*Interdisciplinary Summer School 2022*

# Energy &Transport

## *Prospects for hydrogen and fuel cell vehicles*

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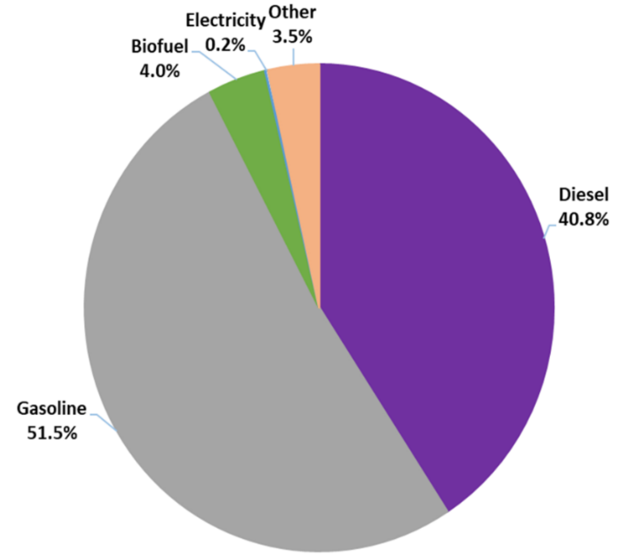
*Vienna, 23.6.2022*

# Content

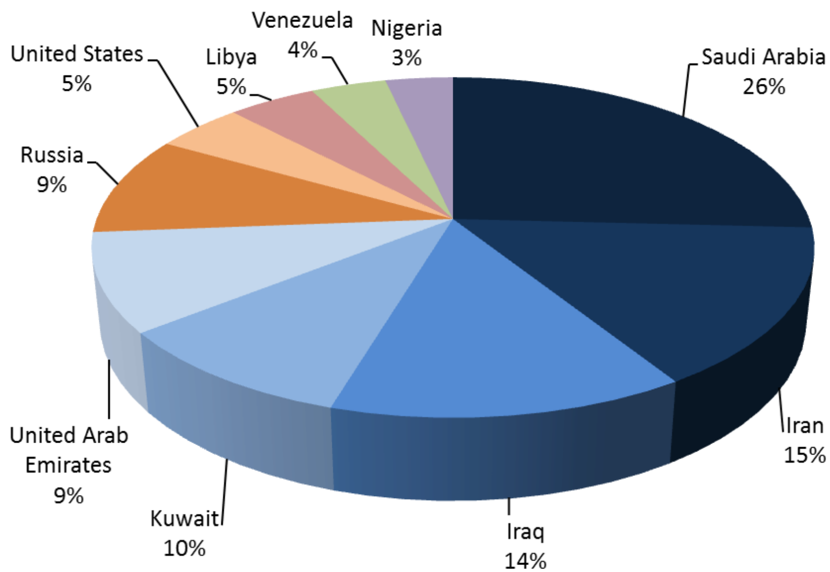
1. Introduction
2. EU hydrogen vision
3. Historical developments
4. Economic and environmental assessment
5. RES and storage
6. Conclusion

# Transport sector

- oil products
- least-diversified
- energy import dependency

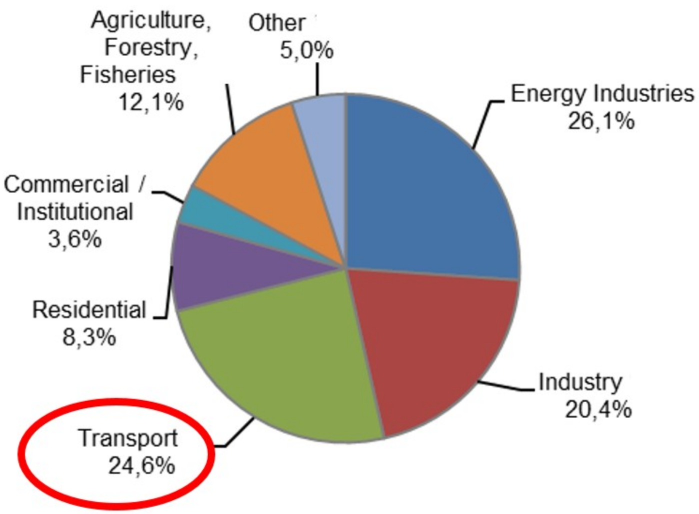


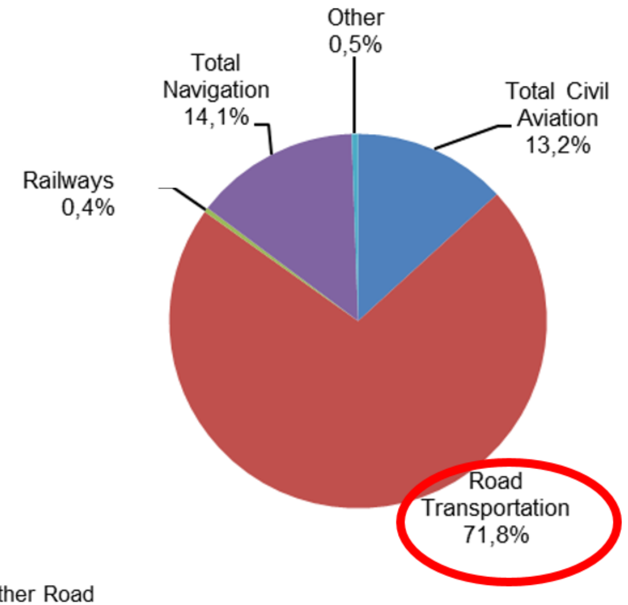

Global energy consumption in road transport

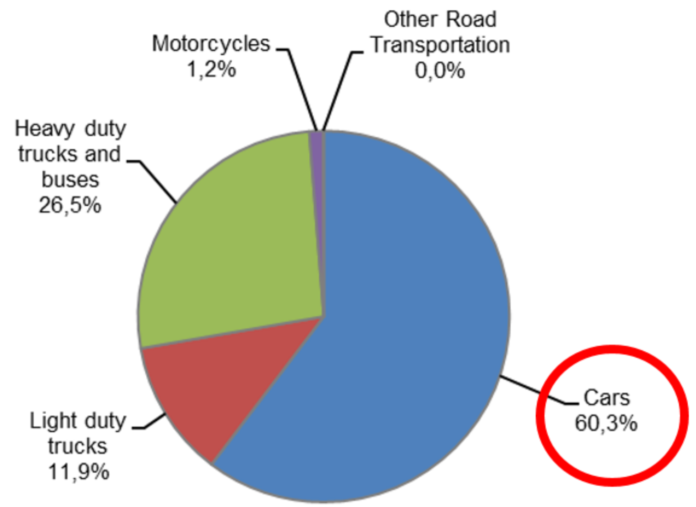



Countries with largest conventional oil reserves

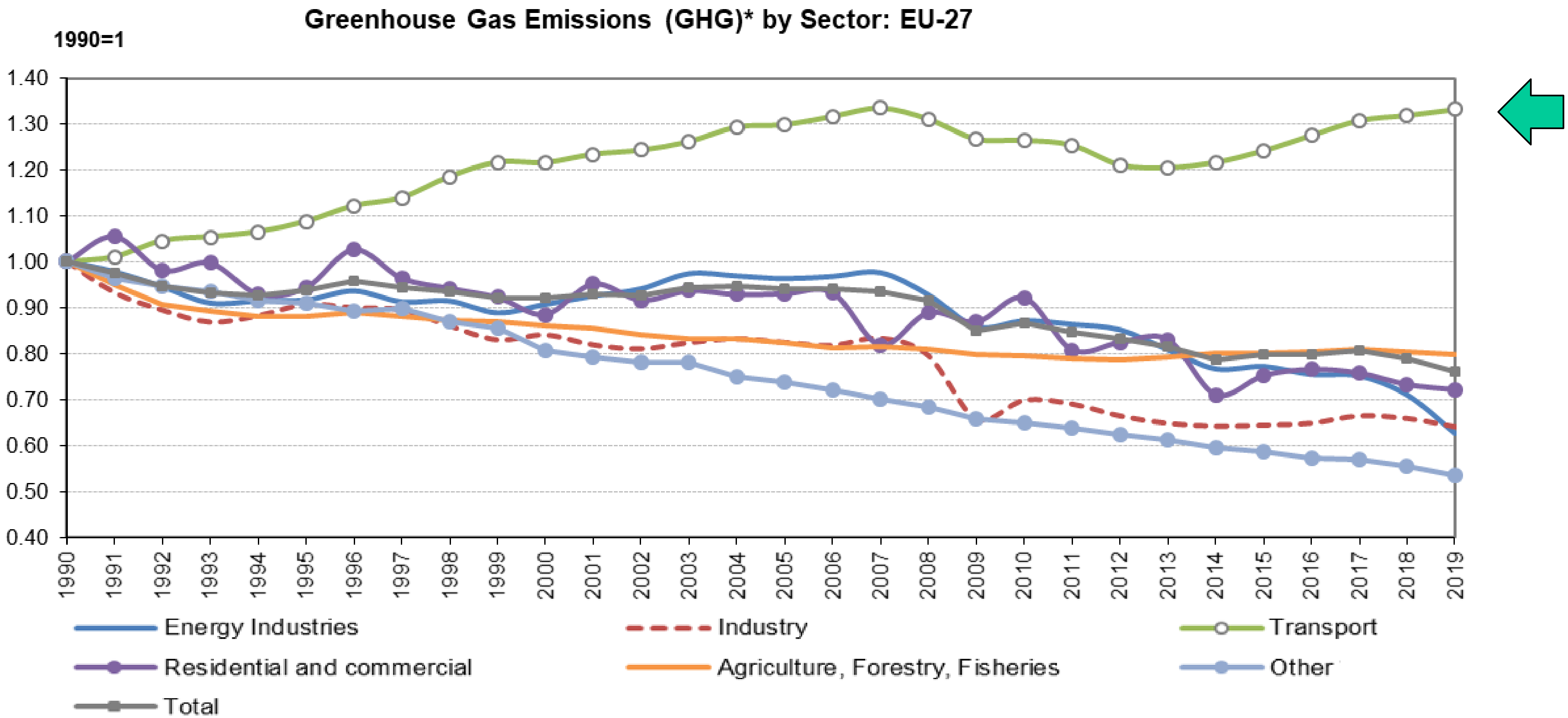
# GHG - EU 27


Agriculture, Forestry, Fisheries 12,1%
Other 5,0%
Energy Industries 26,1%
Commercial / Institutional 3,6%
Residential 8,3%
Industry 20,4%
Transport 24,6%

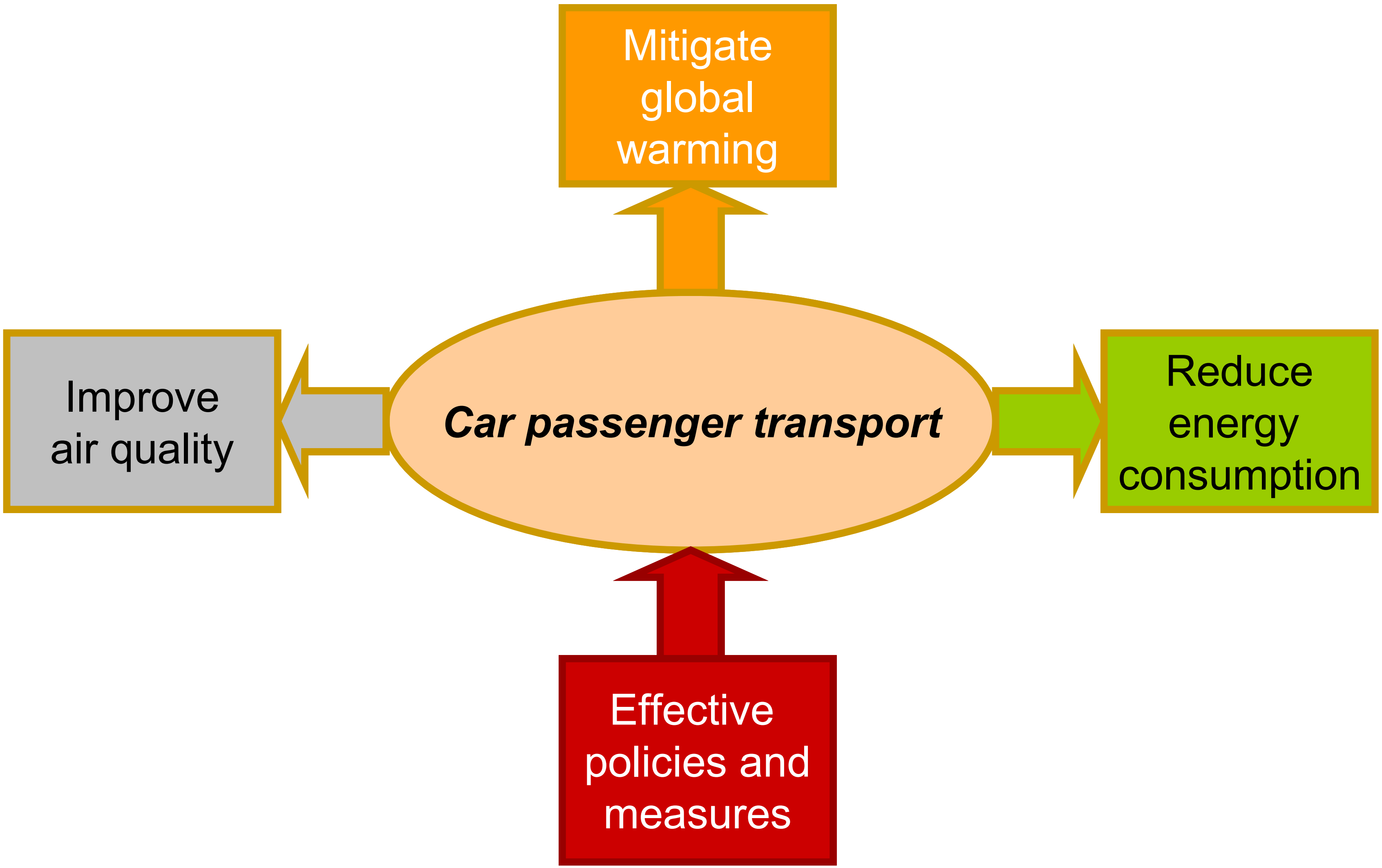

Other 0,5%
Total Navigation 14,1%
Total Civil Aviation 13,2%
Railways 0,4%
Road Transportation 71,8%


Motorcycles 1,2%
Other Road Transportation 0,0%
Heavy duty trucks and buses 26,5%
Light duty trucks 11,9%
Cars 60,3%

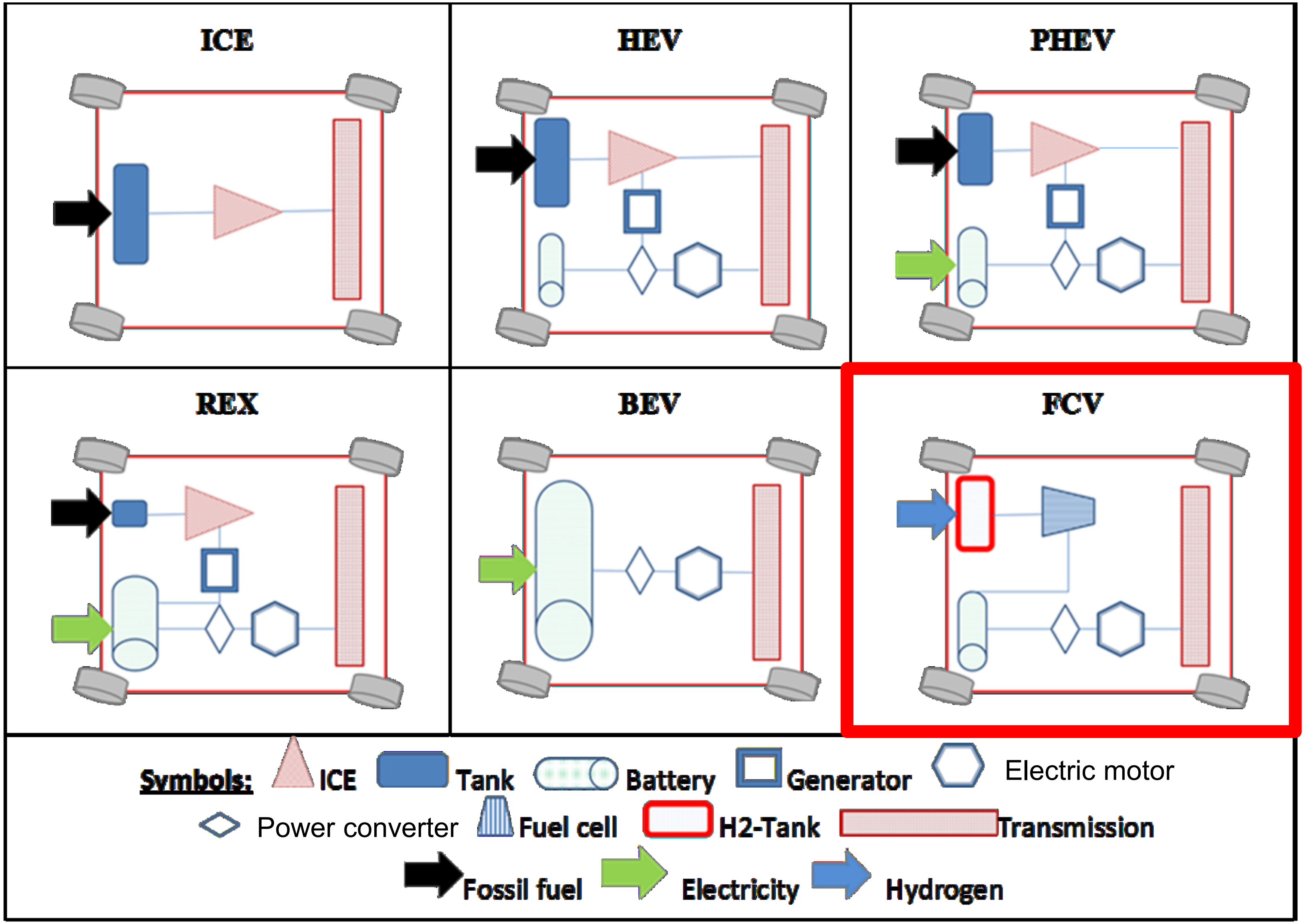
# GHG


Greenhouse Gas Emissions (GHG)* by Sector: EU-27
1990=1
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Energy Industries
Industry
Transport
Residential and commercial
Agriculture, Forestry, Fisheries
Other
Total

# The challenges for EU climate and energy policies

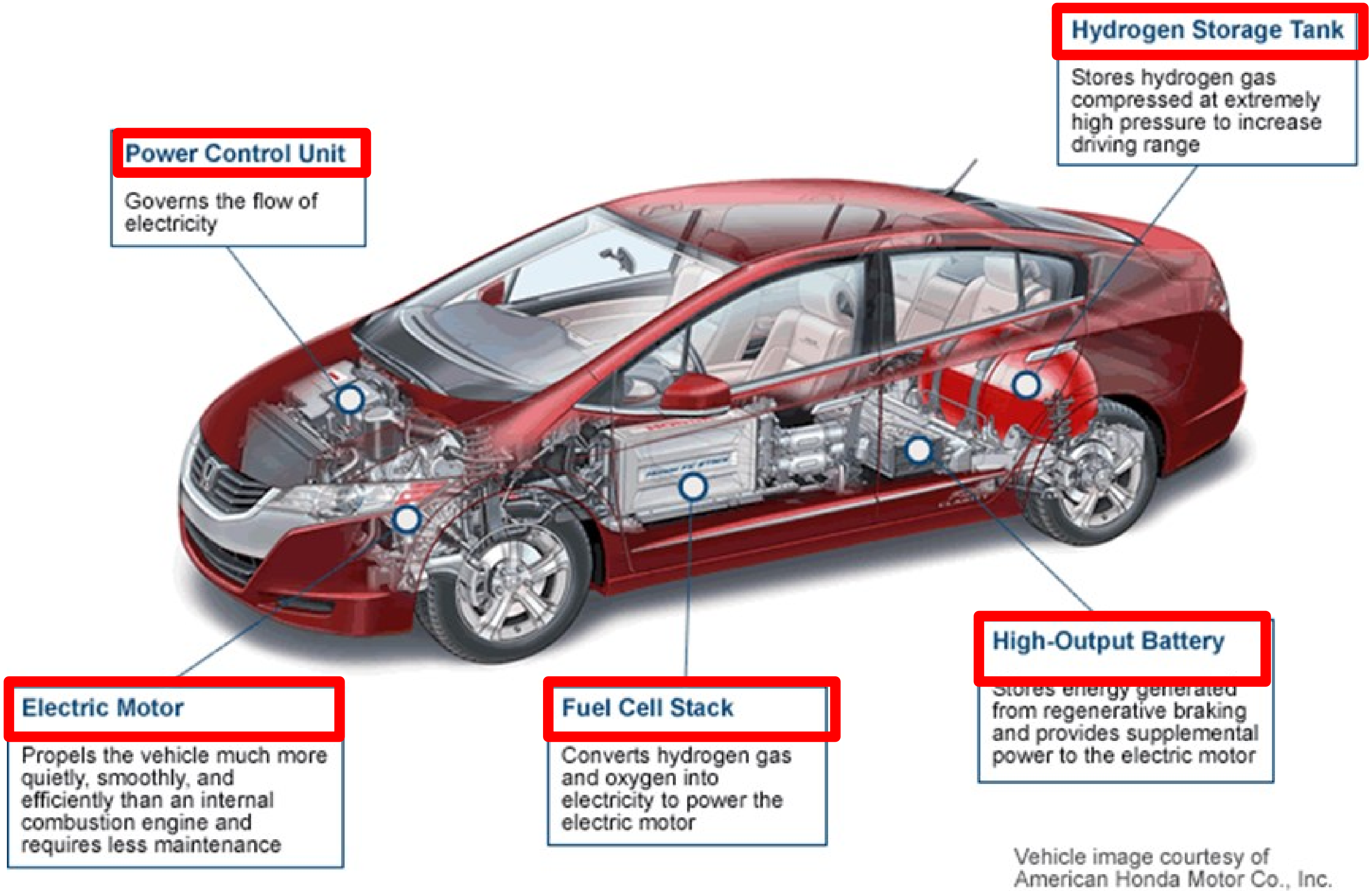


# Electric vehicles



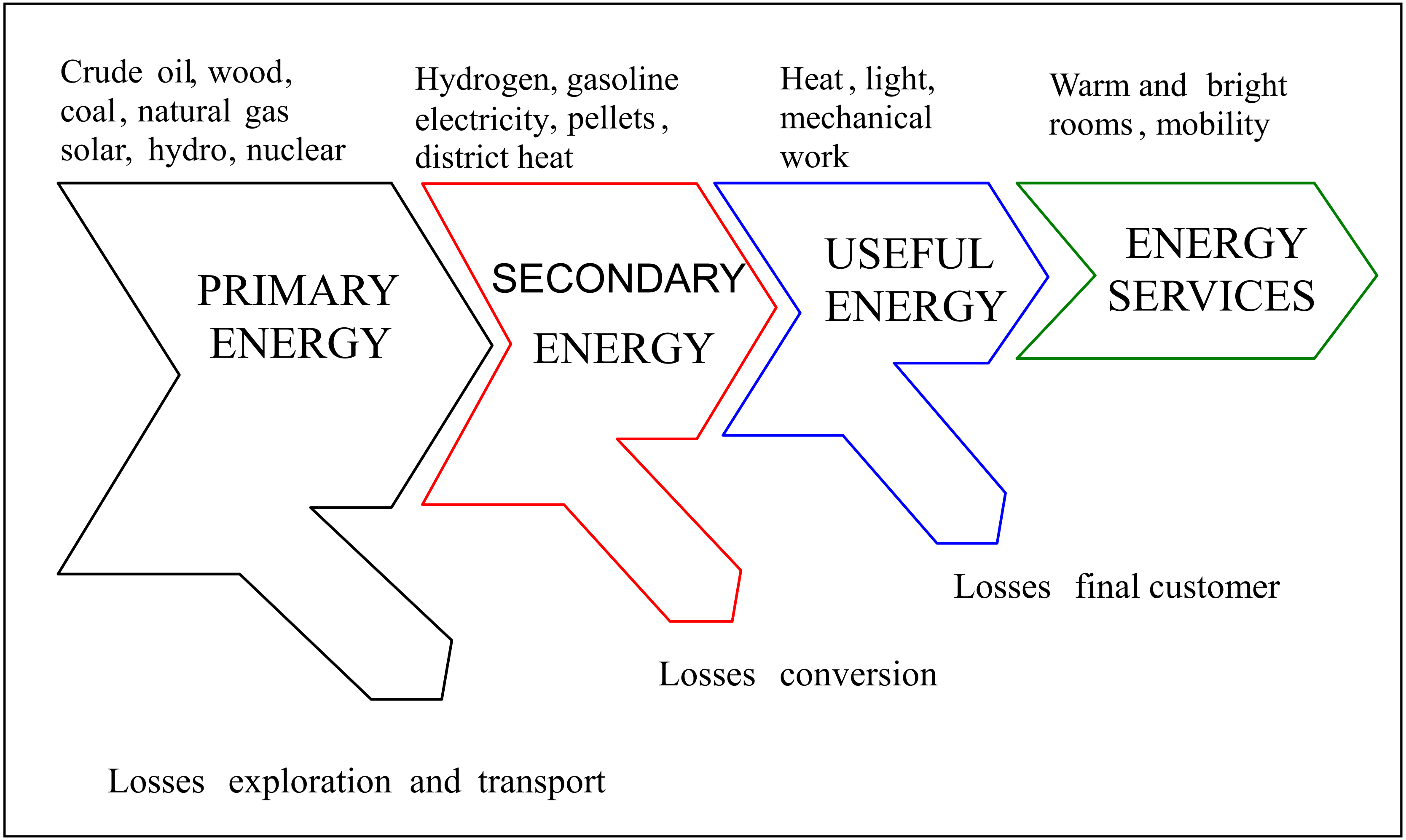
# *FCV*






Major components of a fuel cell-powered passenger car

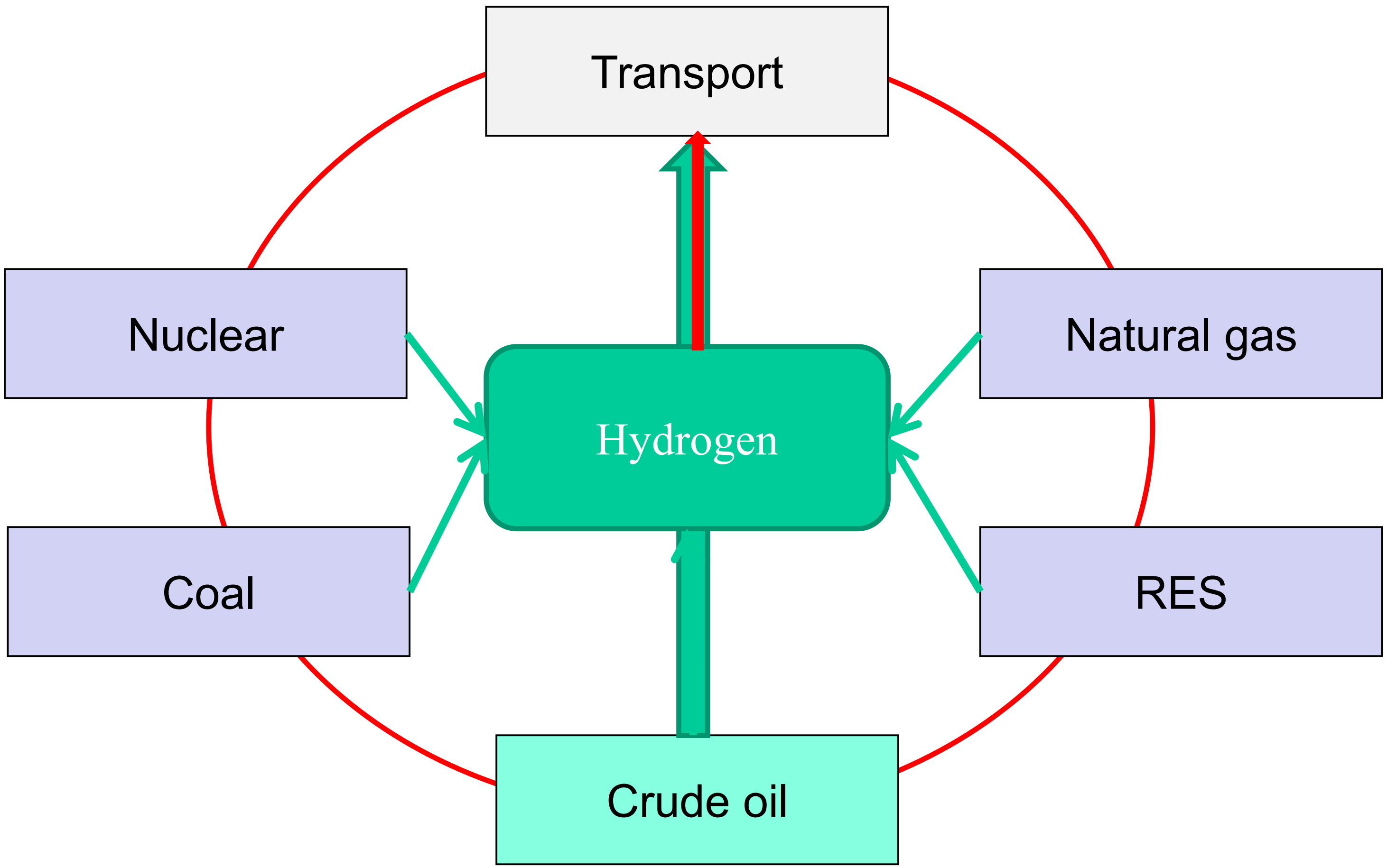
# Energy supply chains



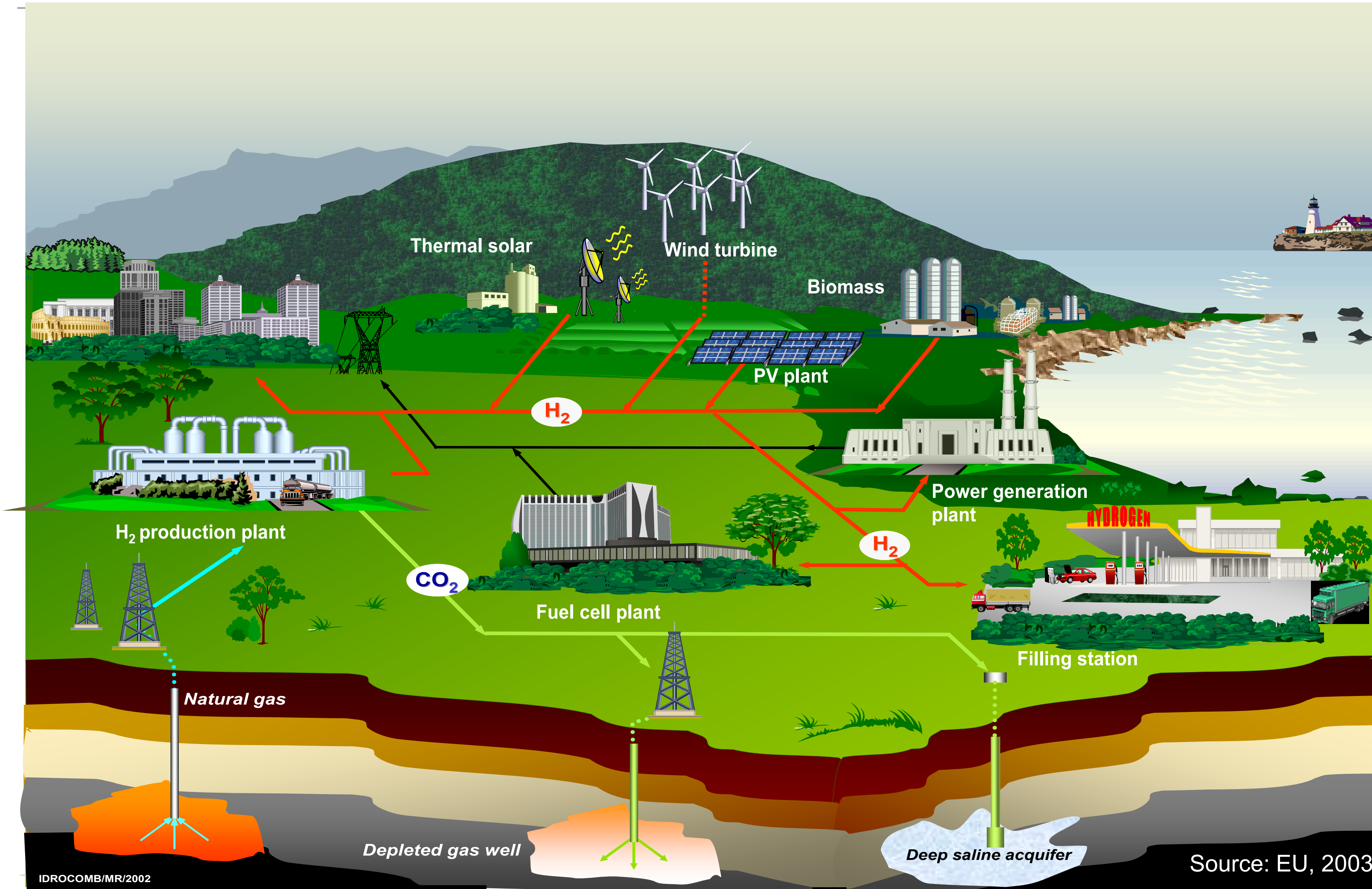
# Hydrogen

- Hydrogen is the simplest, lightest and most abundant element in the universe
- Secondary energy carrier …. It can be produced from different energy sources
- Hydrogen is less flammable than gasoline
- Hydrogen is non-toxic
- Hydrogen combustion produces only water
- Storage for surplus electricity

# *Diversification*

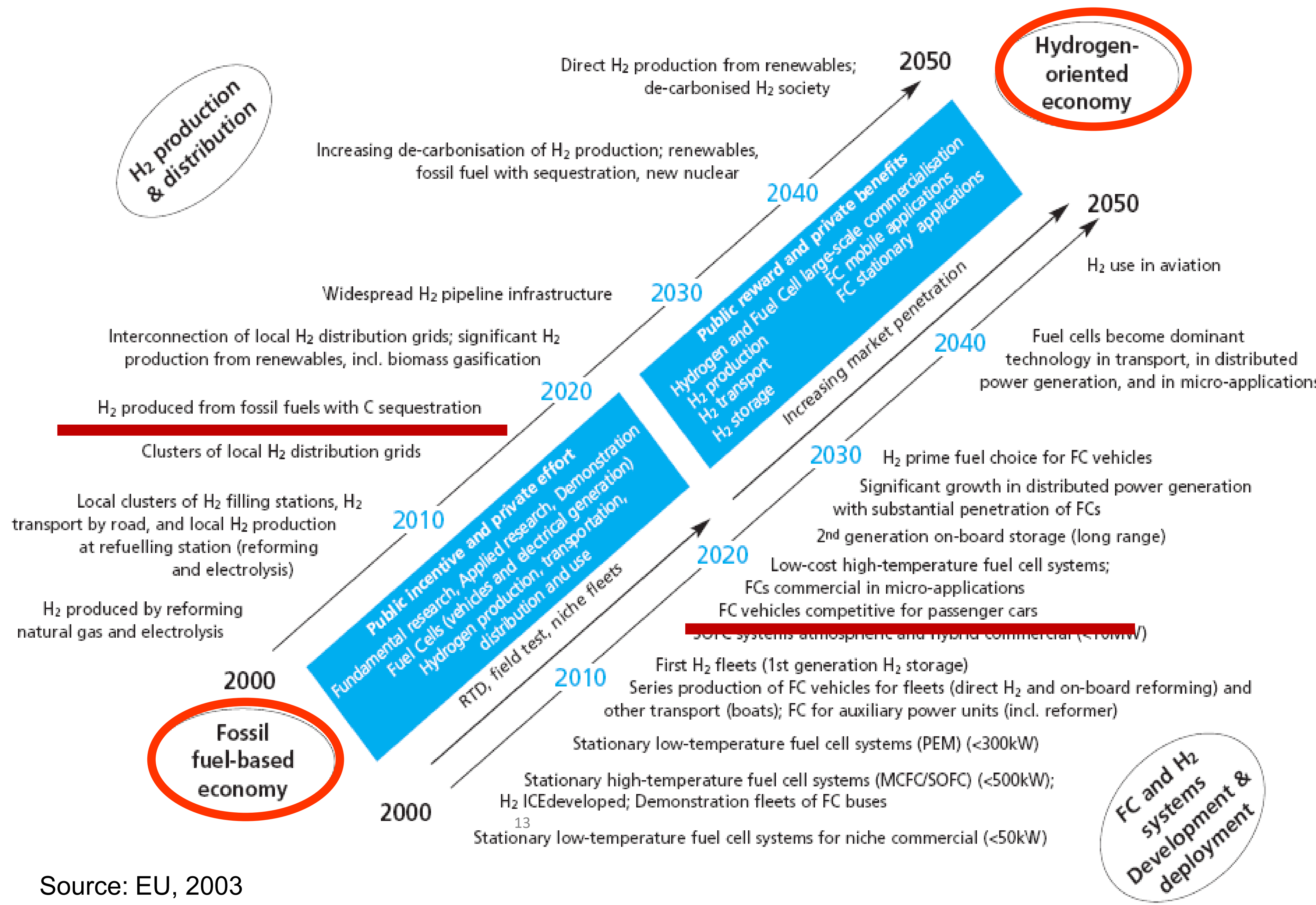


# Hydrogen vision




Source: EU, 2003

# A challenging European hydrogen vision



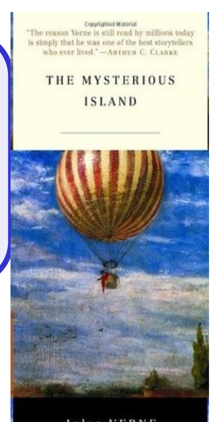

Source: EU, 2003

# Major historical steps and milestones in the development of hydrogen and FCV

**1766**: Hydrogen was first identified as a distinct element

**1838**: Discovered fuel cell effect

**1874:** Vision of hydrogen economy




**1958**: The first PEM fuel cell

**1959**: The first fuel cell vehicle – farm tractor powered by an alkaline fuel cell

**1966**: General Motors used fuel cell technology in production of the Electrovan

**1993:** The first PEMFC car

**2008:** Commercialization begins (FCX Clarity – first FCV commercially available)

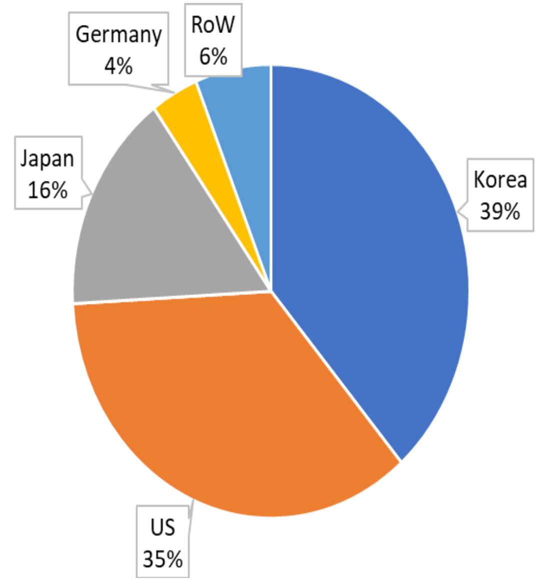
**2011**: > 100 fuel cell buses worldwide

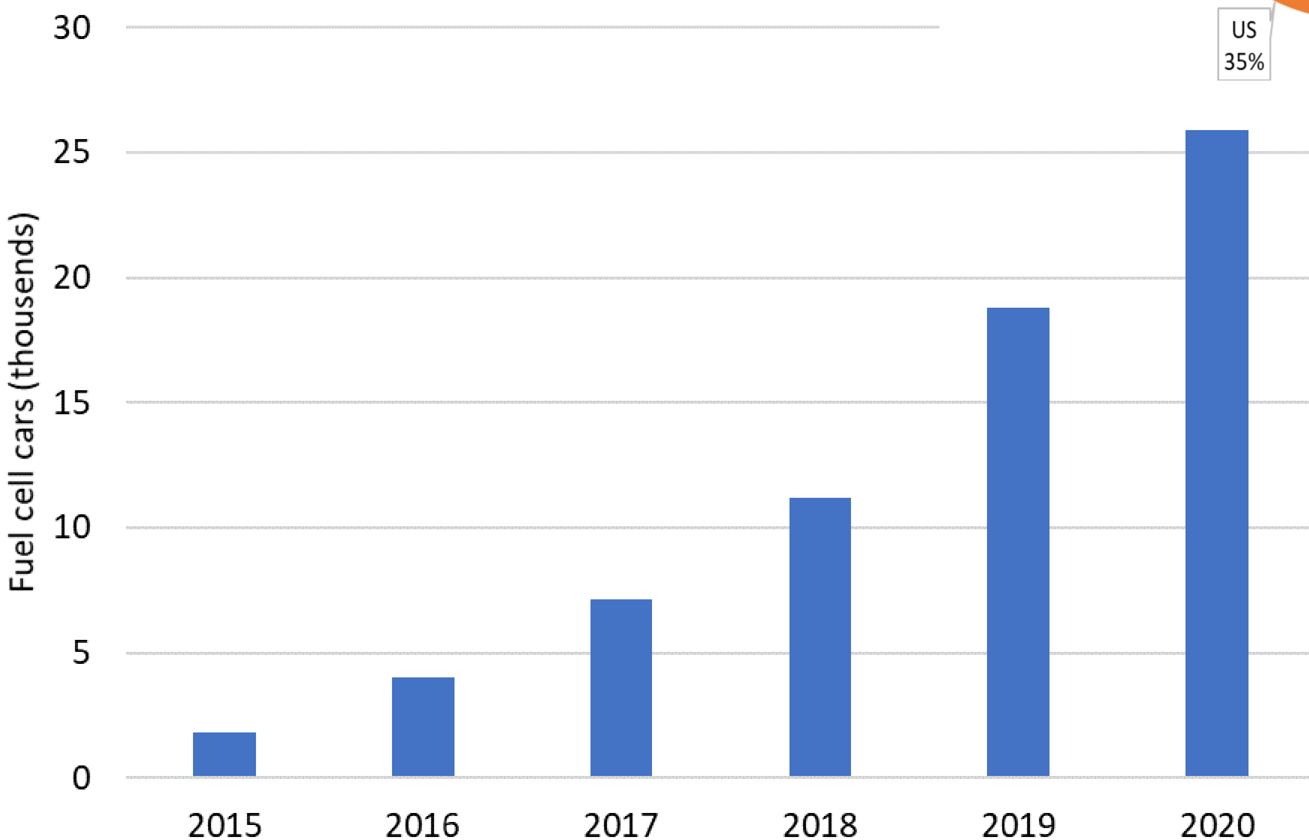
**2013**: > 4000 fuel cell forklifts worldwide

**2015**: First hydrogen fuel cell powered tramcar

**2020**: The global FCV stock >26 000

# FCV


Germany
4%
RoW
6%
Japan
16%
Korea
39%
US
35%


30
25
20
15
10
5
0
Fuel cell cars (thousands)
2015
2016
2017
2018
2019
2020

# FCVs

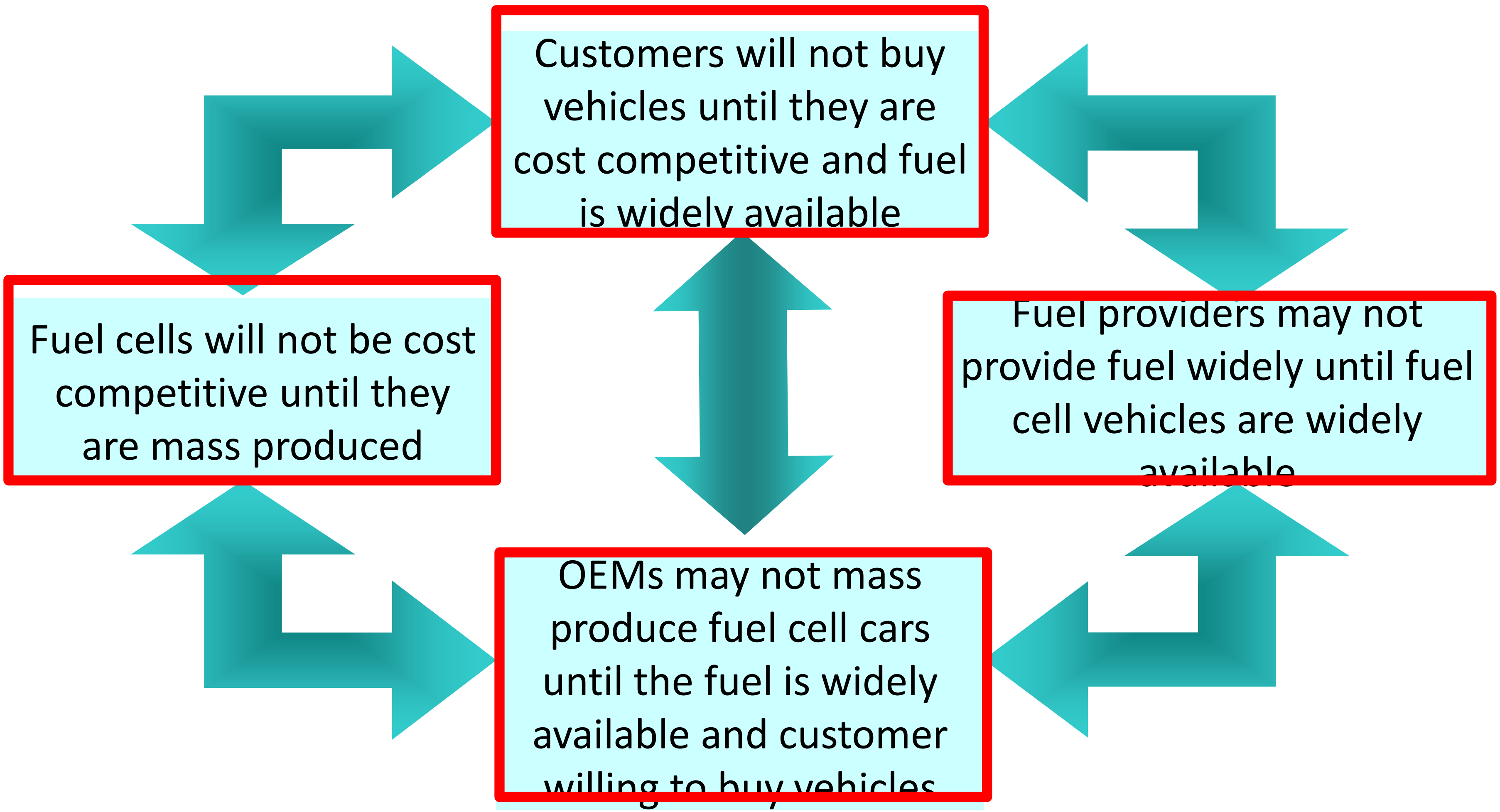
## The main reasons for the slow introduction of FCVs:

- Costs

| Application | Power or energy capacity | Energy efficiency | Investment cost | Lifetime | Maturity |
|---|---|---|---|---|---|
| Fuel cell vehicles | 80 - 120 kW | Tank-to-wheel efficiency 43-60% | USD 60 000-100 000 | 150 000 km | Early market introduction |

- Consumer acceptance
- Infrastructure

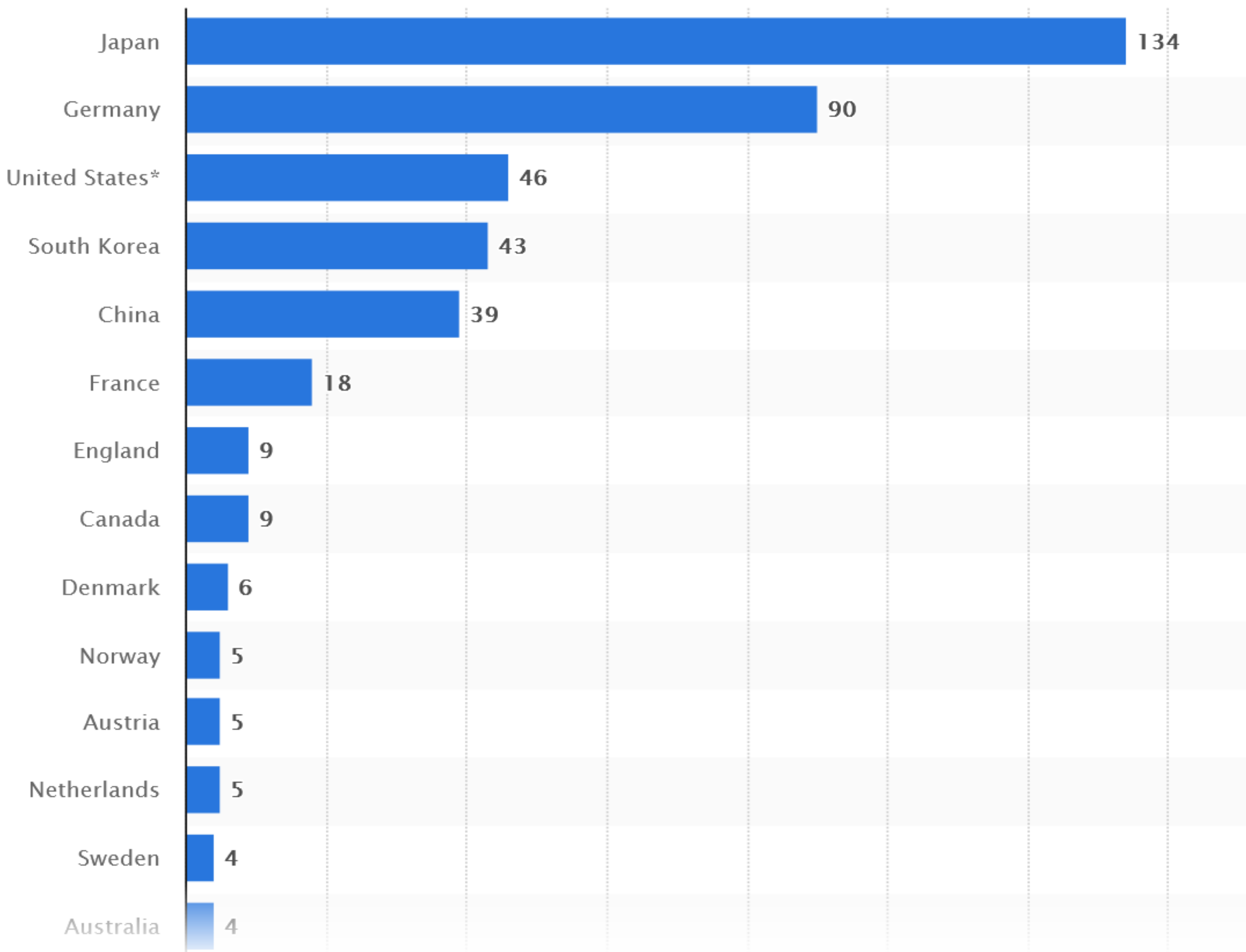
# 'Chicken and egg' dilemma




The transition to a hydrogen economy is complex

OEM-Original Equipment Manufacturer

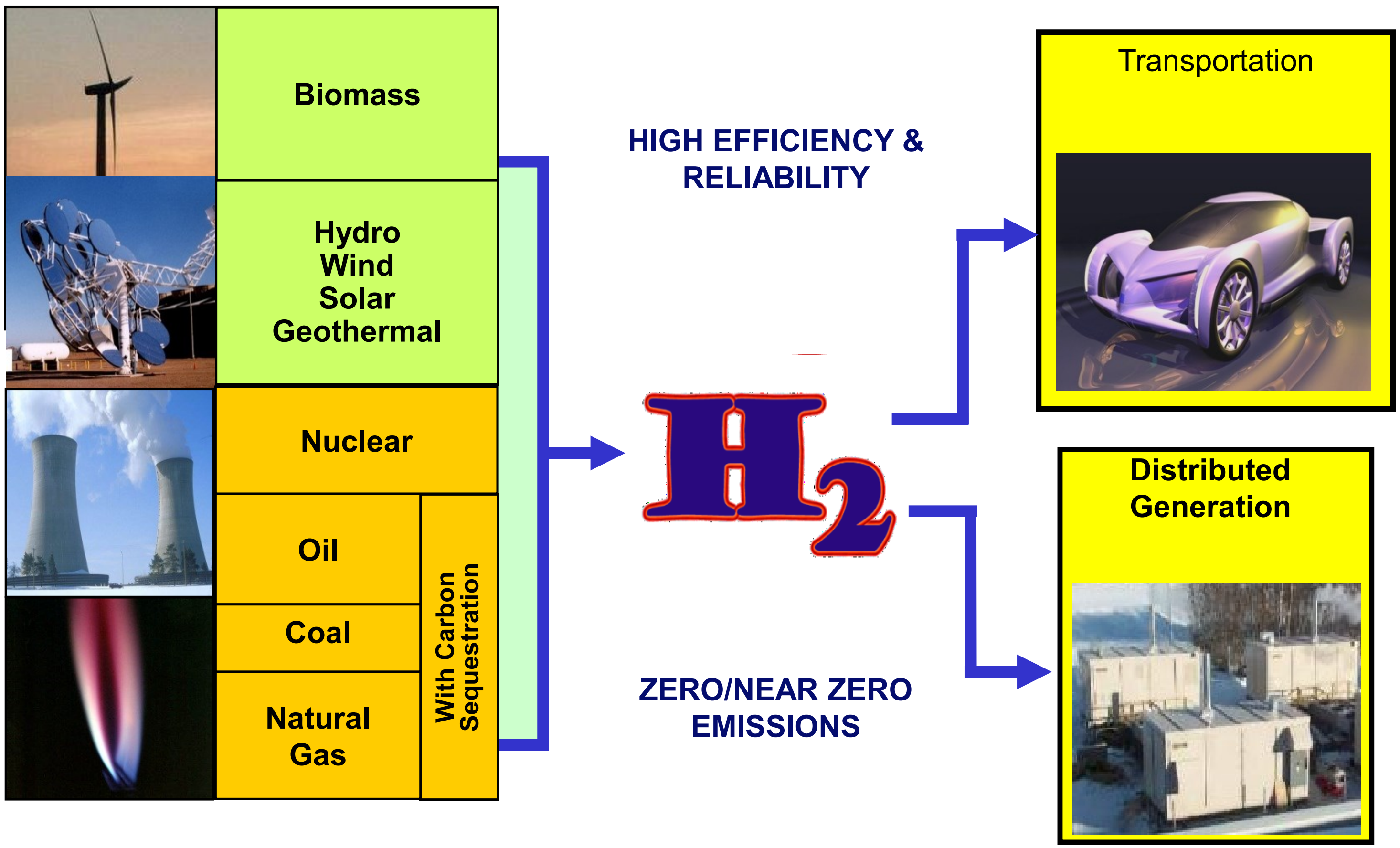
# Refuelling stations



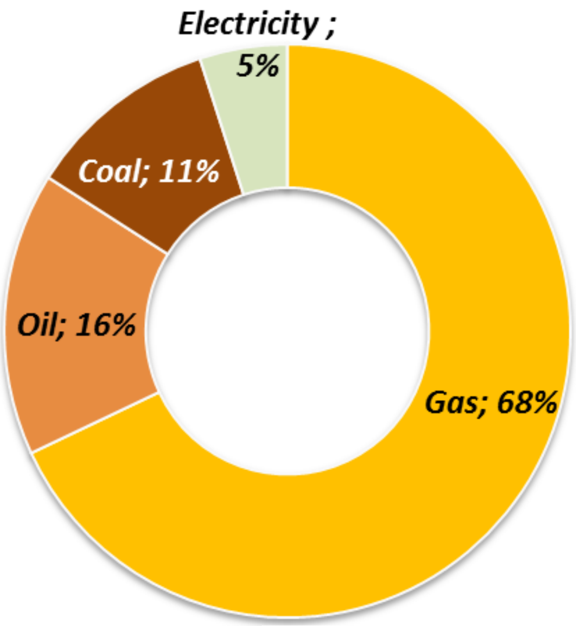

STATISTA, 2021

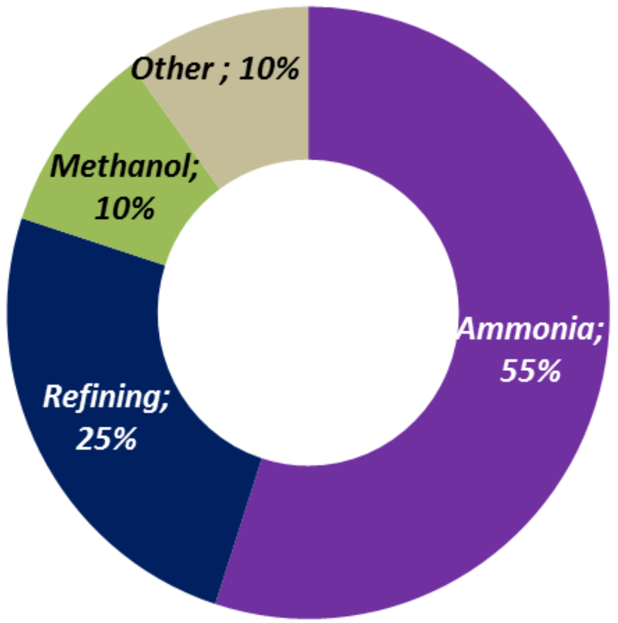
Number of hydrogen fueling stations for road vehicles worldwide as of 2021, by country

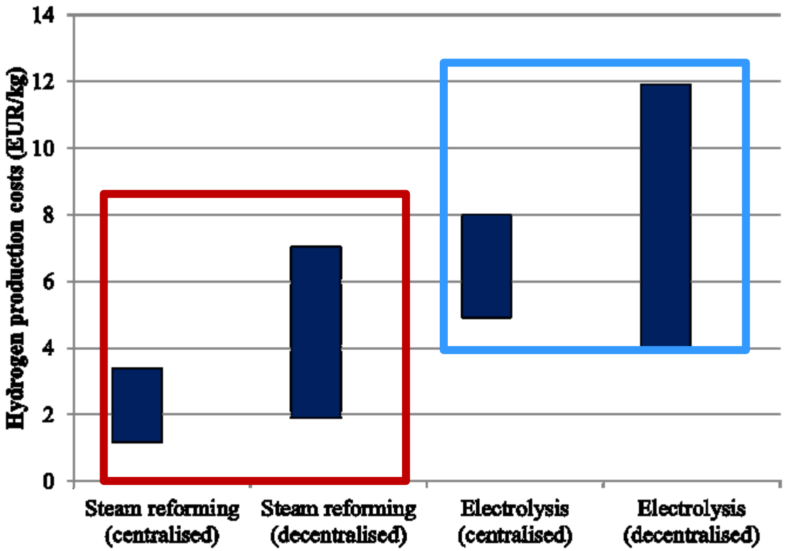
# Hydrogen supply chains



# Global hydrogen use and production



# Hydrogen production

## Steam reforming of natural gas

| *Application* | *Power or capacity* | *Efficiency* | *Initial investment cost* | *Life time* | *Maturity* |
|---|---|---|---|---|---|
| Steam reformer, large scale | 150-300 MW | 70-85% | 400-600 USD/kW | 30 years | Mature |
| Steam reformer, small scale | 0.15-15 MW | ~51% | 3 000-5 000 USD/kW | 15 years | Demon-stration |

In steam reforming of natural gas ca. **7 kg $CO_2$** are produced per kg hydrogen.

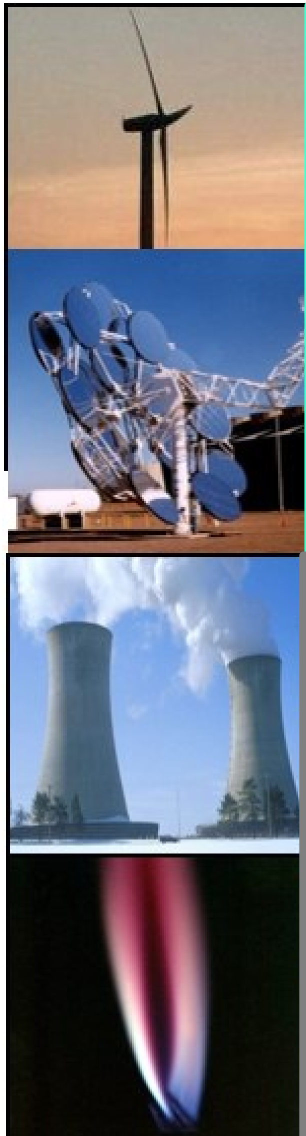
# Electrolyzer

| Application | Power or capacity | Efficiency | Initial investment cost | Life time | Maturity |
|---|---|---|---|---|---|
| Alkaline electrolyser | Up to 150 MW | 63-70% | 500-1 400 USD/kW | 60 000-<br>90 000 hours | Mature |
| PEM electrolyser | Up to 150 kW (stacks)Up to 1 MW (systems) | 56-60% | 1 100-1 800 USD/kW | 30 000-<br>90 000 hours | Early market |

Electrolysis requires ca. **9 liters** of water to produce **1 kg** hydrogen.

IEA, 2019

# Colors of hydrogen



**Biomass**
**Hydro**
**Wind**
**Solar**

→ Green H2

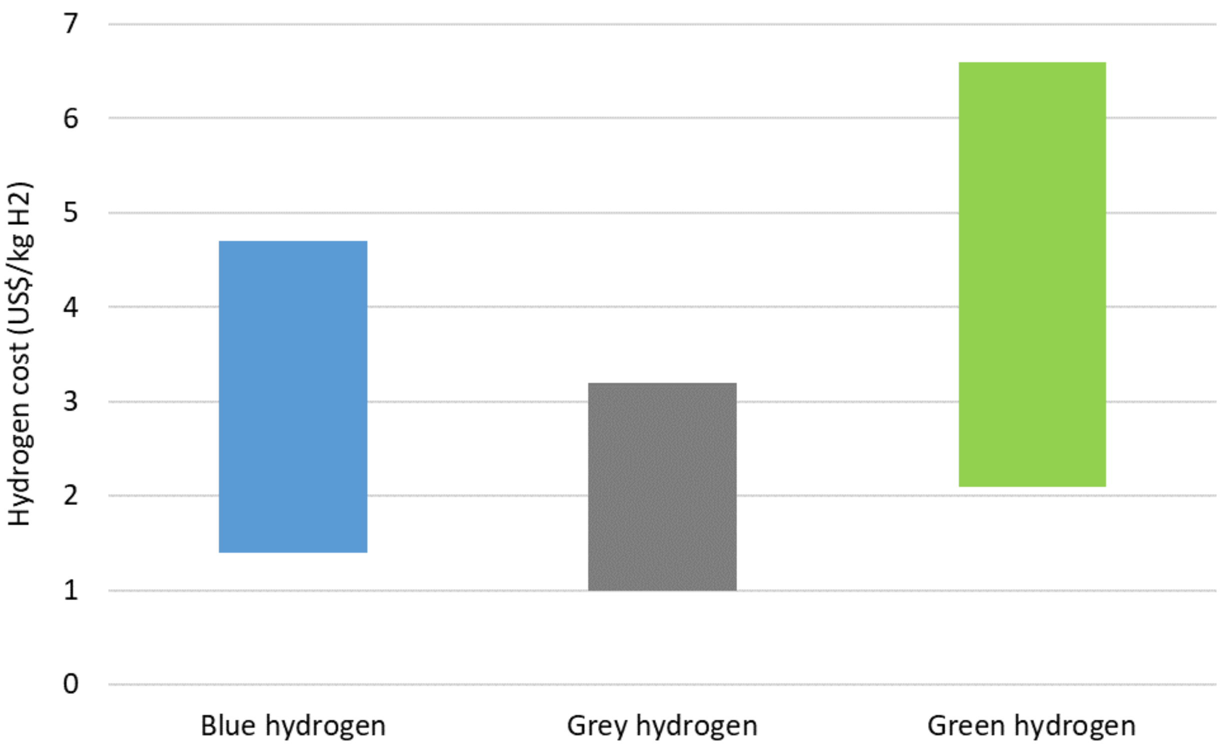
**Oil**
**Coal**
**Natural gas**

→ Grey H2

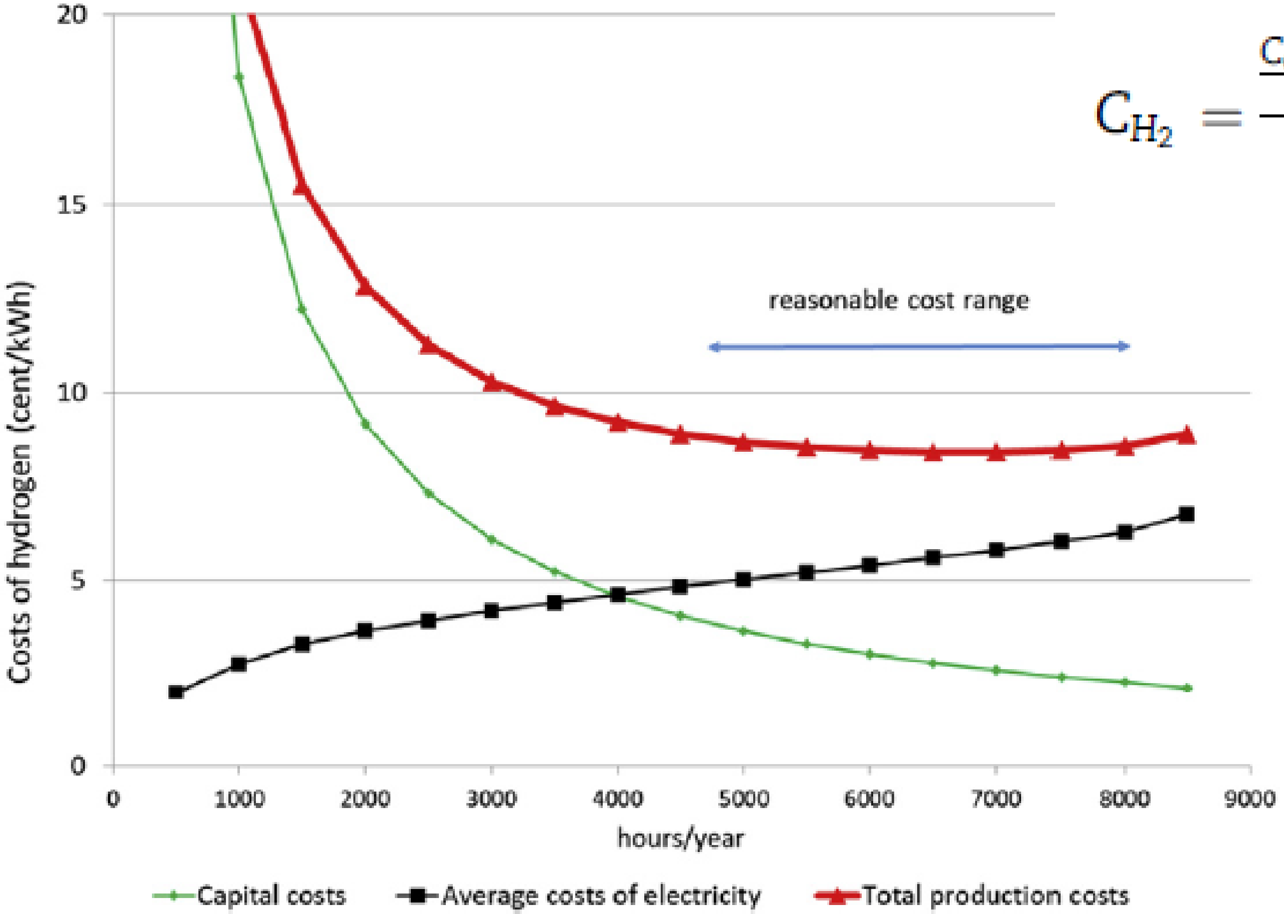
With Carbon Sequestration

→ Blue H2

# Cost of hydrogen production for different production pathways

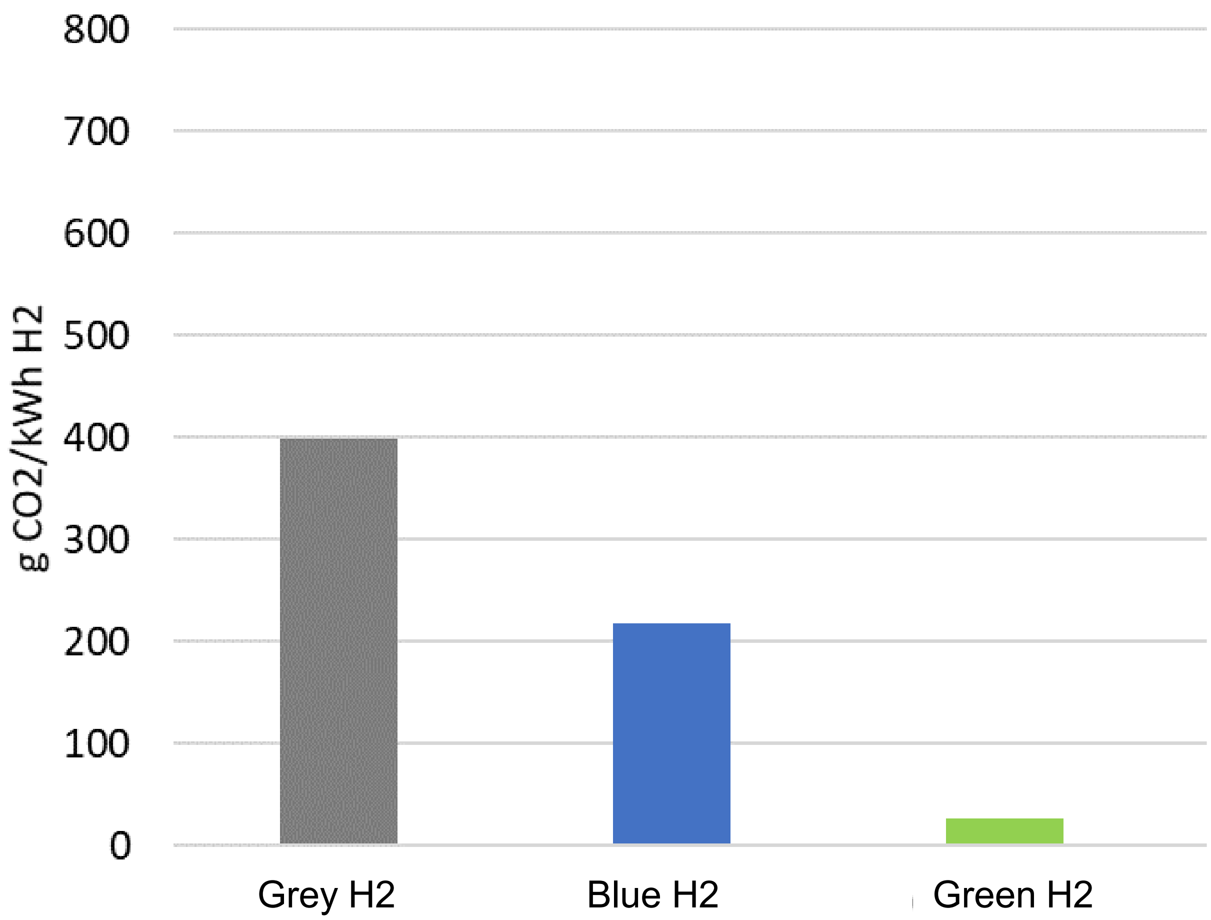


# Electrolysis




$$C_{H_2} = \frac{\frac{C_c + C_{O\&M}}{T} + C_E}{\eta}$$

# Emissions of hydrogen



# Economic assessment

The costs per km driven $C_{km}$ are calculated as:

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm}$$

[€/100 km driven]

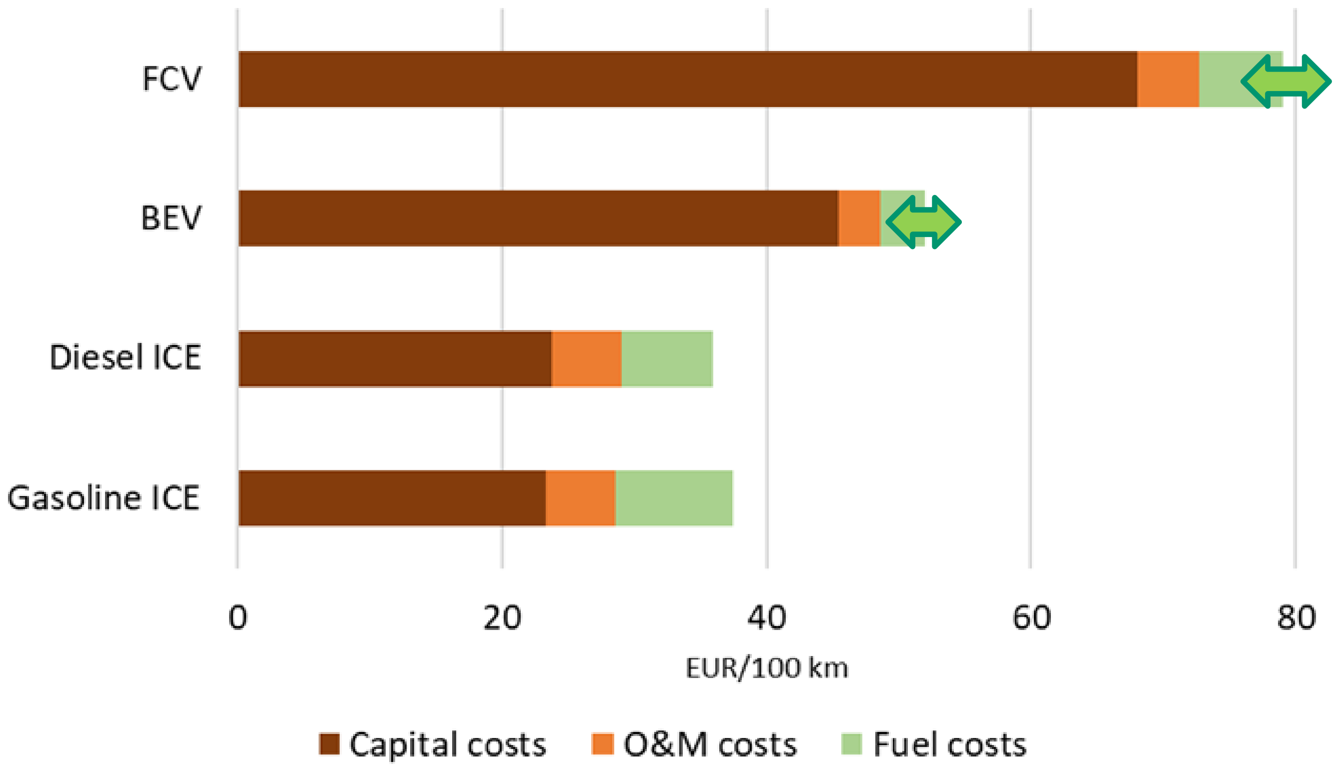
IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……..fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

A capital recovery factor (α) is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. Using an interest rate (z), the capital recovery factor is:

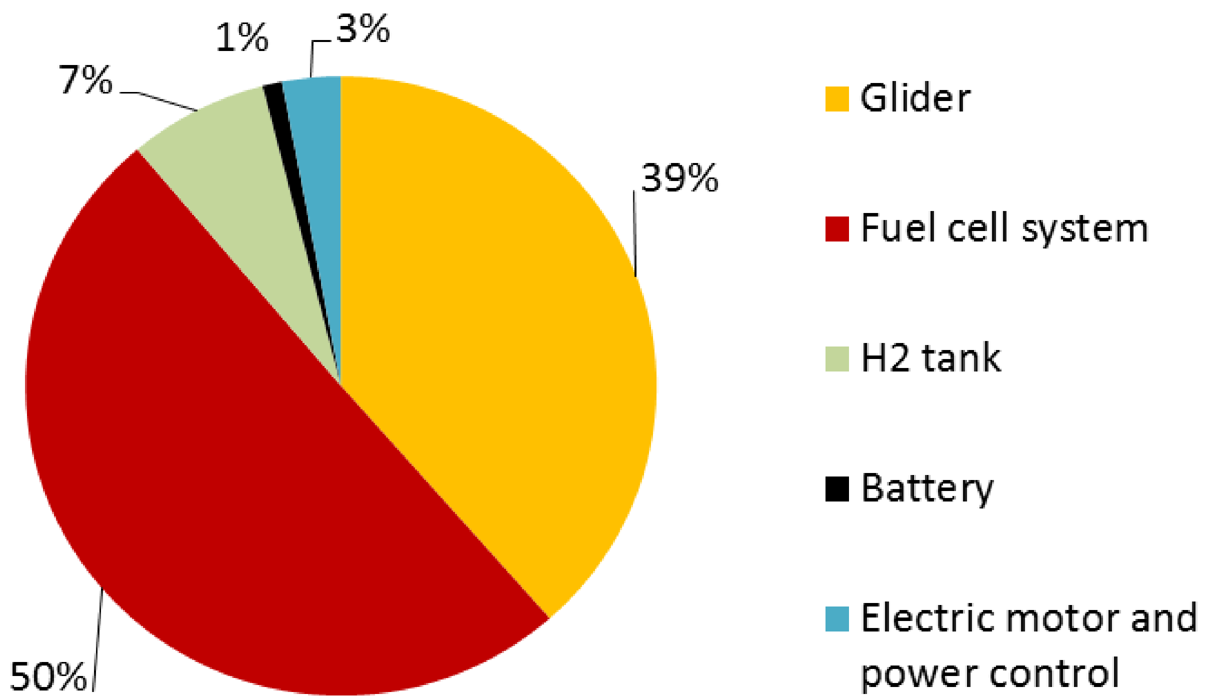
$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

n…..the number of annuities received.

# Mobility costs

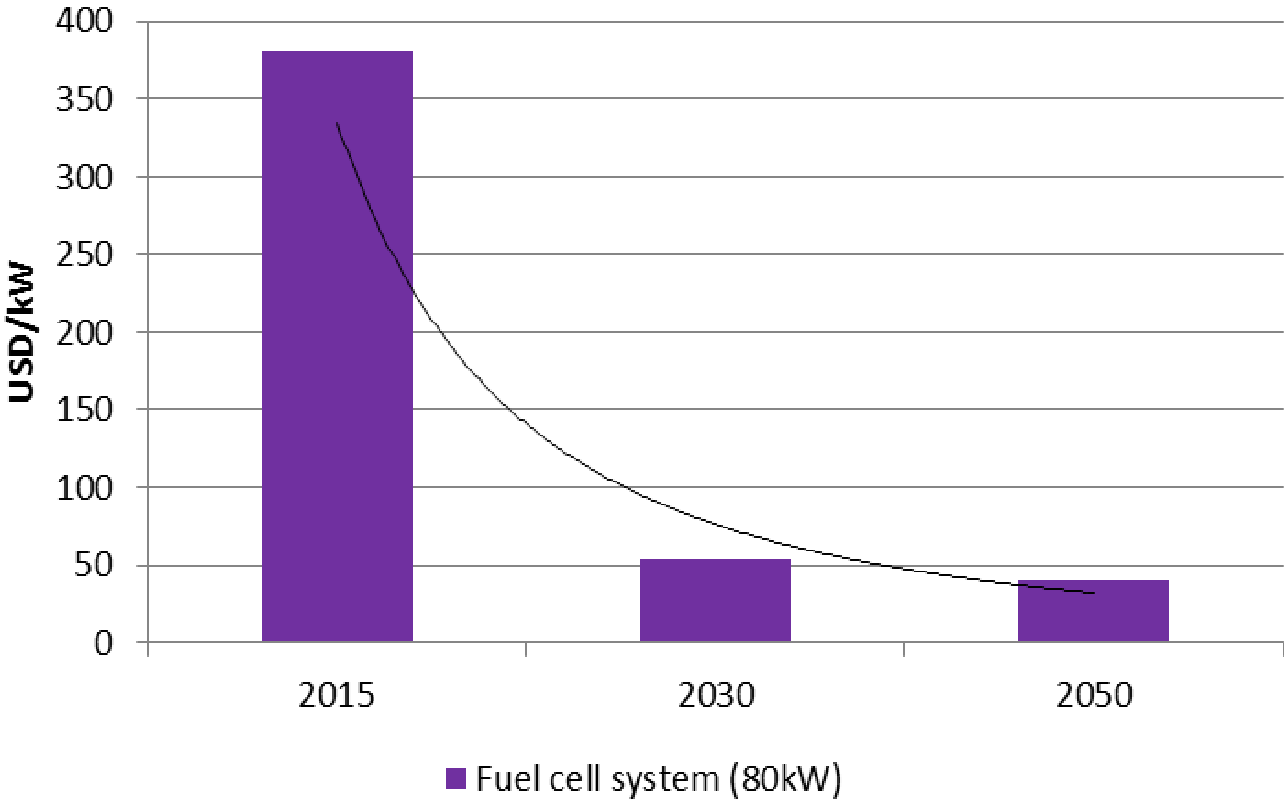


# Fuel cell vehicles




Structure of investment costs of fuel cell vehicles

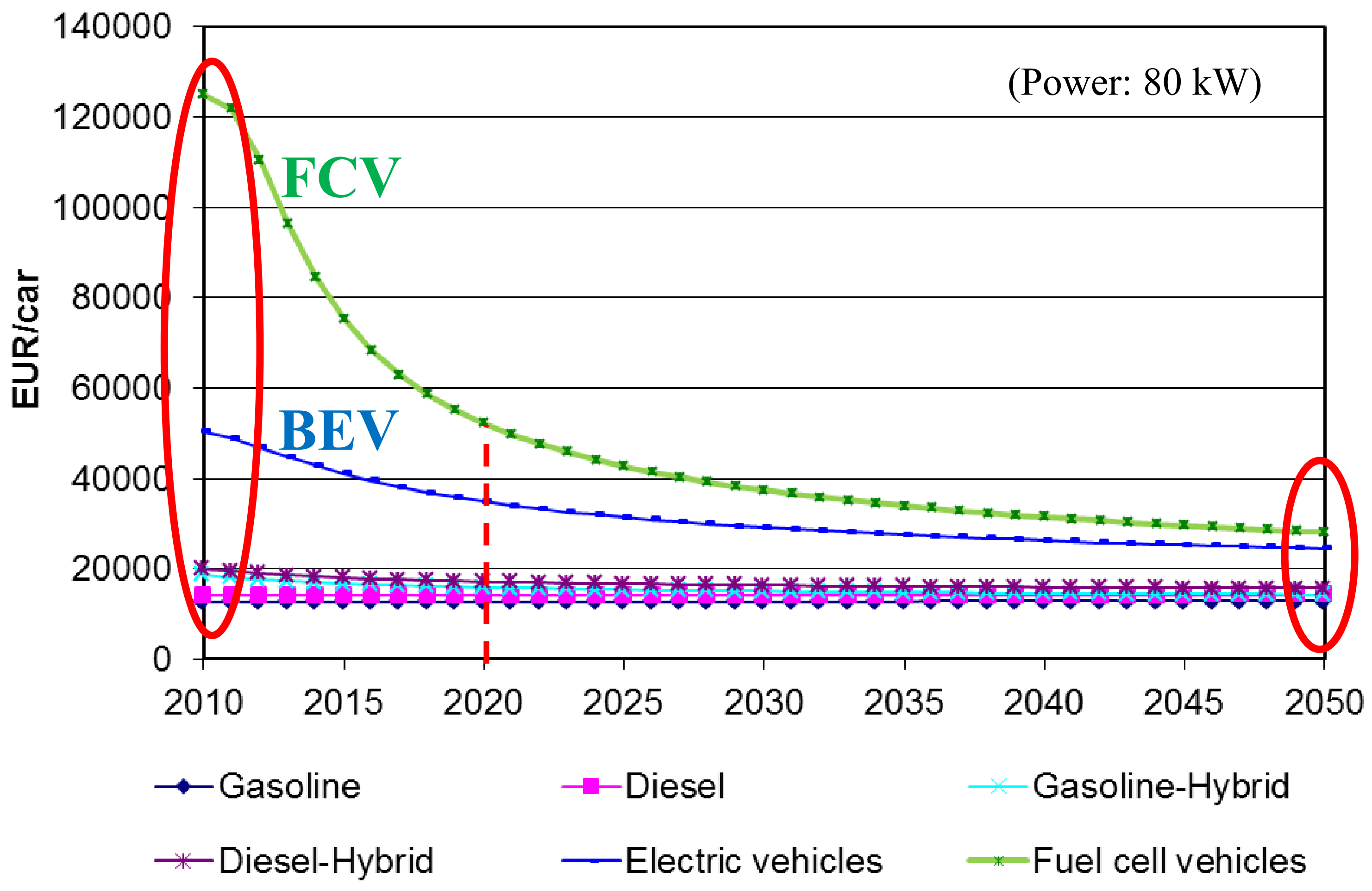
# Technological learning – Fuel cell

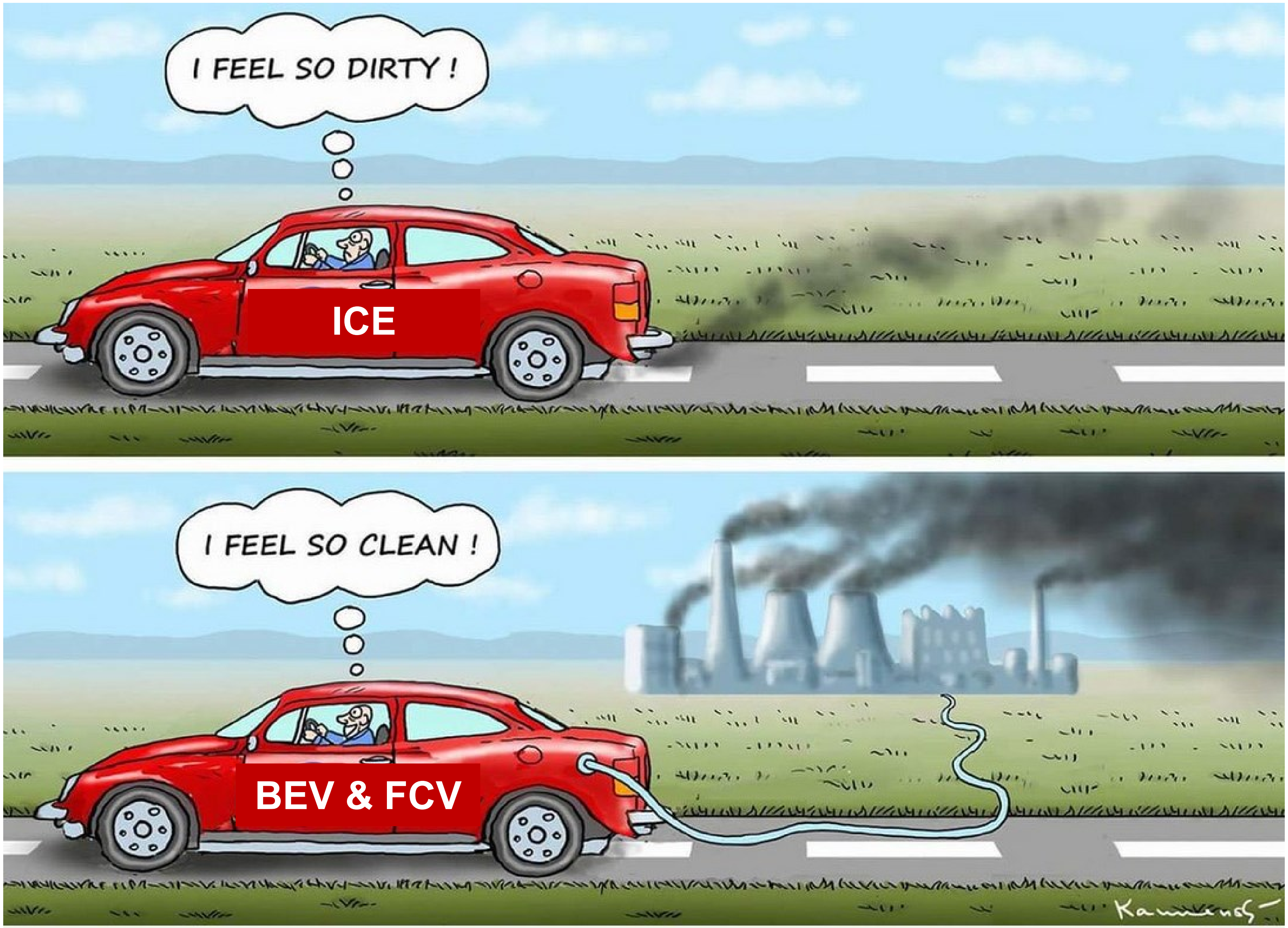



Development of the costs of the fuel cell system

# Scenario for development of investment costs

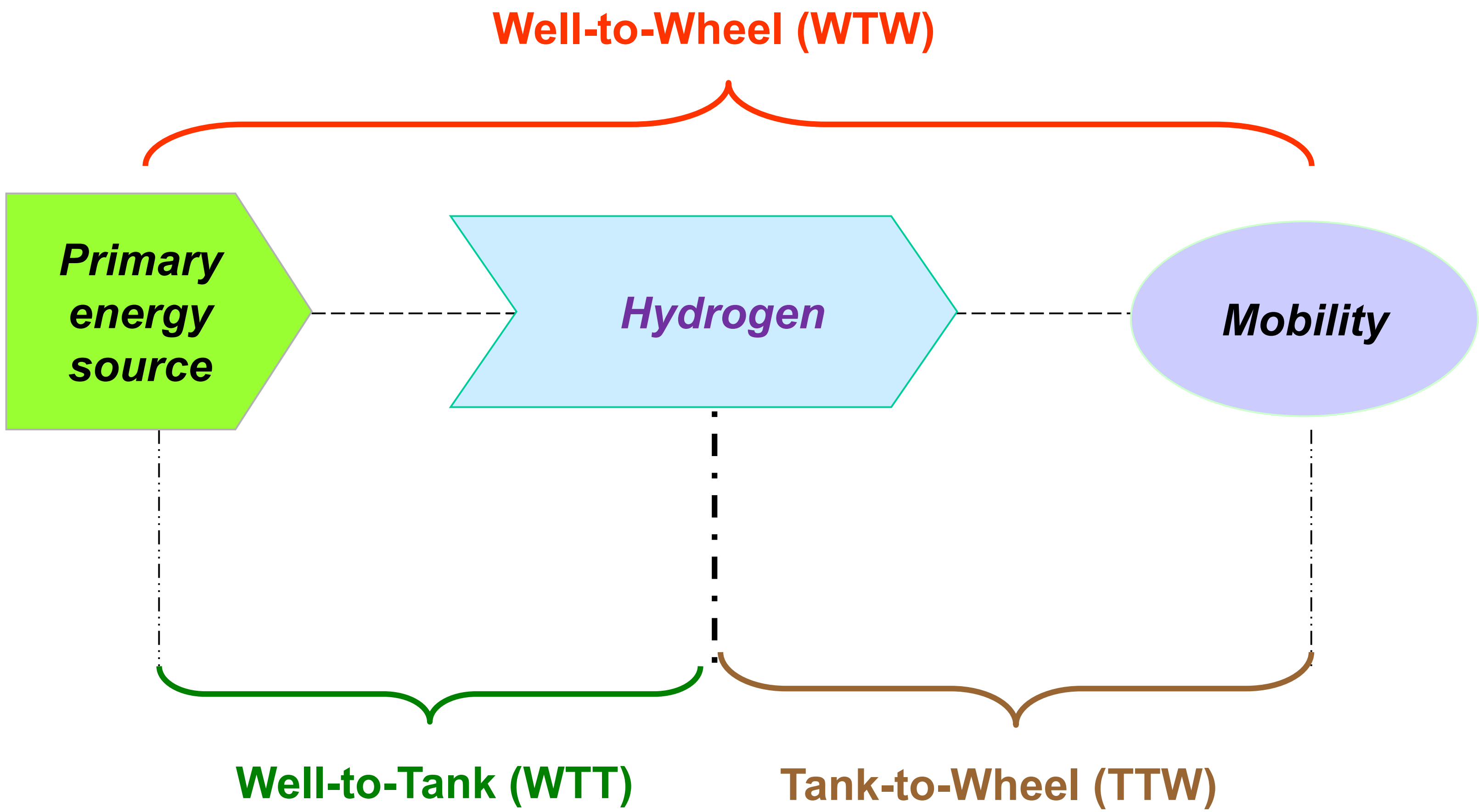
Technological learning:



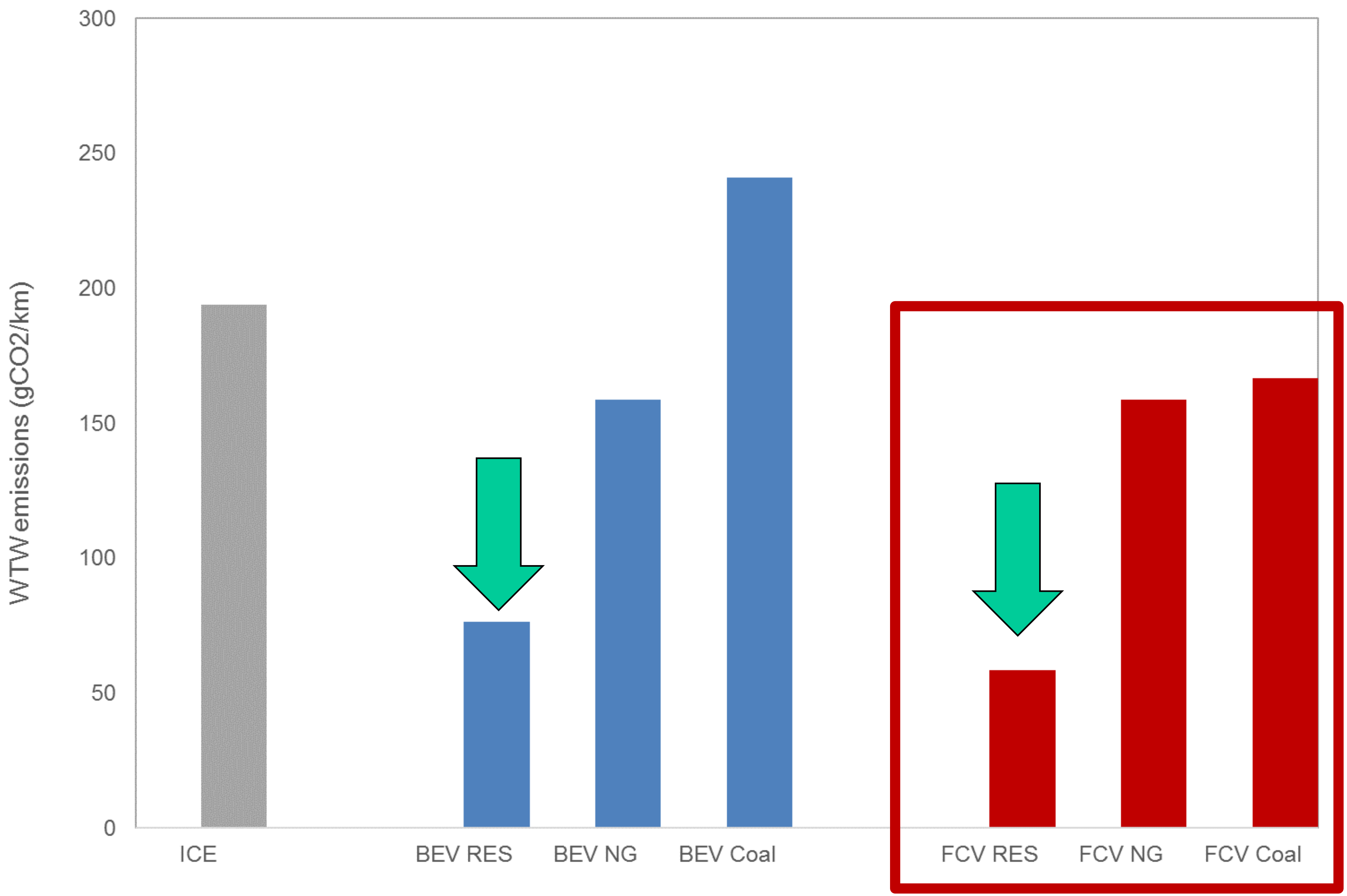



Artist: Marian Kamensky

# Environmental assessment



# Environmental assessment



# FCVs vs BEVs

**BEV**

- Costs
- Infrastructure
- Fuel efficiency

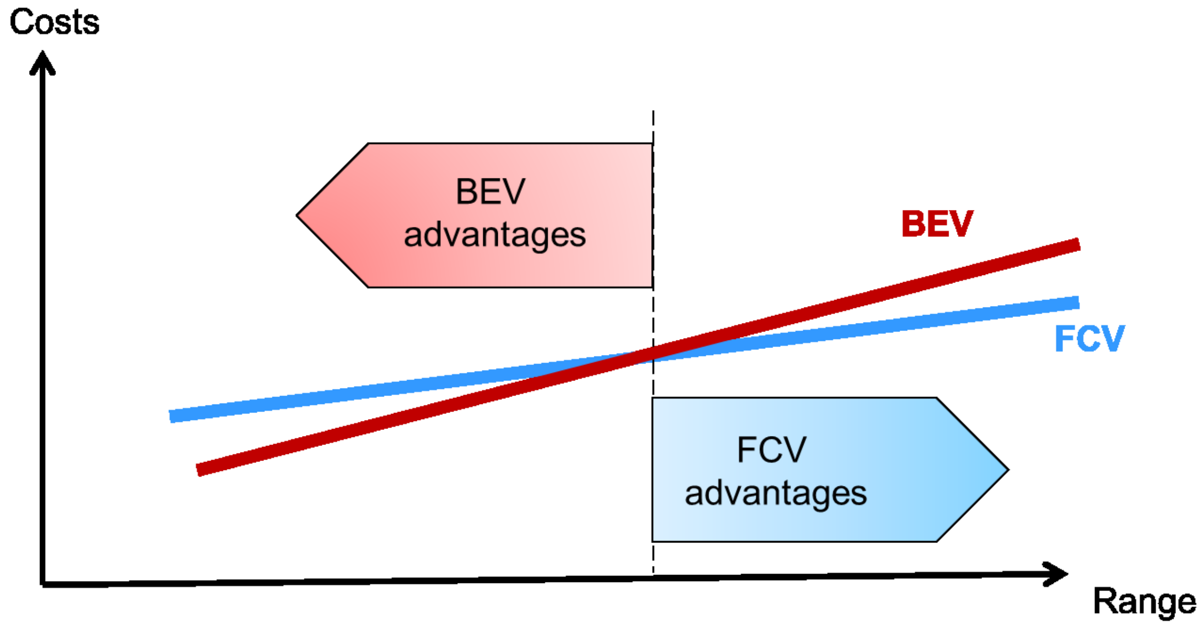
**FCV**

•Refuelling time

•Driving range

•Weight of energy storage

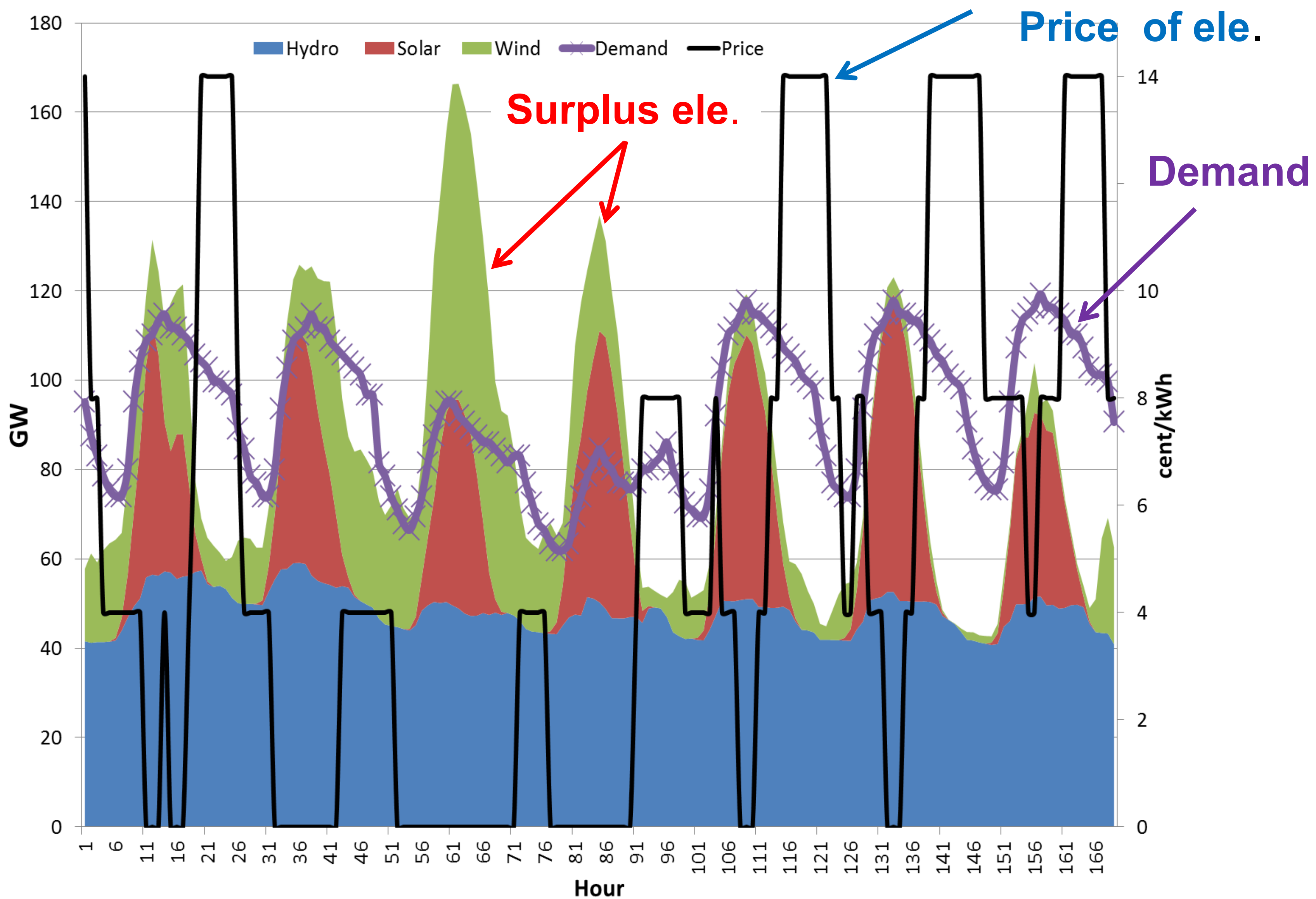
•Environmental benefits



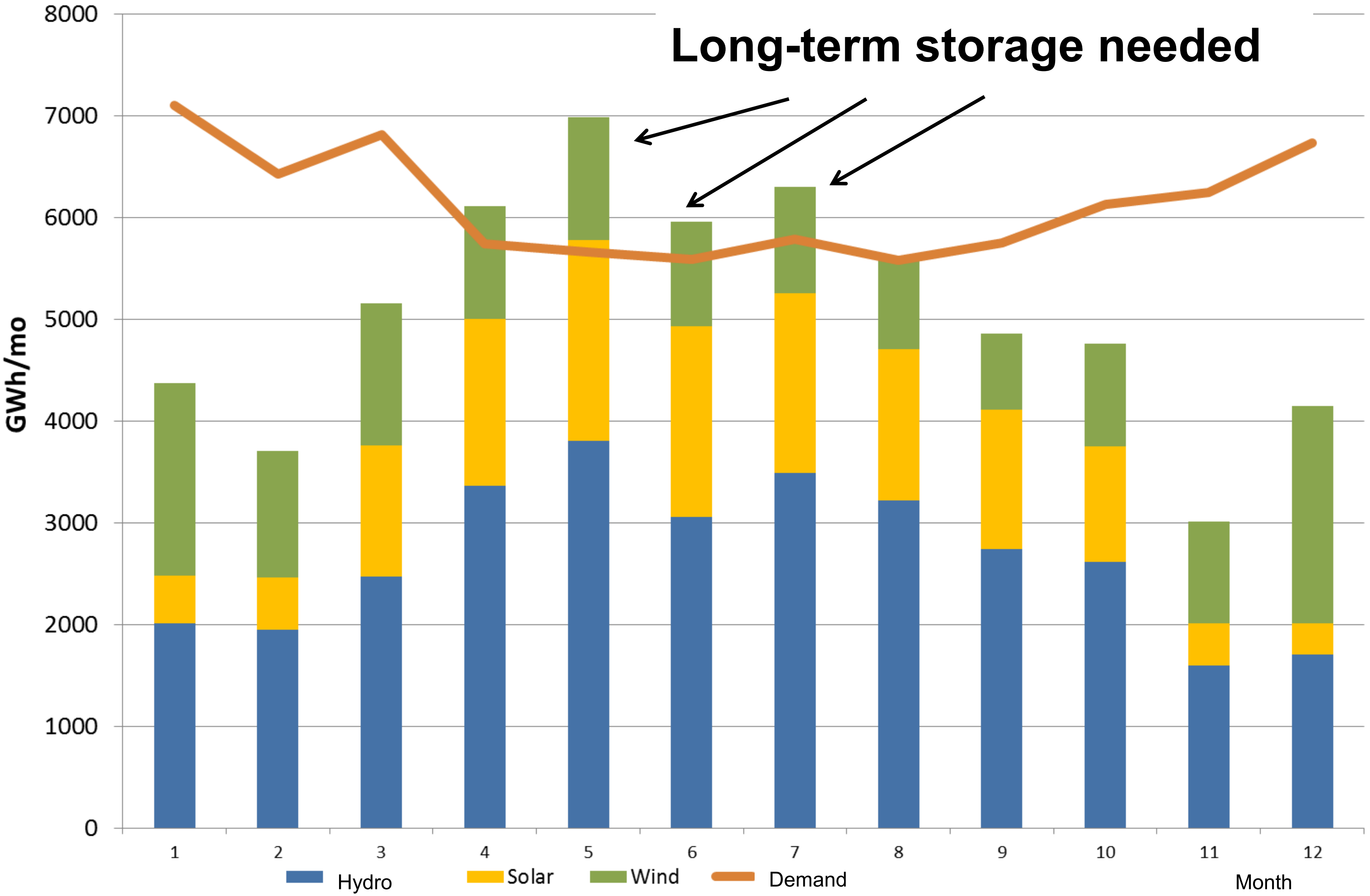
# Hydrogen as storage

- Major challenges of global energy system:
  - sufficient and secure energy supply
  - reduction of energy-related greenhouse gas emissions
- Increase use of renewable energy sources (RES)
- How to cope with excess electricity from RES

# *Integrating large shares of renewable electricity*

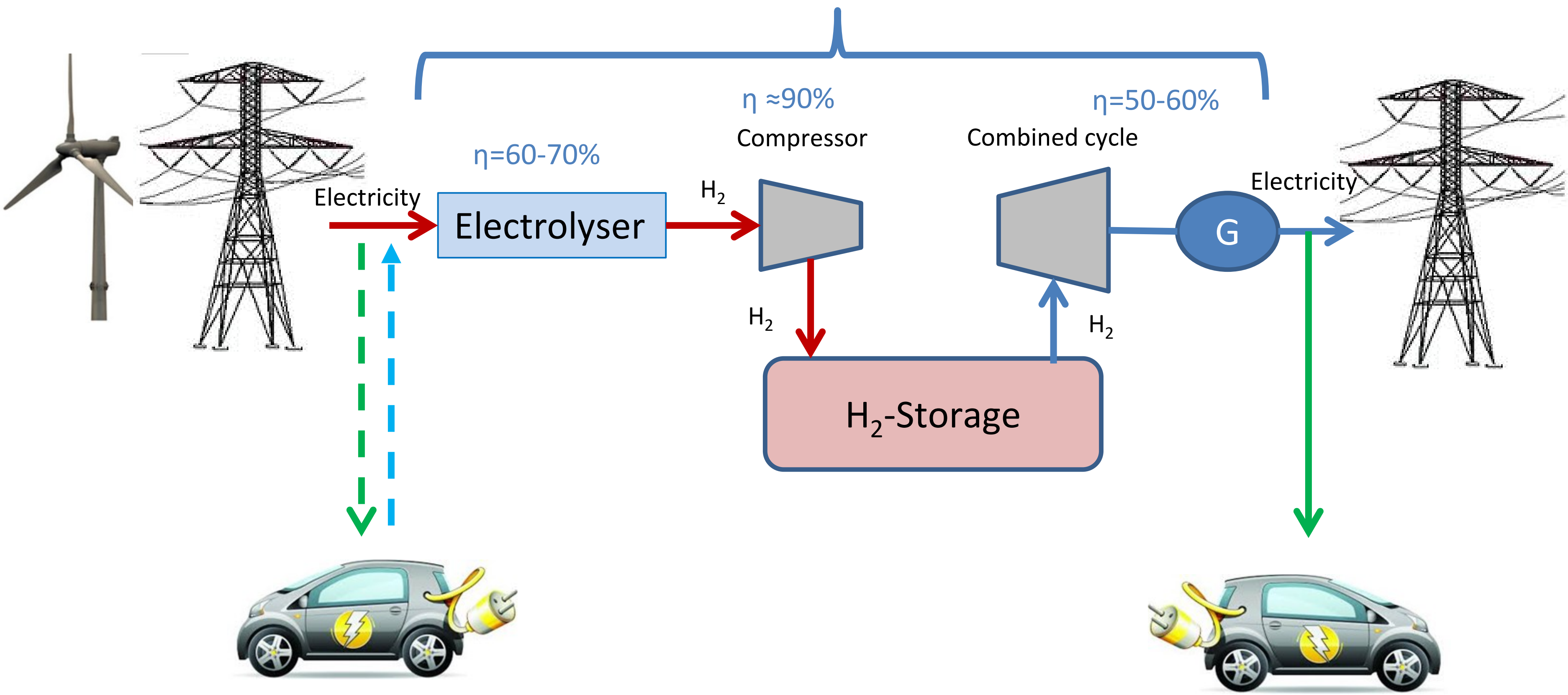


# Demand for long-term storage



# *Storage and fuel*

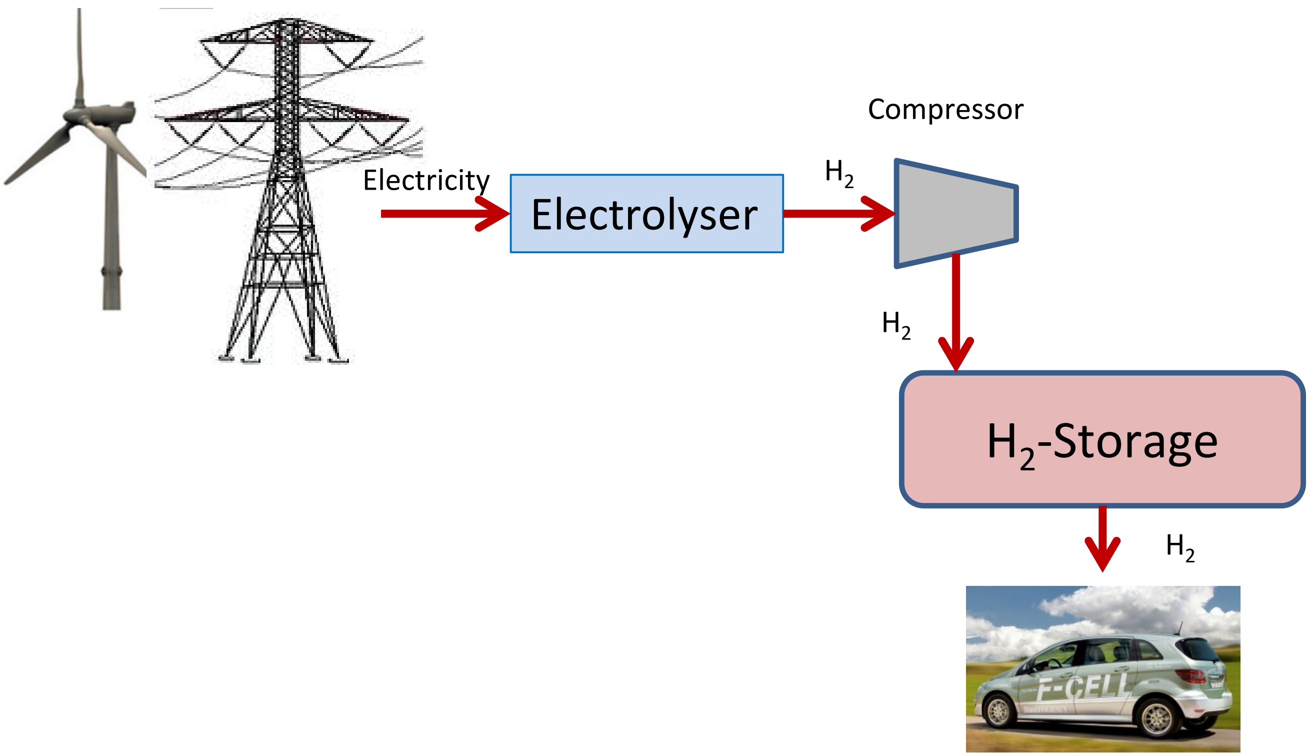
*Very low roundtrip efficiency for electricity!*




*Battery degradation*

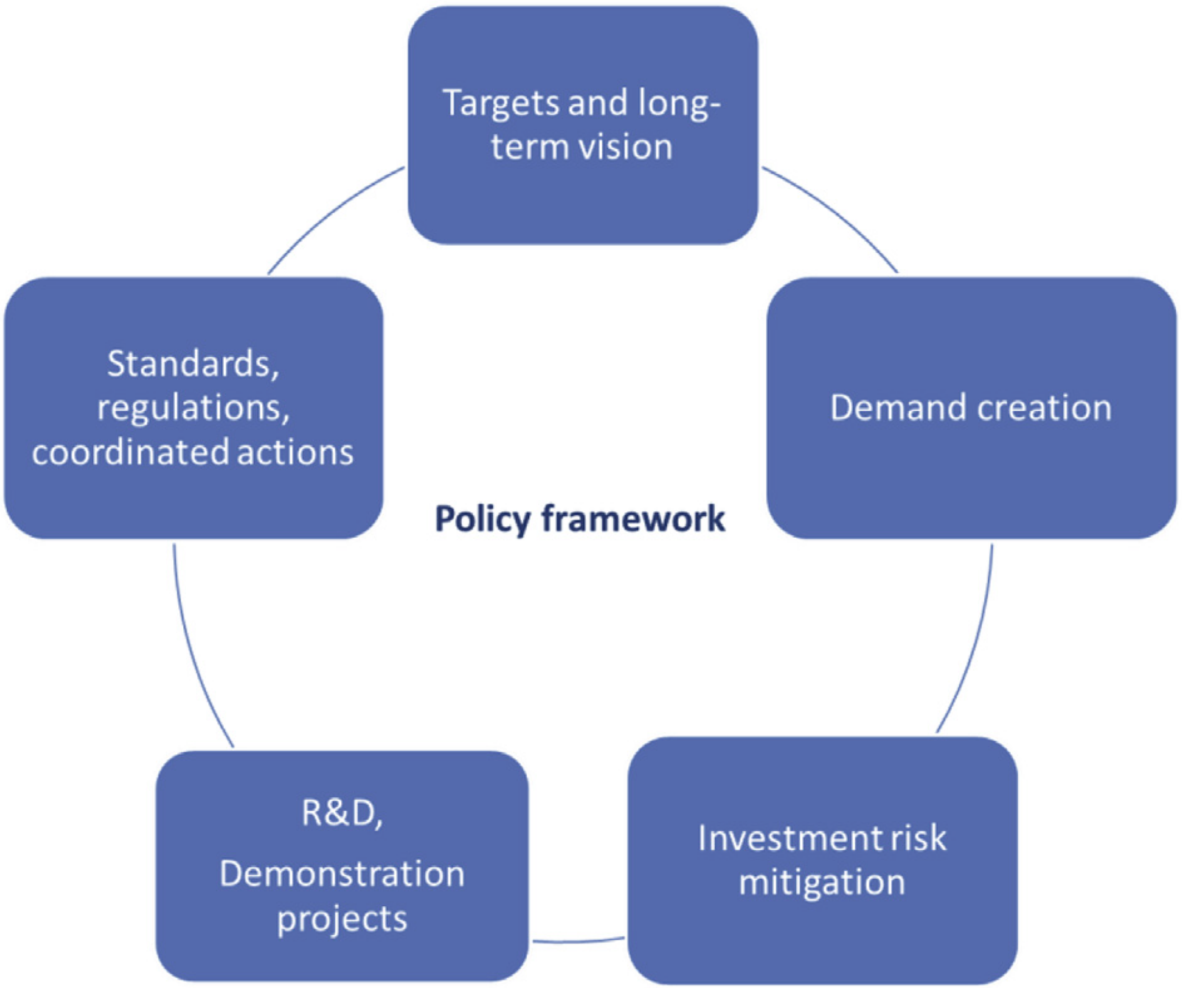
Energy supply chains: Storage and/or use of RES for mobility

# *Hydrogen: storage and fuel*

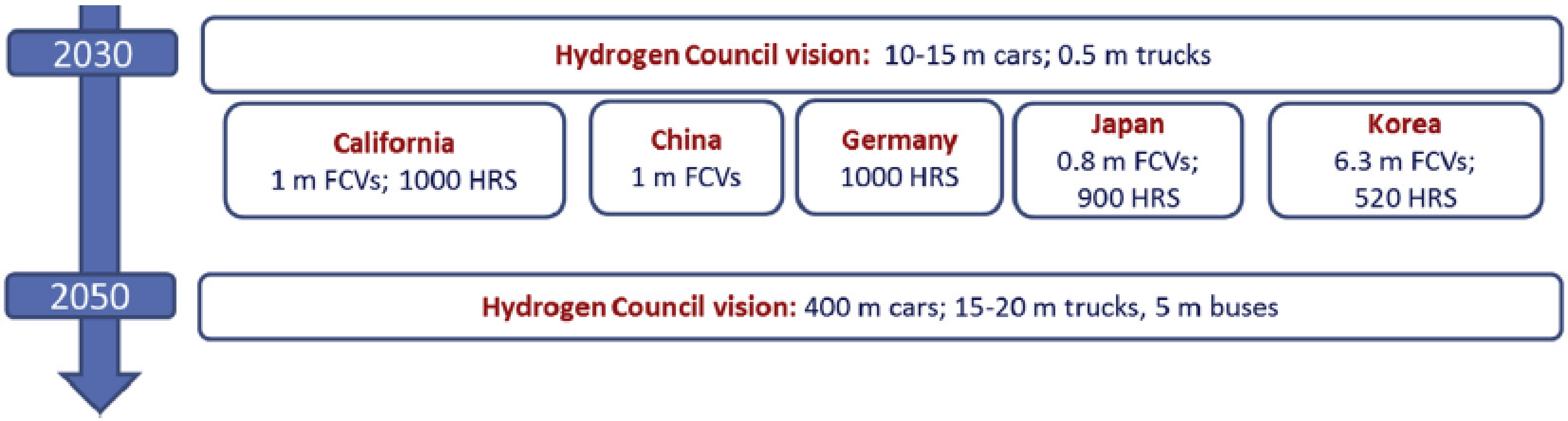



Energy supply chains: Storage and/or use of RES for mobility

# Policy framework



# Announced targets for FCV



# Uses of hydrogen

| | Current role | Demand perspective |
|---|---|---|
| **Cars and vans (light-duty vehicles)** | >28 000 vehicles in operation, mostly in California, Europe and Japan | The global car stock is expected to continue to grow; hydrogen could capture a part of this market |

Toyota Mirai

Honda Clarity


Hyundai Tucson

Hyundai Genesis

# Uses of hydrogen

| | Current role | Demand perspective |
|---|---|---|
| **Trucks and buses**<br>**(heavy duty vehicles)** | Demonstration and niche markets:<br>>25 000 forklifts<br>>500 buses<br>>400 trucks<br>>100 vans. | Strong growth segment; long-haul and heavy-duty applications are attractive for hydrogen |


Hydrogen Bus in the UK


Sunline Transit H2 Bus in CA


Hydrogen Bus in Norway

# Uses of hydrogen

| | Current role | Demand perspective |
|---|---|---|
| **Rail** | Two hydrogen trains in Germany | Rail is a mainstay of transport in many countries |

Coradia iLint Train, Germany

Energy Economics Group

# Applications of hydrogen fuel cells

TU WIEN

# Conclusions

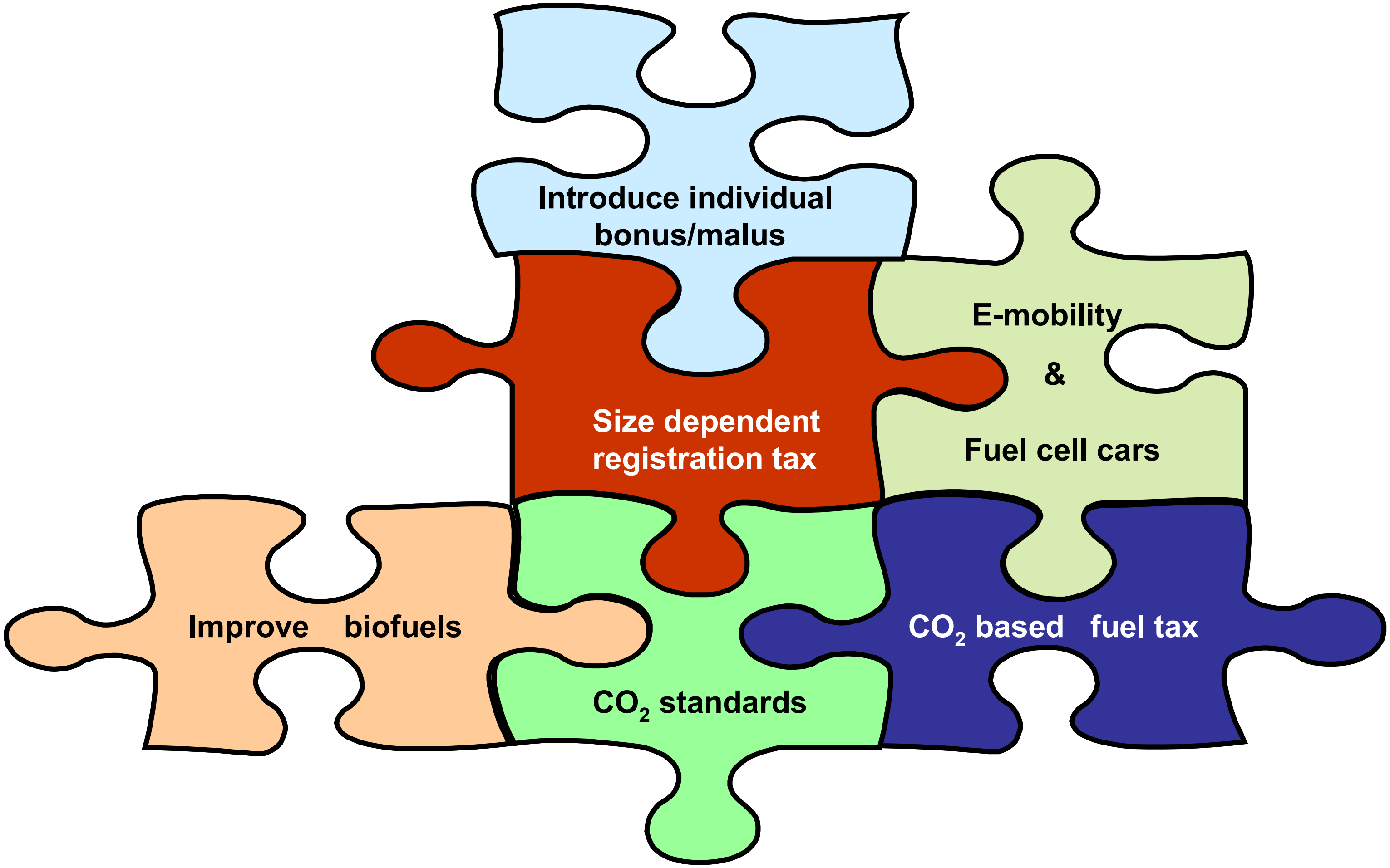
Hydrogen can help to:

- ✓ Increase diversification of energy used in transport
- ✓ Decarbonise different transport modes (incl. trucks, ships, planes)
- ✓ Enhance energy security
- ✓ Integrate more renewables, serving as storage and providing flexibility to grid balance

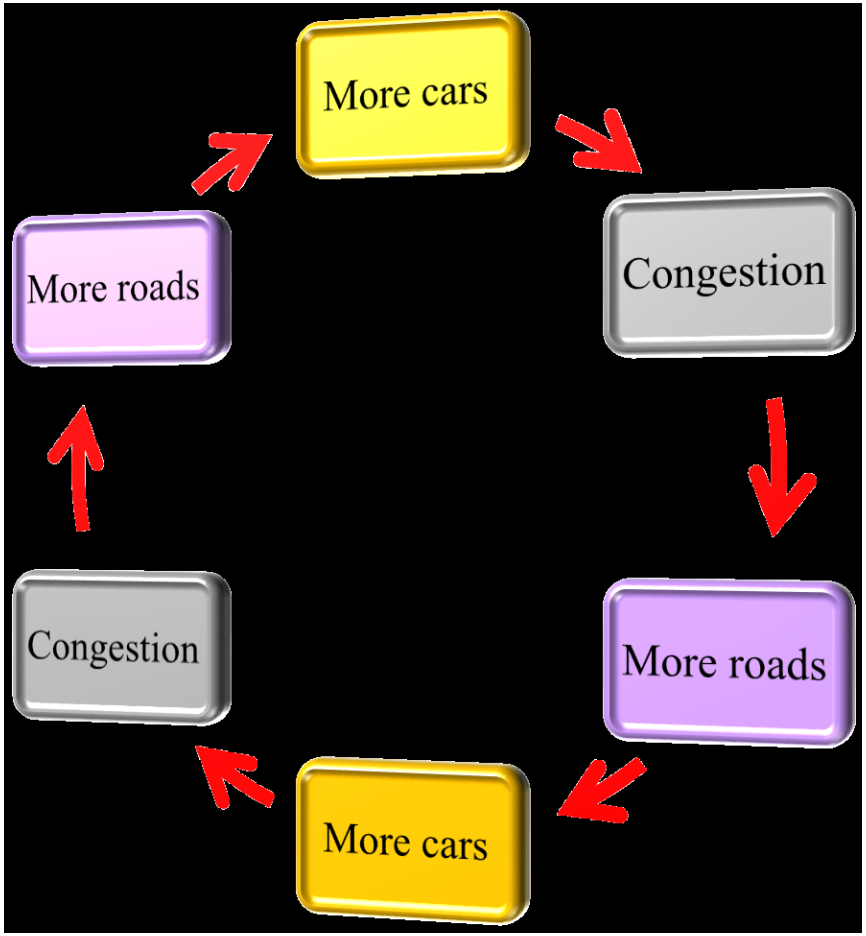
Major challenges for hydrogen and FCV:

- Economics
- Infrastructure
- Policies framework

# Conclusions



# *Car-oriented mobility*

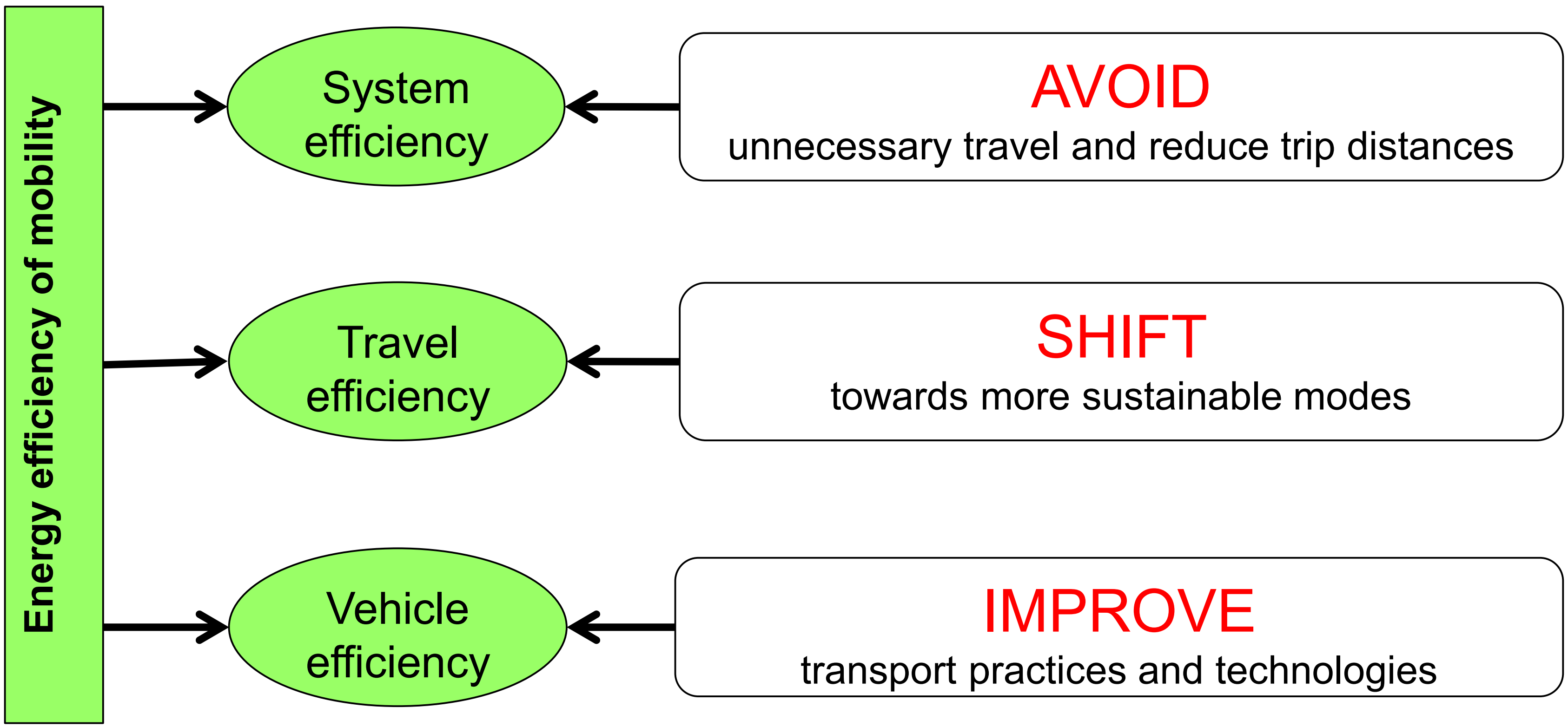


# Conclusions

Car-oriented transport development

https://simotron.files.wordpress.com

# *Strategies for energy efficient mobility*



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