Hydrogen Fuel Cell Vehicle

- a discussion

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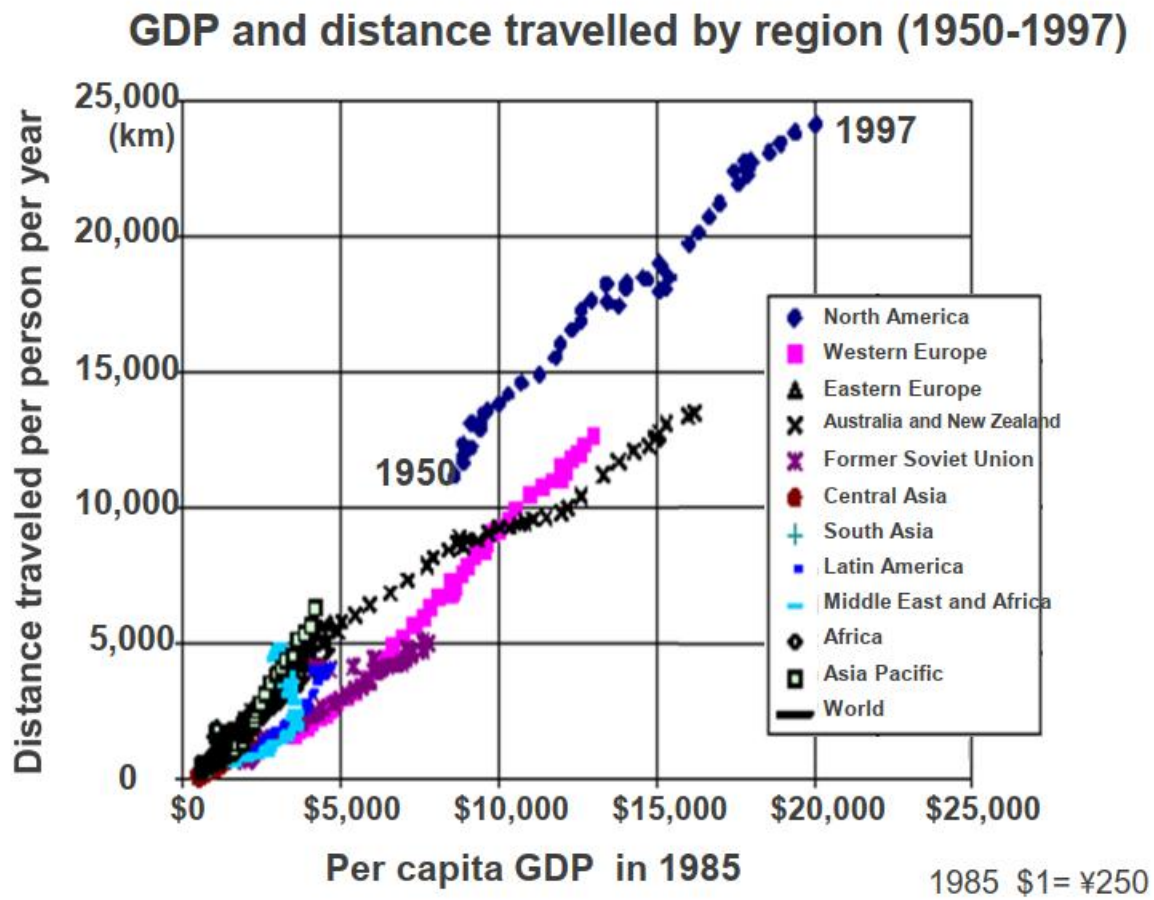
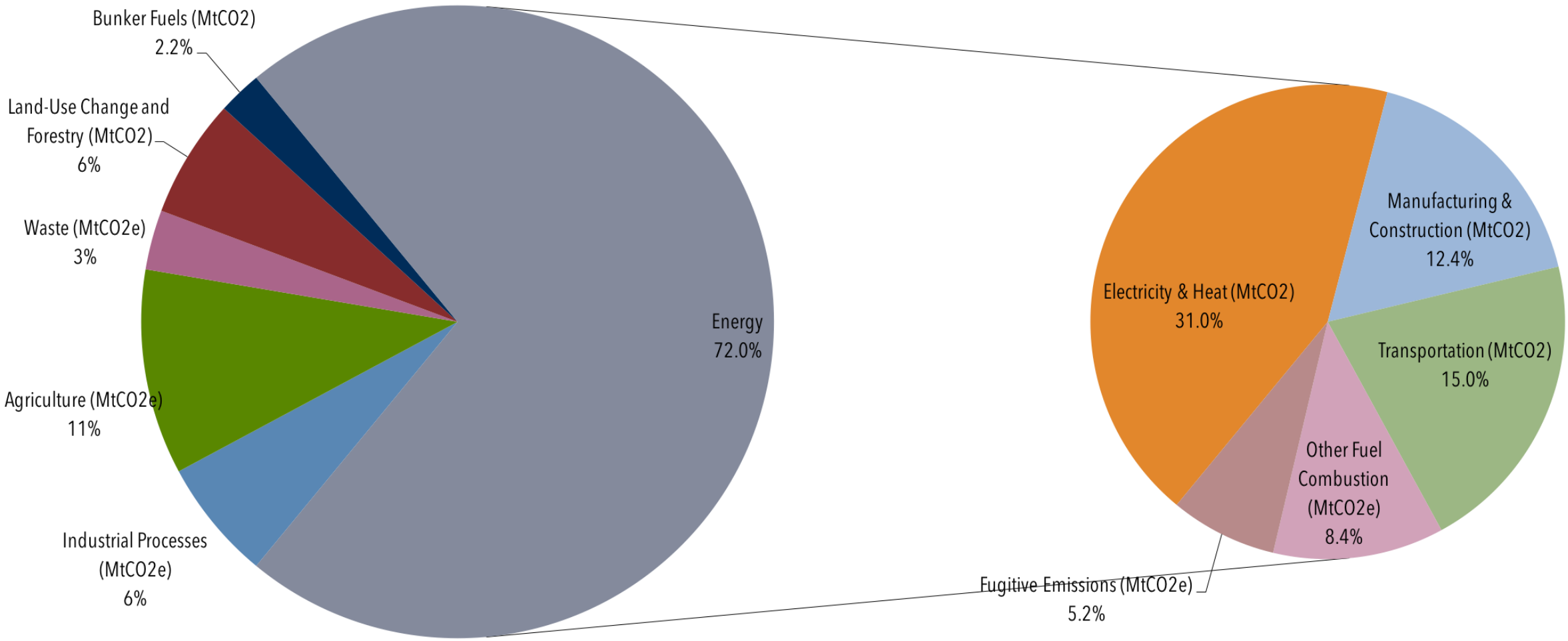
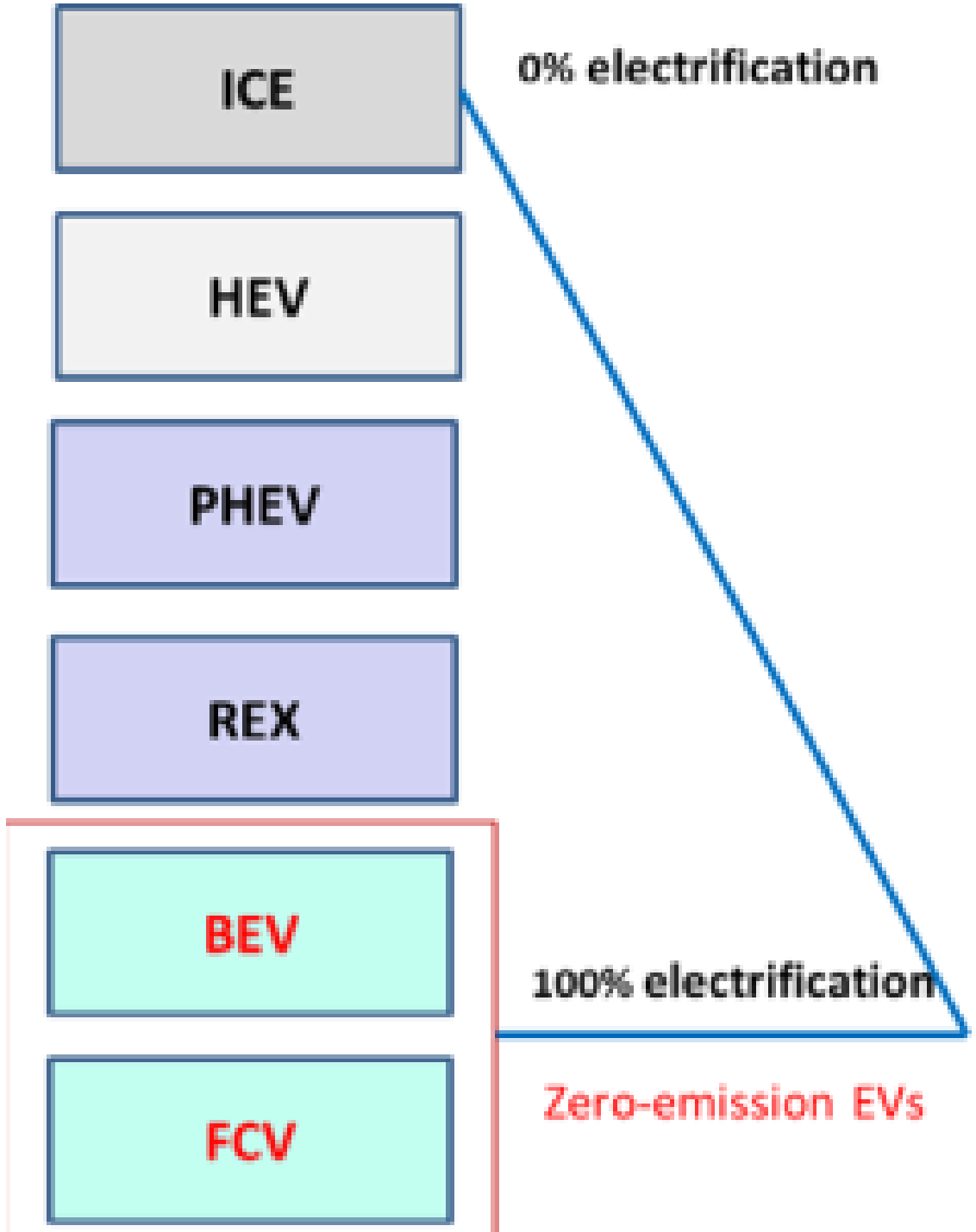
Increase in distance traveled



Distance traveled has increased due to economic growth

Source: WBCSD Mobility 2001

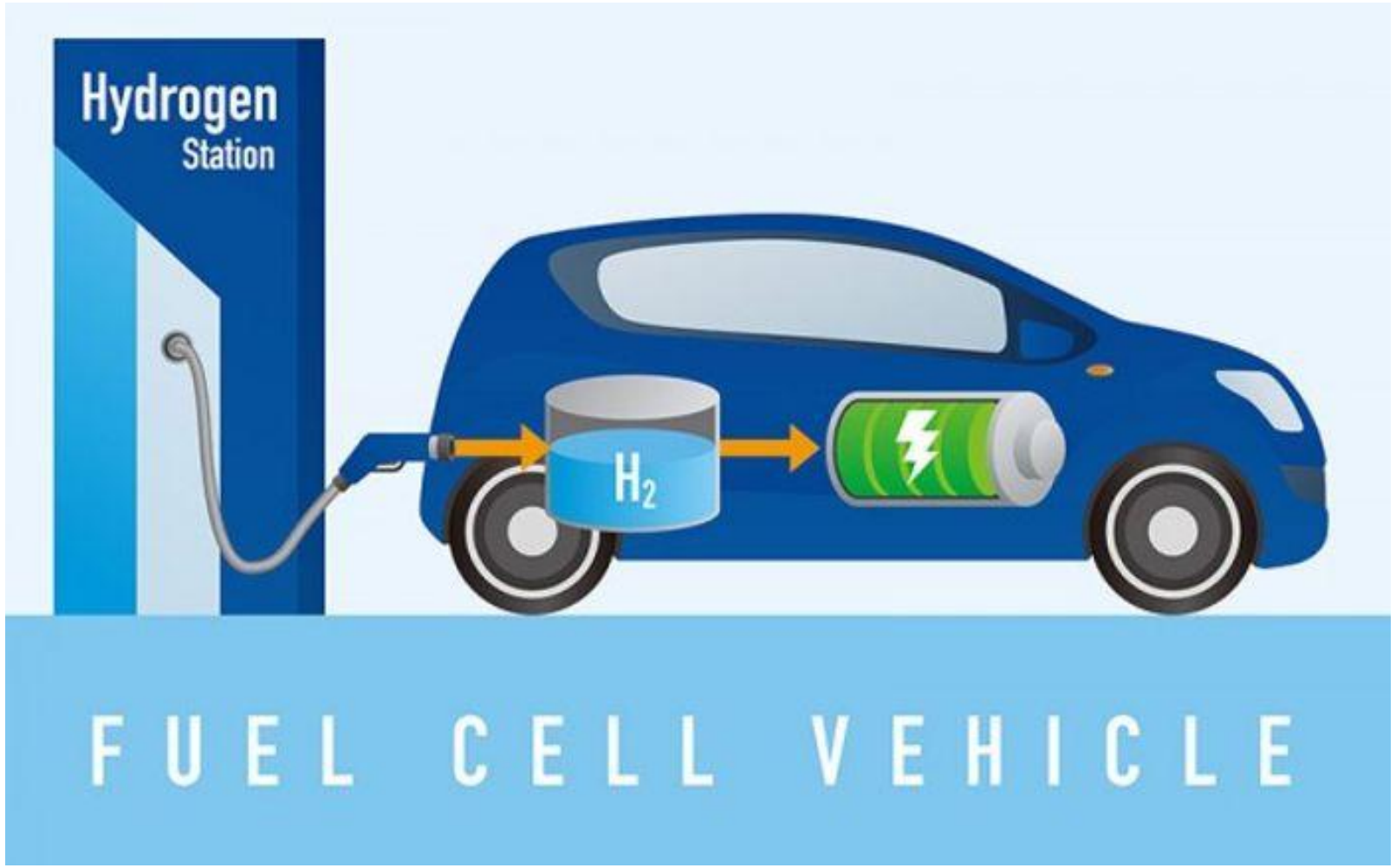

Bunker Fuels (MtCO2)
2.2%
Land-Use Change and Forestry (MtCO2)
6%
Waste (MtCO2e)
3%
Agriculture (MtCO2e)
11%
Industrial Processes (MtCO2e)
6%
Energy
72.0%
Electricity & Heat (MtCO2)
31.0%
Manufacturing & Construction (MtCO2)
12.4%
Transportation (MtCO2)
15.0%
Other Fuel Combustion (MtCO2e)
8.4%
Fugitive Emissions (MtCO2e)
5.2%

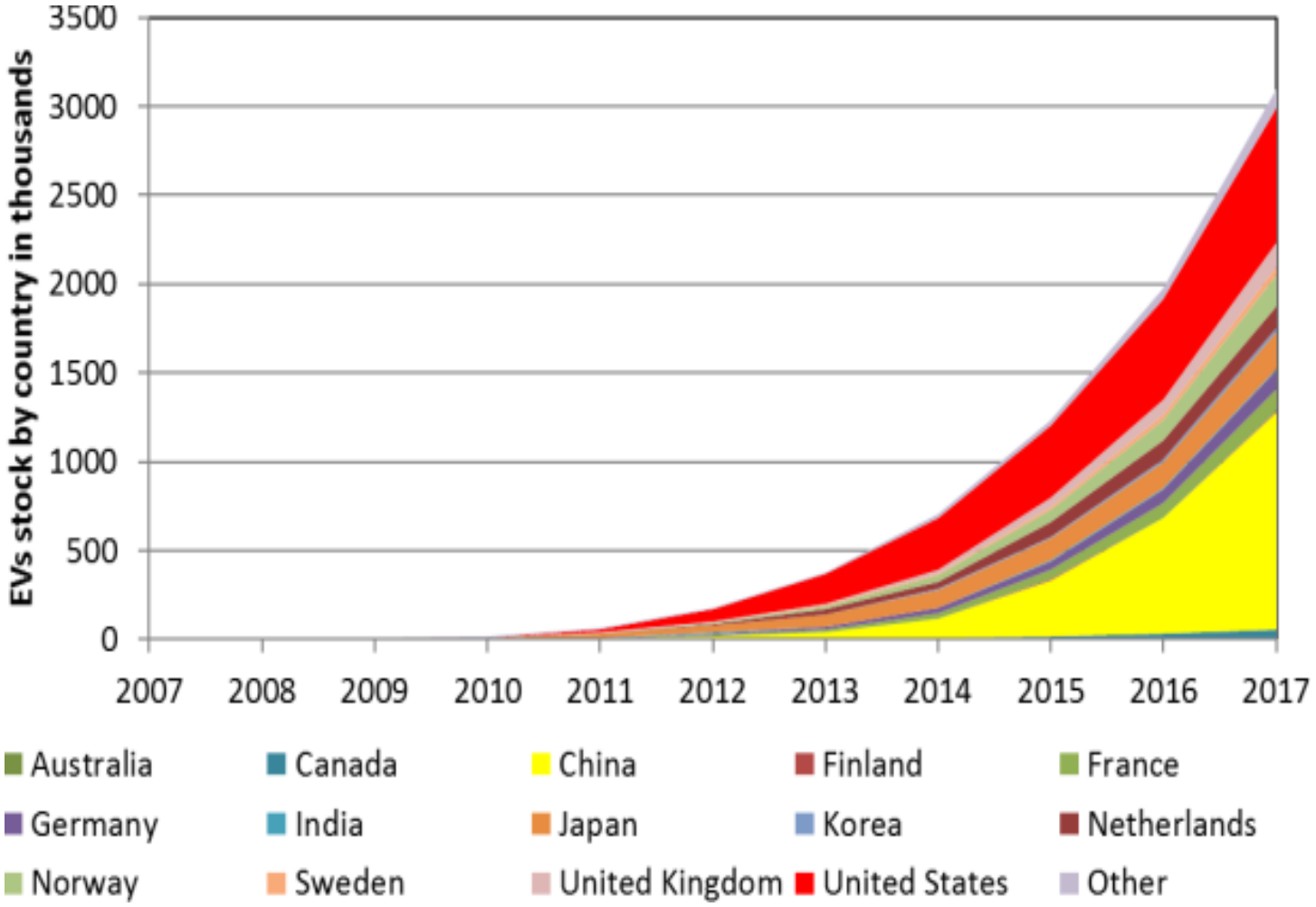


From IC Engines to Electric vehicles

- Internal Combustion Engines (ICE): Modern versions ensure better efficiency and reduces emissions.
- Hybrid Electric Vehicles (HEV) use both ICE and batteries, reduce emissions. Braking energy can be recovered and stored in the batteries.
- Plug-in hybrid electric vehicles (PHEV) could expand the range of hybrid vehicles by operating on battery power alone.
- REX

A **Hydrogen Fuel Cell Vehicle** is an electric car





Development of the global stock of rechargeable EVS

Battery Cost Vs Density

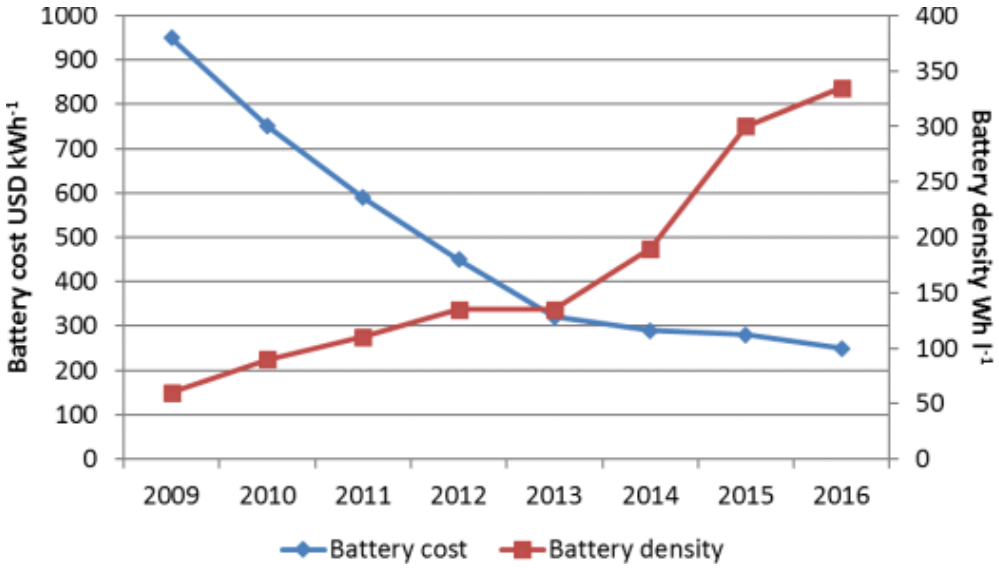
Lithium-ion batteries, since their market introduction in the 1990s, have experienced significant cost reduction. Further cost reductions are expected.

In 2017:

BEV stock: 3.1 Million vehicles

FCV stock: 7,200

Medium sized FCV car ~ 60,000 EUR



Energy content and Power density

Storage technology	Energy density
Lead-acid batteries	100 kJ/kg (0.03 kWh/kg)
Lithium-ion batteries	600 kJ/kg (0.18 kWh/kg)
Hydrogen	120 MJ/kg (33 kWh/kg)
Gasoline	43000 kJ/kg (12 kWh/kg)

EVs tend to be equipped with bulky batteries to maximise their energy storing capacity

Hydrogen:

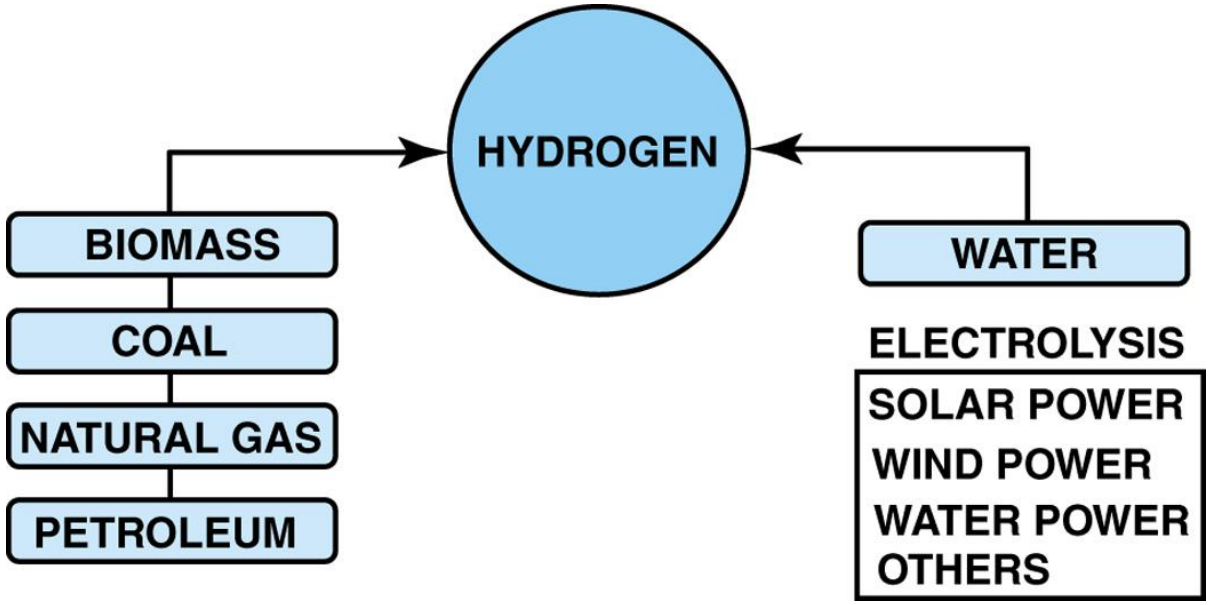
- Hydrogen is the lightest element. Hydrogen has a high energy density by weight but low energy density by volume.
- One kilogram of hydrogen can store about 180 times more energy than a kilogram of lithium-ion batteries.
- So, hydrogen is better for larger vehicles - such as trucks, buses and ships - than electric batteries

ISSUES

- Production
- Transportation
- Distribution
- Storage and Vehicle range
- Safety
- Cost

Hydrogen production

- Steam reforming



- Steam reforming requires a significant amount of heat to generate the steam that allows for the extraction of the hydrogen from the natural gas.
- Hydrogen production through steam reforming produces pollution.
- With pure hydrogen as the input, fuel cells are 60% efficient at converting the stored energy in hydrogen into electricity
- BEVs have losses related to charging, conversion of the stored DC power to AC for the motor, and battery leakages leading to total efficiency from the wire to the wheels of around 75%

Electrolysis of water

- Electrolysis uses electricity to split apart the hydrogen and oxygen in water
- Electrolysis is possible at scale and with renewable electricity as the input
- It has the potential to provide a solution for the zero-emission production of hydrogen. The problem is that it requires even more energy input than steam reforming, with a 30% loss of energy through the process.

Proton-exchange membrane (PEM) electrolysis allows for the extraction of hydrogen from water by using a proton-exchange membrane that only allows protons to flow through it. The filter splits up the hydrogen and oxygen.
The process is currently around 80% efficient, making it significantly more efficient than straight-up electrolysis.

Primarily, hydrogen is a CARRIER not a source of energy.
Hydrogen is required to be transported to refuelling station for hydrogen cars.

Hydrogen transportation

Pipelines

Hydrogen safely transported through pipelines for decades, with or without optimal system. Hydrogen pipelining costs about 2 to 3 times NG, per unit energy-distance. Exacerbates H_2 attack on pipeline steel. Pressure intensity varies seasonally.

Liquid hydrogen

Cryogenically compressing hydrogen into a liquid by supercooling it down to -250°C. But the amount of energy required to supercool and process the hydrogen results in a 40% efficiency loss using present technologies.

High pressure hydrogen cylinder

Compression of hydrogen to 790 ATM is the most realistic optimization of efficiency vs cost of transport, but even compression to this level still consumes 13% of the energy contained in the hydrogen.

Hydrogen can be produced locally by Renewable Electricity

- Solar and wind are intermittent in nature
- Hydrogen can be produced through PEM electrolysis when sun shines or wind blows
- The hydrogen can be stored in tanks at much larger volumes with relatively low cost
- Hydrogen vehicles can pick up fuel from these local production centres
- No need of transporting the hydrogen.

Distributed Energy Resources [DER] are such a good idea. Creating the power we need locally using the most efficient technology we have available is the best solution from and environmental and financial standpoint.

Onboard storage of hydrogen

High-pressure cylinders are one method of storing hydrogen onboard a vehicle for use in a fuel cell. This is a simple and lightweight storage method, but often does not provide sufficient vehicle driving range.

Another approach has been to fuel a modified PEM fuel cell with liquid methanol instead of hydrogen gas. A direct methanol fuel cell uses a methanol/water solution for fuel instead of hydrogen gas

A direct methanol fuel cell can be refueled similar to a gasoline-powered vehicle

Space Agencies use hydrogen:

- Lift space shuttles
- Fuel cells to power ship electrical systems
- Crew drinks H_2O byproduct

Hydrogen fuel cells already

Replacing batteries

- TV cameras and forklifts

Providing power at remote and isolated locations

- cellphone towers
- Powering refrigeration units for trucks.

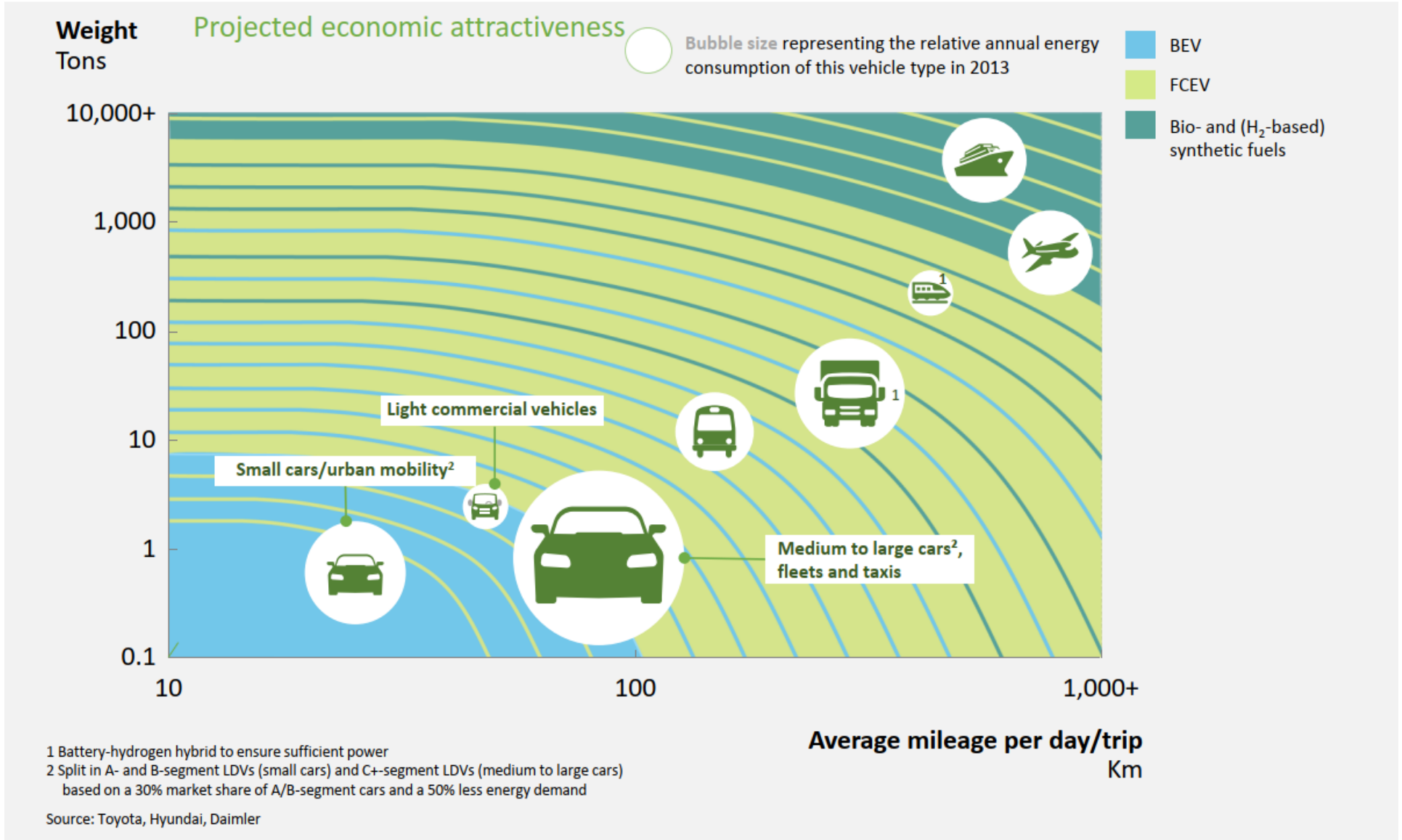
Hydrogen economy is a low carbon economy

Fuel Cells or Combustion of Hydrogen

- No release of carbon di-oxide
- No release of particulates (SOx or Nox)

Only clean water is released.

4. FCEVs will play an essential role in decarbonizing transport



1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

Source: Hydrogen Council

Prospects of FCEVs

Cars:
Cars are required to be electrified. BEVs have started coming in the market. Investing in all-electric battery cars is a more economical choice.

Light Duty Vehicles (LDVs):
Delivery trucks, etc. FCEVs offer the best replacement as it would be a zero-emission alternative with lighter storage without compromising their driving autonomy.

Heavy Duty Vehicles (HDVs):
Trucks, buses, etc. are vehicles that need long range and high-power density. Features that are only available with FCEVs. The same applies to off-road vehicles.

Trains:
FCEV trains are already cost competitive with diesel trains (from a Total Cost of Ownership perspective). Very suitable if electrification of tracks is difficult.
Ships:

Hydrogen has the most potential in decarbonizing long-distance transport

Thank you