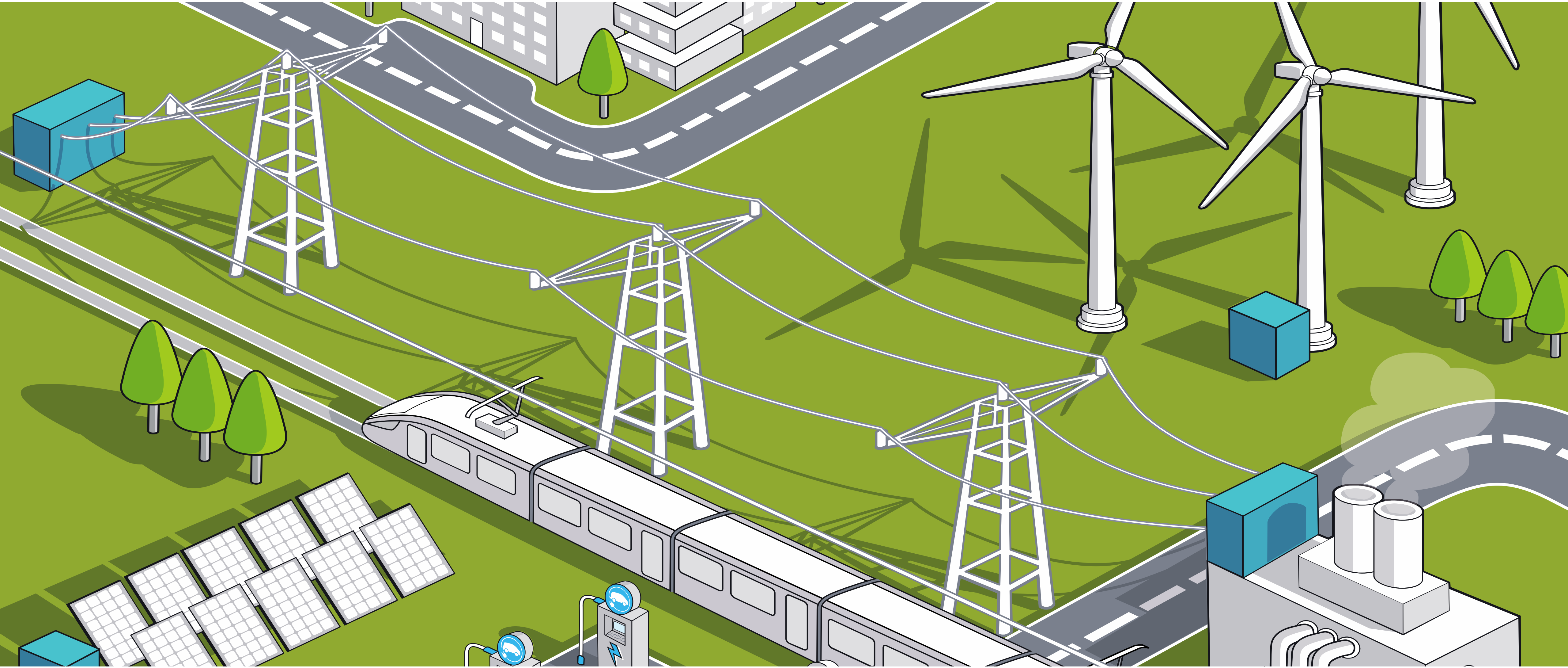
Bühler Networking Days 2019

Energy and Resources for Mobility

Lino Guzzella

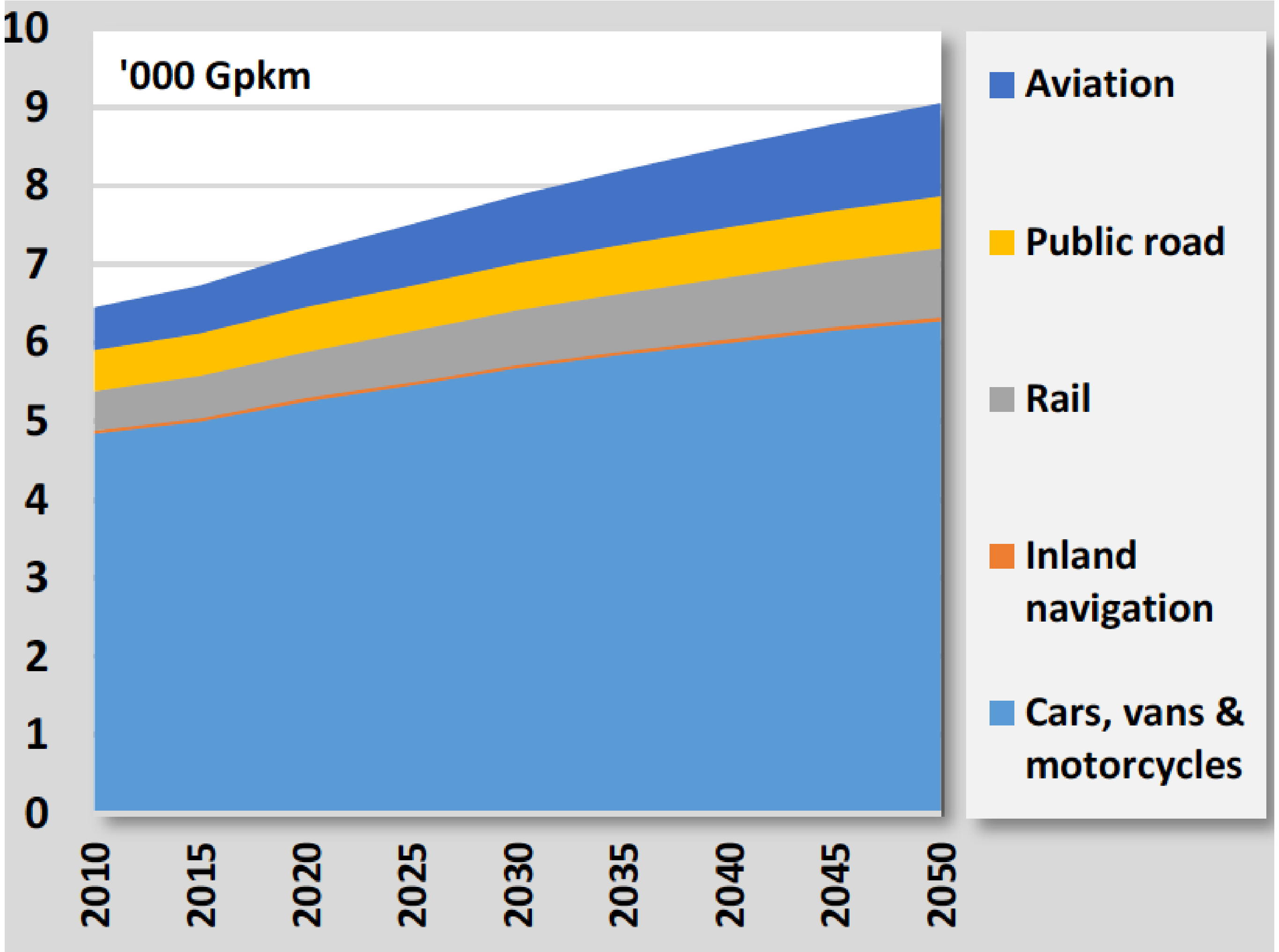


Some Observations to Begin With

- Mobility is an important driver for human well-being and societal progress.
- A modern economy relies on intensive interactions and sophisticated supply chains that require high levels of mobility.
- Most mobility systems need on-board energy carriers with high energy densities.
- Liquid hydrocarbons are ideal for mobility, but – if they stem form fossil sources – cause an increase in global CO_2 concentrations and, therefore, climate change.
- Near-zero toxic pollutant emissions are feasible with all technologies at relatively low costs.

Mobility of People – The EU as an Example

Gpkm = billions of kilometers travelled by one person



260 (short) g CO_2/pkm
150 (long)

50 g CO_2/pkm

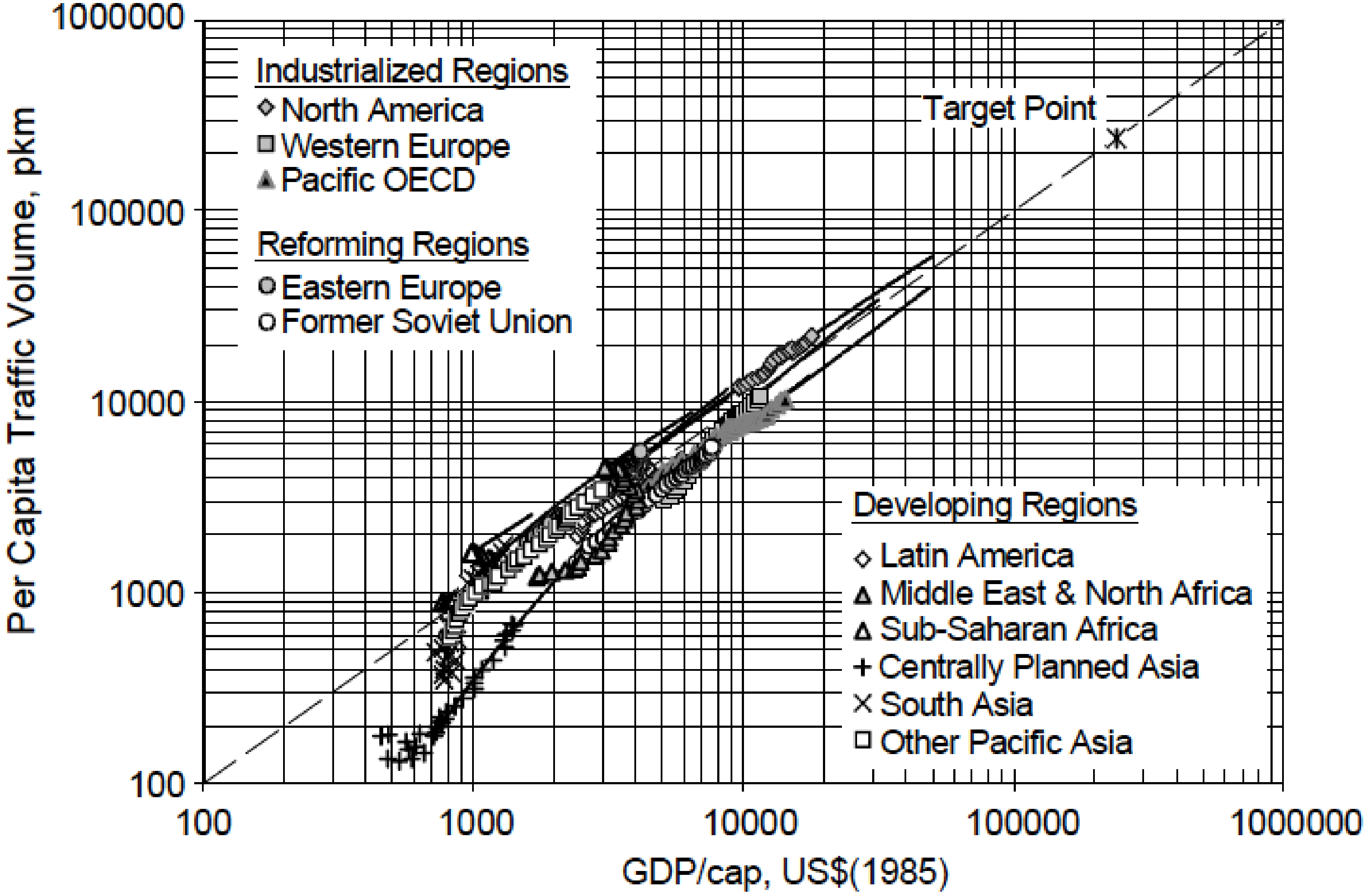
7 g CO_2/pkm (electric)
75 g CO_2/pkm (Diesel)

N.A.

75 g CO_2/pkm

Source: https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

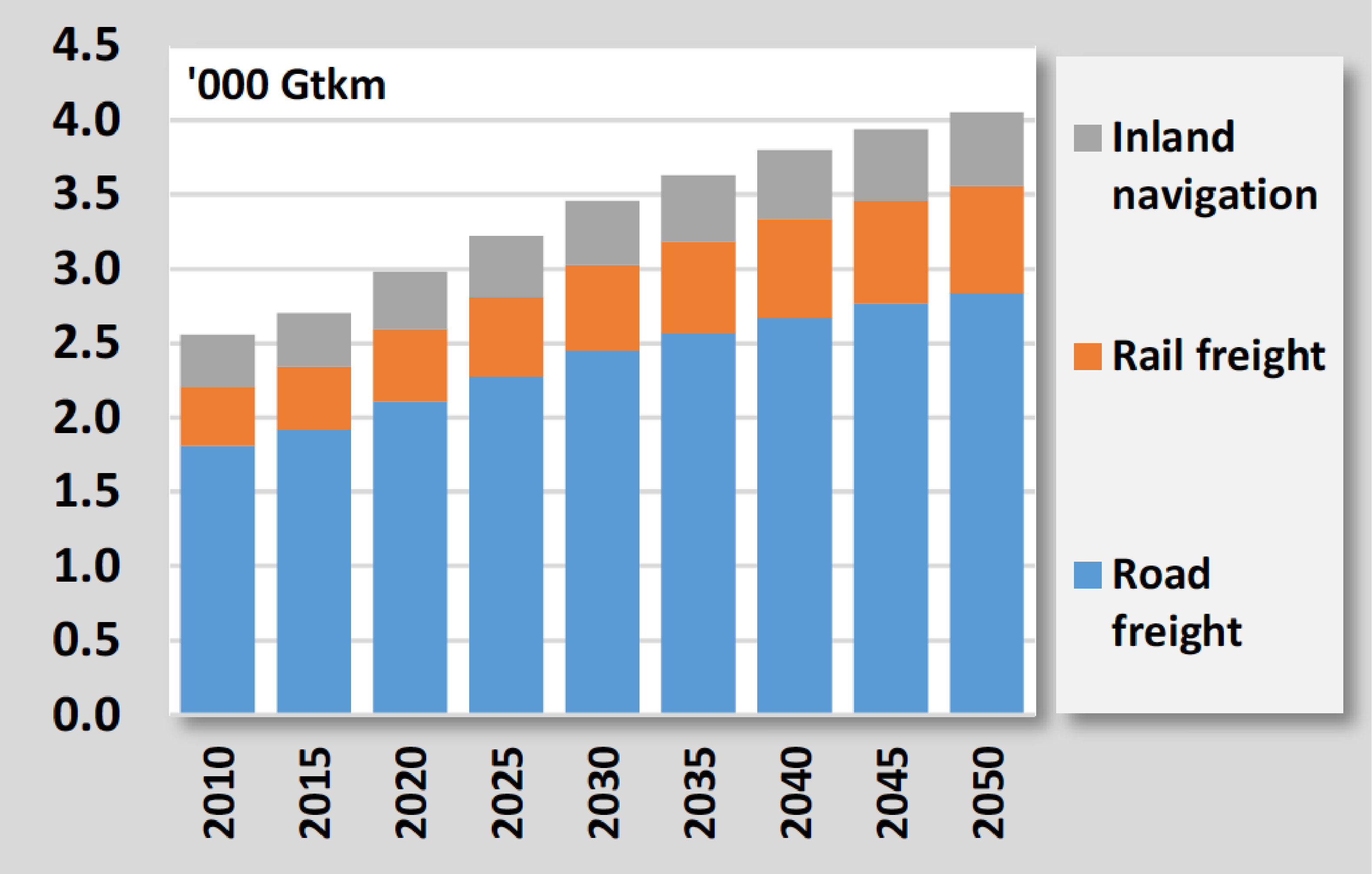
The Richer, the Farther …



Quelle: A. Schäfer et al. (2000), Transportation Research A, 34(3): 171-205

Mobility of Goods – The EU as an Example

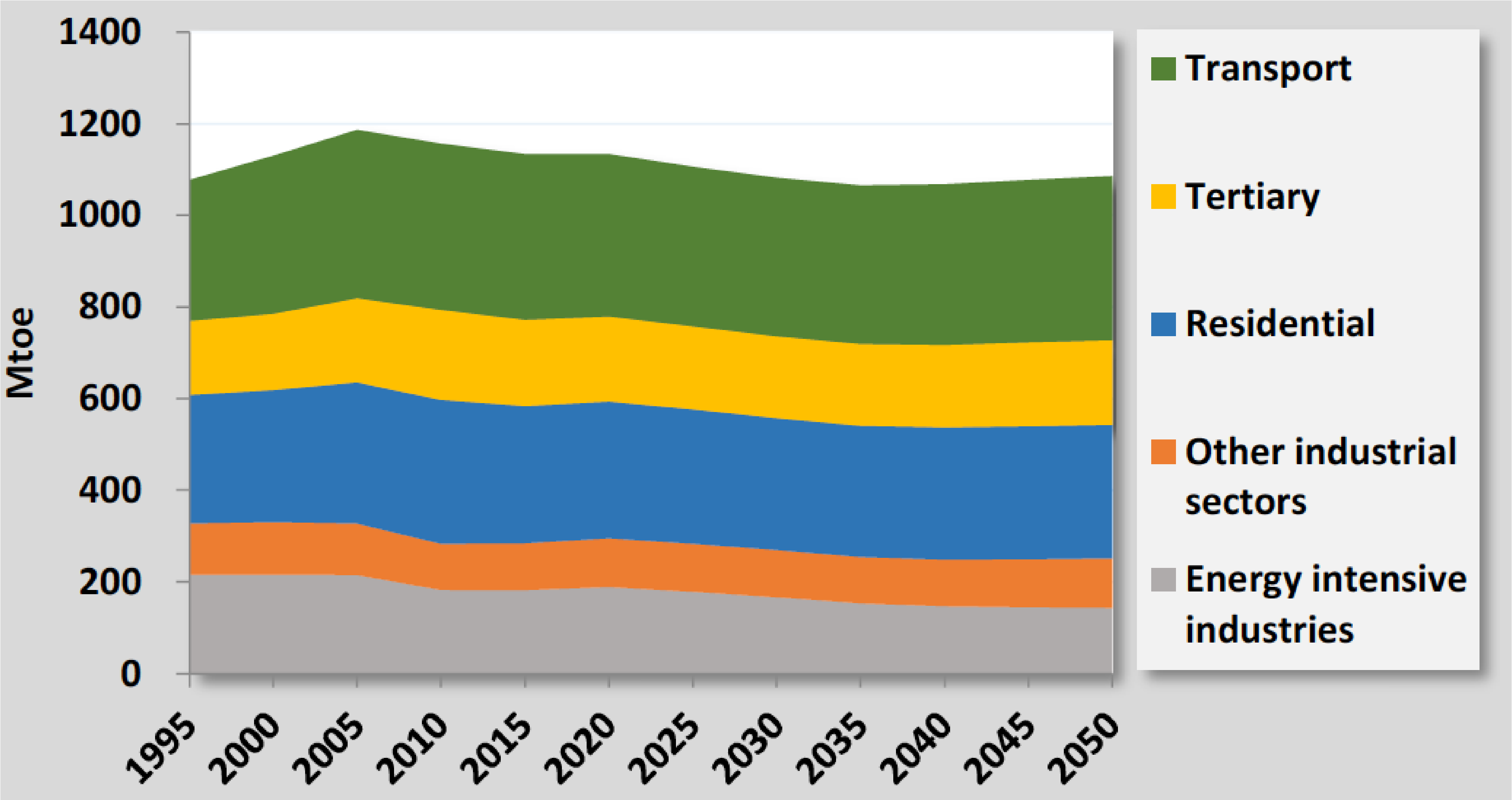
Gtkm = billions of kilometers of 1 ton of goods transported



Source: https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

Transportation is the Largest Energy Consumer – EU

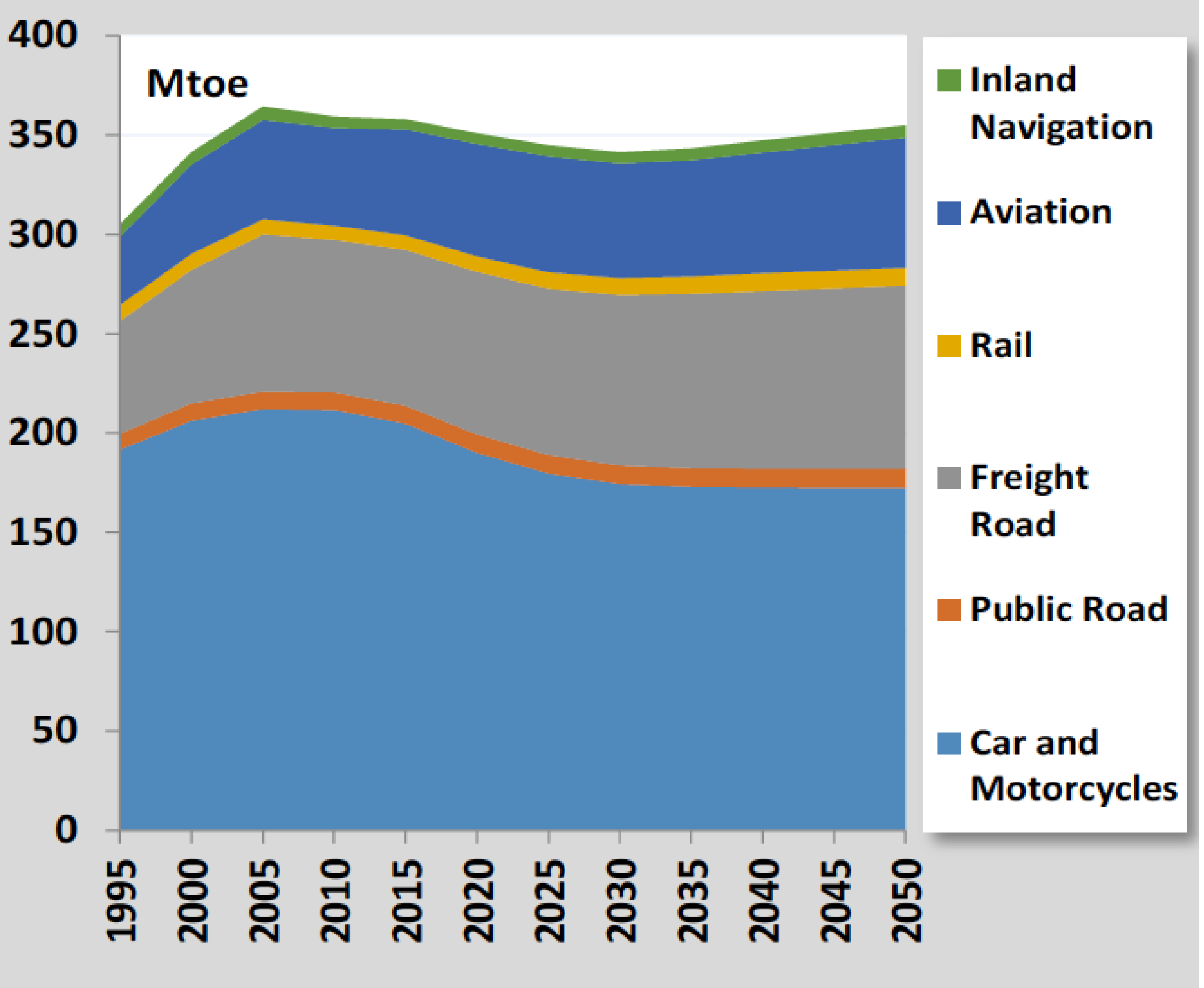
Mtoe = energy contained in 1 million of tons of oil (approx. $4.2 \cdot 10^{16}$ J)



Source: https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

Road Transportation is Dominant

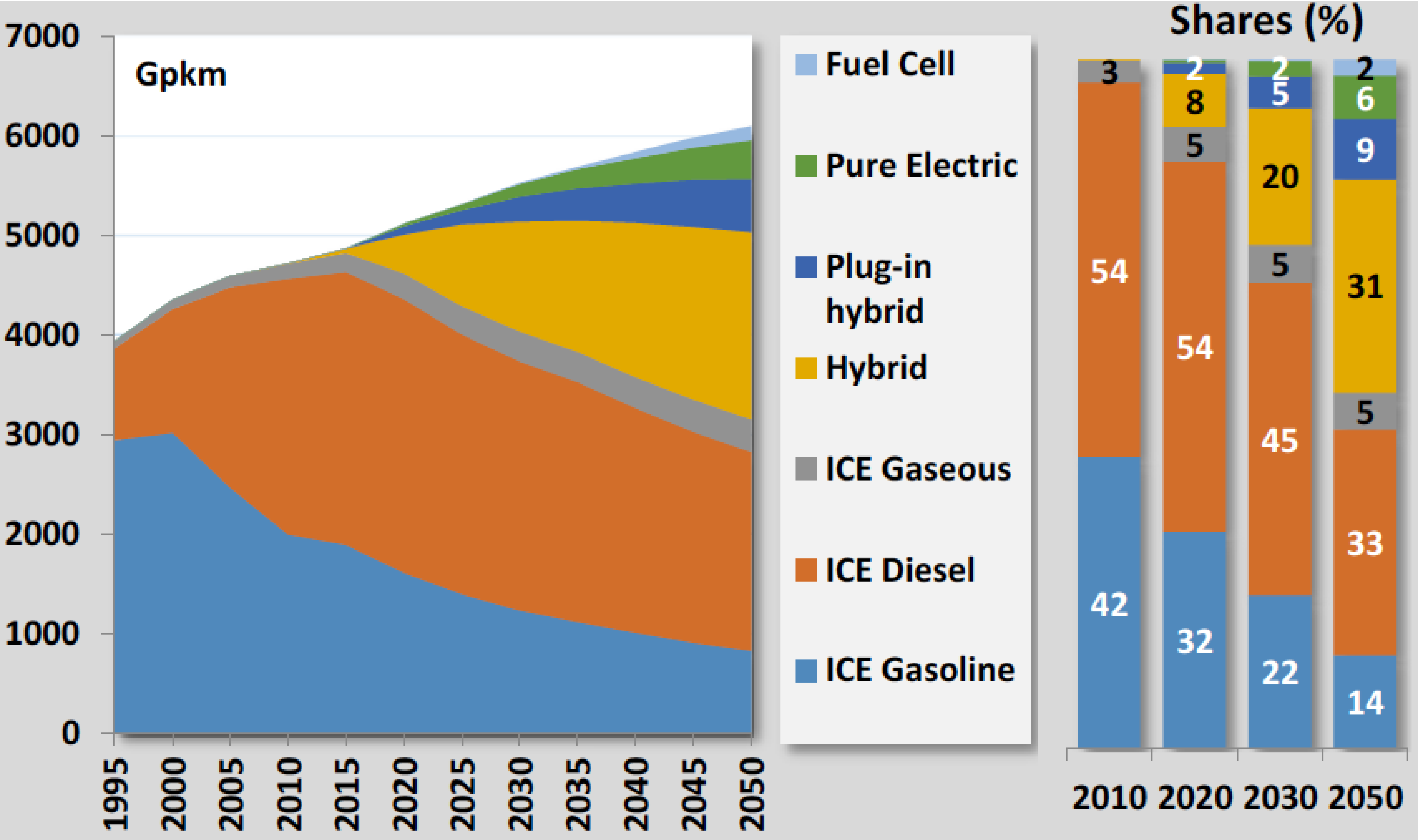
Mtoe = energy contained in 1 million of tons of oil (approx. $4.2 \cdot 10^{16}$ J)



Source: https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

Individual Mobility – Drivetrain Technology Changes

Gpkm = billions of kilometers travelled by one person



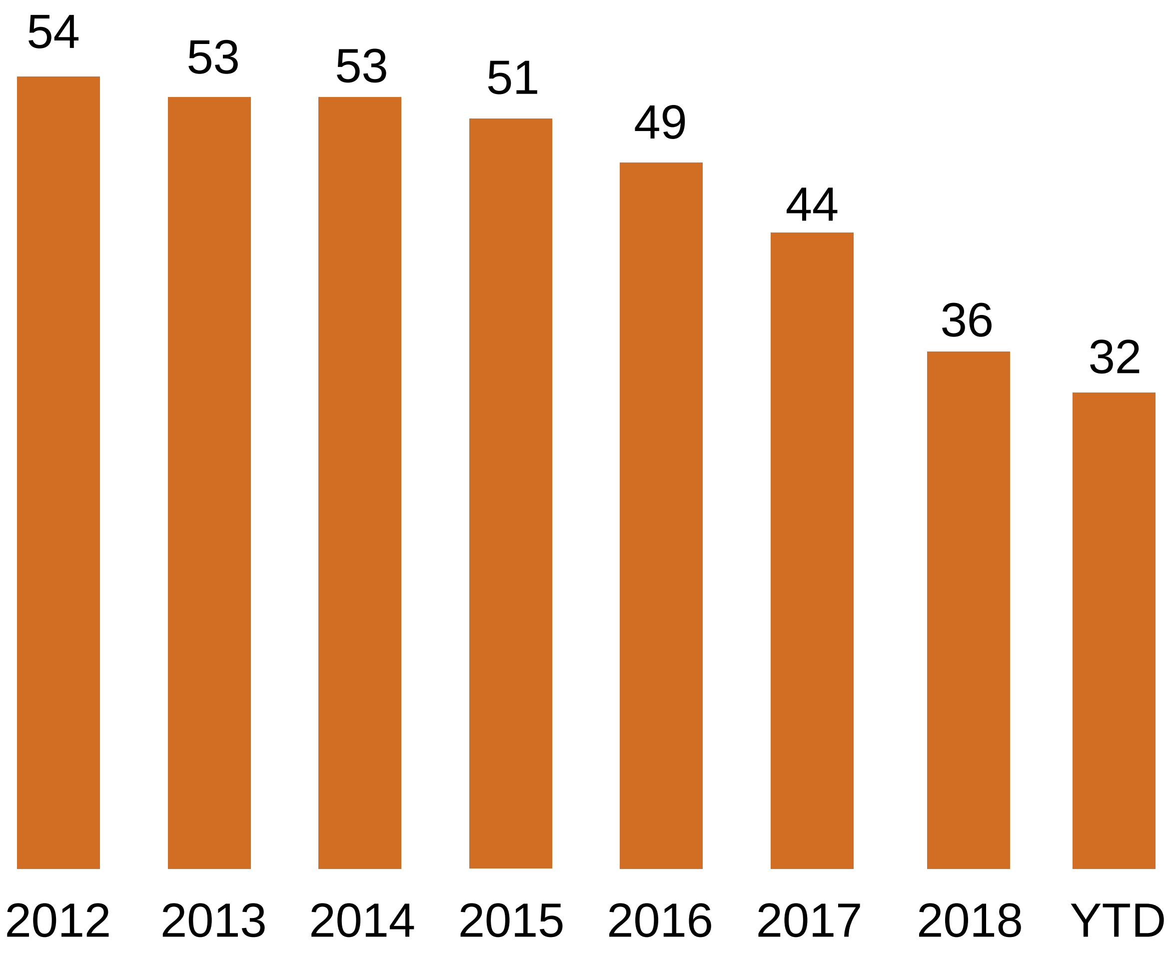
Source: https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

… but Predictions are Difficult

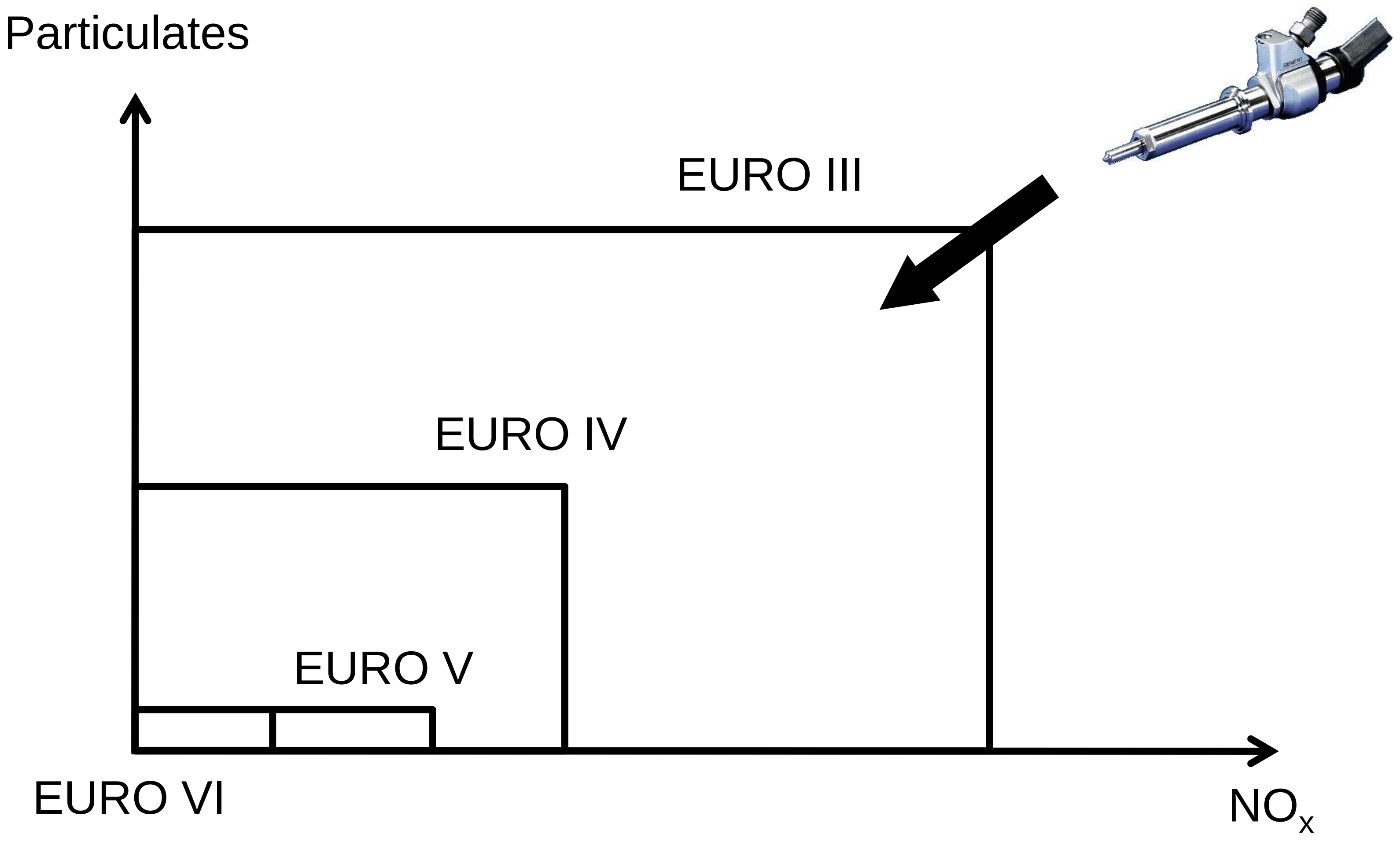
EU-28

Diesel engines

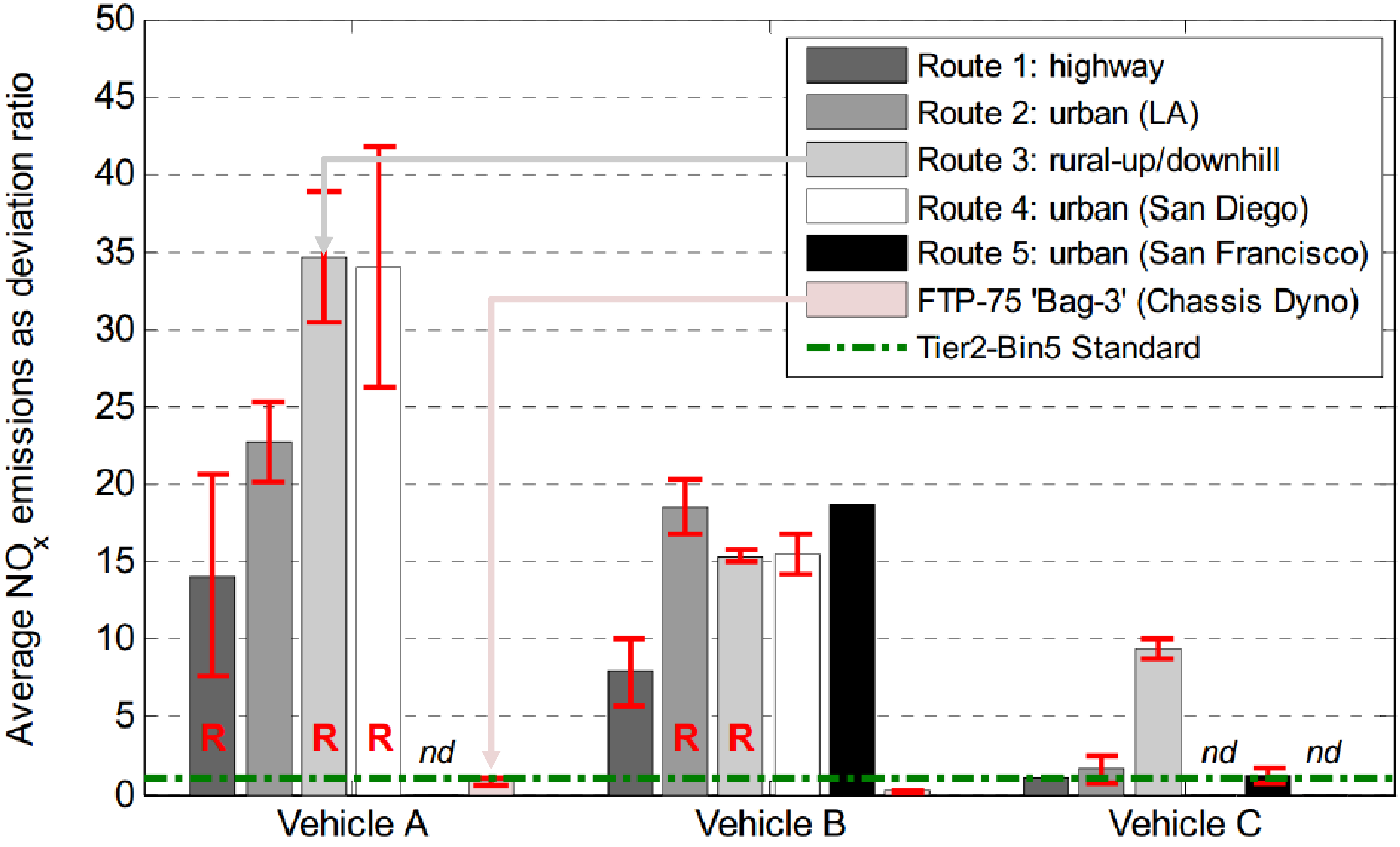
% of car sales



Emission Limits Diesel Engines – EU Legislation



Emission Diesel Engines – Practice

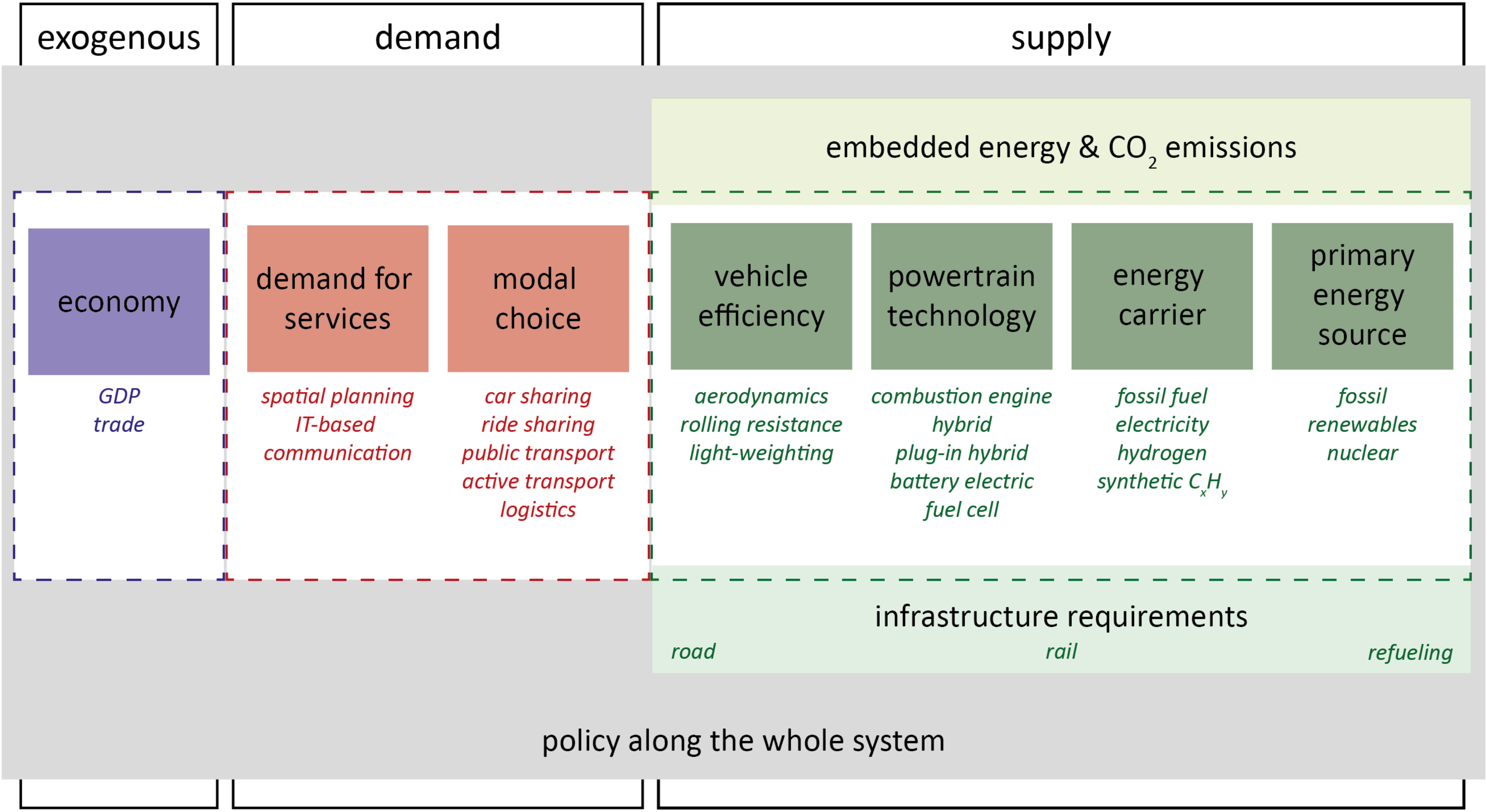


On-road driving test

Federal Test Procedure

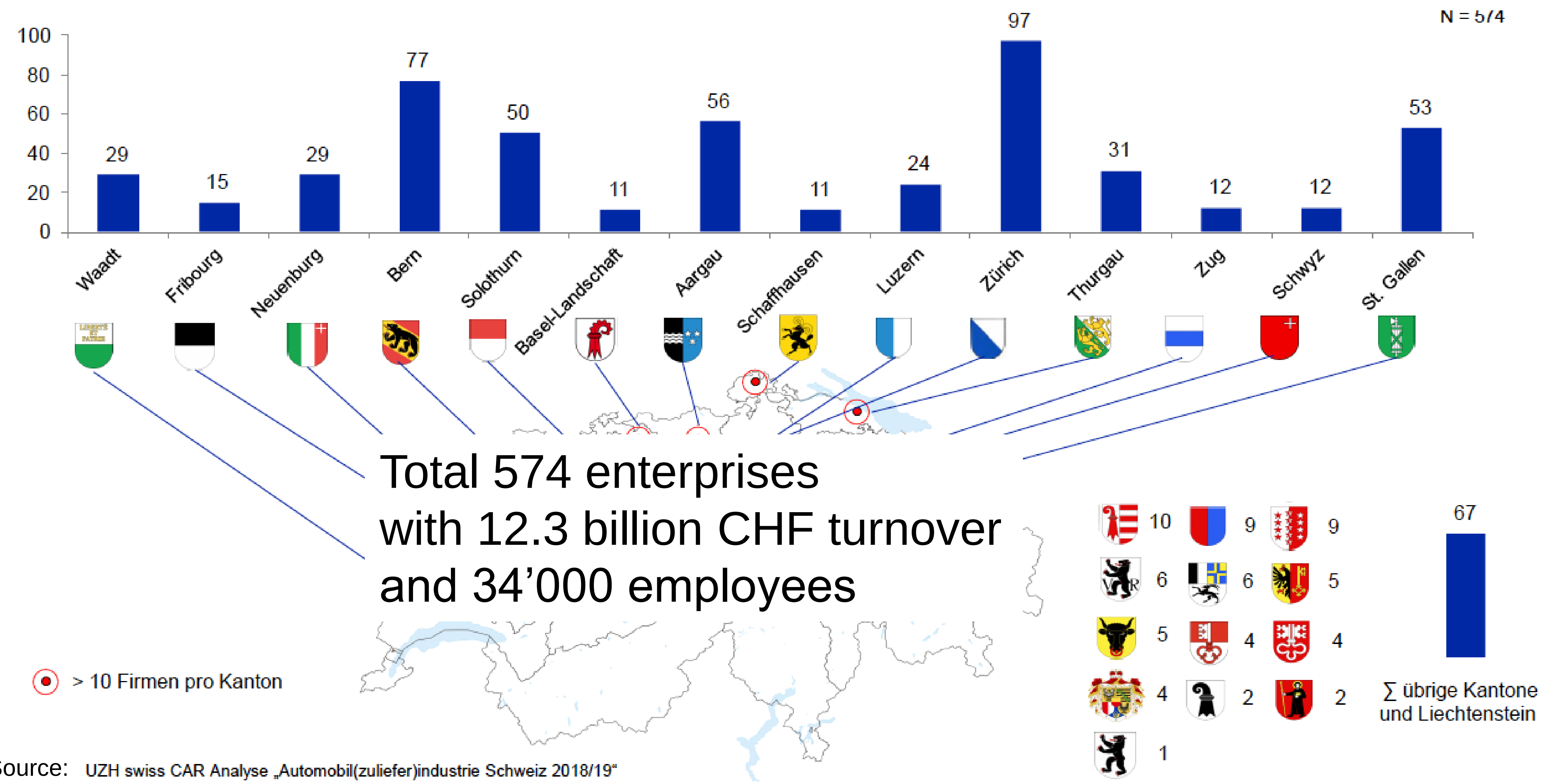
Source: International Council on Clean Transportation and West Virginia University, 2012

Mobility – A Complex Issue …



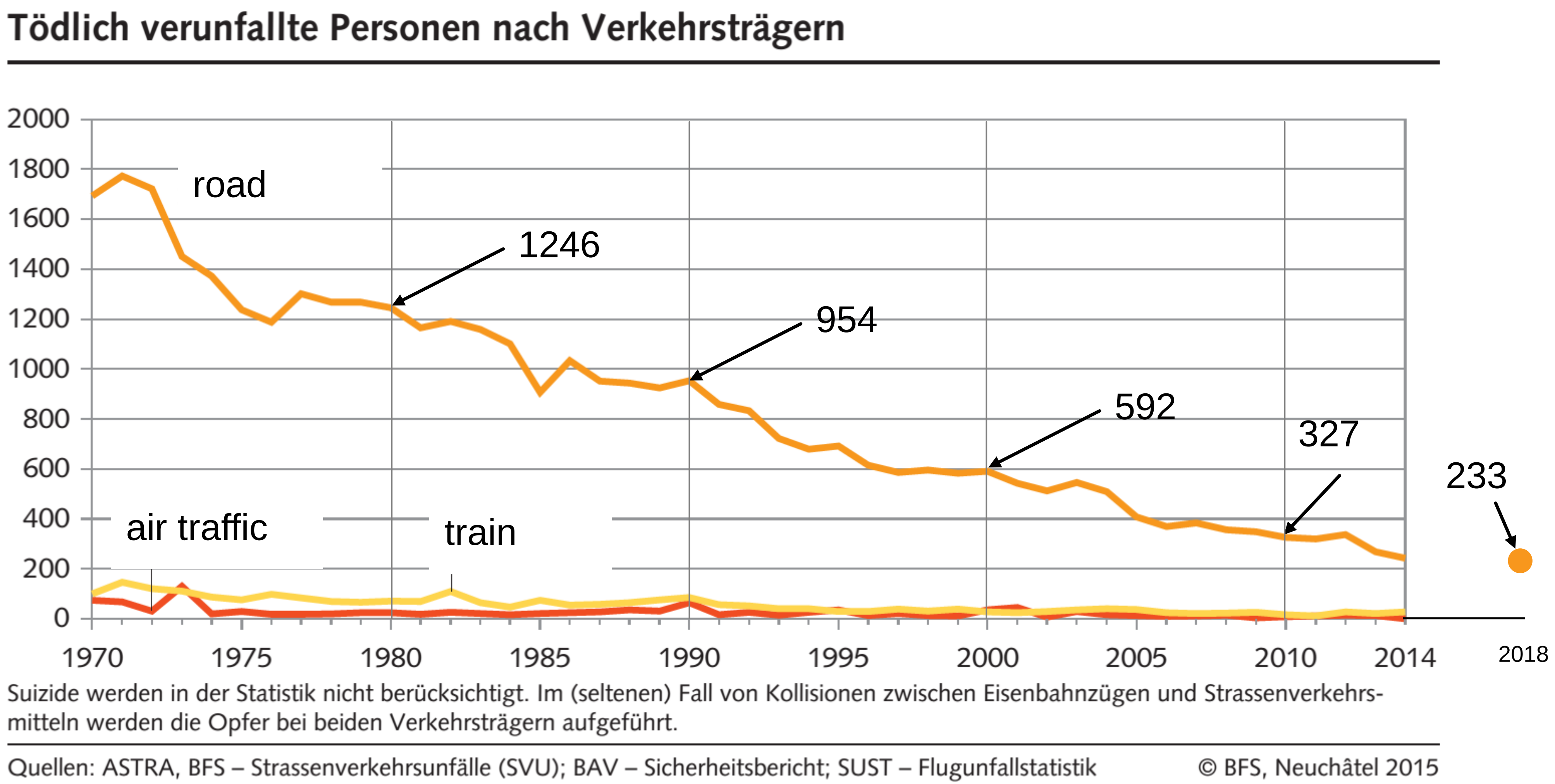
Source: European Academies – Science Advisory Council, Decarbonisation of Transport, 2018

Switzerland – An Automotive Powerhouse …



Source: UZH swiss CAR Analyse „Automobil(zuliefer)industrie Schweiz 2018/19“

Fatalities – Road, Air and Train Switzerland

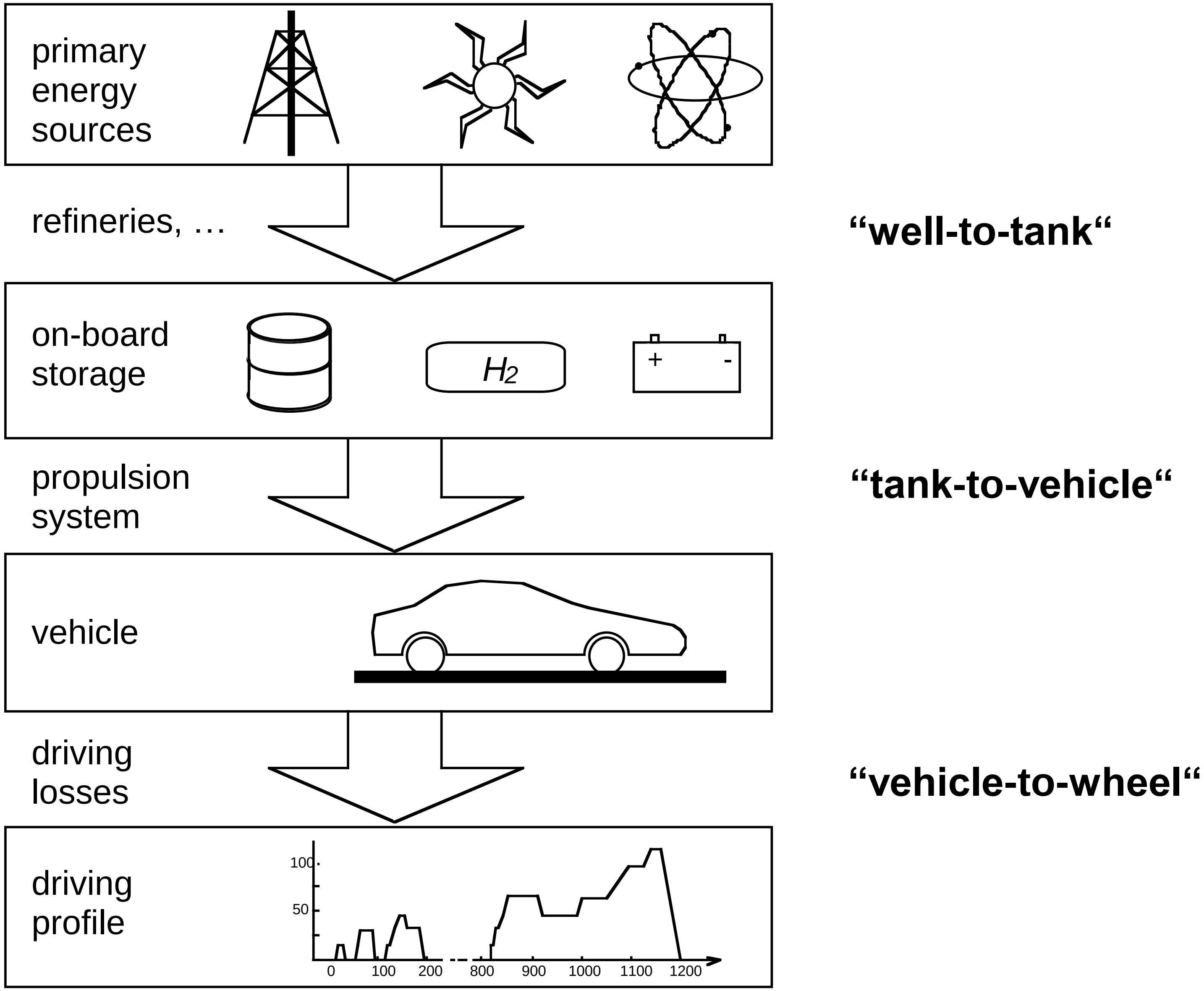


Well-to-Wheel Analysis

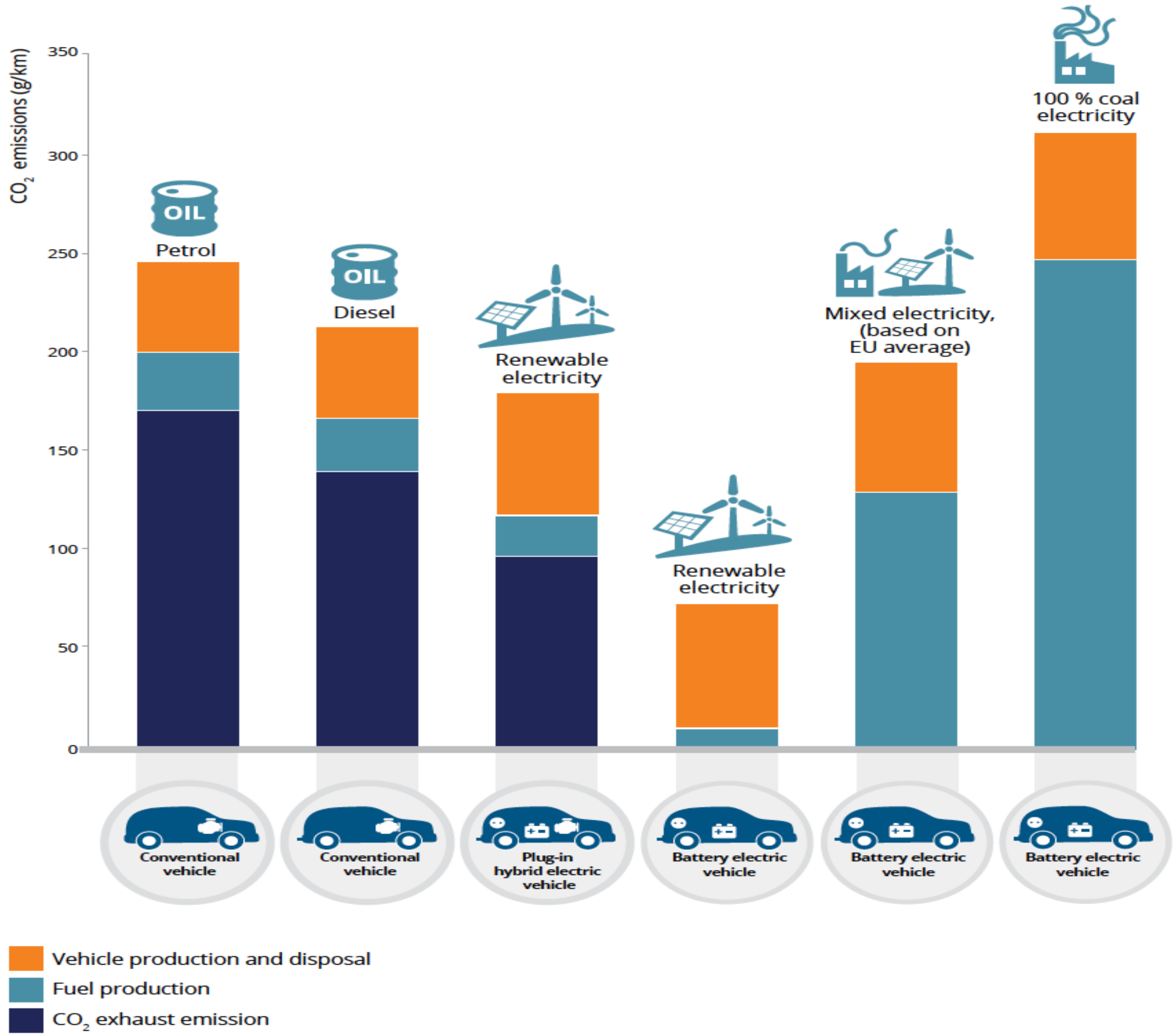
… there is more:

- “grey energy” of vehicles, infra-structure, …
- depletion of resources
- …

Full LCA needed

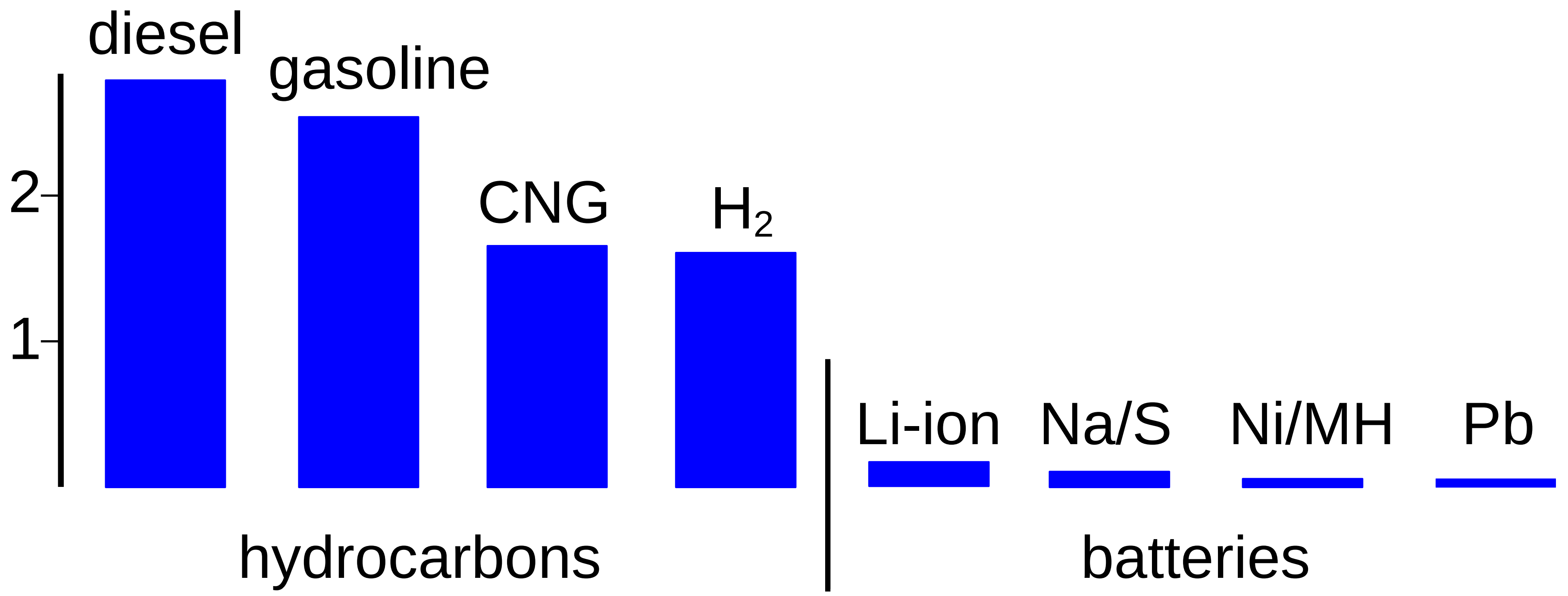


Lifetime CO_2 Emissions – ICE vs. BEV



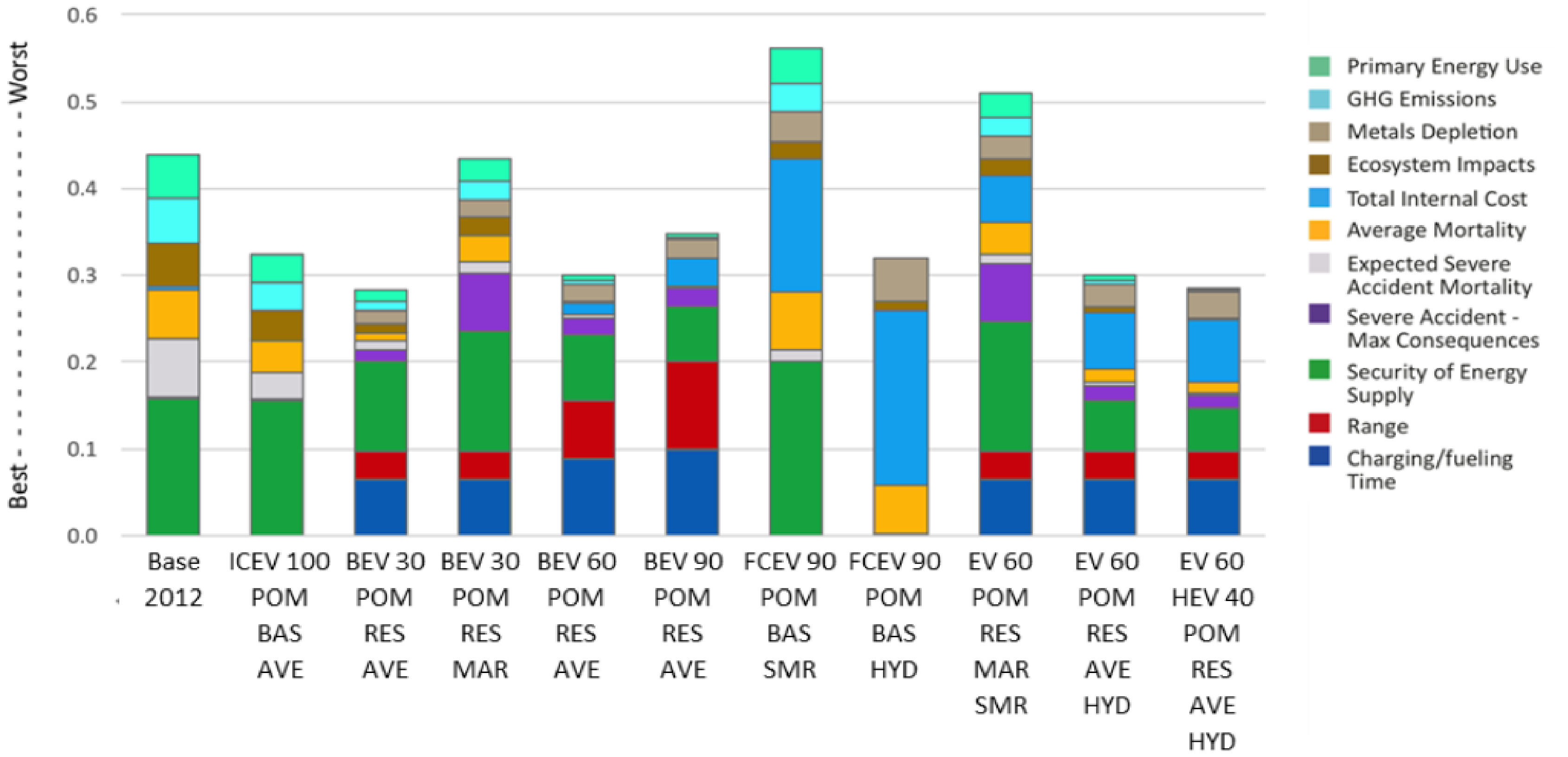
Source: EEA, Electric Vehicles in EU, 2016

Energy Densities of Various «Fuels» – Net Value[1]



1): Including “tank” mass and average ”tank-to-wheel” losses; units: energy / mass [kWh/kg]

Multi-Criteria Decision Analysis



Drivetrains

ICEV - Internal Combustion Engine Vehicles
BEV - Battery Electric Vehicles
FCEV - Fuel Cell Electric Vehicles
EV - ½ BEV, ½ FCEV
HEV - Hybrid Electric Vehicles

Electricity

POM - Demand is SFOE "Political Measures"
BAS - Supply is gas-dependent strategy
RES - Supply is renewables strategy
AVE - Charging is average generation mix
MAR - Charging is marginal generation mix

Hydrogen

SMR - Steam Methane Reforming
HYD - Electrolysis using Swiss Hydropower

Numbers are % fleet penetration in 2050. Balance of fleet is internal combustion vehicles.

Source:
Stephan Hirschberg et al., PSI, 2016

The Economist's View on CO_2-Emissions

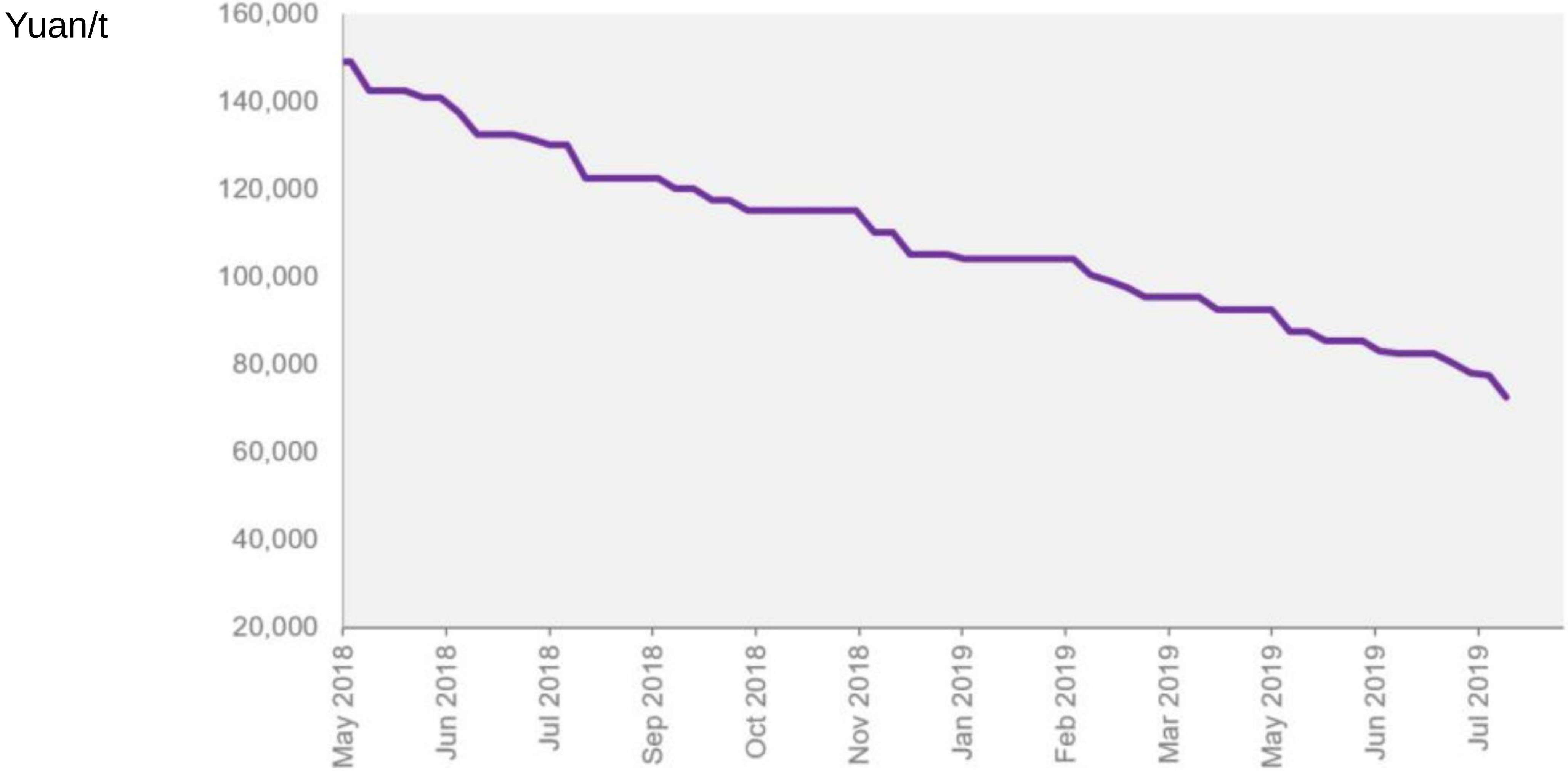
Car	Golf 2.0 TDI, 112 kW	eGolf, 102 kW
Price	27'000 €	40'000 € - 4'000 € subsidy
Consumption[1)]	6.2 l Diesel/100 km	17.5 kWh/100 km
Range, Refueling	890 km, 3 minutes	200 km, 1-17 hours
Lifetime CO_2 Emission	40 tons (250'000 km)	0 tons[2)] (250'000 km)

Cost of CO_2 reduction 9'000 € /40 t CO_2 = 225 € / t CO_2

Alternatives: CO_2 certificates[3)] = 26 €/t CO_2

1) All data "Autotest" 2018 (real road data)
2) Assuming electricity with 0 g CO_2 / kWh and no additional "grey CO_2" caused by battery manufacturing, electricity in Germany produces 527 g CO_2/kWh
3) "myclimate", Mai 2019

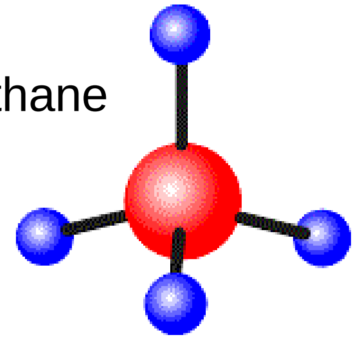
Spot Market Price Lithium Hydroxide, Battery Grade

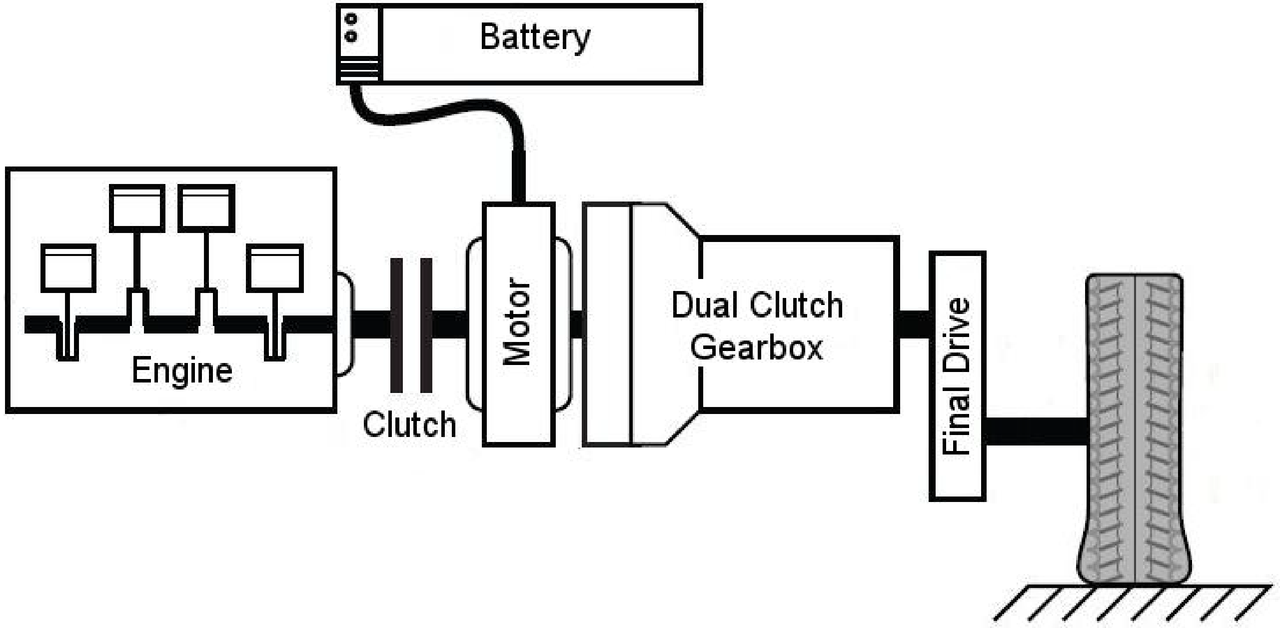


Source: https://www.metalbulletin.com/lithium-prices-update, 2019

My Personal Favorite at the Moment

Methane

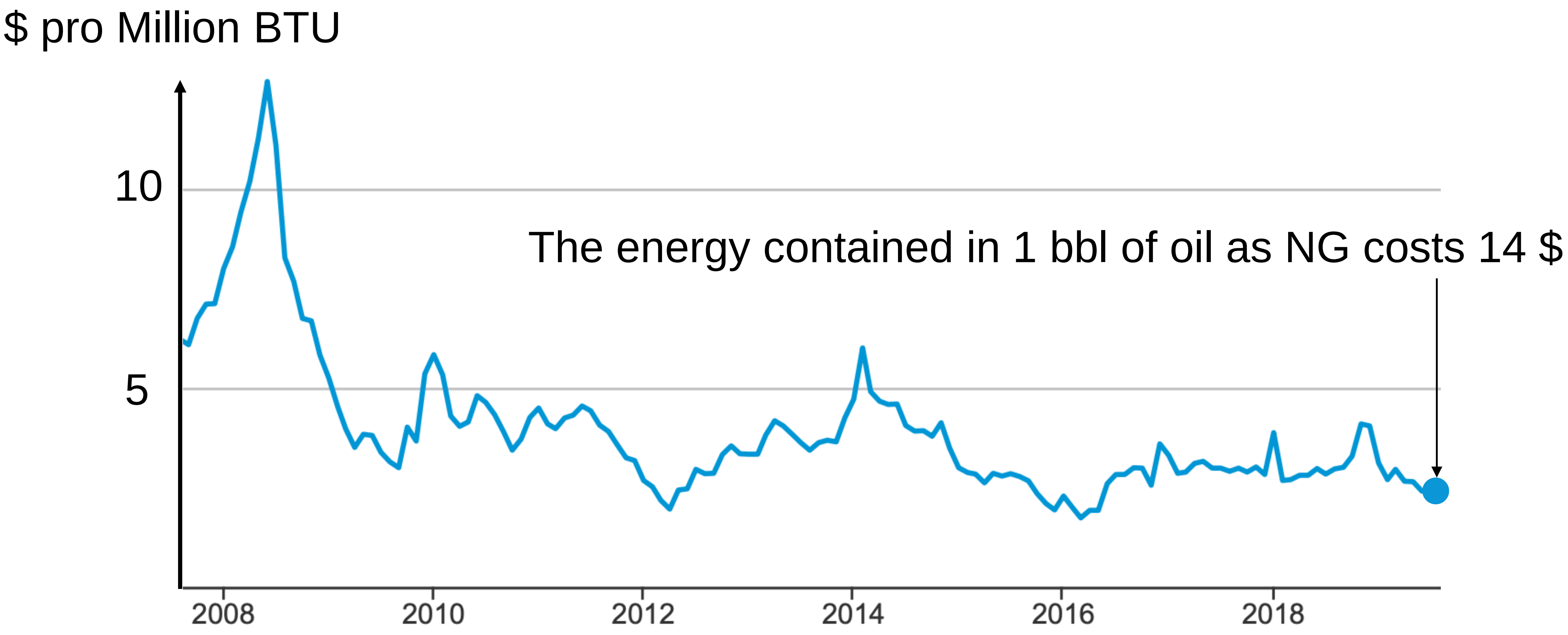




With CNG and mild hybridization: 60 g CO_2/km in compact-class vehicle proven

EU-Limits: 95 g CO_2/km in 2020, 80 g CO_2/km in 2025, and 60 g CO_2/km in 2030

Spot Market Price NG „Henry Hub“



Source: Thompson Reuthers, 2019
1 bbl oil August 13, 2019 US $ 54.6

Climeworks – Renewable “E-Fuels” Demonstrator

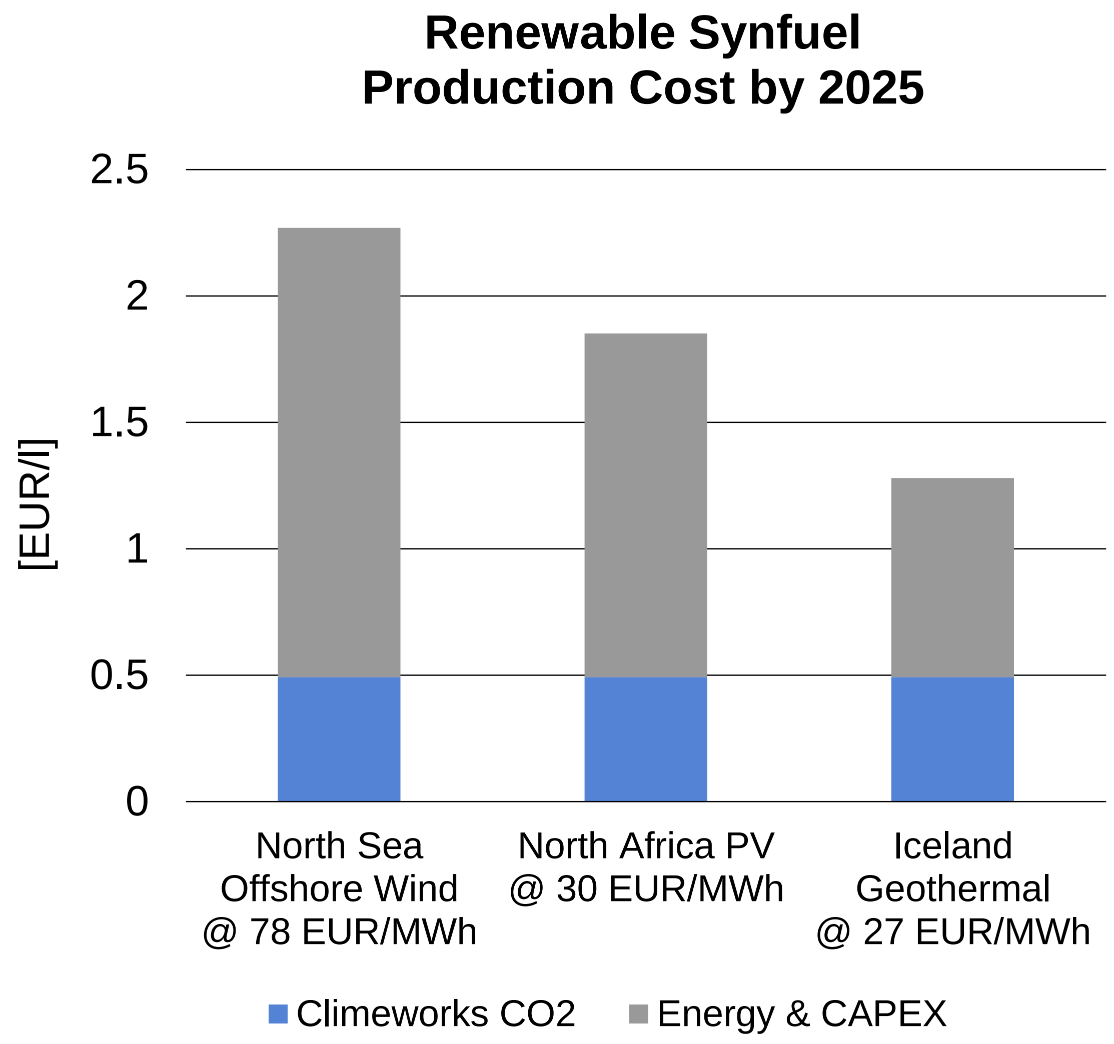
Source Climeworks, 2019

Demonstration of large-volume energy storage with Power-to-X

Plant type:	DAC-3
CO_2 capacity:	410 kg/day
CO_2 application:	Methane synthesis
Heat source:	Heat recovery from synthesis
Location:	Troia, Italy
Commissioning:	1^{st} Oct 2018

Electricity Cost as Main Driver

Costs depend predominantly on local electricity prices, CO_2 is present everywhere in the air.



Quelle Climeworks, 2019

Source: Agora (2018) The Future Cost of Electricity-Based Synthetic Fuels / Climeworks

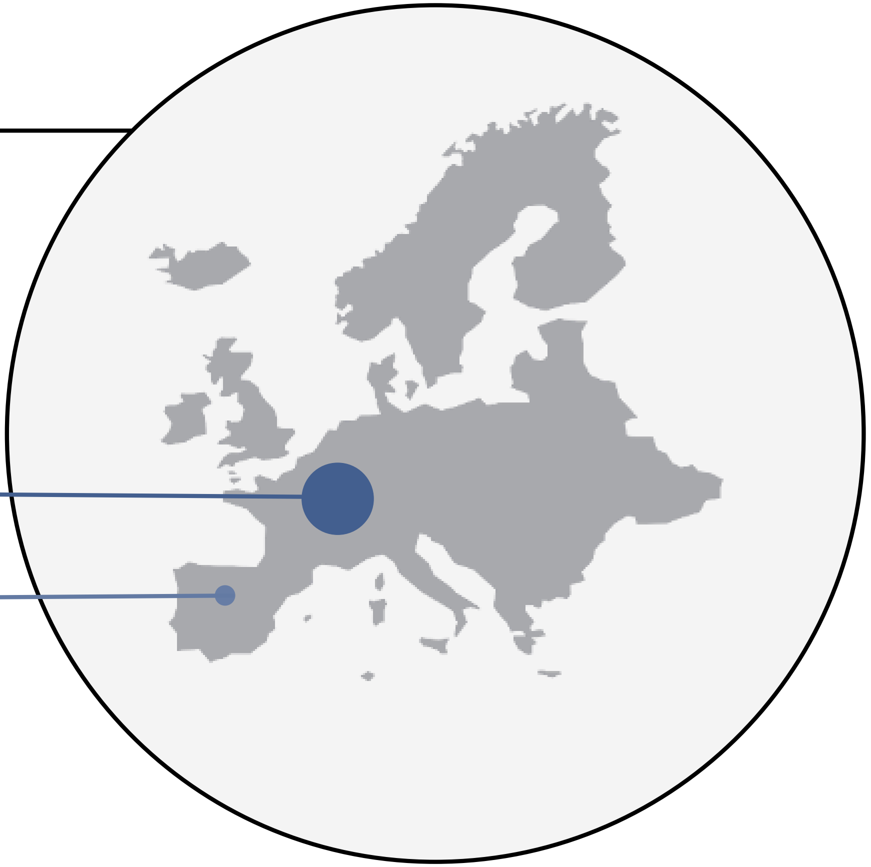
Land Use of Bio and Synthetic Fuels

Surface area needed to meet the 2010 EU transportation energy demand (17,000 pJ/year)

Corn Biofuel
28’000’000 km^2
of arable land
(yield assumption 18 g/ac/y)

Algae Biofuel
200’000 km^2
of barren land
(yield assumption 2’500 g/ac/y)

Renewable Synfuels
14’200 km^2
of barren land
(assumption: 1’900kWh/m^2,
$\eta_{PV} = 25\%, \eta_{PtX} = 70\%$)



Source Climeworks, 2019

Thank you for your attention!

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