Operation of electric buses in public transportation

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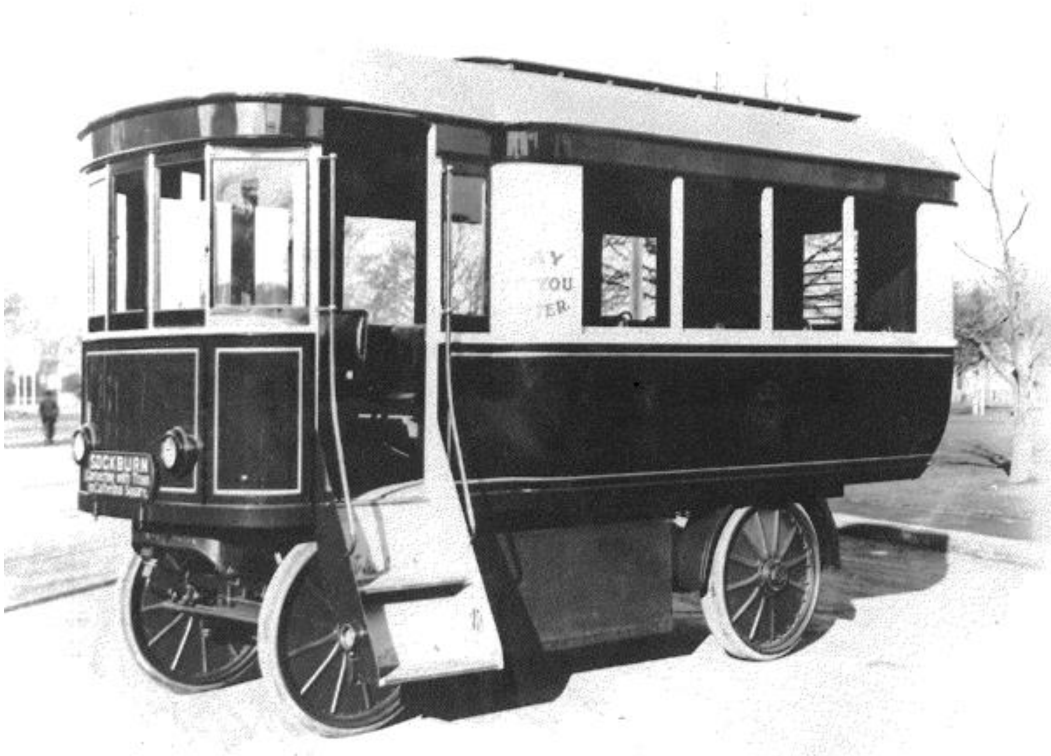
2. Characteristic of mobility services
3. Practices and trend - international
4. Experiences in Hungary
5. Characteristic of charging technology and charging infrastructure
6. Specificities of operation
7. Environmental effects

1. Specification of electric buses



1918

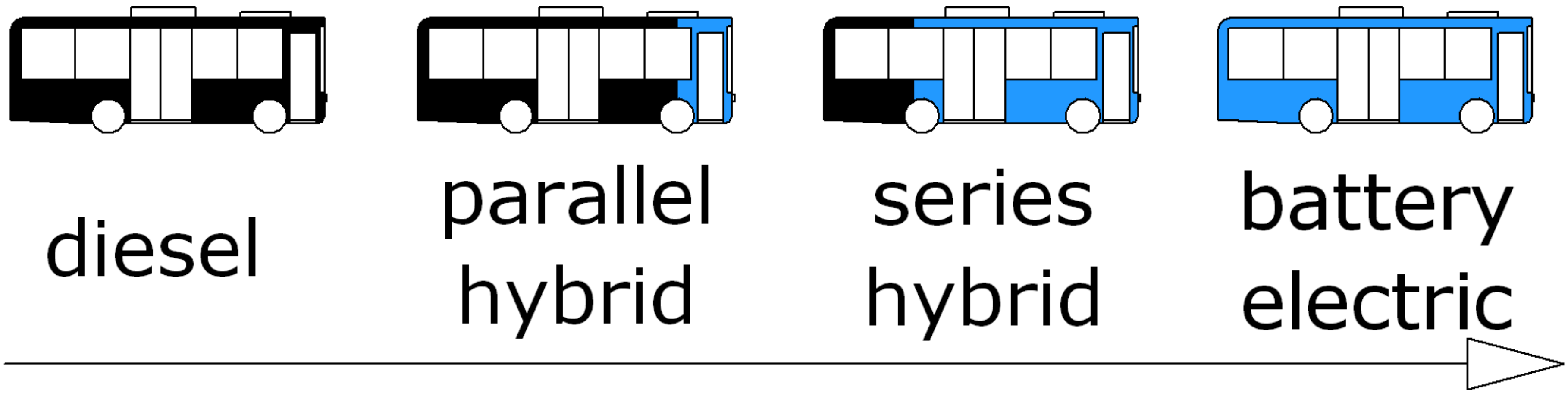
Electric bus in USA

1. Specification of electric buses

16th december 1933.

Vörösvári út – Óbudai temető

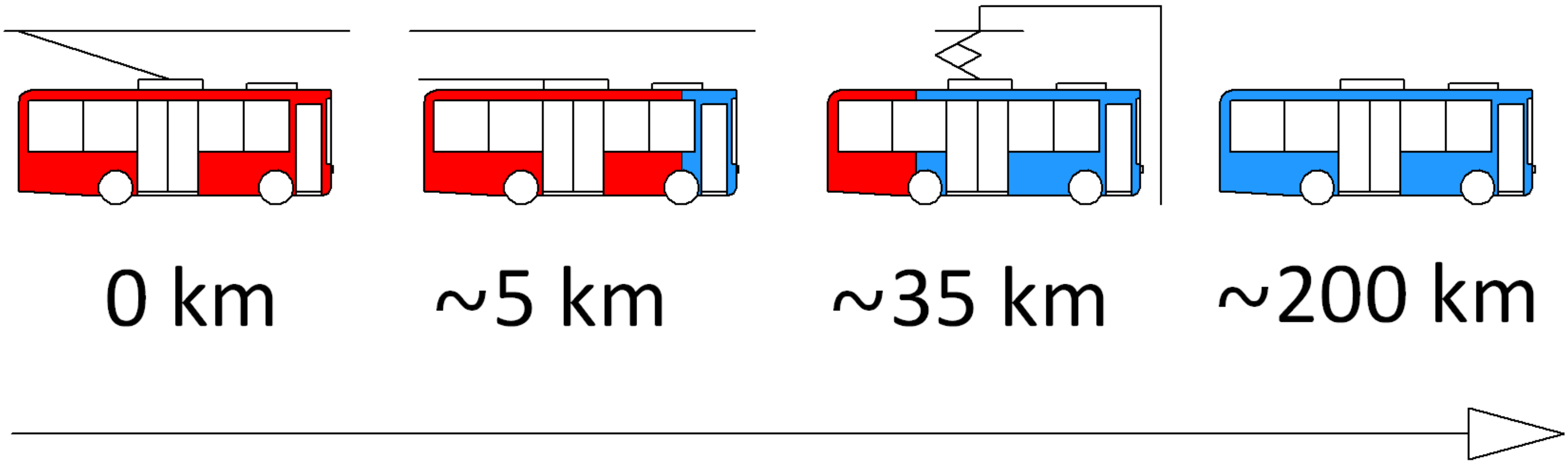
1. Specification of electric buses



ENERGY EFFICIENCY

The increasing rate of the electric drive in the drivetrain system raise the energy efficiency as well as the necessary battery capacity

1. Specification of electric buses



ELECTRIC RANGE

Different models provide a continuous transition between trolley and electric buses

1. Specification of electric buses

Own energy source: the energy is stored in an onboard unit

External energy source: the vehicle gets the energy from an external source in movement, e.g. (pl. trolley)

Energy storage units:

- Battery
- Capacitor
- Hydrogen (fuel-cell)

✓ Low operation costs
✓ High efficiency
✗ High purchase price
✗ Lack of charging infrastructure/ long charging time
✗ Lower availability of vehicles because of the novelty of the technology

1. Specification of electric buses

BYD K9

Battery capacity: 324 kWh; range: 250 km; maximum number of passengers: 59

1. Specification of electric buses

Skoda PERUN HE

Battery capacity: appr. 220 kWh; range: 150 km;

Maximum number of passengers: 82

1. Specification of electric buses

Siemens Rampini Alé El

Battery capacity: 96 kWh; range: 60 km;

Maximum number of passengers: 46

1. Specification of electric buses

Solaris Urbino 18 electric articulated city bus
Battery capacity: 120kWh; range: kb. 100 km;
pantograph is optional

1. Specification of electric buses

BYD C10 coach bus

Range: 321 km; maximum number of seats: 57+1; maximum charging power: 300kW

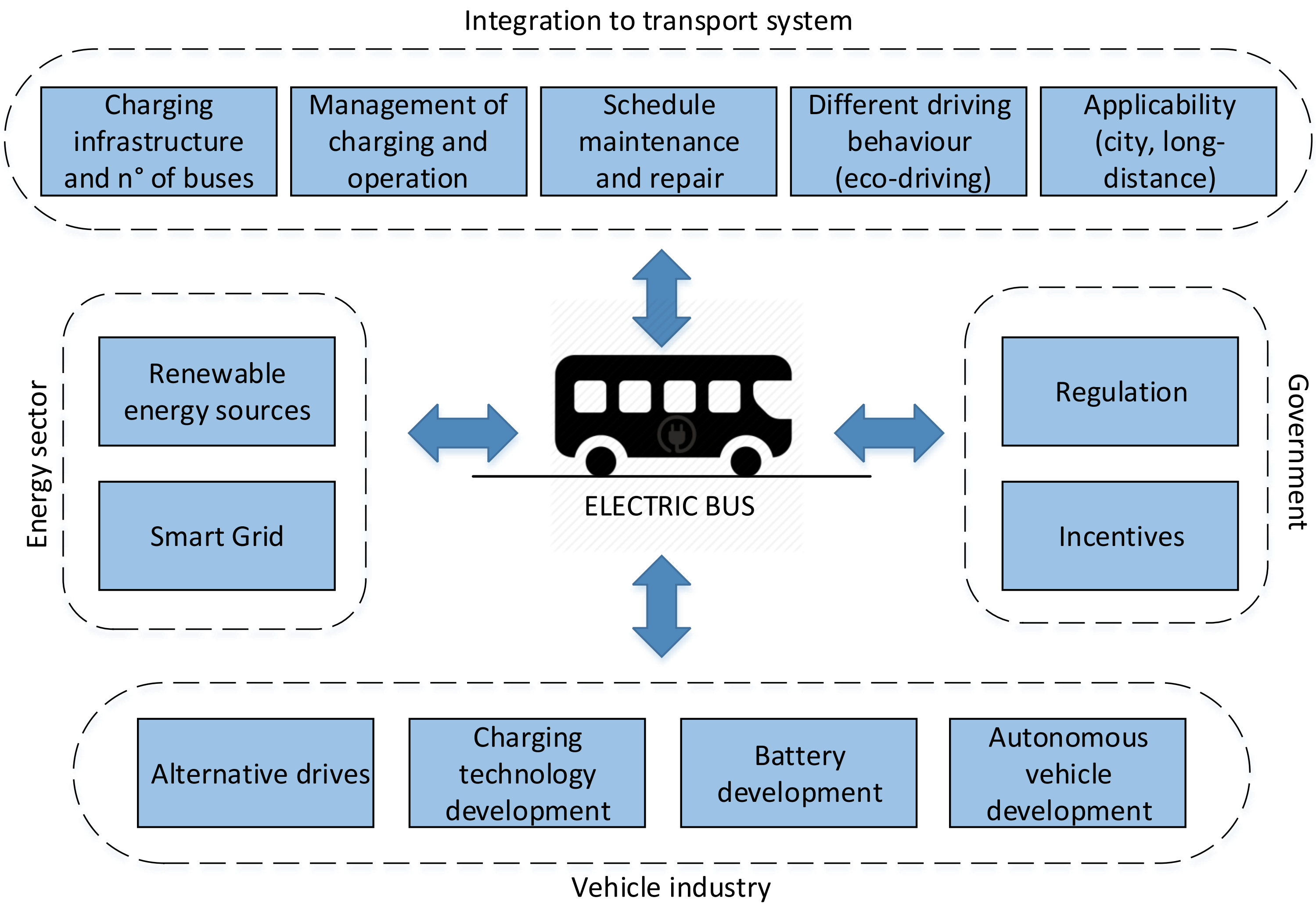
1. Specification of electric buses

Diesel-electric series-hybrid, with OppCharge system (short charging periods at high charging power: 3-4 minutes and up to 450kW)

1. Specification of electric buses

	Bus	Car
Battery capacity	90-300kWh	20-50kWh (Tesla 90kWh)
Range	60-250 km	100-200 (Tesla 400 km)
Energy consumption	1-1,5 kWh/km	0,15-0,2 kWh/km
Charging power	Up to 300kW	Up to 60 kW (Tesla 150 kW)

2. Characteristic of mobility services



2. Characteristic of mobility services

Beneficial in cities because

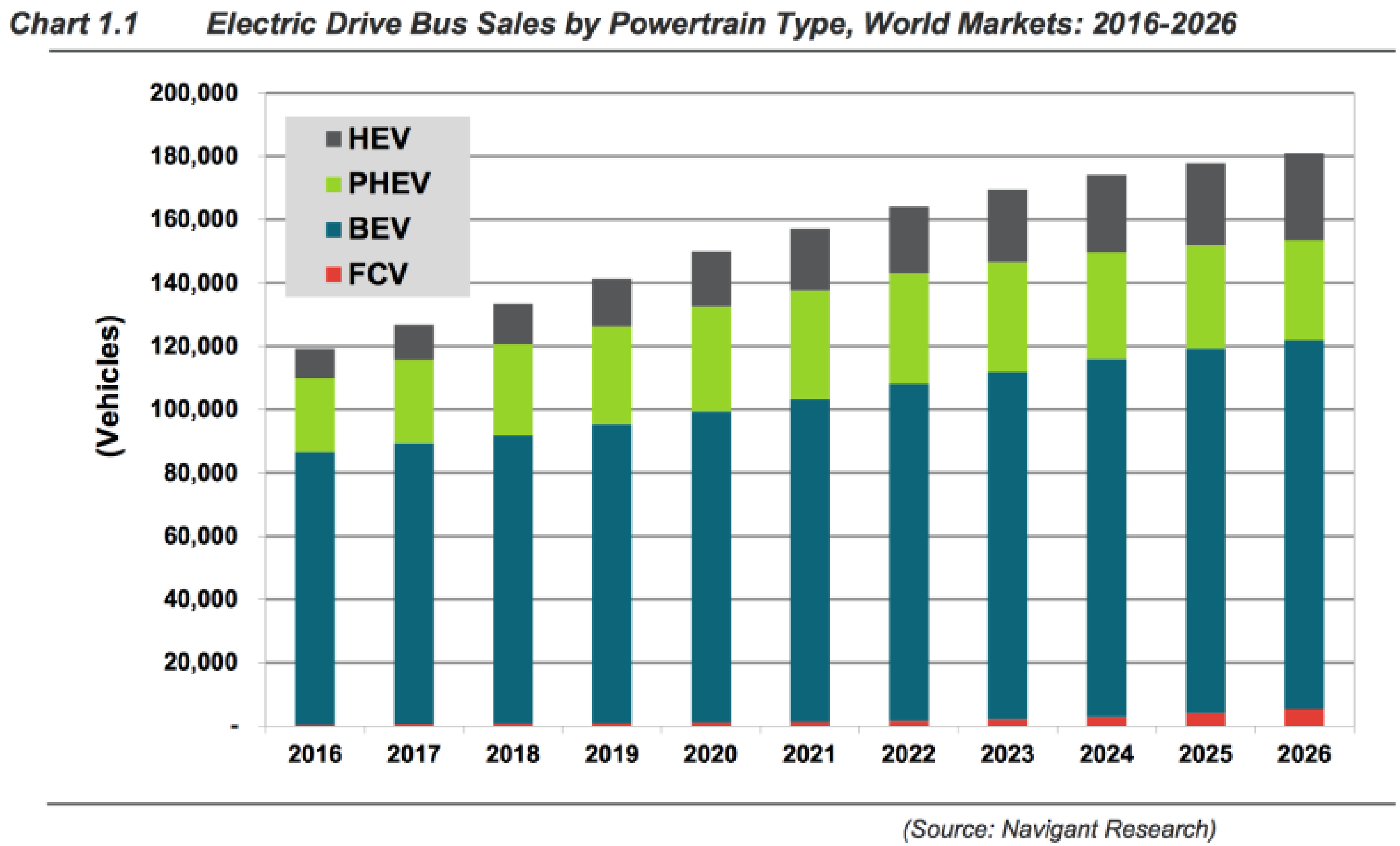
- Low speed – high energy efficiency
- Frequent stops – recuperation, on site charging
- Low local emission (pollutant, noise)
- Importance of emission increases in high density areas
- Highland operation – recuperation during downhill

Long-distance trips

- Not typical (battery capacity range, charging time)

More comfortable to passengers because electric drive makes less noise, bot no essential differencies in the service

3. Practices and trend - international



The rate of battery electric buses is dominant

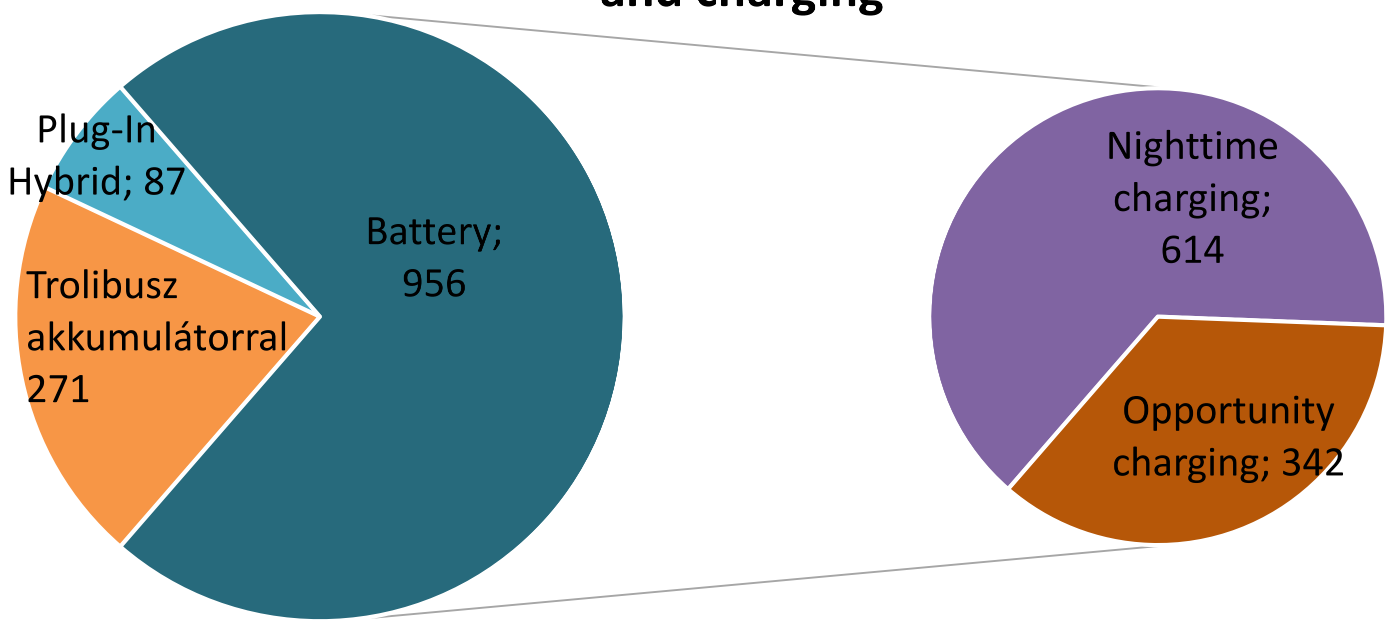
3. Practices and trend - international

2015: 170 000 electric buses out of 173 000 operate in China

The leading countries provide subsidies to support the spread of electric buses

Europe: United Kingdom, Netherland, Switzerland, Polland, Germany

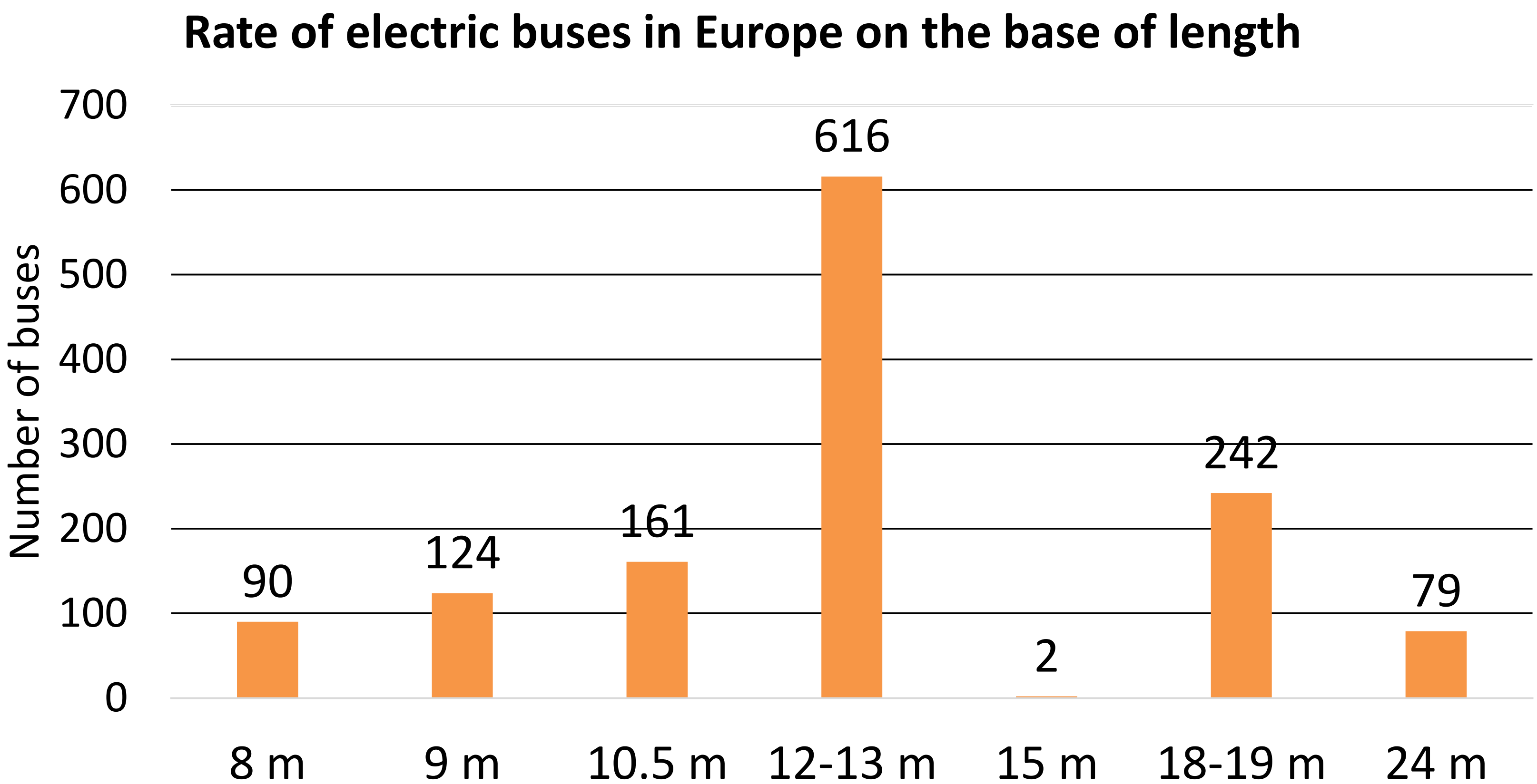
Rates of (partially) battery electric buses in Europe on the base of drivetrain and charging



The rate of battery electric buses is dominant

Source: ZeEUS eBus Report, 2017

3. Practices and trend - international



Operators prefer the electric buses between 12 and 13 meters

Source: ZeEUS eBus Report, 2017

4. Experiences in Hungary

Budapest
20 evopro battery electric bus,
charging: at depot

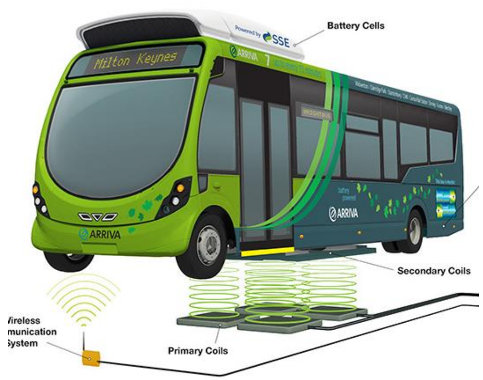
Szeged
13 Ikarus-Skoda battery trolleybus,
charging: overhead line or charging point

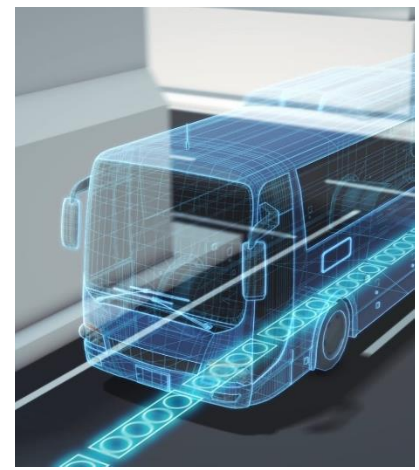
Komárom: BYD opened an electric bus factory in April 2017, the first two buses made in Komárom were ready by September

5. Characteristic of charging infrastructure and charging technology

Point — Wired, Wireless

Line — Wired, Wireless

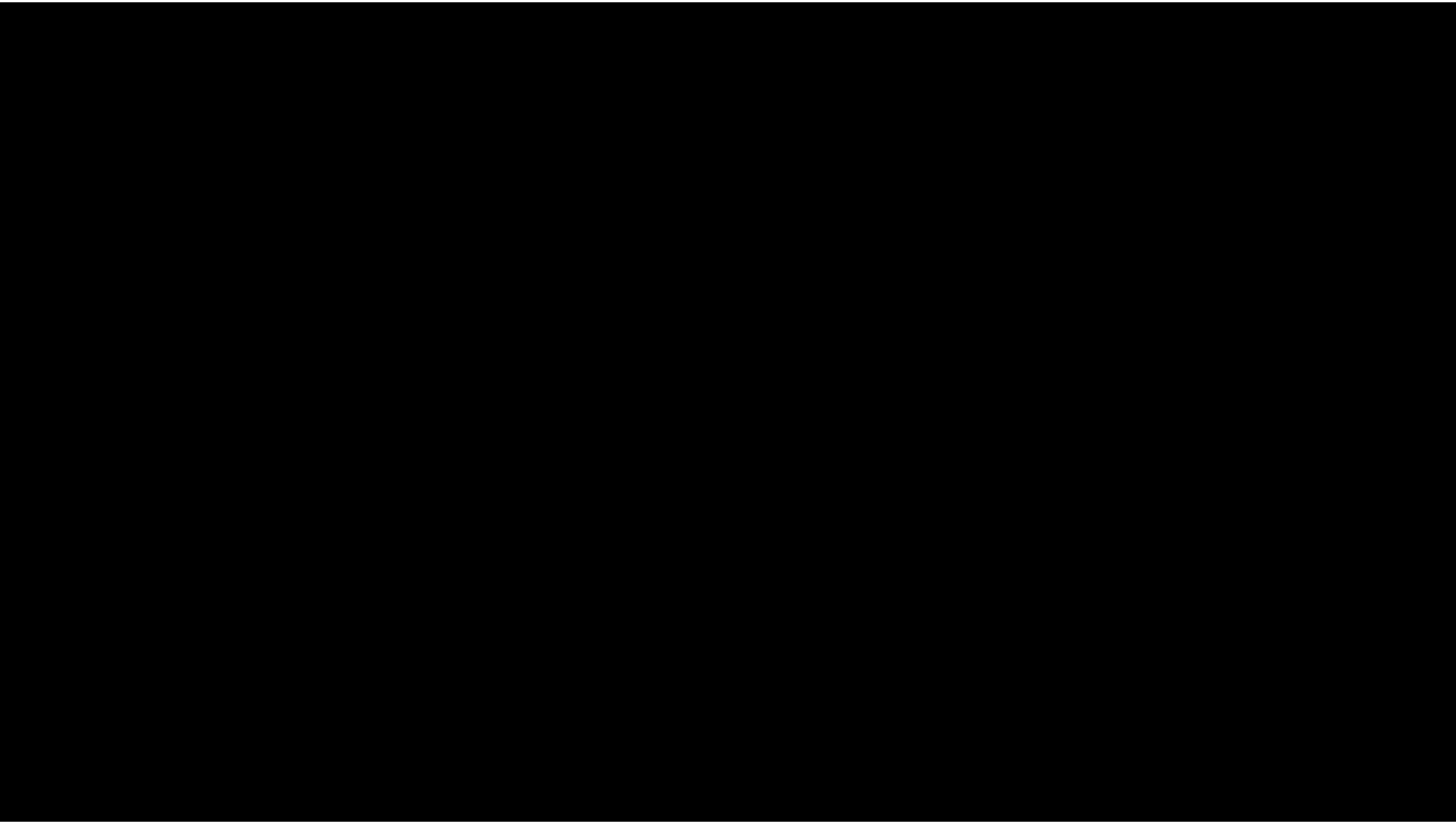




Charging power: **wired:** 450kW, **wireless:** 200 kW.

Efficiency rate of wireless charging at a standstill is up to 95%, now appr. 85%.

5. Characteristic of charging infrastructure and charging technology



5. Characteristic of charging infrastructure and charging technology

5. Characteristic of charging infrastructure and charging technology

Planning charging infrastructure:
optimization considering the local characteristic

Nighttime charging at depot	Nighttime charging at depot and complementary opportunity charging
✓ Charging locations are given	✓ Small battery capacity in buses
✓ No need for special chargers	✓ Decentralized cahrging capacity
✗ Vast battery capacity in buses	✓ Greater availability of buses
✗ Daytime charging is loss	✗ Expensive chargers
✗ Centralized charging capacity	✗ Locations?

6. Specificities of operation

<table>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>✓ Lower operation costs (maintenance, fuel)</td><td>✗ High purchase price</td></tr>
<tr><td>✓ Reliable and robust technology</td><td rowspan="2">✗ Application of electric drivetrain in buses is novel (service and maintenance take longer)</td></tr>
<tr><td rowspan="2">✓ Greater availability</td></tr>
<tr><td>✗ Lack of experiences</td></tr>
<tr><td>✓ Recuperation</td><td>✗ Daily availability of electric buses is lower (limited range, long charging time)</td></tr>
<tr><td>✓ Better dynamic</td><td>✗ Empty running because of charging</td></tr>
<tr><td>✓ Easy-to-drive</td><td>✗ Planning of turns is complicated</td></tr>
<tr><td>✓ Low local emission (noise and pollutant)</td><td>✗ Global emission (fossil fuels)</td></tr>
</table>

6. Specificities of operation

Planning - Turns

- More complicated, the influencing parameters:
  - Static parameters
    - Type of charging, range
    - Characteristic of bus line: ground level difference, road network, distance between stops
  - Dynamic parameters
    - Weather (temperature, snow)
    - Traffic (congestions)
    - Volume of passenger flow (load)
    - Driving behaviour
- Planning of daytime cahrging and location

1 electric bus can not replace 1 diesel bus

6. Specificities of operation

Planning - charging

- Determination of charging power and connector
- Determination of number of charging points at the depot (function of the number of buses)
- Planning of daytime charging: opportunity charging, charging time planning

<u>Diesel buses</u>

- At the depot (or gas station)
- Separate staff to fill the bus
- Few pumps at each depot

  serial service
- Duration: few minutes

<u>Electric buses</u>

- At the depot (or charging station)
  + final station, stops
- driver (staff)
- Many charging points at each depot

  parallel service
- Duration:
  - At the depot: several hours
  - At stops: few minutes
  - At final stations: 20-30 minutes

6. Specificities of operation

Operation – maintenance/repair

- ✓ Robust technology, less part and more durable
- ✓ No need for motor oil, durable brakes

- ✗ Novel use of electric powertrain in electric buses
  probably more failure, and more complicated service because
- ✗ Lack of experience and skilled maintenance staff
- ✗ The importance of electricians arise in maintenance

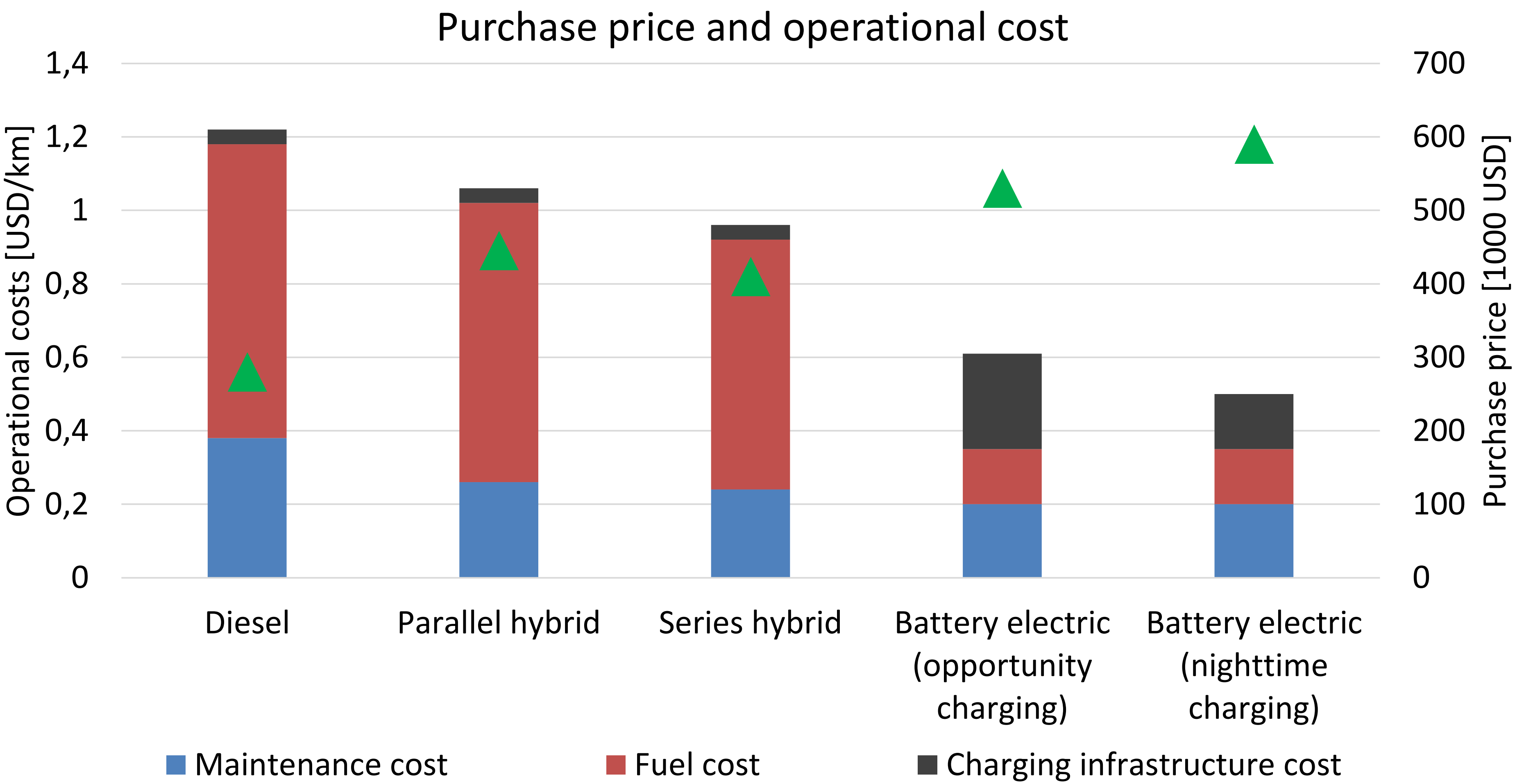
Hangzoo, China[1]:

- Availability compared to conventional buses: 70%
- 1,4 electric bus can replace 1 diesel bus

Huge fleet → experience → better maintenance → greater availability

[1] Source: Real World Performance of Hybrid and Electric Buses, REPIC Final Report, Grütter Consulting AG, 2015

6. Specificities of operation



Higher purchase price, lower operation

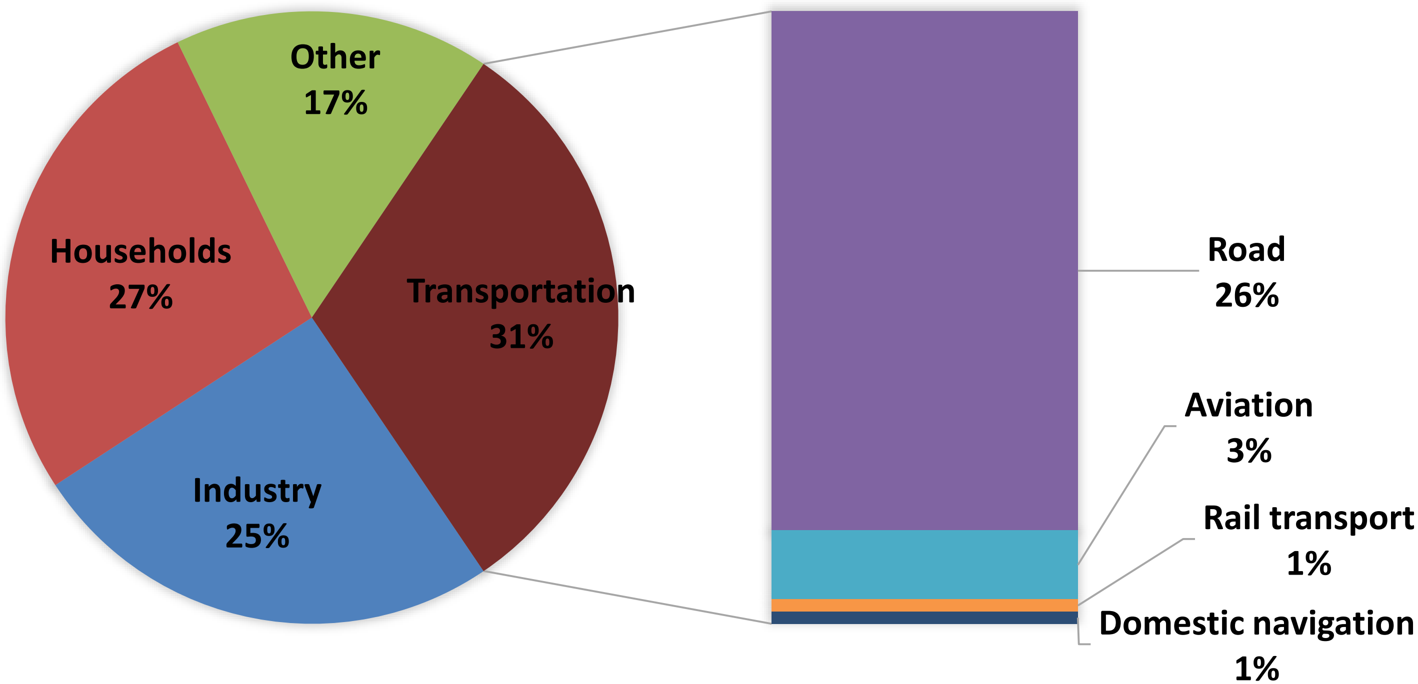
Payback time: 9-10 years

Source: Mahmoud M., Garntt, R., Ferguson, M., Kanaroglou, P. (2017) Electric buses: A review of alternative powertrains. Renewable and Sustainable Energy Reviews, 62, 673-684.

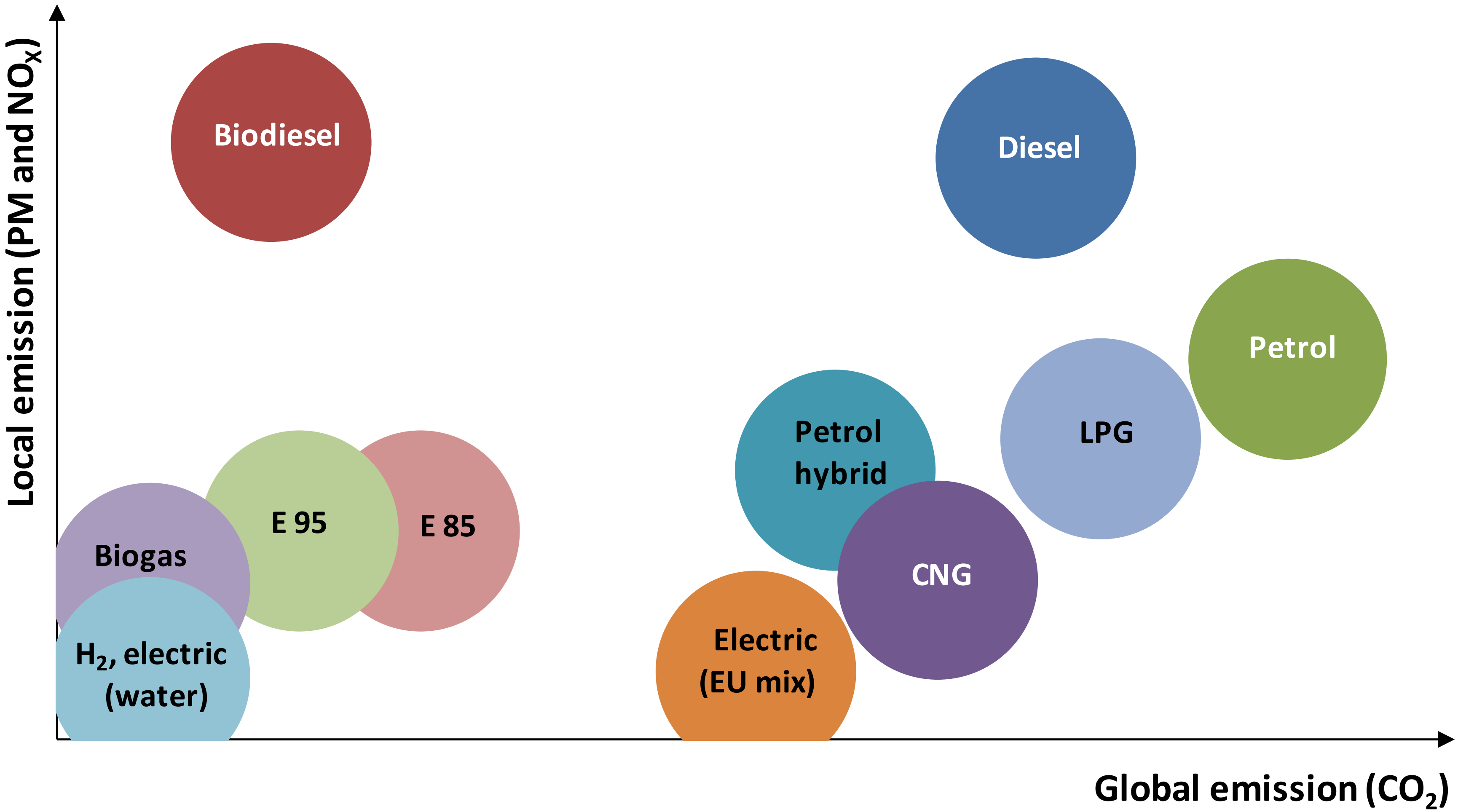
7. Environmental effects

- Limited oil resources, energy dependency: 90% of oil is imported in EU
- Global and local effect of environmental pollution
- 2030: reduce CO_2 emission by 40% in comparison to 1990
- 2050: reduce CO_2 emission by 60% in comparison to 1990

Energy consumption of sectors EU28, 2013 (EUROSTAT)



7. Environmental effects



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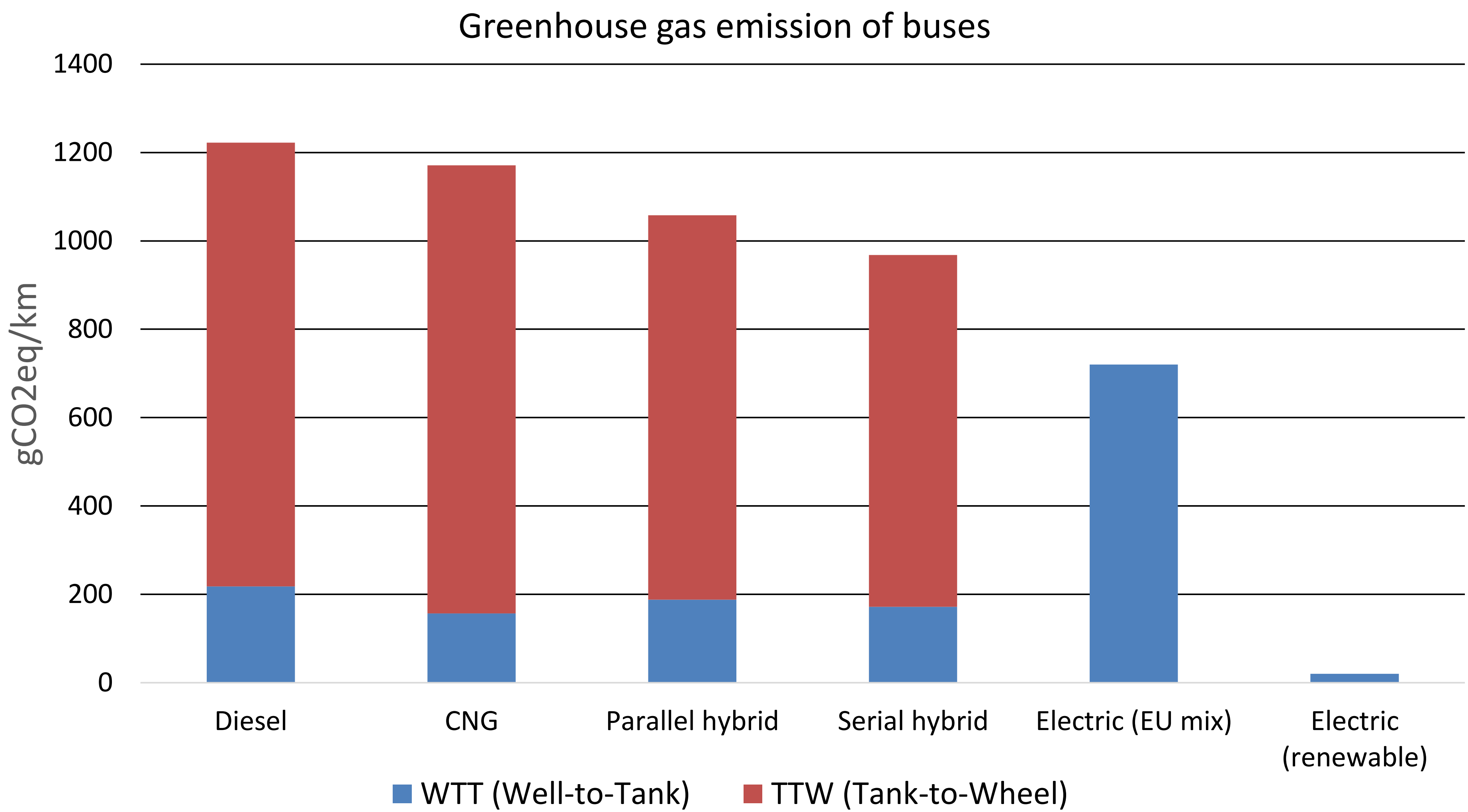


Renewable energy sources → clean operation

Sources: Mahmoud M., Garntt, R., Ferguson, M., Kanaroglou, P. (2017) Electric buses: A review of alternative powertrains. Renewable and Sustainable Energy Reviews, 62, 673-684.

Hydrogen and fuel-cell technology in transport

Basic definitions

Hydrogen:

Colourless, non-toxic gas, wide flammability range, density: 0,09g/L. It is energy carrier, not energy source.

Steam reforming process:

Method for producing hydrogen from hydrocarbon fuels such as natural gas.

Electrolysis of hydrogen:

A technique that uses direct electric to decompose water to hydrogen and oxygen.

Fuel Cell:

Electrochemical device that converts chemical energy to electric energy.

Fuel Cell Hybrid Electric Vehicle (FCHEV):

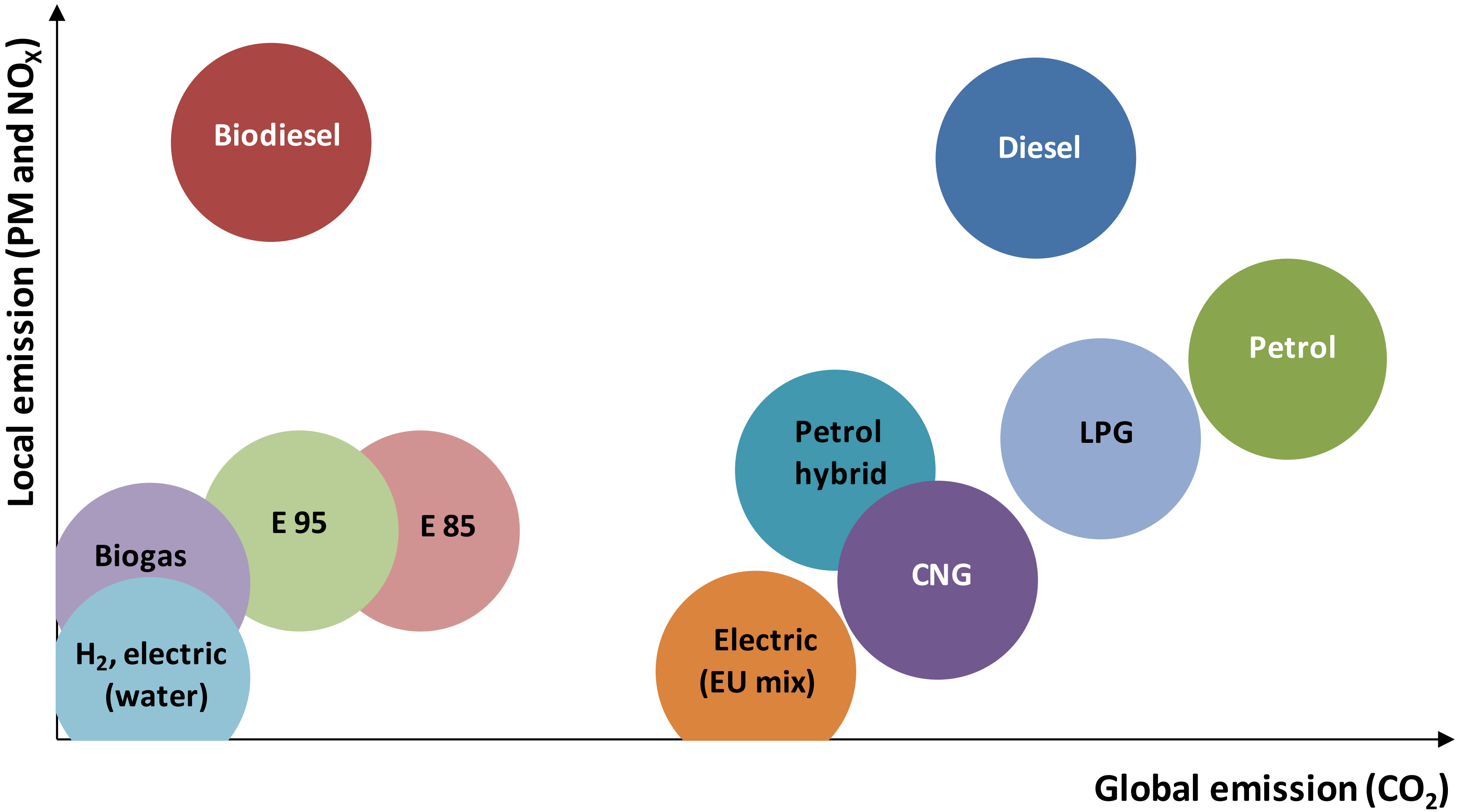
A type of electric vehicle which uses a fuel cell to power the on-board electric motor. The vehicle is also equipped with a battery.

Hydrogen vehicles with internal combustion engines (H_2ICE):

Vehicles that use hydrogen in internal combustion engines. The engine also should run on petrol.

1806: First internal combustion engine – powered by mix of oxygen and hydrogen

Local and global effects of alternative fuels in transport



Characteristic of hydrogen

Pro

- High energy content on a weight basis (33 kWh/kg) compared to petrol (11kWh/kg)
- Variety of methods to produce hydrogen
- Variety of methods to produce energy from hydrogen
- High efficiency of use
- Zero local emission

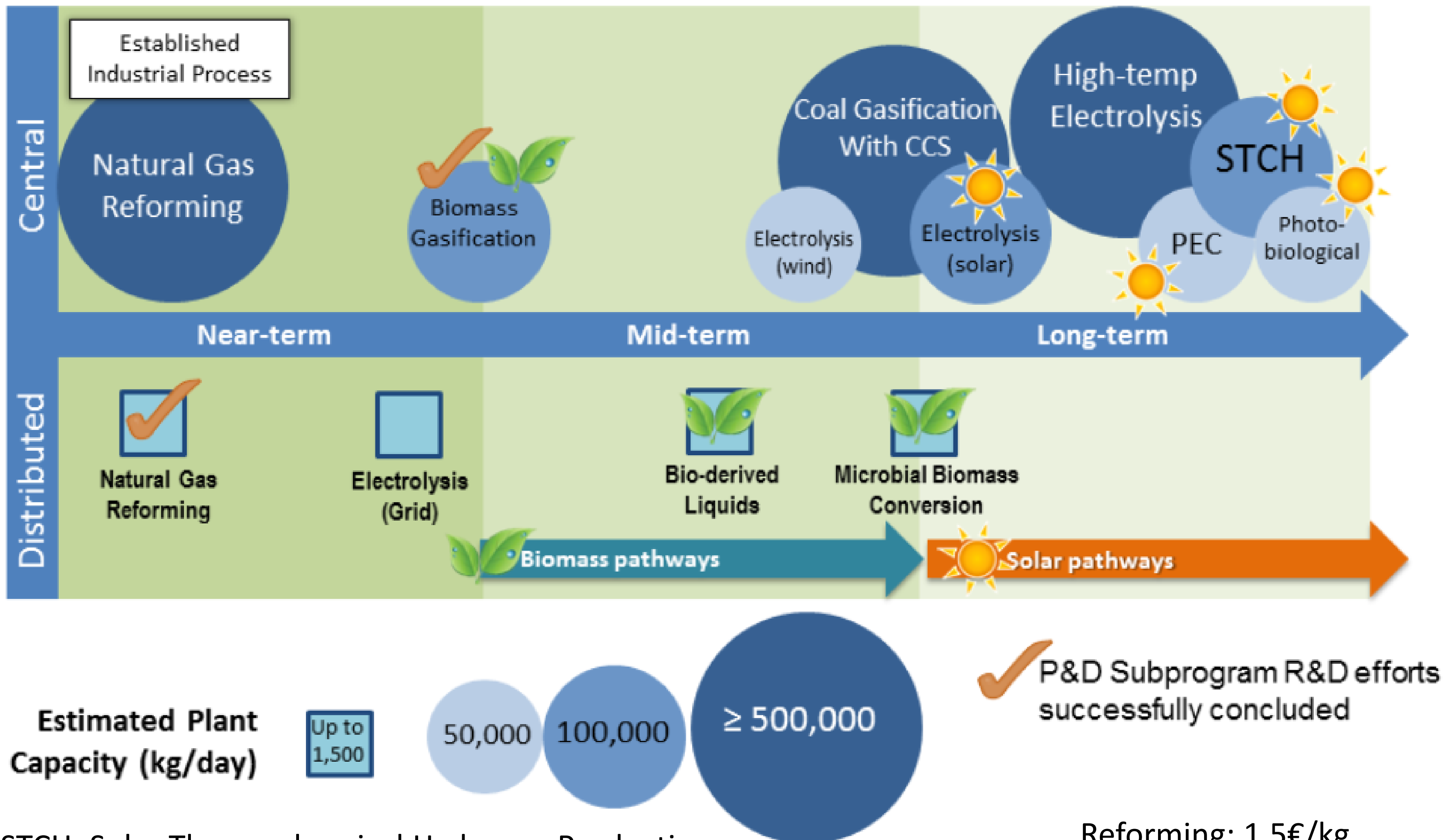
Only fuel-cell vehicles:

- Simplicity of powertrain, easy to maintenance (no transmission, no oil)
- Possible support of Smart Grid systems

Con

- Electrolisys is expensive
- Energy content on a volume basis is low 1kWh/l (700 bar!) compared to petrol (9kWh/l)
- On-board vehicle storage
- Distribution (lack of hydrogen network)

Hydrogen production

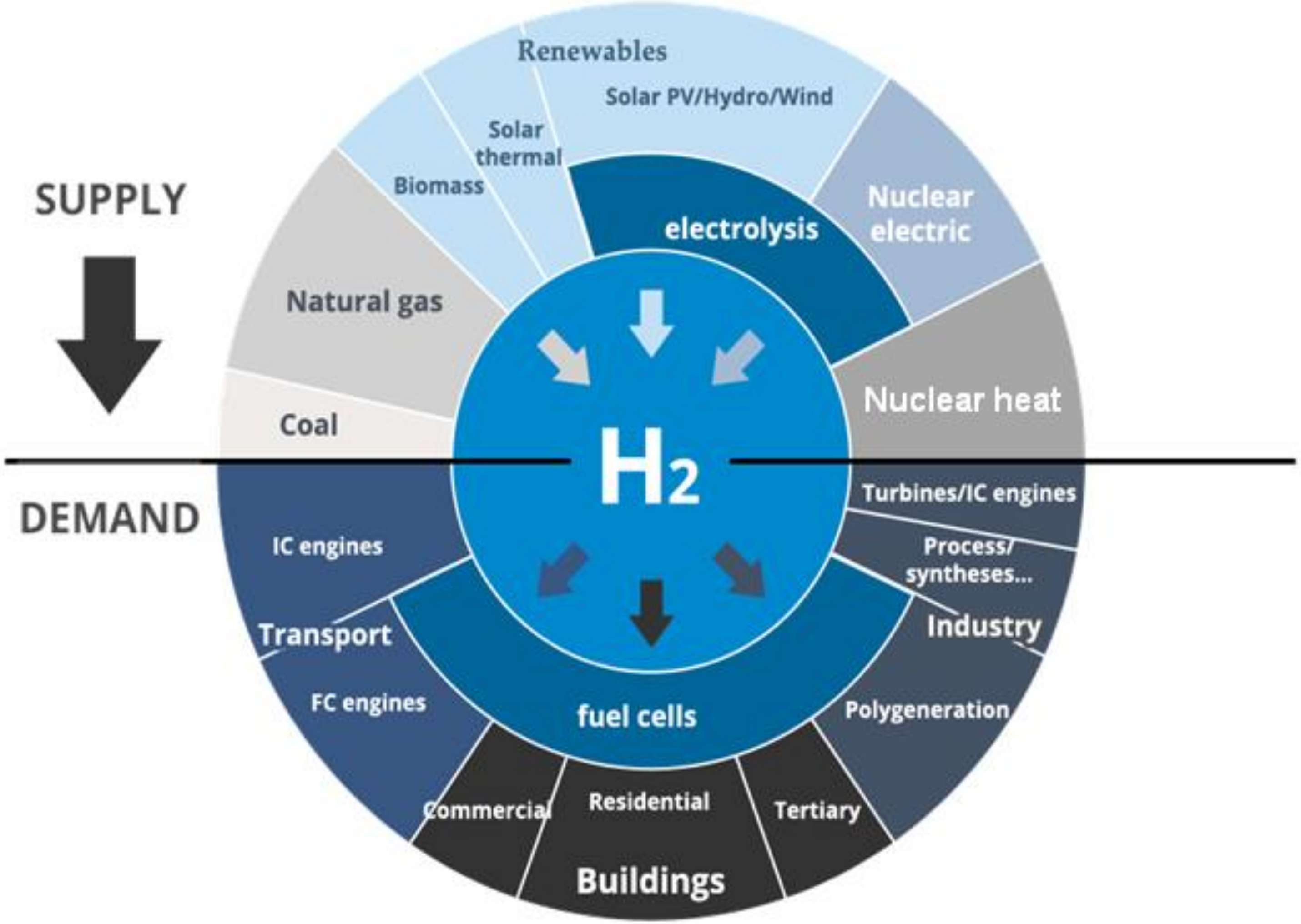


STCH: Solar Thermochemical Hydrogen Production
PEC: Photoelectrochemical water splitting

Reforming: 1,5€/kg
Electrolysis: 4€/kg

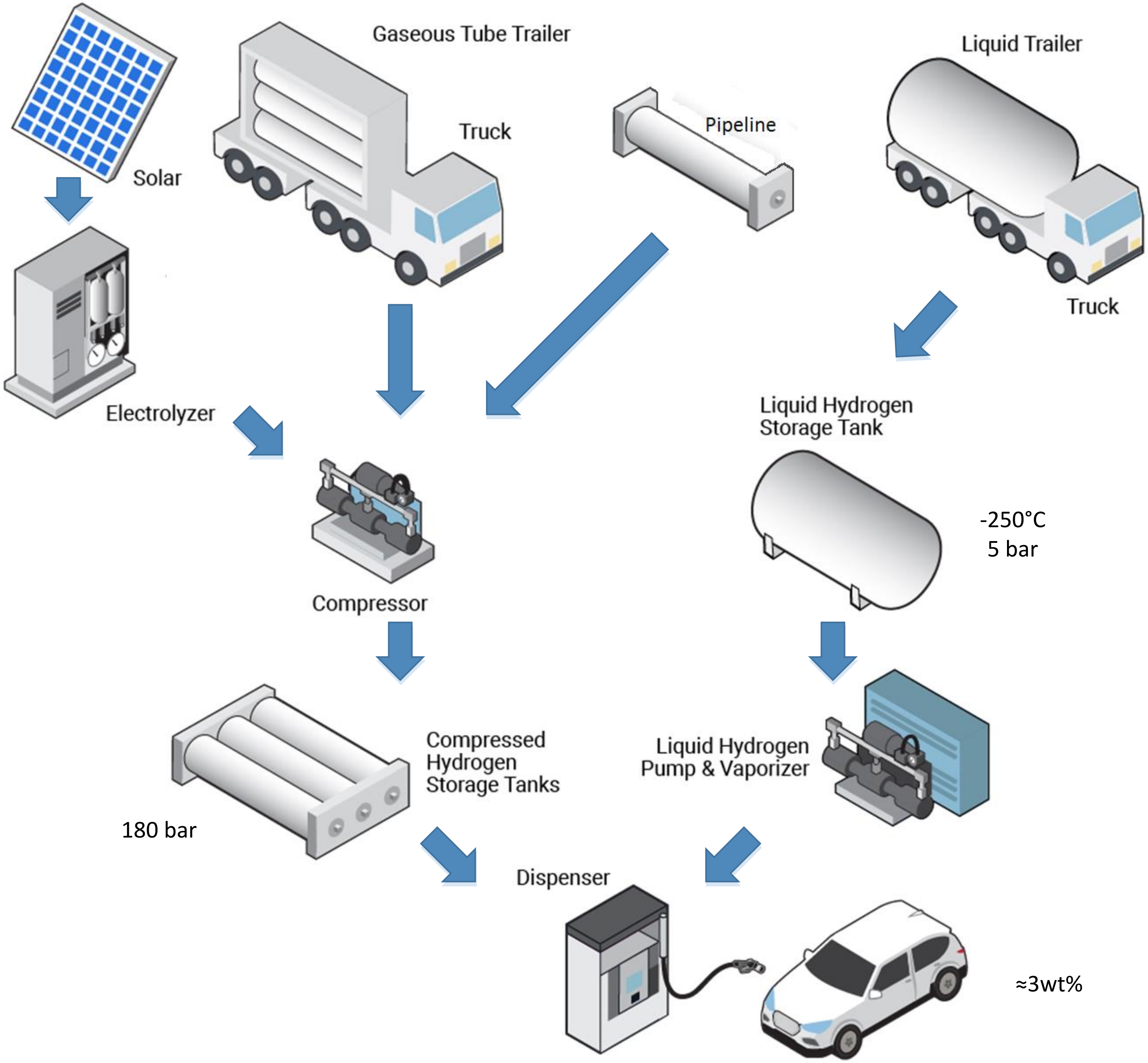
Source: www.energy.gov

Hydrogen supply and demand



Wide range of demand – not just transportation related use
Hydrogen network instead of actual gas network?

Distributed production and hydrogen delivery



Distributed production:

- 120kg/day
- 3,2M $

Delivered as gas:

- 180kg/day
- 2M $
- 180 bar

Delivered as liquid:

- 350kg/day
- 2,8M $
- Requires energy to store H_2 as liquid (30% of energy content of H_2)

Dispensing to vehicles

- Protocols for filling and pressures: SAE J2601
- Lack of component standardization
- Dispensing time: ≈5 minutes

On-board storage

- Cars: 700 bar
- Buses: 350 bar
- Aim: 6,5wt% in commercial use

Novel carriers:

- Solid state hydrogen fuel storage
- Absorption in the interstices of metals and metallic alloys (Mg-based hydrides are promising: 7,5wt%)
- Adsorption on high surface area materials such as activated carbons

Fuel cells

Parts:

- Polymer electrolyte membrane
- Catalyst layers
- Gas diffusion layers

Aims:

- Reduce cost (platinum)
- Performance
- Durability

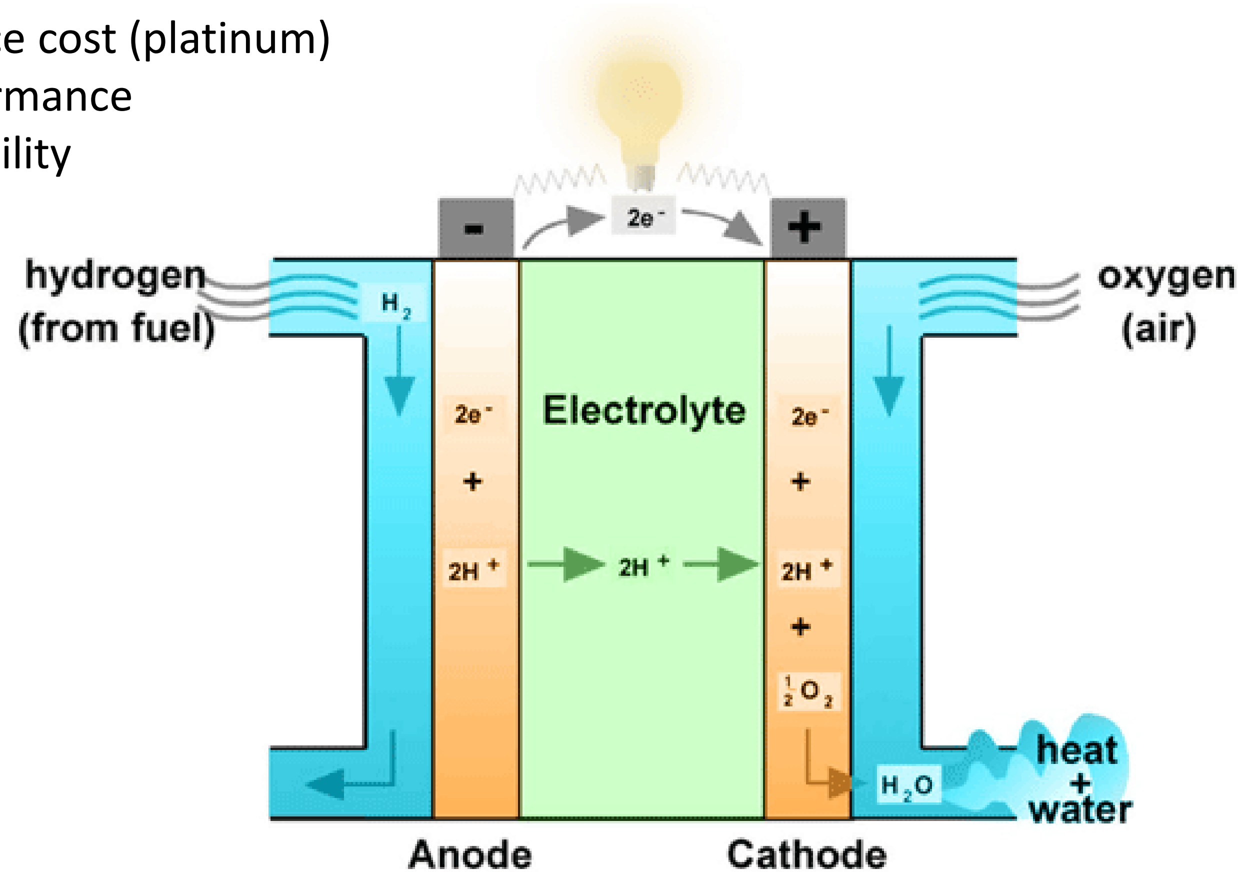
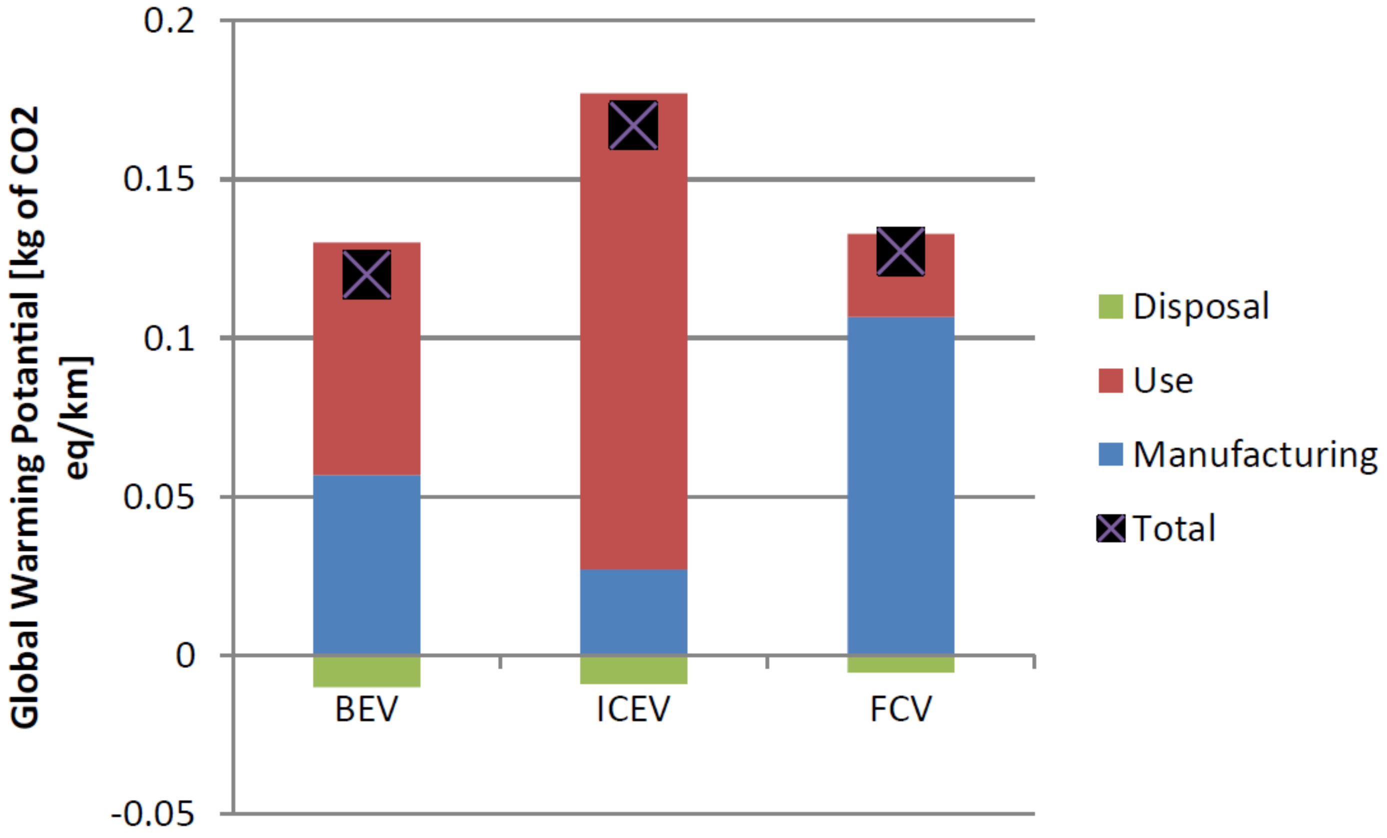


Fig. 2. Schematic of a PEM fuel cell operation. Source: World Fuel Cell Council.

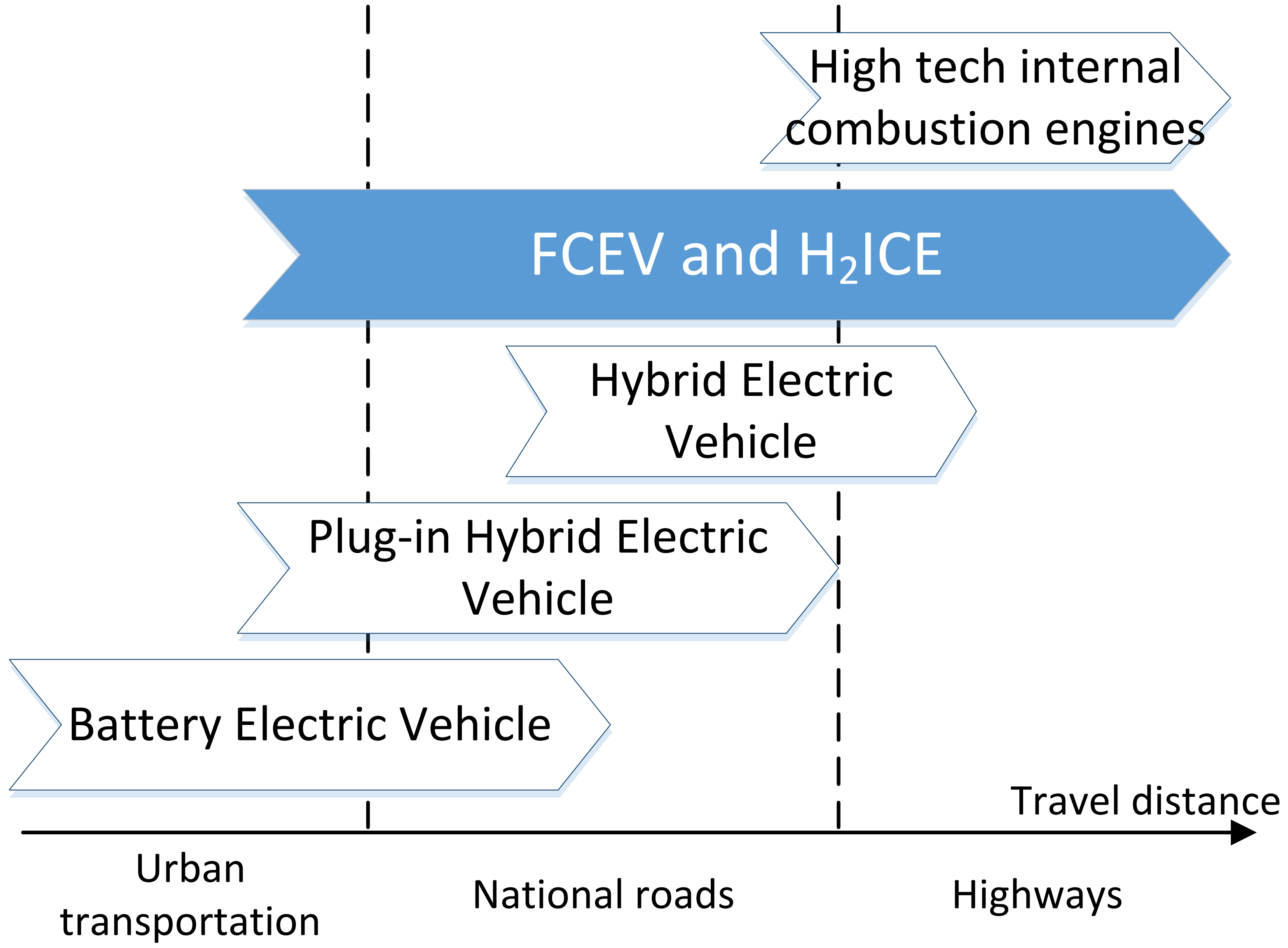
Environmental effects

- FCHEV: decrease in energy consumption and green house gas emission compared to petrol and natural gas. CO_2 emissions can be 75% less than the equivalent diesel vehicle in 2030.
- H_2ICE: increase in both, however by 2045 the energy consumption of a H_2ICE is almost the same as the consumption of FCHEV.



Source: Sara Evangelisti, Carla Tagliaferri, Dan J.L. Brett, Paola Lettieri (2017): Life cycle assessment of a polymer electrolyte membrane fuel cell system for passenger vehicles. Journal of Cleaner Production. 147: 4339-4355.

Fields of alternative propulsions



Hydrogen vehicles in use

Fuel cell buses

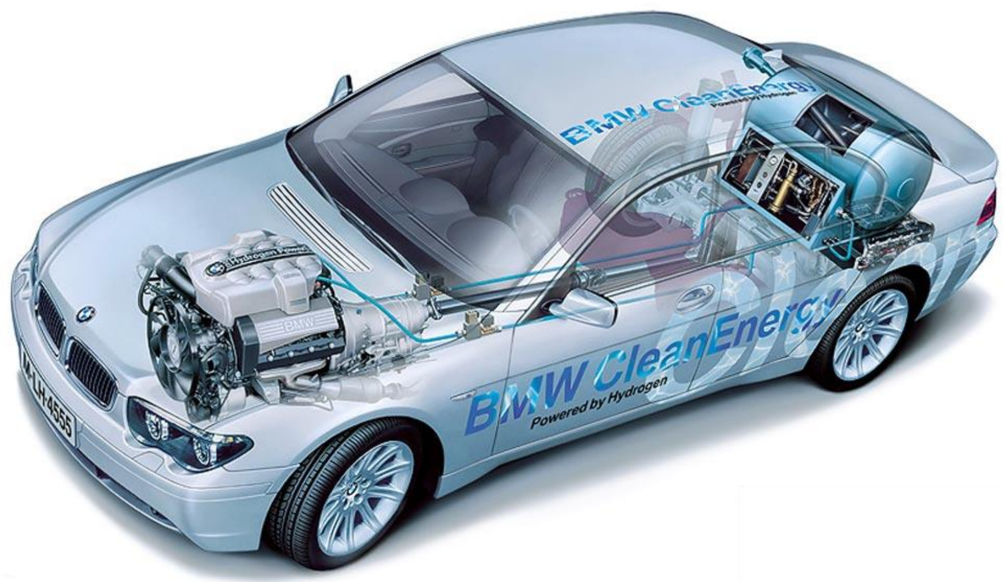
- Oakland, California, USA

Data	Fuel Cell	Diesel
Availability (85% is target)	74%	89%
Fuel economy (miles/kg)	5,47	-
Fuel cost ($/mile)	1,58	0,44
Total maintenance cost ($/mile)	1,15	0,47
- Propulsion only	0,65	0,14
Purchase price ($)	2,5M	330 000

Source: Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report

Hydrogen vehicles in use

Cars



H_2ICE

Publicly available (2016):

- Toyota Mirai (5kg H_2, 500 km, 78000 €)
- Hyundai ix35
- Honda Clarity (4,1kg H_2, 386 km)

In development:

- BMW
- Ford
- Nissan
- Daimler

Widespread appearance: 2035-2045

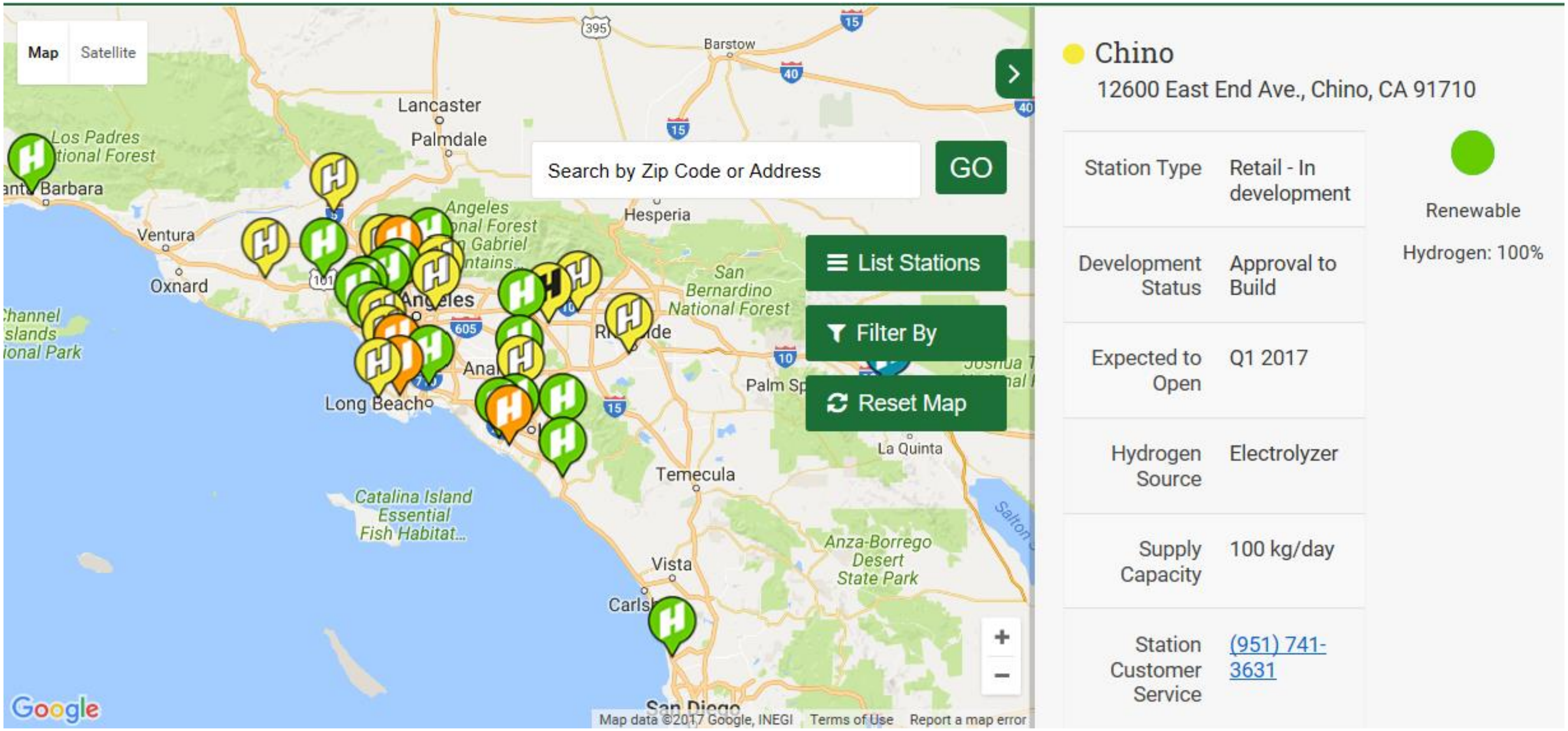
FCHEV

Hydrogen vehicles in use

Trains

Stations

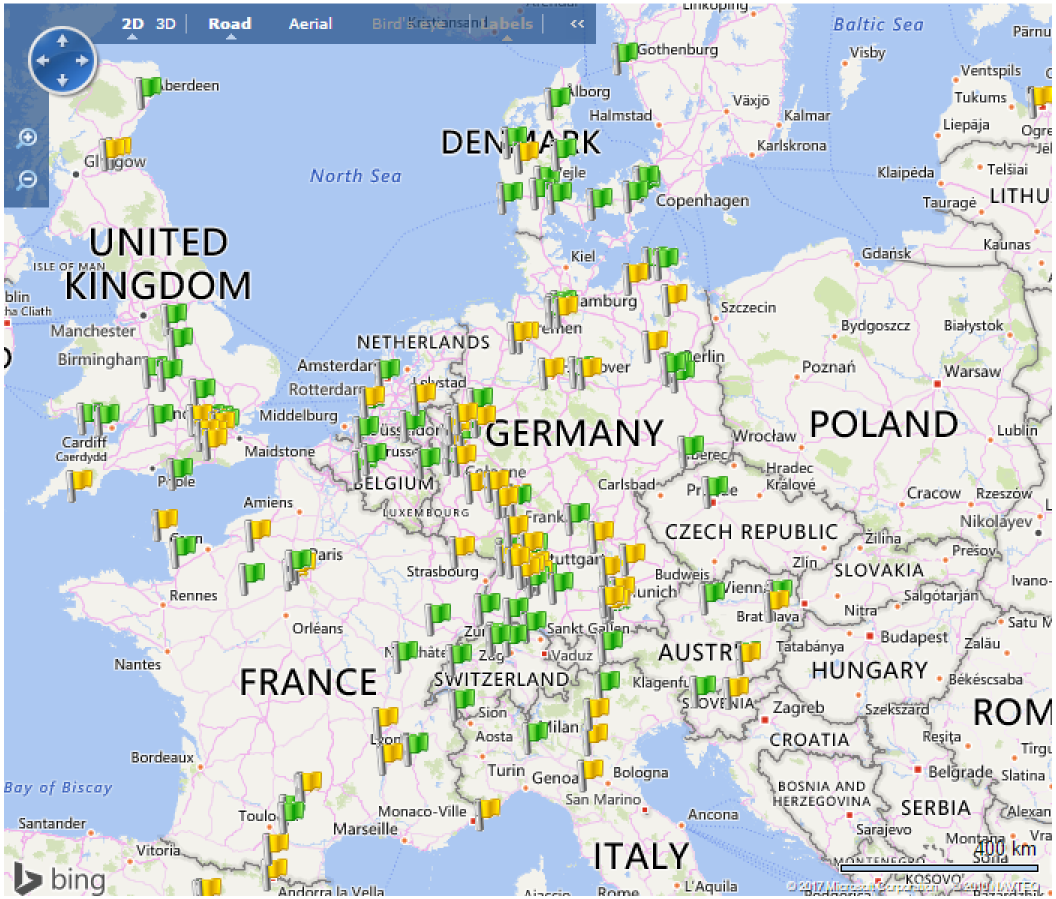
USA



www.h2stationsmaps.com

Stations

Europe



www.netinform.net/

Leading countries:

- USA
- Germany
- United Kingdom

Hungary:

- 0 station
- ≈0 vehicle
- some initiatives

Stations