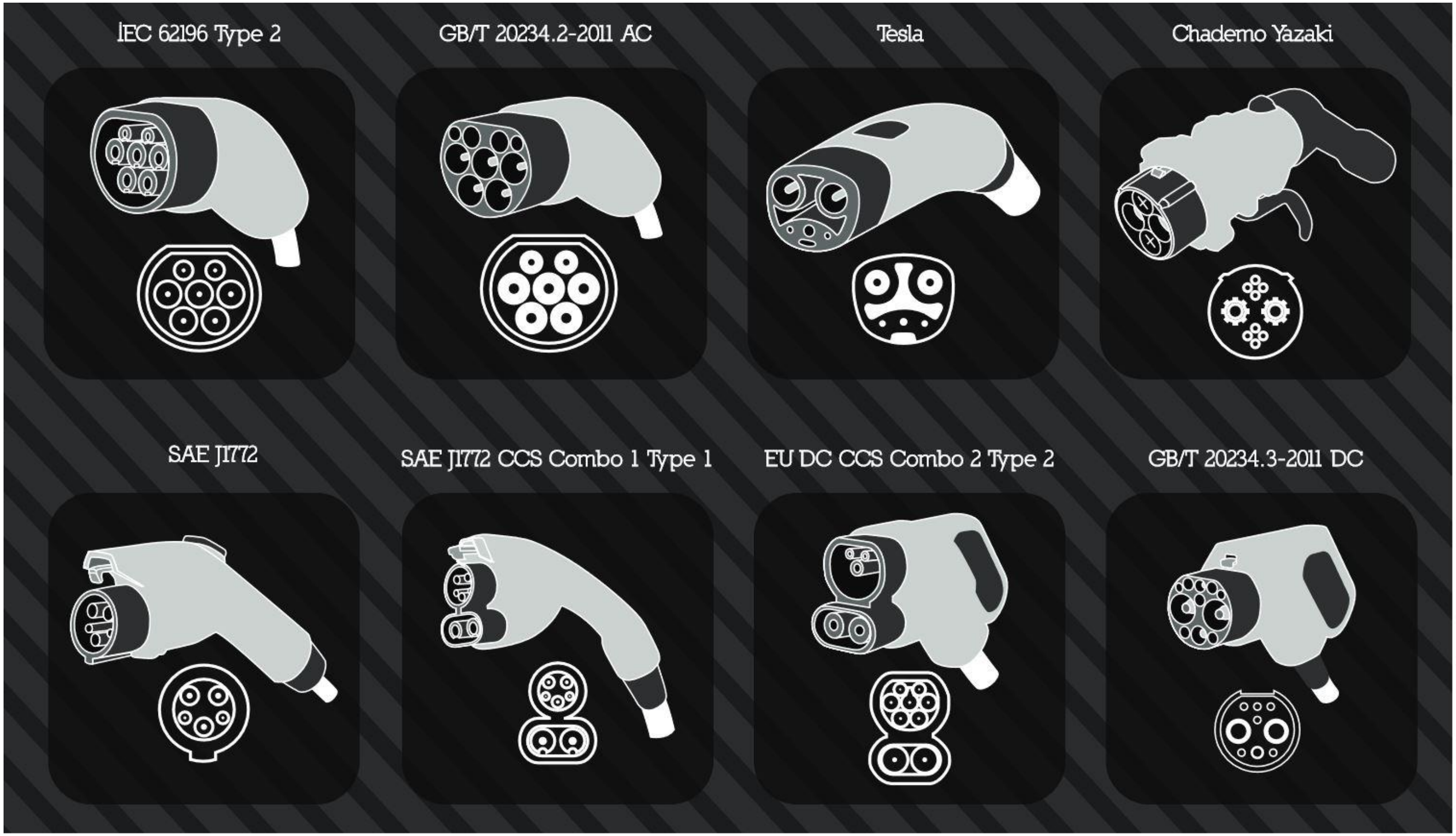
Source:
IEC 61851-1:2012

Coupler Types

- IEC Type 1
  - SAE J1772 Type 1 (AC)
  - SAE J1772 Combo 1 (AC+DC)
- IEC Type 2
  - Type 2 (AC)
  - Combo 2 (AC+DC)
- CHAdeMO (DC)
- Tesla Charging (AC+DC)
- GB/T (China)
  - 20234.2-2011 (AC)
  - 20234.3-2011 (DC)

Coupler = Connector + Inlet

Coupler Types

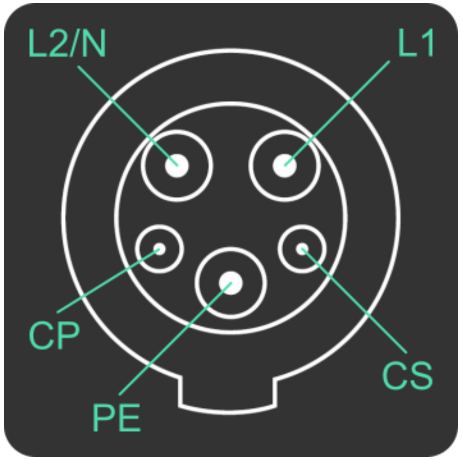


Source: ev-institute.com

Type 1

- SAE J1772 (North American standard)
- Complies with IEC 62196
- Used in North America and Japan
- AC (1-phase)
- AC Level 1
  - Power up to 1.9 kW (120V, 16A)
- AC Level 2
  - Power up to 19 kW (240V, 80A)
- Pins:
  - L1, L2/N – Mains / Neutral
  - PE – Protective Earth
  - CP – Control Pilot
  - CS – Connection Switch (proximity detection)

Coupler

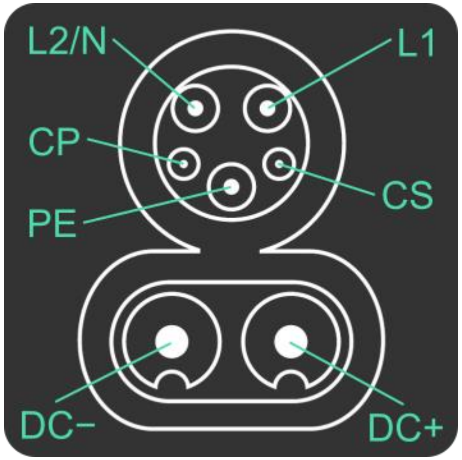


Inlet

Combo 1

- Same as Type 1, but with DC pins added
- Combined Charging System (CCS)
- AC (1-phase) + DC
- DC Level 1
  - Power up to 48 kW (600V, 80A)
- DC Level 2
  - Power up to 120 kW (600V, 200A)

Coupler

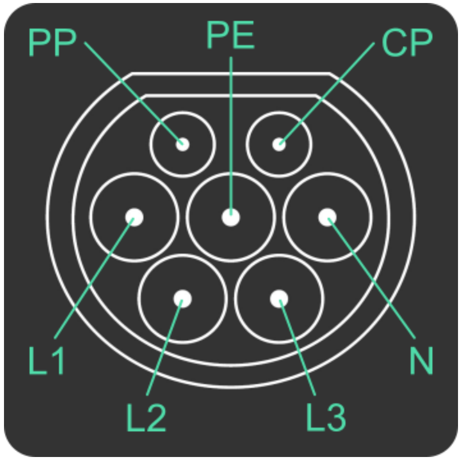


Inlet

Type 2

- VDE-AR-E 2623-2-2 (German standard)
- Commonly referred to as ”Mennekes”
- Complies with IEC 62196
- Used in Europe
- AC (1-phase or 3-phase)
- AC 1-phase
  - Power up to 14 kW (230V, 63A)
- AC 3-phase
  - Power up to 43 kW (400V, 63A)
- Pins:
  - L1, L2, L3, N – Mains, Neutral
  - PE – Protective Earth
  - CP – Control Pilot
  - PP – Proximity Pilot (proximity detection)

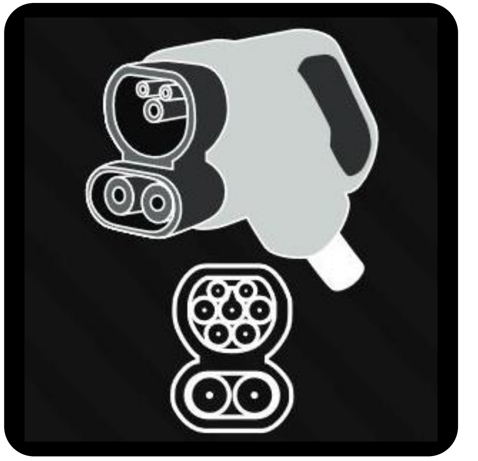
Coupler



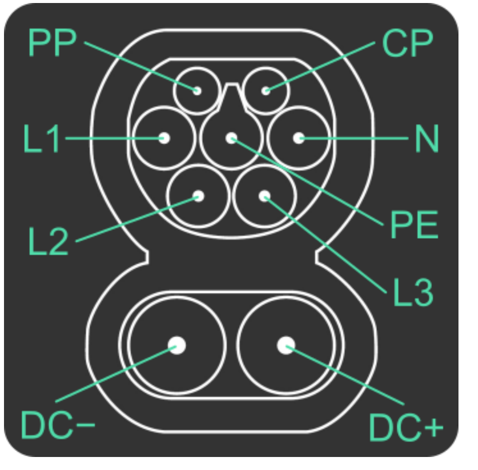
Inlet

Combo 2

- Same as Type 2, but with DC pins added
- Combined Charging System (CCS)
- AC (1-phase or 3-phase) + DC
- DC power up to 200 kW (1000V, 200A)



Coupler

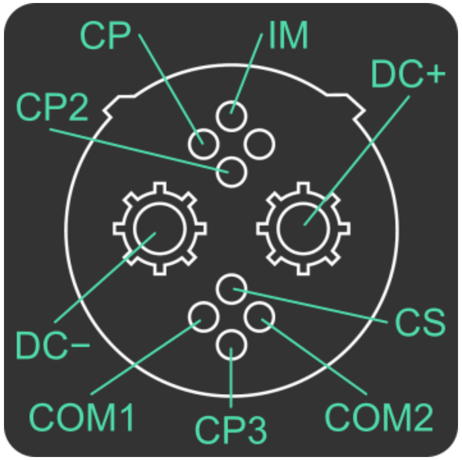


Inlet

CHAdeMO

- Specified by JEVS (Japanese standard)
  - Developed by Tokyo Electric Power Company (TEPCO), Nissan, Mitsubishi, Fuji Heavy Industries and Toyota
- Complies with IEC 62196
- Used mostly in Japan, but also in Europe and USA
- DC only
  - Power up to 120 kW (600V, 200A)
- Pins:
  - CP, CP2, CP3 – Control Pilot
  - COM1, COM2 – Communication (+/–)
  - IM – Isolation Monitor
  - CS – Connection Switch (proximity detection)

Coupler



Inlet

Tesla Charging

Coupler

- Designed for Tesla EVs
- Used in USA
- AC (1-phase) + DC
- AC power up to 19 kW (240V, 80A)
- DC power up to 125 kW (500V, 250A)
- Term ”supercharger” refers to fast DC chargers
- Remarks:
  - In Europe, Tesla uses Type 2 connector for both AC and DC (not Combo2)
  - Various adapters available (e.g. CHAdeMO)

GB/T

- Chinese standards:
  - GB/T 20234.2-2011 (AC)
  - GB/T 20234.3-2011 (DC)
- AC 1-phase
  - Power up to 7 kW (220V, 32A)
- AC 3-phase
  - Power up to 21 kW (400V, 32A)
- DC
  - Power up to 187 kW (750V, 250A)

Coupler

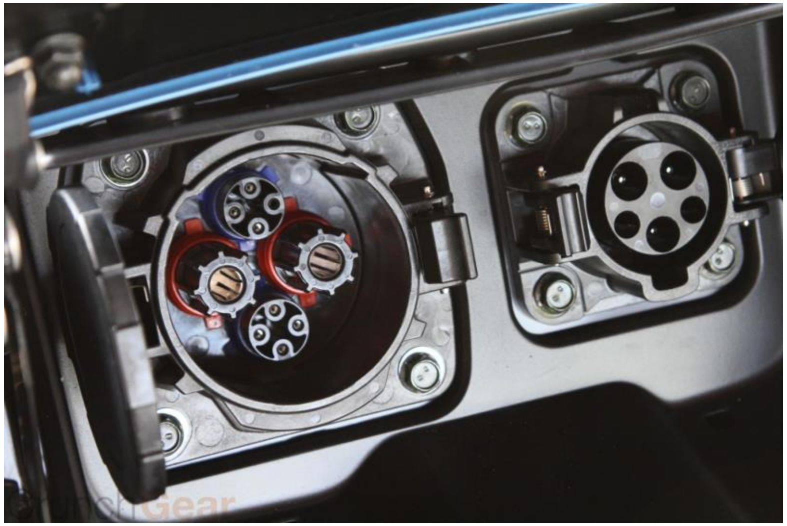
Coupler

Examples

Coupler: Combo 2

Example – Nissan Leaf

Inlets: CHAdeMO and Type 1

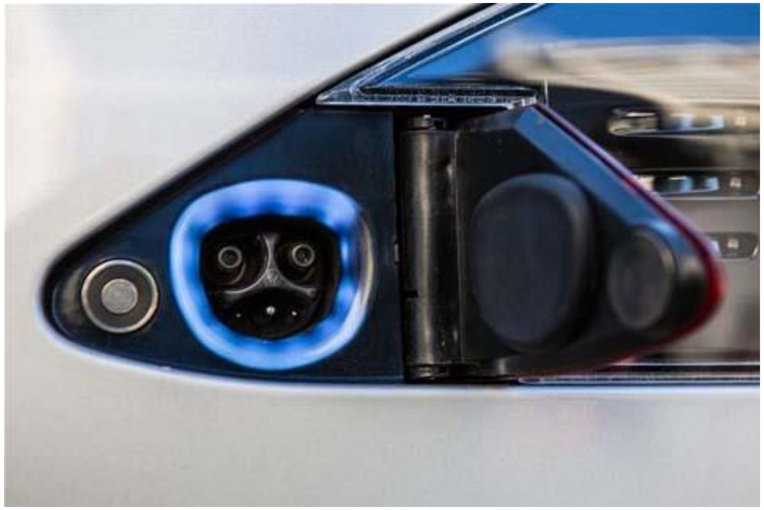


Example – Renault Zoe

Inlet: Type 2

Example – Tesla Model S

Inlet: Tesla



Example – Tesla

Tesla charging station

Connector: Tesla

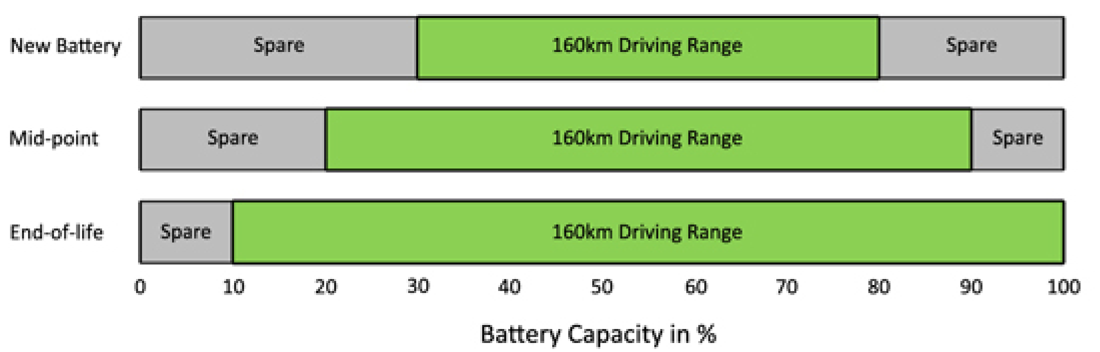
Battery Swapping

Remaining Problems

- Long charging times
- Widespread utilization of fast chargers is not sustainable from the perspective of the power system, and it is also still slower than the gas station
- The situation is still much worse as compared to the infrastructure for internal combustion engine power vehicles – infrastructure investments needed

Remaining Problems

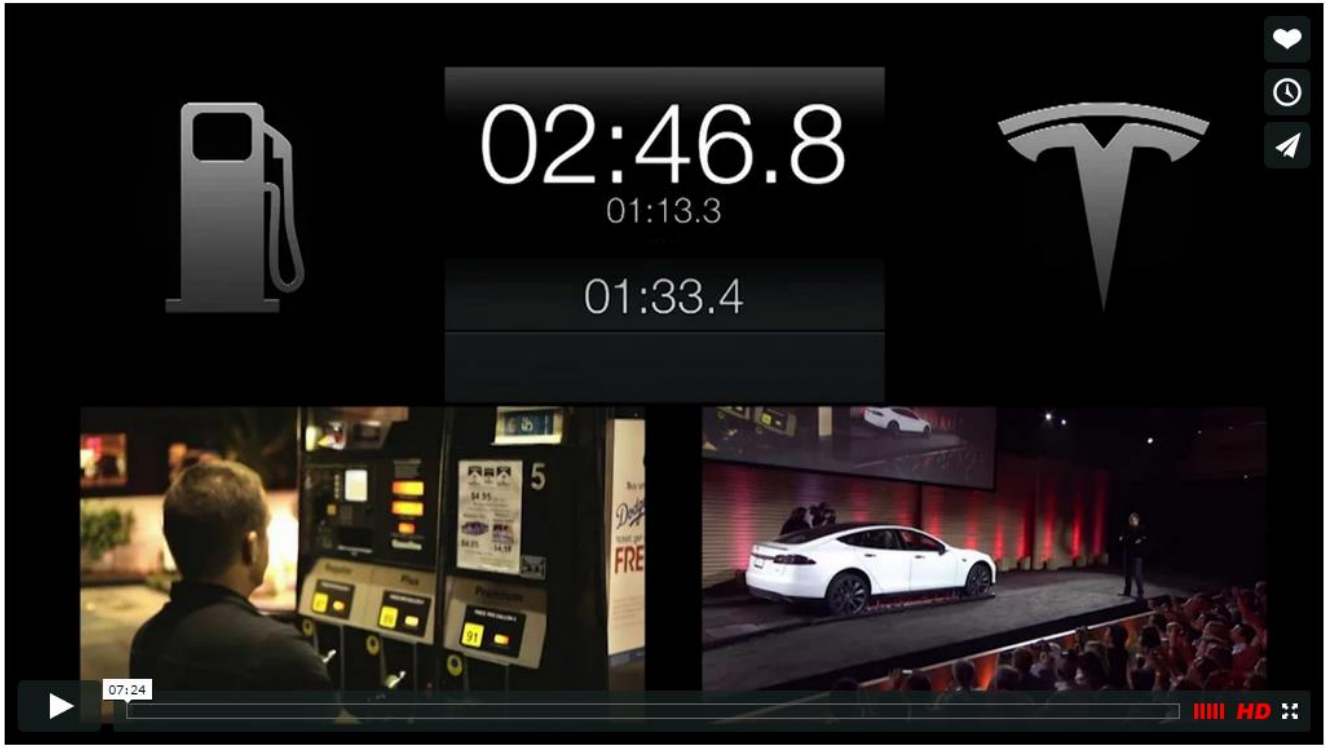
- The most widespread battery technology is Lithium-ion
- The price of new battery is around 10 000 USD (500-600 USD/kWh)
- Batteries degrade with usage and time – the best state-of-health indicator is capacity
- EV manufacturers account for capacity fade:



Source: batteryuniversity.com

(The Final) Part of the Solution?

- Battery Swapping Stations (BSS) swap depleted batteries with fully charged ones



(The Final) Part of the Solution?

- Battery in a Tesla S Model chassis
- The 85kWh battery has 7,616 18650 cells in parallel/serial configuration
- At $250 per kWh, the cost is lower than other Li-ion designs

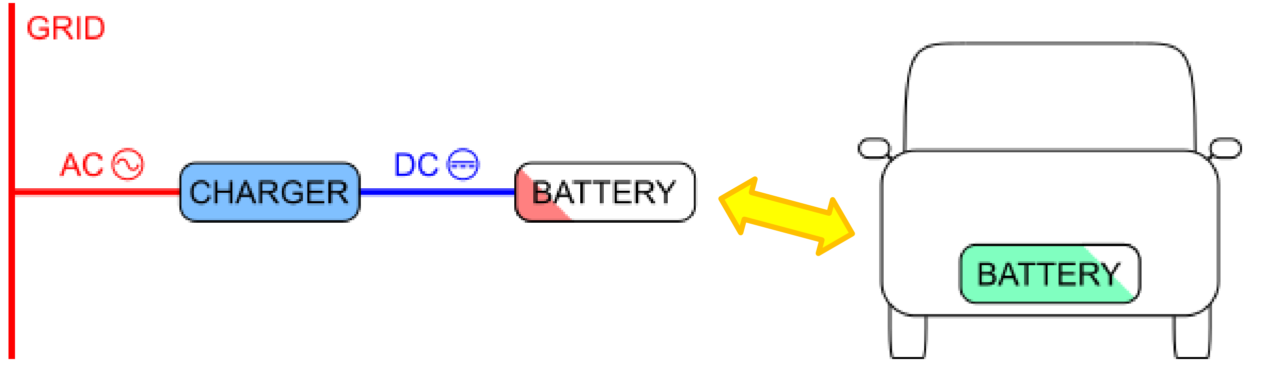
Source: batteryuniversity.com and Tesla motors

(The Final) Part of the Solution?

- BSS – the concept that requires the least changes compared to the current driving habits
- In case of many BSSs, there is no long waiting time to charge the EV and no range anxiety – actual substitute for gas stations
- The most common BSS model – batteries are owned by the BSS and leased to the customers
  - Initial investment reduced by the price of the battery (20% - 40% of total EV's price)
  - Additionally, users that use only BSS do not have to invest in home charging equipment

(The Final) Part of the Solution?

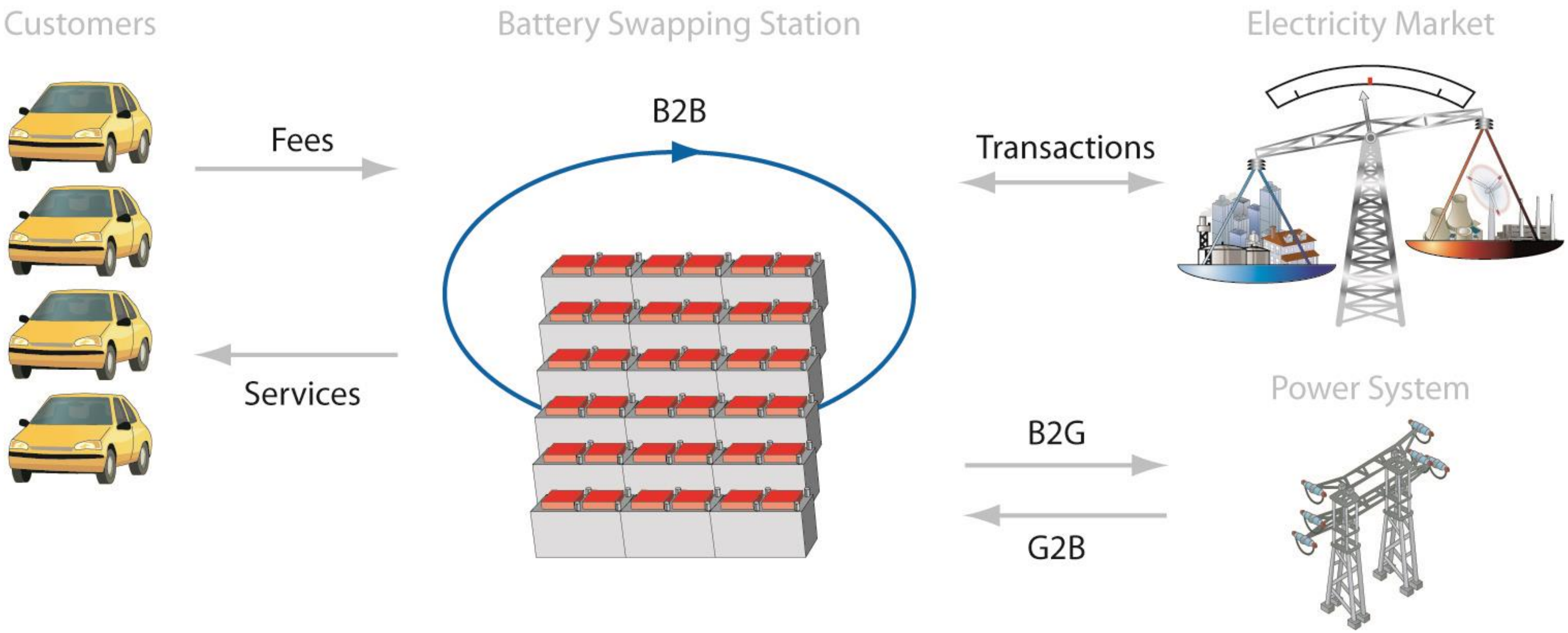
- Since batteries are owned by the BSS the customer does not need to worry about:
  - Maintenance cost or battery lifetime
  - Battery degradation problem
  - Charging speed (fast charging degrades batteries more than slow charging)
- All these costs need to be considered when a BSS charges its service fee to end-clients



BSS Business Model

- BSSs are new players in electricity markets
- The BSS energy storing policy is based on time-changing prices: real-time pricing (RTP)
- BSS maximizes its profits by utilizing periods of low prices to charge its batteries in *Grid-to-Battery* (G2B) mode, and periods of high prices to discharge its batteries in *Battery-to-Grid* (B2G) mode
- Additionally, a BSS can perform *Battery-to-Battery* (B2B) discharging some of its batteries in order to fully charge others

BSS Business Model



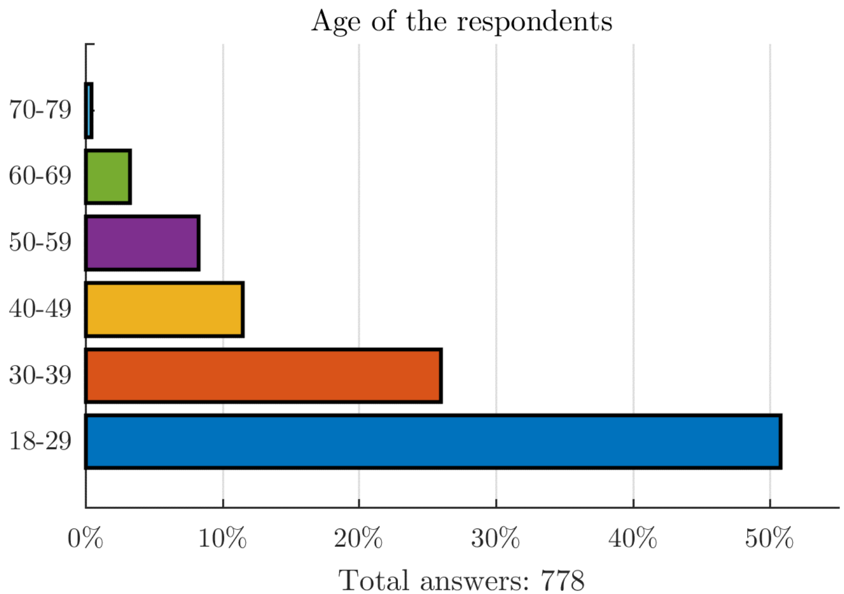
BSS Business in Practice

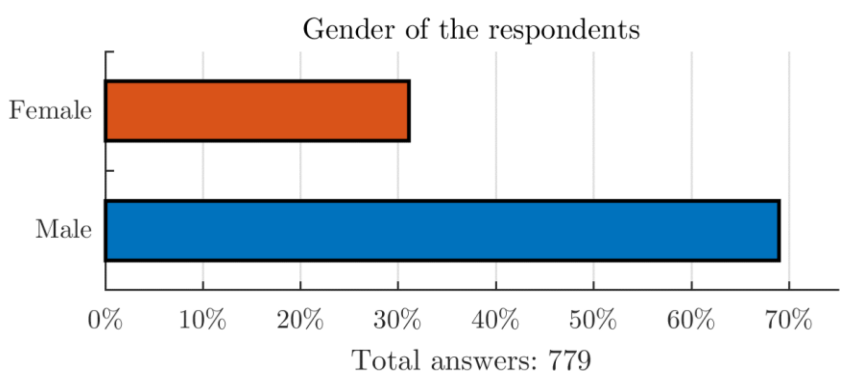
- Better Place
  - Launched in 2008. in partnership with Renault-Nissan
  - Used the same technology to swap batteries that F-16 jet fighter aircraft use to load their bombs
  - Started commercialization in six countries
  - Filed for bankrupcy in 2013.
- Tesla
  - Introduced battery swapping technology for their EVs in 2013.
  - Project has been put on hold
- Other emerging BSS providers
  - BattSwap
  - …

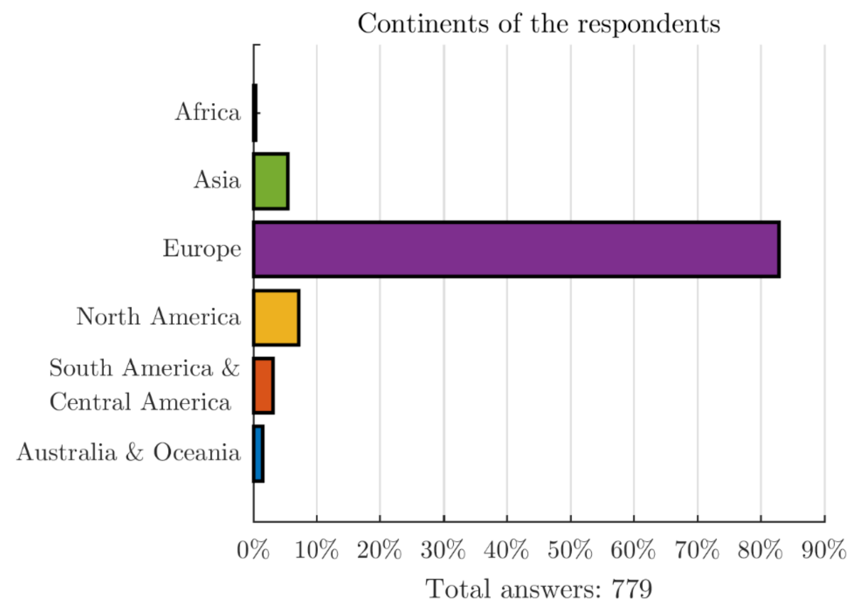
Survey on EVs and BSSs

- An on-line survey on electric vehicles and battery swapping stations
- The survey has two main goals:
  - Identifying problems and reasons that make people defer their purchase of an EV
  - Gaining insight into people's perception of battery swapping
- The questions were formulated in a way that both current and potential EV owners can answer them

Survey – sample description







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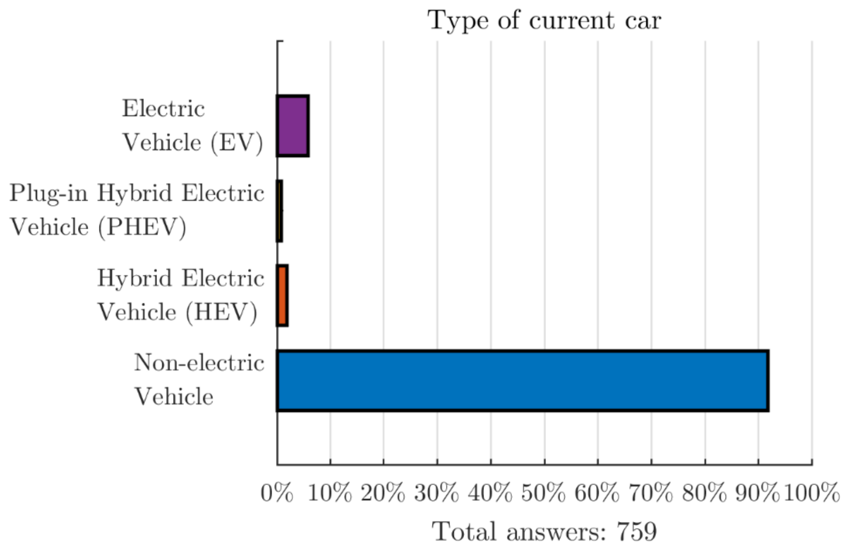
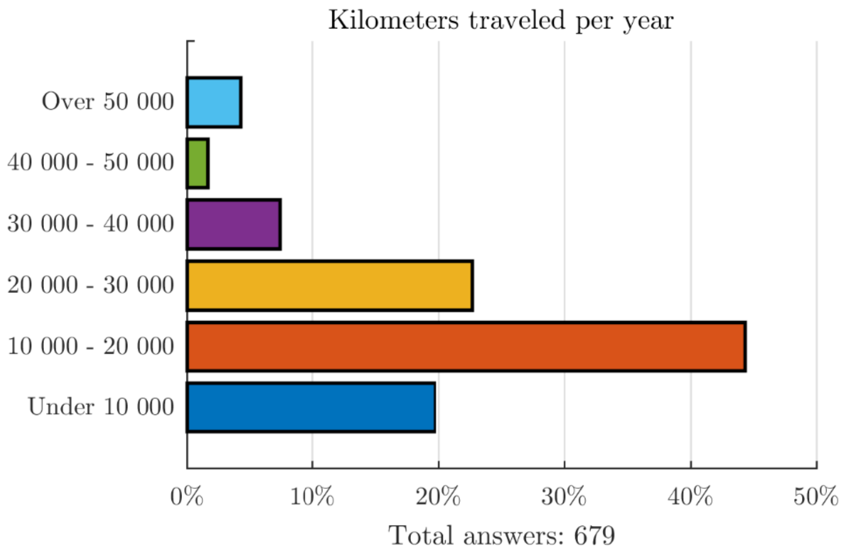
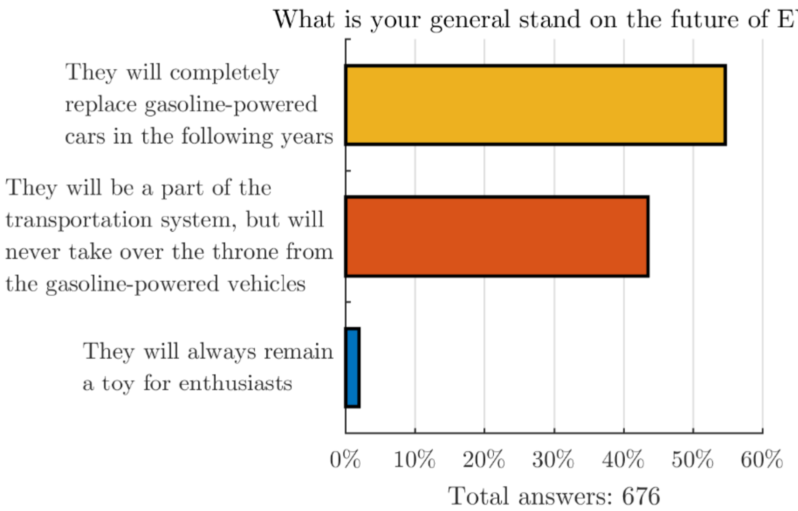
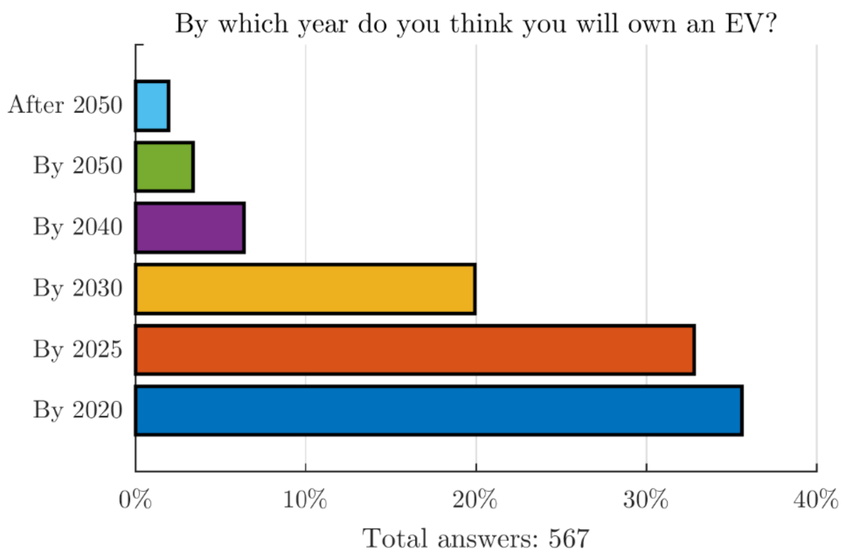




Survey – results





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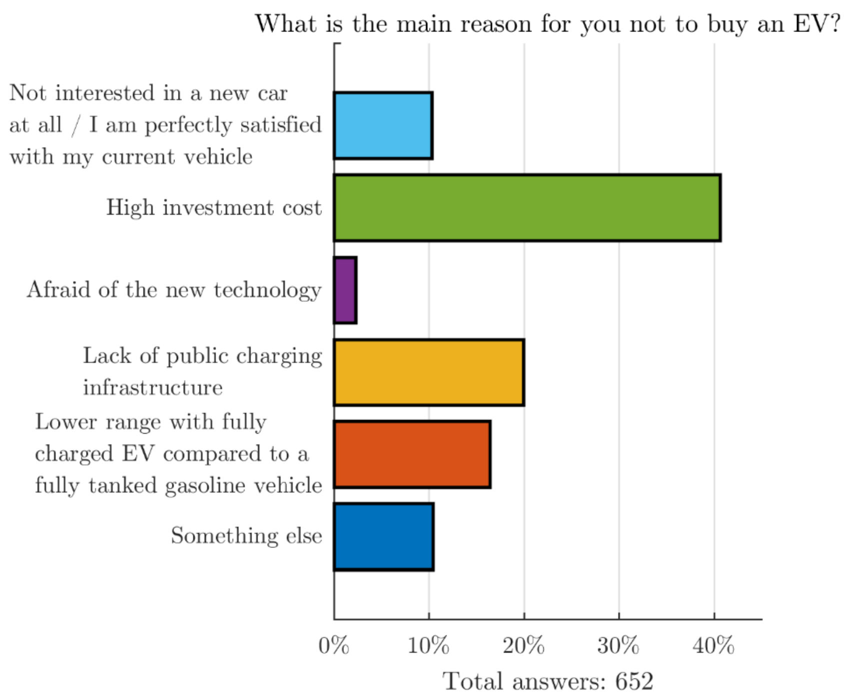

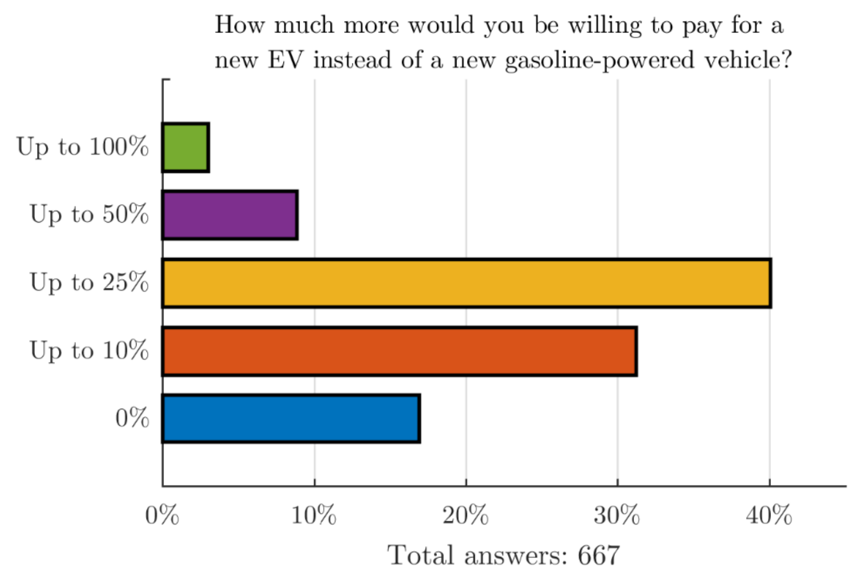

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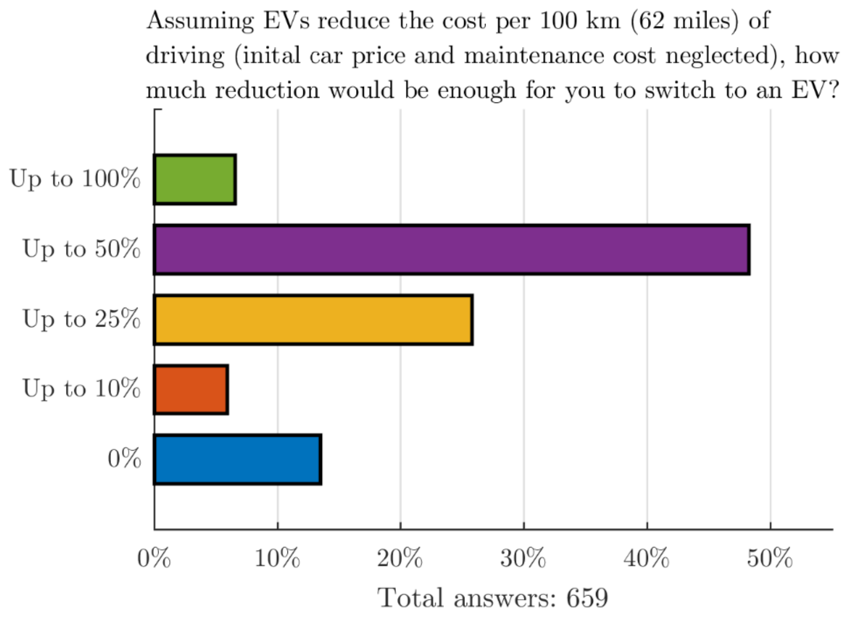

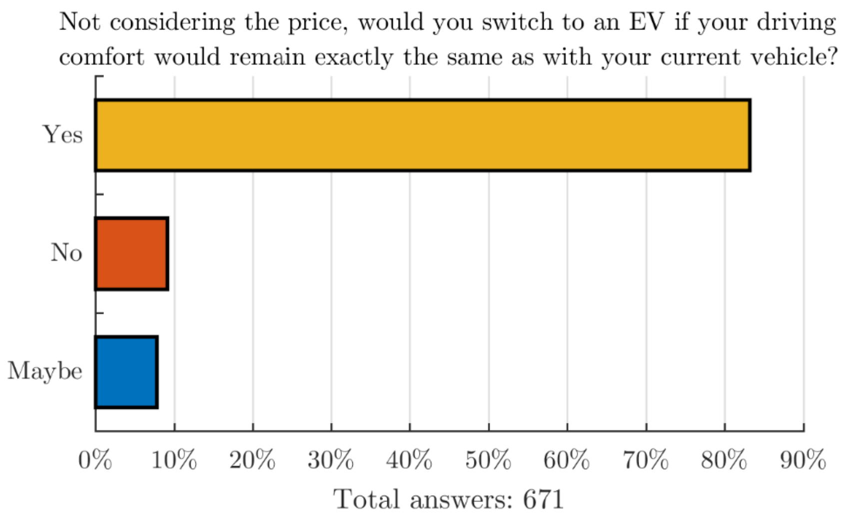

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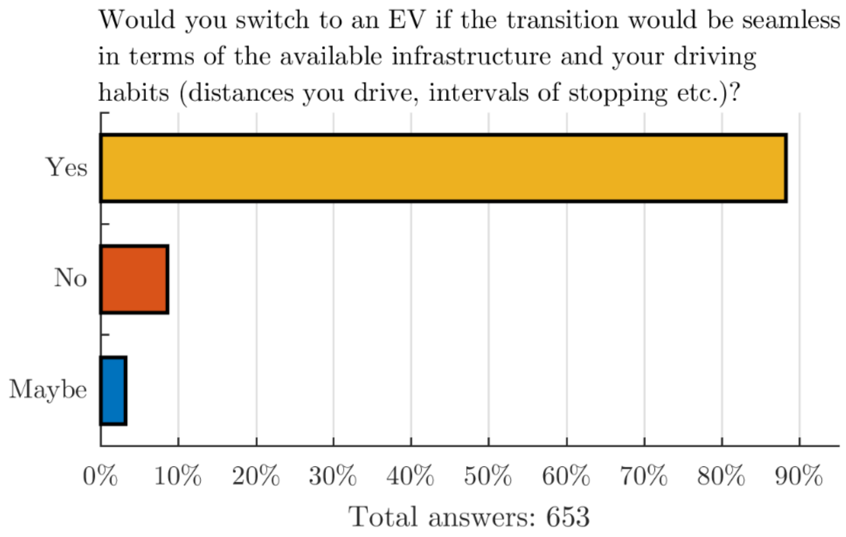

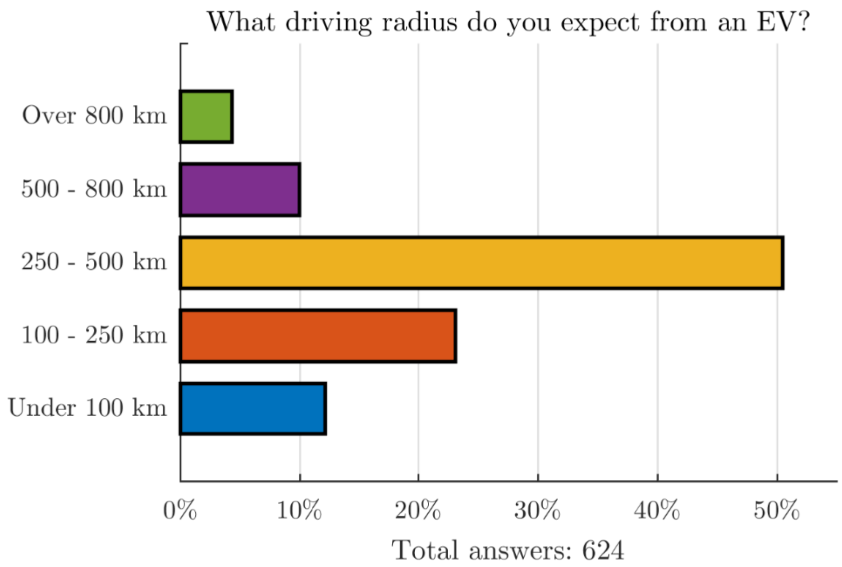

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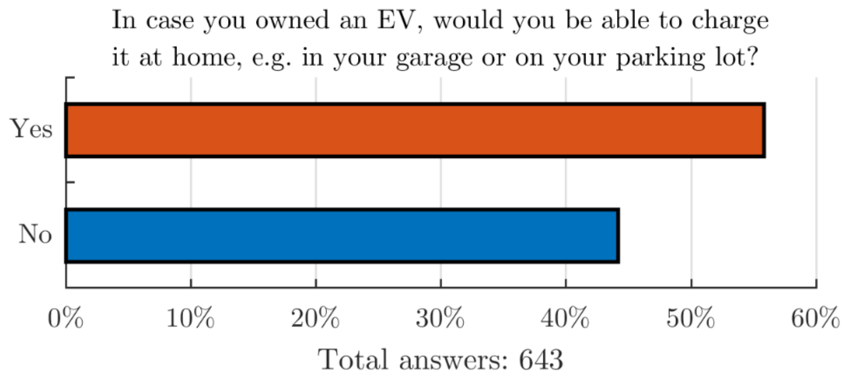

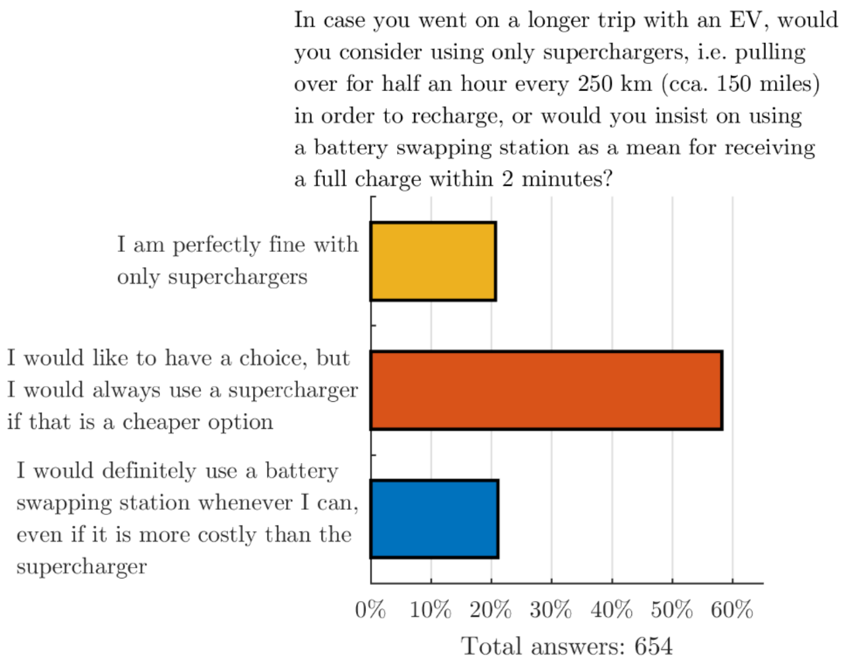

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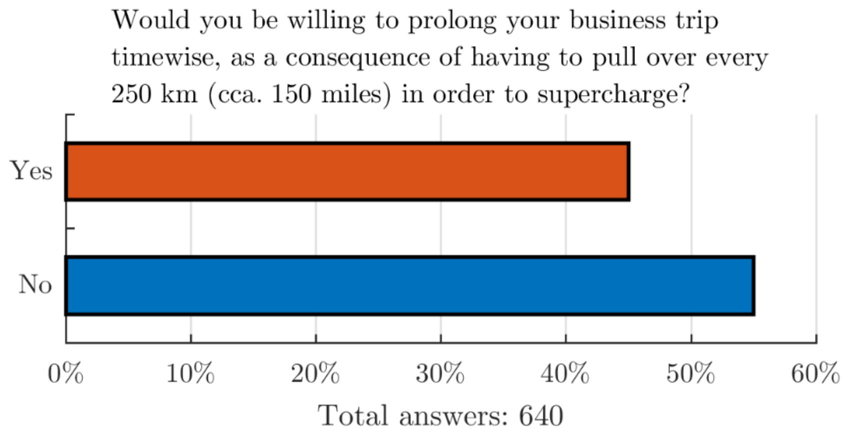
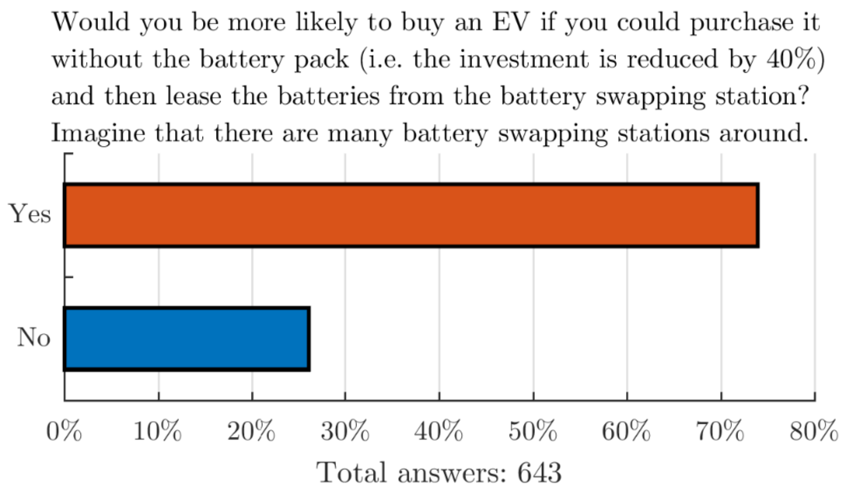
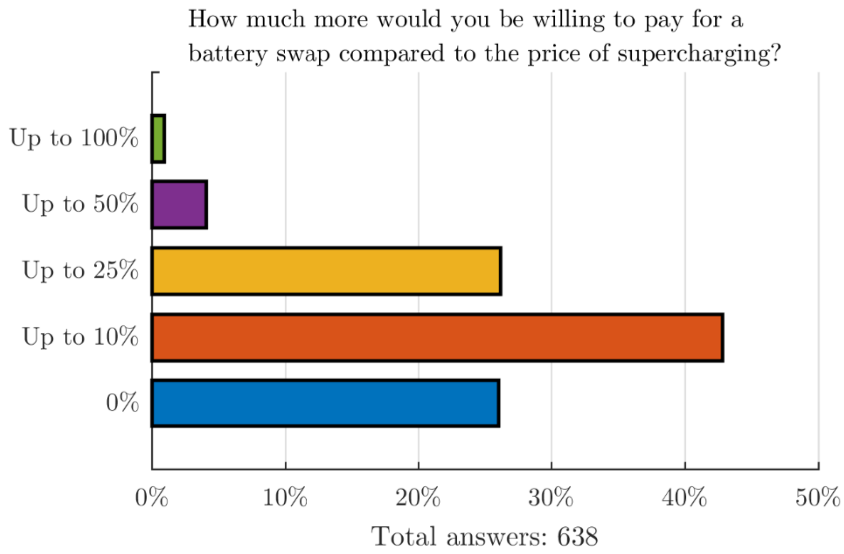
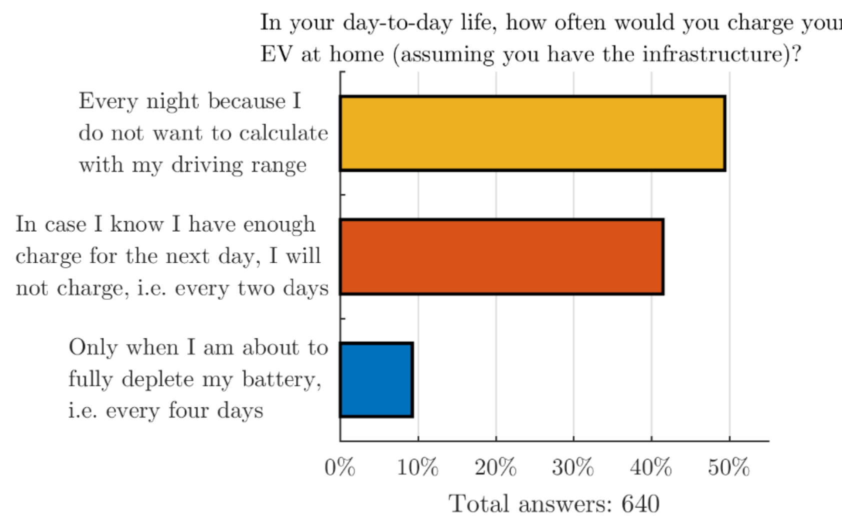




Survey – results





Survey – results