Energy Economics in Transport

Hydrogen and Fuel Cell Vehicles

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Content

- Introduction
- Recent developments in the transport sector
- EU policy goals
  - ZEV
- Hydrogen
  - Energy carrier
  - Storage
- Conclusions

Energy system

….decarbonisation, energy efficiency, affordability and reliability of the energy system.

…planning and operation of the energy system as a whole:

- multiple energy carriers (e.g. electricity, gas, heat)
- infrastructures
- consumption sectors (industry, buildings, transport)

Energy crisis

….energy security

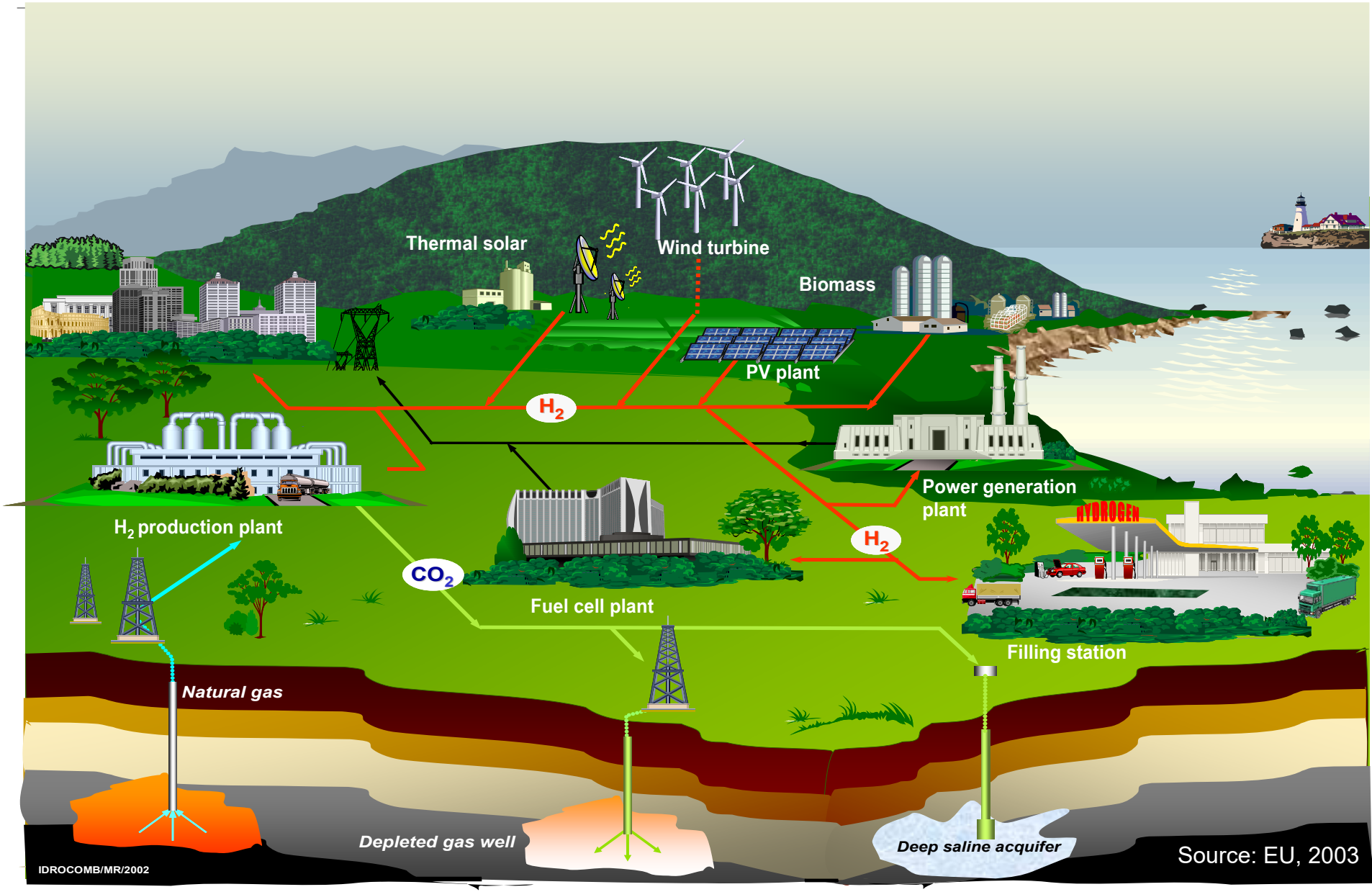
…reduce energy import dependency

…reconsider material and energy supply chains

…energy resilience

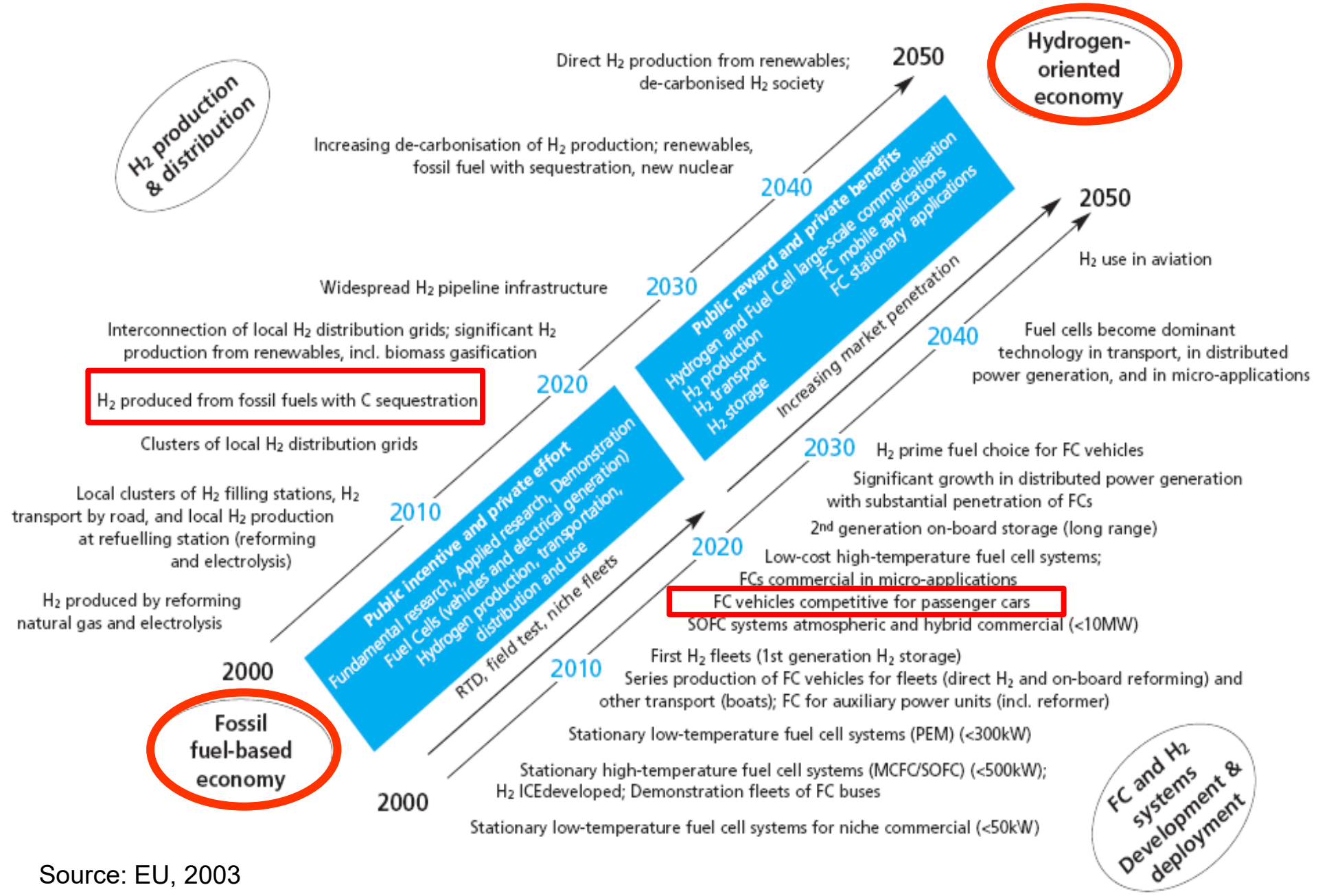
…accelerate transition towards more sustainable energy system

Hydrogen vision



Source: EU, 2003

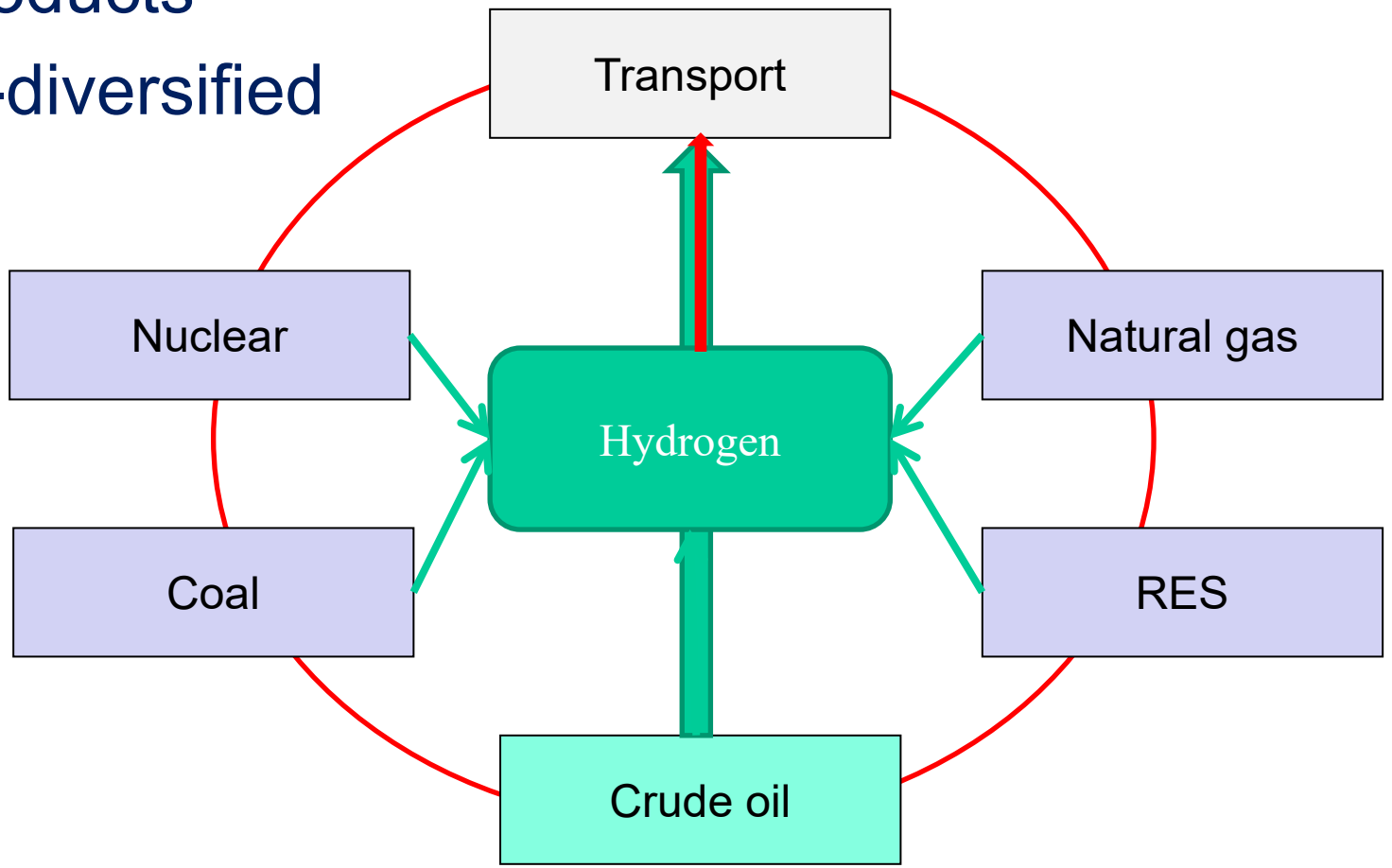
A challenging European hydrogen vision



Source: EU, 2003

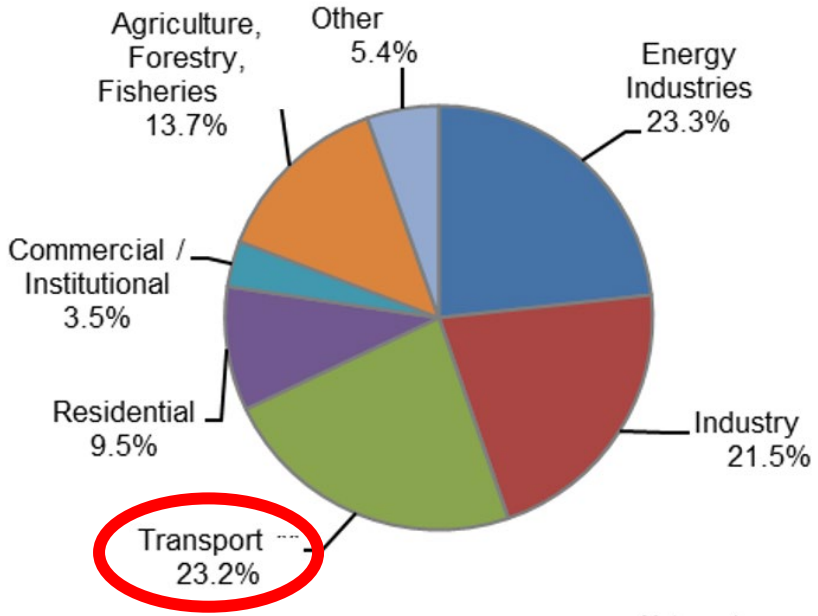
Transport sector

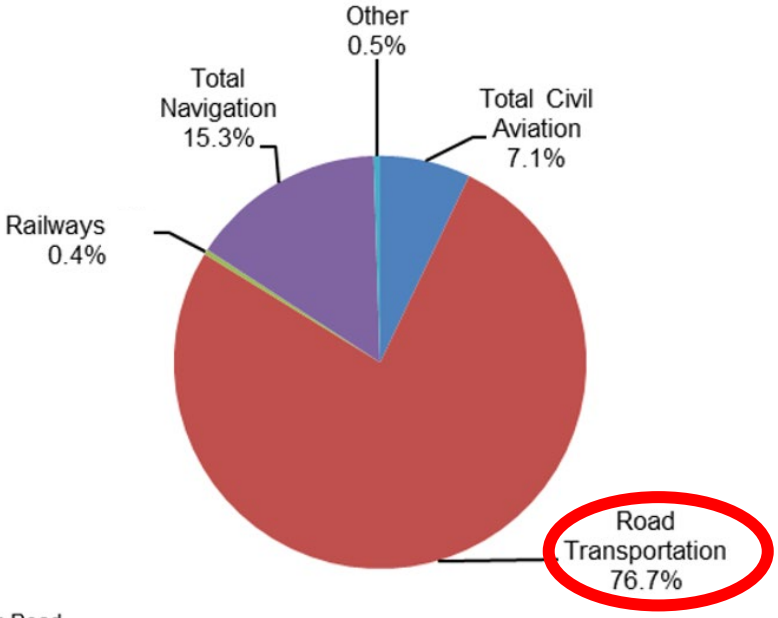
- oil products
- least-diversified

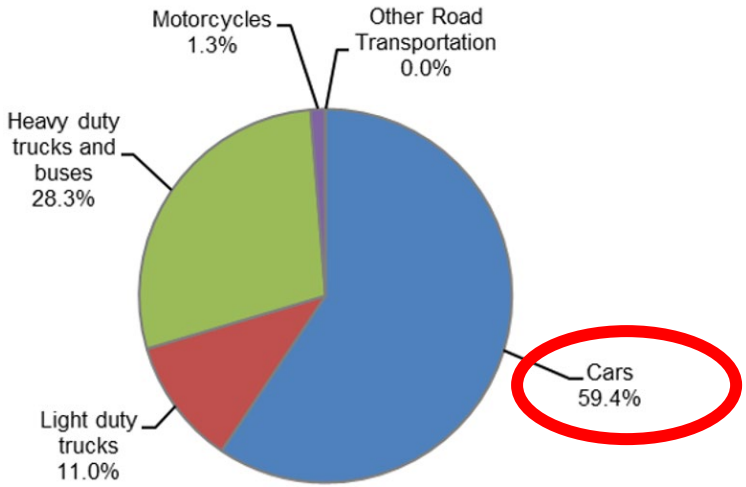


- energy import dependency

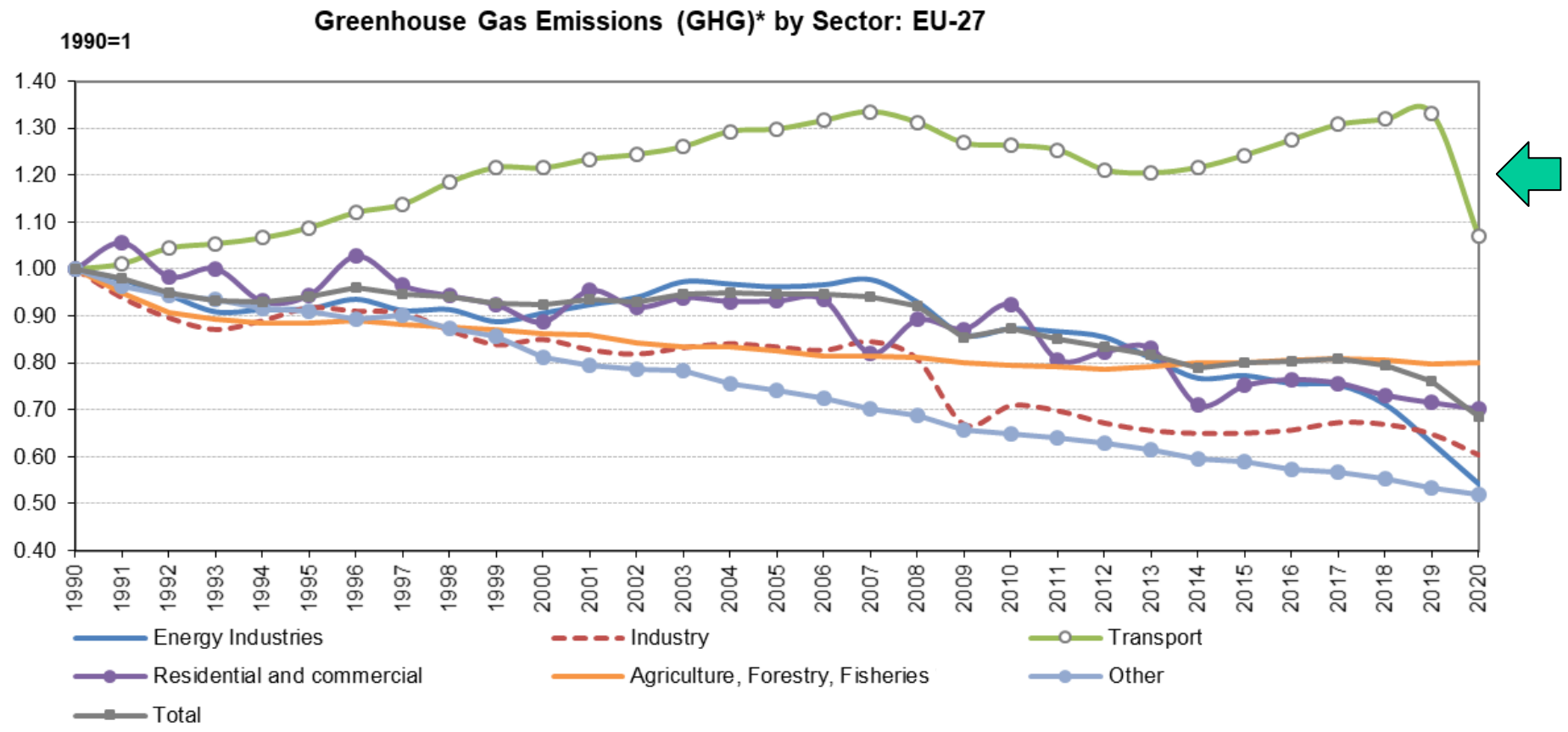
GHG, EU-27


Agriculture, Forestry, Fisheries 13.7%
Other 5.4%
Energy Industries 23.3%
Commercial / Institutional 3.5%
Residential 9.5%
Industry 21.5%
Transport 23.2%


Other 0.5%
Total Navigation 15.3%
Total Civil Aviation 7.1%
Railways 0.4%
Road Transportation 76.7%


Motorcycles 1.3%
Other Road Transportation 0.0%
Heavy duty trucks and buses 28.3%
Cars 59.4%
Light duty trucks 11.0%

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
Energy Industries
Industry
Transport
Residential and commercial
Agriculture, Forestry, Fisheries
Other
Total

EU targets

EU - the first climate-neutral continent by 2050

European Green Deal

2030 climate & energy framework

40-32-32,5

14%

Sustainable and Smart Mobility Strategy

at least 30 million zero-emission cars will be in operation on European roads

nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission.

2010 2020 2030 2050

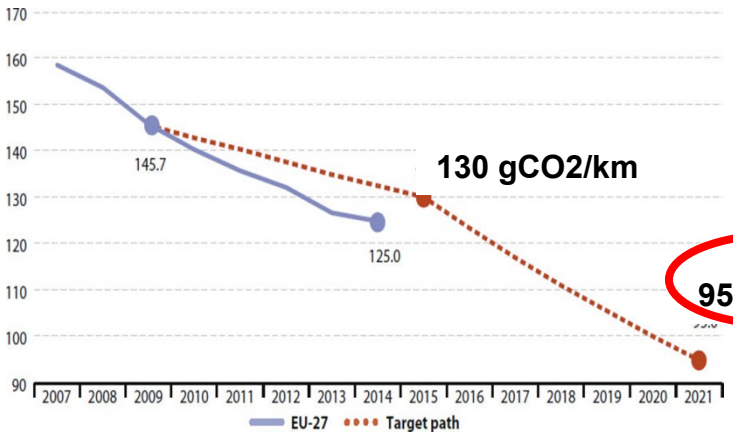
ICE -50% in city

20% GHG (2008)

No ICE in city

60% GHG (1990)

Transport White Paper



-15%

-37,5%

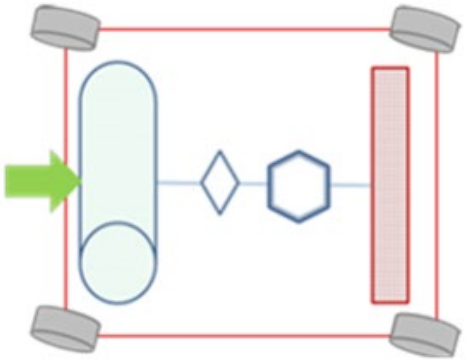
Targets and average CO_2 emissions from new passenger cars in EU countries

Announced 100% ZEV sales targets and bans on ICE vehicle sales

	2025	2030	2035	2040	2045	2050
Costa Rica						●
Denmark		●				
France				●		
Iceland		●				
Ireland		●				
Israel*		●		●		
Netherlands		●			●	
Norway	●					
Portugal				●		
Slovenia		●				
Spain				●		●
Sri Lanka				●		
United Kingdom				●		

● ICE sales ban or 100% ZEV sales target ● Fleet without ICEs

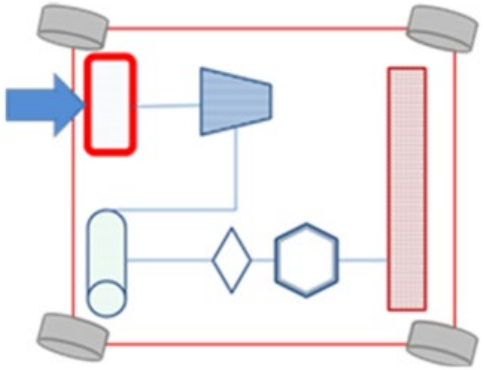
Zero-emission vehicles



BEV

> 11 000 000

> 51 600



FCV

ZEV

100% electrification

Advantages

- ✓ Energy efficiency
- ✓ Energy security
- ✓ Air pollution
- ✓ Noise reduction
- ✓ GHG emissions

Disadvantages

- Costs
- Infrastructure

FCVs vs BEVs

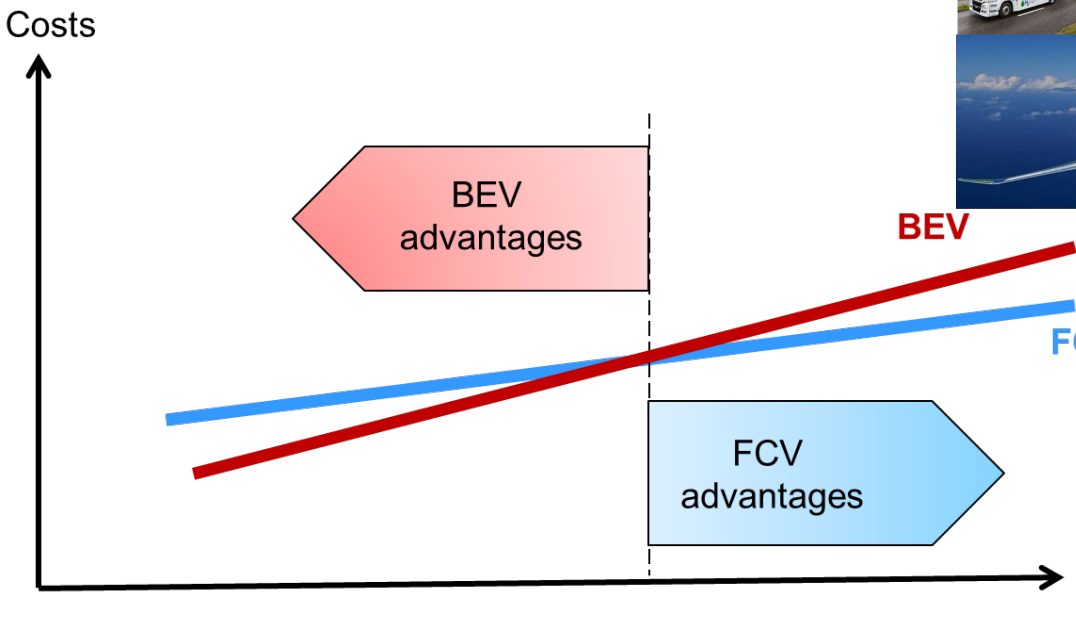
BEV

- Costs
- Infrastructure
- Fuel efficiency

FCV

- Refuelling time
- Driving range
- Weight of energy storage

- Environmental benefits



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

2021: The global FCV stock >51600

2011: > 100 fuel cell buses worldwide

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)

2013: > 4000 fuel cell forklifts worldwide

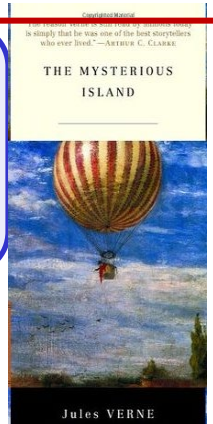
2015: First hydrogen fuel cell powered tramcar

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

1958: The first PEM fuel cell

1838: Discovered fuel cell effect

1874: Vision of hydrogen economy



1766: Hydrogen was first identified as a distinct element

FCV

Citroën ë-Jumpy Hydrogen

PEUGEOT e-Expert Hydrogen

Honda Clarity Fuel Cell

Hyundai ix35

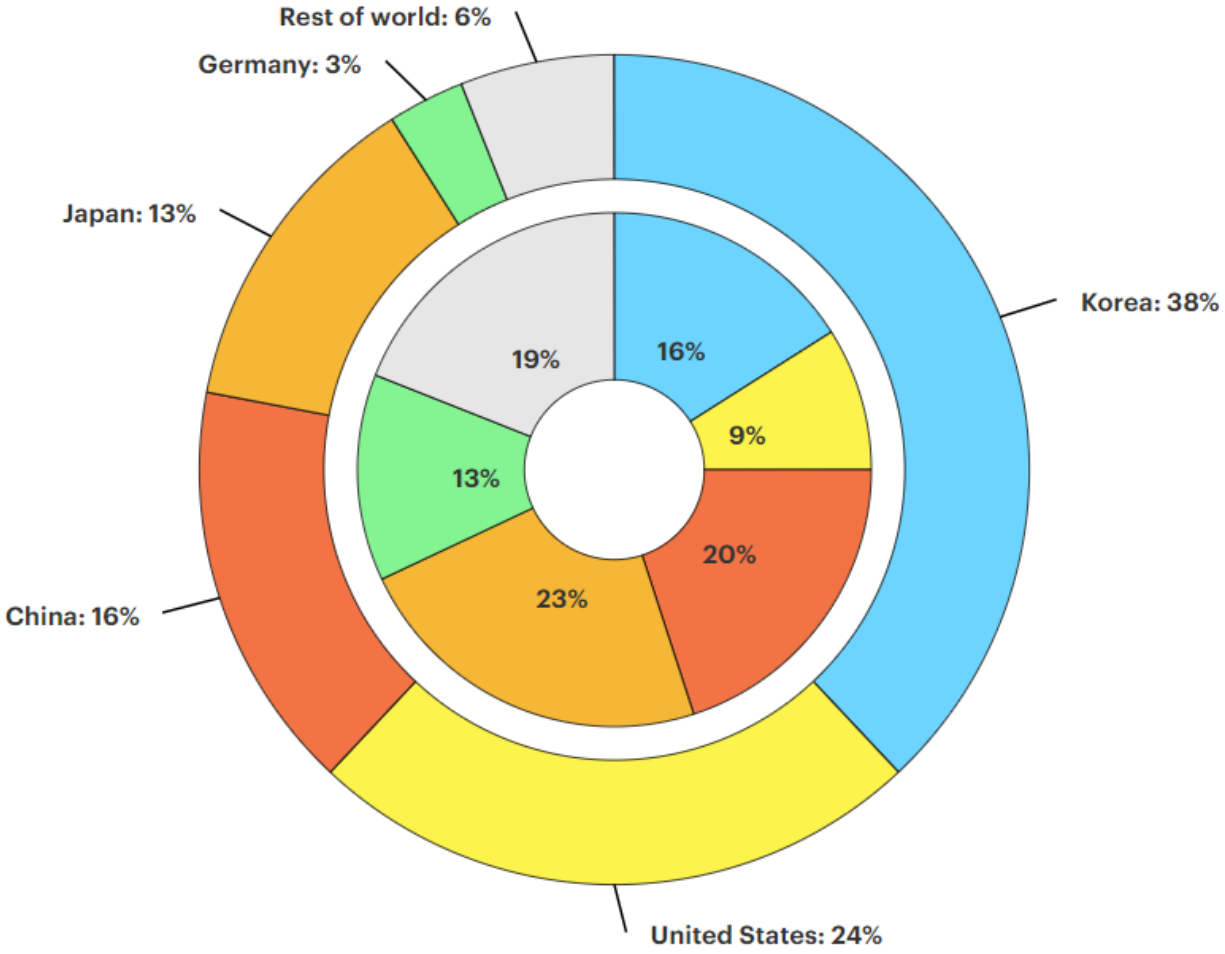
Toyota MIRAI

Toyota MIRAI II

Hyundai NEXO

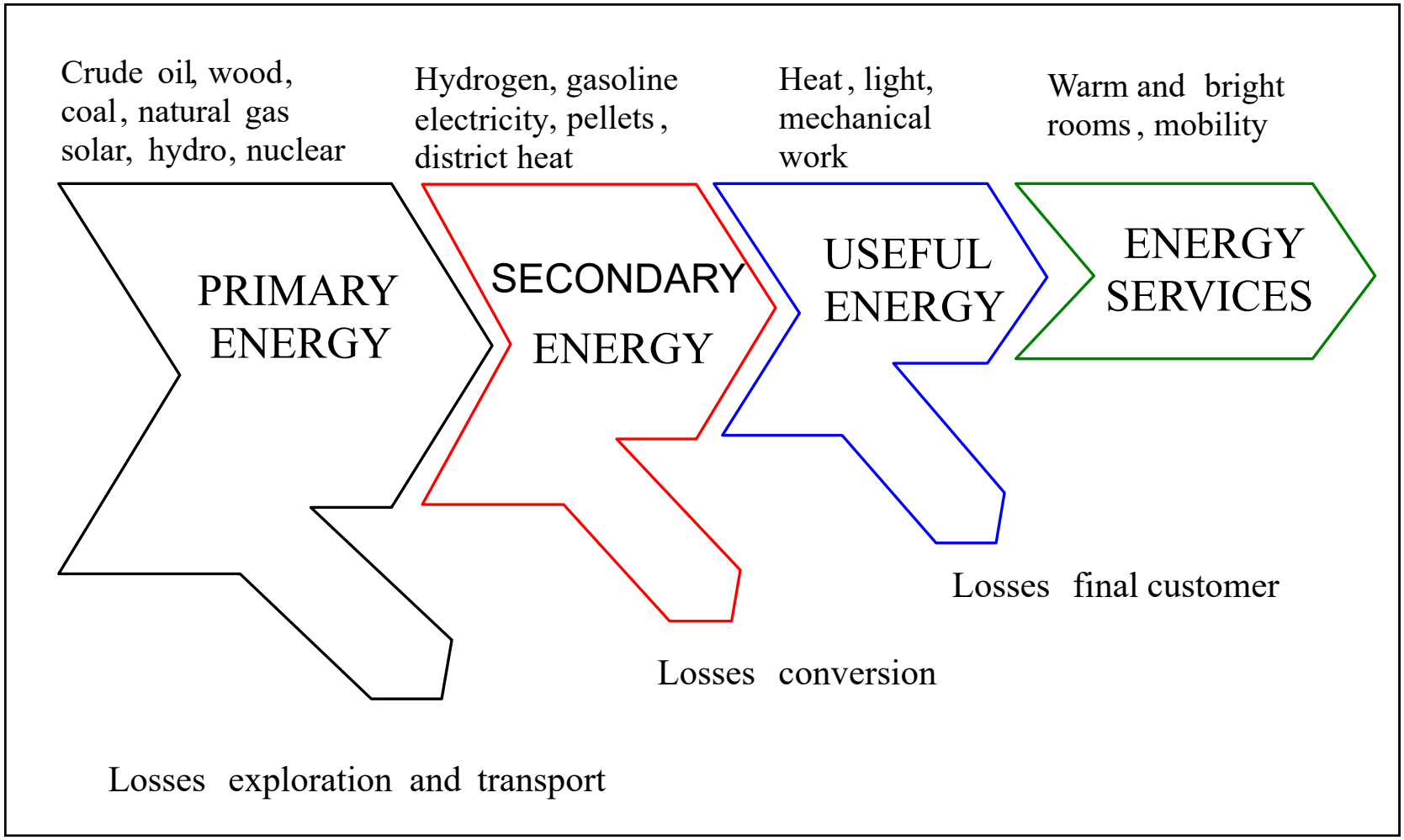
Opel Vivaro-e HYDROGEN

FCV

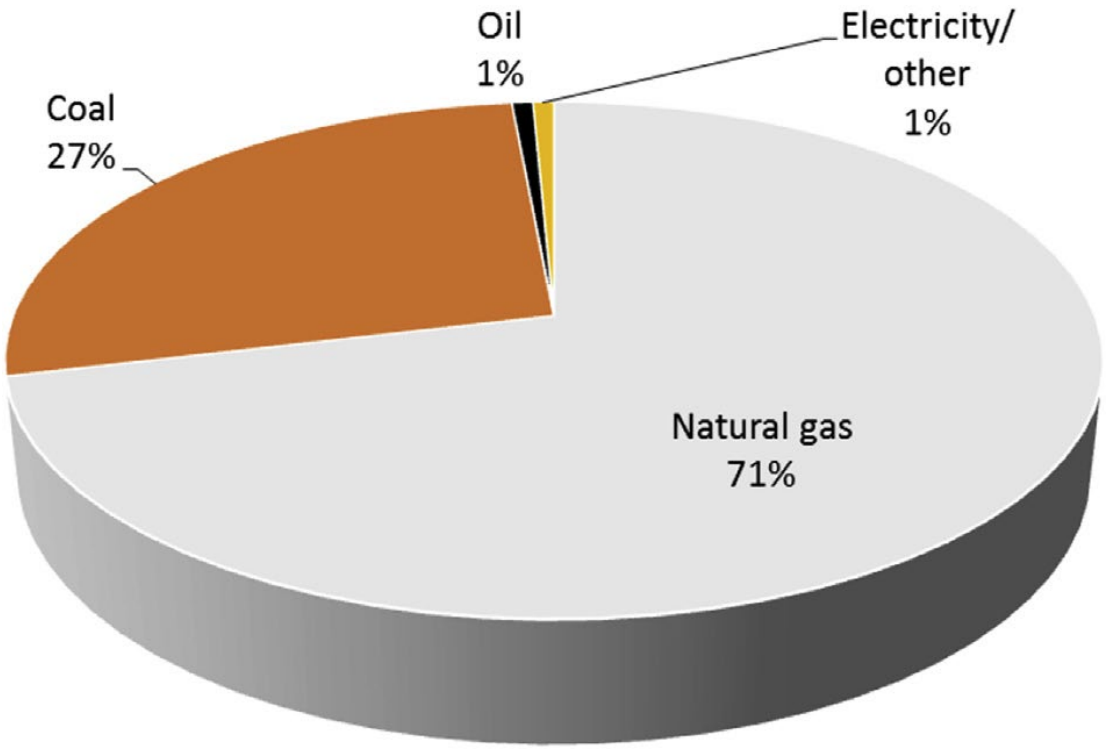

Rest of world: 6%
Germany: 3%
Japan: 13%
China: 16%
United States: 24%
Korea: 38%
19%
16%
9%
13%
20%
23%

IEA, 2022

Energy supply chains



Hydrogen production



Colors of hydrogen

Biomass
Hydro
Wind
Solar

→ Green H2

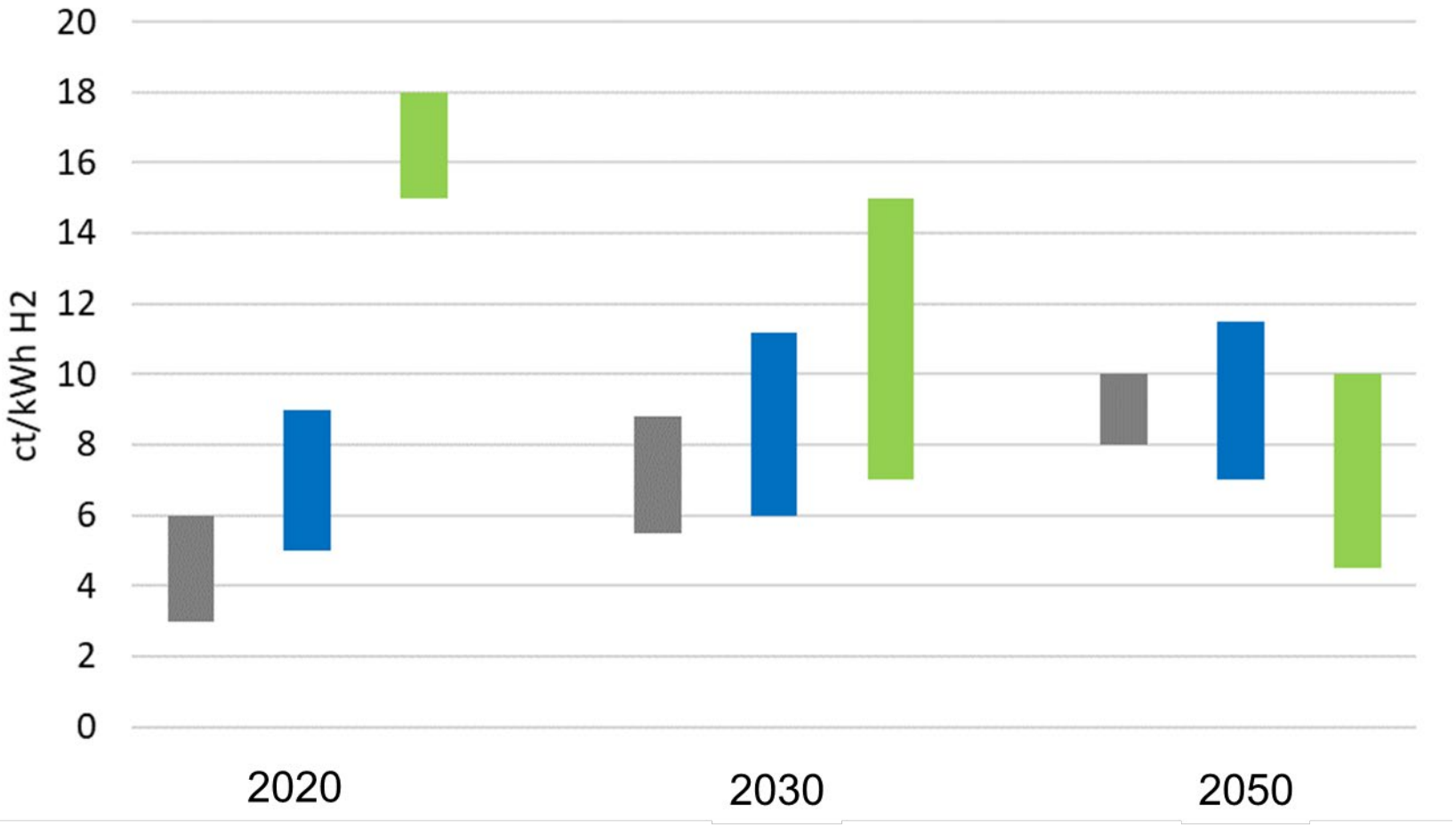
Oil
Coal
Natural gas

→ Grey H2

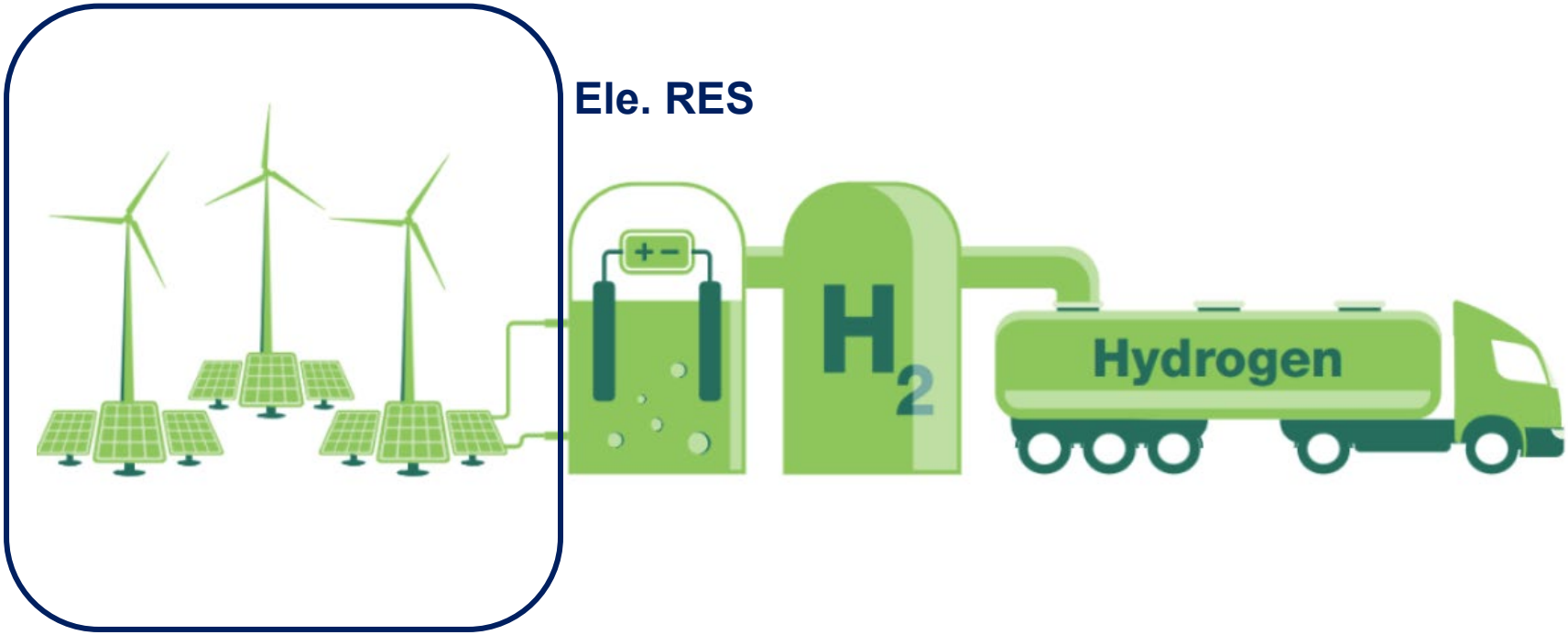
With Carbon Sequestration

→ Blue H2

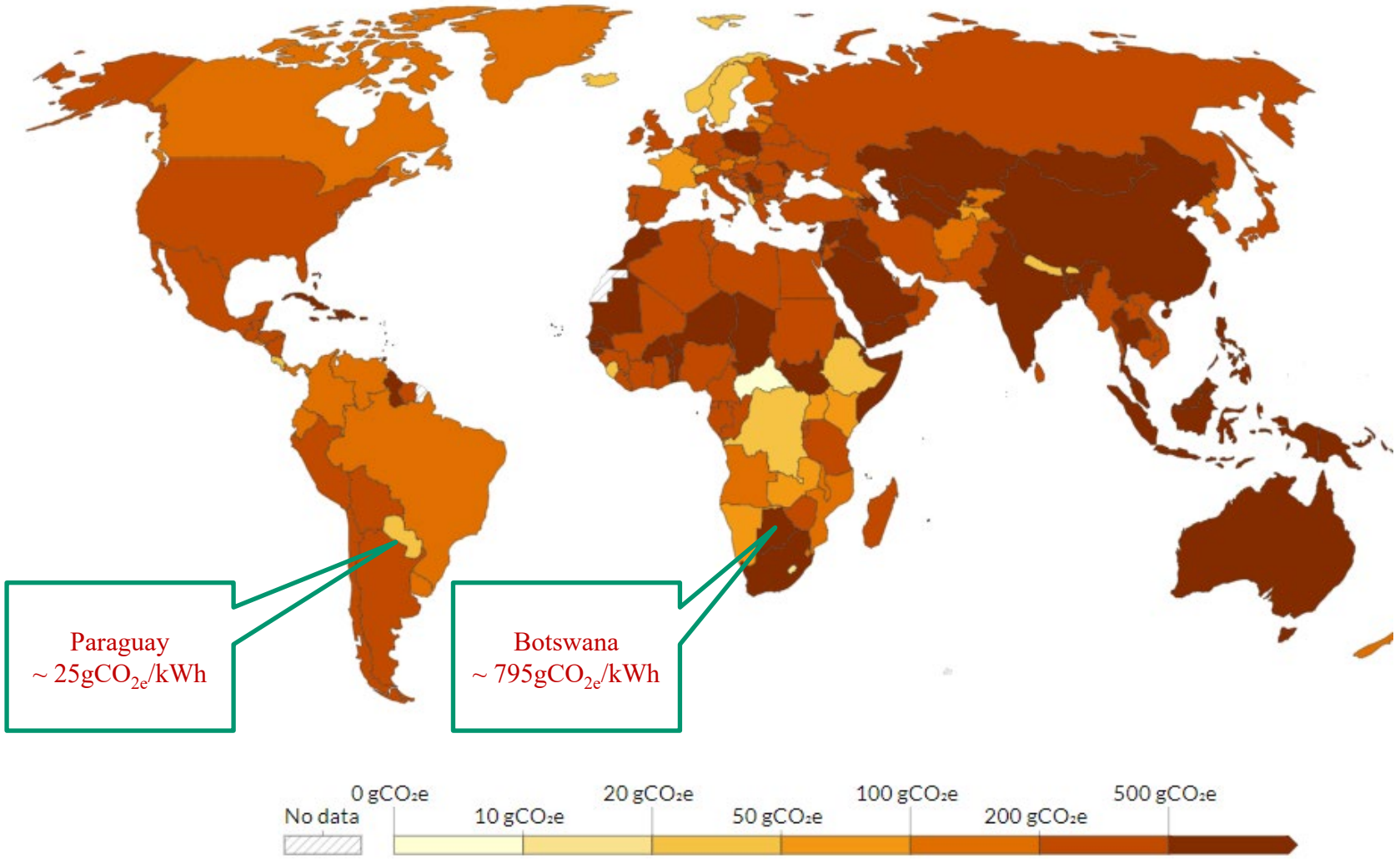
H2 production costs



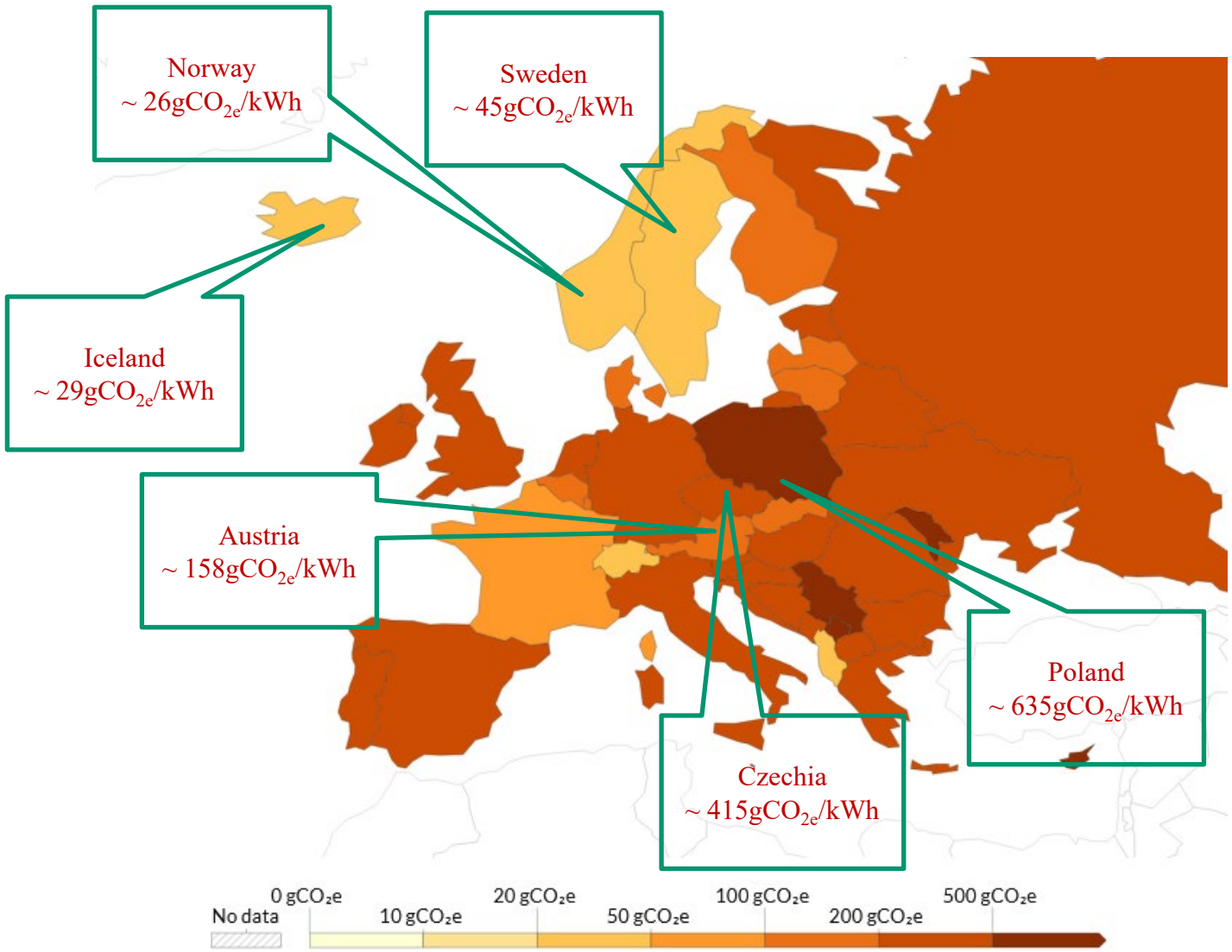
Green hydrogen



Carbon intensity of electricity, 2022

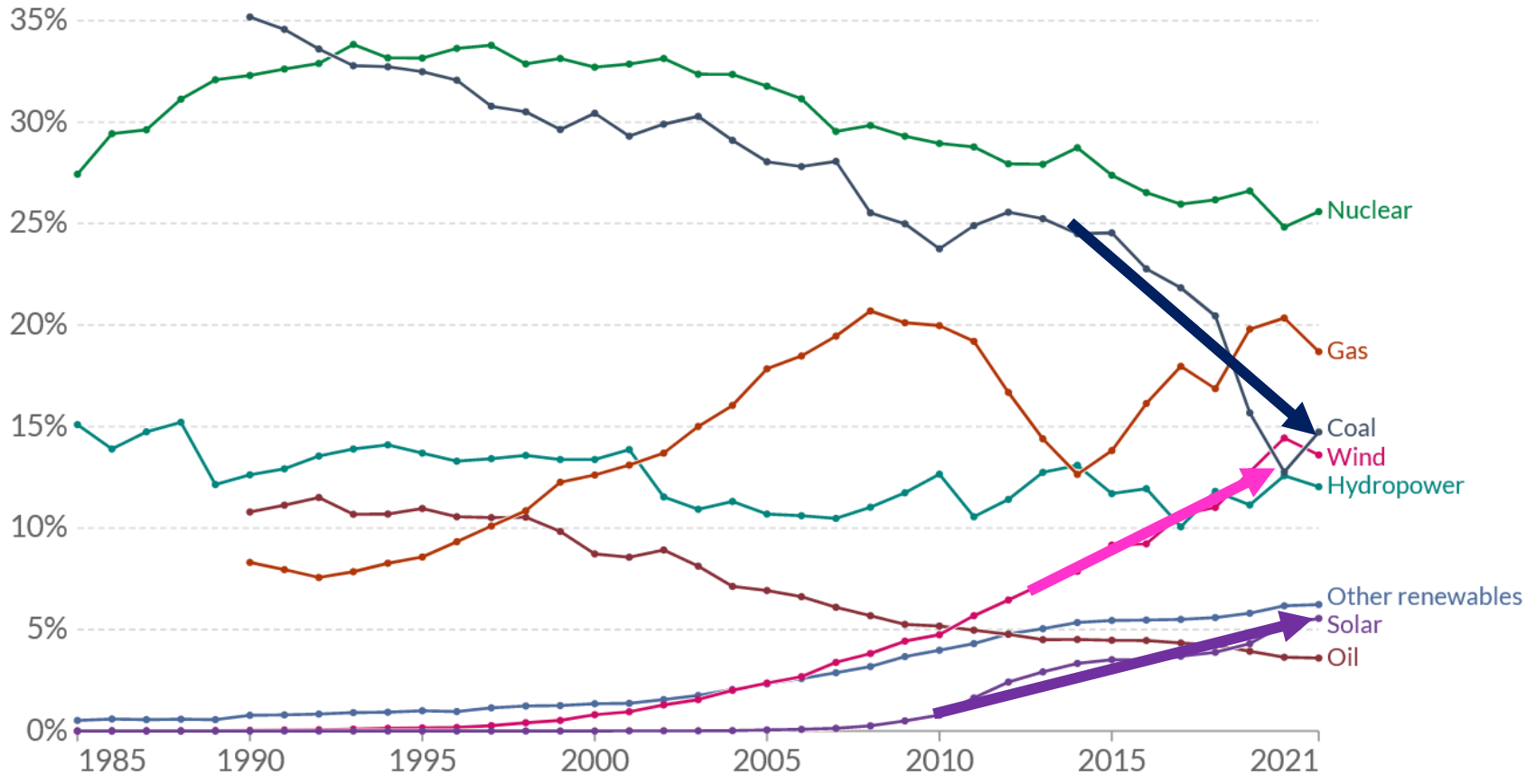


Carbon intensity of electricity in Europe



Carbon intensity is measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity.

Share of electricity production by source, EU-27

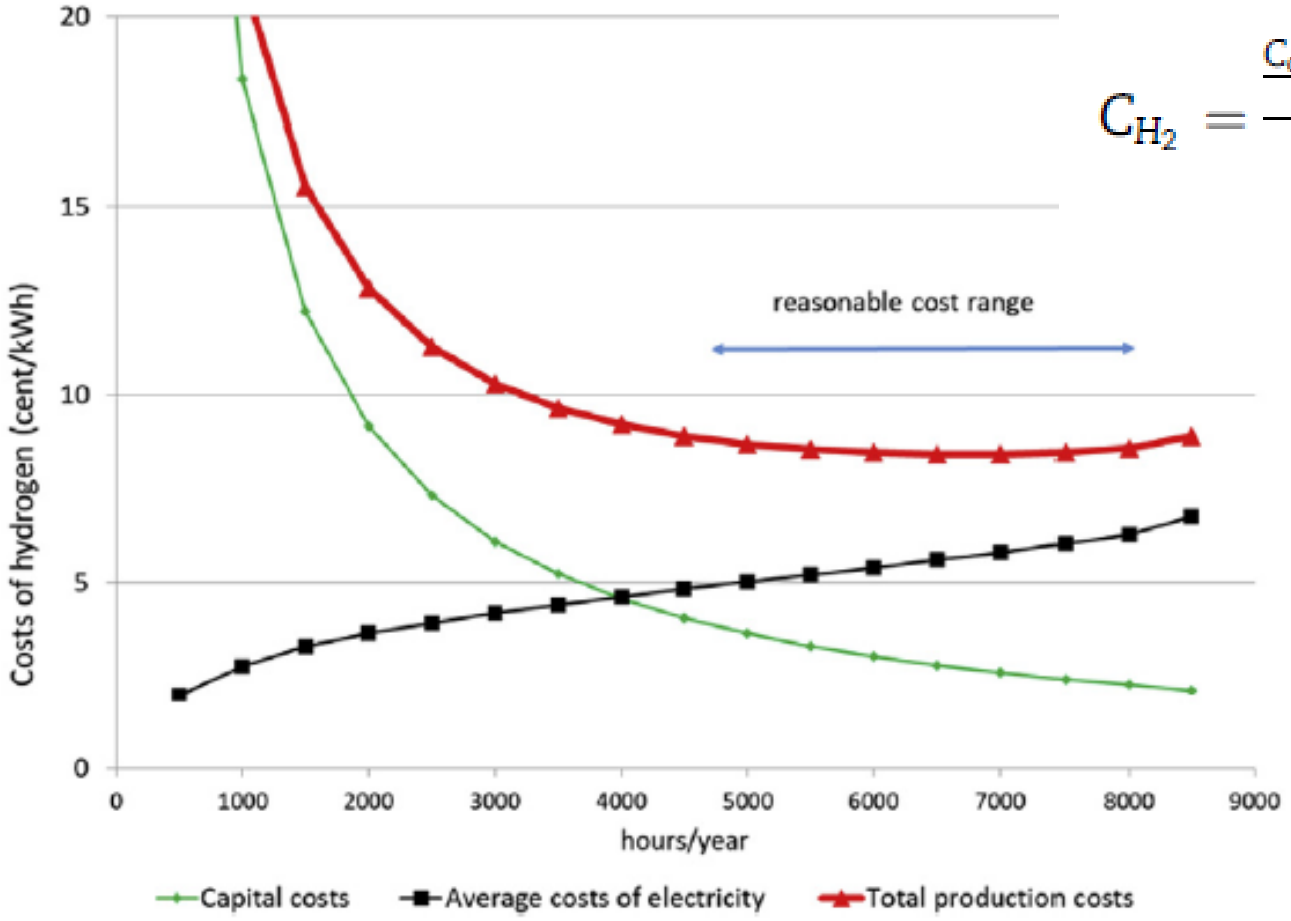


Source: Our World in Data based on BP Statistical Review of World Energy & Ember

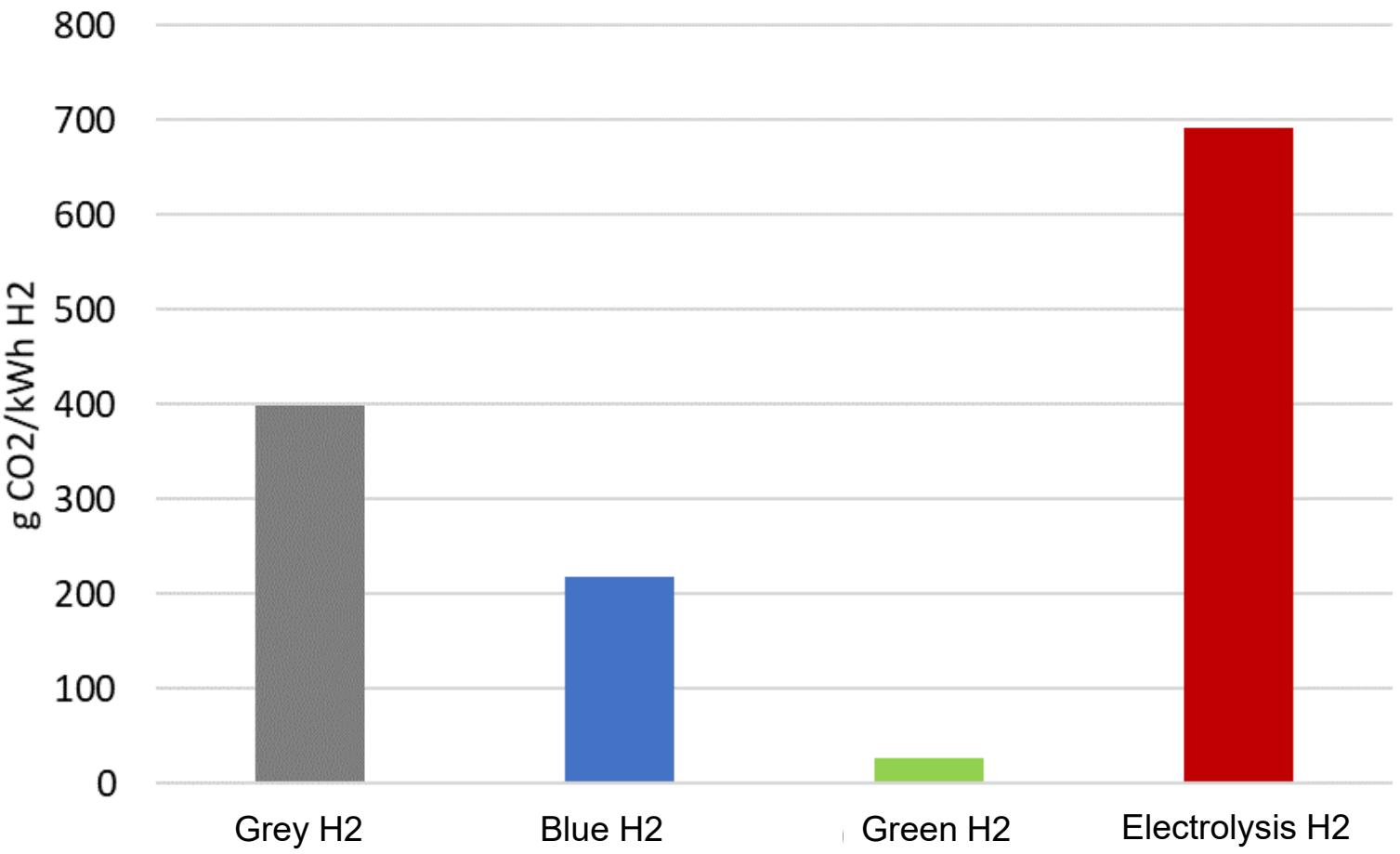
OurWorldInData.org/energy • CC BY

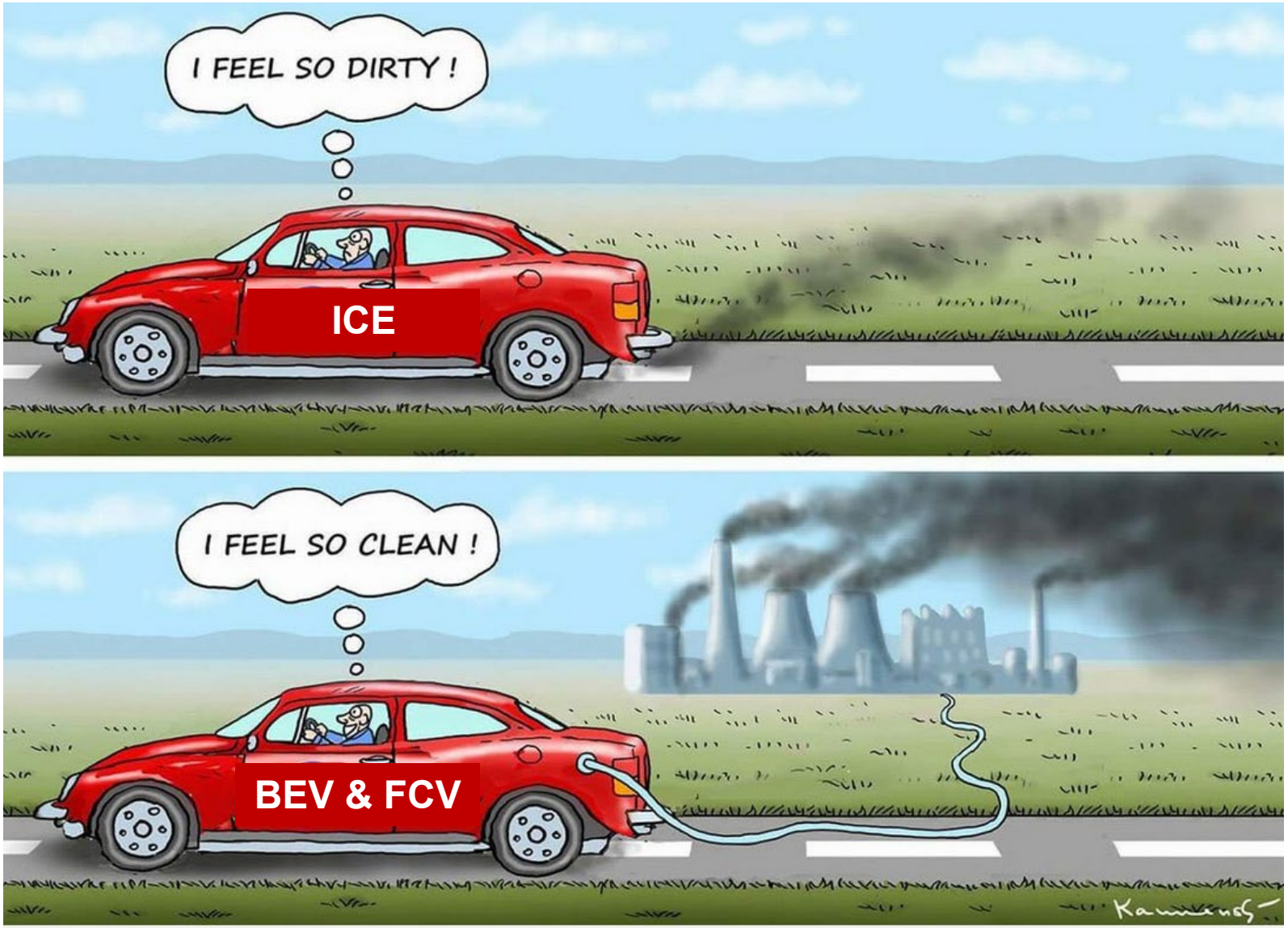
Electrolysis

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



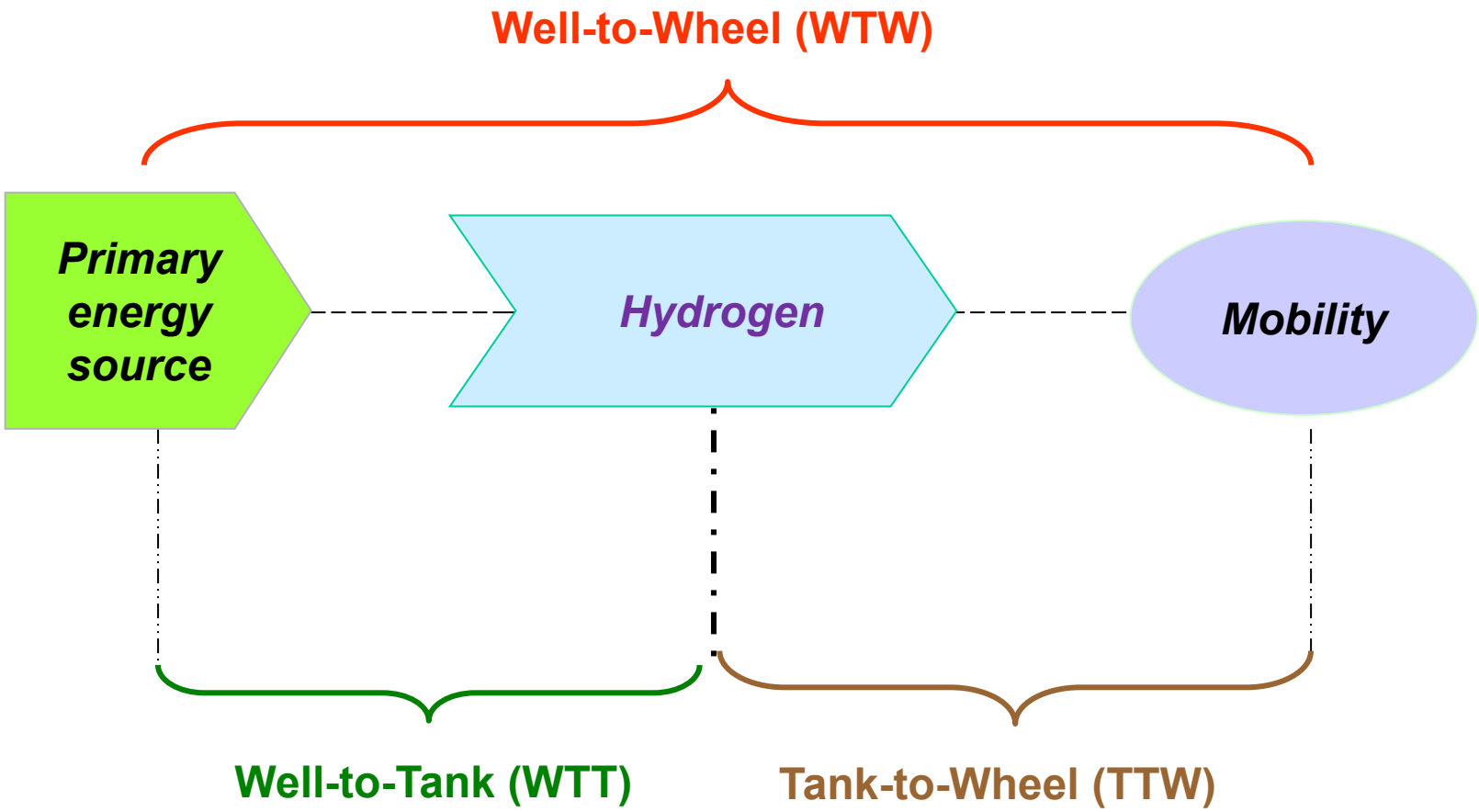
Emissions of hydrogen



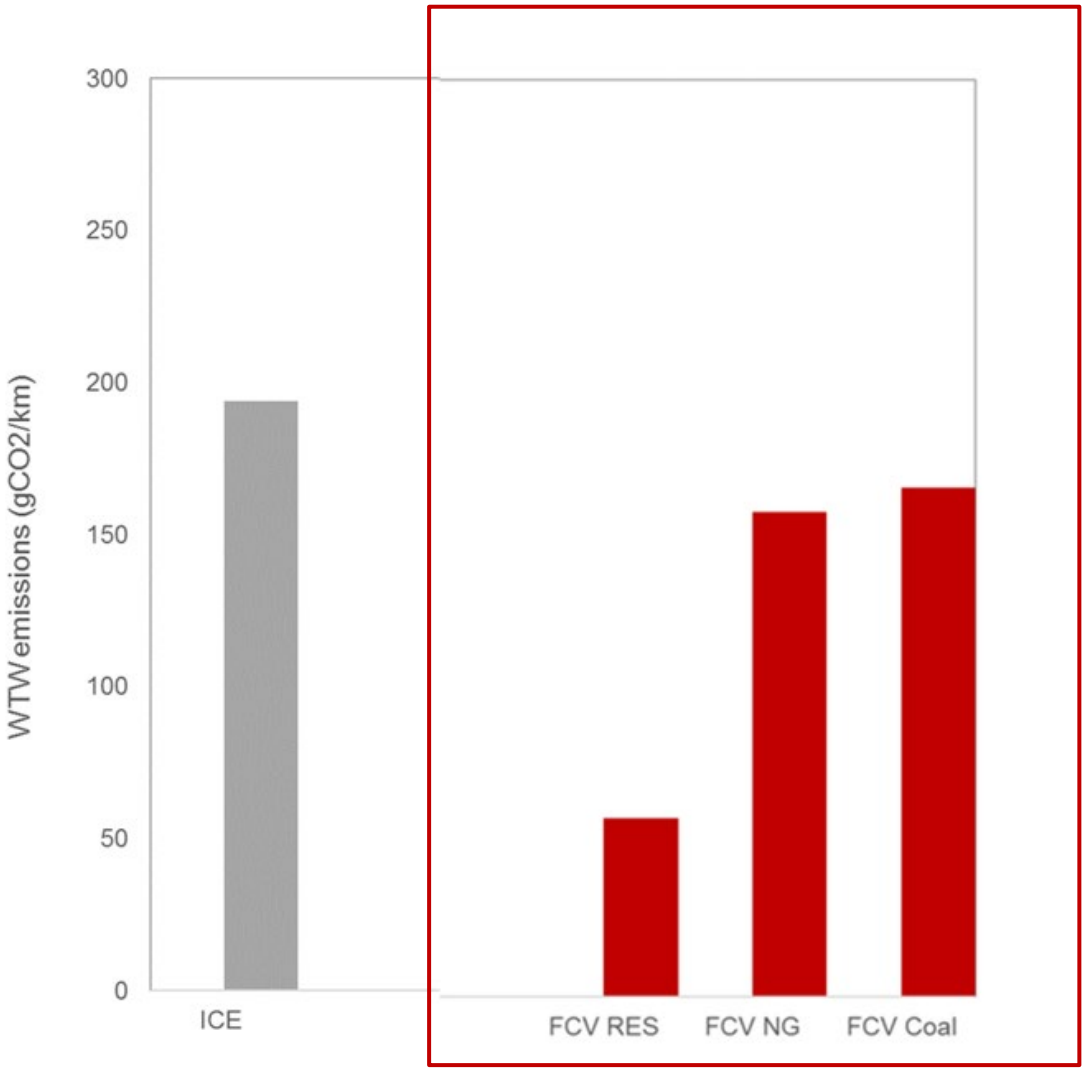


Artist: Marian Kamensky

Environmental assessment



Environmental assessment



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]

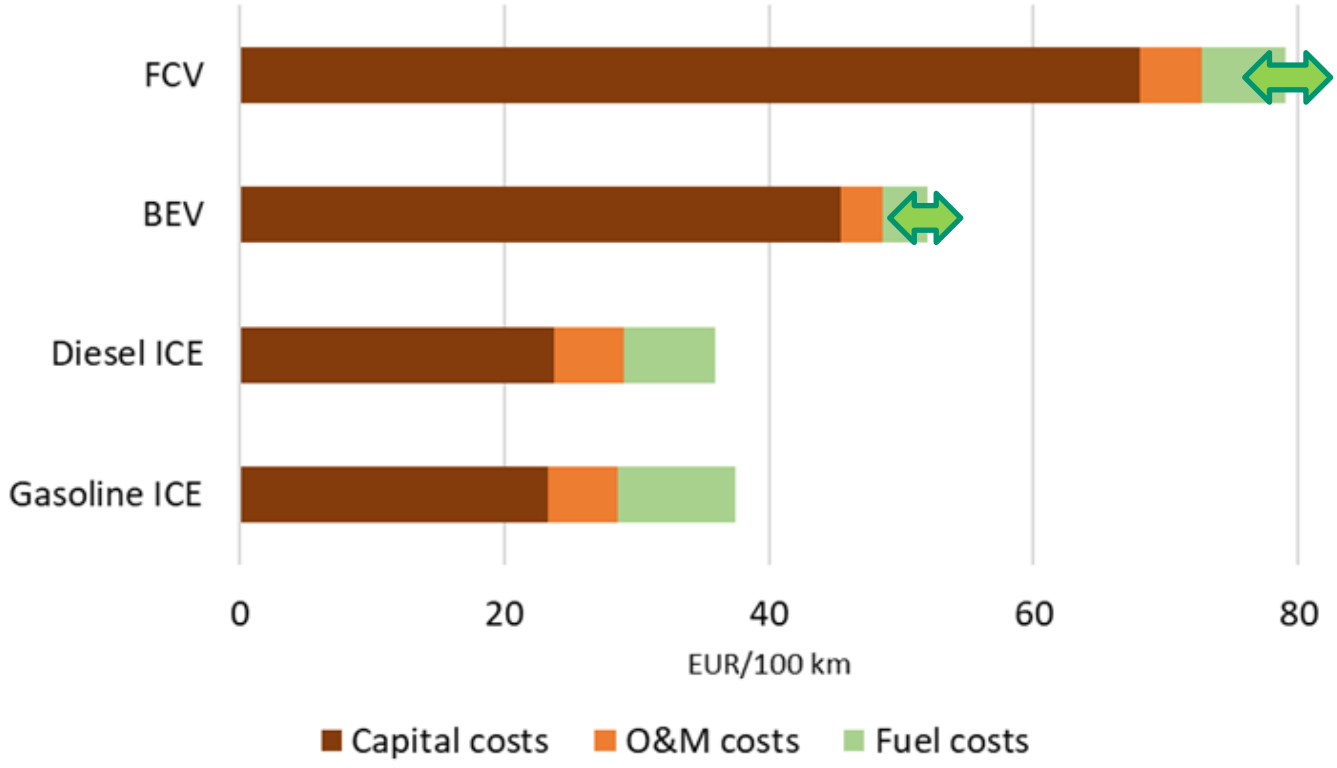
IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

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:

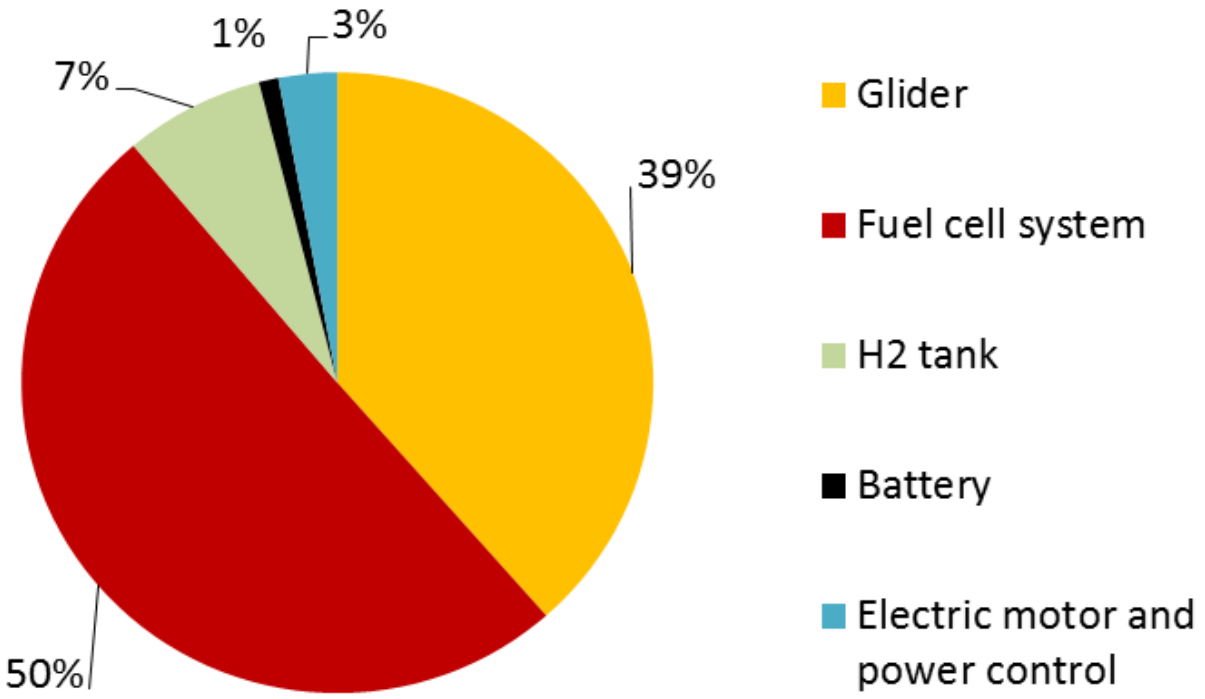
$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

n…..the number of annuities received.

Mobility costs

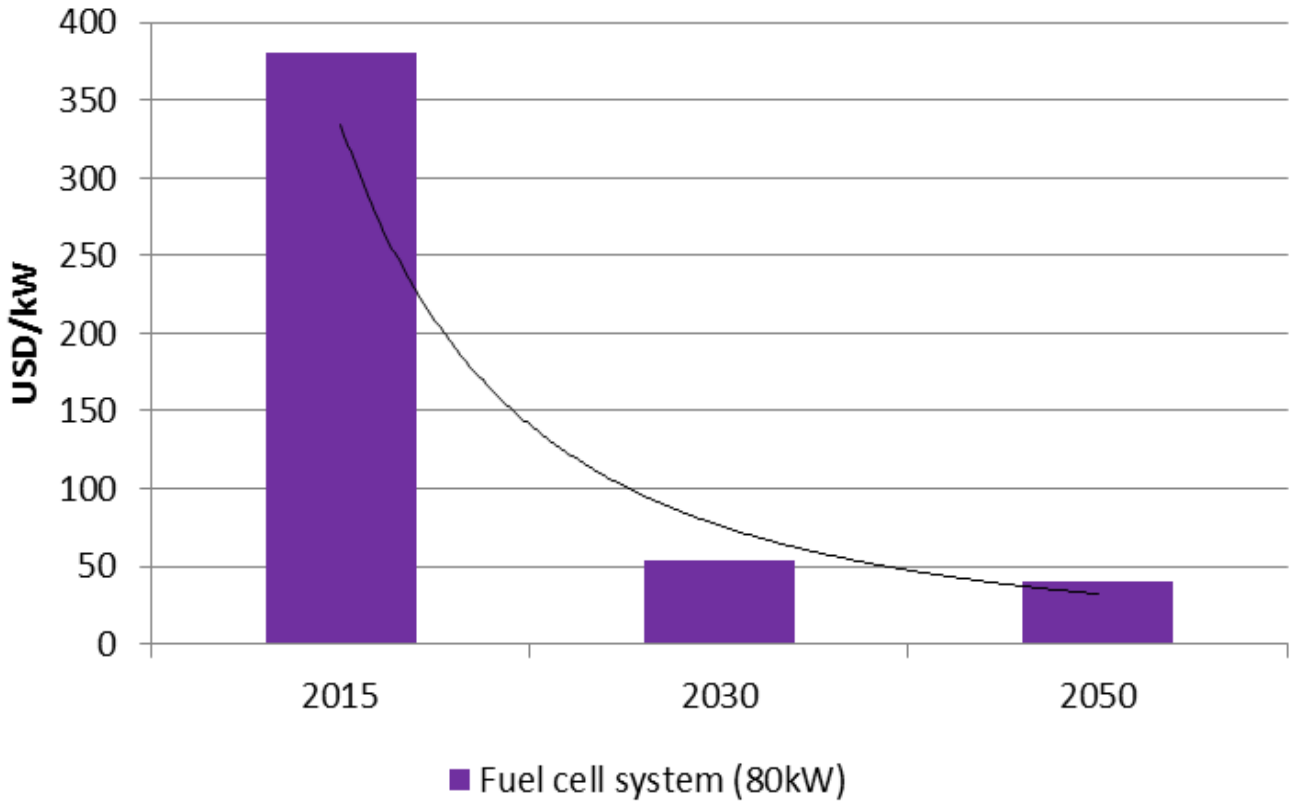


Fuel cell vehicles



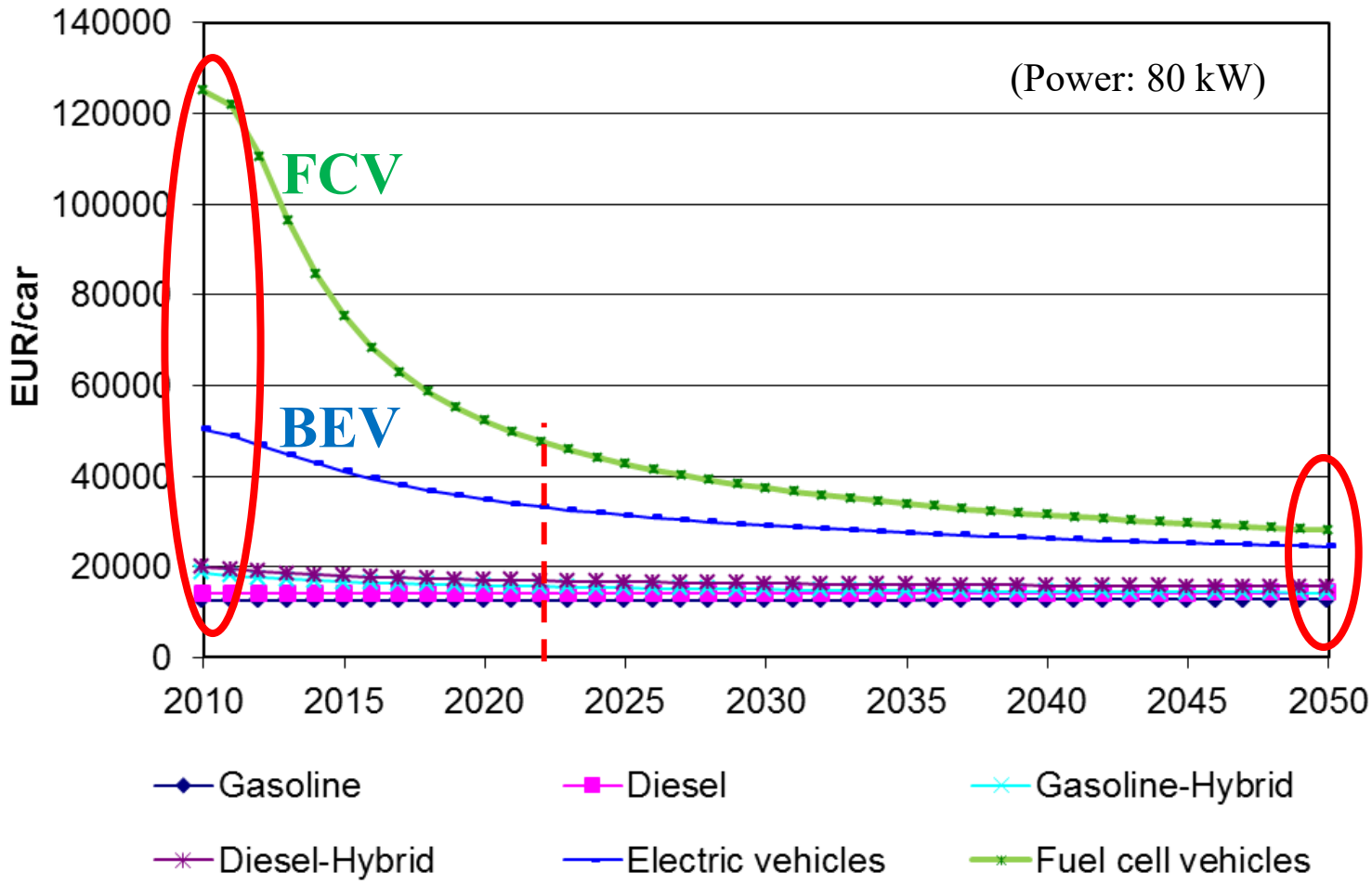
Structure of investment costs of fuel cell vehicles

Technological learning – Fuel cell



Development of the costs of the fuel cell system

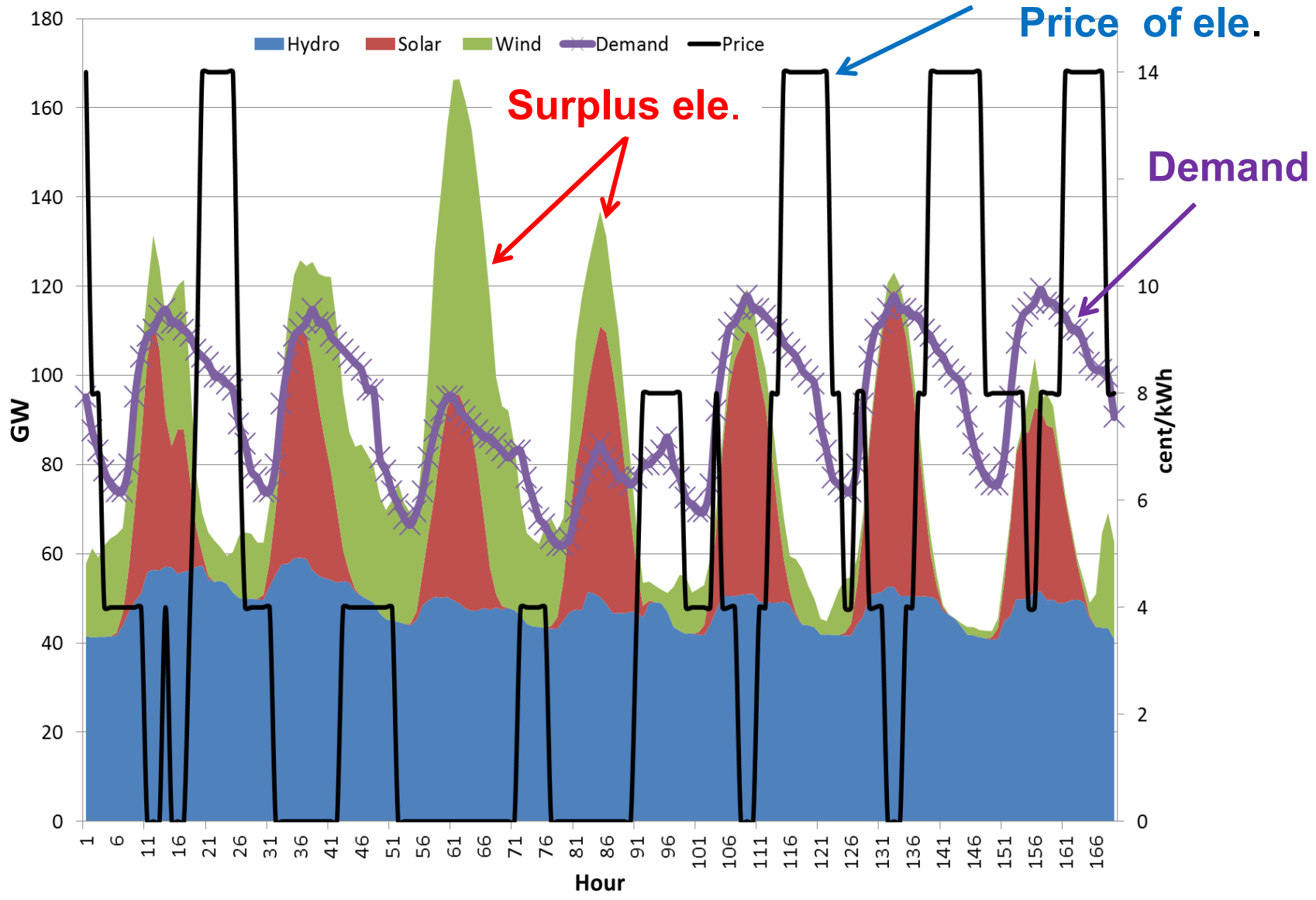
Scenario for development of investment costs



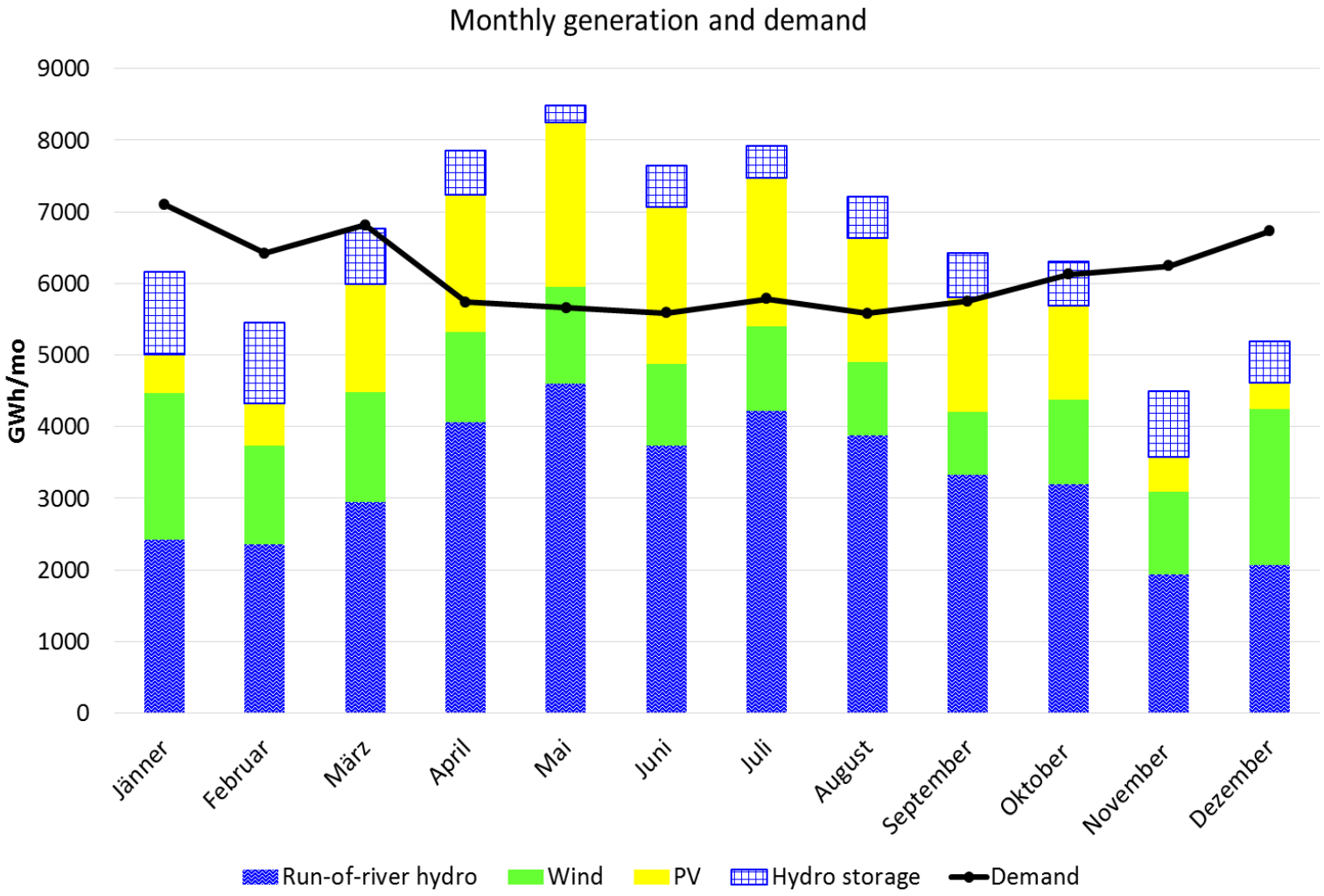
Energy system

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

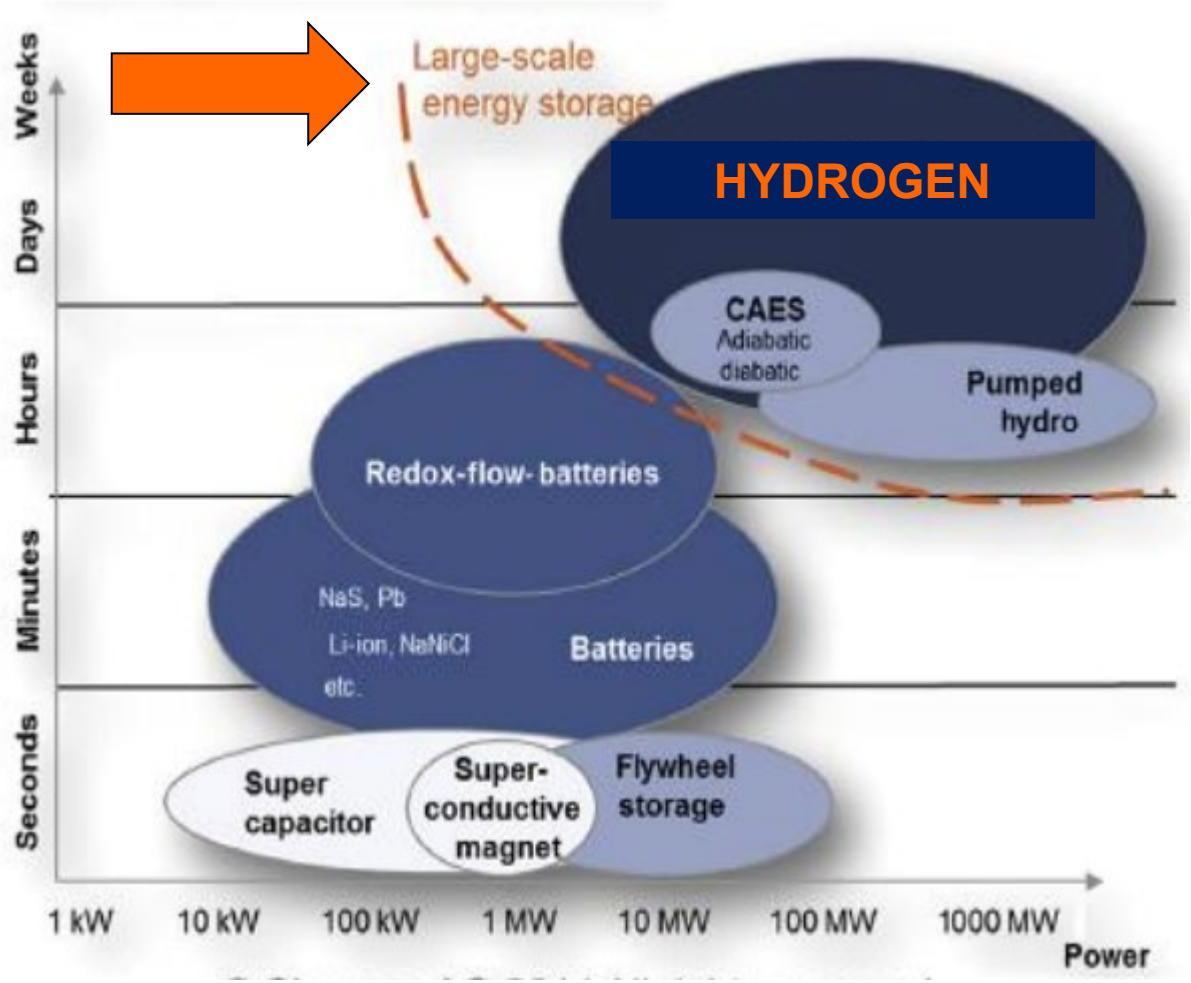
Integrating large shares of renewable electricity



Integrating large shares of renewable electricity

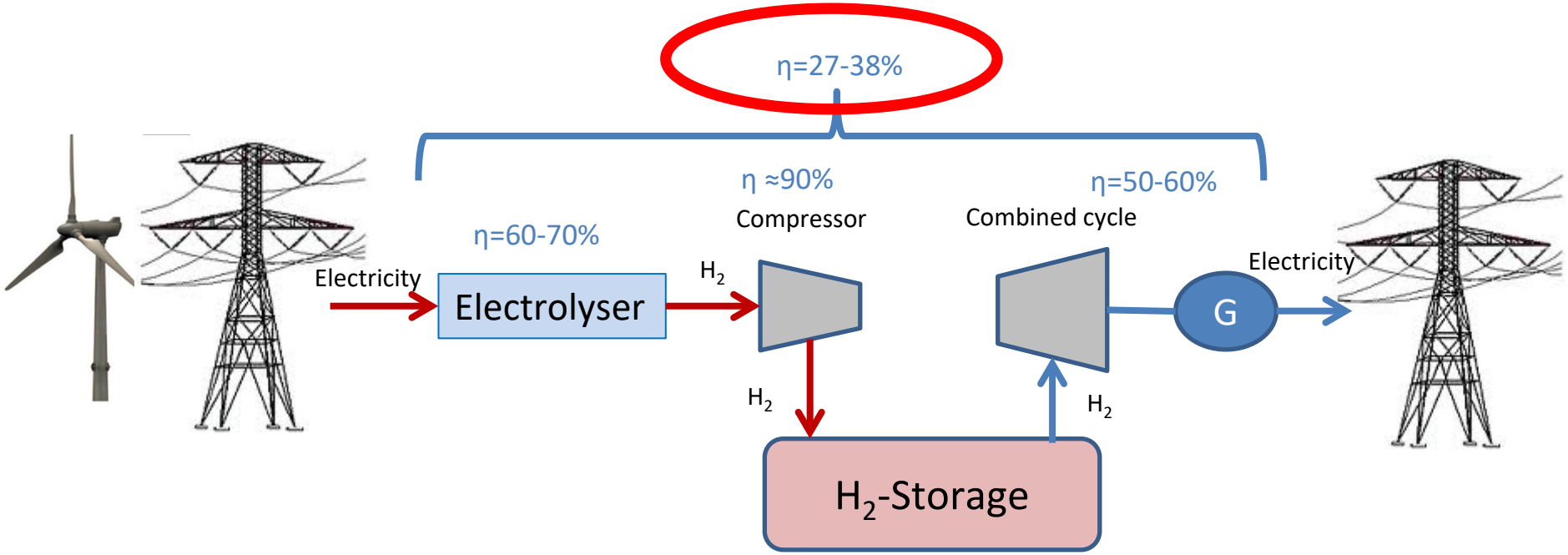


Storage

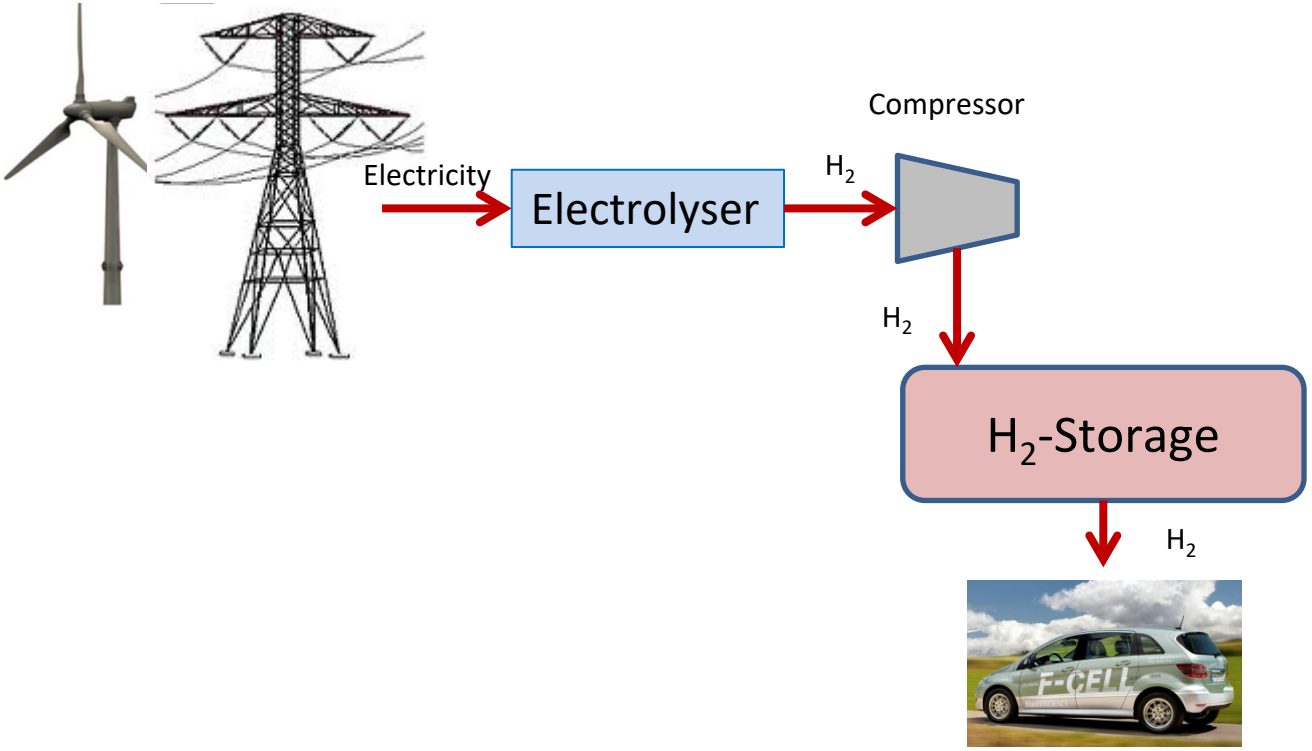


Hydrogen as storage

Very low roundtrip efficiency for electricity!

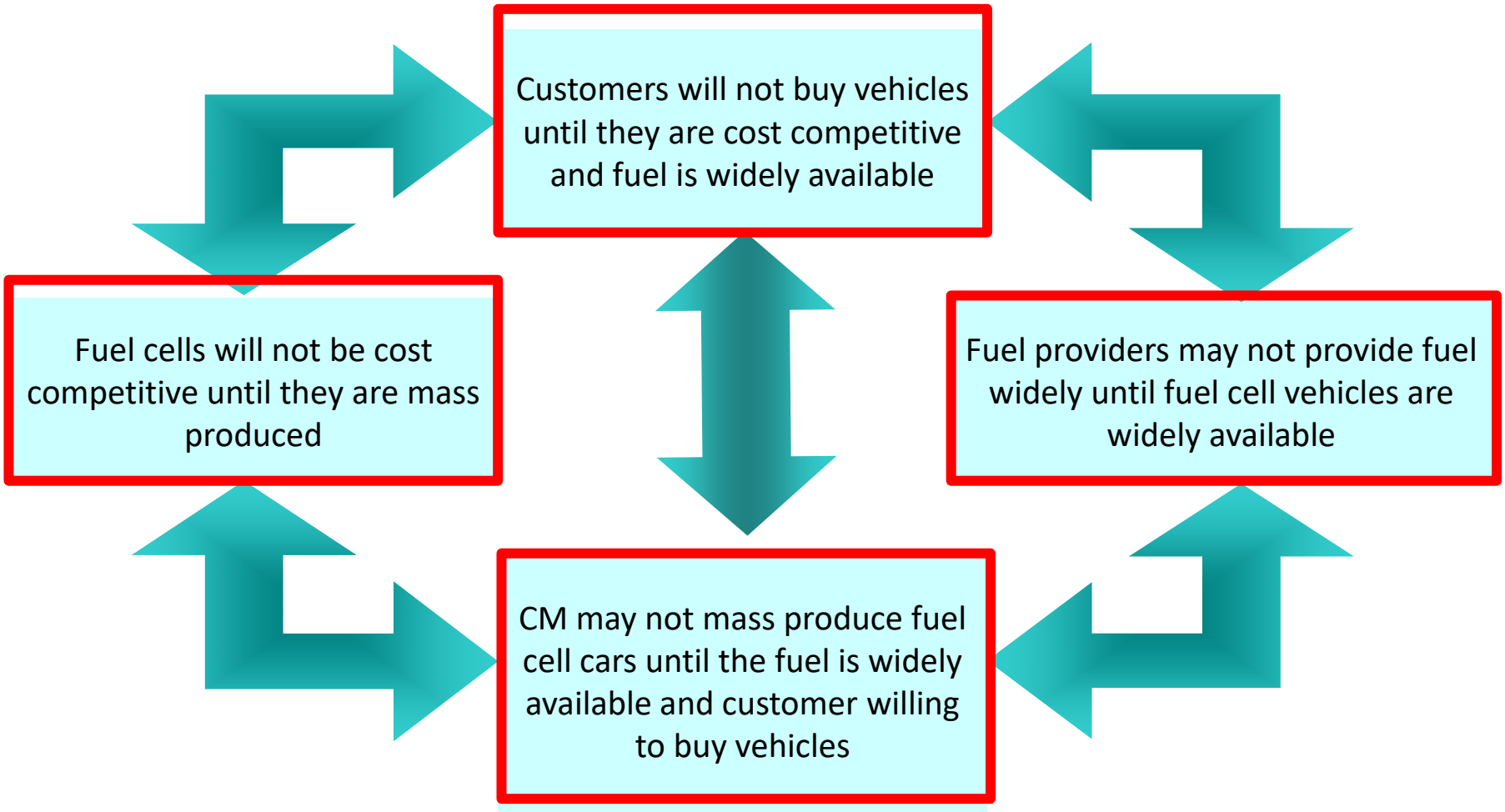


Hydrogen: storage and fuel



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

'Chicken and egg' dilemma



The transition to a hydrogen economy is complex

CM-Car Manufacturer

GDP and EV sales

73% of all electric cars are sold in just 4 countries (with some of the highest GDPs)

Electric cars < 3% of total sales
= average GDP < €17,000

Electric cars > 15% of total sales
= average GDP > €46,000

ACEA

GDP and charging infrastructure

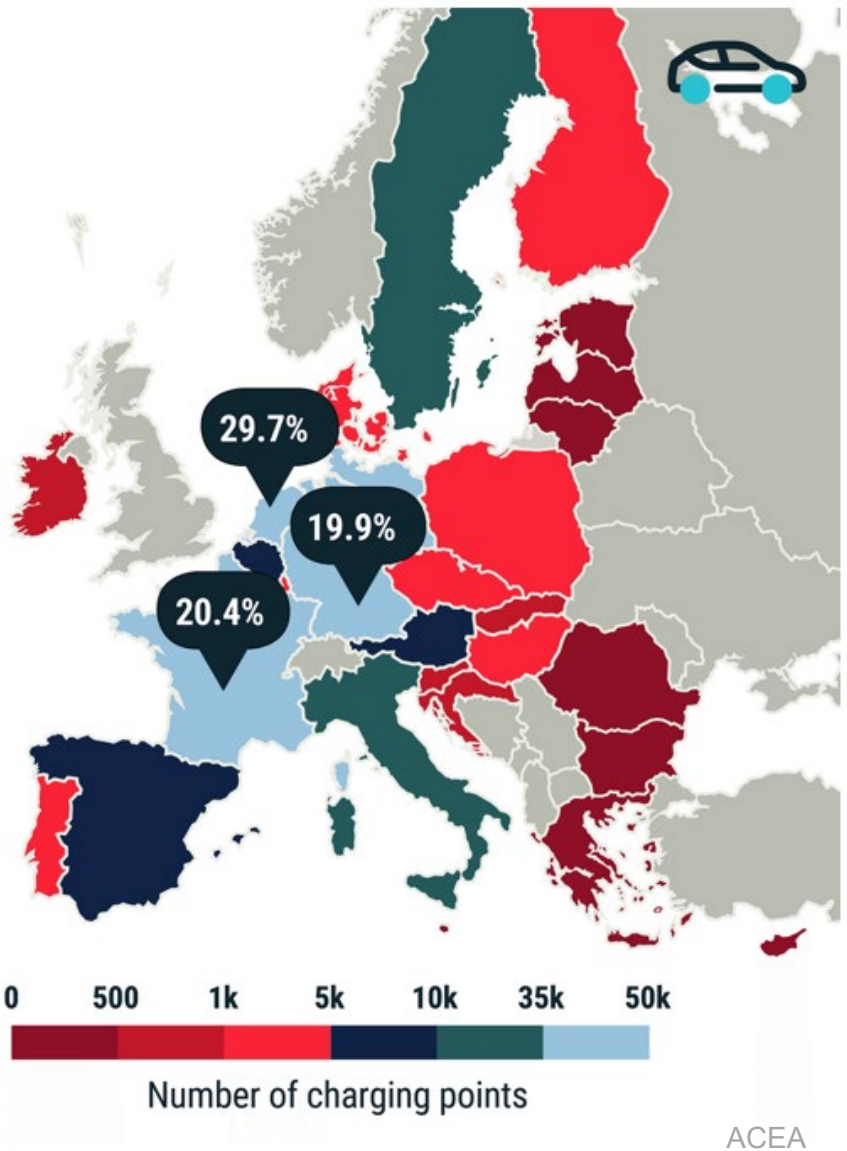
70% of all charging points:

Located in just 3 EU countries

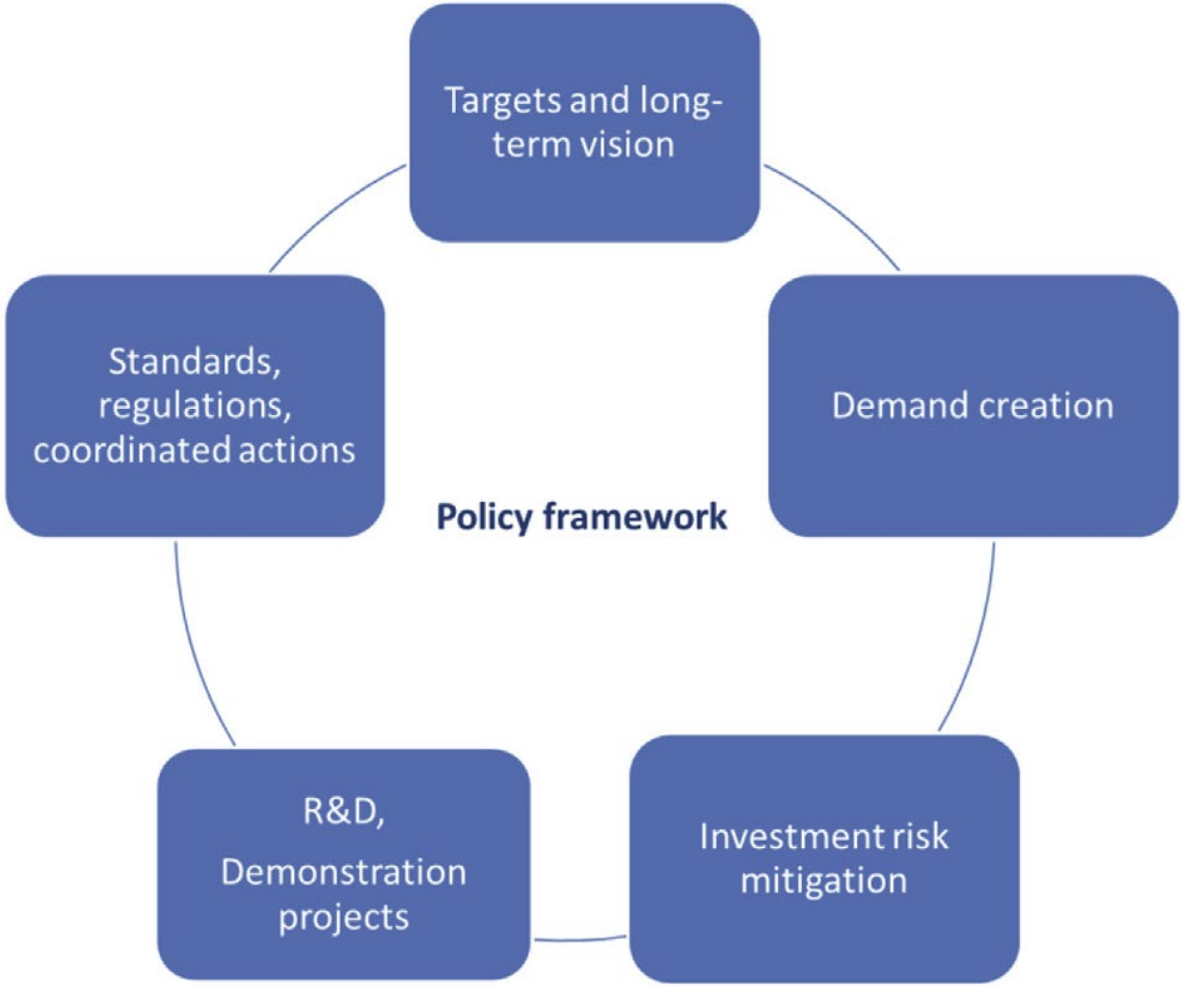
29.7% Netherlands

20.4% France

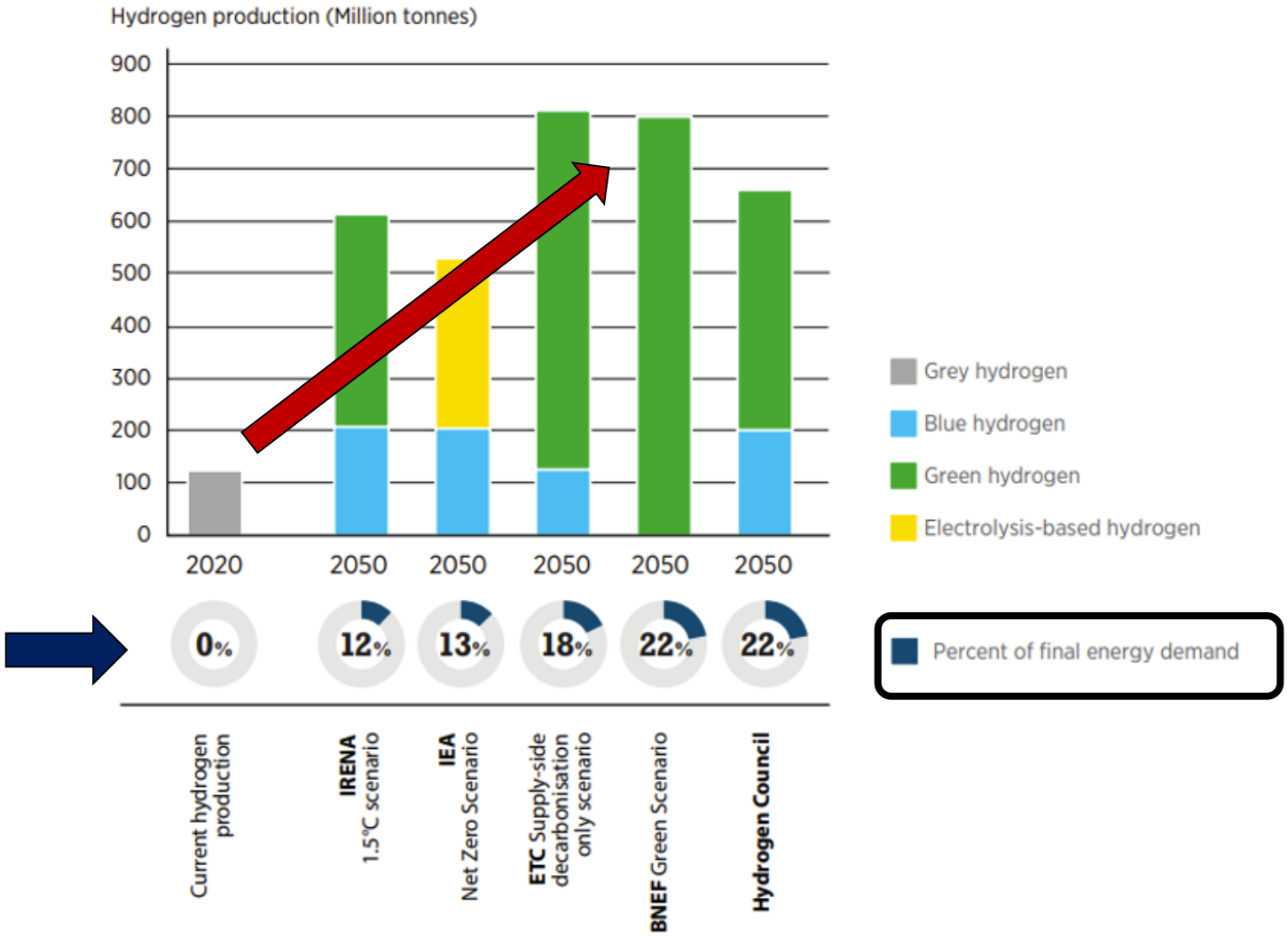
19.9% Germany



Policy framework

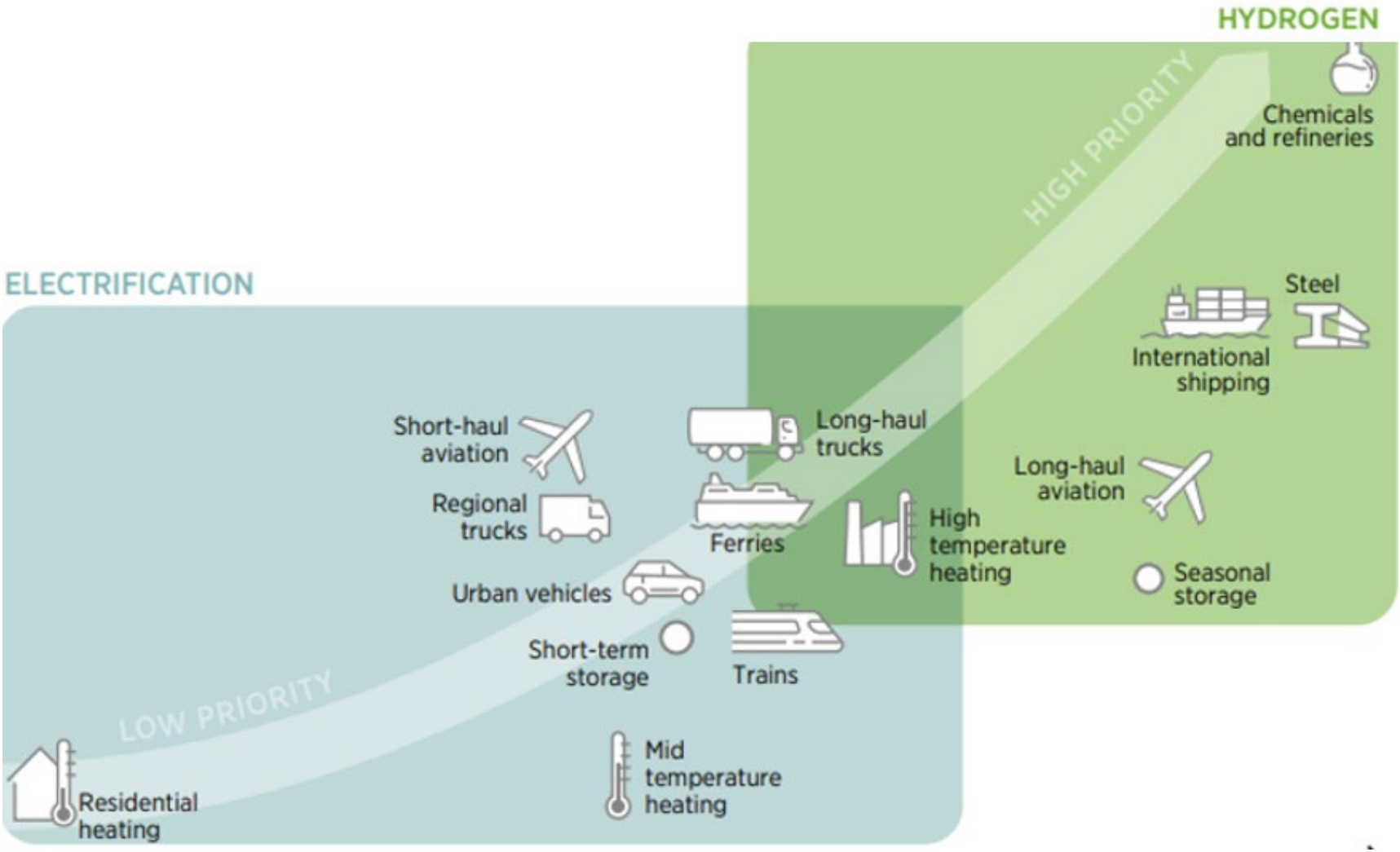


Scenarios: hydrogen production



Sources: BloombergNEF (2021a); ETC (2021); Hydrogen Council (2021); IRENA (2021a); IEA, (2021a).

Hydrogen policy priorites



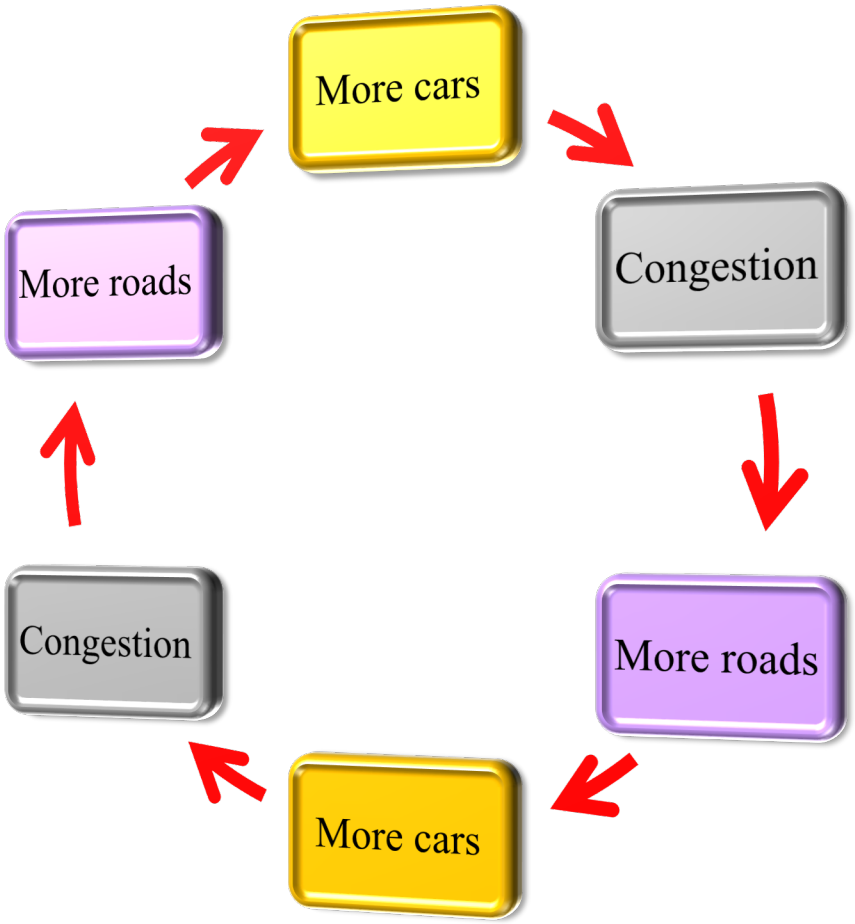
IRENA

Announced targets for FCV

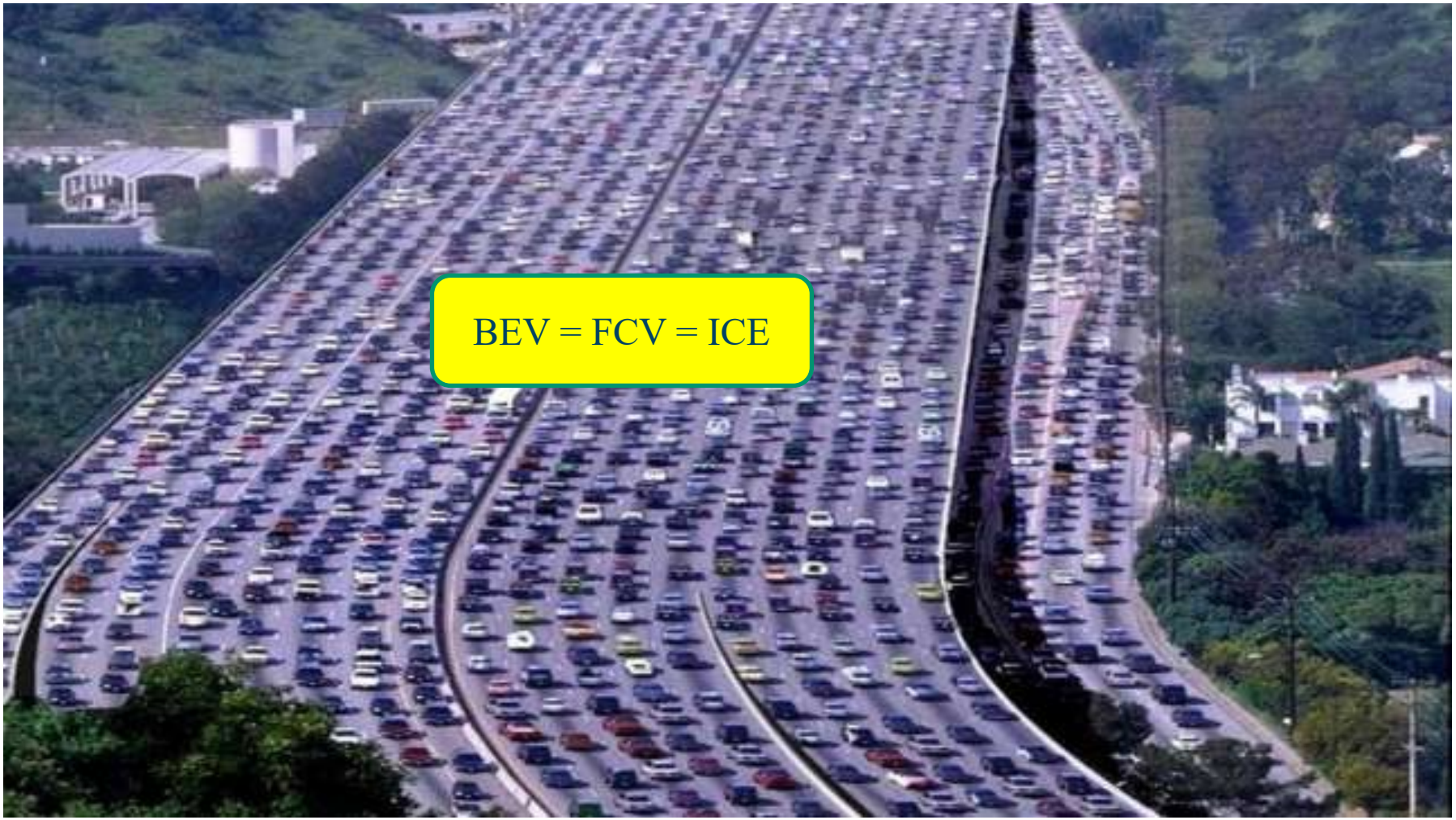
Hydrogen roadmap plan in Europe

Hydrogen Infrastructure		**~3,700** hydrogen refueling station by 2030
Support for passenger vehicles		a fleet of **3.7 million** fuel cell passenger vehicles
Support for commercial vehicles		**500,000** fuel cell light commercial vehicles on road
		**45,000** fuel cell trucks and buses projected to be on the road
		Fuel cell trains replace **570** diesel trains

Car-oriented mobility



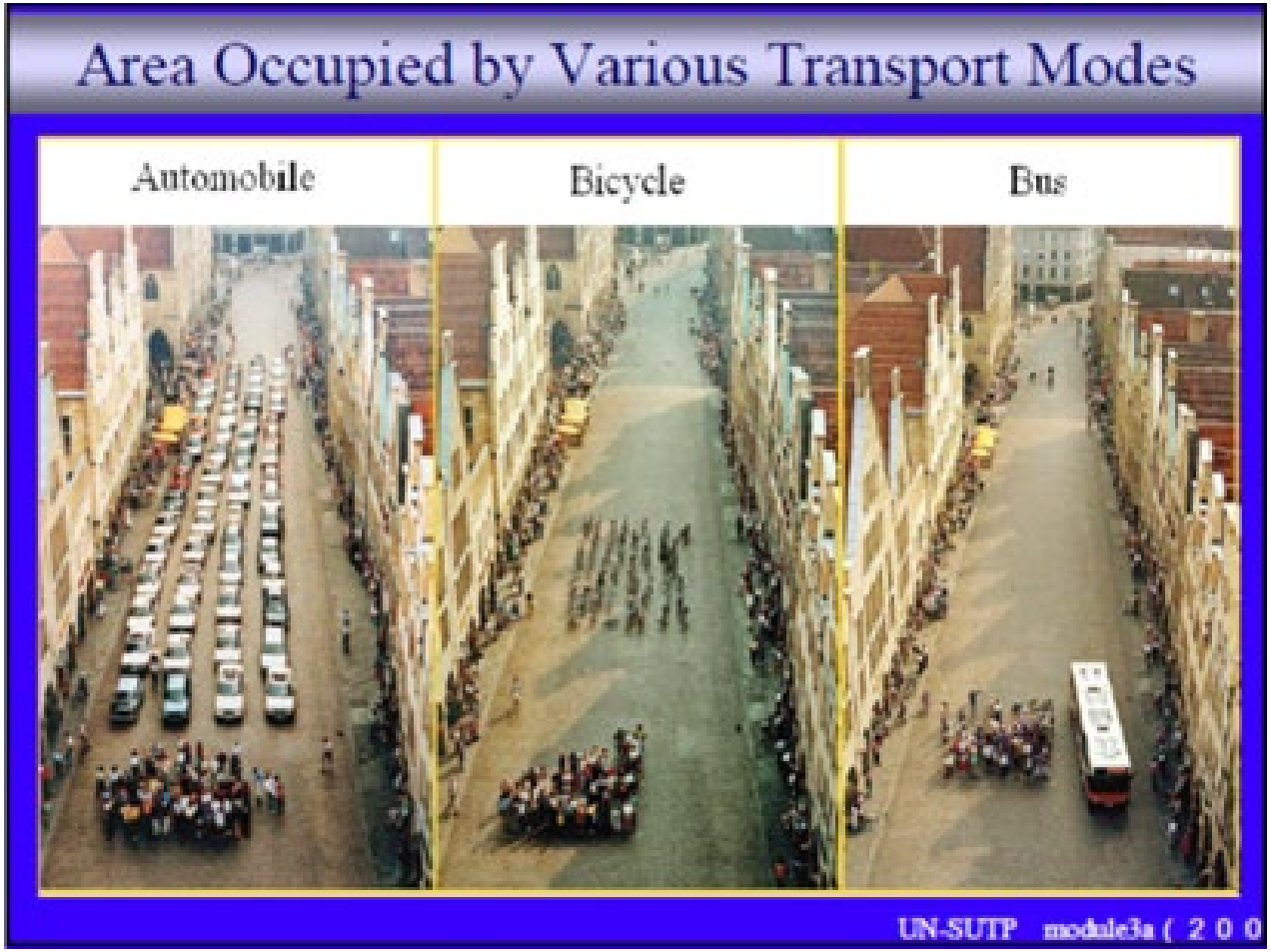
Car-oriented mobility



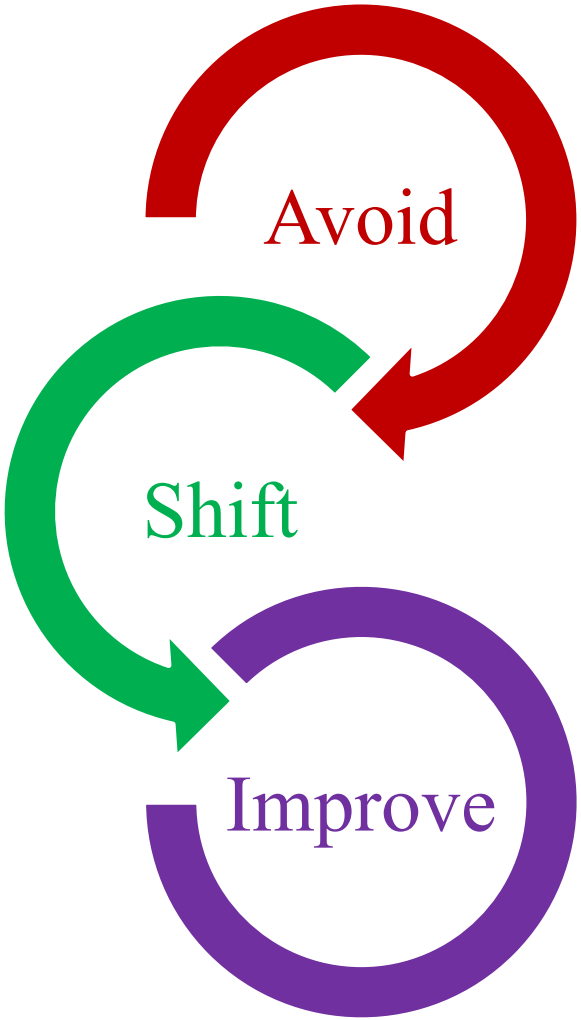
Car-oriented transport development

https://simotron.files.wordpress.com

Car-oriented mobility



Towards Sustainable Mobility

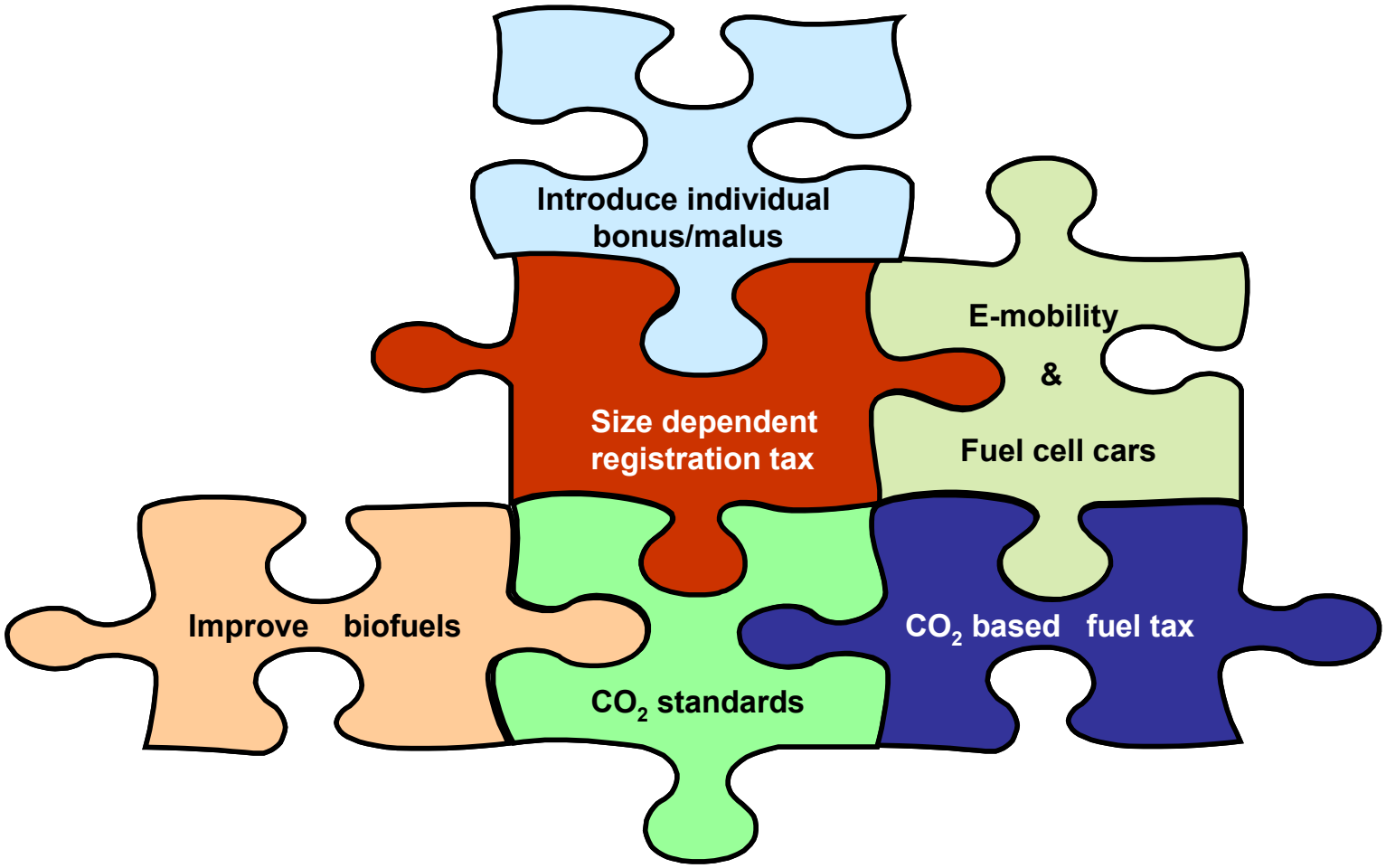


…unnecessary travel and reduce trip distances

….towards more sustainable modes

…transport practices and technologies

Conclusions



Conclusions

Hydrogen can help to:

- ✓ Increase diversification of energy used in transport
- ✓ Decarbonize 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

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International Journal of Hydrogen Energy
Available online 4 March 2022
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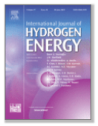

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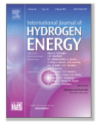

Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector

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