Interdisciplinary Summer School 2024

Energy &Transport

Prospects for hydrogen and fuel cell vehicles

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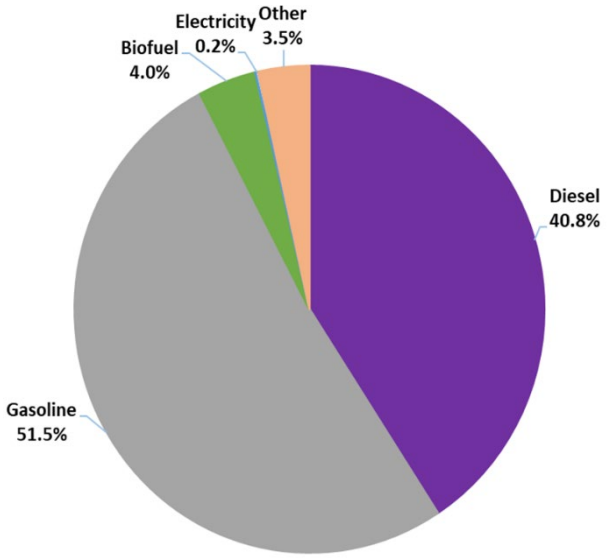
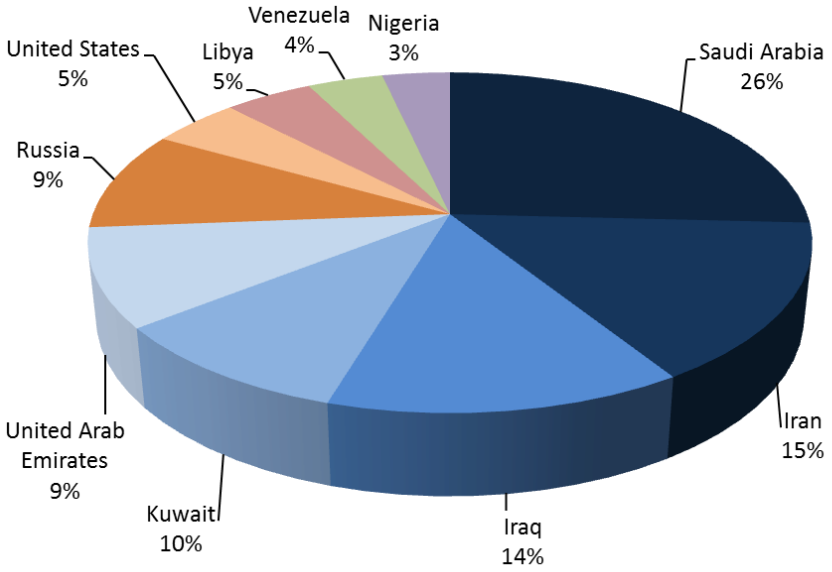
5. RES and storage
6. Conclusion

Transport sector

- oil products
- least-diversified
- energy import dependency

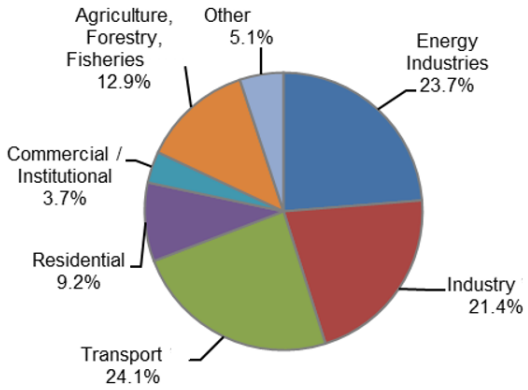


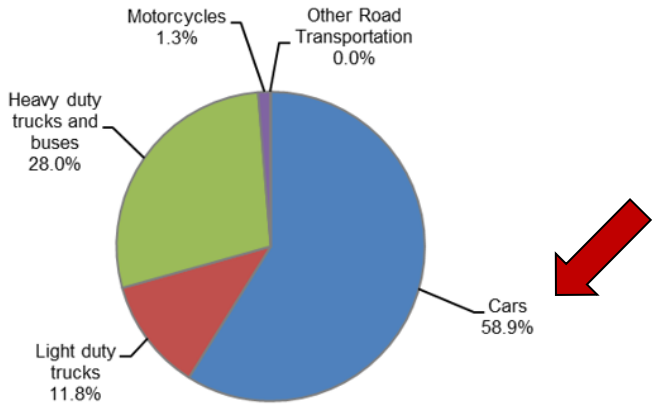
Global energy consumption in road transport

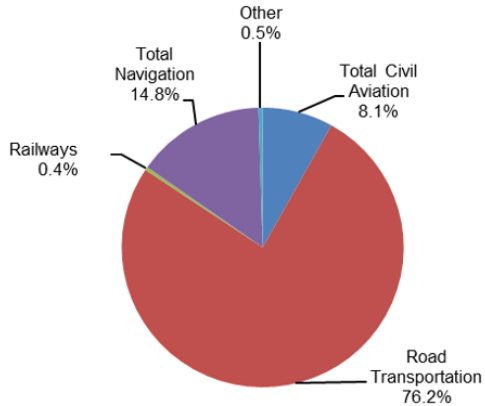


Countries with largest conventional oil reserves

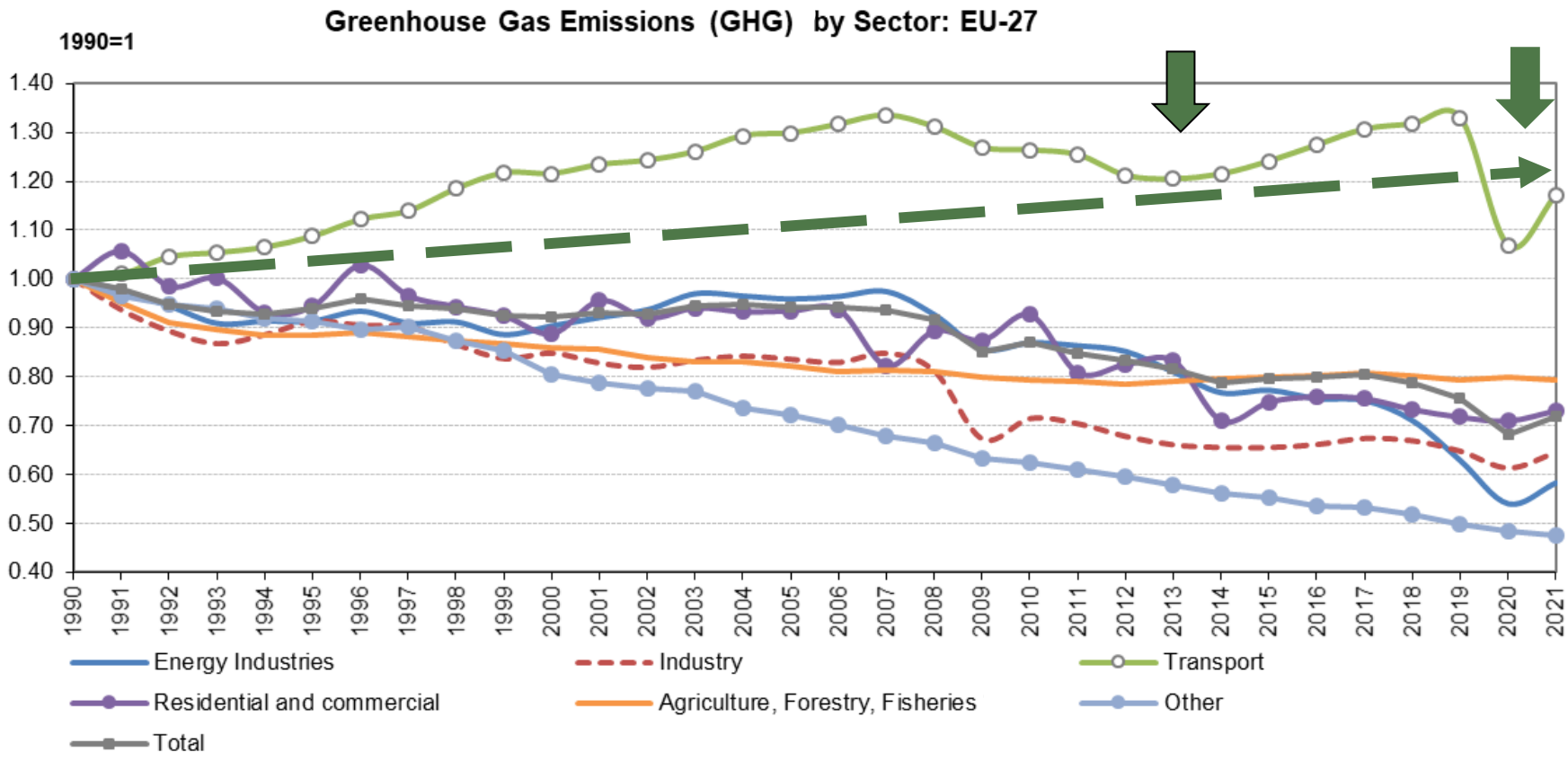
GHG by sector: EU-27



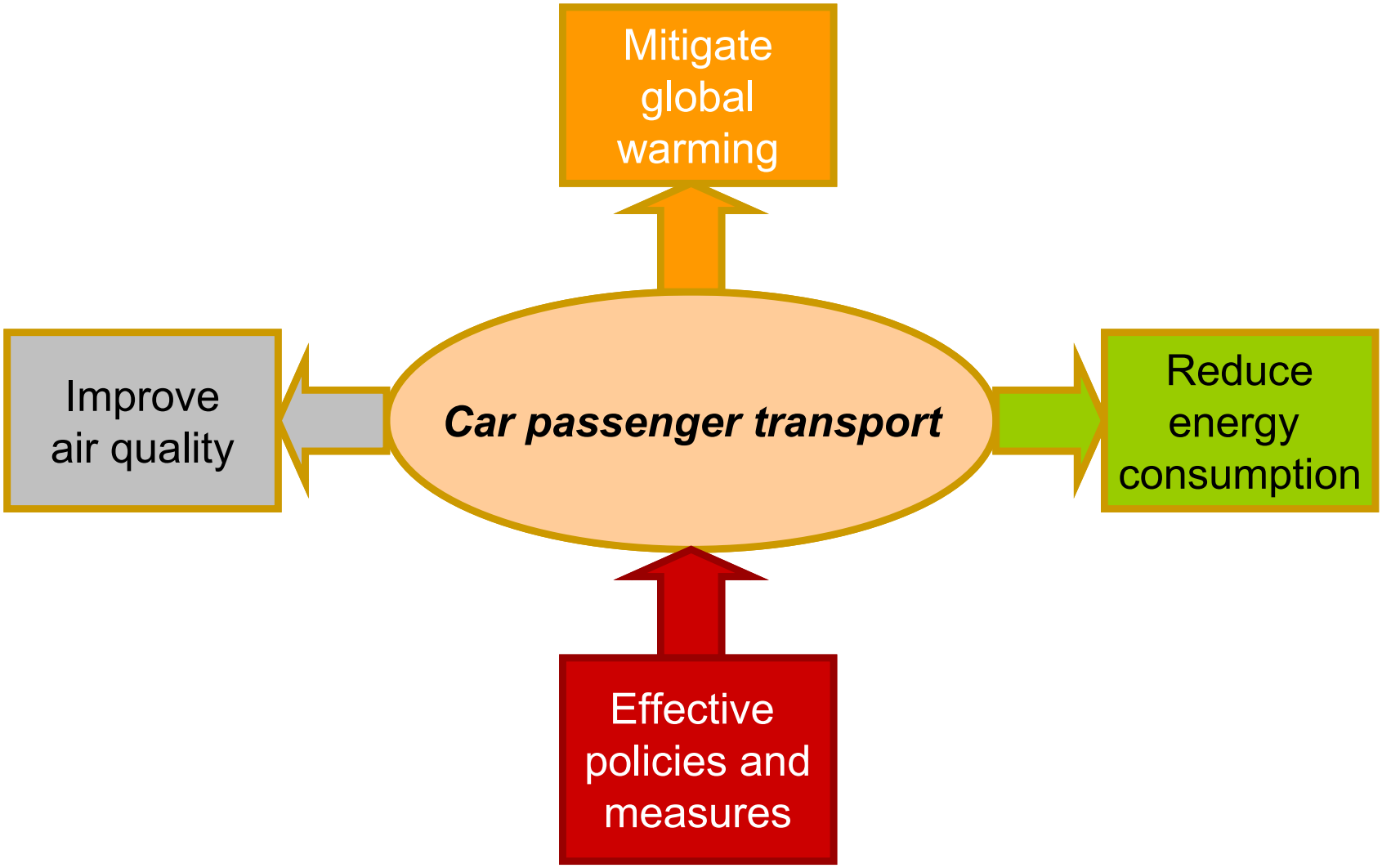




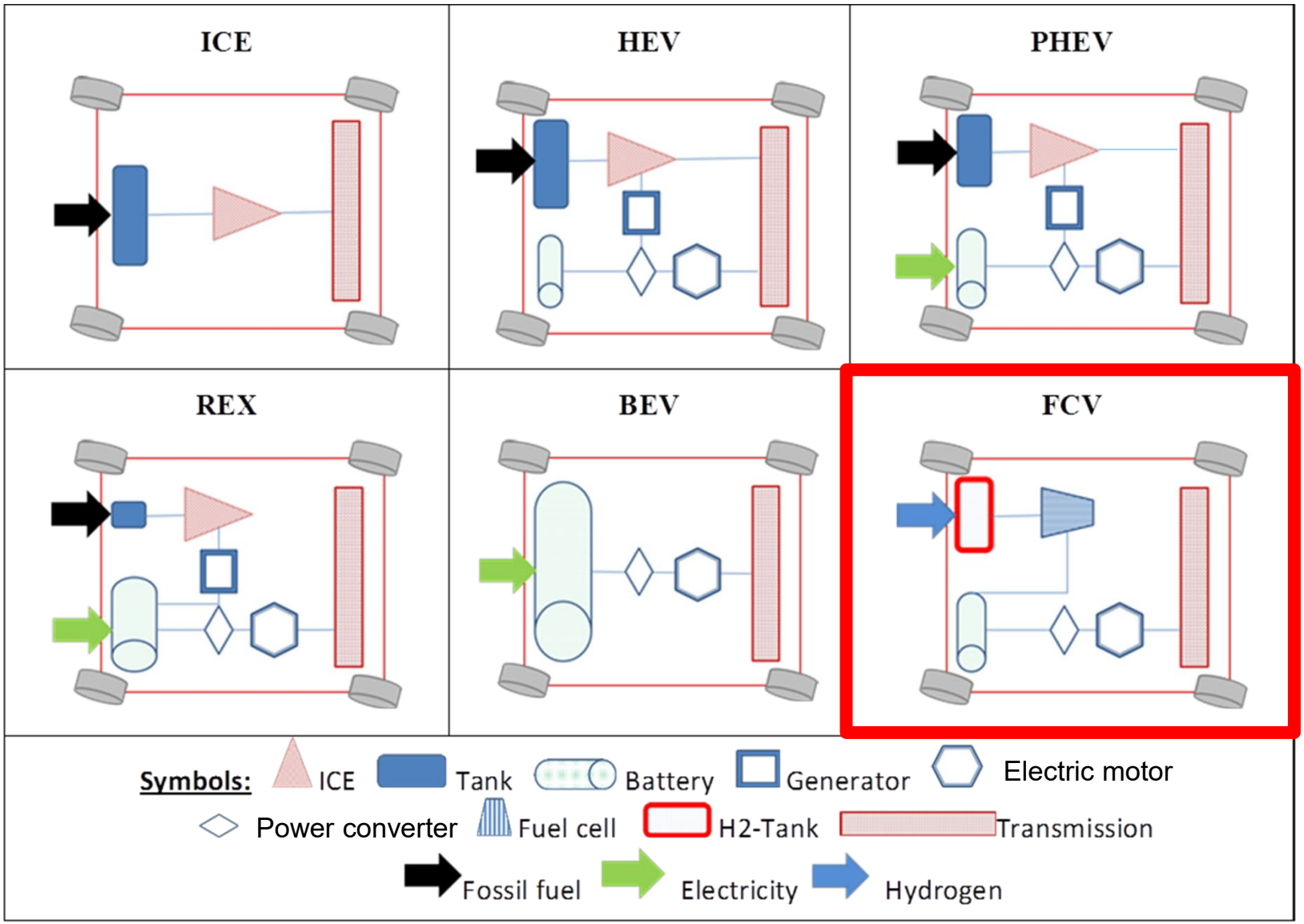
GHG

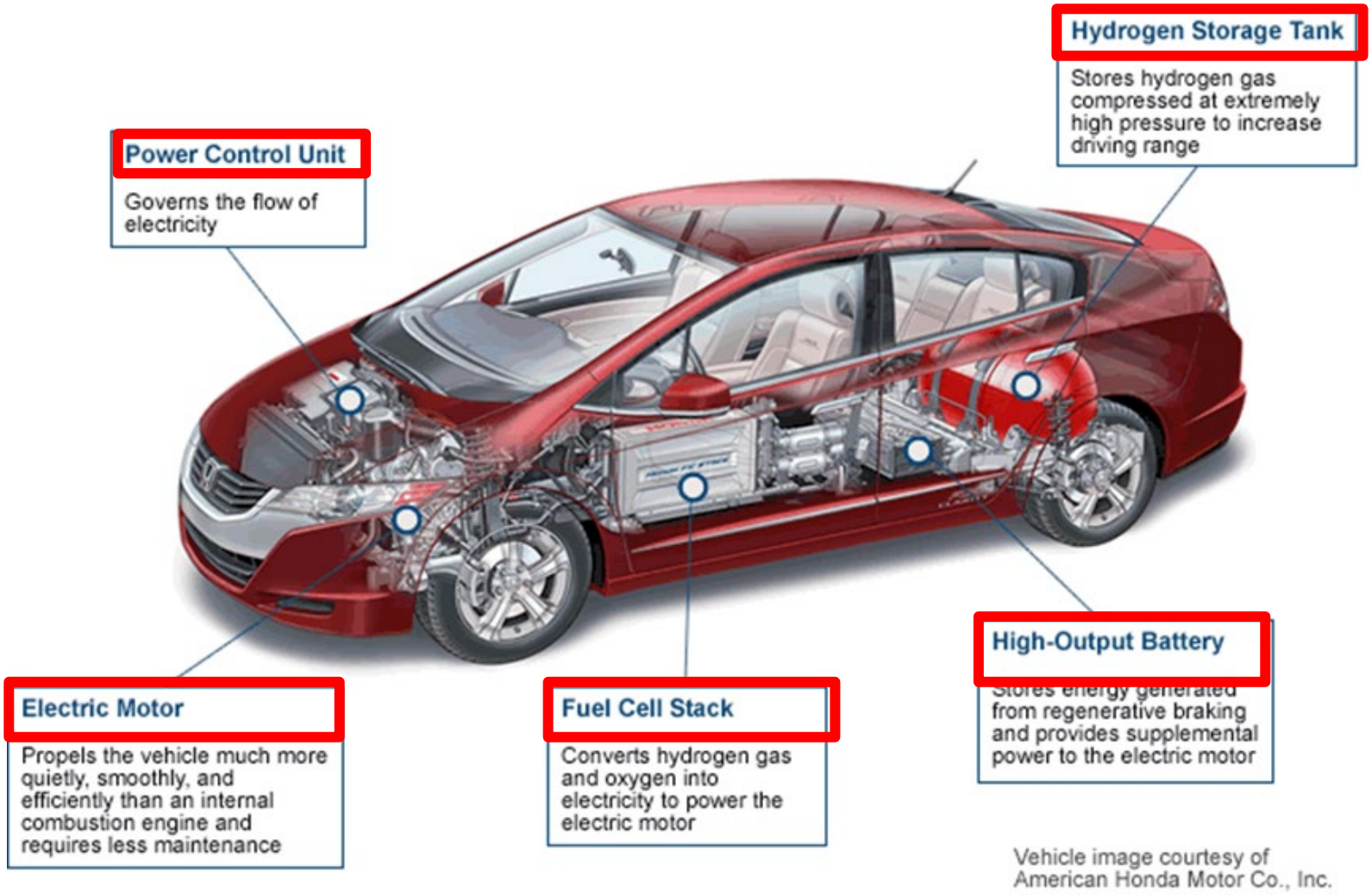

Greenhouse Gas Emissions (GHG) by Sector: EU-27
1990=1
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Energy Industries
Industry
Transport
Residential and commercial
Agriculture, Forestry, Fisheries
Other
Total

The challenges for EU climate and energy policies



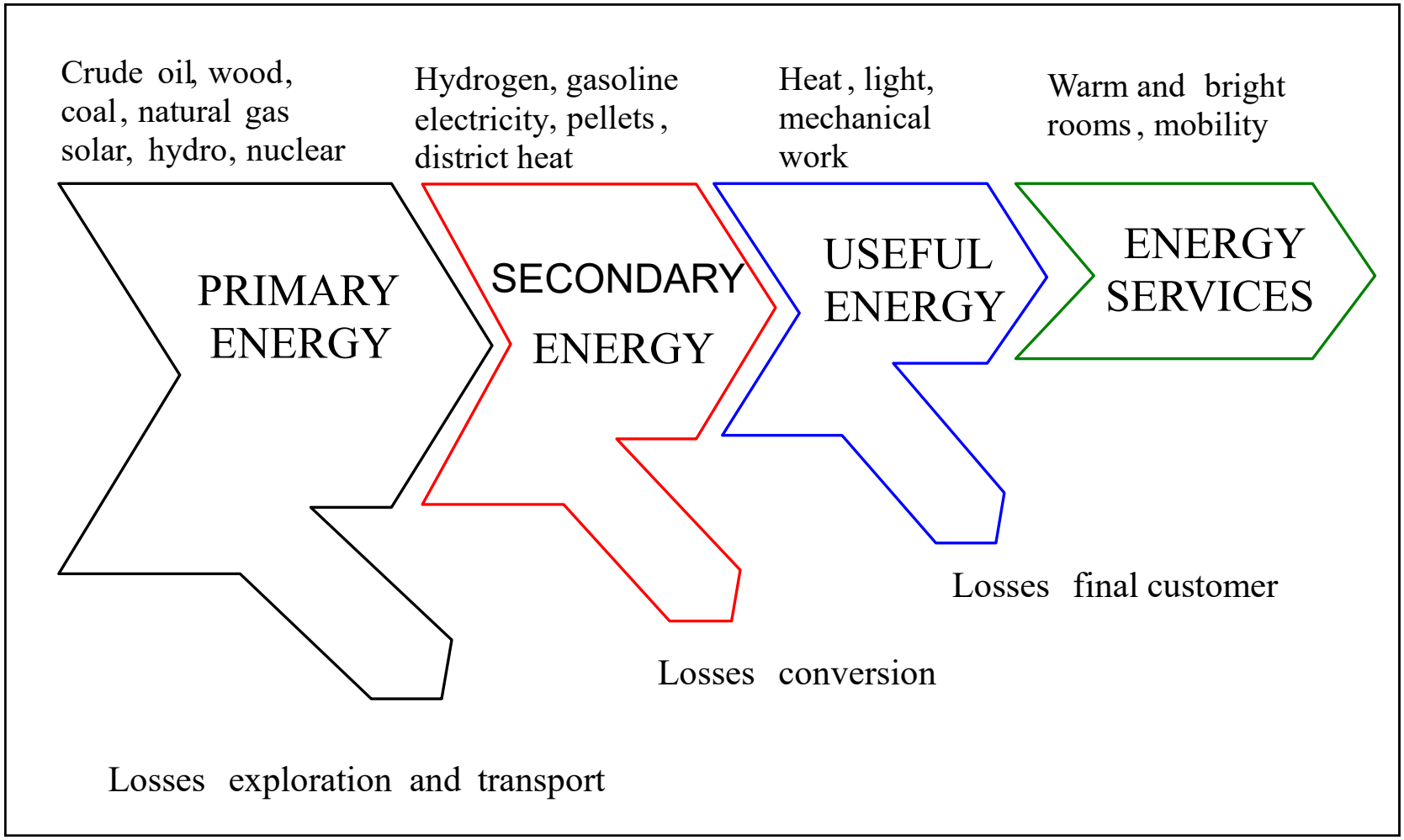
Electric vehicles





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

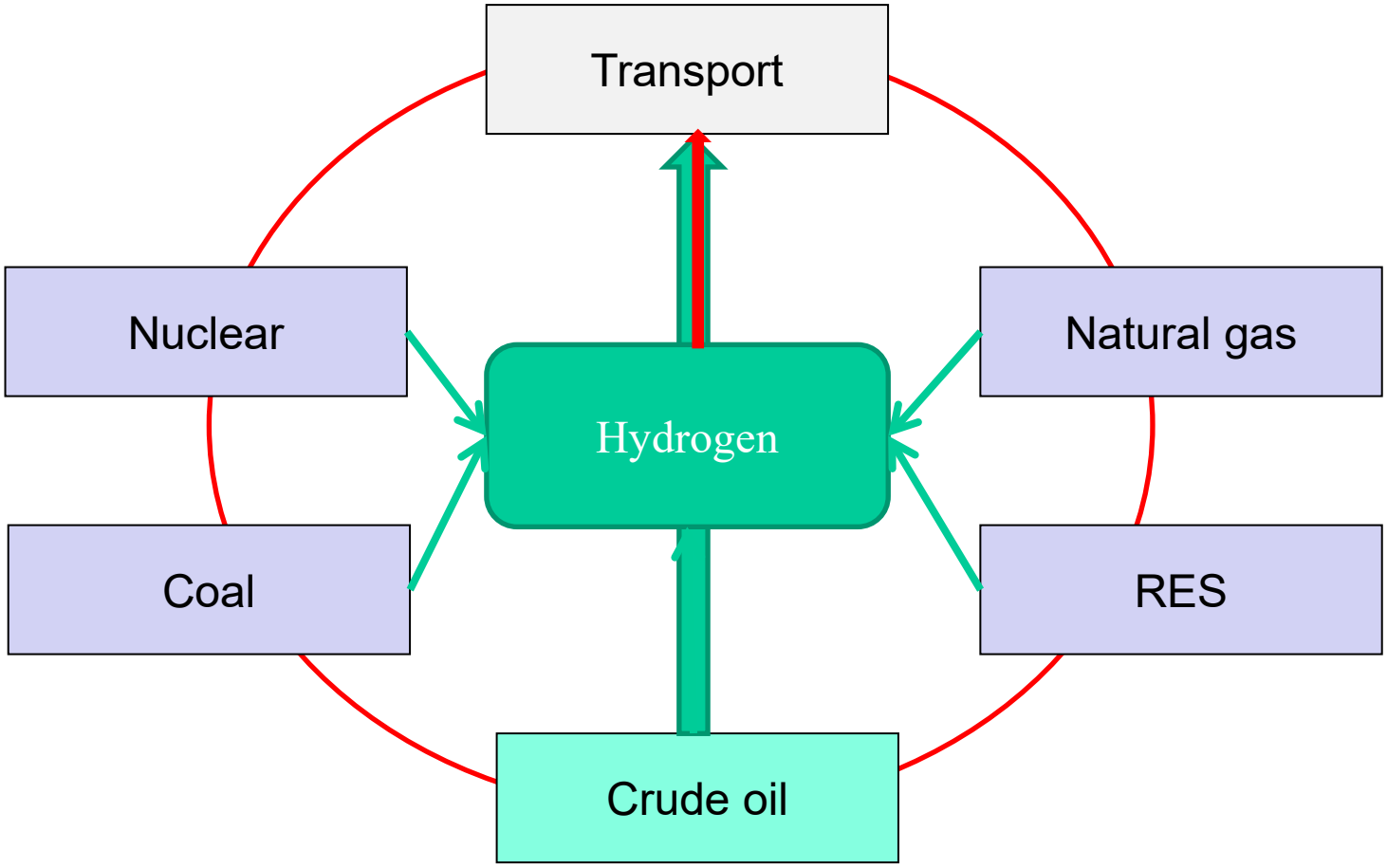
- Hydrogen is less flammable than gasoline

- Hydrogen is non-toxic

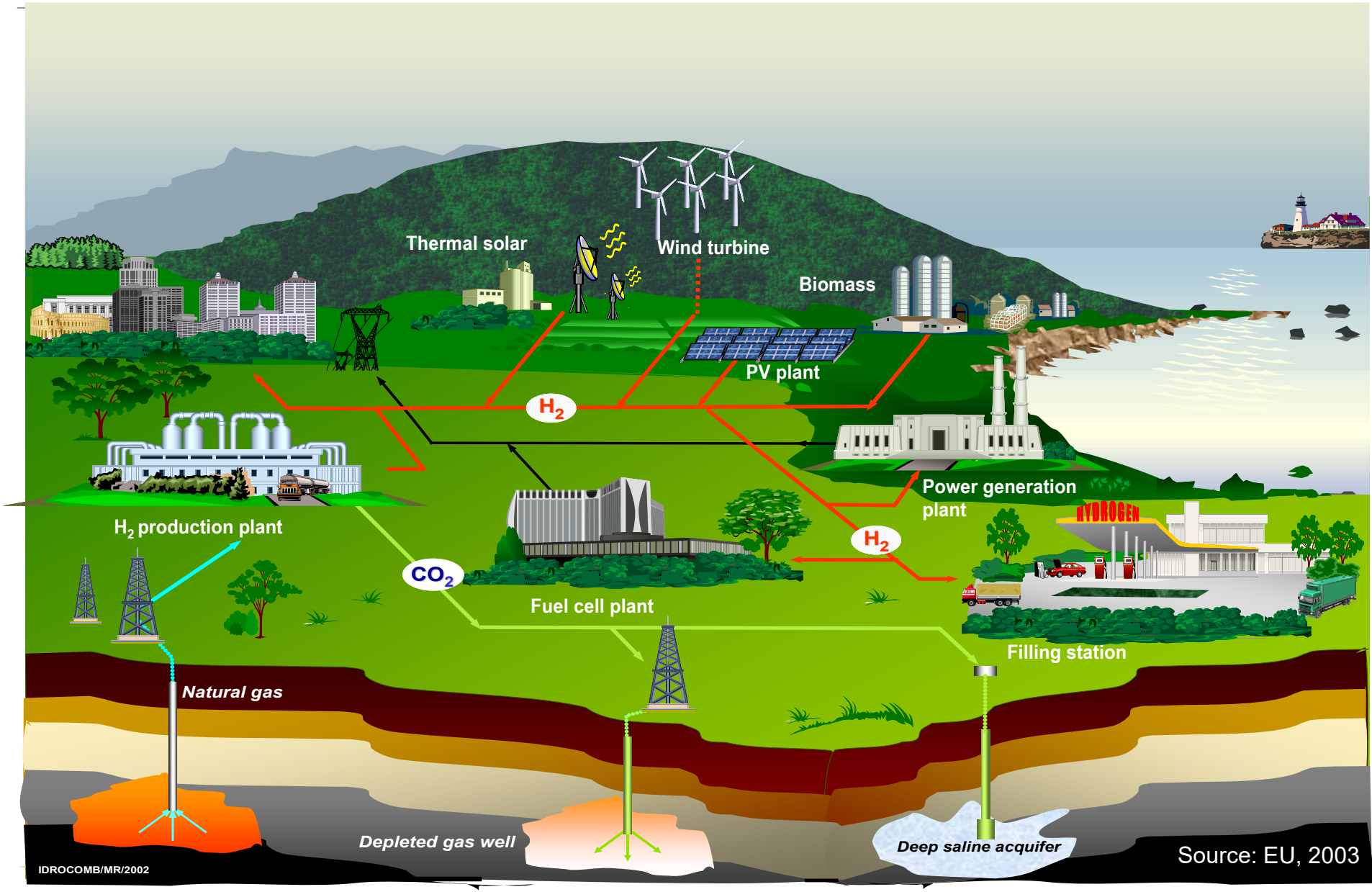
- Hydrogen combustion produces only water

- Storage for surplus electricity

Diversification

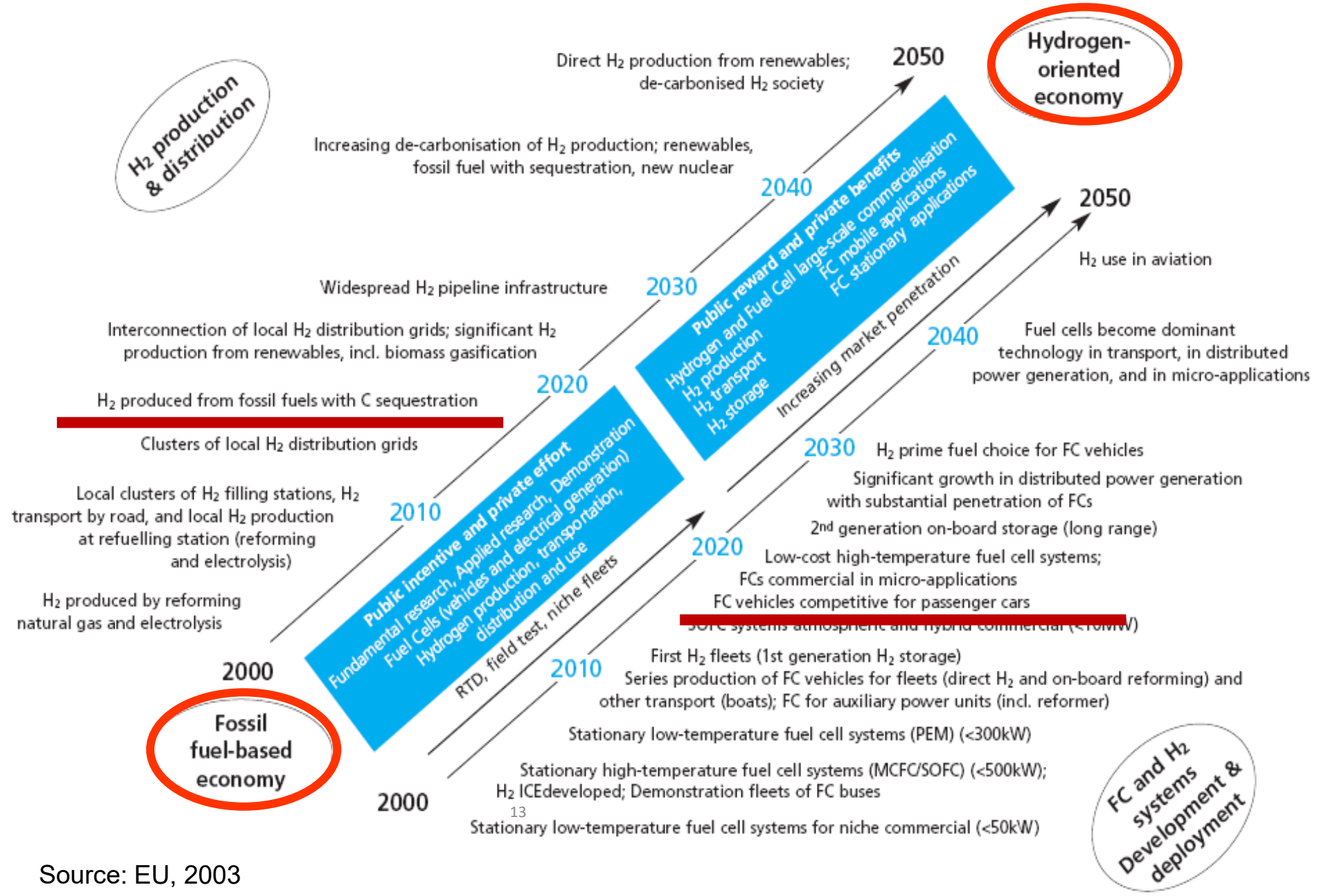


Hydrogen vision



Source: EU, 2003

A challenging European hydrogen vision



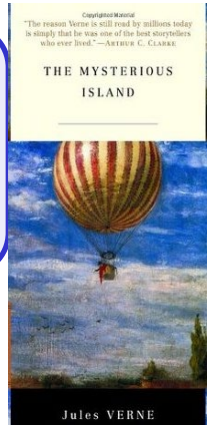
Source: EU, 2003

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)

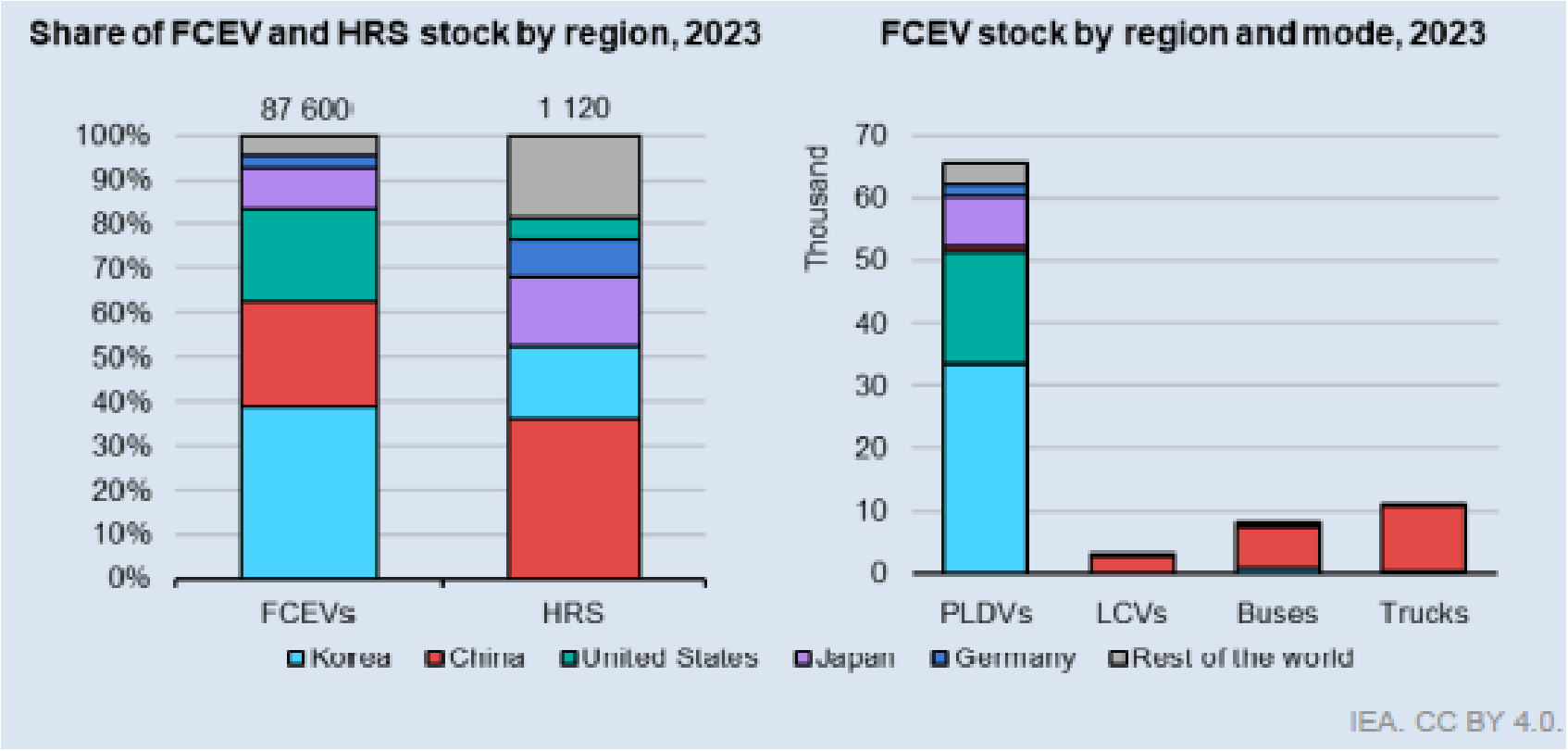
2011: > 100 fuel cell buses worldwide

2013: > 4000 fuel cell forklifts worldwide

2015: First hydrogen fuel cell powered tramcar

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
Korea
China
United States
Japan
Germany
Rest of the world
FCEV stock by region and mode, 2023
Thousand
70
60
50
40
30
20
10
0
PLDVs
LCVs
Buses
Trucks
IEA. CC BY 4.0.

FCVs

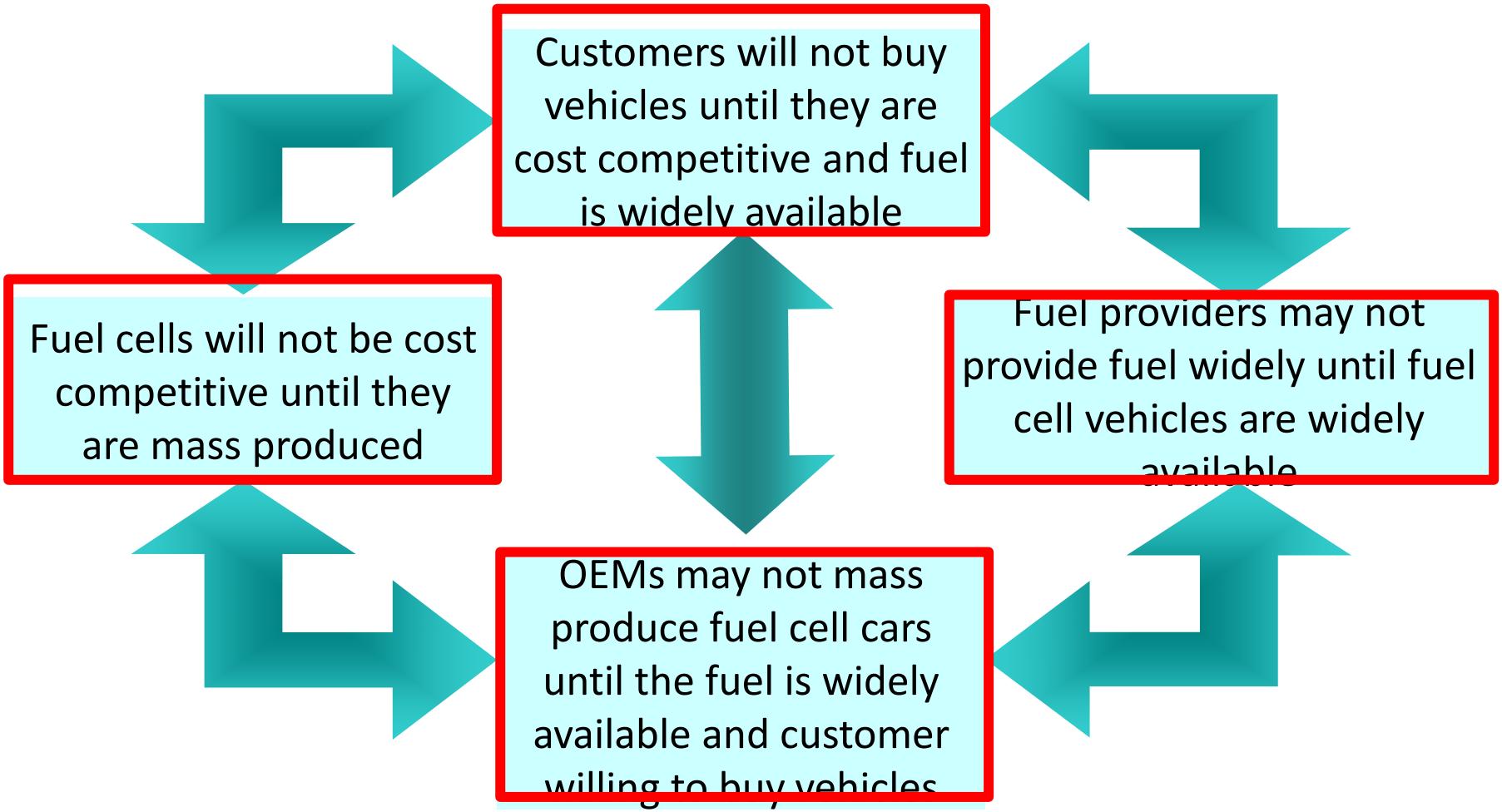
The main reasons for the slow introduction of FCVs:

- 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

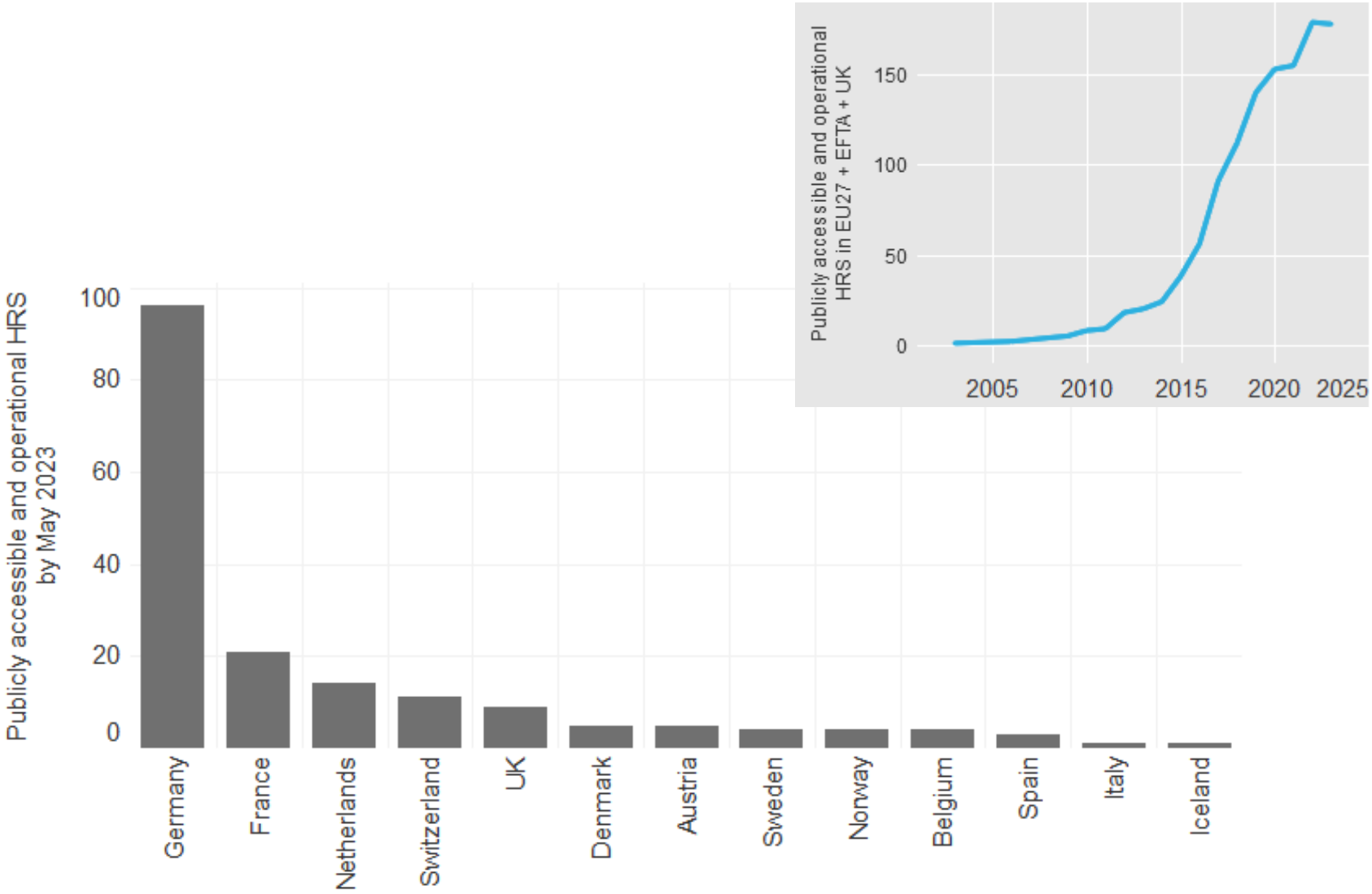
'Chicken and egg' dilemma



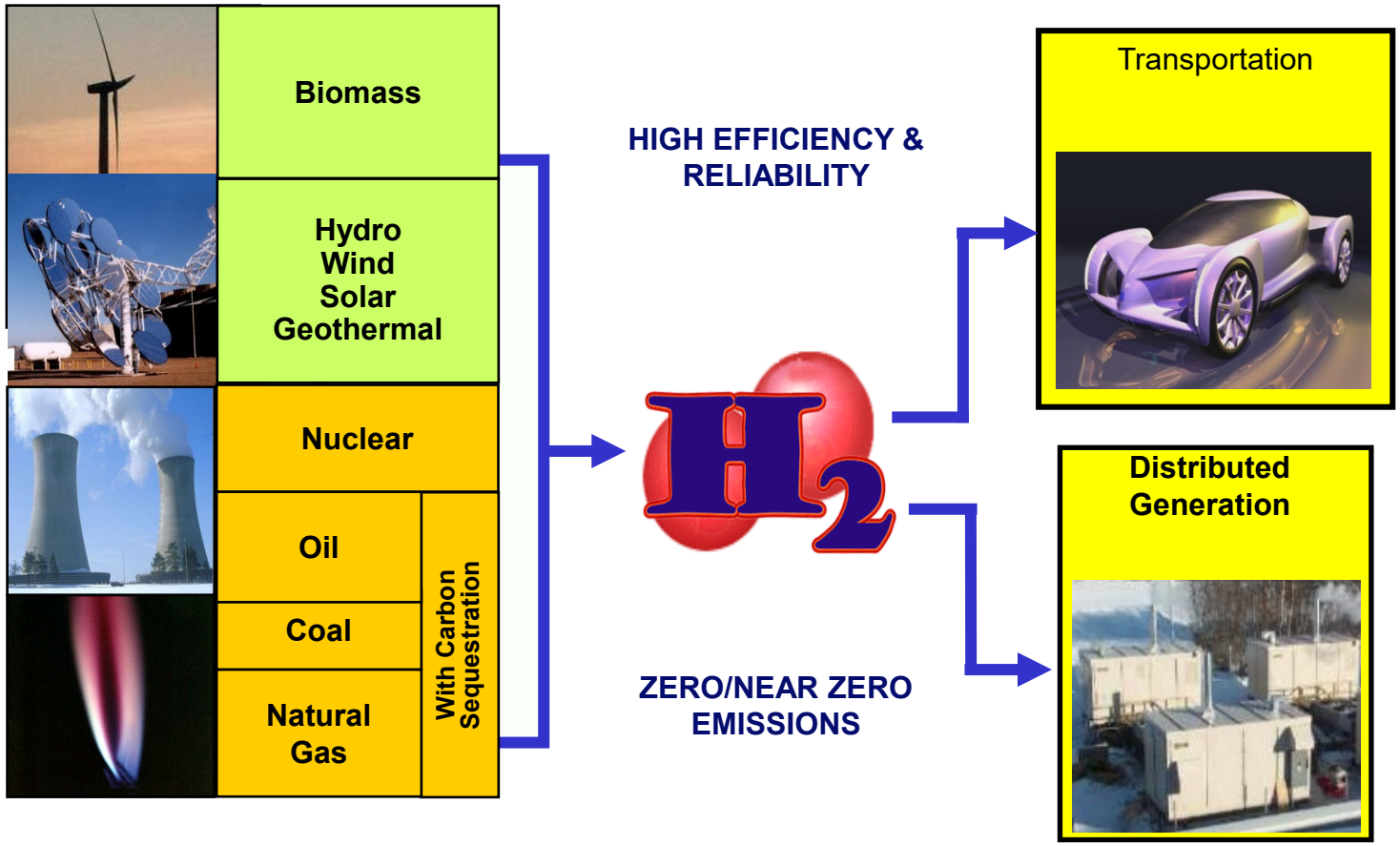
The transition to a hydrogen economy is complex

OEM-Original Equipment Manufacturer

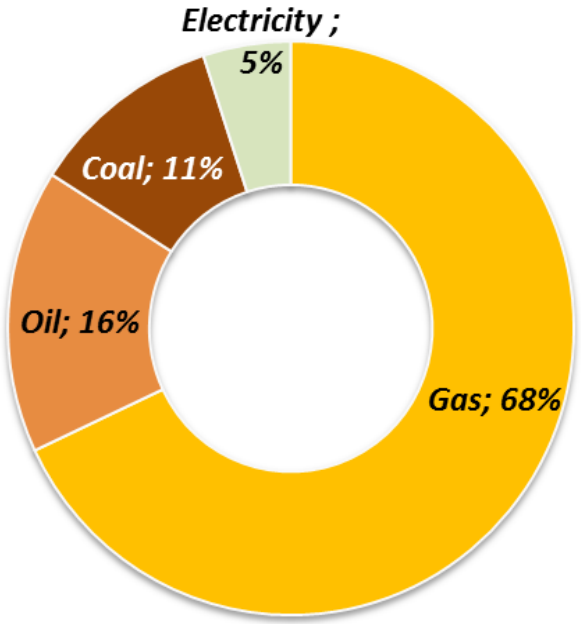
Refuelling stations

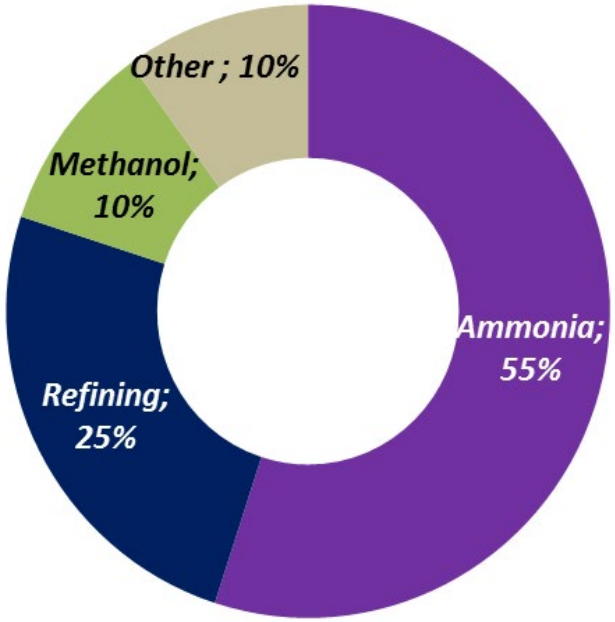


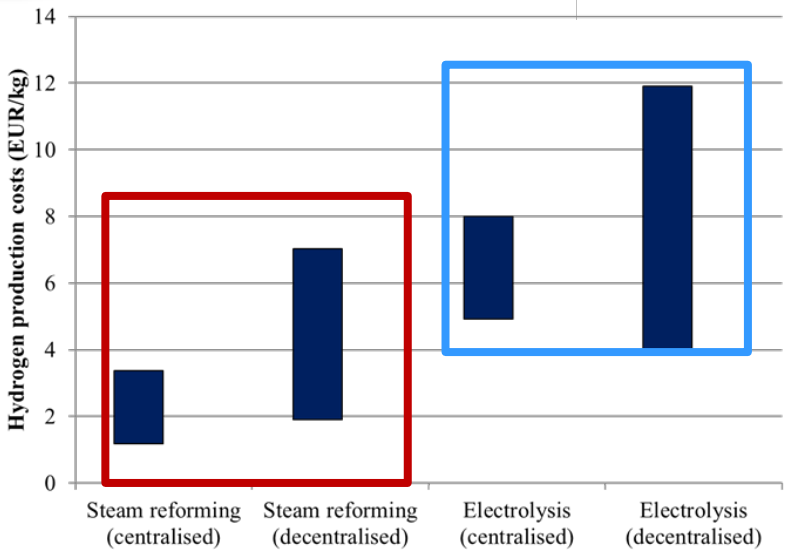
Hydrogen supply chains



Global hydrogen use and production







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	60 000-90 000 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

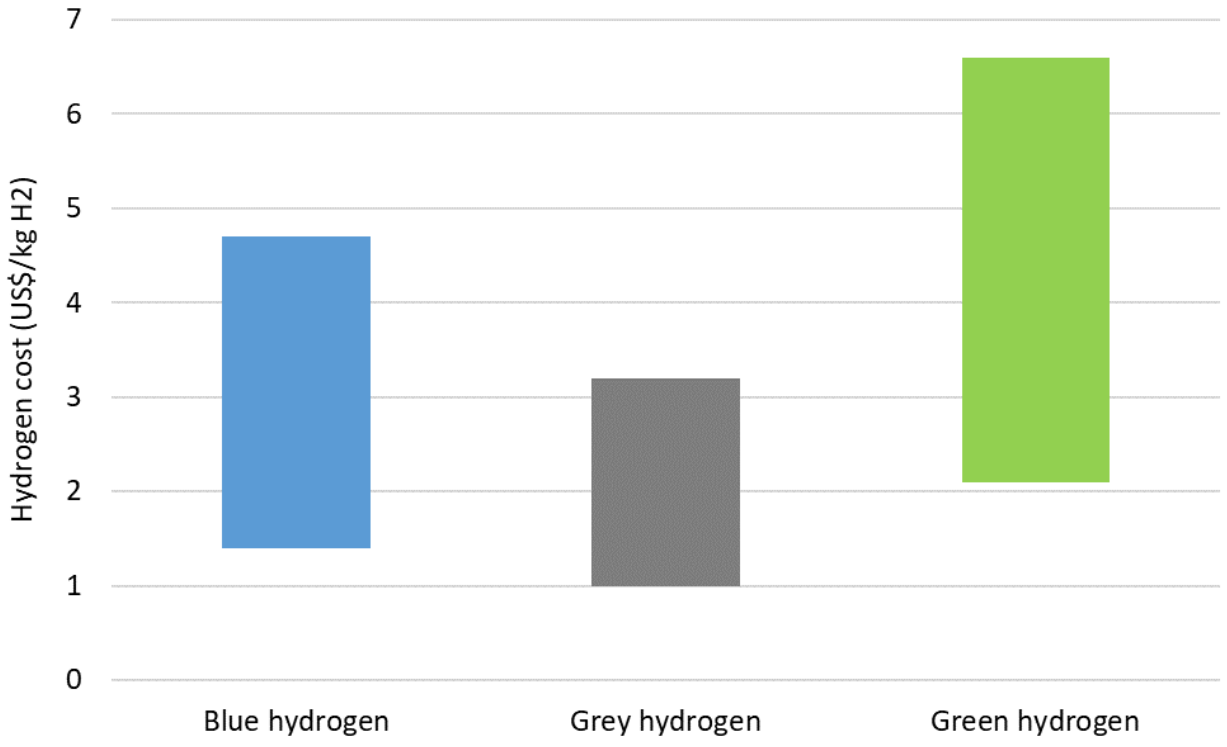
Oil
Coal
Natural gas

→ Grey H2

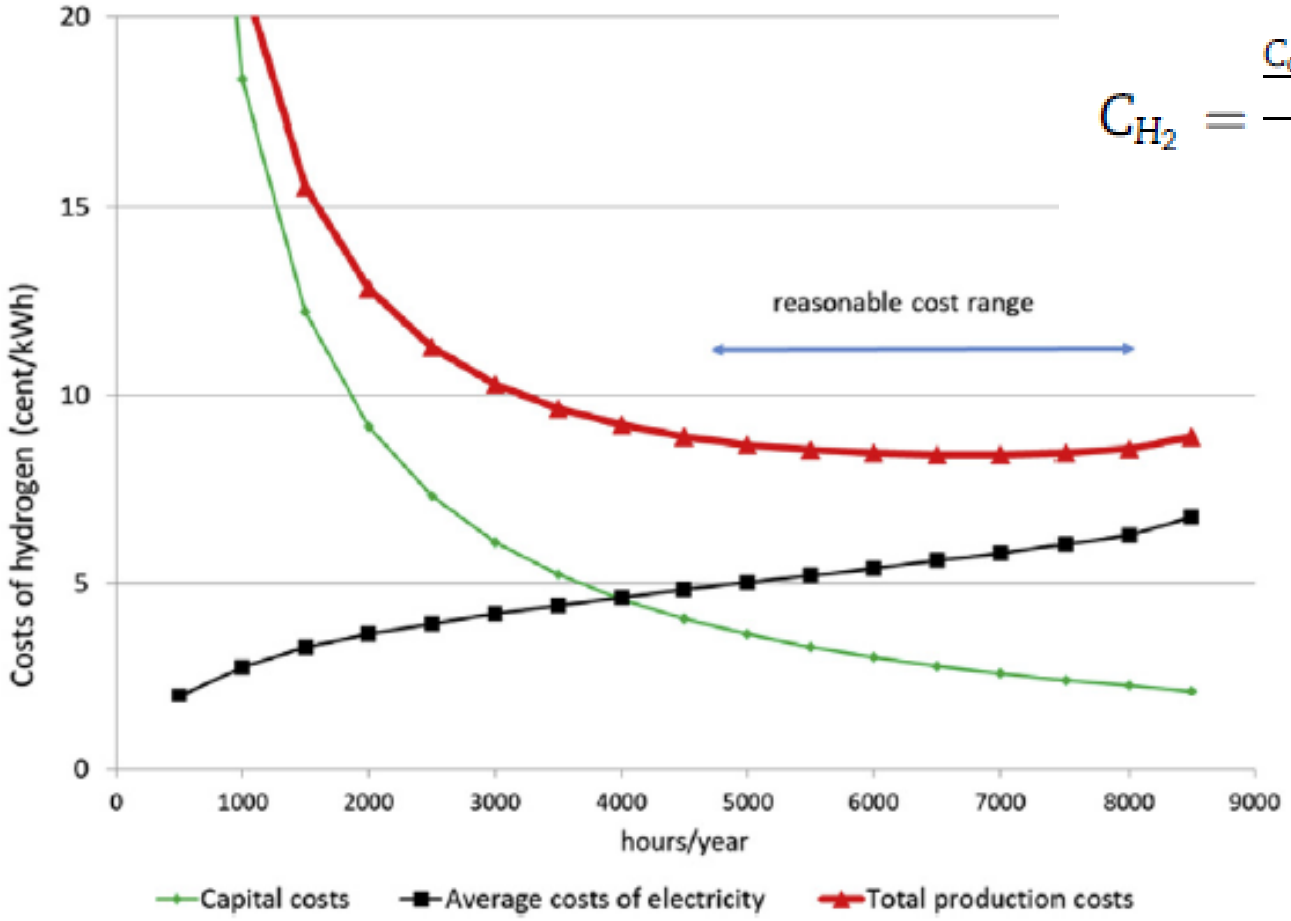
With Carbon Sequestration

→ Blue H2

Cost of hydrogen production for different production pathways

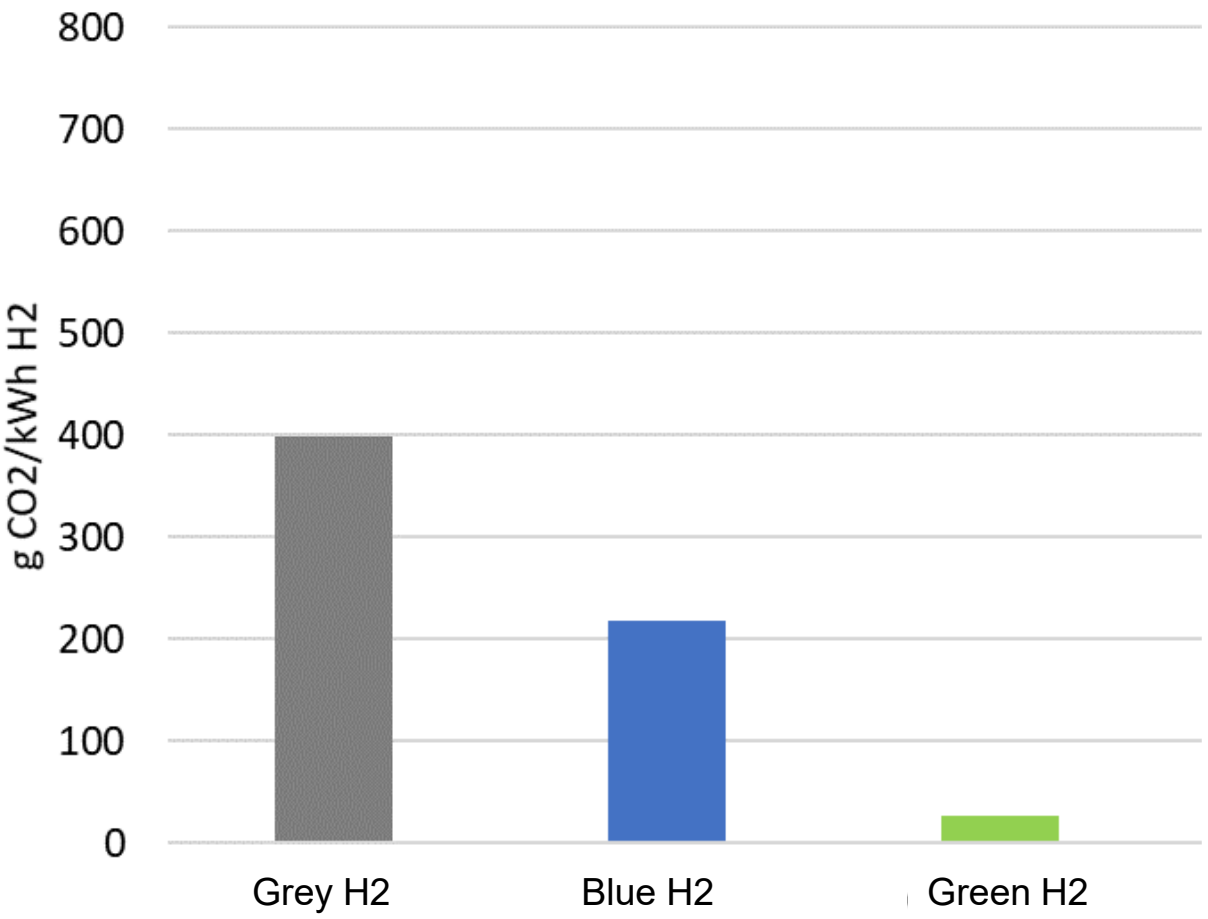


Electrolysis



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

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]

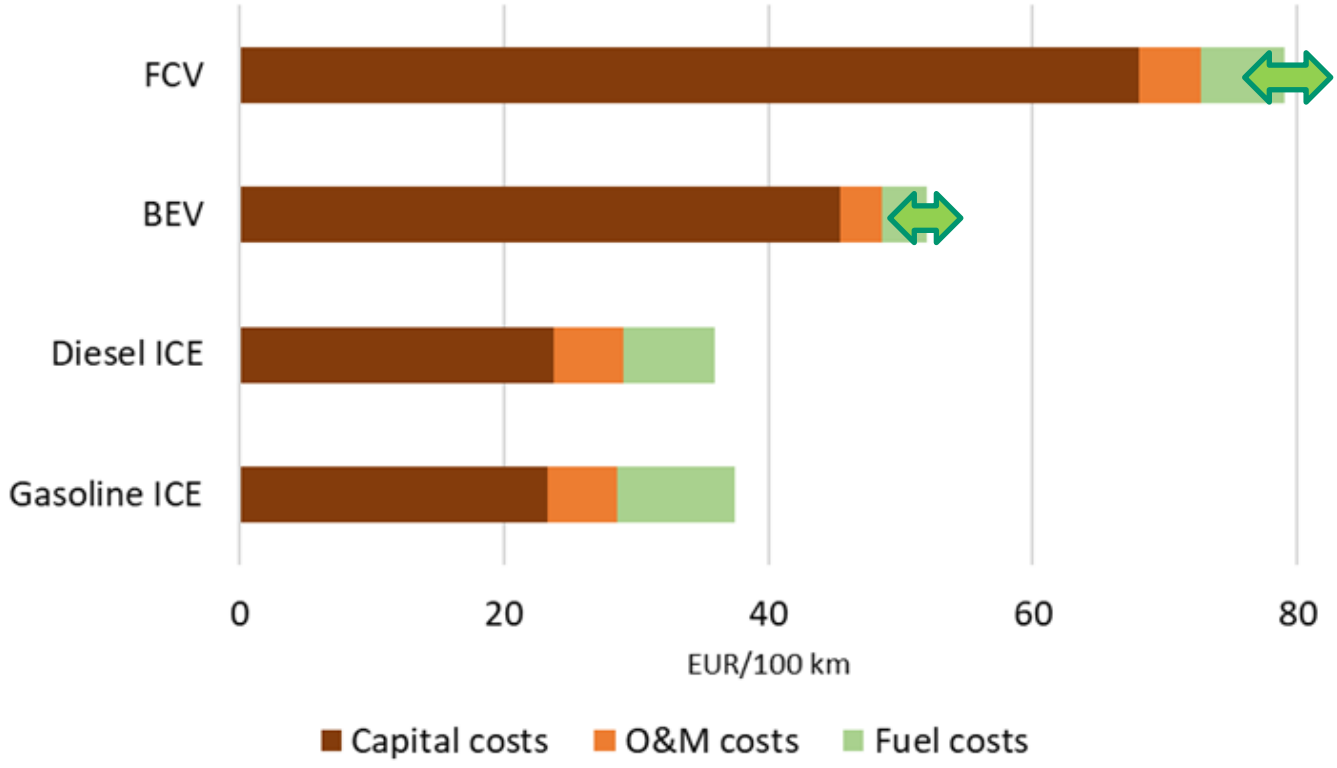
IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……..fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

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:

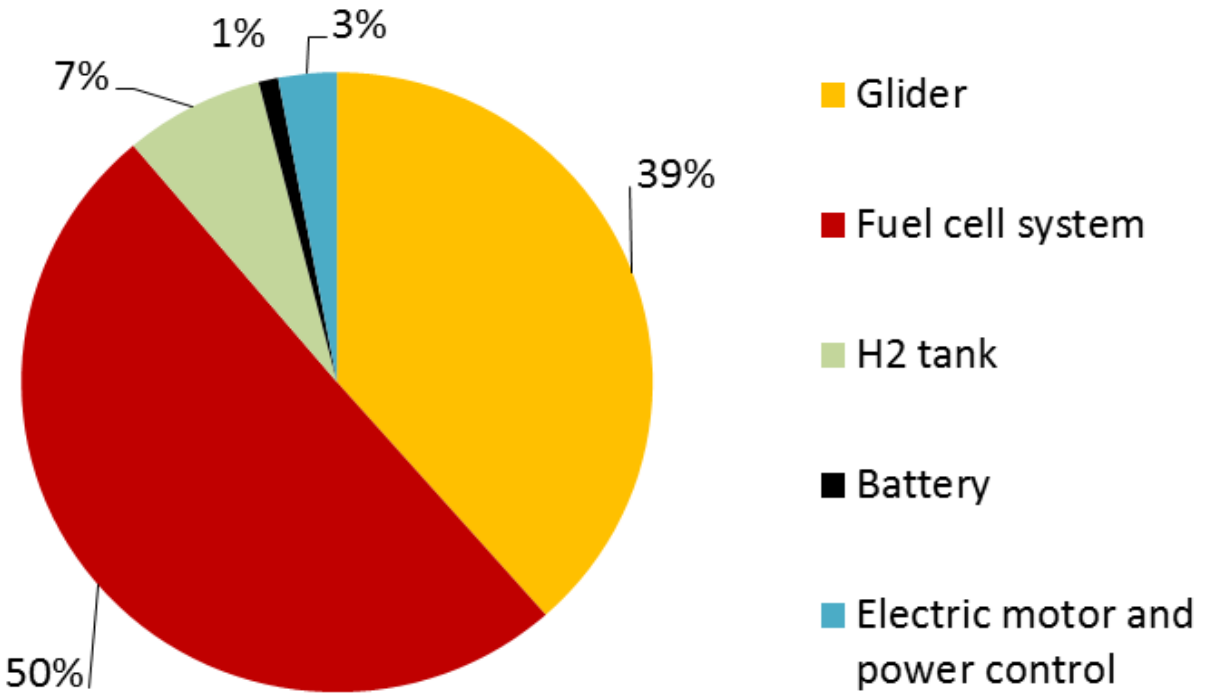
$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

n…..the number of annuities received.

Mobility costs

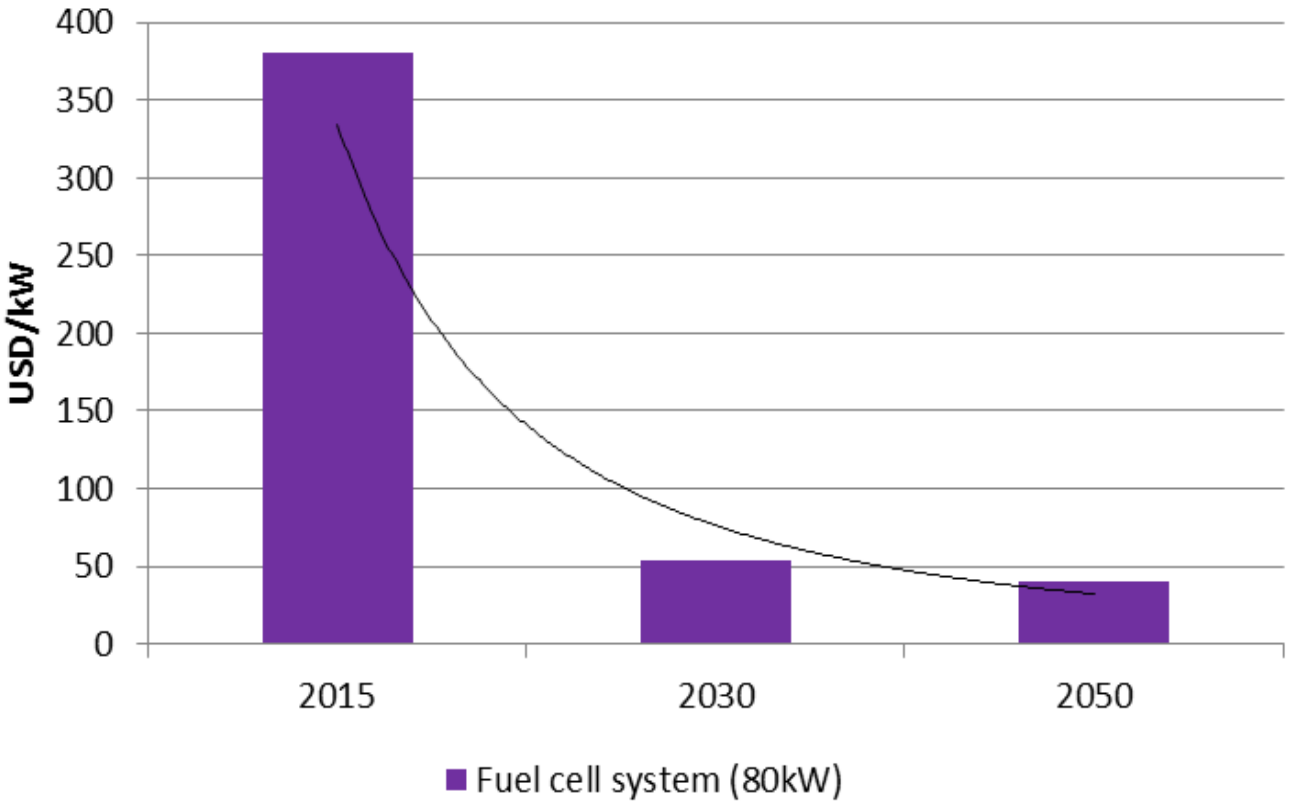


Fuel cell vehicles



Structure of investment costs of fuel cell vehicles

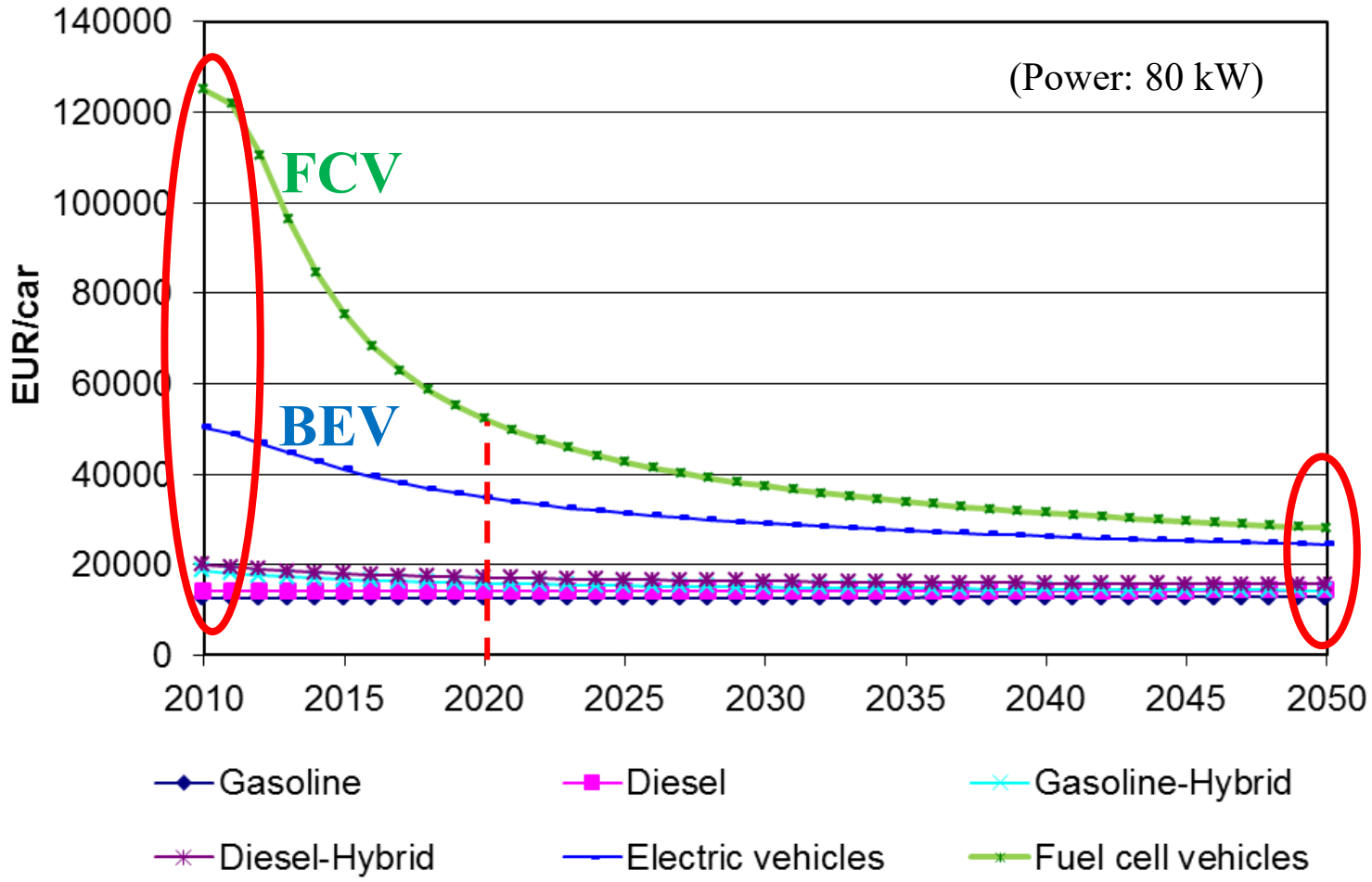
Technological learning – Fuel cell

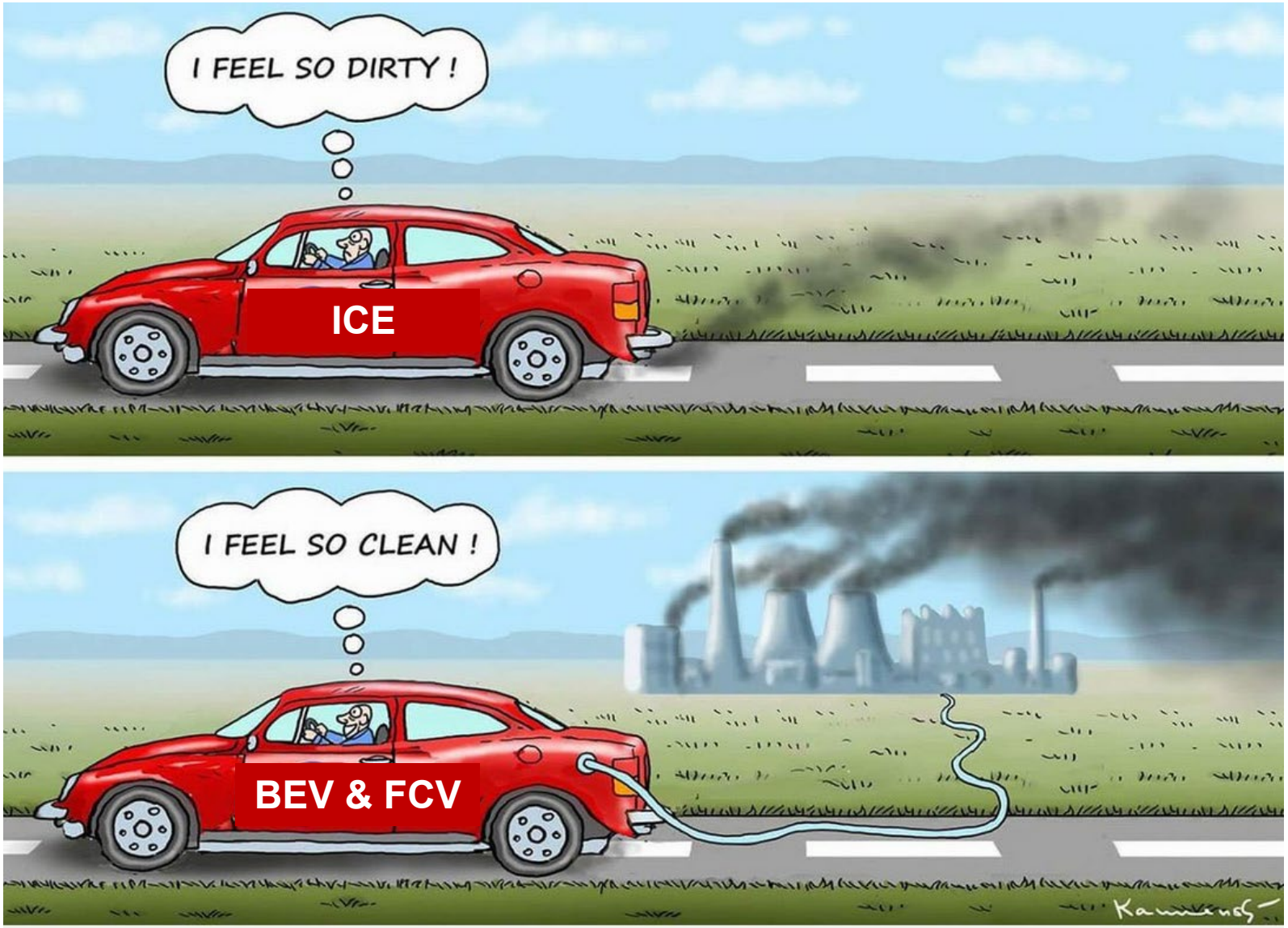


Development of the costs of the fuel cell system

Scenario for development of investment costs

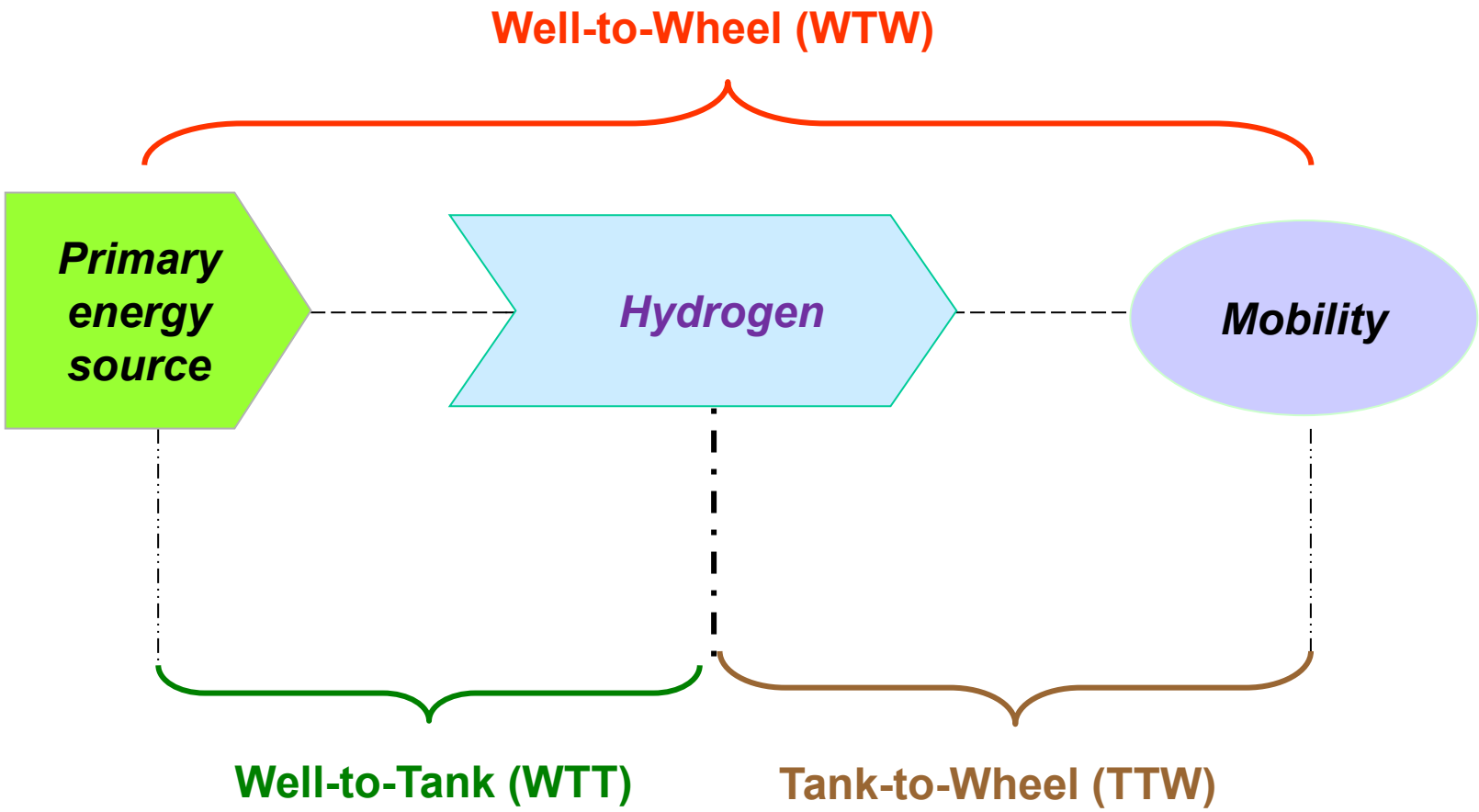
Technological learning:



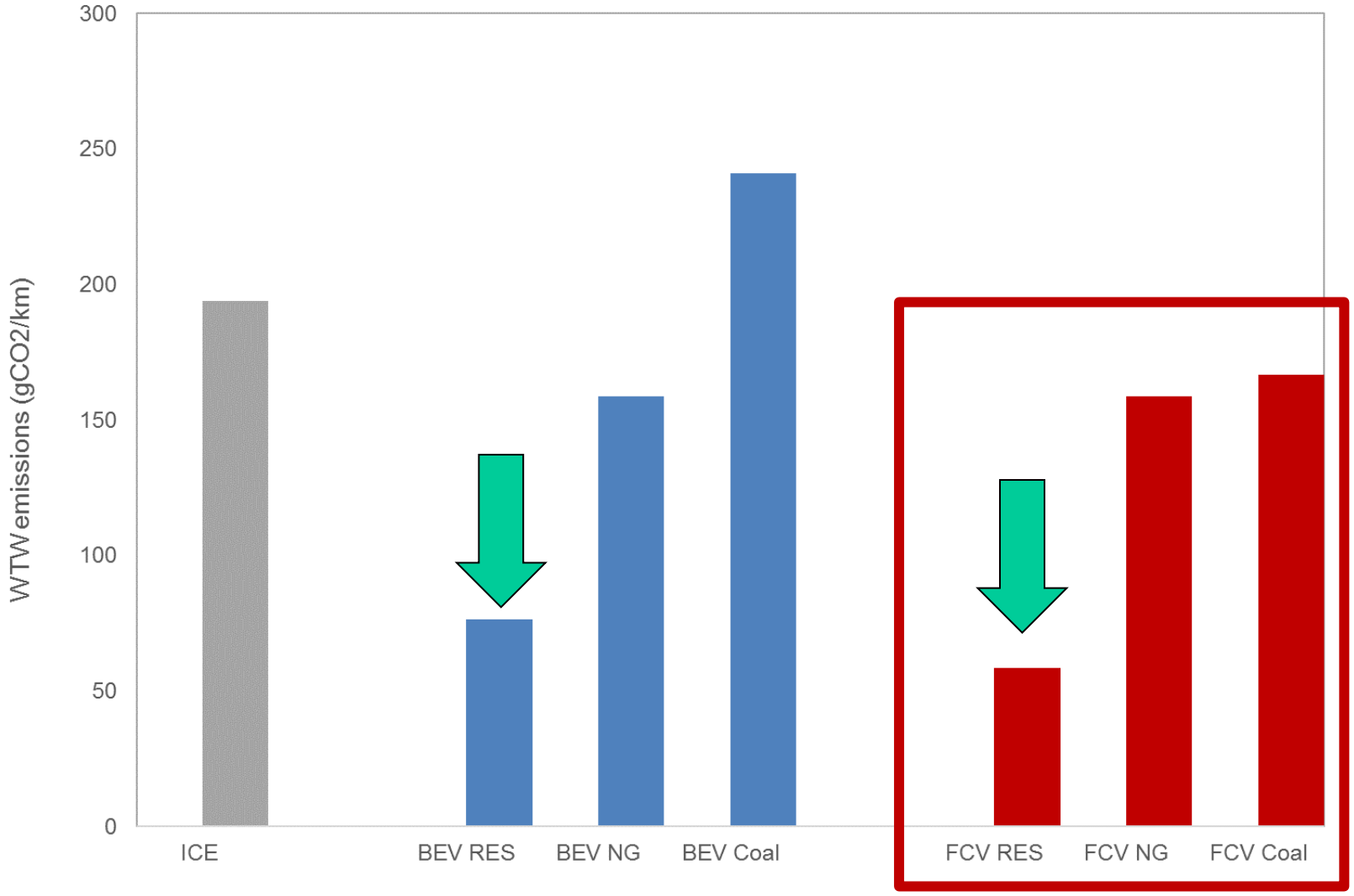


Artist: Marian Kamensky

Environmental assessment



Environmental assessment



FCVs vs BEVs

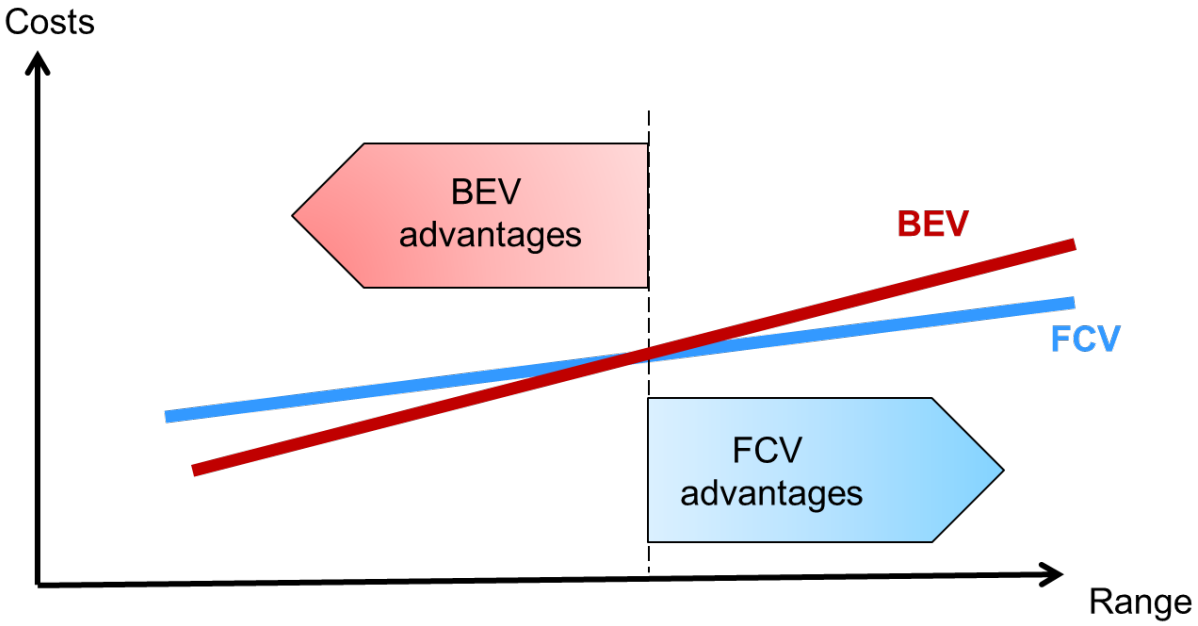
BEV

- Costs
- Infrastructure
- Fuel efficiency

FCV

- Refuelling time
- Driving range
- Weight of energy storage

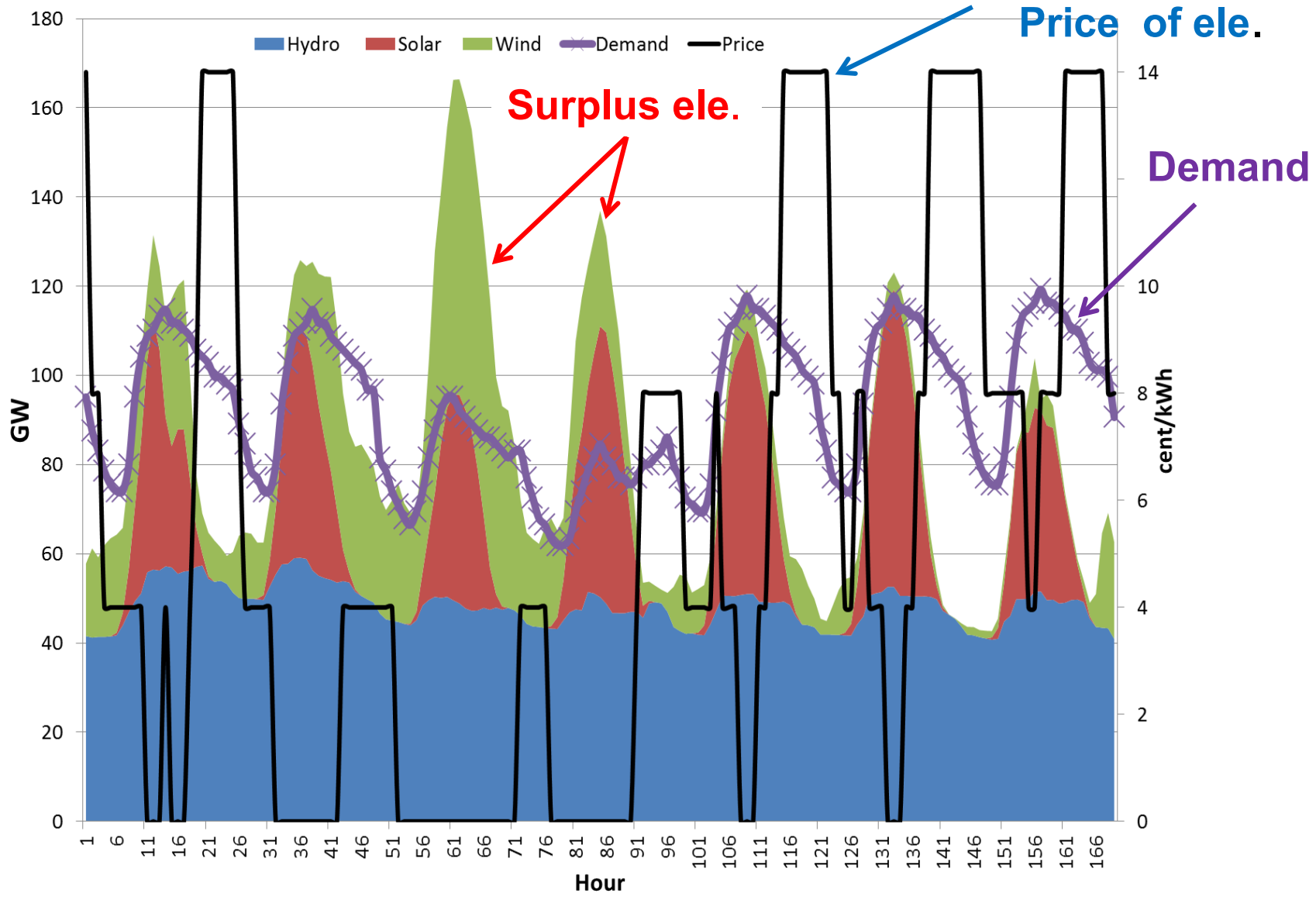
- Environmental benefits



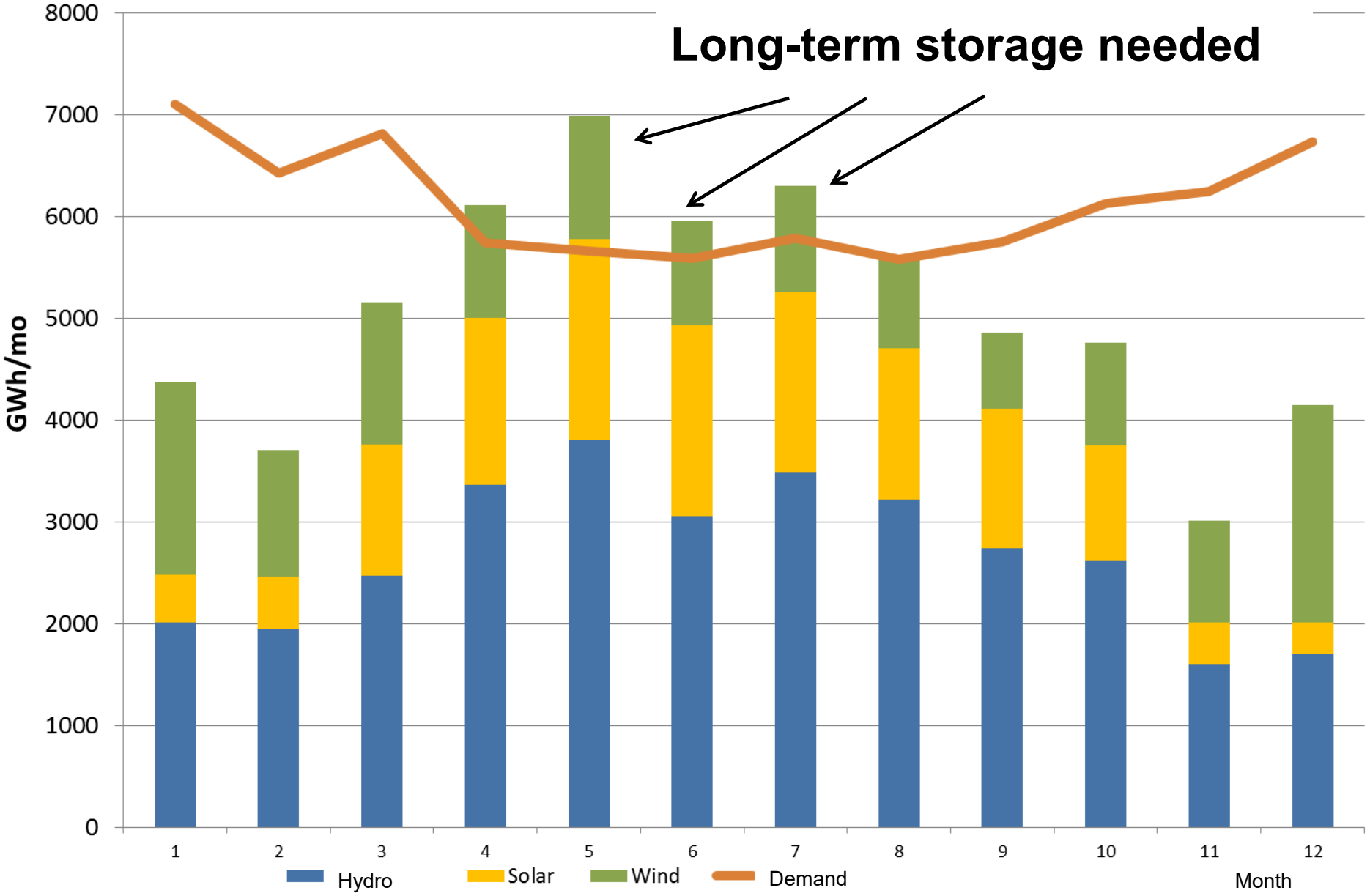
Hydrogen as storage

- 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

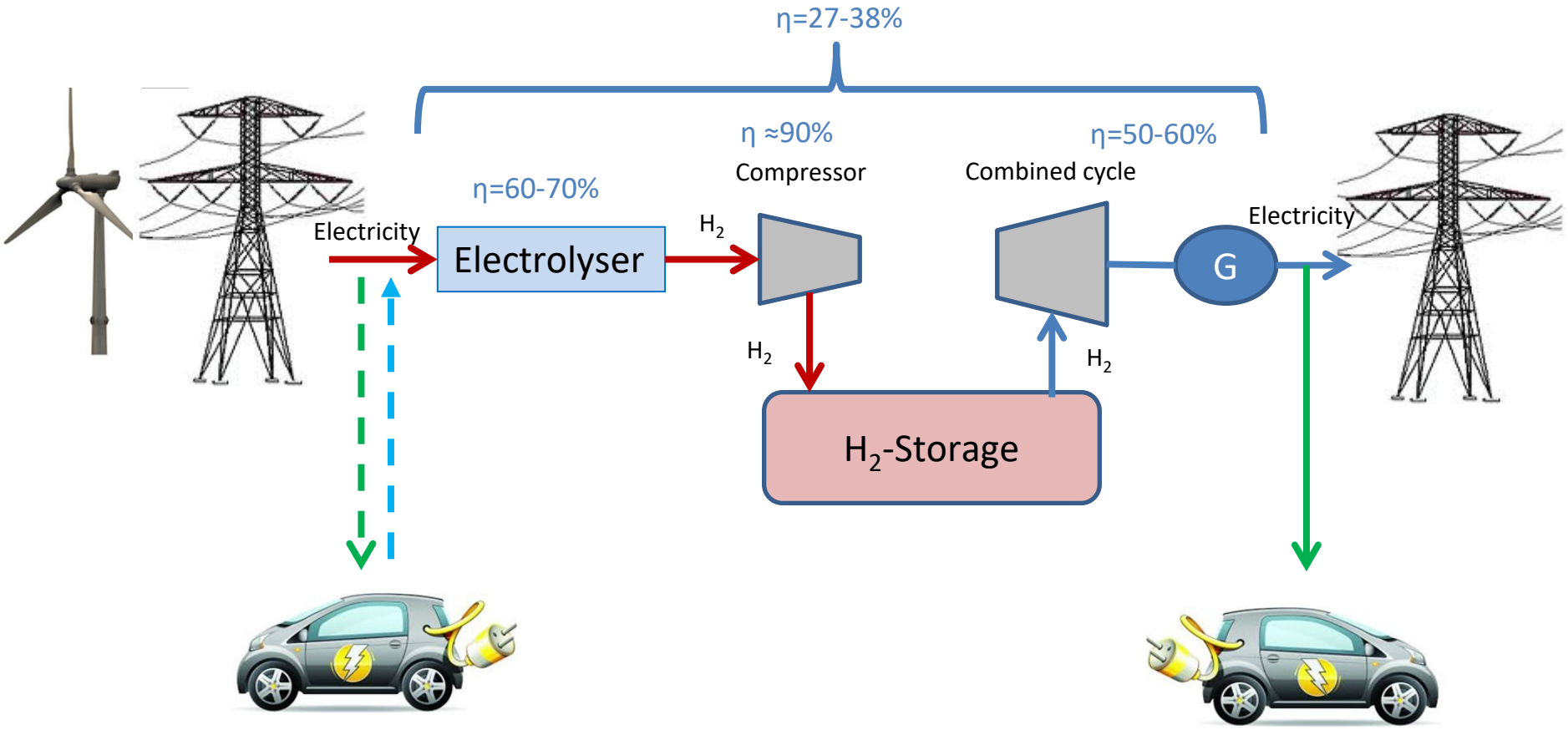


Demand for long-term storage



Storage and fuel

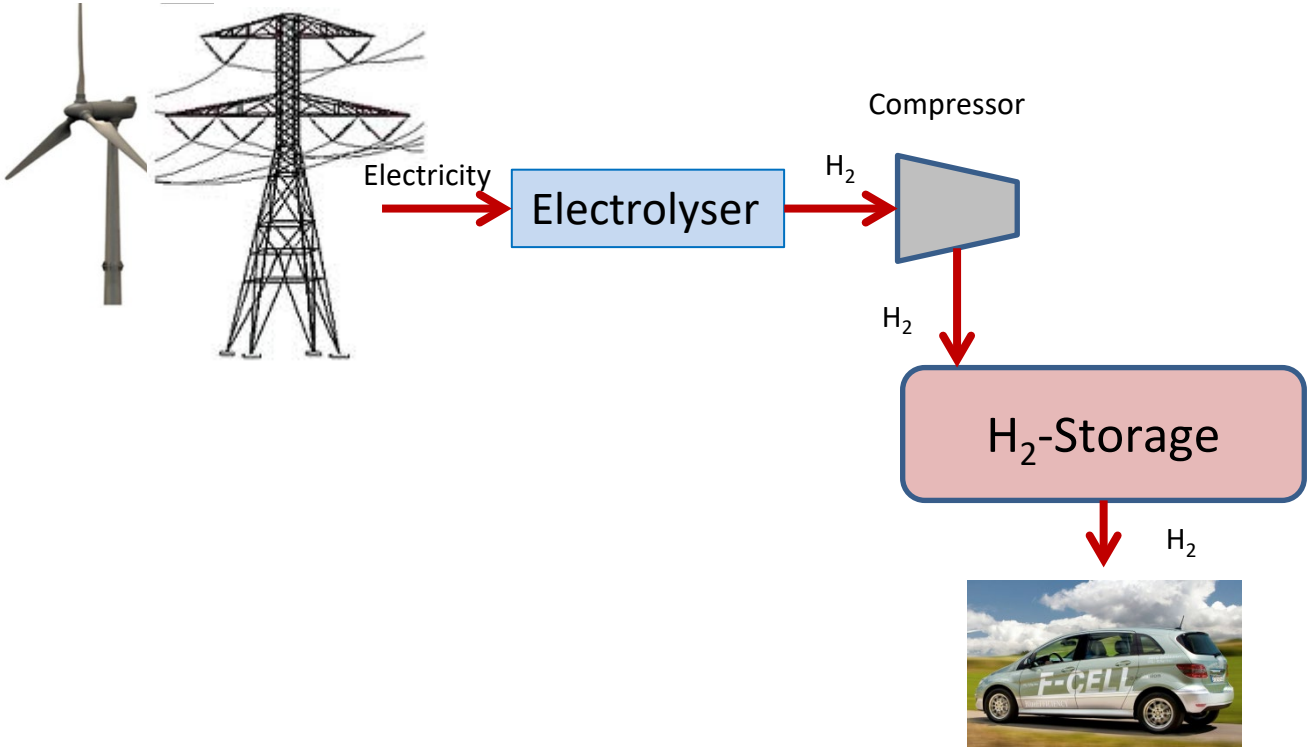
Very low roundtrip efficiency for electricity!



Battery degradation

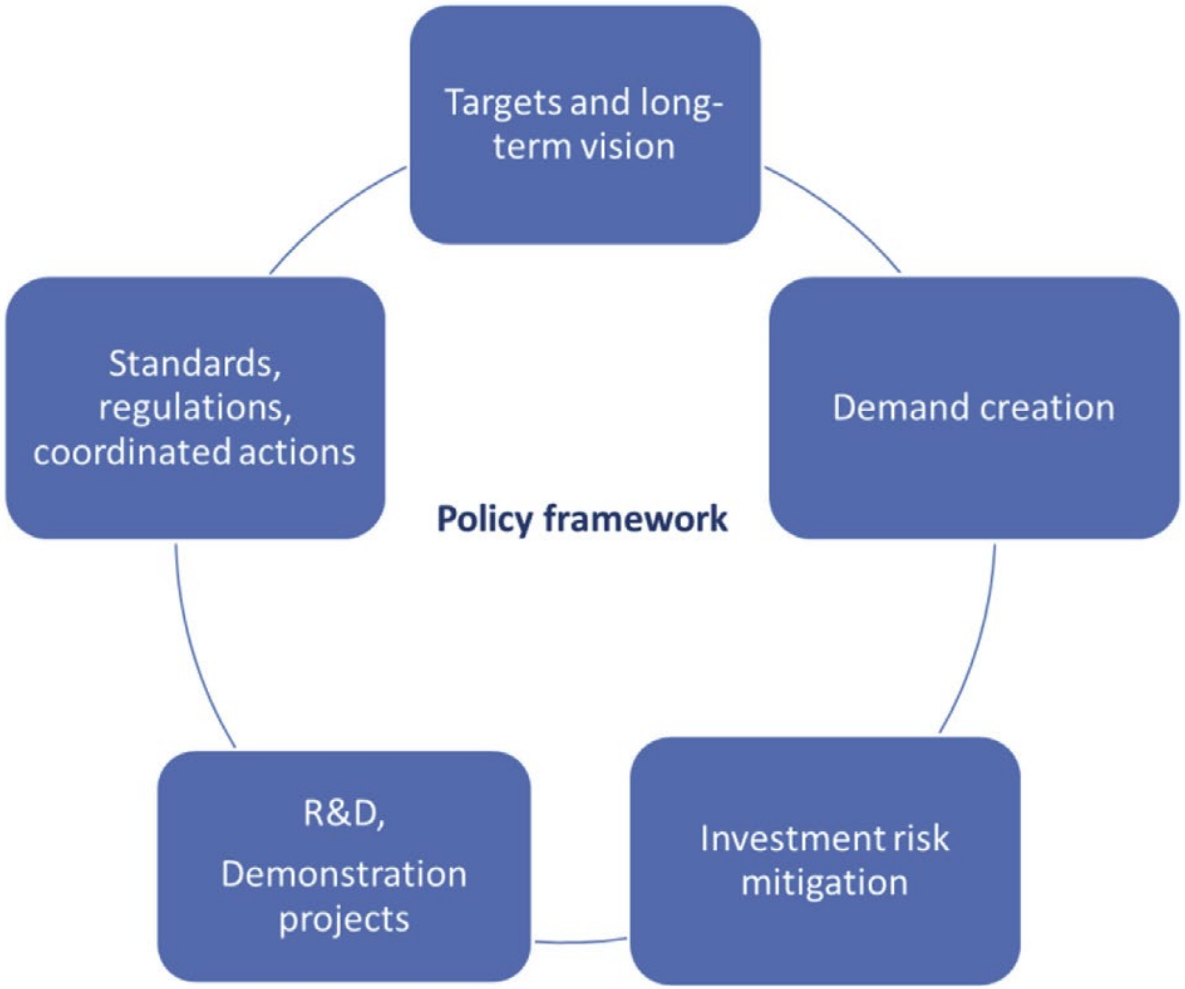
Energy supply chains: Storage and/or use of RES for mobility

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)	>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

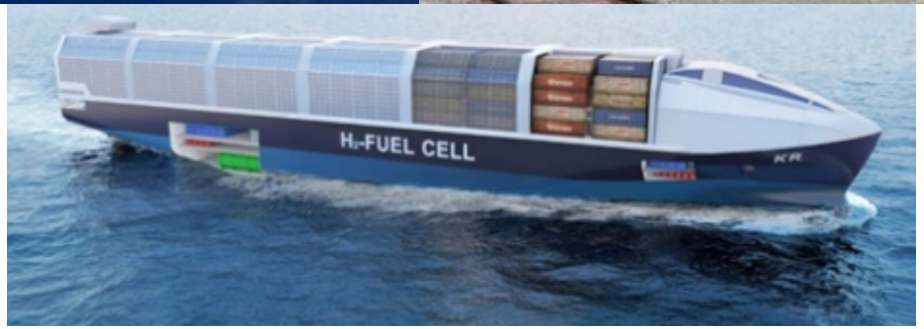
Hydrogen Bus in Norway

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

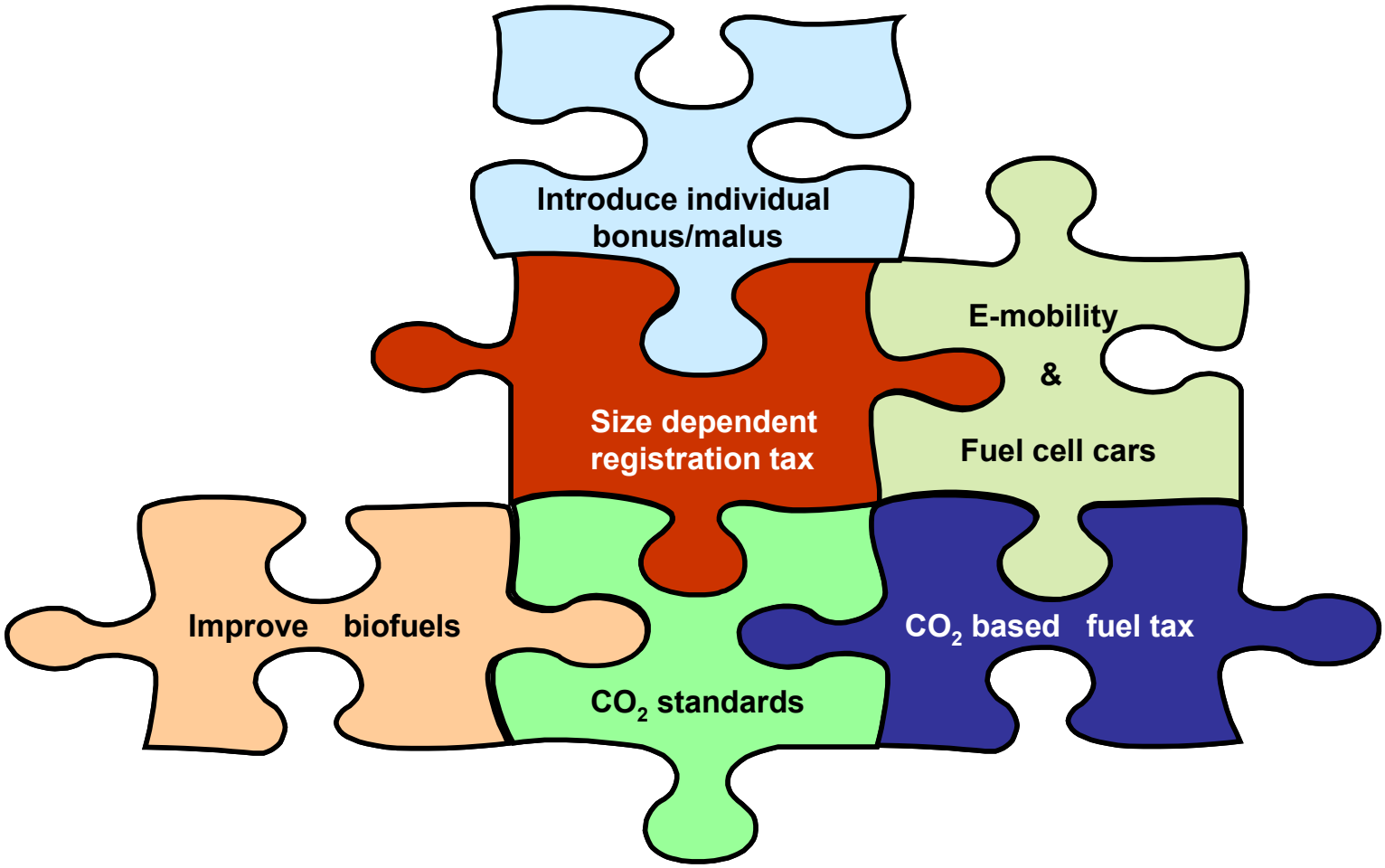
Hydrogen can help to:

- ✓ 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

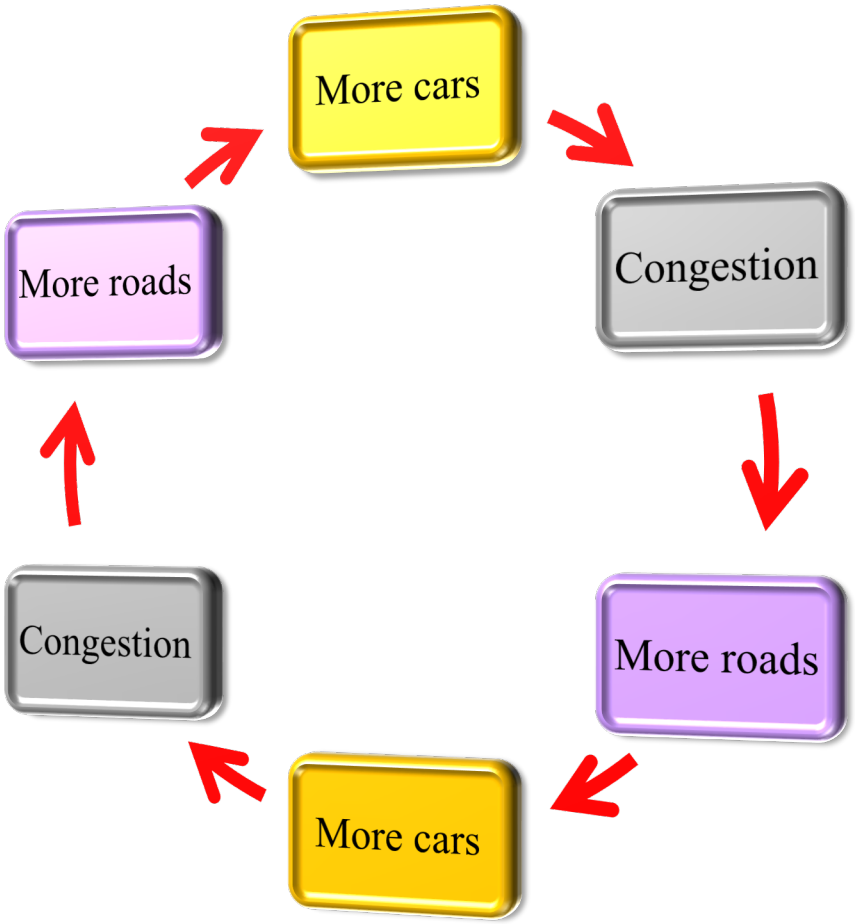
Major challenges for hydrogen and FCV:

- Economics
- Infrastructure
- Policies framework

Conclusions



Car-oriented mobility

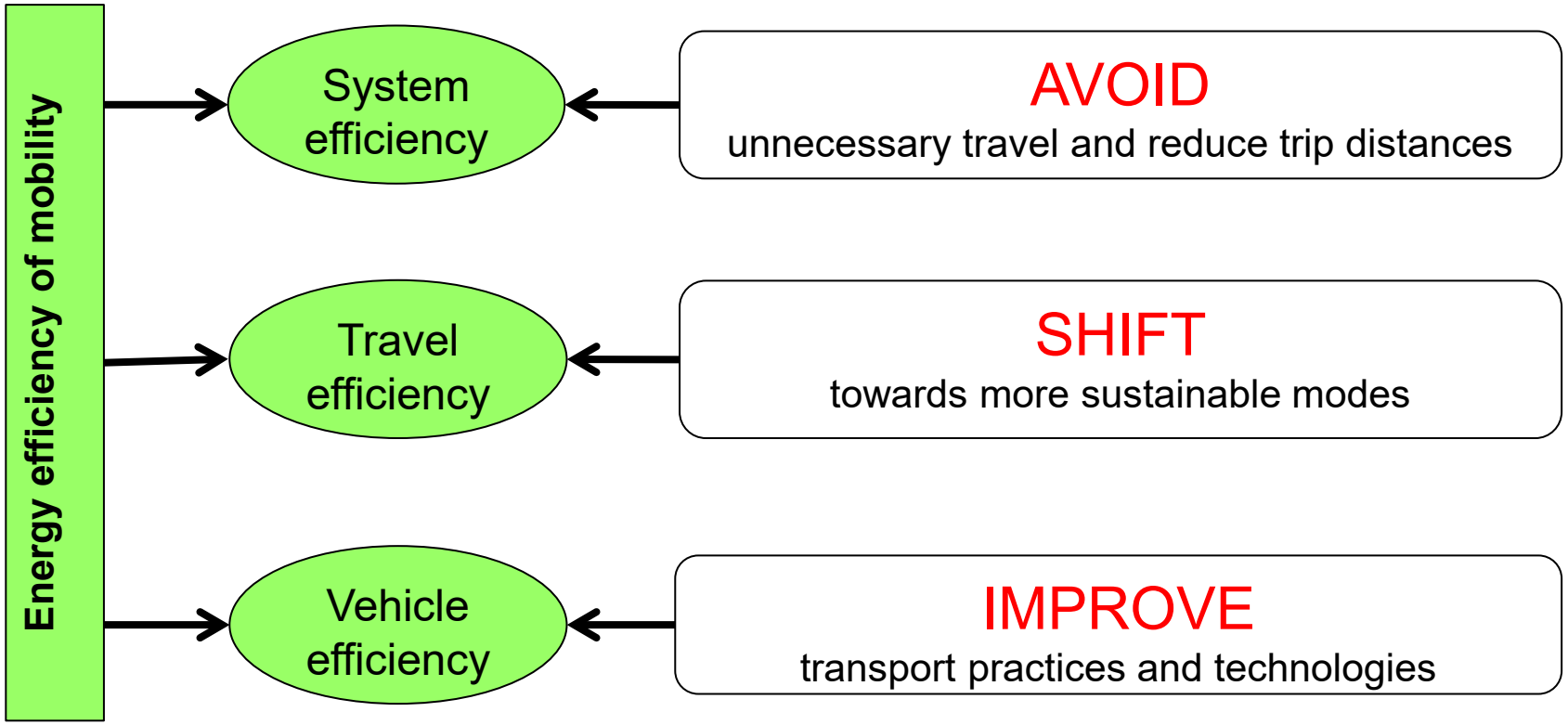


Conclusions

Car-oriented transport development

https://simotron.files.wordpress.com

Strategies for energy efficient mobility



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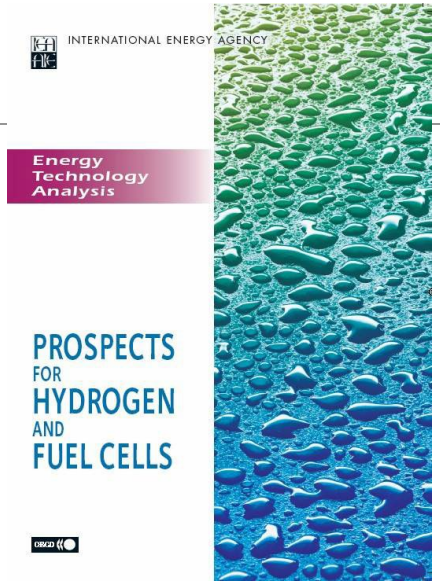
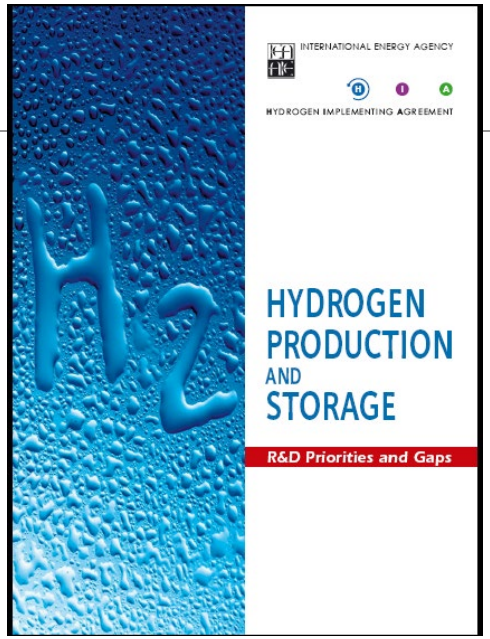
Energy Economics Group

TU WIEN





iea hydrogen

GLOBAL TRENDS AND OUTLOOK FOR HYDROGEN

December 2017

The Future of Hydrogen

Seizing today's opportunities

Global Hydrogen Review 2021