Interdisciplinary Summer School 2025

Energy &Transport

Prospects for hydrogen and fuel cell vehicles

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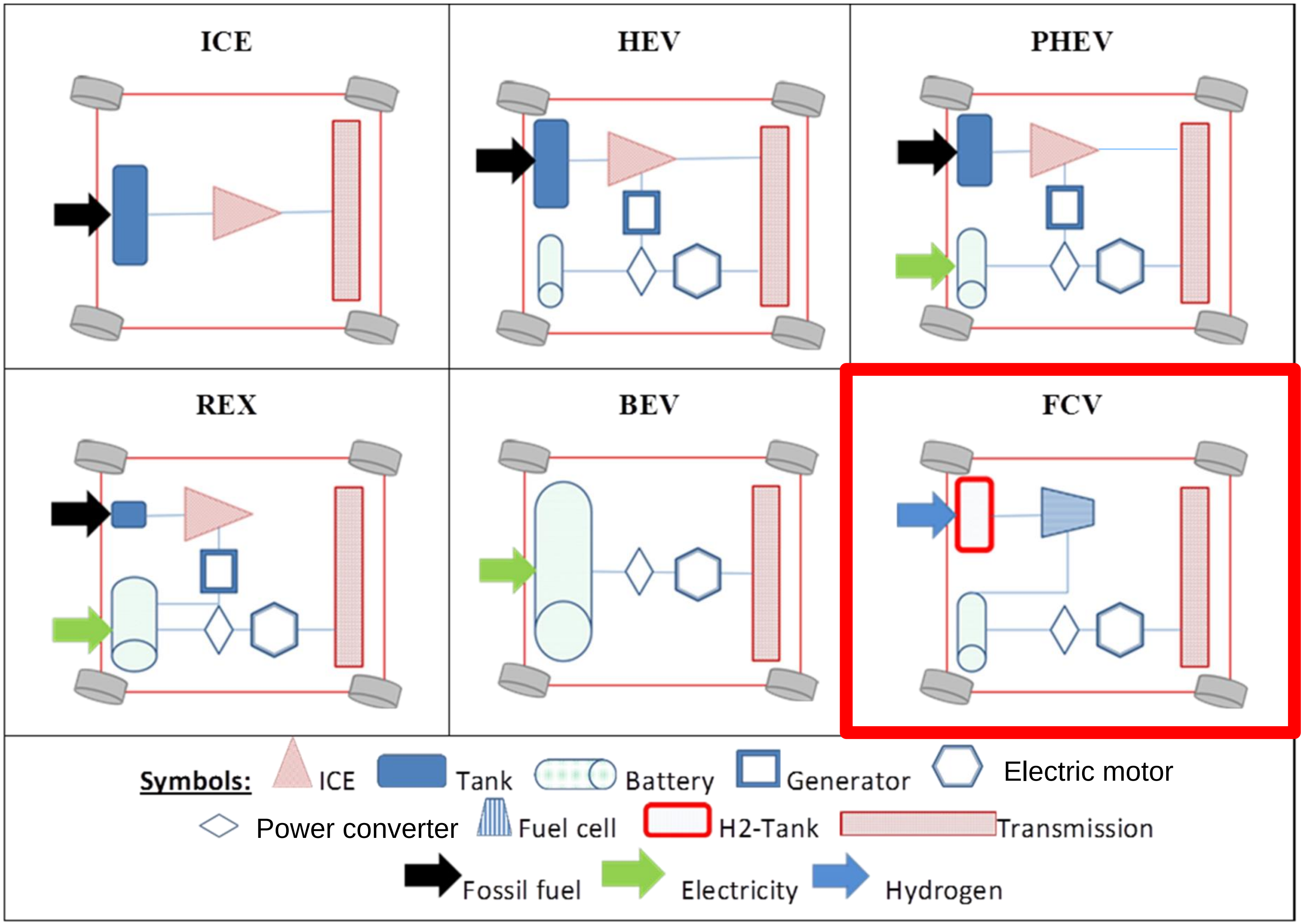
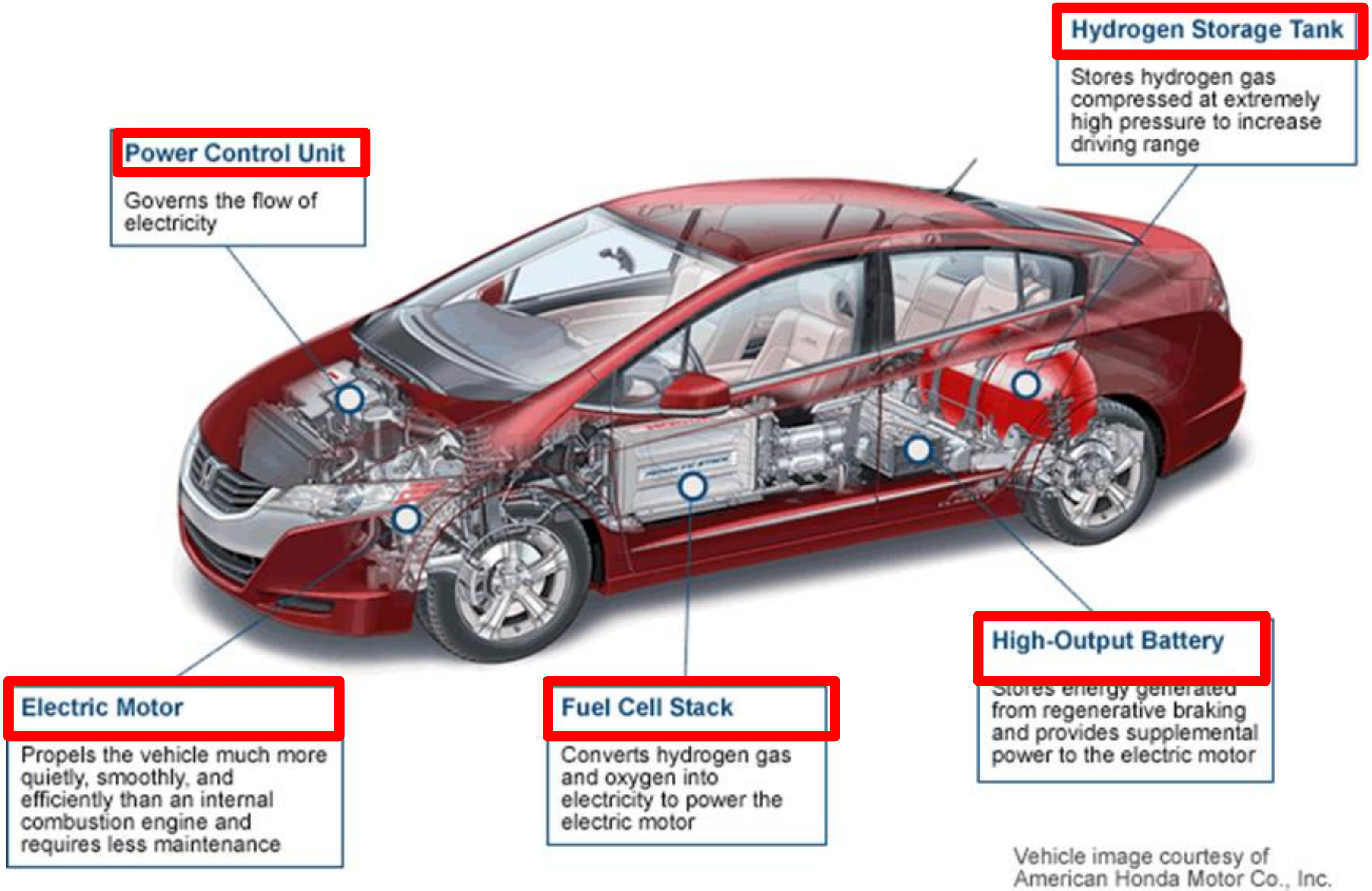
Electric vehicles

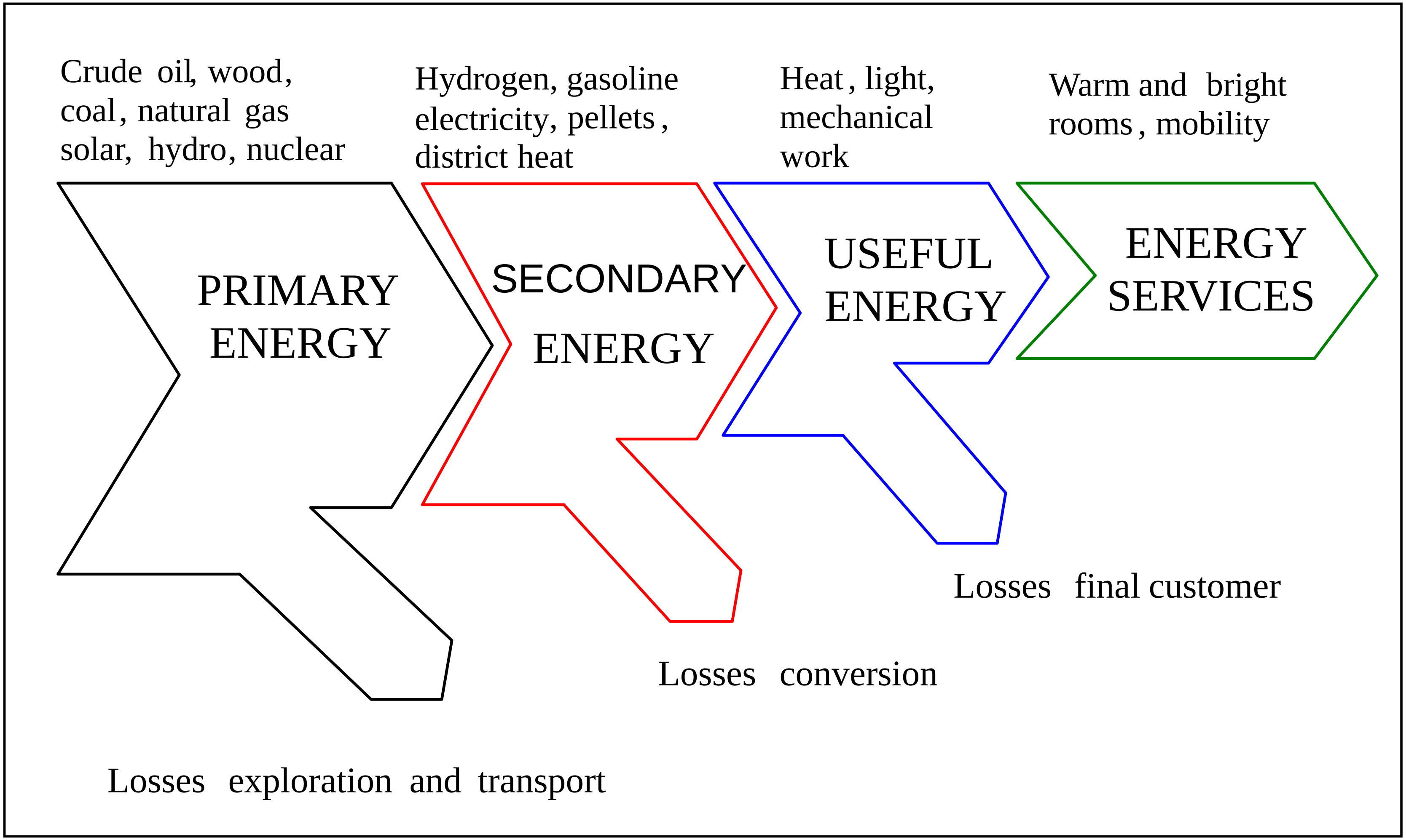


FCV



Major components of a fuel cell-powered passenger car

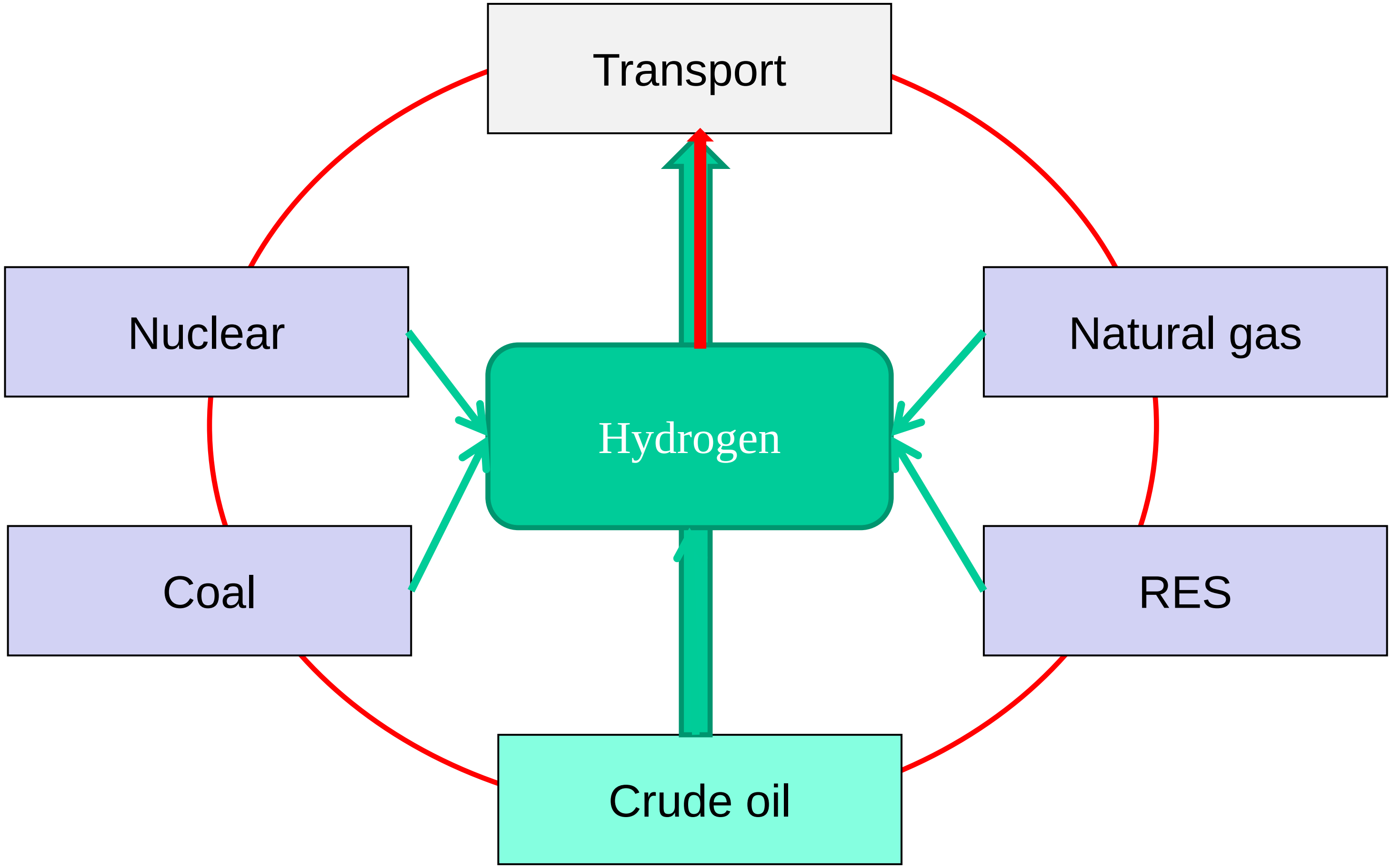
Energy supply chains



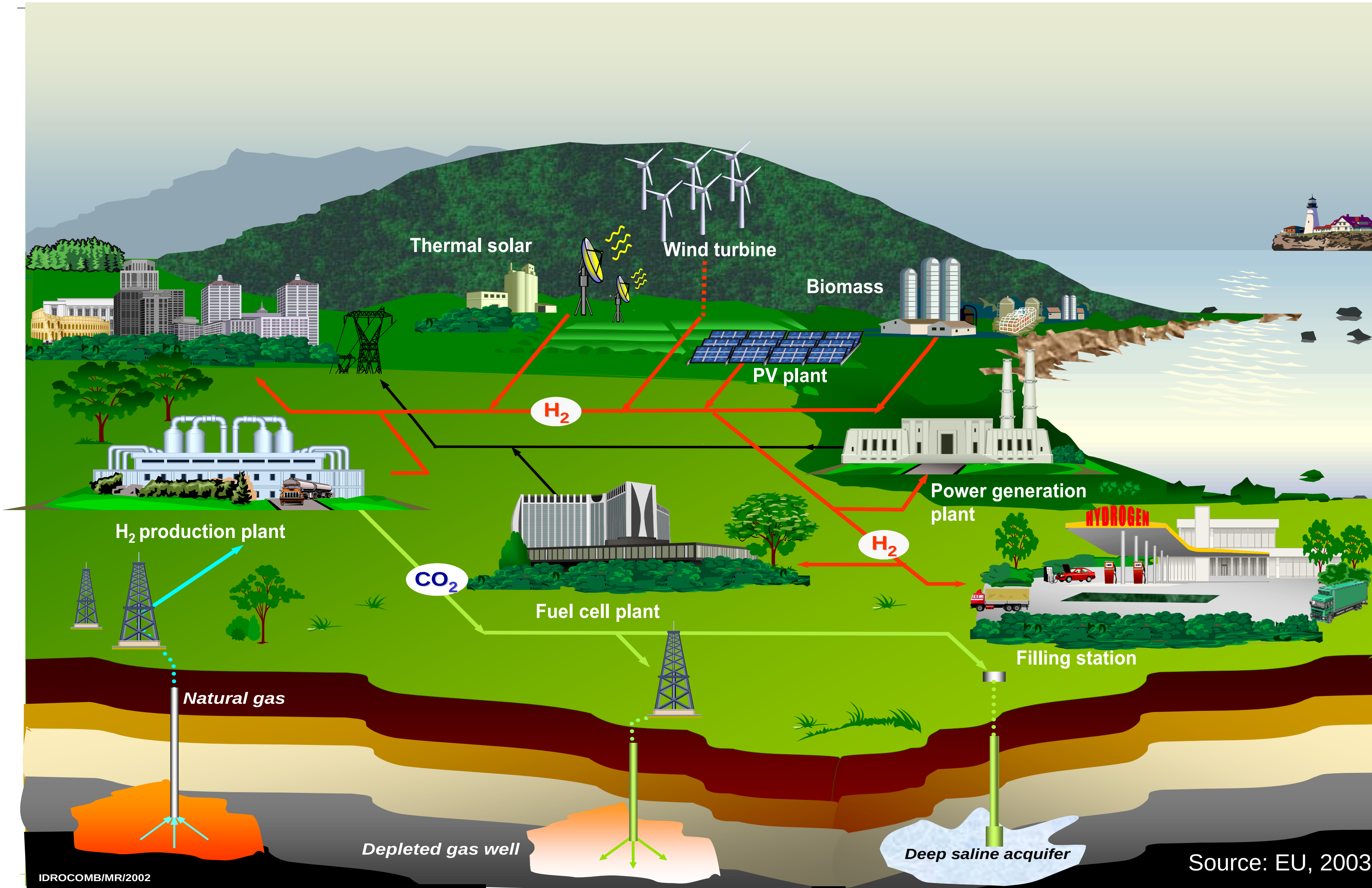
Hydrogen

- 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



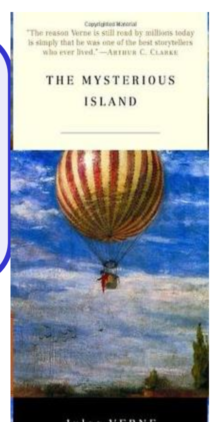
Source: EU, 2003

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)

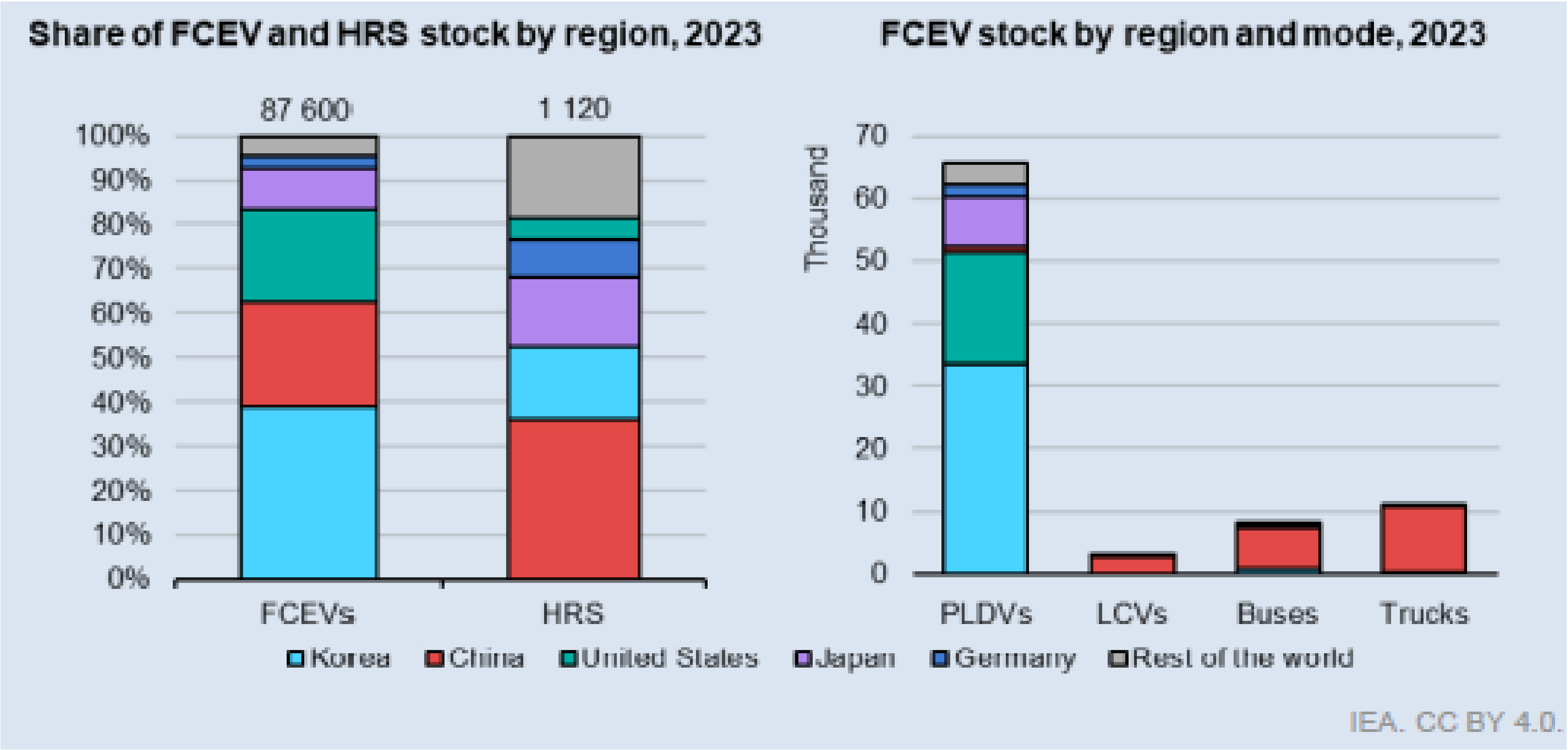
2011: > 100 fuel cell buses worldwide

2013: > 4000 fuel cell forklifts worldwide

2015: First hydrogen fuel cell powered tramcar

2023: The global FCV stock >87 000

FCV



Share of FCEV and HRS stock by region, 2023
87 600
1 120
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
FCEVs
HRS
FCEV stock by region and mode, 2023
Thousand
70
60
50
40
30
20
10
0
PLDVs
LCVs
Buses
Trucks
Korea
China
United States
Japan
Germany
Rest of the world
IEA. CC BY 4.0.

FCVs

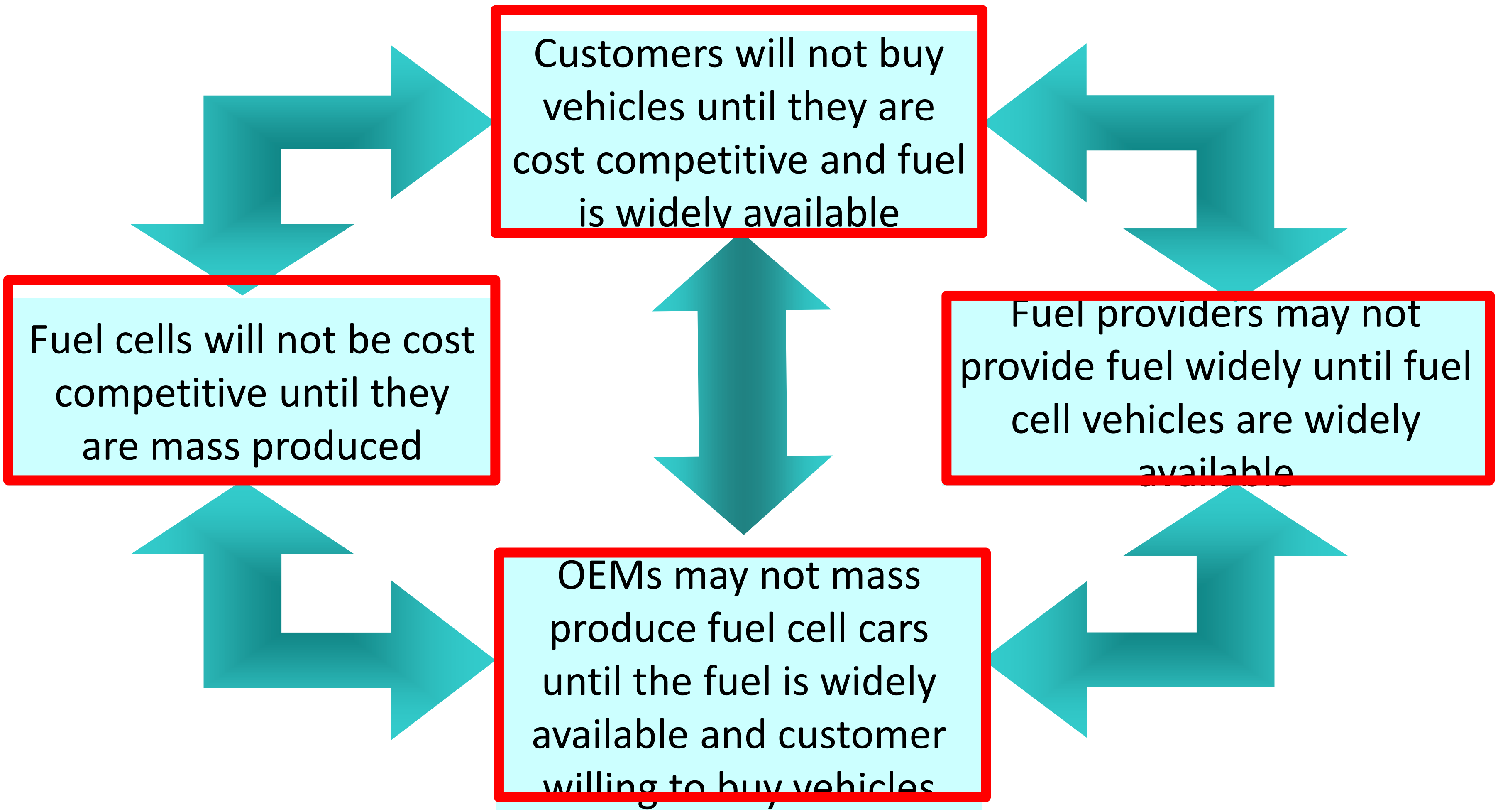
The main reasons for the slow introduction of FCVs:

- 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

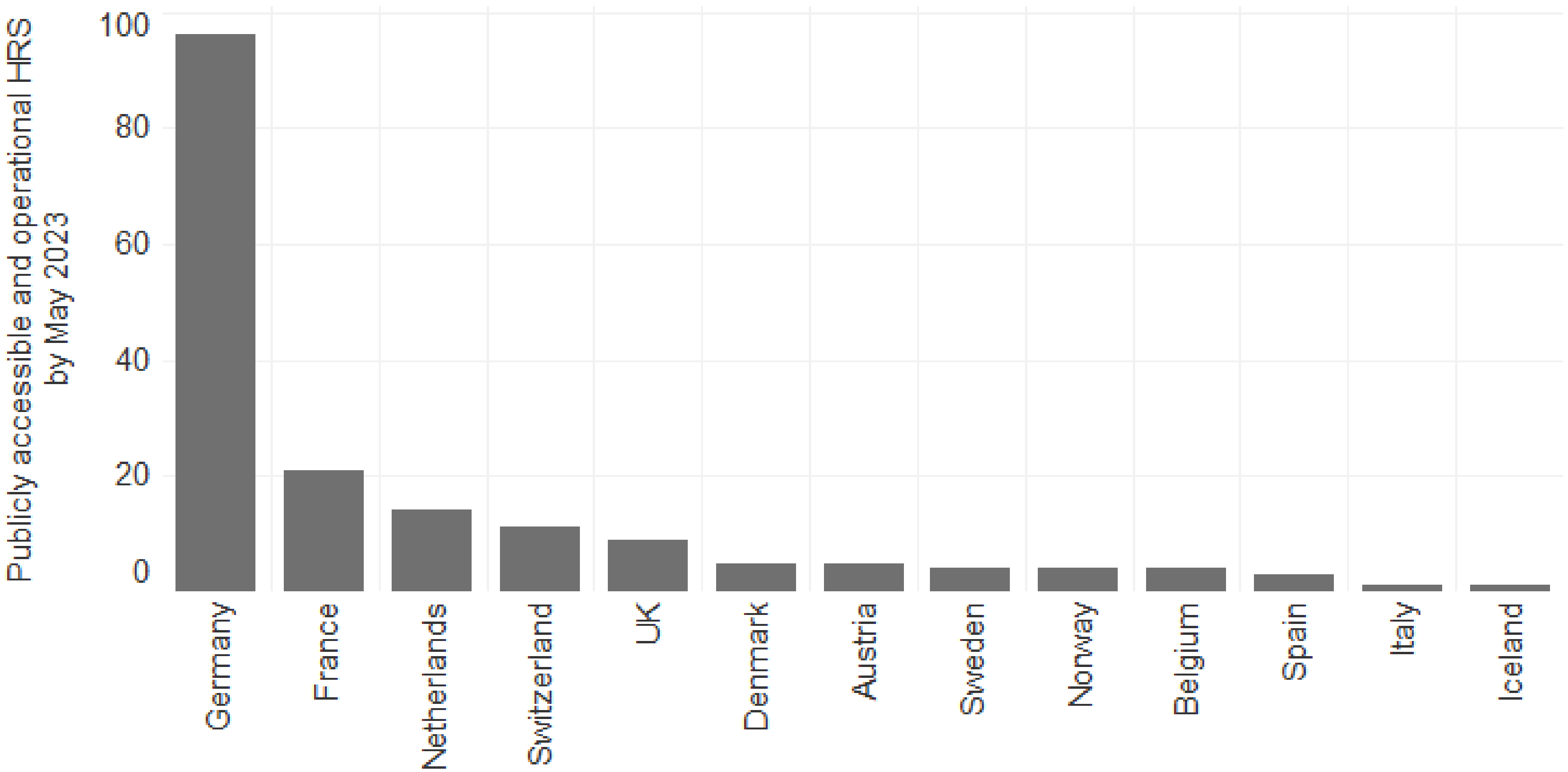
'Chicken and egg' dilemma



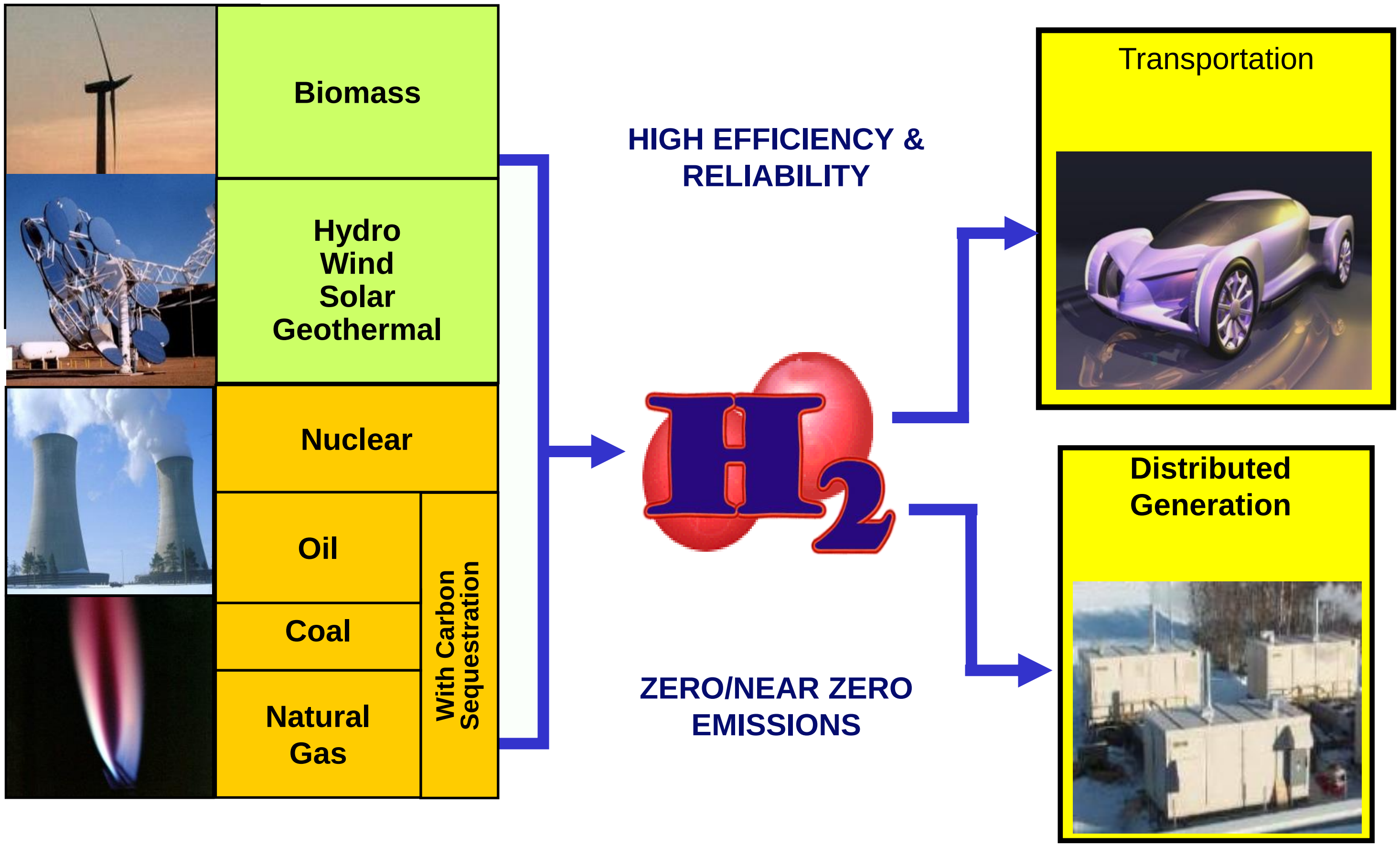
The transition to a hydrogen economy is complex

OEM-Original Equipment Manufacturer

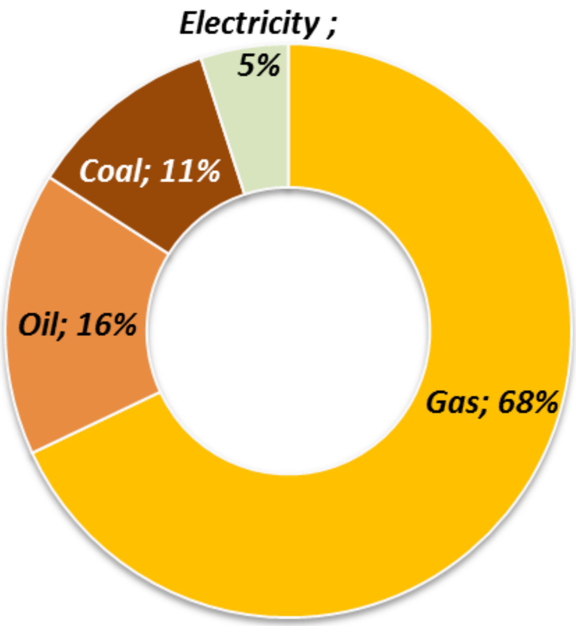
Refuelling stations

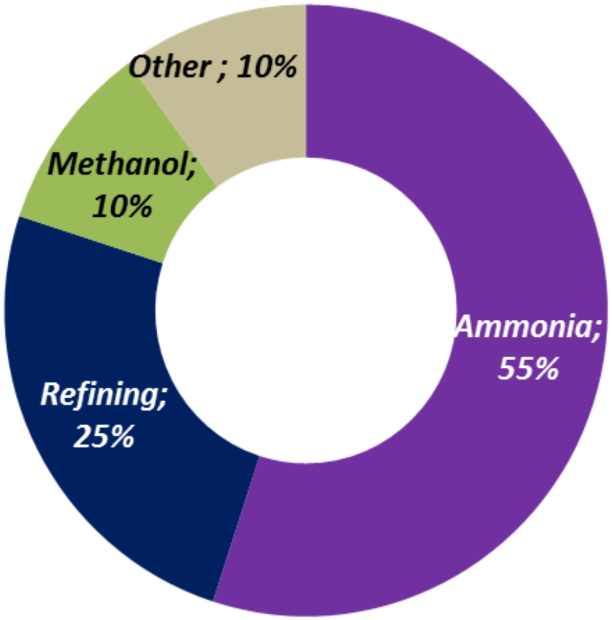


Hydrogen supply chains



Global hydrogen use and 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- 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- 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

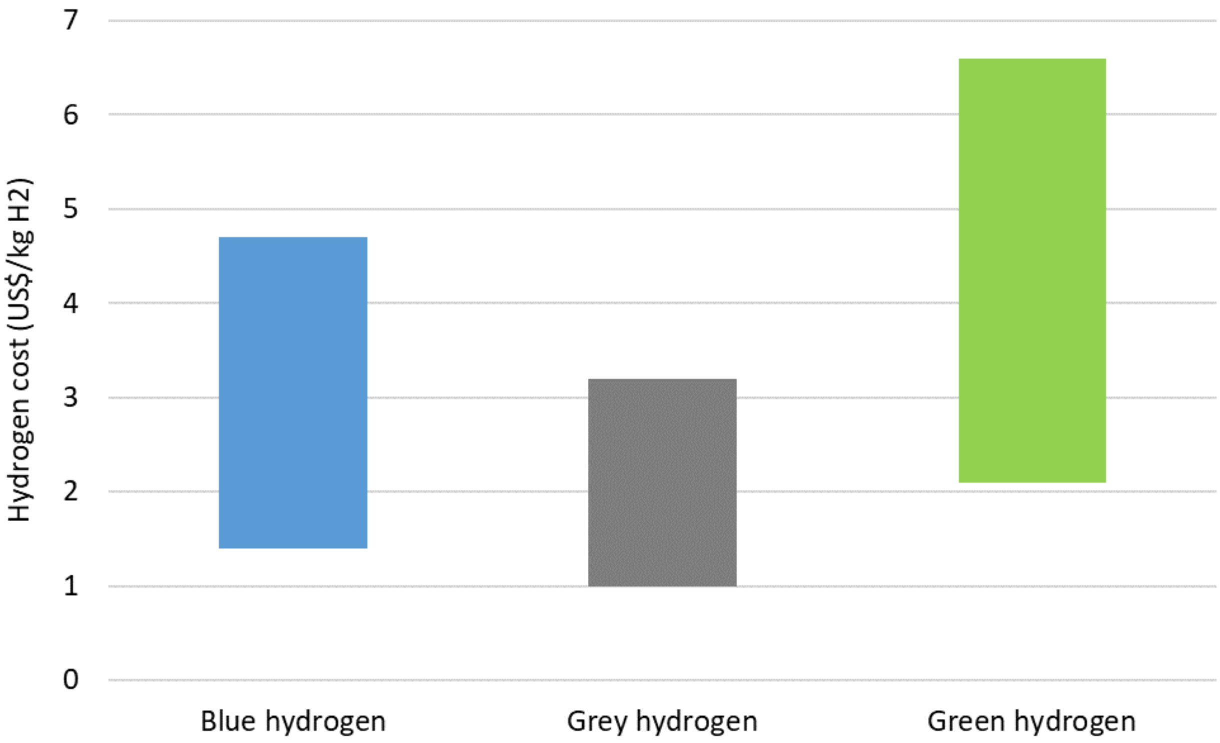
Oil
Coal
Natural gas

→ Grey H2

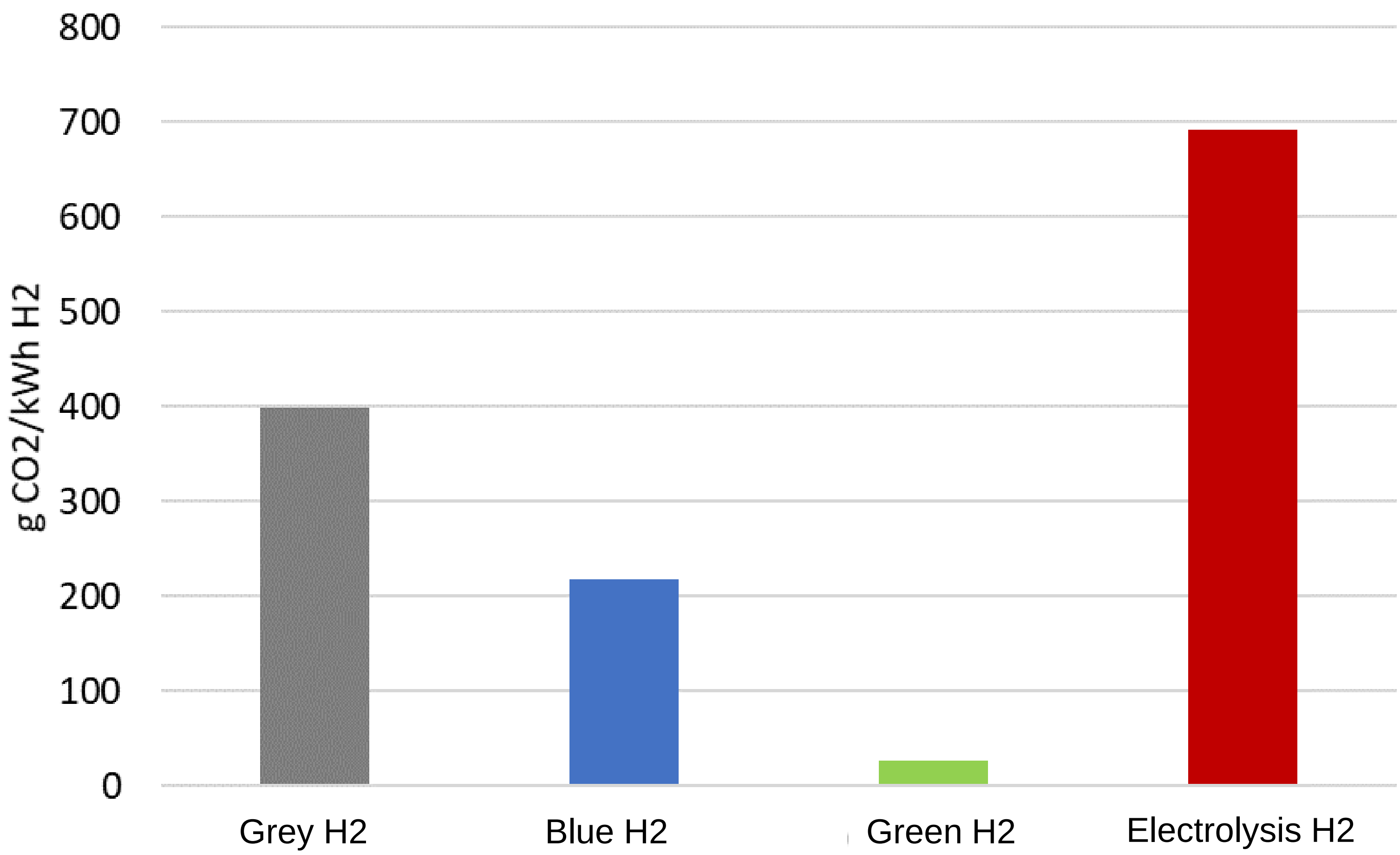
With Carbon Sequestration

→ Blue H2

Cost of hydrogen production for different production pathways



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]

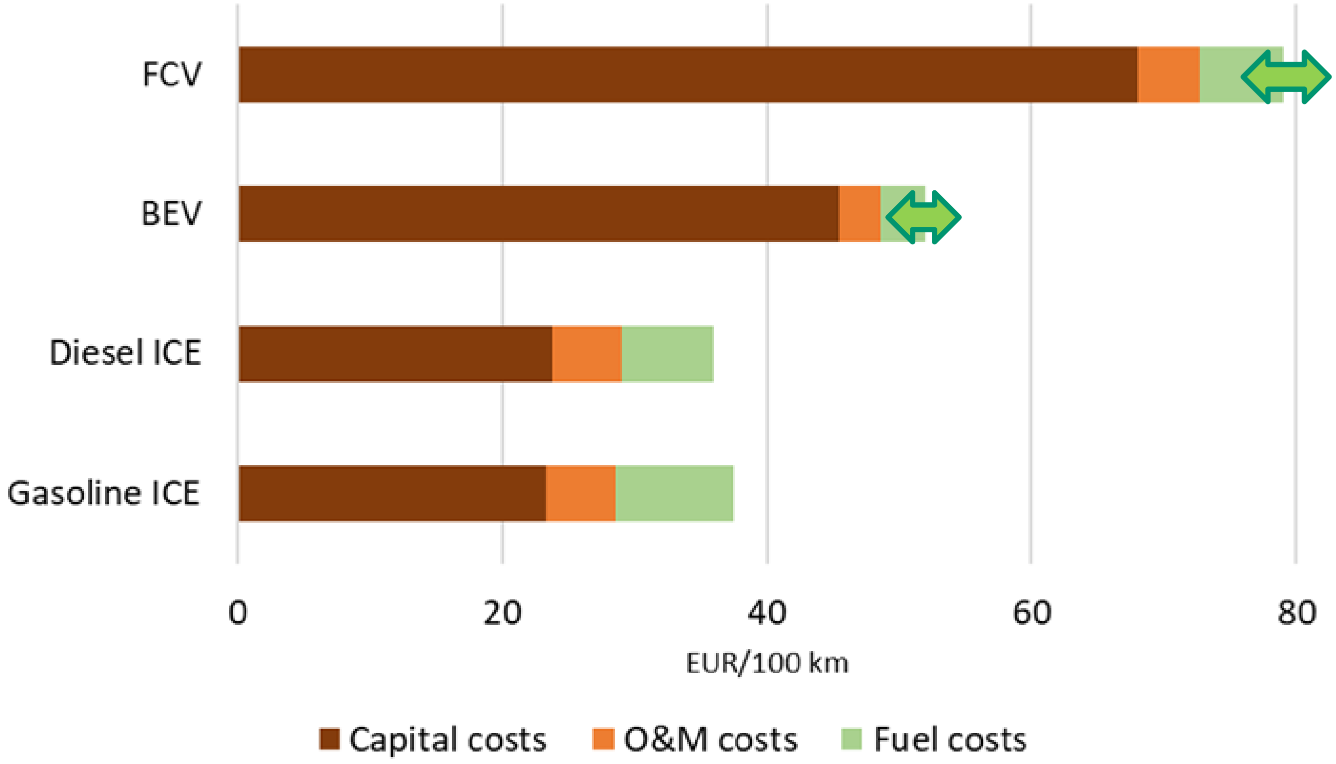
IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……..fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

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:

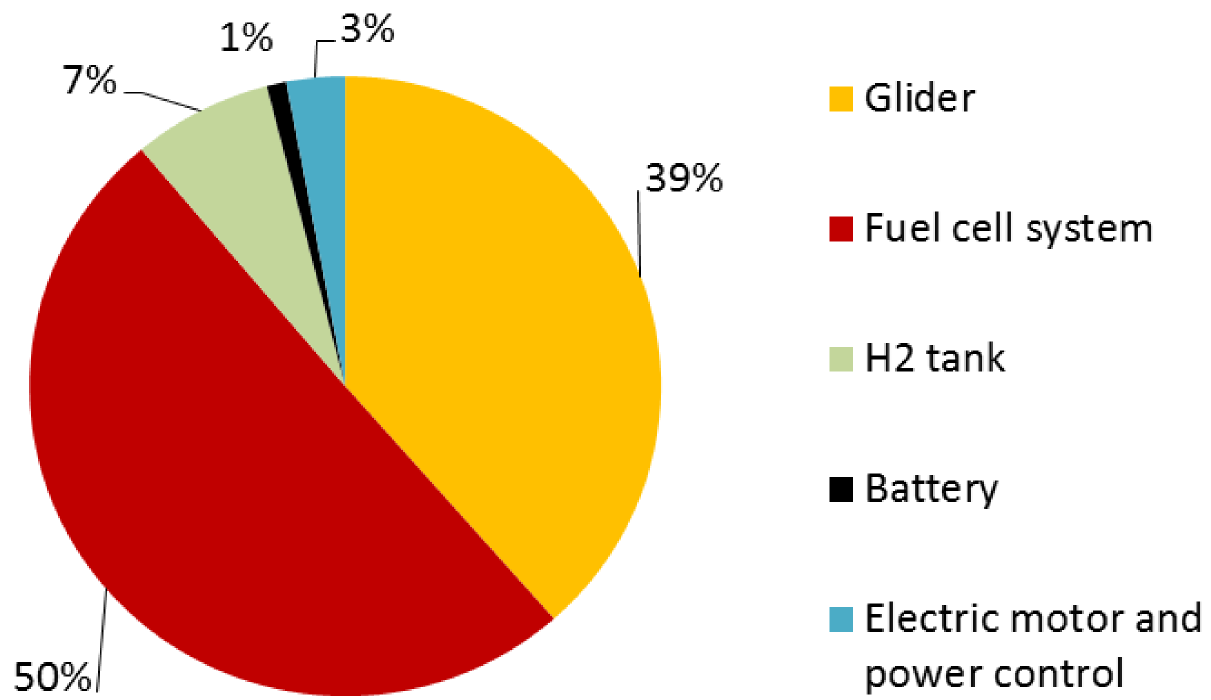
$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

n…..the number of annuities received.

Mobility costs

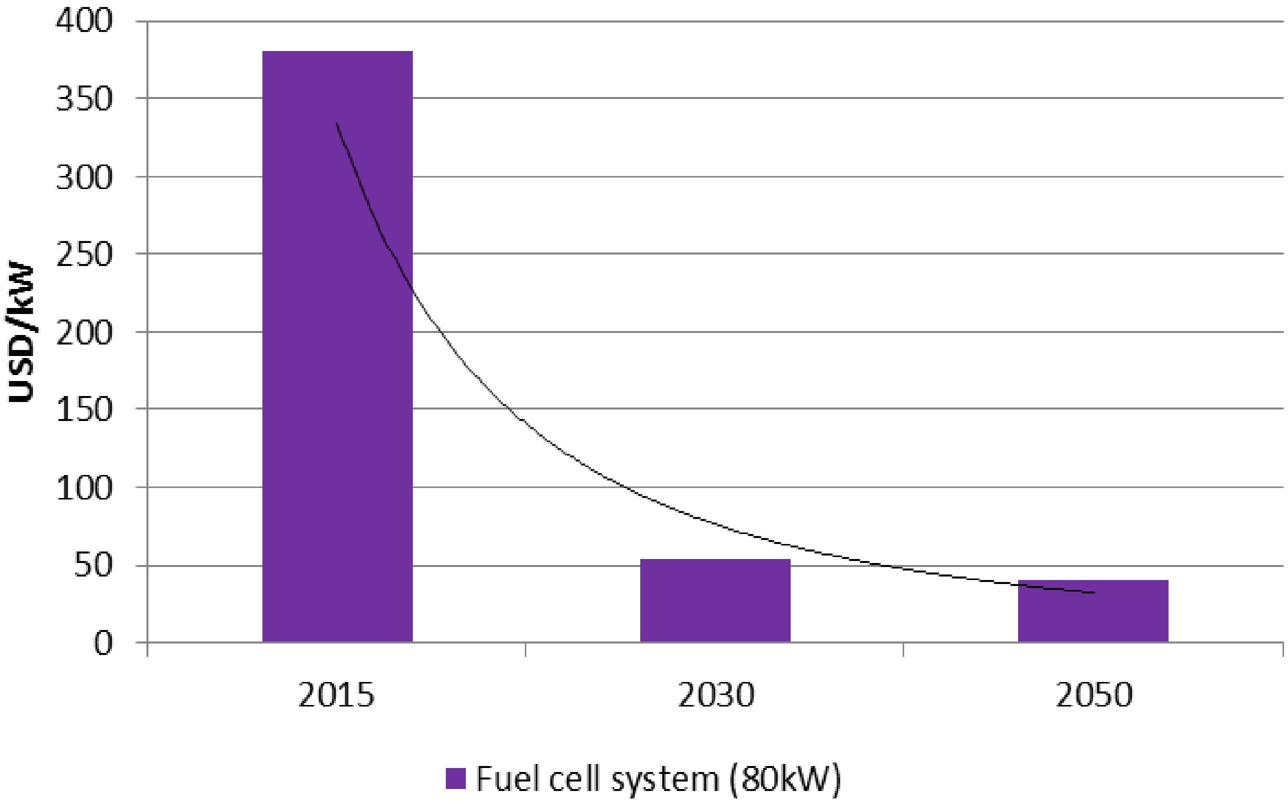


Fuel cell vehicles



Structure of investment costs of fuel cell vehicles

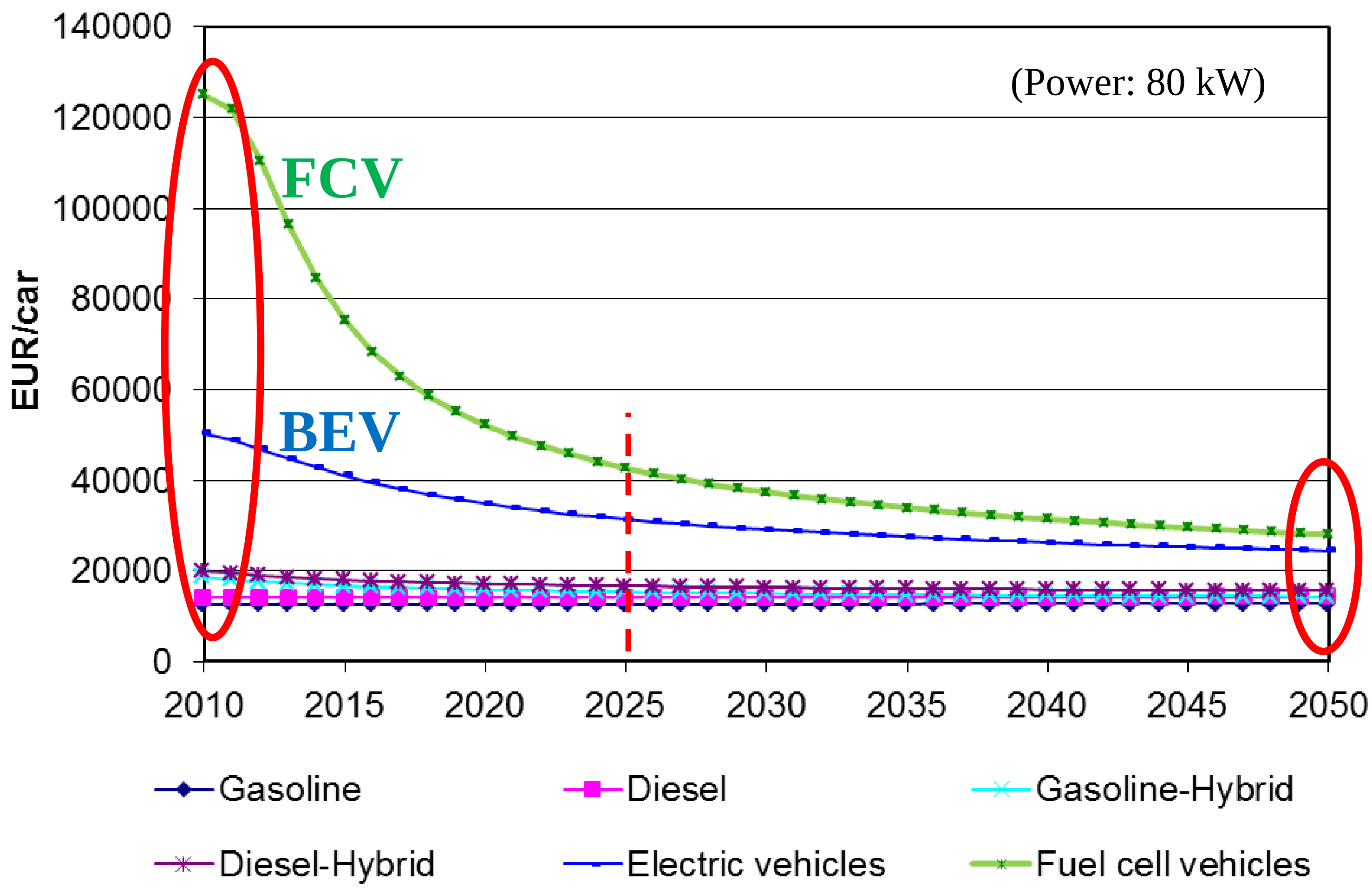
Technological learning – Fuel cell



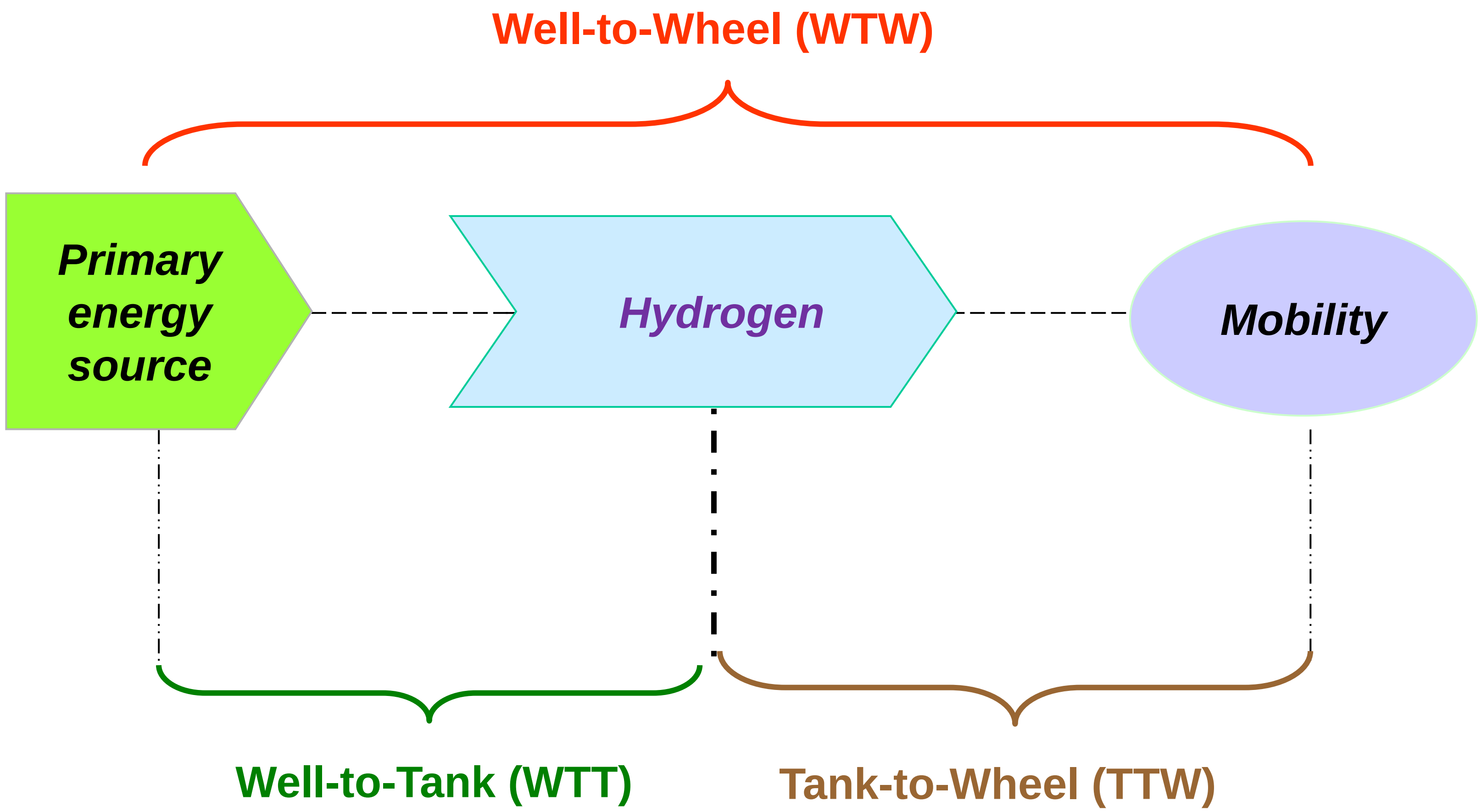
Development of the costs of the fuel cell system

Scenario for development of investment costs

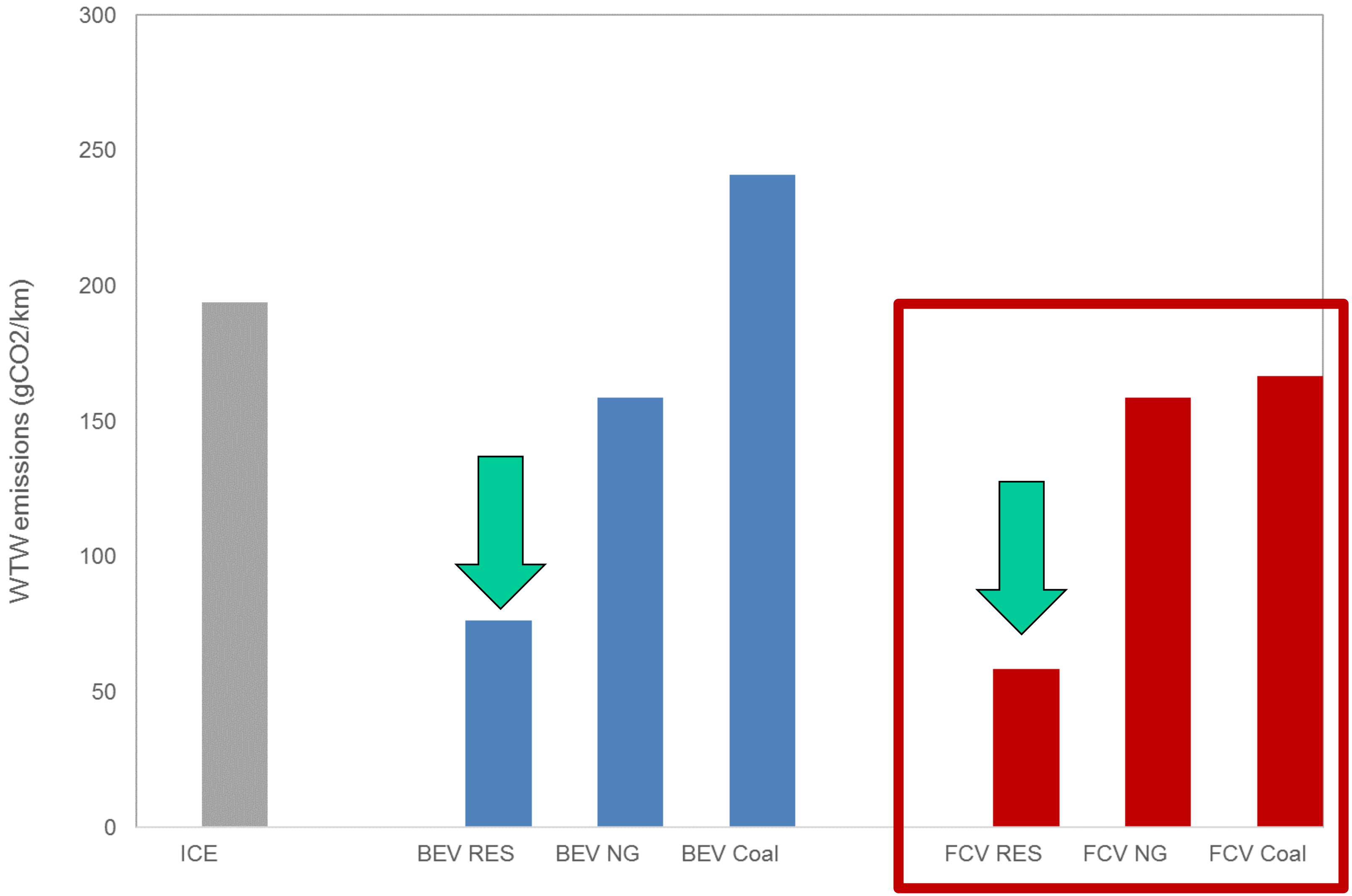
Technological learning:



Environmental assessment



Environmental assessment



FCVs vs BEVs

BEV

- Costs
- Infrastructure
- Fuel efficiency

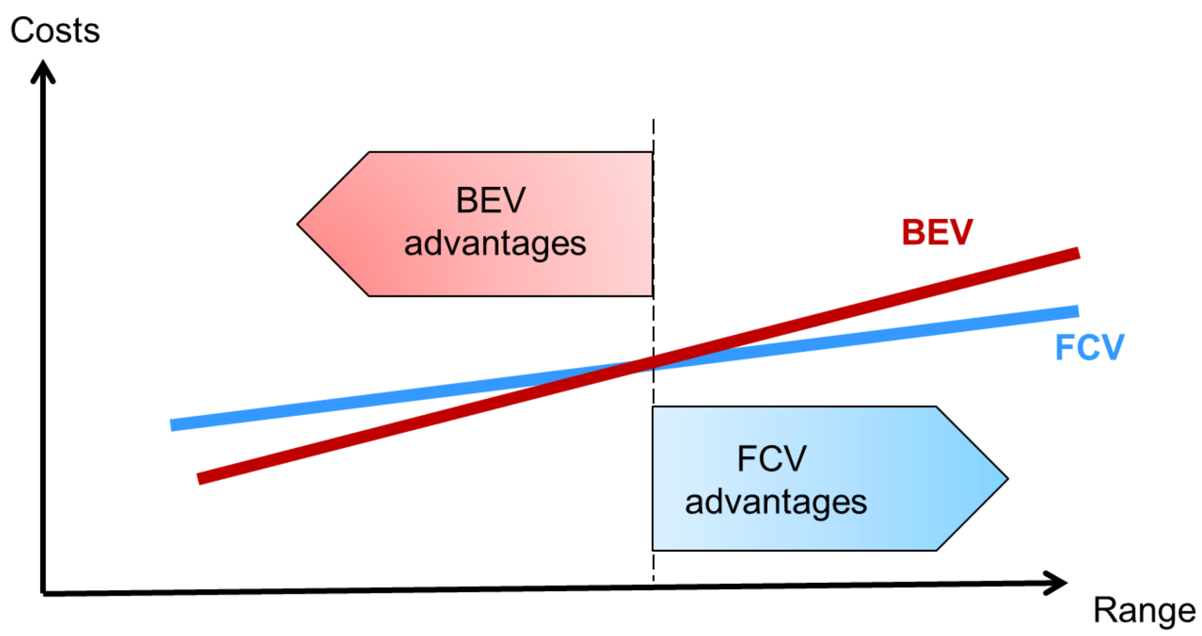
FCV

•Refuelling time

•Driving range

•Weight of energy storage

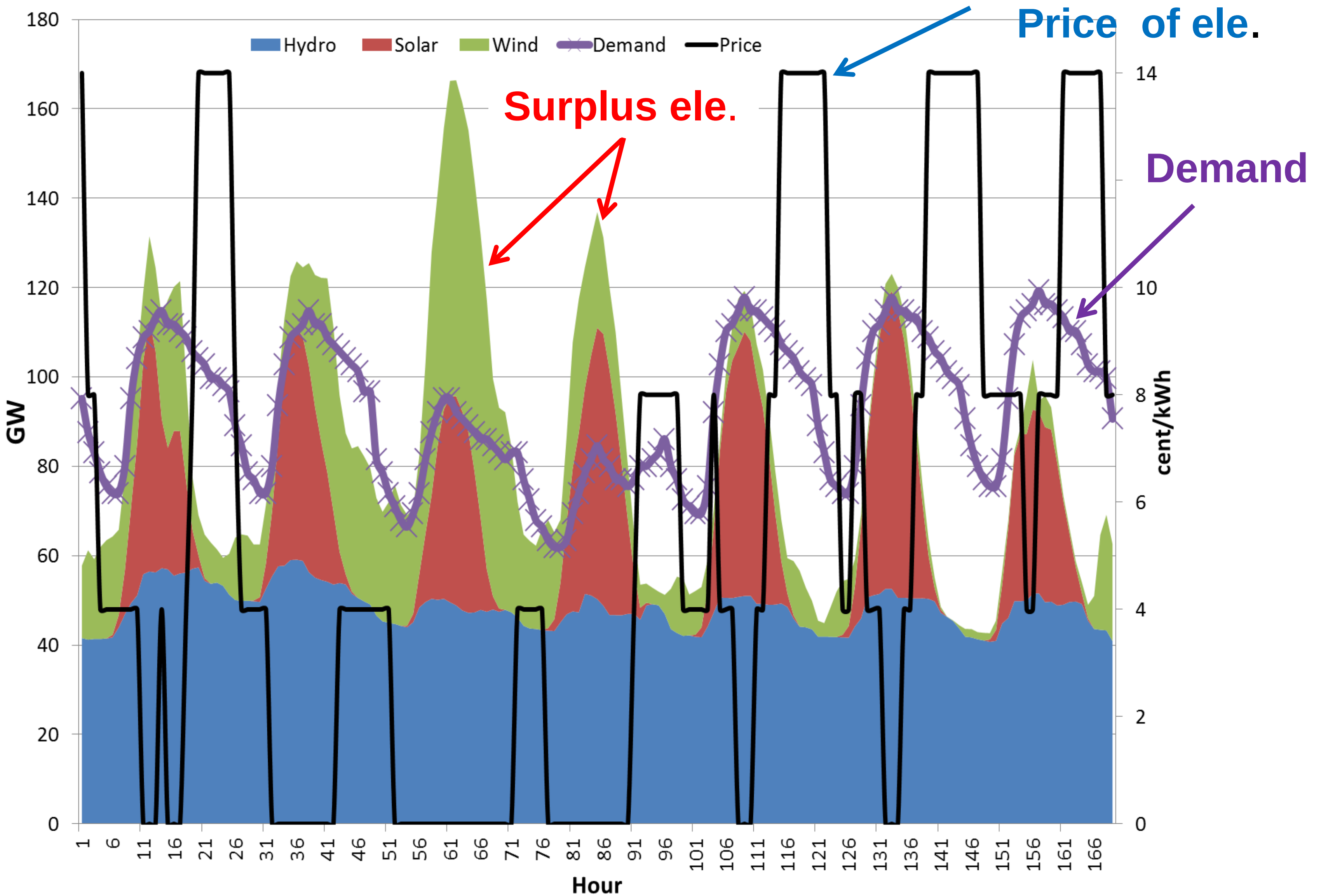
•Environmental benefits



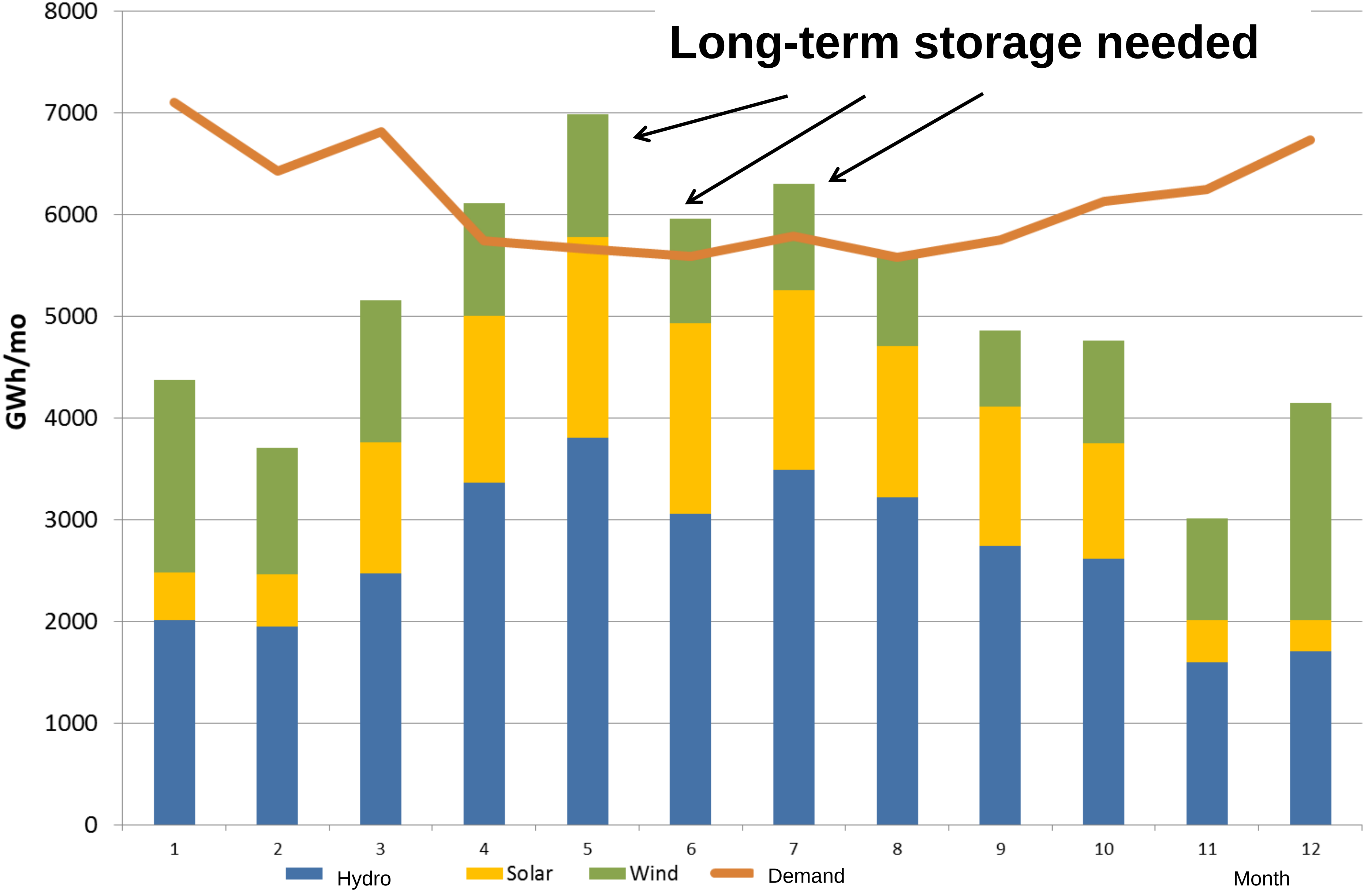
Hydrogen as storage

- 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

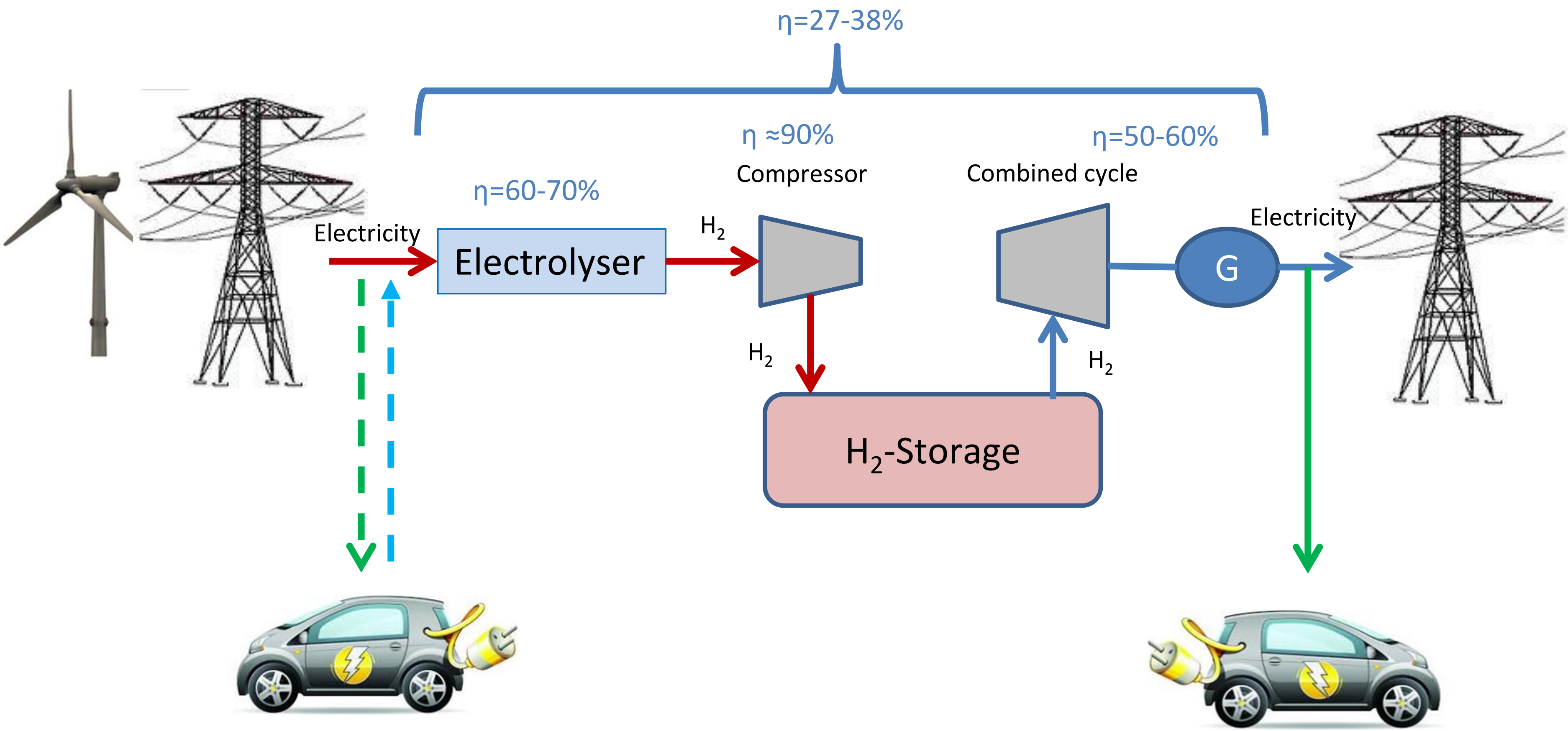


Demand for long-term storage



Storage and fuel

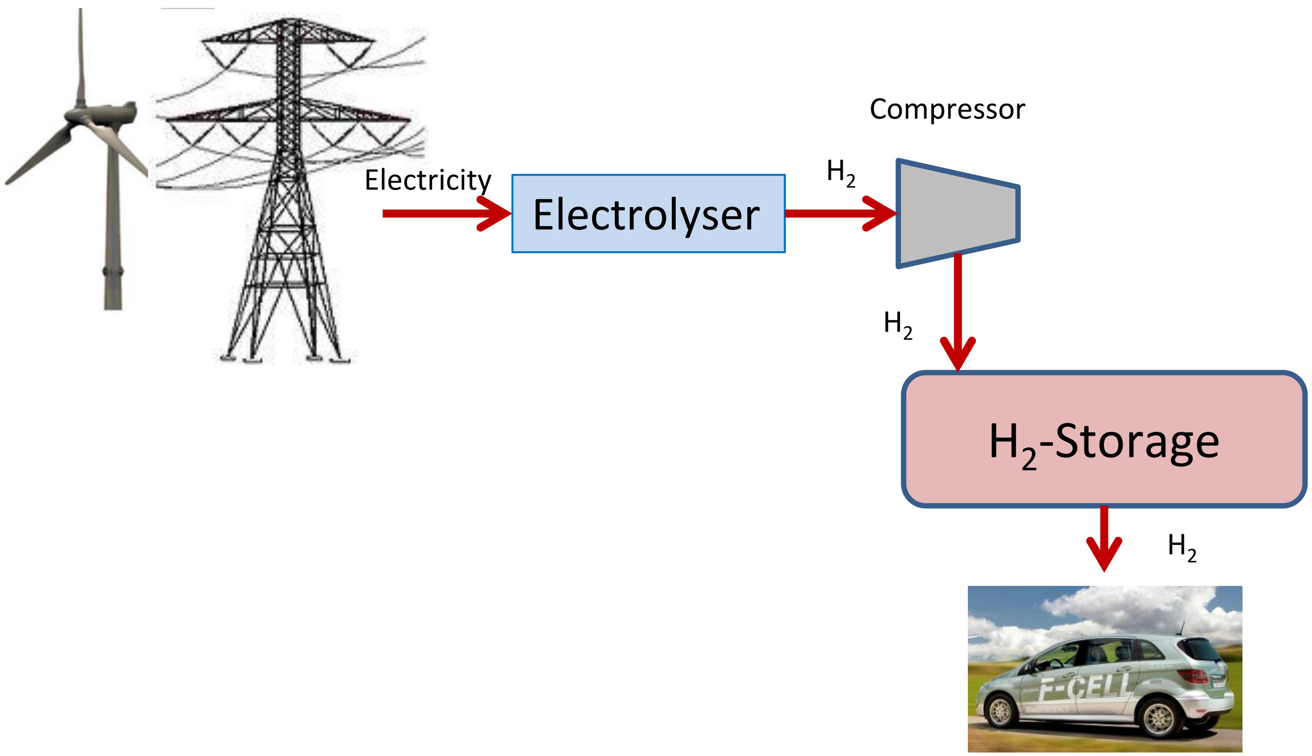
Very low roundtrip efficiency for electricity!



Battery degradation

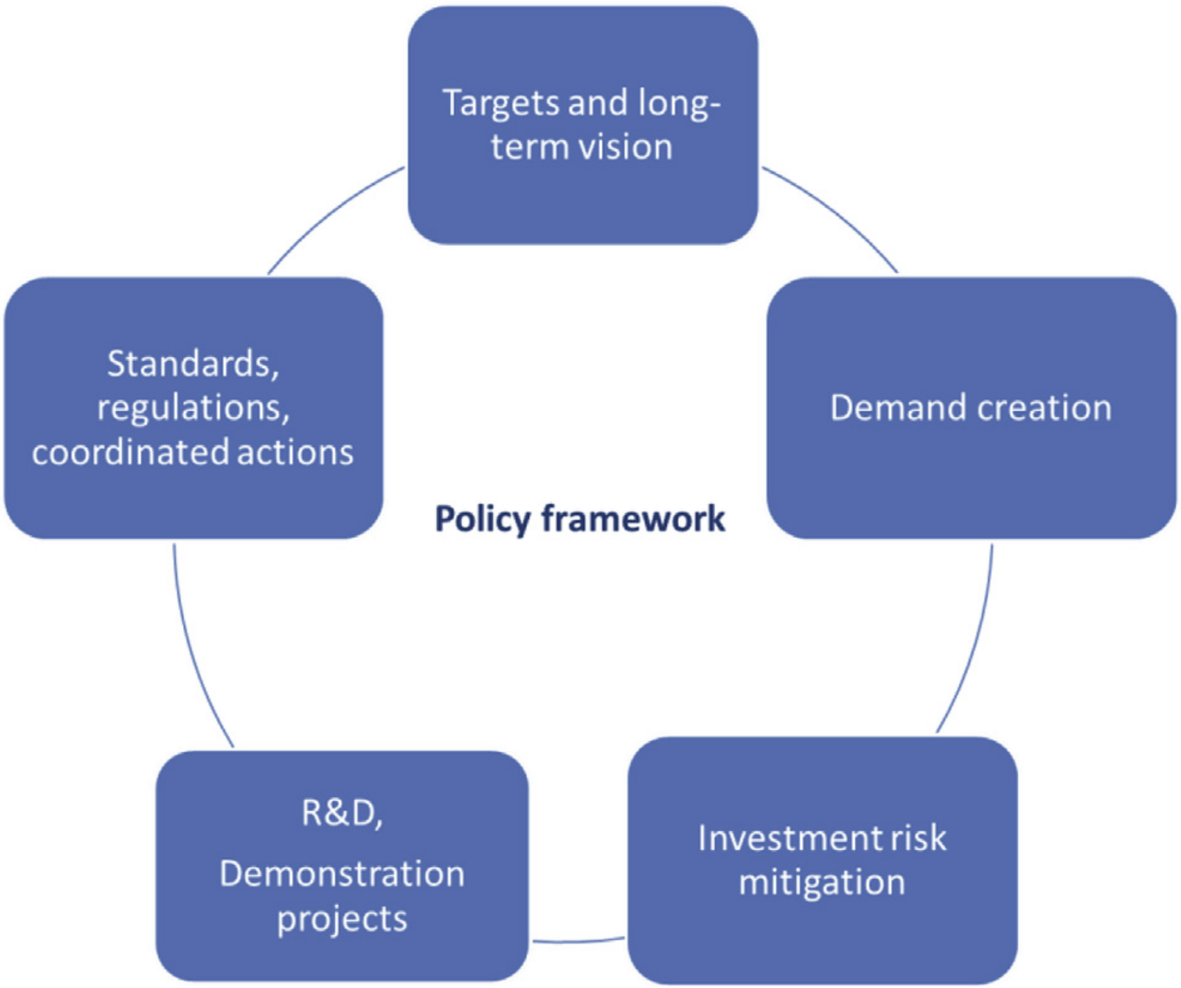
Energy supply chains: Storage and/or use of RES for mobility

Hydrogen: storage and fuel

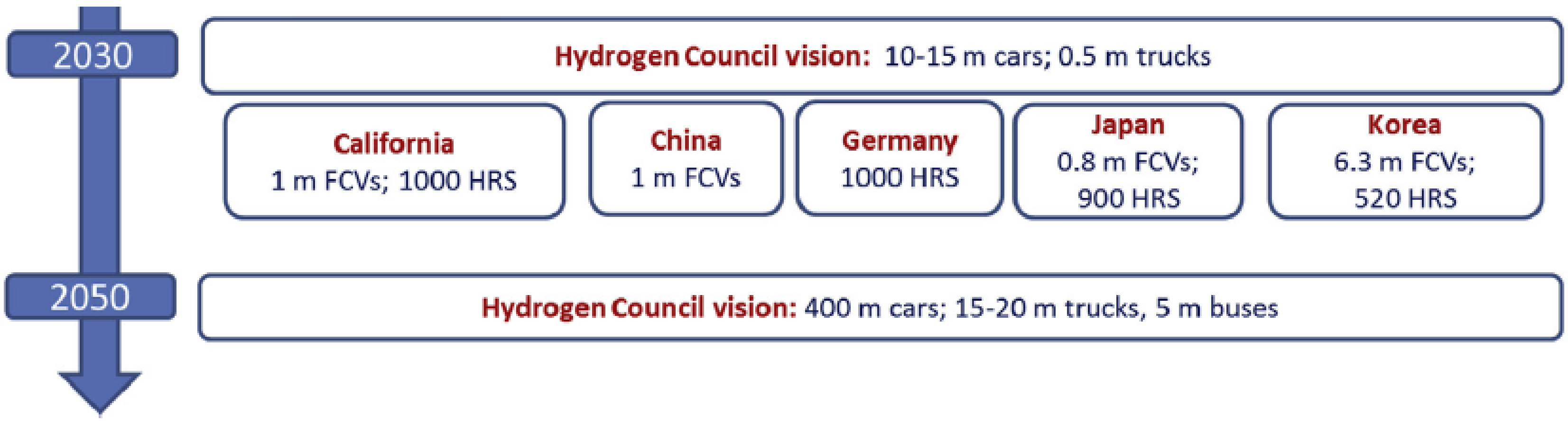


Energy supply chains: Storage and/or use of RES for mobility

Policy framework



Announced targets for FCV



Uses of hydrogen

	Current role	Demand perspective
Cars and vans (light-duty vehicles)	>87 000 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 **(heavy duty vehicles)**	Demonstration and niche markets: >50 000 forklifts >5000 buses >400 trucks >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	> 14 hydrogen trains	Rail is a mainstay of transport in many countries

Coradia iLint Train, Germany

Applications of hydrogen fuel cells

Conclusions

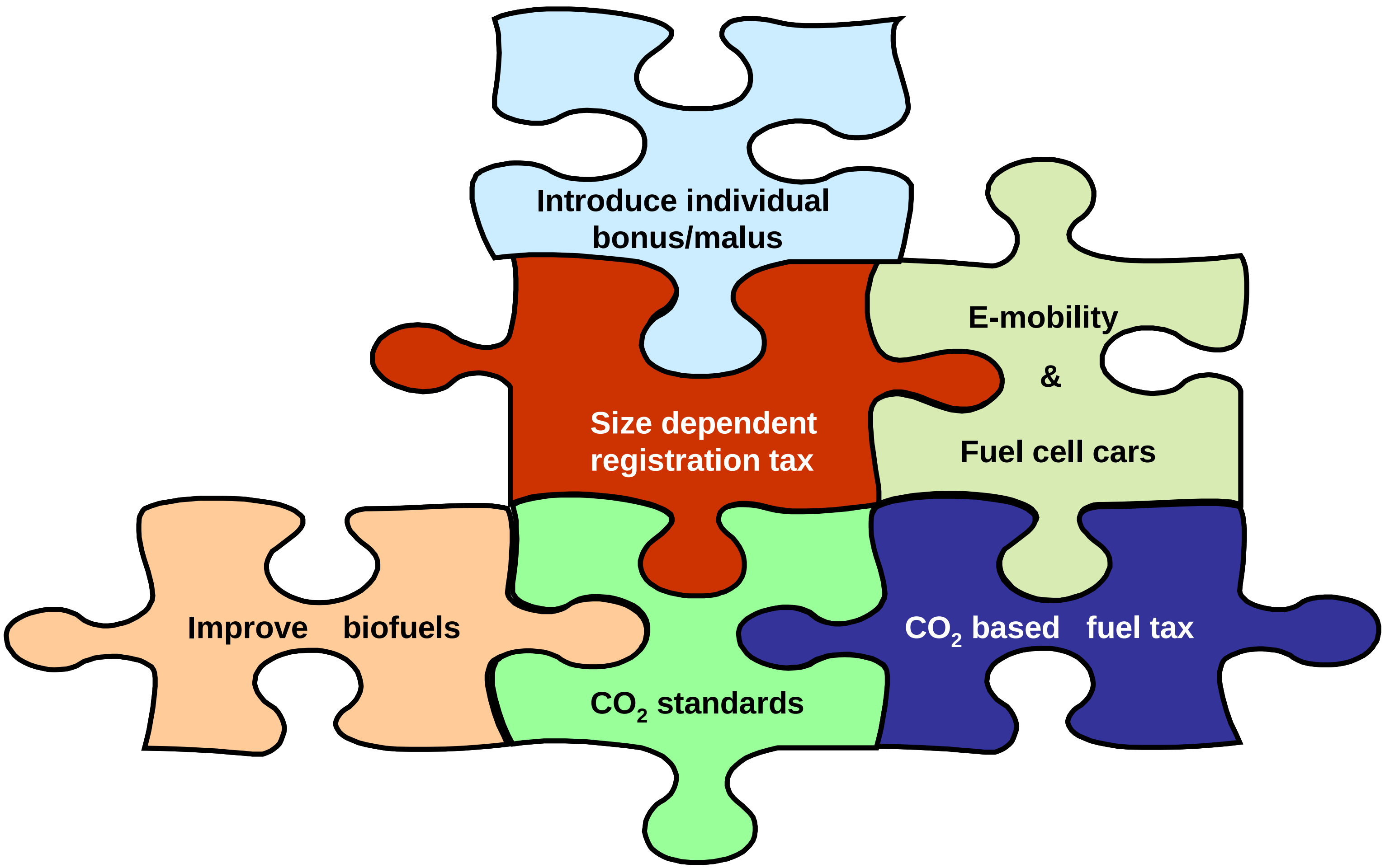
Hydrogen can help to:

- ✓ 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

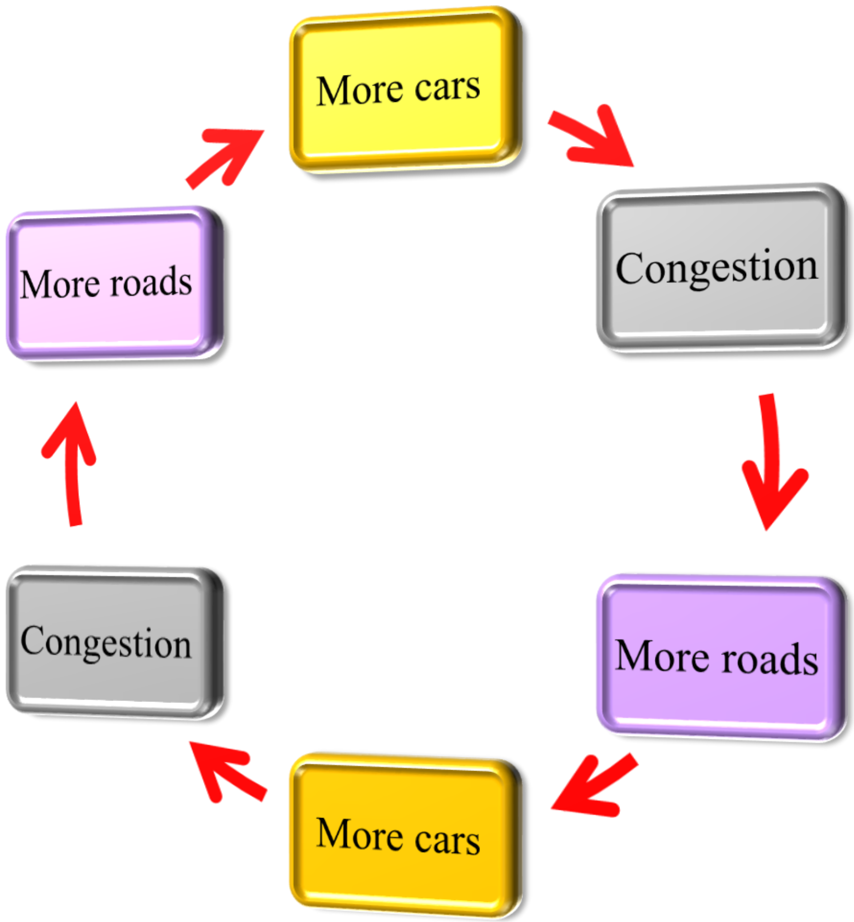
Major challenges for hydrogen and FCV:

- Economics
- Infrastructure
- Policies framework

Conclusions



Car-oriented mobility

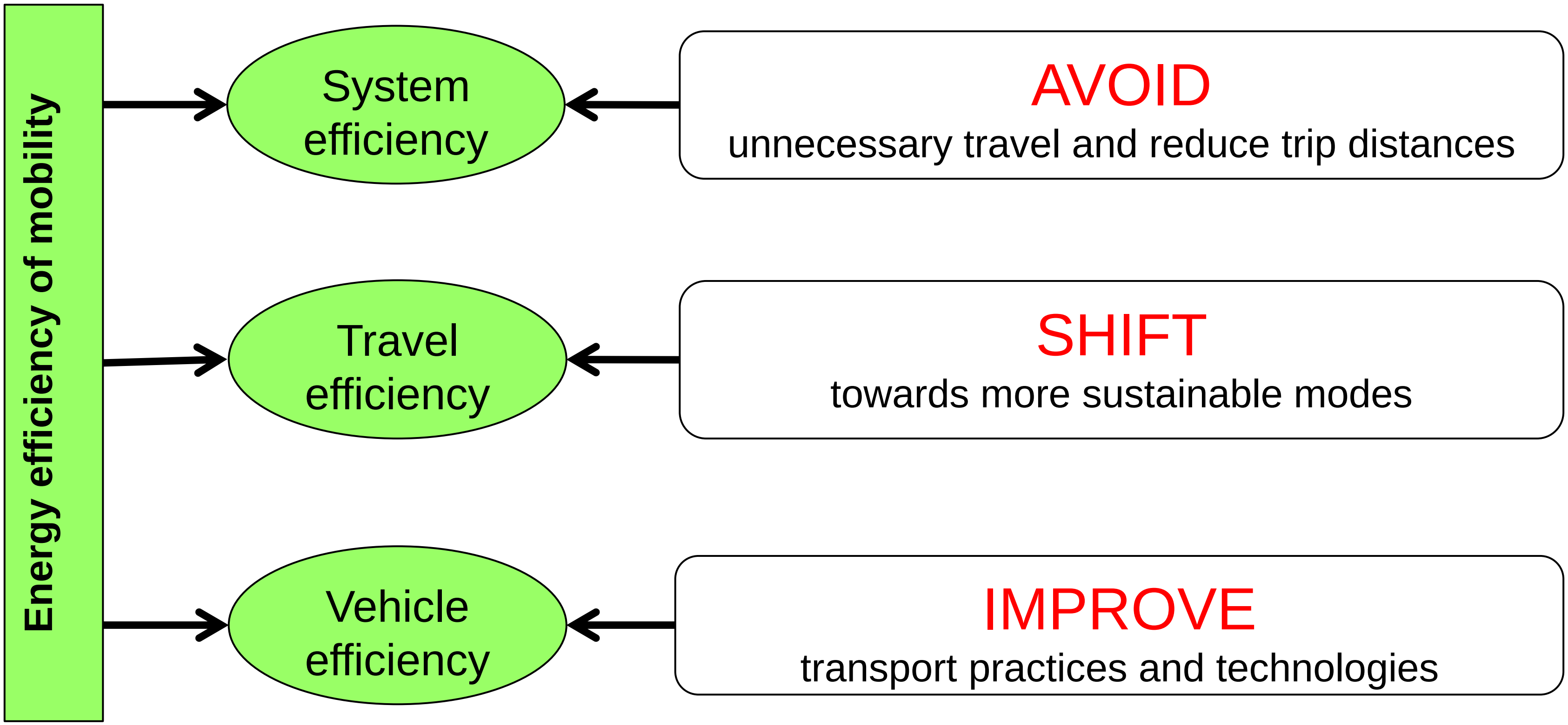


Conclusions

Car-oriented transport development

https://simotron.files.wordpress.com

Strategies for energy efficient mobility



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