Electric Vehicle Charging Integration

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Tutorial

- Goal:
  - get insight into the charging process and procedures
  - understand the different technology concepts and business models to implement this
  - learn about the problems caused by and opportunities offered through a large fleet of EVs in the electricity system

- Overview
  - EV overview: history, types, charging level
  - Charging technology
  - Grid interaction

Electric Vehicles overview

including how to “charge”

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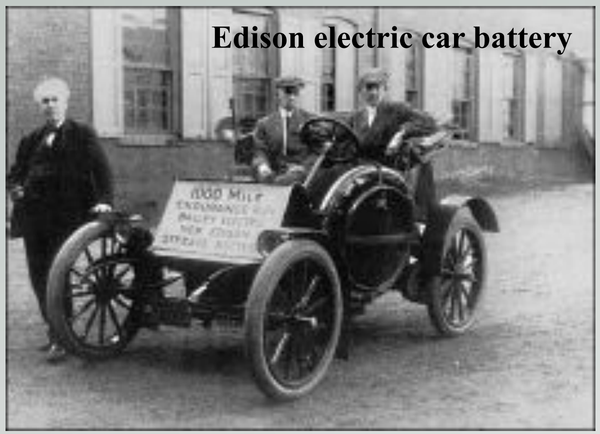
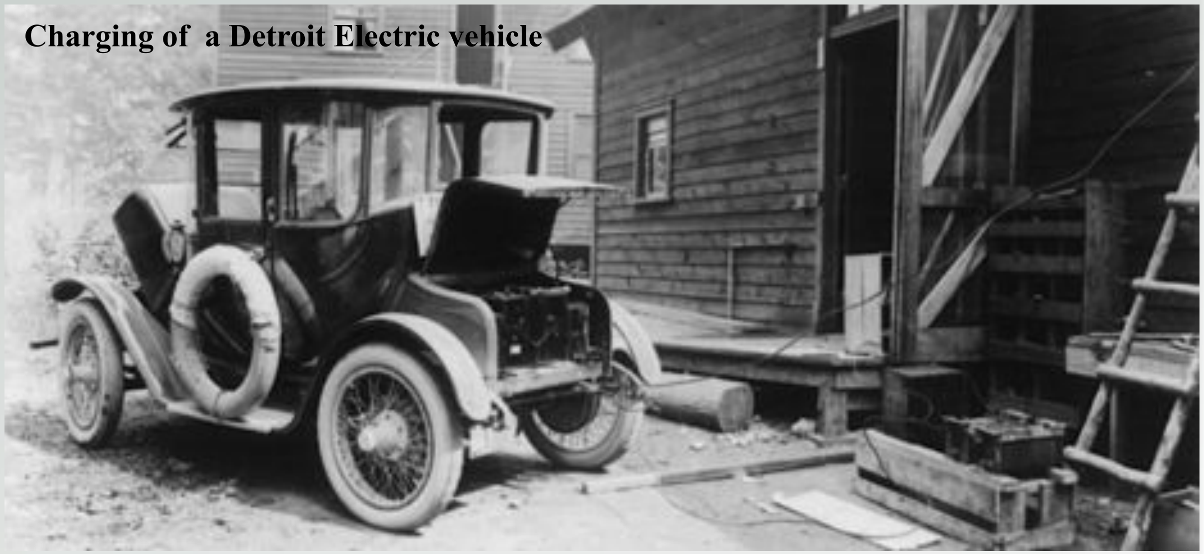
History: 1895-1910

- electric vehicles were the most promising drive technology end 1800s: speed records, neater cars
- combustion engine took over in early 1900s: became more powerful, easy to take with cheap fuel



Edison electric car battery



Charging of a Detroit Electric vehicle

Early EVs

- Baker Inside Driven Coupe
  - 1.5 kW cont.
  - 4.5 kW peak
  - 40 km/h top speed
- 12 x 6V battery cells
  - 175 km range
  - Edison Nickel Iron Alkaline
- 2475 $ in 1915
  - Vs. 440 $ for 1915 Ford model T

Janetzy Jamais Contente

- first car ever to exceed 100 km/h
  - 24/04/1899
  - 105.882 km/h
  - 2 electric motors in 'aerodynamic' car
  - driven by Camille Janetzy (B.) in Achères (Fr.)
  - named "Jamais Contente"

History: 1905-1925

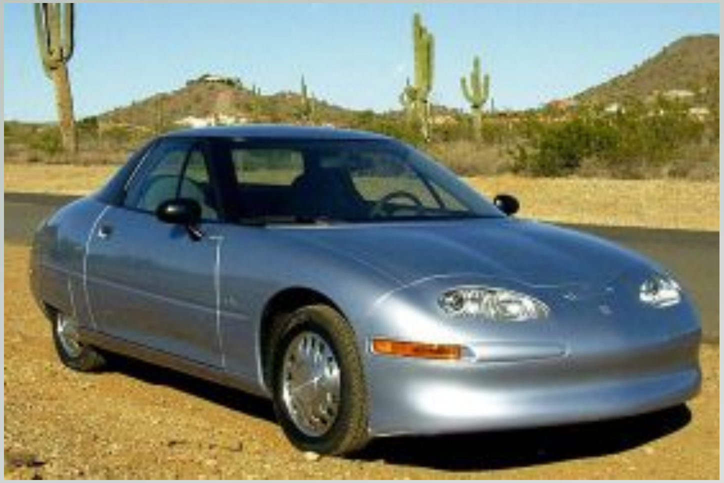
- gasoline vehicles take over completely: discovery of many oil wells drop fuel prices
- mass production techniques introduced by Ford
- short revivals:
  - Edison battery (NiFe)
  - WW I: oil shortage
- 1900 US car production: 1575 electric cars vs. 936 gasoline cars down to 4% in 1925

history: after WW II

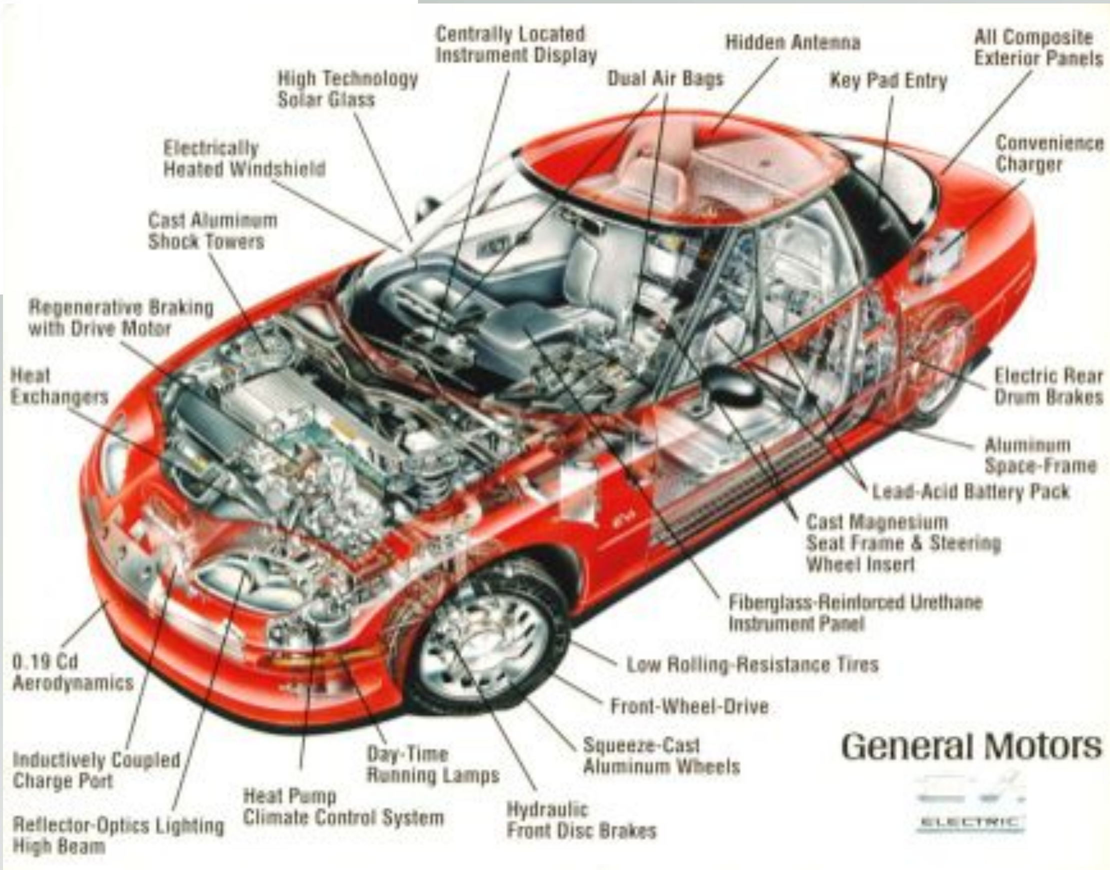
- 60s: small ‘smog buster’ cars
  - GM 512, Ford Comuta (failed to sell: smog reduction incentive too limited)
- 1973: oil crisis
  - economical push to revive EV R&D as a mean to reduce oil dependence
- 80s: growing environmental concerns
  - Clean Air Acts (California) and other
- 90s: evolution in power electronics
- after ’00: battery evolution

GM EV-1

- First ‘modern’ EV
  - 1996-1999
- AC induction motor
  - 102 kW @ 7000 rpm
  - 149 Nm @ 0-7000 rpm
- Lead-acid (gen1)
  - 26 Delco 12-volt/ 533 kg
  - 16.2 kWh/ 100-145 km range
  - 18.7 kWh/ 100-130 km Panasonic pack for initial gen 2
- NiMH batteries (gen 2)
  - Ovonics 26.4 kWh
  - 160-225 km range



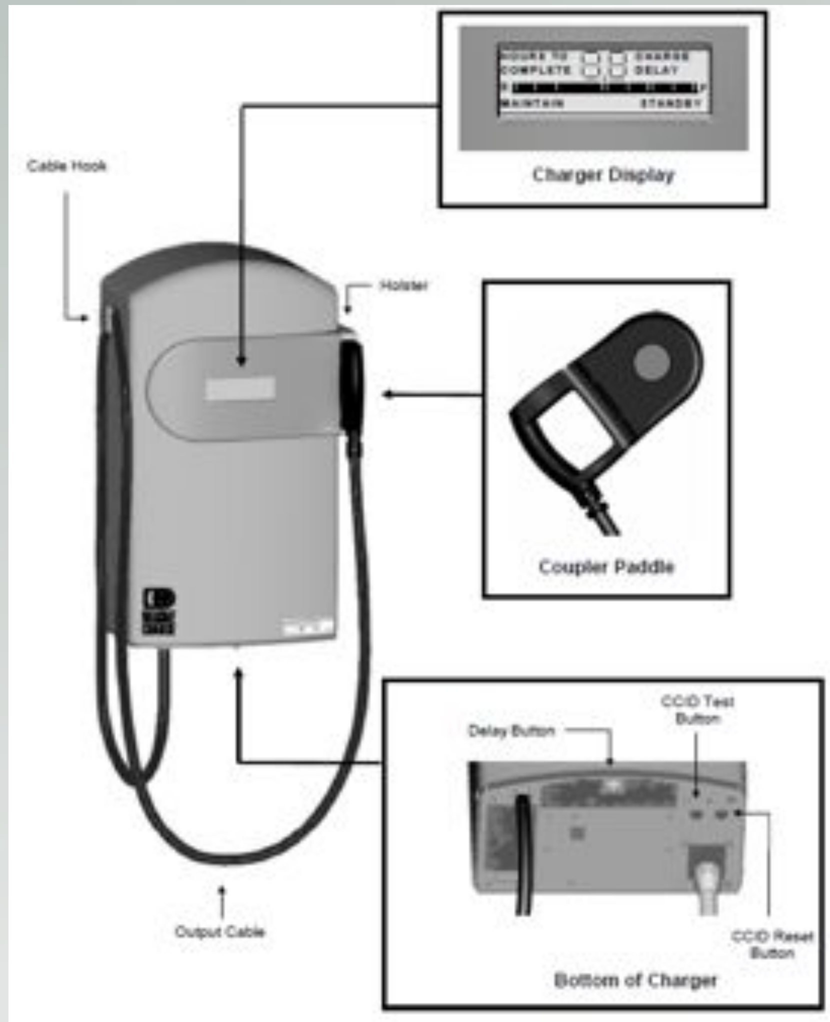
GM EV-1



Centrally Located Instrument Display
Hidden Antenna
All Composite Exterior Panels
High Technology Solar Glass
Dual Air Bags
Key Pad Entry
Electrically Heated Windshield
Convenience Charger
Cast Aluminum Shock Towers
Regenerative Braking with Drive Motor
Heat Exchangers
Electric Rear Drum Brakes
Aluminum Space-Frame
Lead-Acid Battery Pack
Cast Magnesium Seat Frame & Steering Wheel Insert
Fiberglass-Reinforced Urethane Instrument Panel
Low Rolling-Resistance Tires
Front-Wheel-Drive
0.19 Cd Aerodynamics
Squeeze-Cast Aluminum Wheels
Inductively Coupled Charge Port
Day-Time Running Lamps
Heat Pump Climate Control System
Hydraulic Front Disc Brakes
Reflector-Optics Lighting High Beam
General Motors
ELECTRIC

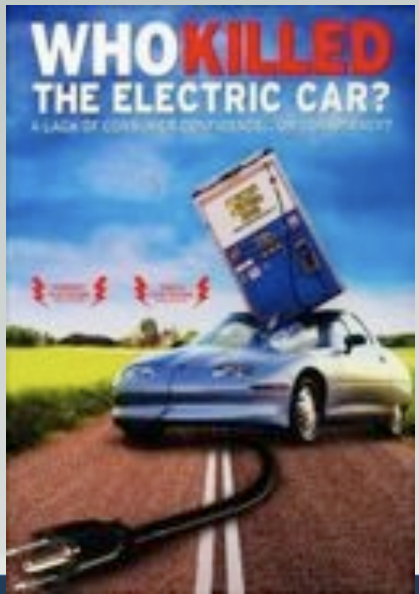
GM EV-1

- Magne Charge
  - Inductive charging system
  - Safety reasons
- Supplied by Delco
  - Also for Toyota RAV4 EV
- Small and large paddle
  - 6.6 and 50 kW
  - Both fit in the EV1
- Obsolete infrastructure now

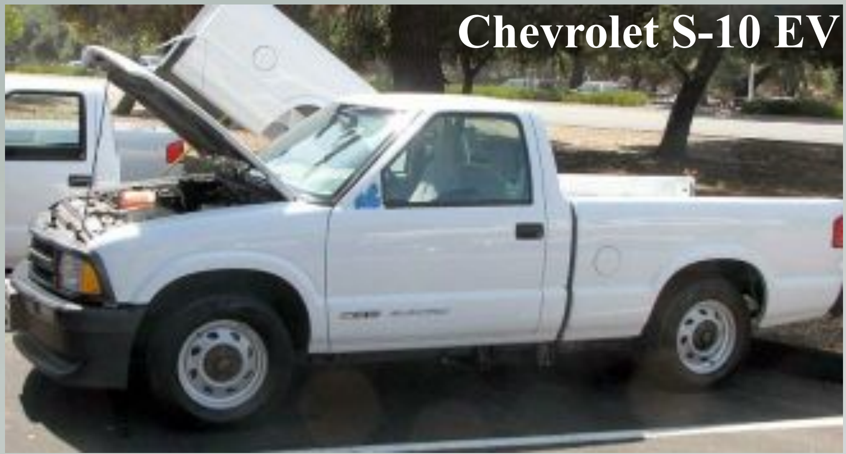


Controversy GM EV-1





Other 90s EVs



Battery Electric Vehicles

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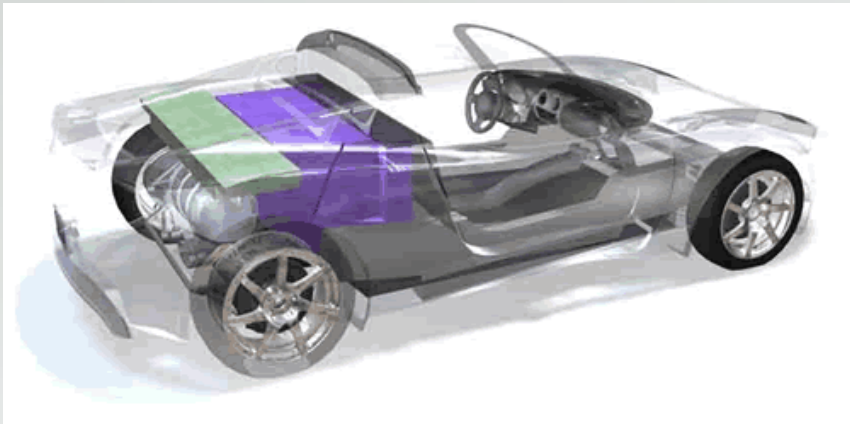
A lot of new EVs

Tesla Roadster

Tesla Roadster

- MG: 225 kW_{peak}/370 Nm 4-pole induction motor
- Battery: 53 kWh Li-on battery pack, 69 cells in parallel, 99 parallel stacks in series, 365 V, 410 kg
- Single speed transmission
- Range: 390 km
- Charge at 70 A/240 V (17 kW)
  - ± 500 complete charge-discharge cycles & ± 400 km/charge = ± 200.000 km
- Top: 210 km/h, 0-100 km/h in 4 s
- Mass: 1134 kg
- 2008



Battery Electric Vehicles

Tesla Model S

- MG: 225/270/310 kW_{peak}
- 430/440/600 Nm
- Battery: 60/85 kWh Li-on battery
- Single speed transmission
- Range: 390/502 km
- 11/22 (10/20 in US) kW on-board charger
- DC fast charging up to 120 kW
- Top: 193/201/209 km/h
- 0-100 km/h in 6.2/5.6/4.4 s
- Mass: 2025/2108 kg
- 73,040/83,590/97,990 EUR (incl. VAT BE)
- 2013

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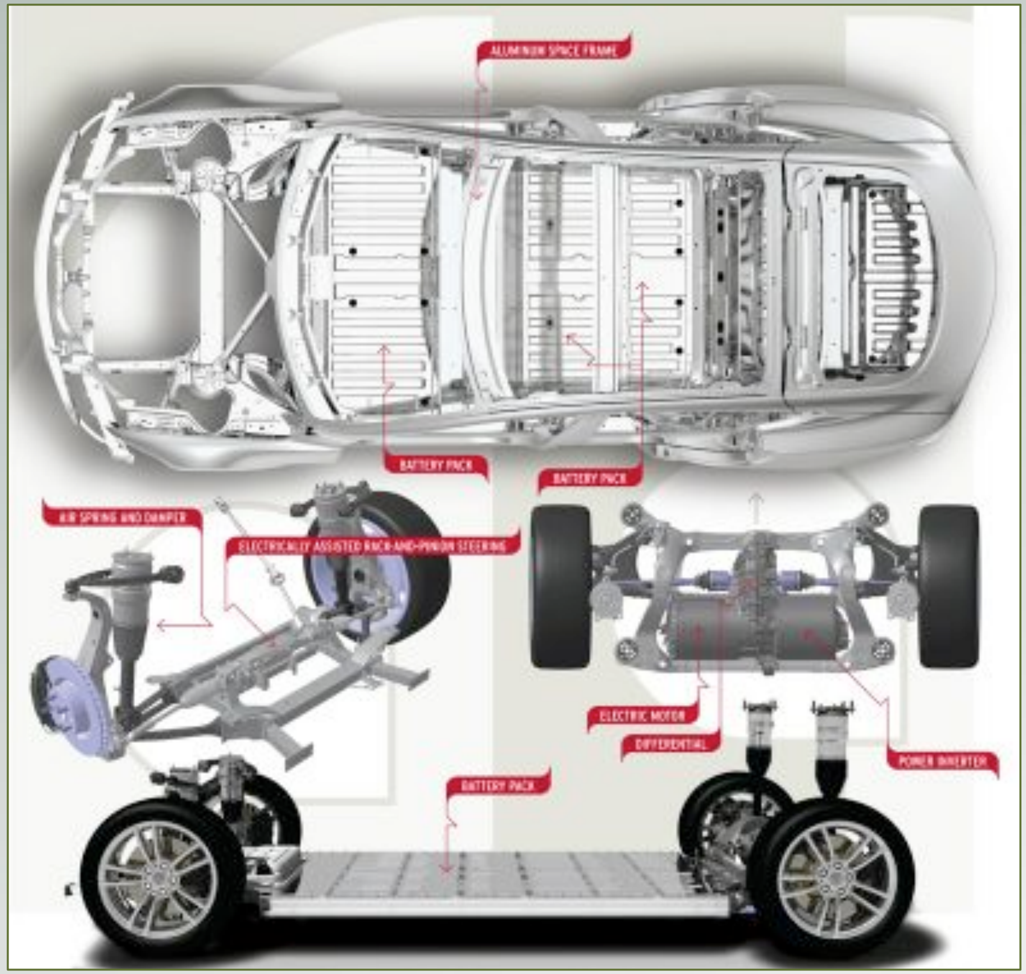

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MODEL S MODEL X SUPERCHARGER ENTHUSIASTS FIND US BUY MY TESLA

Press Release

TESLA MODEL S ACHIEVES BEST SAFETY RATING OF ANY CAR EVER TESTED

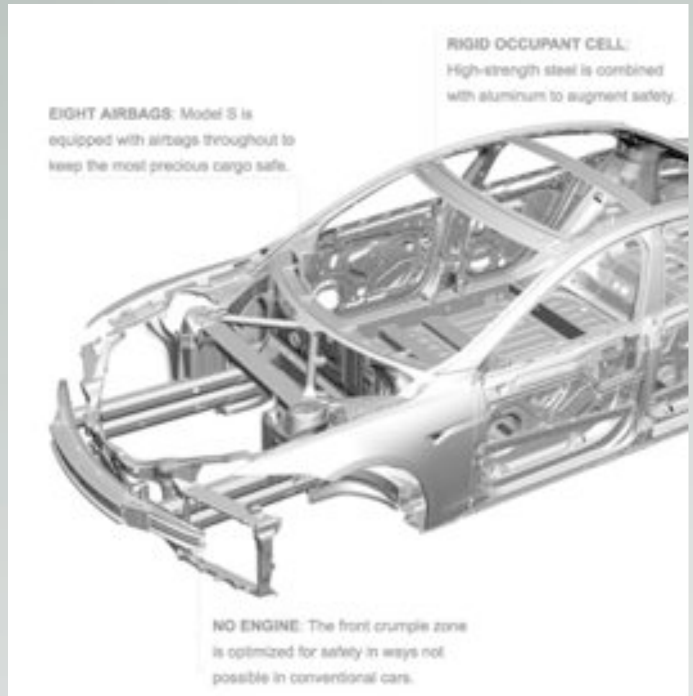
SETS NEW NHTSA VEHICLE SAFETY SCORE RECORD

MONDAY, AUGUST 19, 2013

Palo Alto, CA — Independent testing by the National Highway Traffic Safety Administration (NHTSA) has awarded the Tesla Model S a 5-star safety rating, not just overall, but in every subcategory without exception. Approximately one percent of all cars tested by the federal government achieve 5 stars across the board. NHTSA does not publish a star rating above 5, however safety levels better than 5 stars **are** captured in the overall Vehicle Safety Score (VSS) provided to manufacturers, where the Model S achieved a new combined record of 5.4 stars.

Of all vehicles tested, including every major make and model approved for sale in the United States, the Model S set a new record for the lowest likelihood of injury to occupants. While the Model S is a sedan, it also exceeded the safety score of all SUVs and minivans. This score takes into account the probability of injury from front, side, rear and rollover accidents.

The Model S has the advantage in the front of not having a large gasoline engine block, thus creating a much longer crumple zone to absorb a high speed impact. This is fundamentally a force over distance problem – the longer the crumple zone, the more time there is to slow down occupants at g loads that do not cause injuries. Just like jumping into a pool of water from a tall height, it is better to have the pool be deep and not contain rocks. The Model S motor is only about a foot in diameter and is mounted close to the rear axle, and the front section that would normally contain a gasoline engine is used for a second trunk.



Tesla Model S vs. competitors

Tesla Model S
- MG: 225/270/310 kW_{peak}
- 430/440/600 Nm
- Battery: 60/60/85 kWh
- Range: 390/502/502 km
- Top: 193/201/209 km/h
- 0-100 km/h: 6.2/5.6/4.4 s
- Mass: 2025/2108 kg
- 73,040/83,590/97,990 EUR

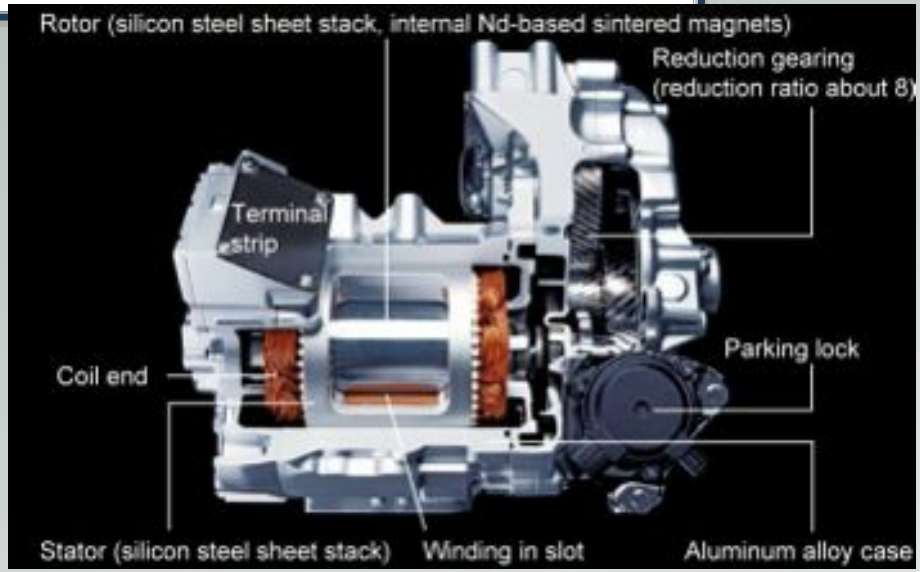
BMW 7-series (740i/750i)
- ICE: 235/330 kW_{peak}
- 450/650 Nm
- Fuel tank: 80 l
- Range: 1,012/930 km
- 7.9/8.6 l/100 km
- 0-100 km/h: 5.7/4.8 s
- Mass: 1900/2015 kg
- 91,500/103,150 EUR

Nissan Leaf

- MG: 80 kW_{peak}/280 Nm PMSM
- Battery: 24 kWh Li-on battery pack
  - 192 cells in parallel, 480 V
  - 300 kg
  - Air cooled
- Retaining 70-80 % of battery capacity over 10 years
- Single speed transmission
- Range: 117 km
- Charge at 16 A/230 V or DC (Chademo)
- Top: 150 km/h, 0-100 km/h in 10 s
- Mass: 1521 kg
- 2010

Nissan Leaf


POWER INVERTER AND TRANSFORMER
BATTERY CHARGER
CONNECTOR BOX
ELECTRIC MOTOR AND REDUCER
LITHIUM-ION BATTERY


Rotor (silicon steel sheet stack, internal Nd-based sintered magnets)
Reduction gearing (reduction ratio about 8)
Terminal strip
Parking lock
Coil end
Stator (silicon steel sheet stack)
Winding in slot
Aluminum alloy case

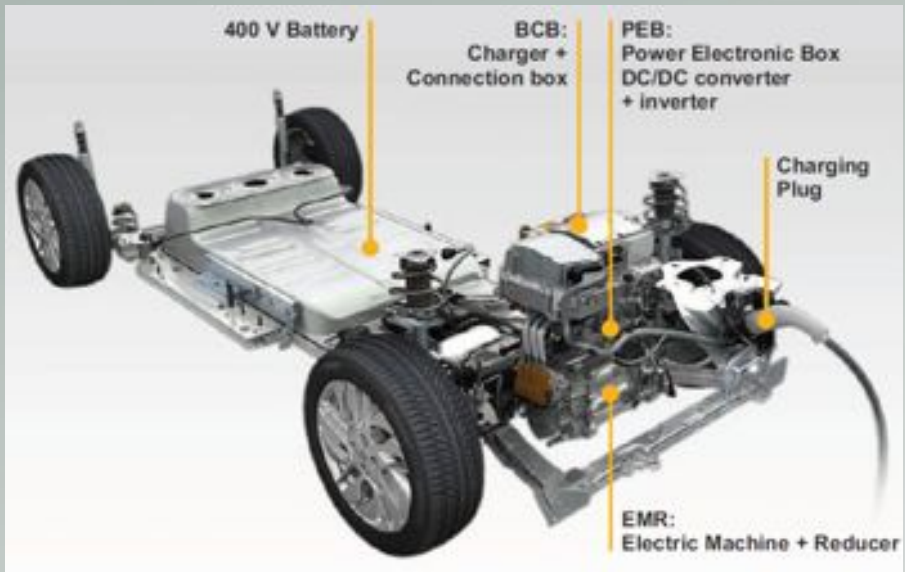
Nissan Leaf


EPA Fuel Economy and Environmental Comparisons
Electric Vehicle
99
MPGequivalent
106
92
combined city/hwy
city
highway
34 kW-hrs per 100 miles
Charge & Range
Annual Electric Cost
$561
73
How This Vehicle Compares
Environment
See the FREE Fuel Economy Guide at dealers or www.fueleconomy.gov

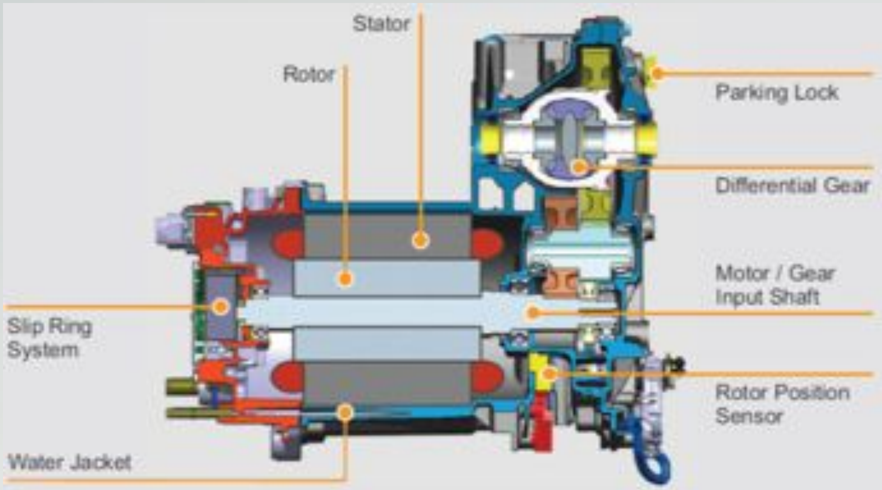
Renault ZOE

- MG: 66 kW_{peak}/220 Nm
- External excited synchronous motor
- Single speed transmission
- Battery: 220 kWh Li-on battery pack
  - 270-400 V
  - 300 kg
  - Air cooled
- Range: 210 km
- Charge at up to 63 A/400 V
  - Chameleon charger
  - Up to 43 kW
  - 0.03 m^3
  - Usage of powertrain PE components
- Top: 135 km/h, 0-100 km/h in 8.1 s
- Mass: 1392 kg
- 2012

Renault ZOE


400 V Battery
BCB:
Charger +
Connection box
PEB:
Power Electronic Box
DC/DC converter
+ inverter
Charging
Plug
EMR:
Electric Machine + Reducer

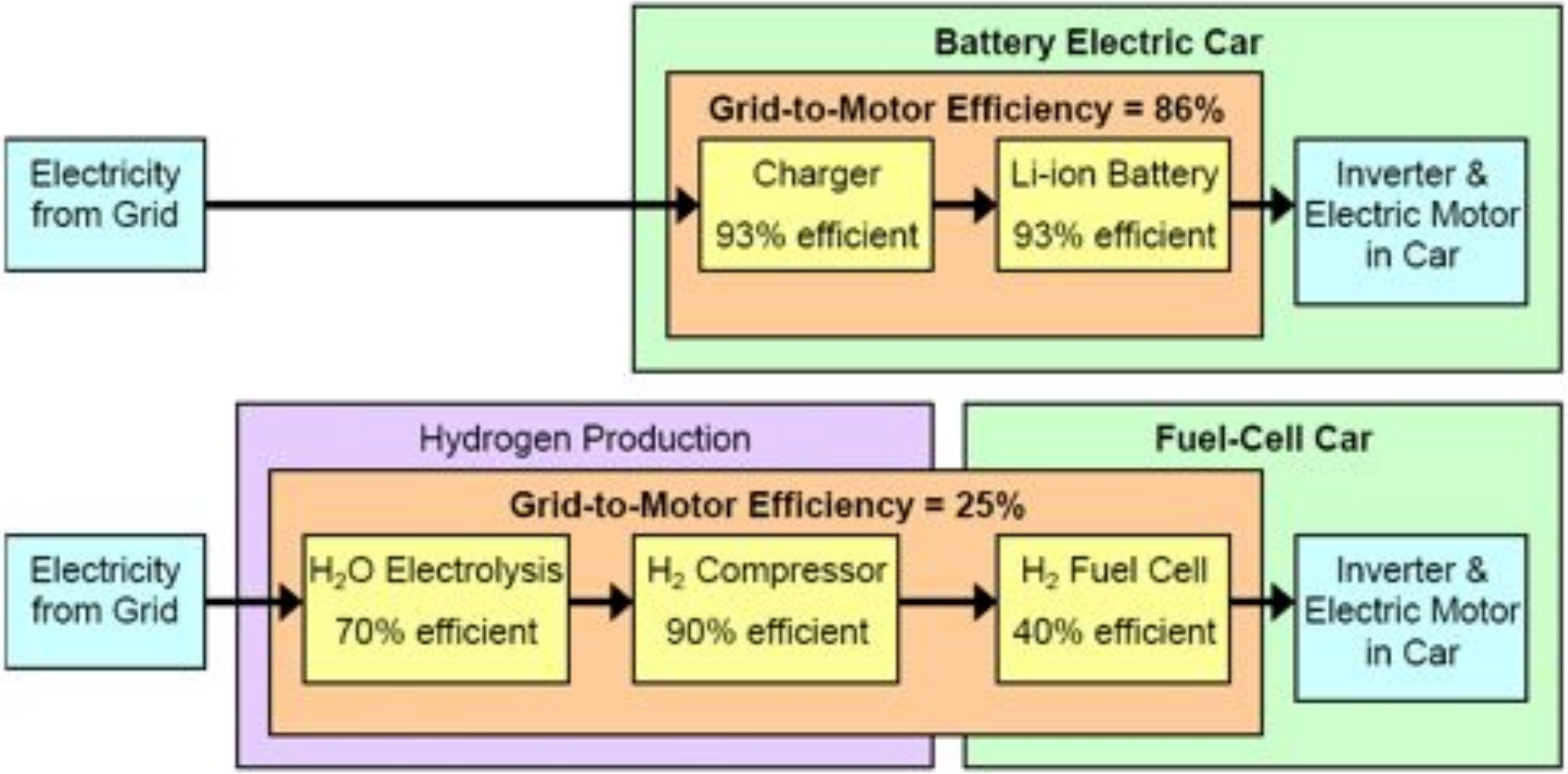

Integrated Inverter
and Converter + Connector Box


Stator
Rotor
Parking Lock
Differential Gear
Motor / Gear
Input Shaft
Slip Ring
System
Rotor Position
Sensor
Water Jacket

Pure battery EV

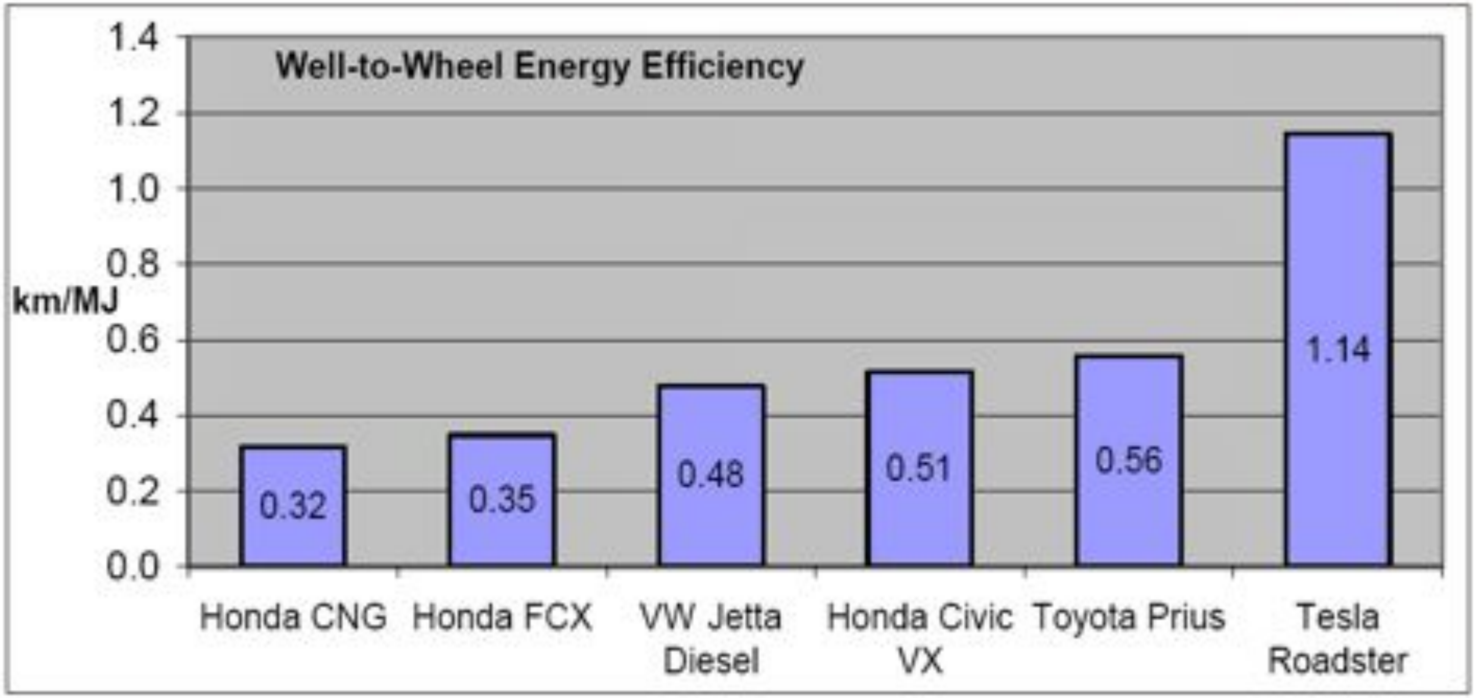
- emissions are moved to (more efficient) power plants
- need recharging stations
- recharging = ‘slow’ (?)
- recharge overnight (cheap power)
- batteries are heavy and spacious
- extremely silent

BEV vs. Fuel cell car



Well to Wheel

Technology	Example Car	Source Fuel	Well-to-Station Efficiency	Vehicle Mileage	Vehicle Efficiency	Well-to-Wheel Efficiency
Natural Gas Engine	Honda CNG	Natural Gas	86.0%	35 mpg	0.37 km/MJ	0.318 km/MJ
Hydrogen Fuel Cell	Honda FCX	Natural Gas	61.0%	64 m/kg	0.57 km/MJ	0.348 km/MJ
Diesel Engine	VW Jetta Diesel	Crude Oil	90.1%	50 mpg	0.53 km/MJ	0.478 km/MJ
Gasoline Engine	Honda Civic VX	Crude Oil	81.7%	51 mpg	0.63 km/MJ	0.515 km/MJ
Hybrid (Gas/Electric)	Toyota Prius	Crude Oil	81.7%	55 mpg	0.68 km/MJ	0.556 km/MJ
Electric	Tesla Roadster	Natural Gas	52.5%	110 Wh/km	2.18 km/MJ	1.145 km/MJ



True ZEV: solar challenge cars

- regular race for photovoltaic powered cars: in Europe, Australia
- extreme efficiencies required

Plug-in Hybrid Electric Vehicles

Plug-in hybrid electric vehicles

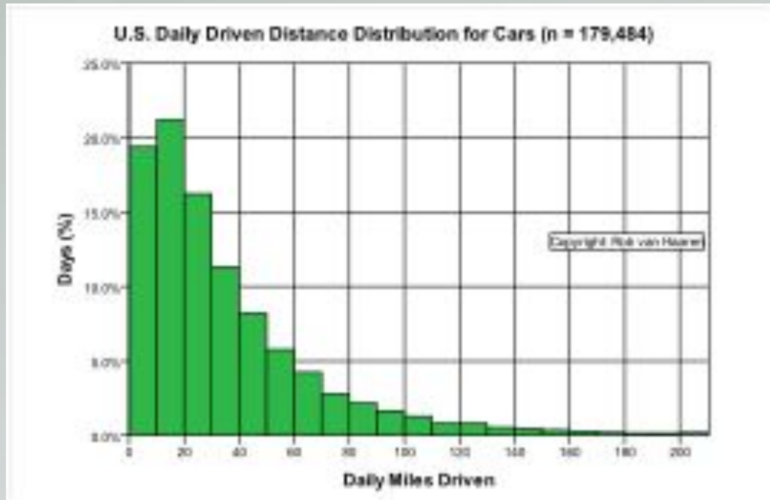
- HEVs which can be plugged in a standard outlet to charge the batteries: PHEV
- Same power train topologies as for full hybrids
  - Series
  - Parallel
  - Mixed

PHEVs

- Charged directly from the power grid.
- Larger battery pack.
- Short distances: in full electric mode.
- Internal combustion engine (ICE)
  - to extend their driving range.
  - boost performance.
- Tank to wheel efficiency is high (between hybrid and pure electric vehicles).
  - Up to 50% more efficient compared to hybrids, because they could run much longer on electricity alone.
- Use of cheaper energy at least at current fuel prices.
- Low carbon fuel profile.

PHEVs

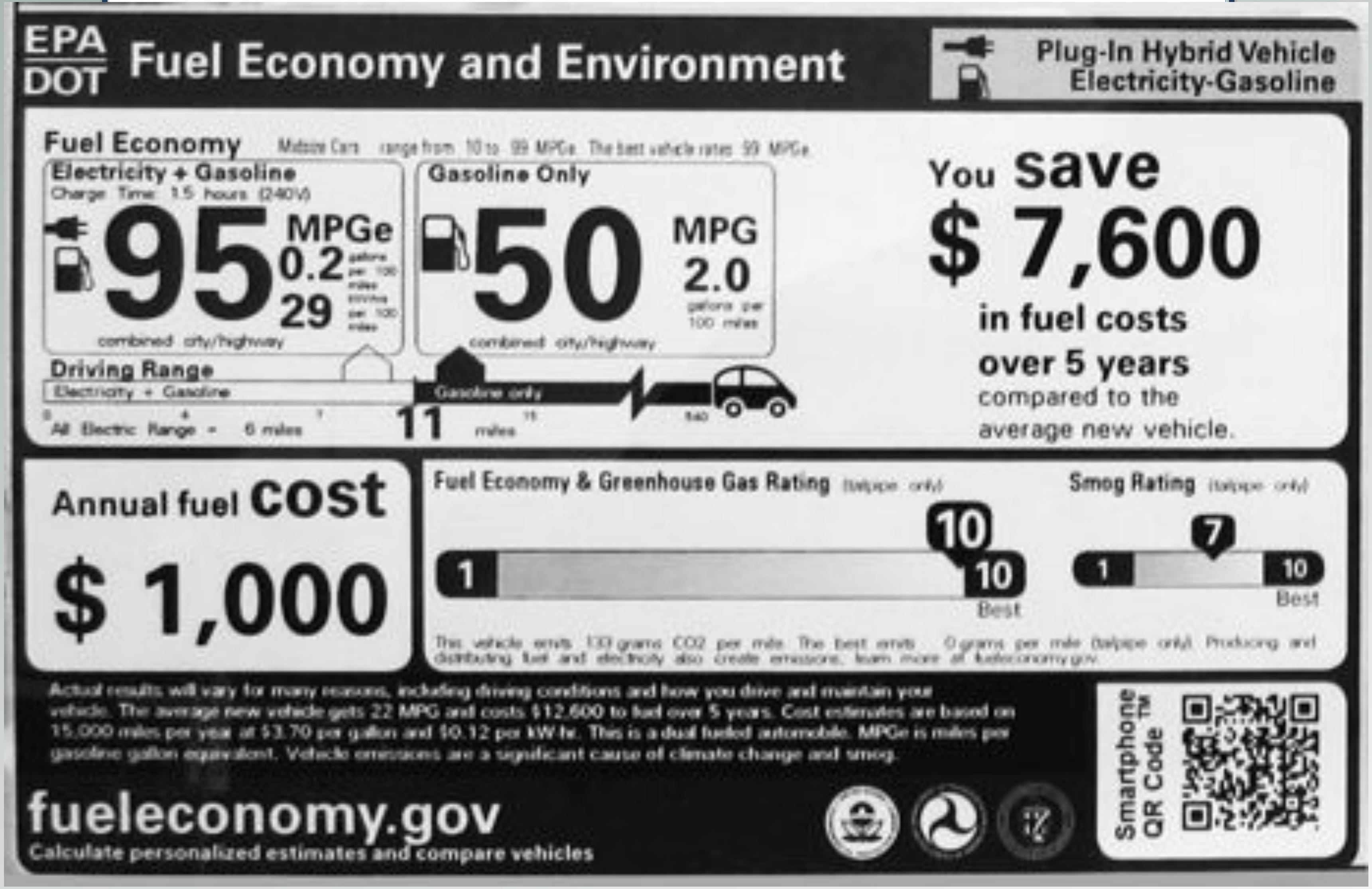
- Limited electric range
  - Typically low daily driven distance/ trip distance
- Charging infrastructure is available: standard sockets
- ICE for occasionally long trip
  - Reduced range anxiety
- Smaller battery pack than BEV
  - Challenging requirments
- More complex architecture than pure BEV
  - Both ICE and electric motor(s)



Prius plug-in

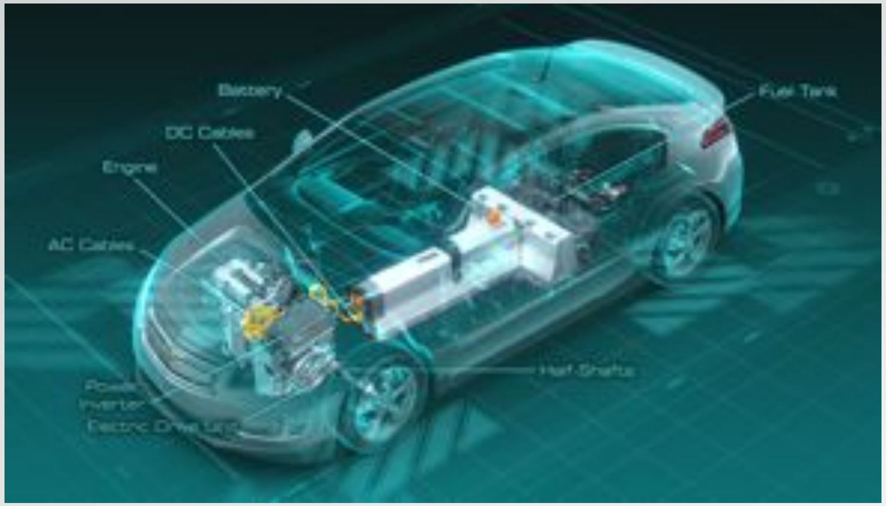
- Same configuration as regular Prius
- Larger battery pack
  - 4.4 kWh Li-ion pack
  - 23 km electric range
  - 1.5 hours recharging time
- Electric driving possible at speeds up to 100 km/h
- Regular Prius behavior if battery is depleted

Prius plug-in



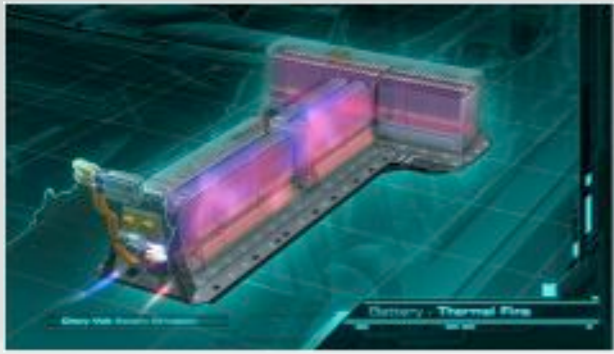
Chevrolet Volt

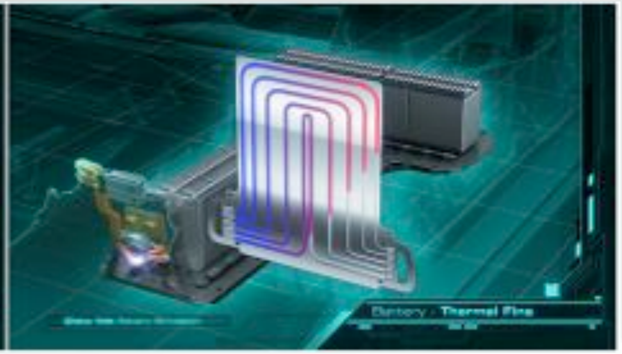
- Extended Range Electric Vehicle
- 1.4 l gasoline engine
  - 60 kW
- 2 electric motors
  - 111 kW traction motor
  - 55 kW generator
- Li-ion battery pack
  - 16.5 kWh
  - 10.8 kWh (30-85 %) used
  - 40-80 km electric range
- Hybrid if battery is depleted
- similar: Opel Ampera



Chevrolet Volt

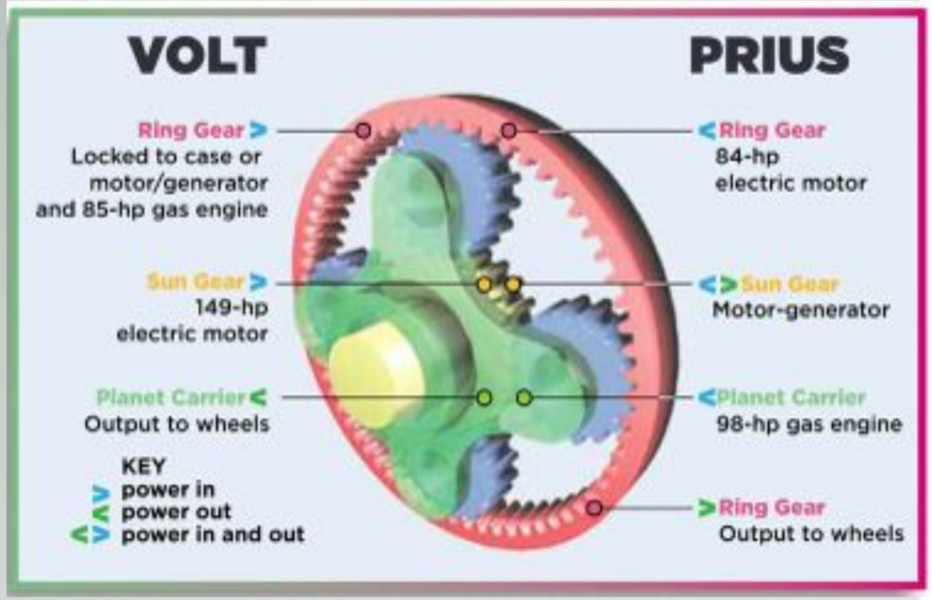
- 288 individual battery cells
  - Individual cell balancing
- 9 modules
- Nominal voltage 360 V
- Liquid cooled
  - ΔT < 2K in all 3 dimensions

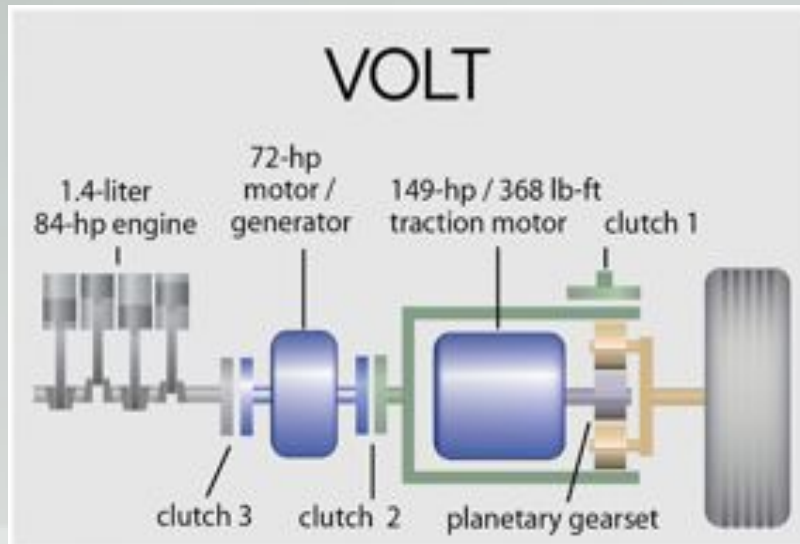




Chevrolet Volt

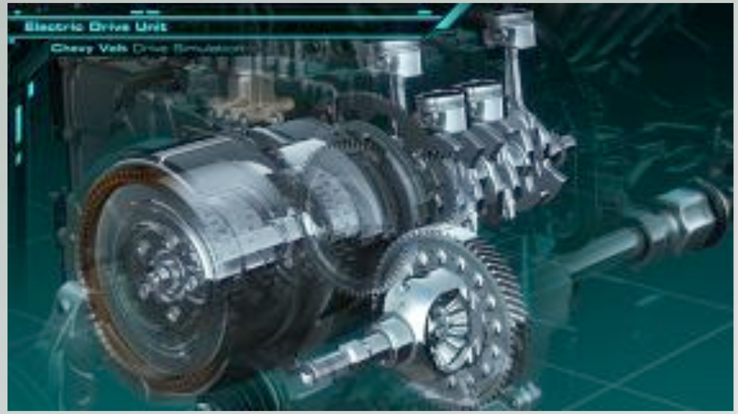
- Also planetary gearbox
  - But different configuration
- Reconfigurable hybrid
  - Through 3 clutches
  - ICE only active if battery is depleted





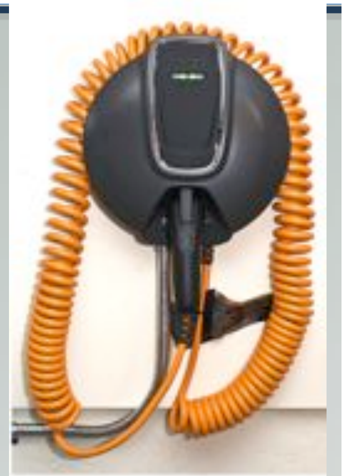
Chevrolet Volt

- **Single Motor EV driving**
  - Only traction motor is active
- **Two Mode EV driving**
  - Both electric motors
  - Reduces rpm at high speeds (>110 km/h)
- **Single Mode Extended-Range Driving**
  - Series hybrid, if battery is depleted
- **Two Motor Extended-Range Combined driving**
  - Both electric motors and ICE, if battery is depleted
  - At high speeds



Chevrolet Volt

- Realtime monitoring of these vehicles
- Majority of miles is driven electrically
  - Charging opportunity at standstill near household socket or charging station



Chevrolet Volt

Fisker Karma

- Extended Range Electric Vehicle
  - Series hybrid configuration
- Li-ion battery pack
  - Li-iron-phosphate
  - 20.1 kWh
  - Up to 80 km electric range
- 2 electric motor
  - 120 kW/650 Nm each
- 2.0 l gasoline engine (GM)
  - Turbo + direct injection
  - 190 kW / 350 Nm

Fisker Karma

- Not the most efficient EV
  - 40.6 kWh/100 km
  - Chevrolet volt: 21.9 kWh/100 km

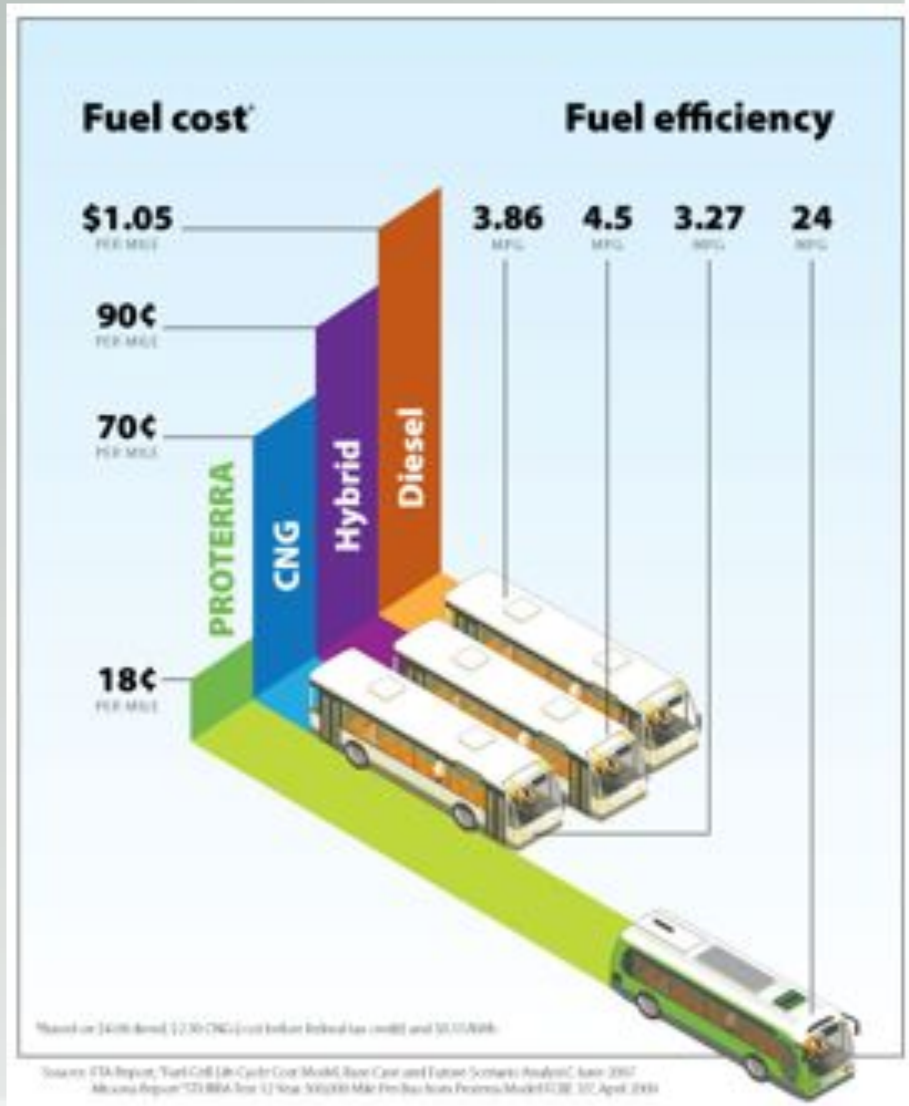
Heavy Duty Electric Vehicles

Battery Electric truck

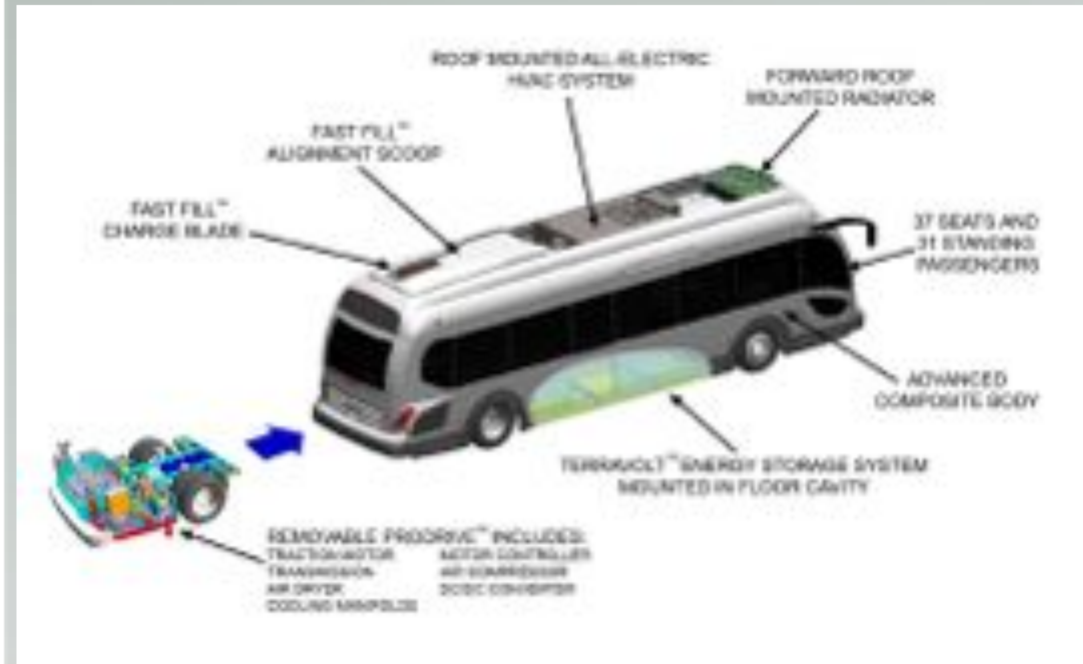
- Delivery services
  - Scheduled routes
  - Limited distances
- Economical decision
  - Low total cost of ownership
- Less noise
- Low emission areas

Battery electric Heavy Duty

- High efficiency as main advantage
  - Stop and go traffic
  - Energy recuperation
- Using fast charging
  - During scheduled standstill
  - Smaller batteries needed



Proterra Electric Bus



Proterra Electric Bus

Opbrid Busbaar

Charging concepts and infrastructure

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Charging up

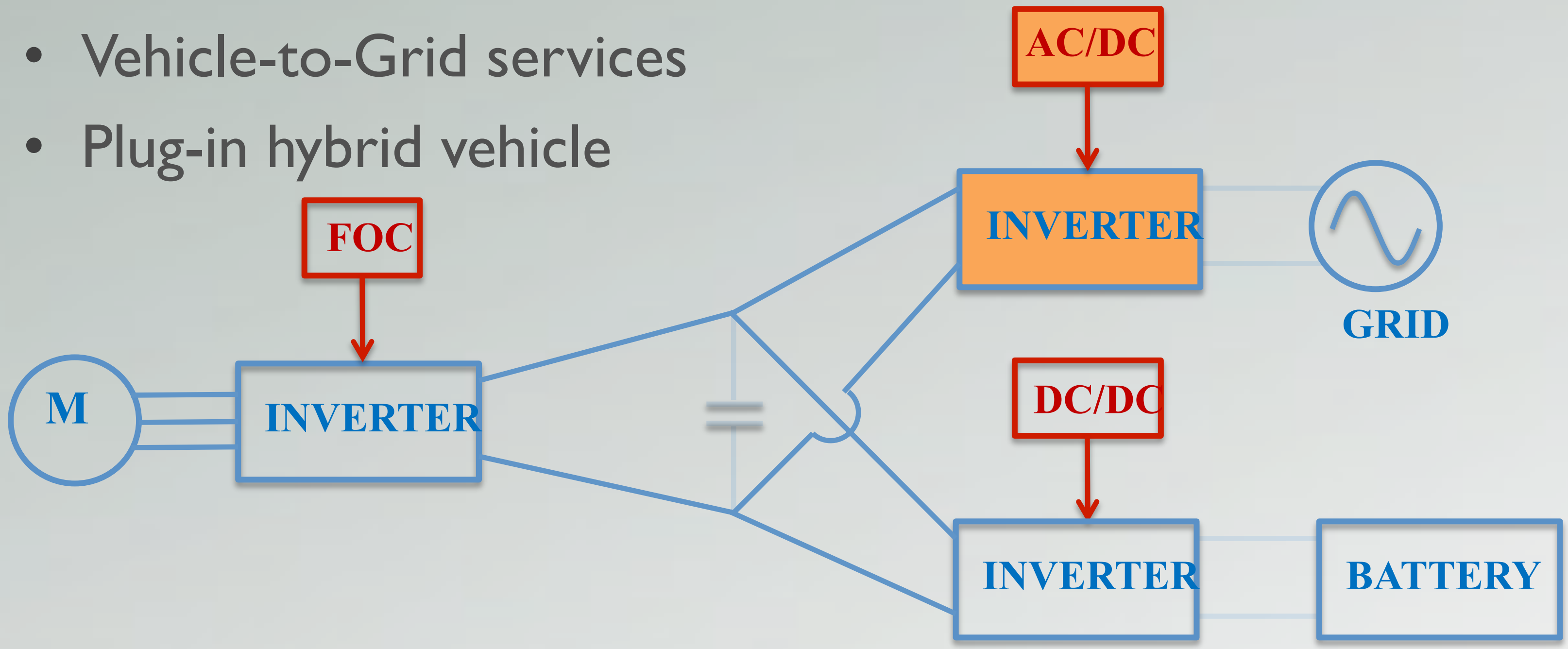
- filling up a classical car with gasoline is the equivalent of an MW energy transfer
- using an electrical cable: tens of kWh (need several hours)
- 2 systems: conductive, inductive coupling

Charging: further considerations

- Necessary infrastructure for PHEVs is already in place
  - Many homes and garages have outlets capable of recharging PHEVS (?)
- Charging off-peak (e.g. during the night)
  - The transmission grid: no problem?
  - The distribution grid: controlled charging will probably be necessary.
    - PHEV means controllable loads for the grid
- Storage function
  - Renewable sources: intermitted.
  - Fluctuations can be captured by the batteries of the PHEVs?
- Vehicle to grid?
  - Balancing
  - Spinning reserves
  - Reactive power
  - ….

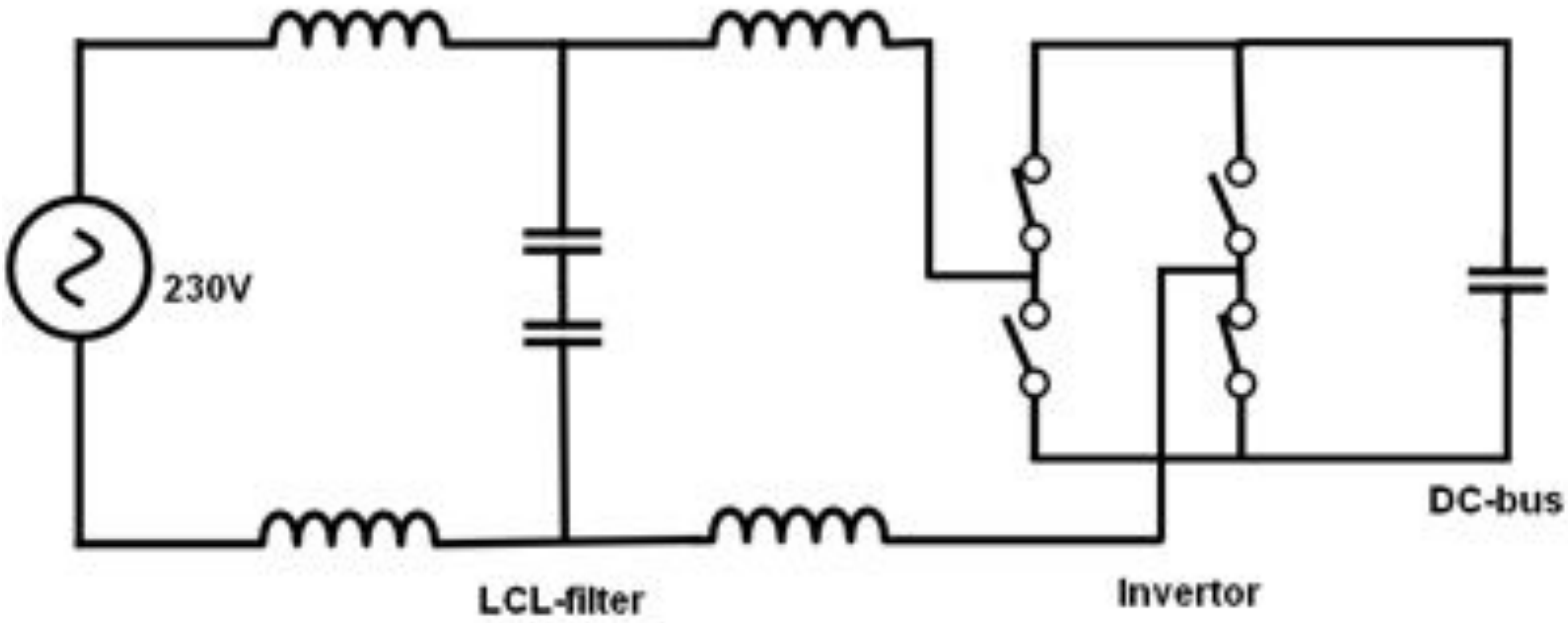
Concept
Grid coupling

- Single phase grid coupling : AC/DC converter
- Goal:
  - Charging batteries: Grid → DC-bus
  - Vehicle-to-Grid services
  - Plug-in hybrid vehicle



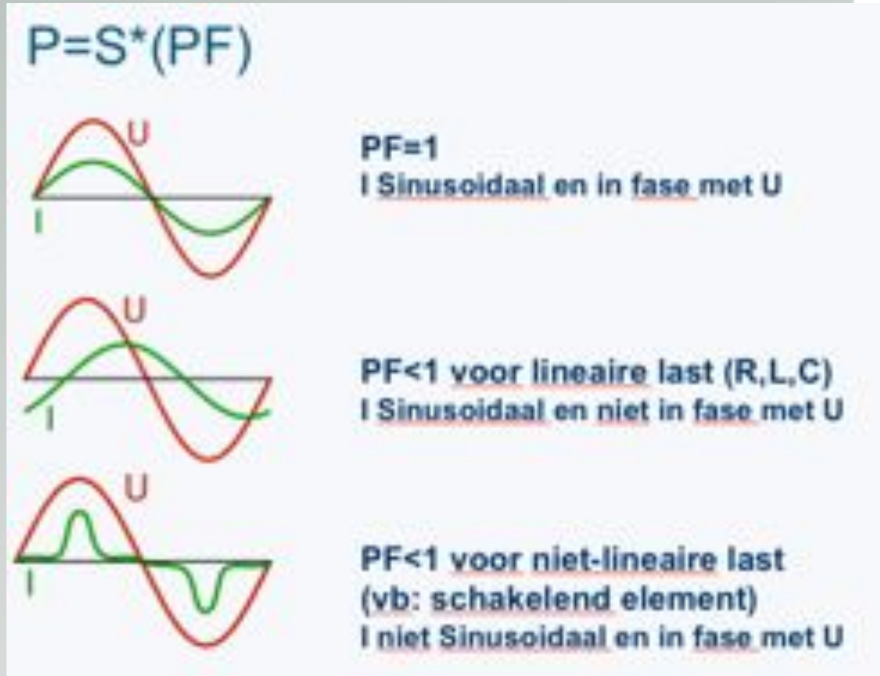
Concept
Grid coupling

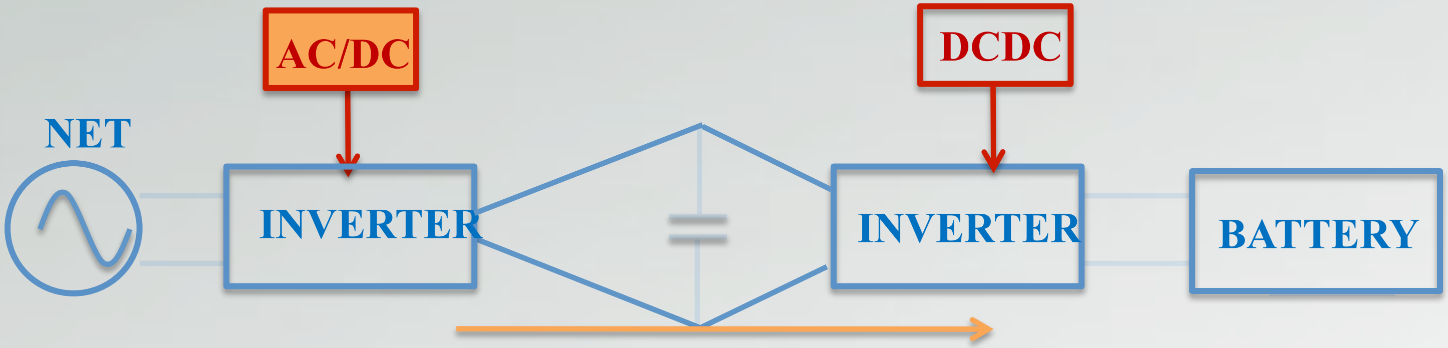
- Topology



Concept
Grid coupling

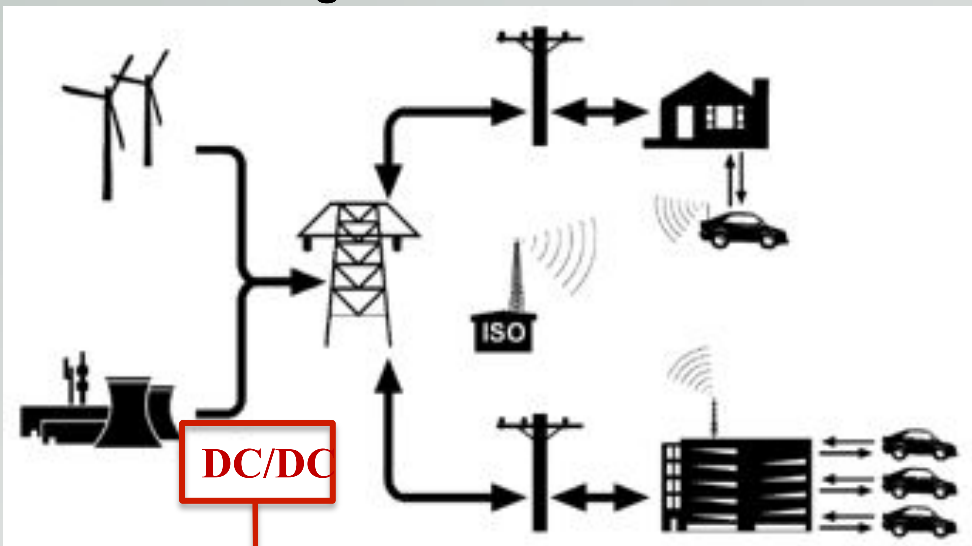
- Goal 1: charging battery
  - AC-grid → batteries
  - Power factor
    - Displacement Power Factor
    - Distortion

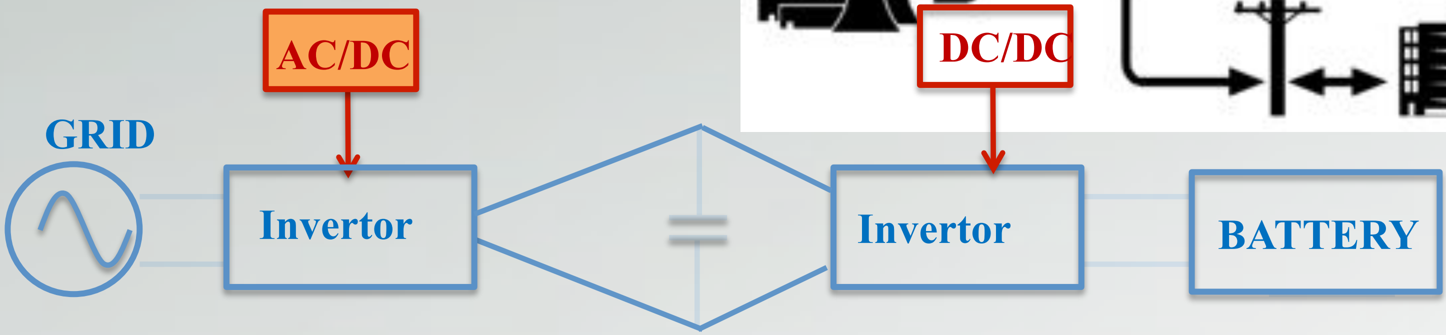




Concept
Grid coupling

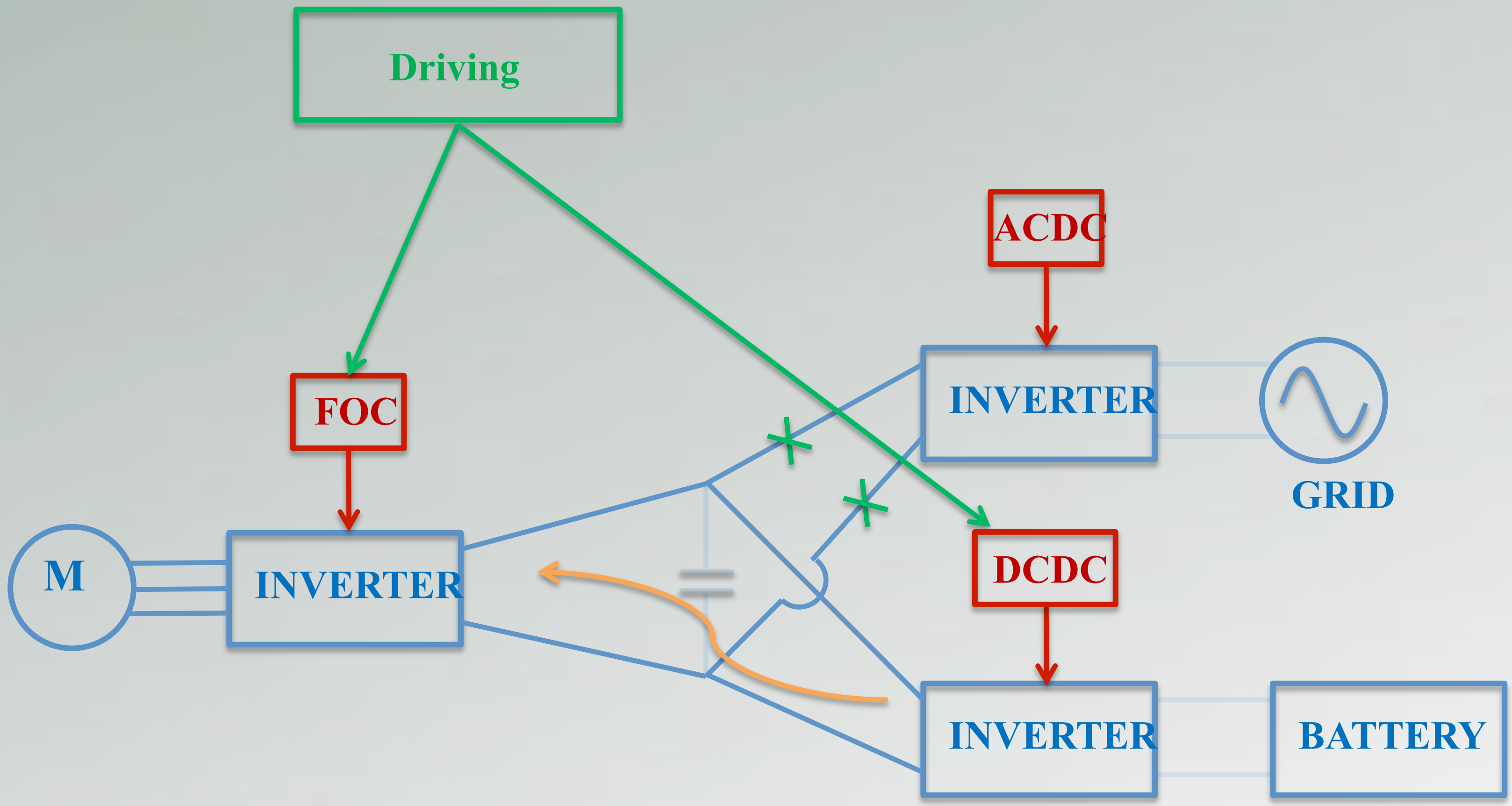
- Goal 2: Vehicle-to-Grid (V2G)
  - Bidirectional current streams
    - Vehicles produce services to support the grid
    - Active en reactive streams deliver to the grid
      - PF ≤ 1
      - Distortion





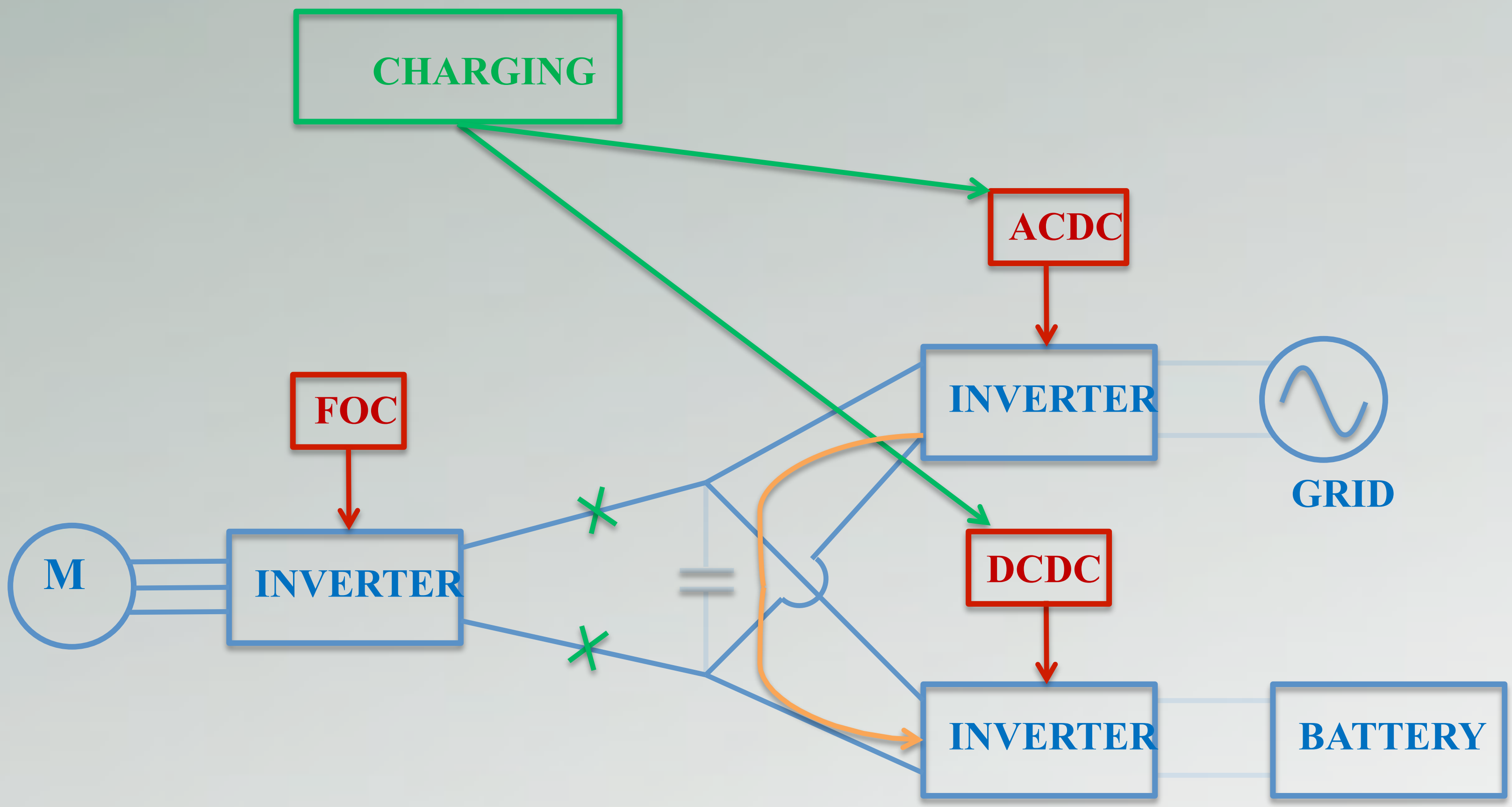
Concept
Plug-in electric vehicle

- Control for driving
  - Pure electric driving



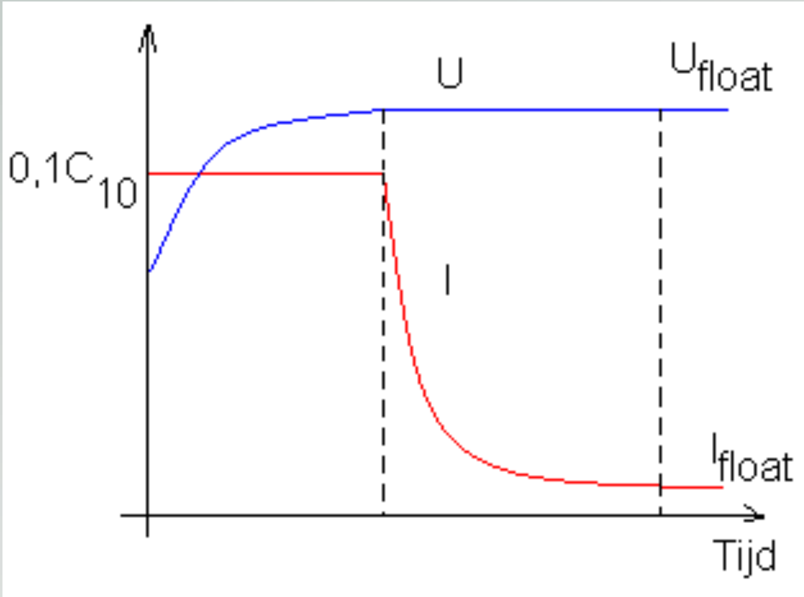
Concept
Plug-in electric vehicle

- Control for charging
  - Loading batteries when connected to the grid



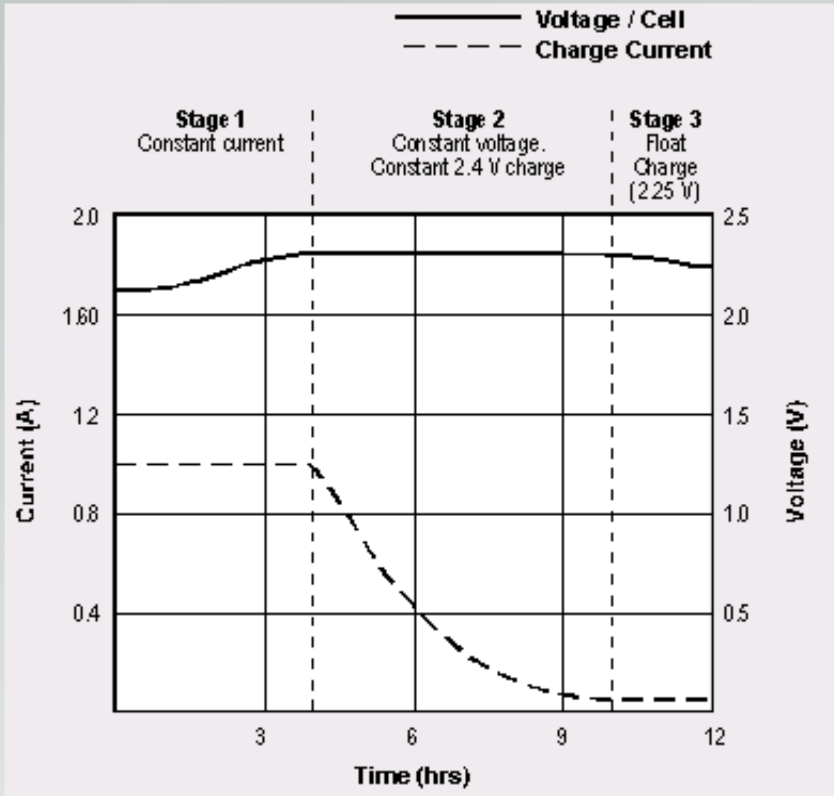
How to charge

- Constant Current Constant Voltage (CCCV)
- Most used and safest method to charge
- The battery is charged with a constant current (CC) until a certain voltage is reached.
- The battery voltage (CV) is kept constant while the current is throttled back.
- When the constant voltage is reached it takes a long time until the battery is charged completely.
- Also charging power limitation through available grid connection.



battery charging

- constant current (CC)
  - voltage rises to maximum
  - speed determined by current level
  - fast charge: only this stage
- constant voltage (CV)
  - current drops to 5-3%
  - conditioning of the battery
  - CC and CV typical for most charging processes
- trickle-charge
  - compensated self-discharge
  - only for standby-applications

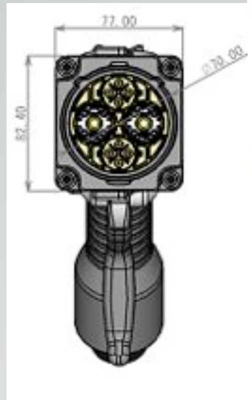


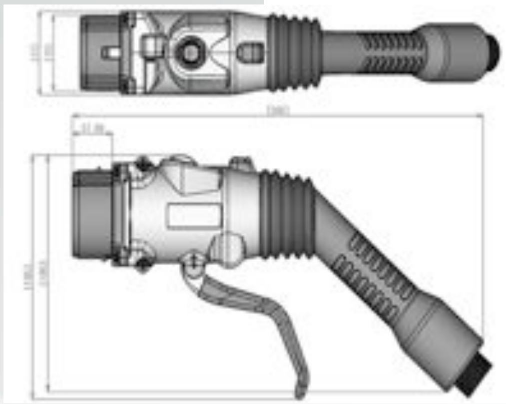
charging powers (1/2)

- Consumption EV: +/- 0,2 kWh/km
  - assume 1 kW charger
  - 1 hour charging adds 5 km range
  - "charging speed" of 5 km/h
- "Normal" charging
  - 1-phase: 16 A and 230 V=> maximal 3,68 kW
  - charging speed: 18,4 km/h
  - drawing 16 A for longer time from a socket not advisable?
- "Semi-fast" charging
  - 1-phase: 32 A and 230 V => 7,36 kW (36,8 km/h)
  - 3-phase: 16 A and 400 V => 11,09 kW (55,4 km/h)
  - 3-phase: 32 A and 400 V => 22,17 kW (110,9 km/h)

charging powers (2/2)

- fast charging
  - 50 kW and higher
  - >250 km/h charging speed
- special charging infrastructure
  - large part of converter electronics in the charging unit
  - large power grid connection
- Chademo standard
- Psychological effect
  - may help overcome range anxiety



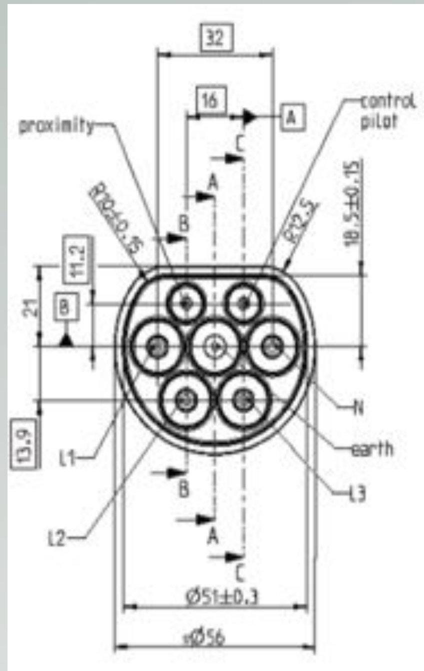


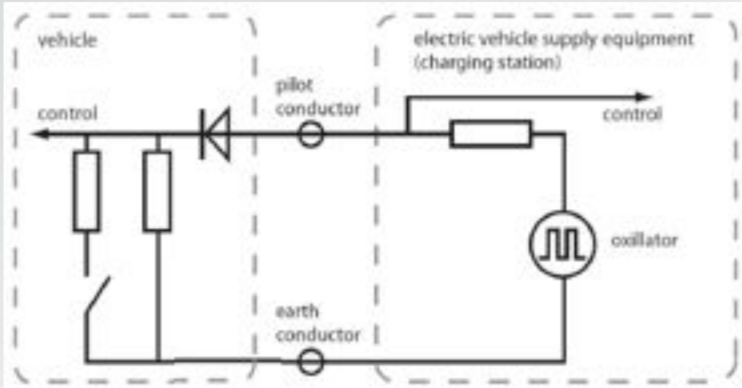
charging modi (1/2)

- defined in IEC 61851-1
- Mode 1
  - through standard 16 A sockets
  - applicable everywhere, simple and cheap
  - needs correct protection for single earth fault
    - earthing
    - differential protection
    - overcurrent protection (e.g. fuse)
  - forbidden in USA
- Mode 2
  - also through standard 16 A sockets
  - protection in the cable
  - protects the vehicle, not the plug

charging modi (2/2)

- Mode 3
  - specialized charging infrastructure
  - uses a control function
    - check correct connection
    - checks earthing
    - switches charging system on/off
    - selects charging current (duty-cycle)
  - Control signal through pilot wire or PowerLine Communication (PLC)
- Mode 4
  - for fast charging: external charger
  - also pilot wire
  - communication link for battery condition





Connectors (1/2)

- Standard plug: 16 A
  - Mode 1
  - Mode 3, with PLC
  - industrial type for intensive use

- plugs met pilot signal
  - Type 1: 1-phase
    - 16A/120V, 32A/240V, 80A/240V
    - Japan and US: SAE J1772
  - Type 2: 3-phase
    - 16-63 A per phase
    - also suitable for 1-phase: multifunctional
    - Western-Europe (Mennekes)
  - Type 3
    - 32 A per phase
    - "'shutters": compulsory in certain countries

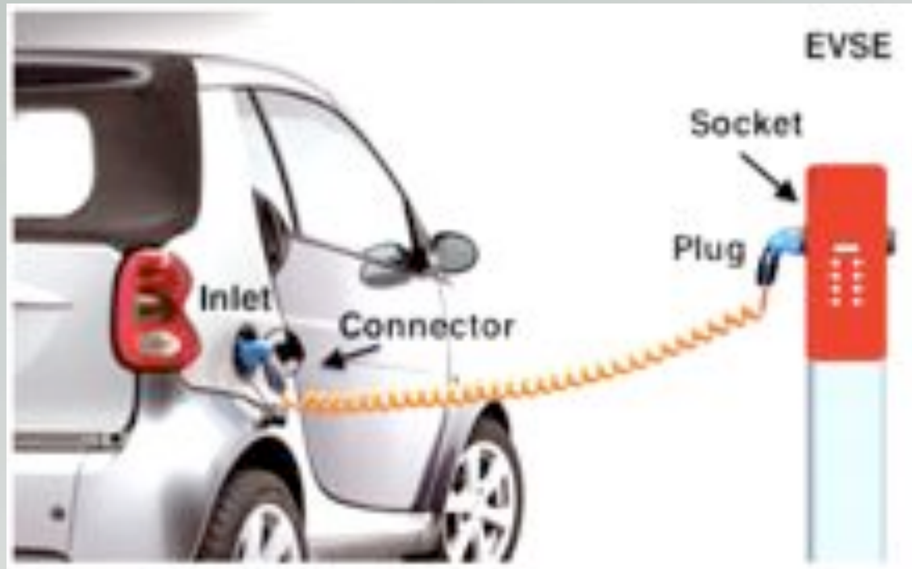
Connectors (2/2)

- Type 4 : DC charging
  - DC, external charger
  - large power
  - possibly combined "universal" plug

○ many standards

Charge cases: cables

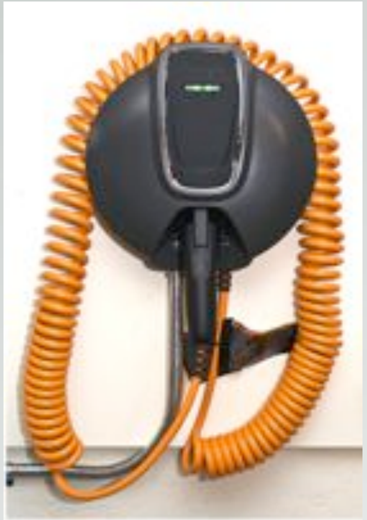
- IEC 61851-1 standard
- Case A: the charging cable is attached to the EV.
  - Renault Twizy
  - Standard domestic socket.
- Case B: a loose cable is used
  - Connector at the EV side and a plug at the EVSE side
  - Most currently used configuration.
  - High degree of compatibility
- Case C: the cable is attached to the EVSE
  - Dedicated charging stations
  - The connector is chosen to be compatible with the EV inlet.



Charge cases

Charging modes

- Mode 1: low power (up to 16 A)
  - 3.7 kW single phase and 11 kW three phase
  - Standard, non-dedicated domestic or industrial socket
    - Without communication at standard safety level.
  - The power coding is supplied by a resistor
  - Case A and B can use this charging mode.
- Mode 2: low power (up to 32 A)
  - 7.4 kW single phase and 22 kW three phase.
  - Standard, non-dedicated domestic or industrial socket
  - In-cable protection device that provides the control pilot signal to the EV
  - Case A and B can use this charging mode
- Mode 3: dedicated charging infrastructure
  - up to 32 A for case B or 63 A for case C
  - Control pilot signal is supplied by the EVSE
  - maximum charging power is controlled by the EVSE
- Mode 4: DC-fast charging (up to 400 A)
  - High power off board charger, and is not further discussed.



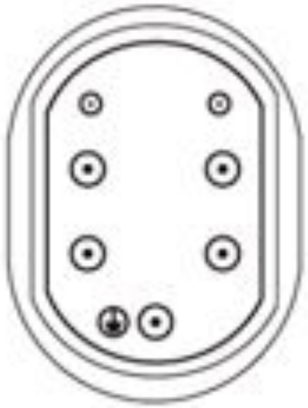
Connections

- Standard domestic plug/socket
  - Case A and B
  - Limited power rating, to be sure fuse won't trip
  - Typically limited to 10 A
- IEC 62196-2 Type 1
  - SAE J1772
  - Only used as connector/inlet for case B and C.
  - Allows Mode 1, 2 and 3, depending on the connection with the EVSE.
  - Standard vehicle inlet/connector In the USA and Japan
  - Also in Europe, several vehicles are currently equipped with this vehicle inlet
    - Nissan Leaf, Chevrolet Volt/Opel Ampera

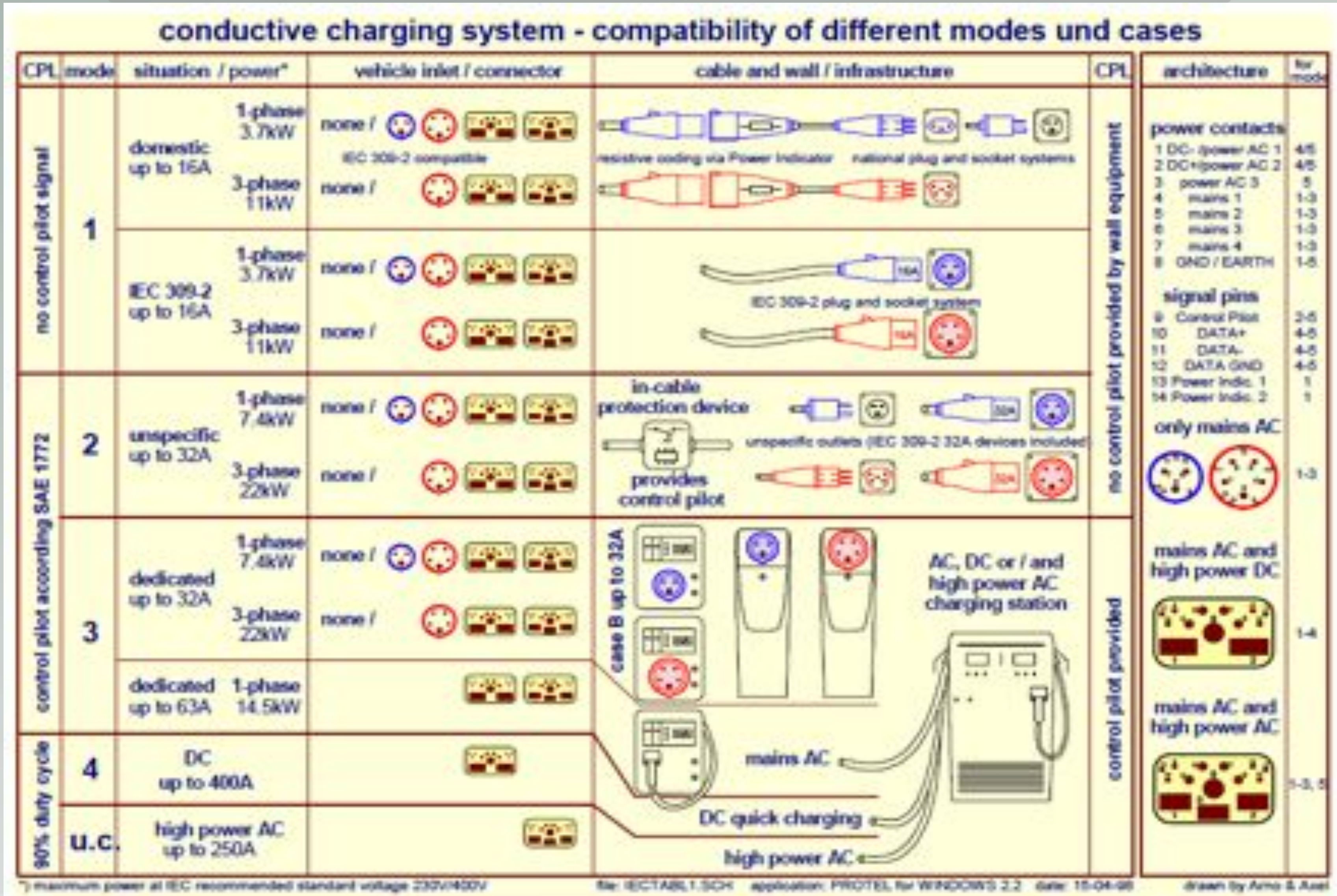
Connections

- IEC 62196-2 Type 2
  - “Mennekes” plug
  - used as plug/socket and/or connector/inlet
  - case A, B and C
  - Mode 1, 2 and 3 charging
- IEC 62196-2 Type 3
  - EV plug alliance
  - Shutters for safety
  - Only used as plug/socket
  - Case A and B for Mode 3 charging
  - In competition with type 2
- Compatibility

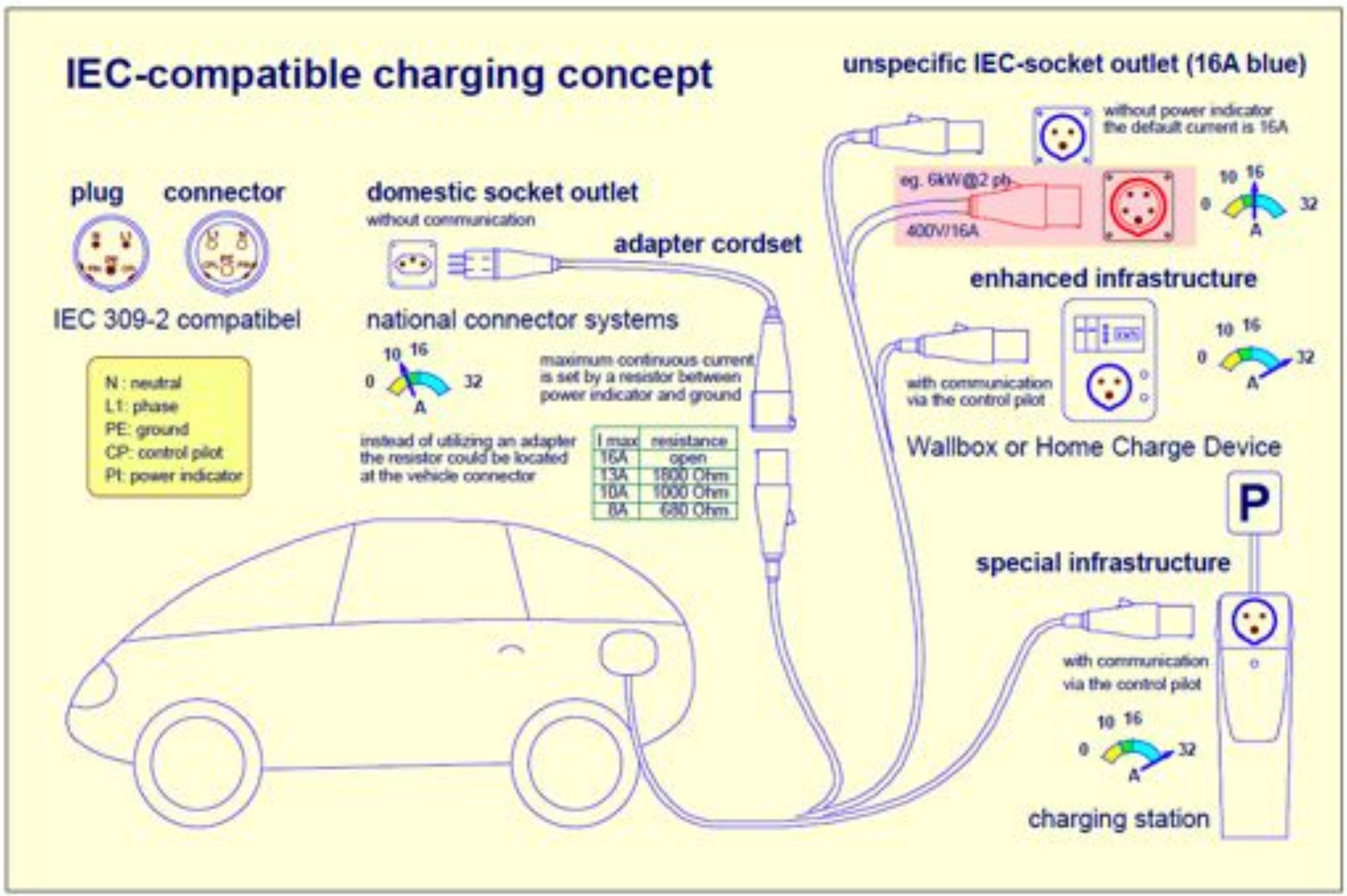
Compatibility

Characteristics	Type 1	Type 2	Type 3
Phase	Single-phase	Single-phase / 3-phase	Single-phase / 3-phase
Current	32 A	70 A (single-phase) 63 A	32 A
Voltage	250 V	500 V	500 V
No. of prongs	5	7	5 or 7
Blanking device	No	No	Yes
Diagram			

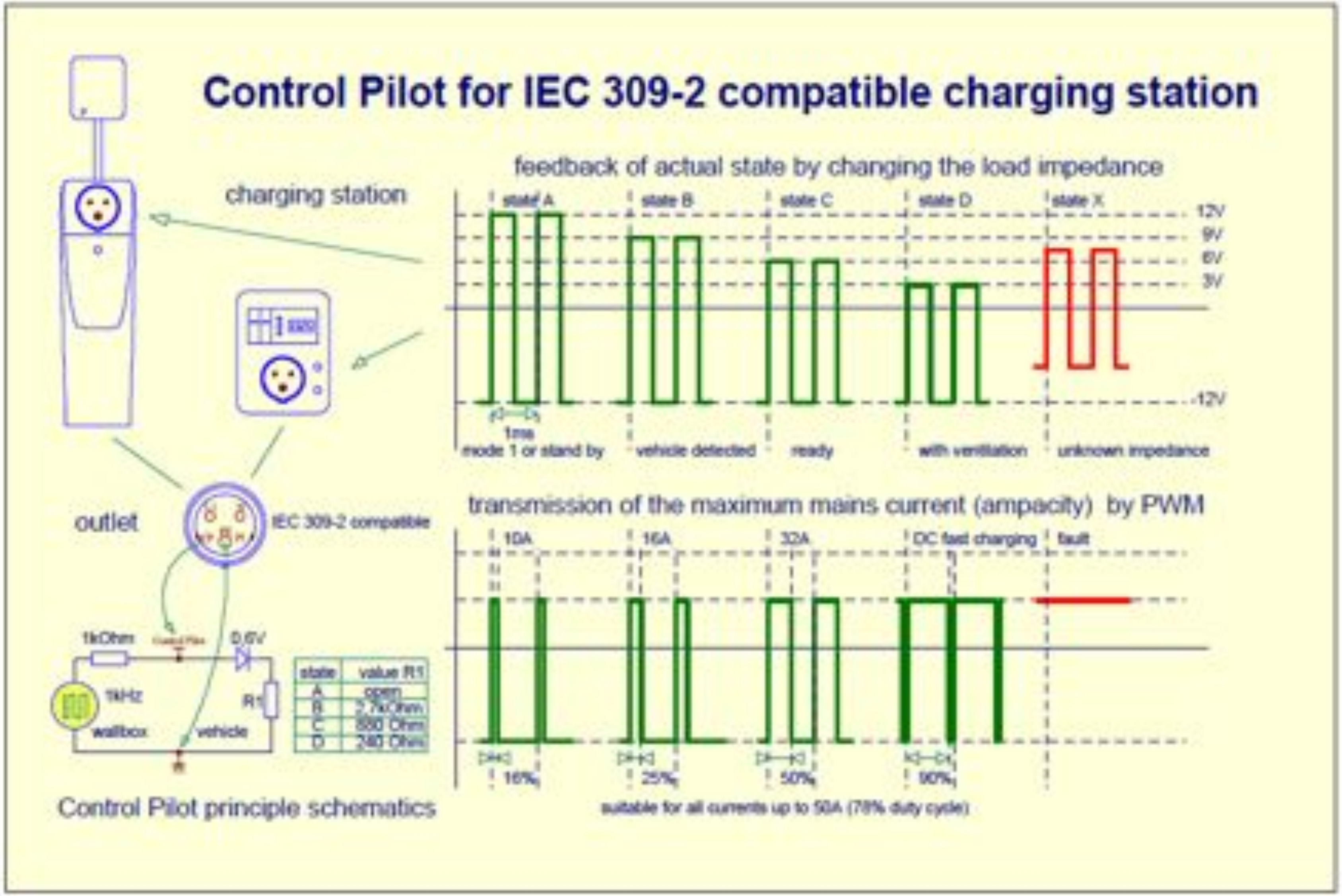
Compatibility



Compatibility



Control Pilot



state	value R1
A	open
B	2.7kOhm
C	880 Ohm
D	240 Ohm

Control Pilot

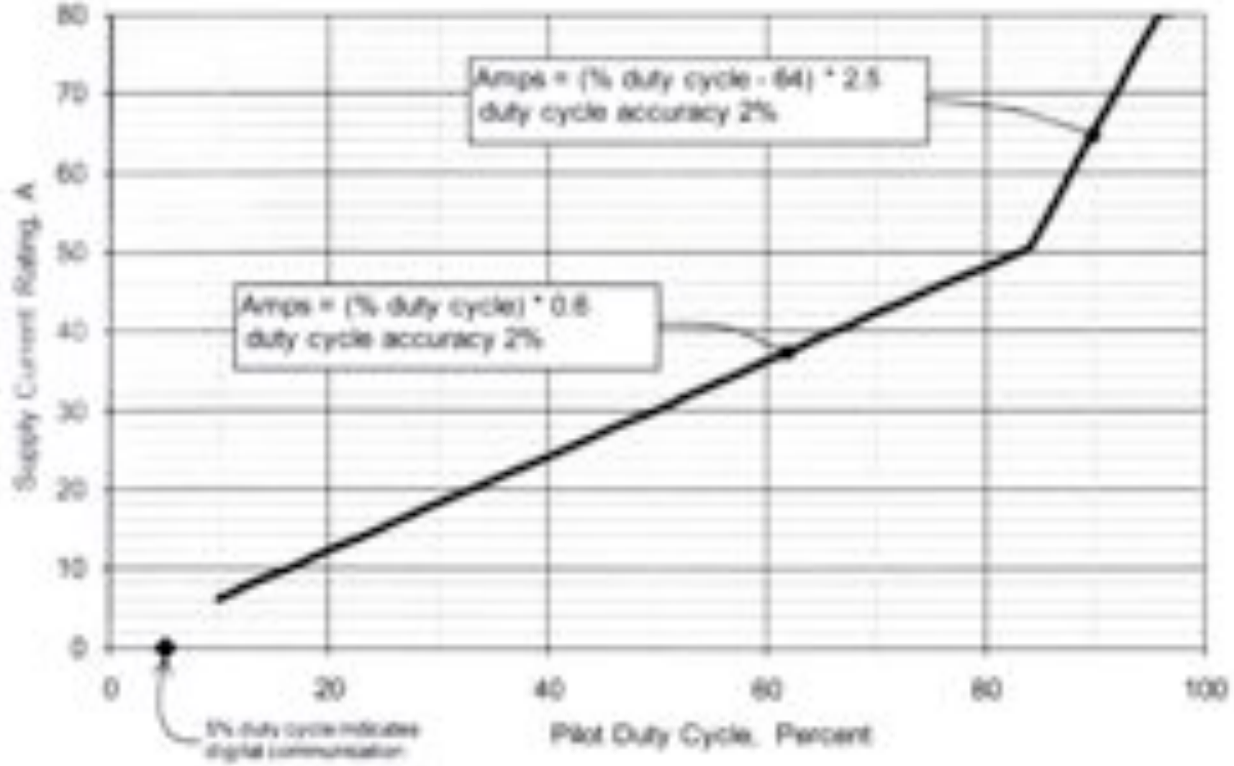


FIGURE 7 - SUPPLY CURRENT RATING VS. PILOT CIRCUIT DUTY CYCLE

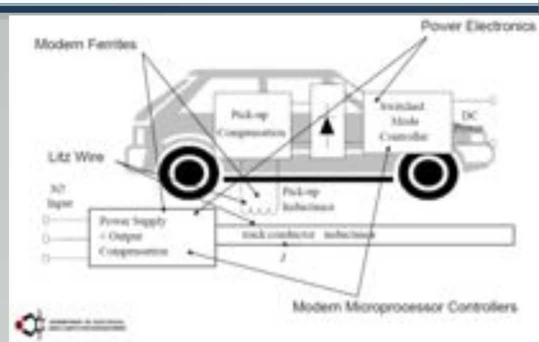
As an example, a 20% duty cycle would be 20 x 0.6 = 12 A. In this case, the vehicle must adjust its current draw to a maximum of 12 A.

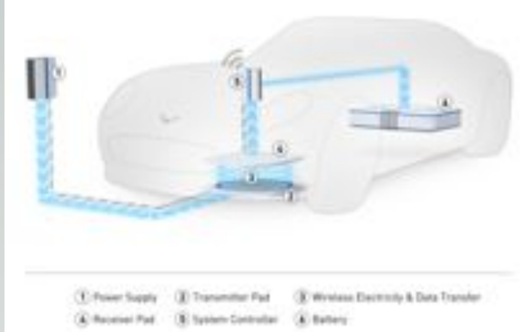
battery exchanging (swapping)

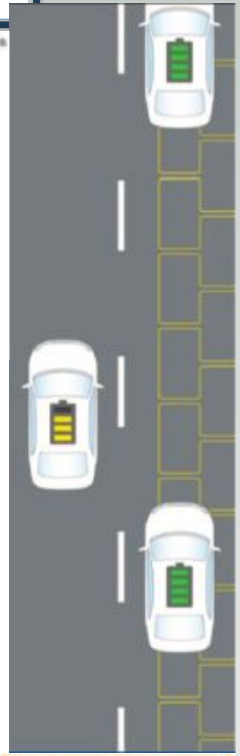
- alternative for fast charging
- similar principle as service station
- battery leased
- standardisation of batteries necessity
- needs more than 1 battery per EV
- warehousing problem

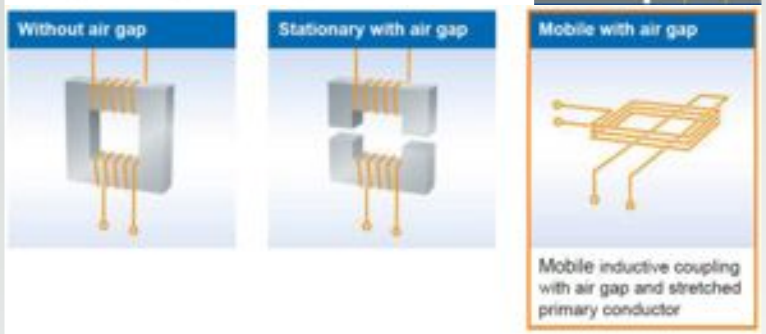
Inductive charging

- Contactless
  - Safety
  - No wear
  - Weather resistant
- Flexibility
  - Power ratings
  - Statis, continuous
- EMC
  - Within limits
  - Only field present if vehicle is charging
- Technology under development
  - Bombardier, Siemens, etc.
  - Halo IPT, Evatran, etc.
  - Volvo, Audi, etc.
  - …







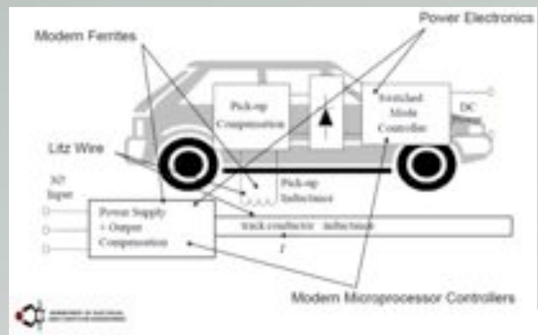


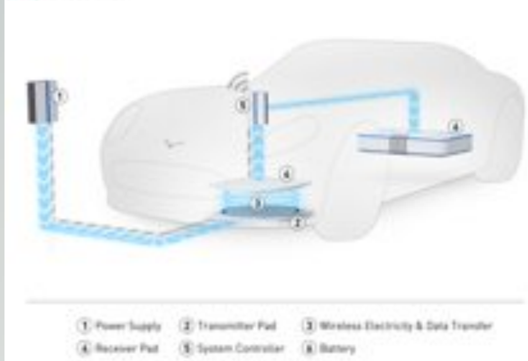
Inductive charging

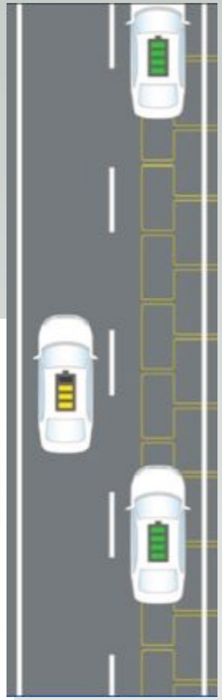
- Flanders Drive project (Lommel)
  - Busses and cars
  - Both static and continuous
  - EMC/EMF measurements
  - Efficiency measurements
  - System evaluation

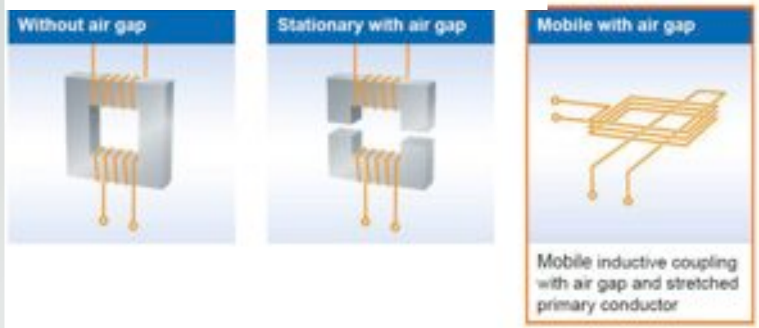
Inductive charging

- Contactless
  - Safety
  - No wear
  - Weather resistant
- Flexibility
  - Power ratings
  - Statis, continuous
- EMC
  - Within limits
  - Only field present if vehicle is charging
- Technology under development
  - Bombardier, Siemens, etc.
  - Halo IPT, Evatran, etc.
  - Volvo, Audi, etc.
  - …

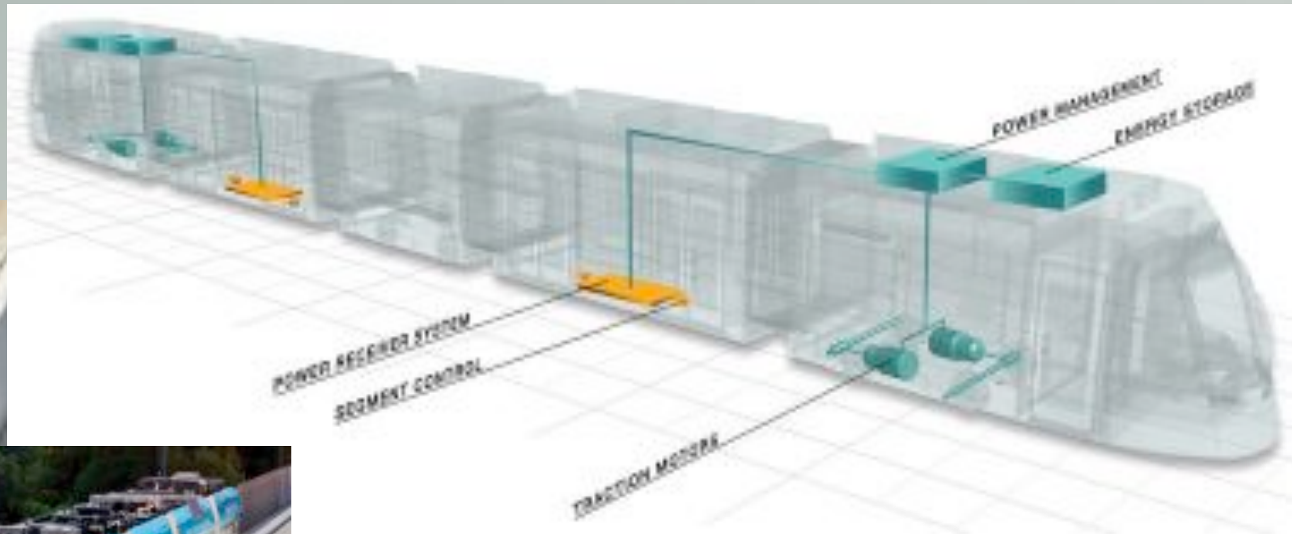




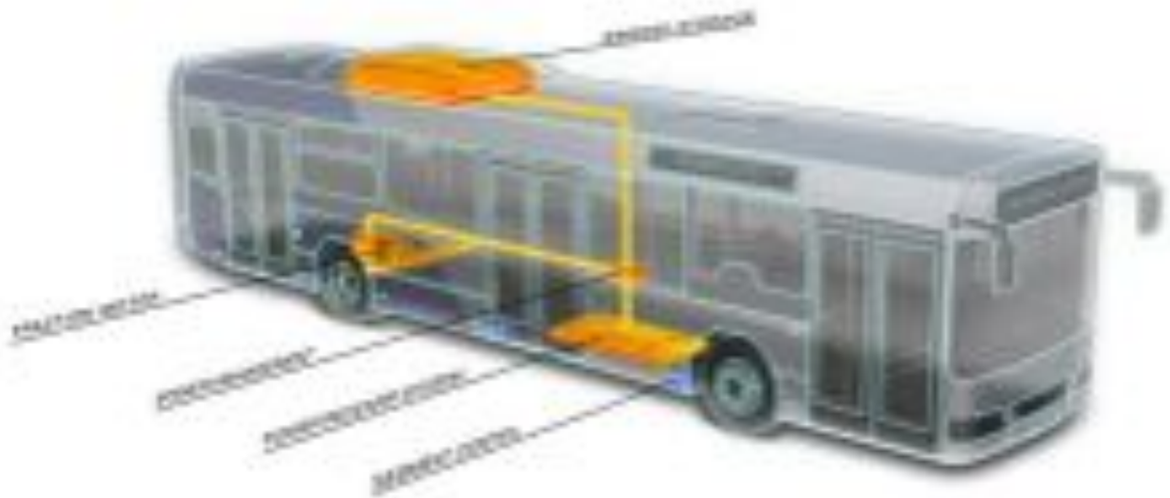




Bombardier Primove



Bombardier Primove



what to use when?

- standard charging through standard plug will be used most
  - needs no special plug
  - low power sufficient for nightly charging
- Mode 3 charging is very applicable for public charging
  - reasonably fast charging
  - power not to large to require complicated hardware and heavy grid connection
- battery exchanging suitable for standardised fleets
  - e.g. taxis
  - requires standardisation of battery pack, etc.
  - needs large investment in infrastructure
- Inductive charging is very user-friendly and flexible
  - charge as well during driving: leads to smaller batteries
  - requires large infrastructure, especially for driven charging

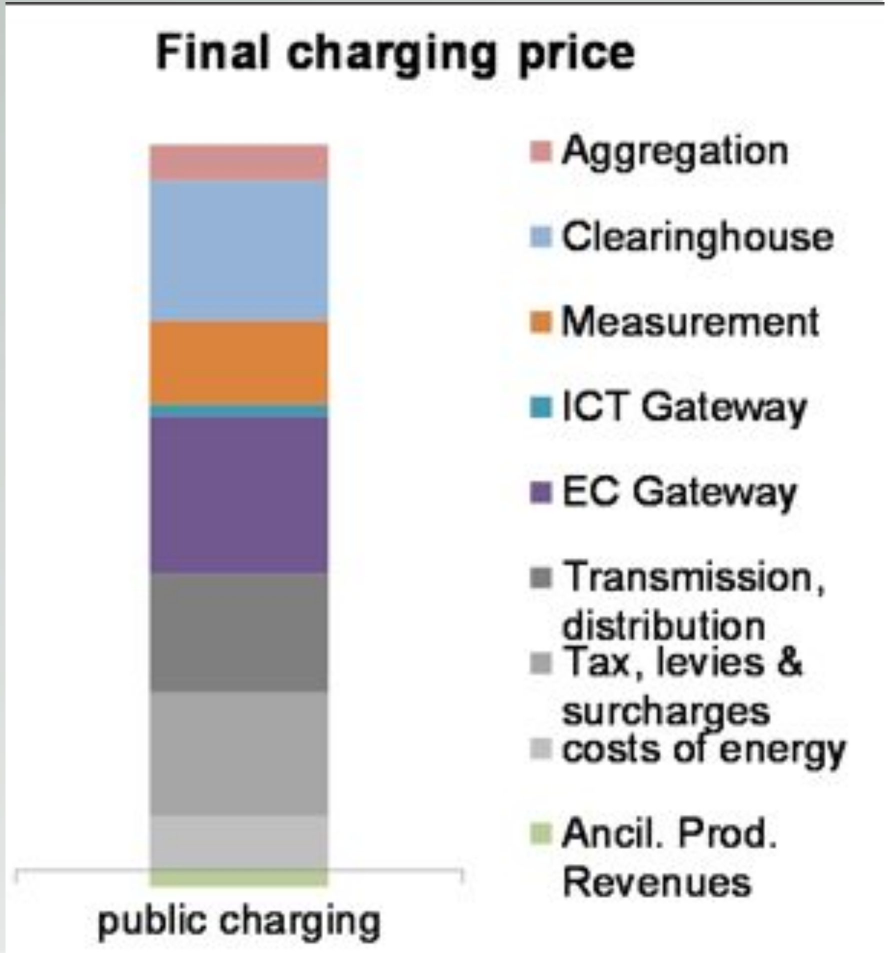
Where to get the power ?

- Grid connection to charge
- Potentially large additional load to the grid
- Candidate for ‘demand control’ balancing?
- “V2G”

Public Charging & Payment systems

Exploitation cost of electric vehicles

- Electricity cost is the variable cost factor
- Public charging: opportunity charging
  - 20 % of the charging actions
  - Energy consumption: 2-10 kWh
- Consumption cost: 0,5-2,5 EUR/dag
  - Finale charging price will include more than this cost factor
  - Overhead cost must remain relatively low



Payment model

- Energy consumption measurement
  - Ferrarris: Cheap and reliable, but needs monitoring
  - Electronic: automated reading at a higher cost
- Time measurement
  - Simply measurable
  - Occupation of the infrastructure has a cost
  - Energy cost divided over time usage
- flat fee system
  - No need for measuring infrastructure at every charging pole
  - Access via key or verification via tag
- Integration in the parking cost
  - Relatively high parking cost compared to charging
  - No need for additional high-end infrastructure

Payment procedure

- Low cost required
  - Low cost of charging action
- Different possibilities
  - GSM and GPRS: simple and cheap
  - Modules for vehicles and infrastructure
  - Communication with the user (e.g. through sms)
- Charging procedure
  - Vehicle identification at arrival
  - Proposal of charging tariff
  - User confirmation, start of charging
  - Notification charging end to the EV driver and EVSE operator
- Settling of payment after finishing charging action.

Payment method (1/2)

- Coins
  - Cfr. parking payment
  - Sensitive to vandalism and theft
- Specific EV-payment card
  - Cfr. phone card
  - Both pre-paid and contract is possible
  - “tagging” with RFID
- Banc /credit card
  - Maestro, Visa, etc…
  - High transaction cost, so less suitable
- Vignet
  - flat-fee system, payment at purchase
  - Monitoring required

Payment method (2/2)

- Electronic purse
  - Chip on bank card
  - Advanced and expensive infrastructure required
    - Modem for the transaction
    - Microcontroller for controlling the sockets
    - Socket locking
    - Communication with the terminal
  - x % commission per transaction
  - Unsuitable at low usage rate of EV infrastructure
- Payment with SMS
  - Already used for public transport and parking
  - Low initial investment, widely accessible
  - Safe, anonymous and fast payment

Example: The Plugin Company

- Distributor of Electrobay charging infrastructure
- Simple home charging unit
- Charging point with back office for public charging infrastructure
  - Acces with RFID card
  - Payment via contract

http://www.theplugincompany.com/

Example: The Plugin Company

Example: BeCharged

- Different types
  - Pole/wall model
  - Robust aluminum model
  - Integration with solar panels
- Different versions
  - Hardware/software
  - Different packs
  - Different types of sockets/connectors
- Service package
  - Vehicle owner
  - Infrastructure owner

http://www.becharged.be

Example: Enovates

- Modular charging infrastructure
  - Easily expandable
  - Easily to adapt for other socket types
- Different types
  - Home: simple version
  - Business: networked and controllable
  - Trader: integration of payment systems
  - Public: robustness
- Management software

http://www.enovates.com/

Electricity Grid Interaction

© K.U.Leuven – ESAT/Electa

More than just a plug…

Not only home charging

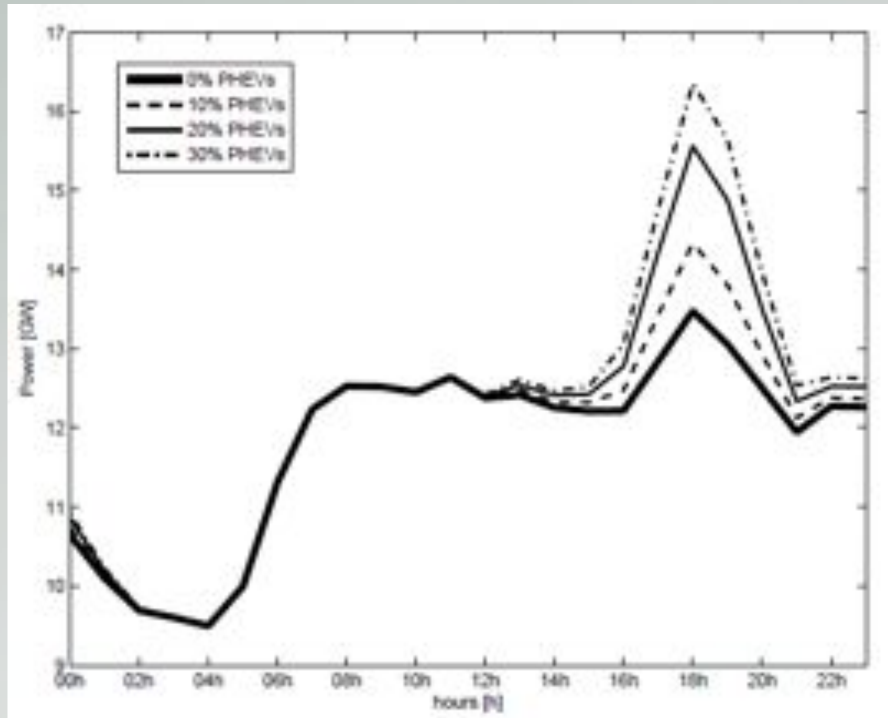
Energy consumption

- 1 car on average: +/- 3,300 kWh/year
  - 4-7 kWh/km, 90 % efficiency of charger
  - 15,000 km/year
- Significant increase in household electricity consumption
  - 3,500 kWh/year
  - Same order of magnitude
- Modest on national scale
  - 90 TWh (Belgium)
  - 3.3 TWh for 1 million vehicles
    - 3.7 % increase

Uncoordinated charging

Power production

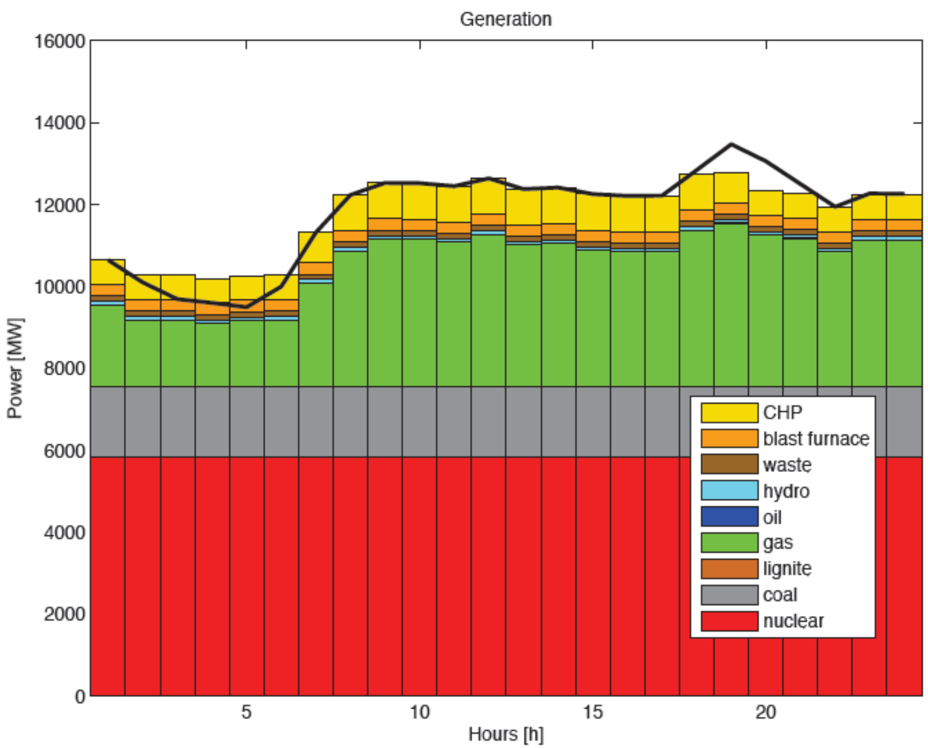
- EV charging energy must be generated
- Power generation
  - Nuclear, gas, coal, pumped storage
  - Base, modulating, peak
  - Installed capacity in 2011: 16.8 GW
- Simultaneity household and EV charging demand
  - High peak power
  - High ramp rate

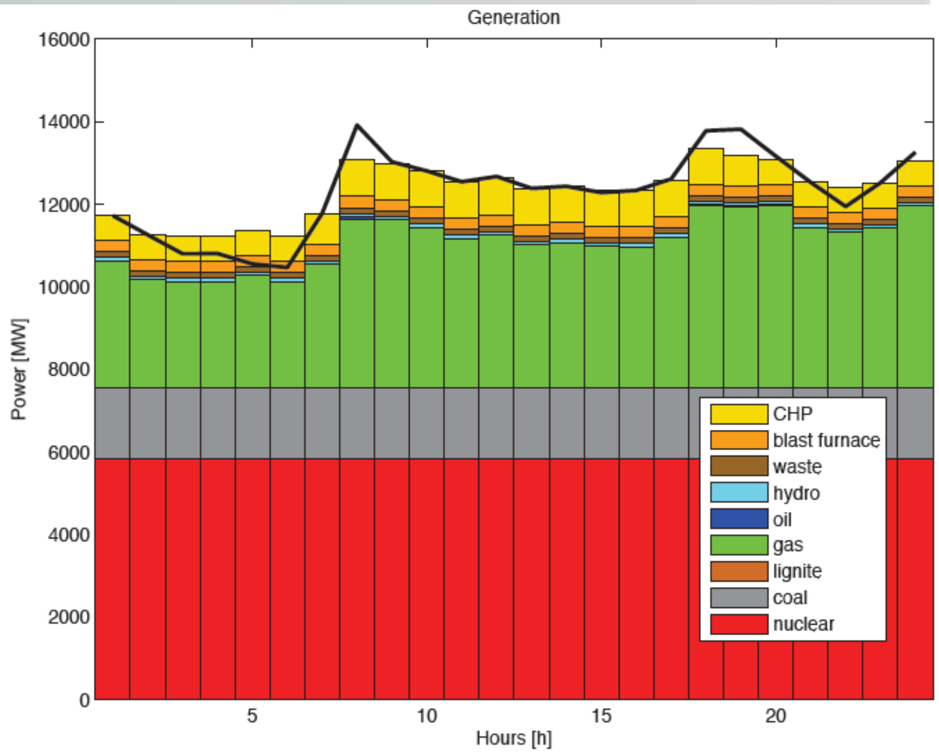


K. Clement, "Impact of Plug-in Hybrid Electric Vehicles on the Electricity system", PhD Thesis, K.U.Leuven, 2010

Uncoordinated charging
Power production

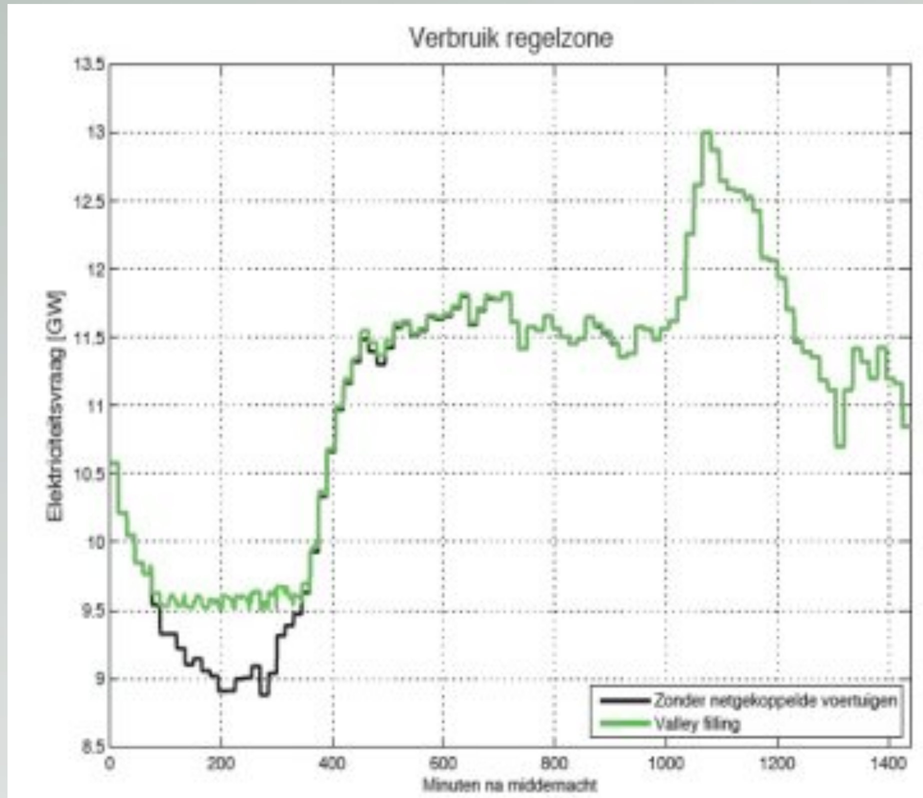
- Without expansion of the production parc
  - 30% EVs: with coordination
  - 10% EVs: without coordination





Coordinated charging
Transmission level

- Long distance, high volume transfer of electrical energy
  - Centralized power plants => LV/MV substations
  - National TSO: Elia in Belgium
- Enough available capacity?
  - Only limited increase in energy demand
  - No problem with coordinated charging
- Is stability guaranteed?
  - Shifting in load/generation patterns
  - Anticipating through grid planning
  - Gradual rise of EV penetration rate

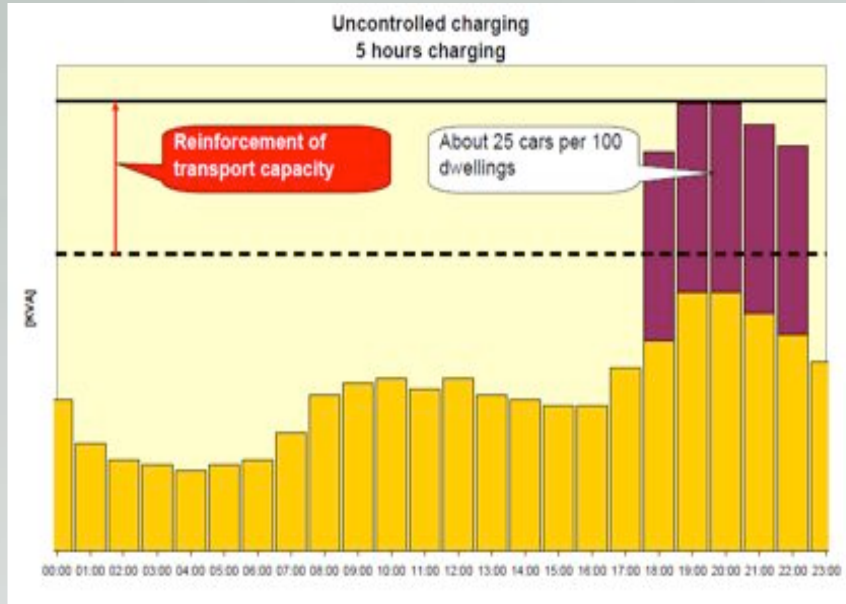


J. Van Roy, and K. Vogt. Analyse van verschillende batterijcapaciteiten voor plug-in hybride elektrische voertuigen, Master's thesis, KU Leuven, 2010.

Uncoordinated charging

Distribution level

- HV/MV substation => households (400/230 V)
  - Extensive infrastructure
  - High variety of topologies
- Charging typically at LV level
  - Relative high R/X ratio
  - Voltages strongly influenced by loads
  - Unbalanced situations
- Local high penetration grades

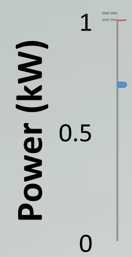


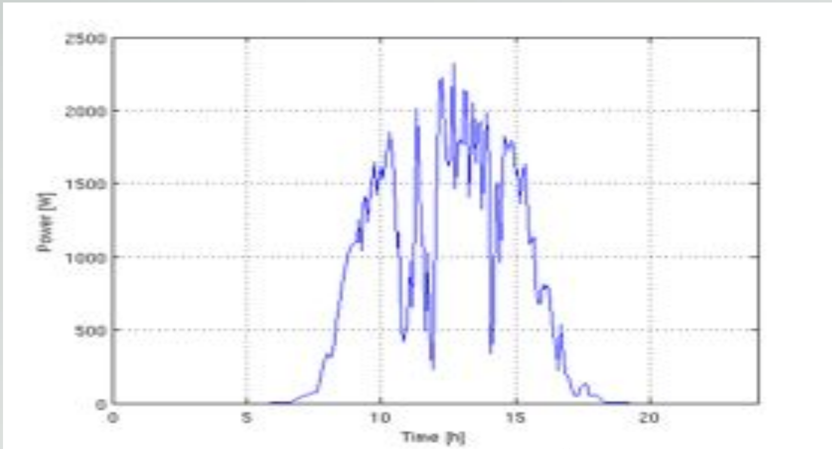
K. Kok, M. Venekamp, “Market based control in decentralized electric power systems”, ECN, 2010

Uncoordinated charging
Distribution level

- Highly stochastic loads
  - lack of aggregation
  - Inaccurate predictions
  - Strong voltage variations
- Voltages should stay within limits
  - EN 50160
- Interaction with PV not straightforward
  - Unbalanced situation
  - Both can worsen each other

VREG SLP profiles: 19-26/03/2012



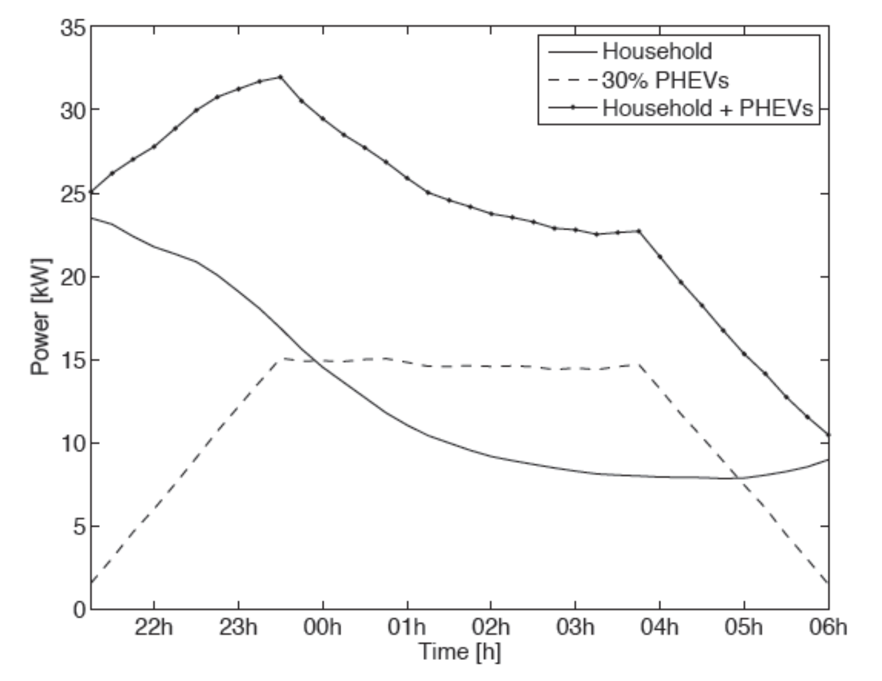


Source: KU Leuven

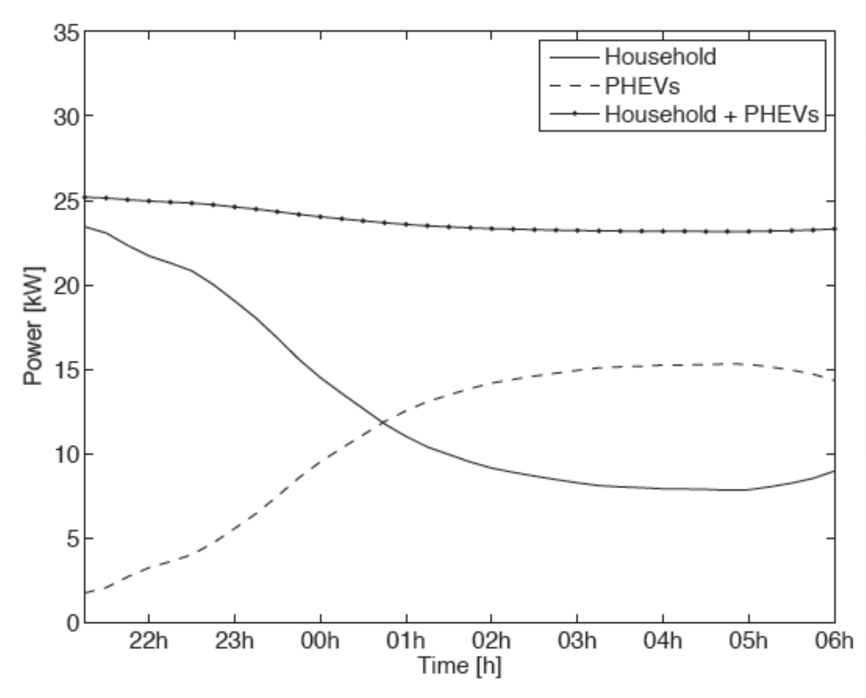
Coordinated charging
Distribution level

- Shift load (DSM)

Without coordination



Perfect coordination



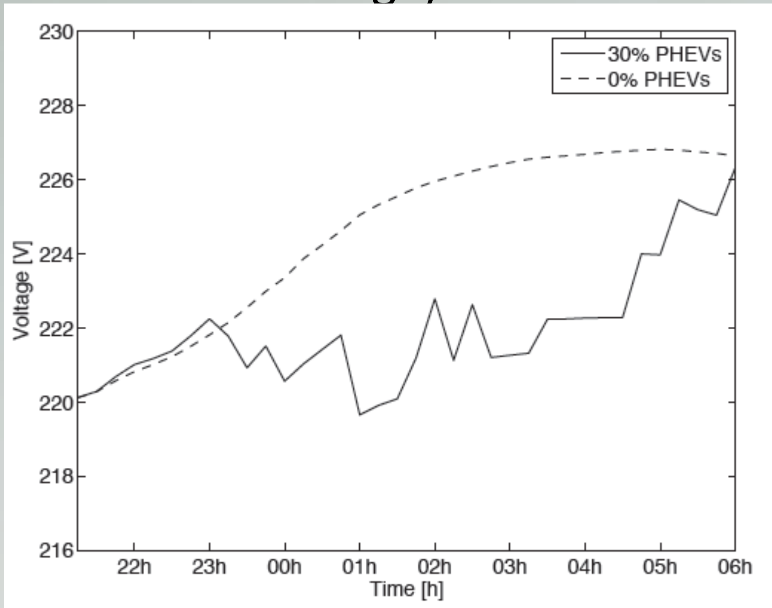
Coordinated charging
Distribution level: losses

- Uncoordinated charging
  - Increased peak: need for new investments
  - Higher load→ higher currents→ higher losses
    - Higher losses→ influence electricity price

	Uncoordinated	Coordinated		
PHEVs [%]		double tariff	voltage deviations	power losses
0	2.2	2.2	2.2	2.2
10	2.4	2.2	2.2	2.2
20	2.7	2.4	2.4	2.2
30	2.9	2.6	2.5	2.3

Coordinated charging
Distribution level: voltage deviations

- Uncoordinated
  - Higher load→ higher currents→ higher voltage deviations: standard EN 50160
    - 230 V ± 10 % for 95 % of time
    - VUF < 2% for 95 % of time (ratio of inverse/forward component of voltage)



	Uncoordinated	Coordinated		
PHEVs [%]		double tariff	voltage deviations	power losses
0	9.9	9.9	9.9	9.9
10	10.4	9.9	9.9	9.9
20	11.4	9.9	9.9	9.9
30	12.3	9.9	9.9	9.9

Spanningsafwijkingen

Coordinated charging

Coordination objective

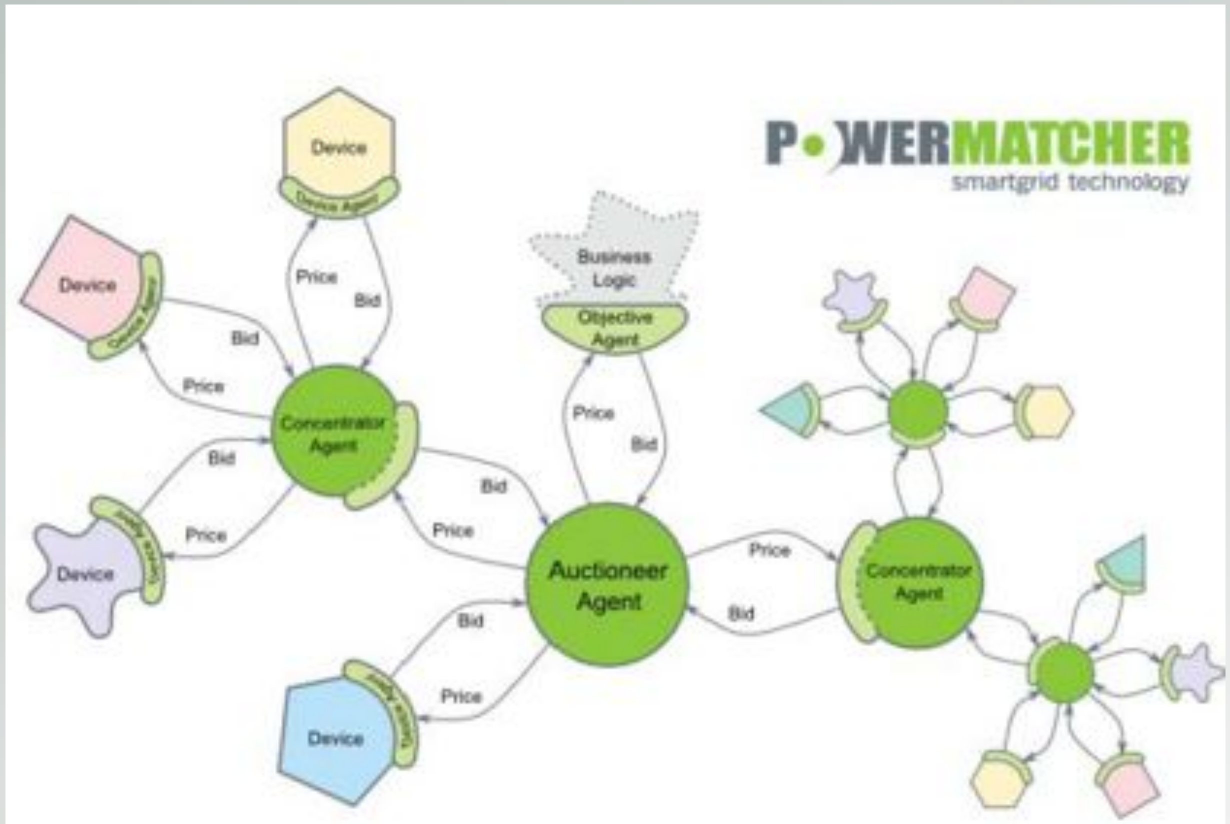
- Grid operators
  - Optimal usage of infrastructure
  - Limiting the losses
  - Limiting voltage deviations

Minimizing investments

- Users
  - Minimizing charging costs
- Combination of objectives for general optimum
- Coördination methods
  - Central
  - Distributed
  - Hiërarchical

Example PowerMatcher

- Distributed multi-agent systeem
  - Matching of demand and supply
  - Bid curves

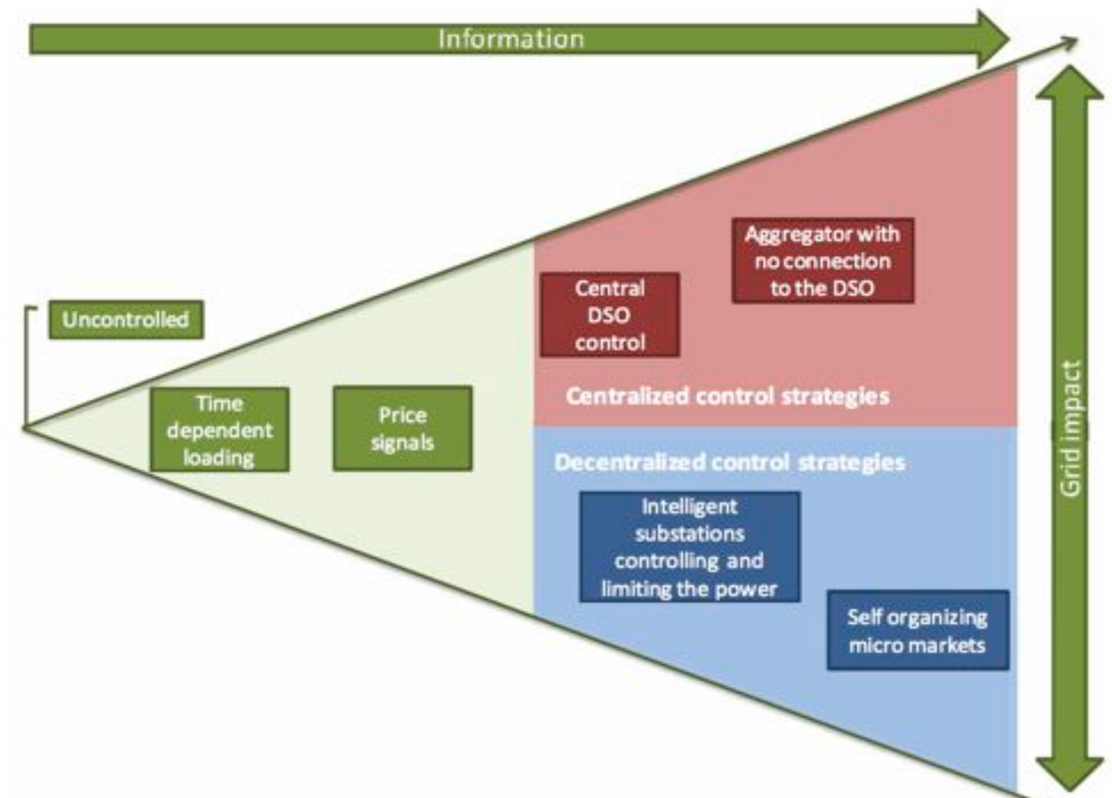


Limiting grid impact

- limit voltage deviations
  - adapt PF, proportional to ΔV
  - difficult when R/X is high
  - droop control
- local balancing
  - coordination – load activation
  - use storage?
- V2G

Controllability

- Charging
  - Delay
  - On/off
  - Continuously variable



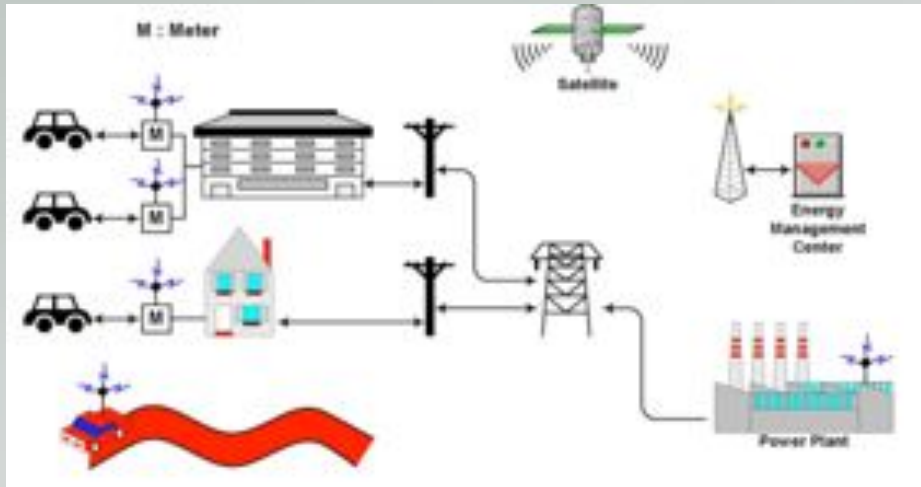
Grid For Vehicles WP1.3 Parameter Manual, 2010.

- Discharging

- Vehicle-to-grid, vehicle-to-home, vehicle-to-building

Vehicle-to-Grid (V2G)

- Vehicle-to-Grid intelligent charging
  - Adaptation of charging power
  - Injecting power into the grid
- Bidirectional power flows
  - Active and reactive
- Limited storage in the grid
  - E.g. pumped storage
  - High flexibility required
  - Increasing amount of intermittend sources
- Potential flexibility of vehicle charging
  - Long standstill times
  - Average short daily driven distance



Electric vehicles availability

- 15 - 50 kWh per vehicle
- > 90 % of the time at standstill
- Large flexibility potential when being plugged in sufficiently
- Grid support
  - Controlled charging
    - Bidirectional / unidirectional / Q?
  - V2G / V2H
- Expensive due to degradation of battery

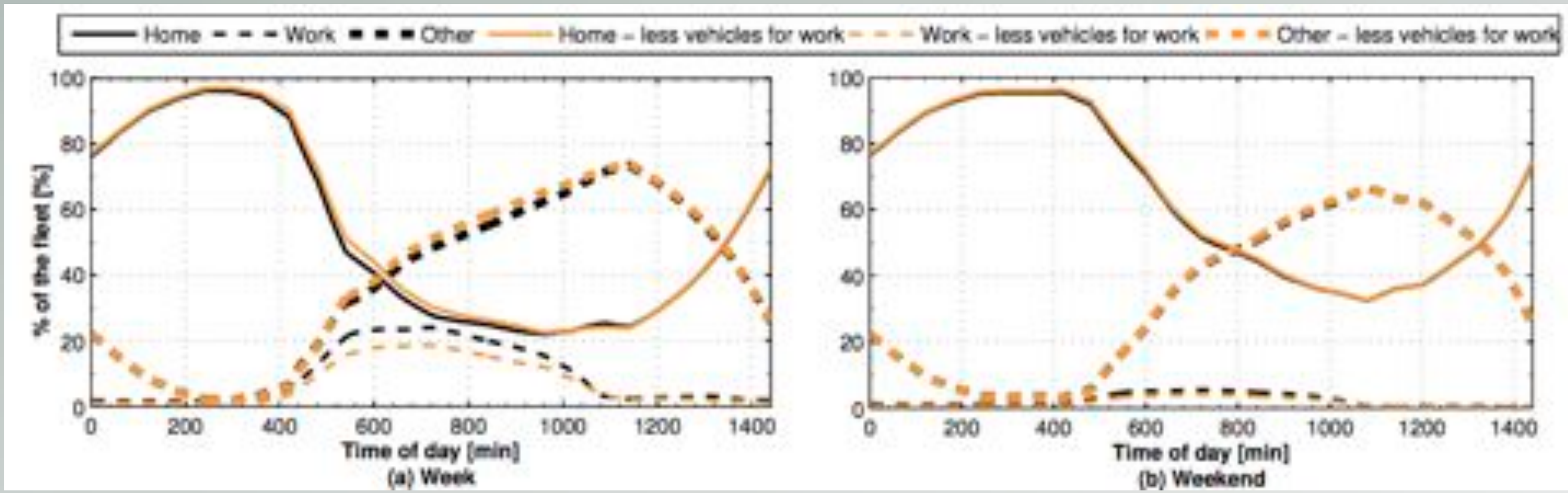
Potential of EV fleet?

Electric utility generation compared with the light vehicle fleet (for the US)

Metric	Electric generation system	Current light vehicle fleet (mechanical power)	Hypothetical fleet with 25% EDVs
Number of units	9351[a]	176,000,000[f]	44,000,000
Average unit power (kW)	64,000	111[g]	15[k]
Total system power (GW)	602[b]	19,500[h]	660
In-use	57%[c]	4%[i]	4%
Response time (off to full power)	Minutes to hours[d]	Seconds	Milliseconds to seconds[l]
Design lifetime (h)	80,000–200,000[e]	3000	>3000
Capital cost (per kW)	US$ 1000+	US$ 60[j]	US$ 10–200[m]
Cost of electricity (US$/kWh)	.02–.09 average, .05–.80 peak[e]	n.a.	.05–.50[n]

W. Kempton and J. Tomic, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, Journal of Power Sources, vol. 144, no. 1, pp. 280-294, Jun. 2005.

Vehicles at home



J. Van Roy, N. Leemput, S. De Breucker, F. Geth, P. Tant, and J. Driesen, An Availability Analysis and Energy Consumption Model for a Flemish Fleet of Electric Vehicles, in European Electric Vehicle Congress (EEVC), 2011, pp. 1-12.

V2G pros and cons

- Pro
  - Delivering grid support in peak situations
  - Increasing amount of renewables to be integrated in the grid
  - Could be activated very fast: power electronic interface
  - Large fleet of EVs= large power and energy buffer
- Con
  - Battery wear?
  - Total cost
  - Needs substantial coordination

V2G potential?

- Tesla Roadster
  - 53 kWh
  - 393 km range
  - Battery cost 40 000 $ = 30 000 EUR
- Warranty
  - 7 year
  - 160 000 km

160 000 km / 400 km
= 400 cycles
30 000 EUR / 400 cycles
= 75 EUR / cycle

53 kWh	⇔	75 EUR
1 kWh	⇔	1.41 EUR

53 kWh x 0.230 EUR/kV
= 12.2 EUR / cycle

Grid impact

Conclusions

- EVs will significantly impact of the power system
  - Energy production
  - Grid load
- Uncoordinated charging will increase peak power demand
- Potential for coordinated charging
  - Shifting charging to off-peak moments
  - Flexibility within the mobility objective
- Challenges first on the local level
  - High local penetration grade
  - Highly stochastic behavior
  - Grid constraints on the LV grid

Thank you!