What is the most efficient way to defossilize the EU transport sector?

How to minimize global warming?

Life Cycle Assessment (LCA) based on results of the “FVV Fuel Studies IV and IVb”

Dr. Ulrich Kramer

CEE Clean Energy & Mobility Summit 2026
Prague, 22 April 2026

Content

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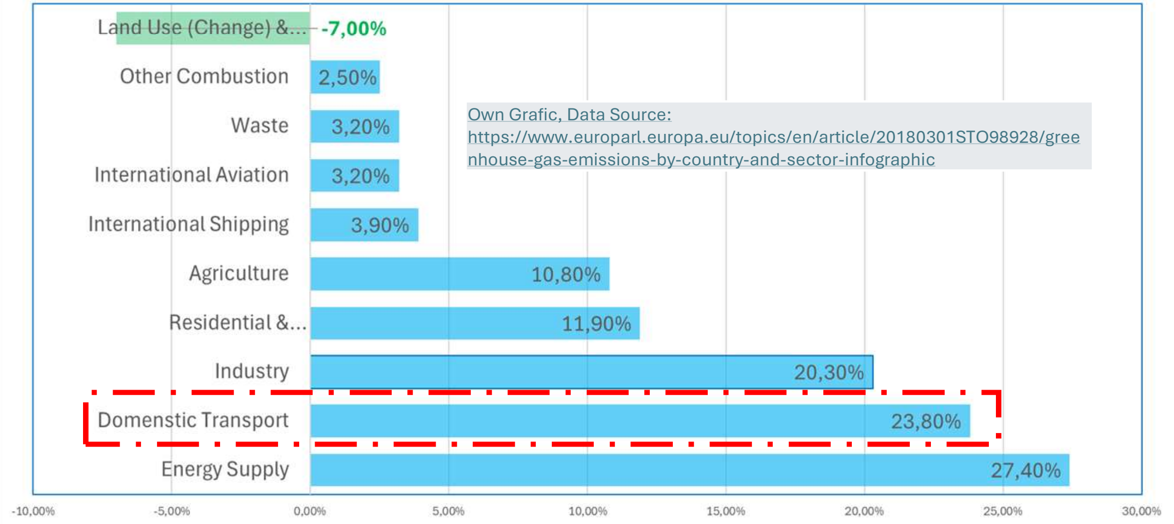
Motivation: EU Targets 2050

European Green Deal → Climate-Neutral Economy by 2050

- **Climate-Neutral → Avoiding anthropogenic green-house-gas (GHG) emissions by 2050** (net zero)
- **The EU assesses greenhouse gas emissions by sector:**

EU GHG Emissions by Sector 2022 (CO2eq Share)



Own Grafic, Data Source: https://www.europarl.europa.eu/topics/en/article/20180301STO98928/greenhouse-gas-emissions-by-country-and-sector-infographic

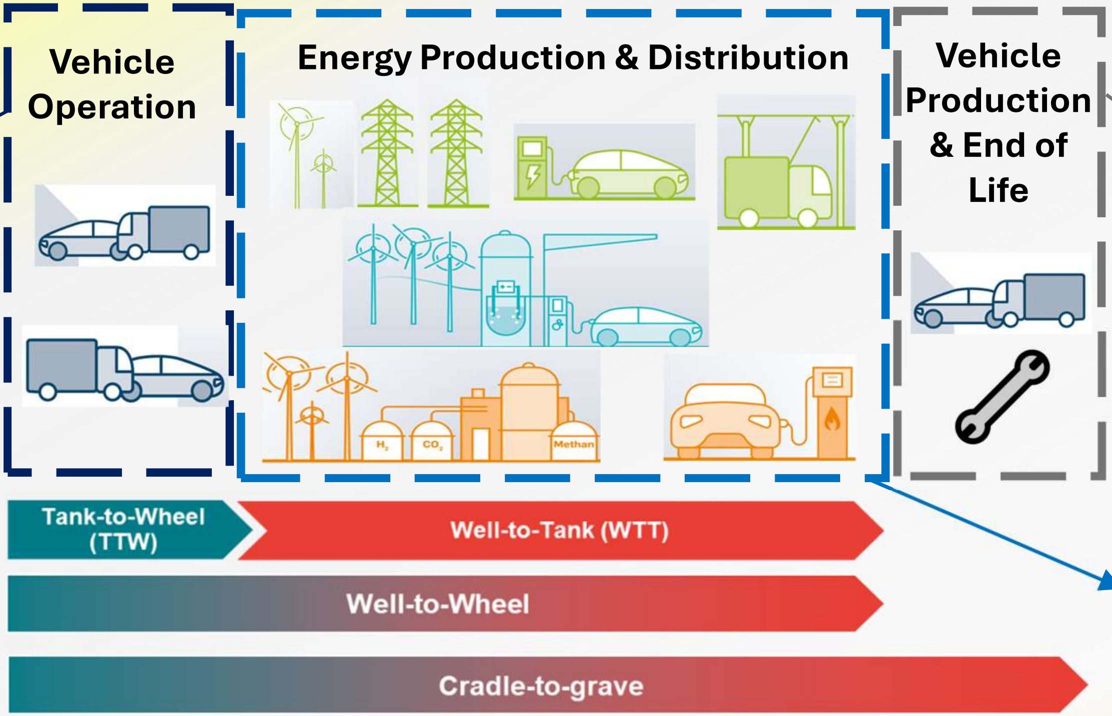
- **≈ 24 % Transport-related GHG emissions**
  (Dominant GHG (≈ 90%): Fossil CO_2)
- **Vehicle Legislation: “Transport-related” GHG (CO_2) emissions are measured solely at the tailpipe!**
- **Inadequate sector-specific legislation → serious errors in the GHG accounting process.**

Motivation: Total GHG Emissions from Transportation

Affect various sectors - but only a portion is limited

Tank-to-Wheel (TTW) →
ONLY TAILPIPE GHG emissions are regulated by EU legislation for vehicles

→ "Sector Target"



Vehicle Operation

Energy Production & Distribution

Vehicle Production & End of Life

Tank-to-Wheel (TTW)

Well-to-Tank (WTT)

Well-to-Wheel

Cradle-to-grave

Cradle-to-Grave → Life Cycle Assessment (LCA)

Vehicle manufacturing and scrapping.

Have not yet been addressed in EU legislation !

Well-to-Tank (WTT)

Energy production and transportation (fuel or electricity)

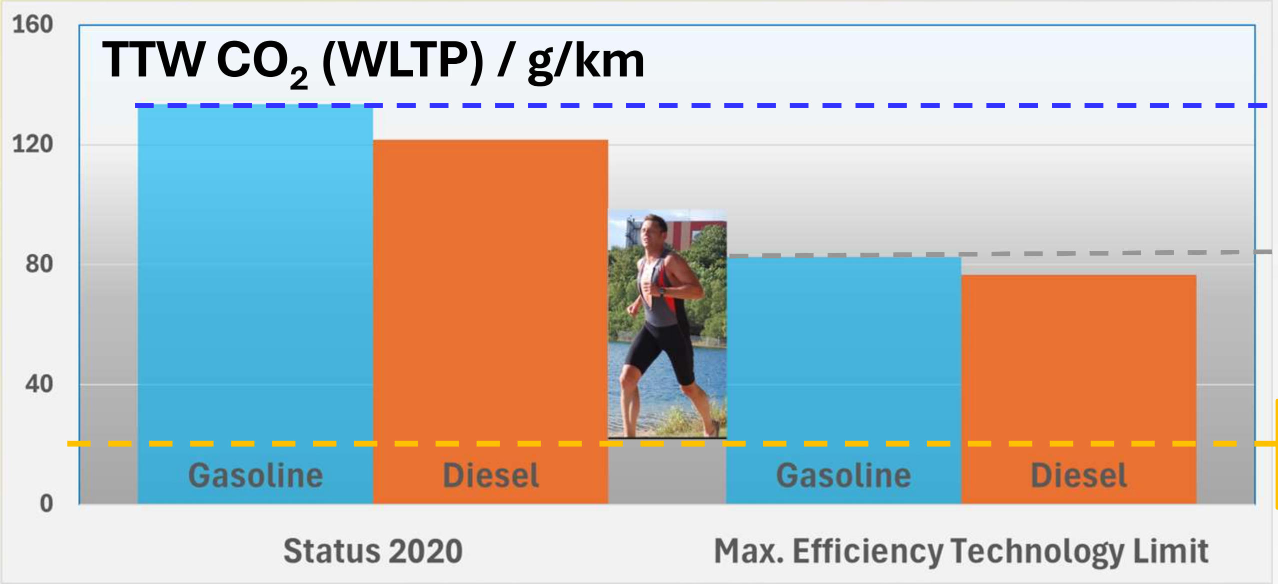
These are not taken into account in EU vehicle legislation.

Can be negative if CO$_2$ from the atmosphere is used for fuel production **(e.g., e-fuel, bio-fuel)**

Motivation: Gasoline/Diesel ICE* Vehicles – Physical Limits TTW CO_2

*ICE: Internal Combustion Engine

Reminder: **“TTW”** (Tank-to-Wheel) → only “exhaust pipe” emissions are regulated



Status 2020: typical C-Segment Vehicle
(e.g., Ford Focus, VW Golf, …)

Realistically achievable minimum TTW CO_2
- **High efficiency engine**
- **Max. hybridization**
- **Lightweight**

→ expensive

For comparison: Marathon runner (75 kg man)
≈20 g CO_2/km (in addition to the basal metabolic rate)

Typical C-Segment Vehicle: 1360kg

EU „Fit for 55“ target 2035: „0 g TTW CO_2“
(EU Parliament 08.06.22; EU Council 28.06.22; Trilogue agreement 27.10.22).

De facto ban on internal combustion engines

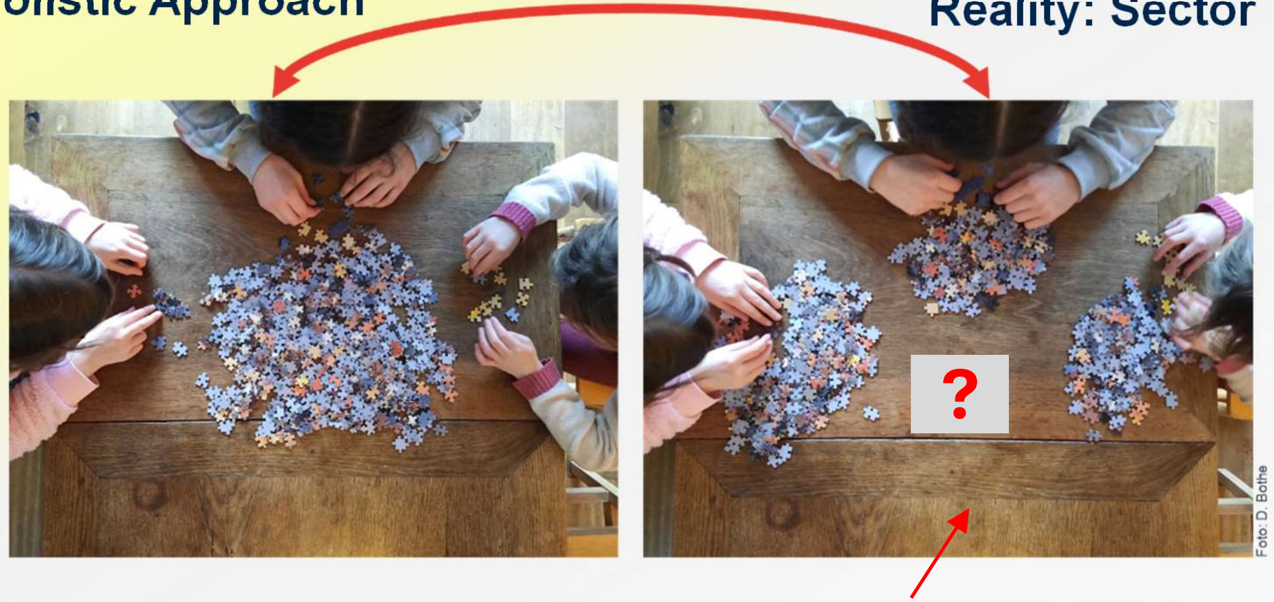
Other GHG emissions (WTT, LCA) and also CO_2-reduction effects of non-fossil fuels (biofuels, e-fuels) are ignored by the European CO_2 regulation for vehicles

Motivation: GHG - Sector Targets are inefficient and counterproductive

Not a particularly smart way to reduce greenhouse gas emissions

Holistic Approach

Reality: Sector Targets



Status quo EU-Legislation: Sector Targets

→ prevent a holistic solution to the problem

What is the real problem?

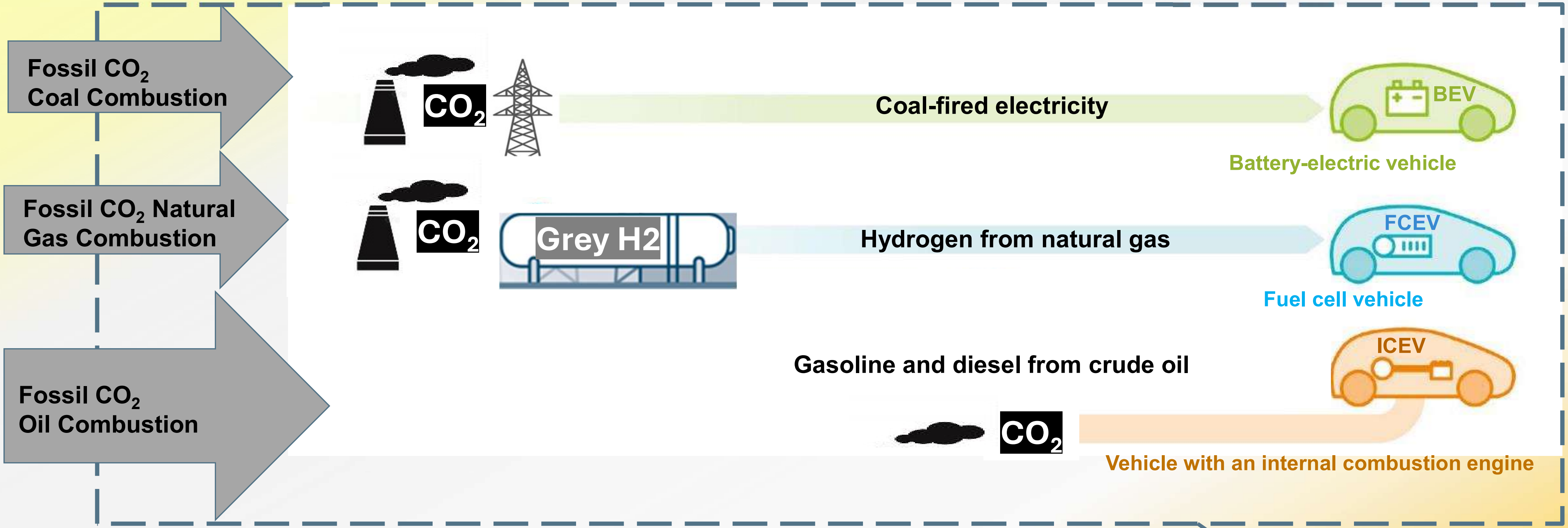
- **NOT TTW CO_2 emissions,**
- **NOT internal combustion engines (ICE),**

but… ….

Motivation: WTW* GHG** Emissions of EU Transport ...

... are dominated by fossil fuels (coal, oil, natural gas)

REAL PROBLEM: Enrichment of the atmosphere with GHG (fossil CO_2) → Global Warming



Fossil CO_2 Coal Combustion

CO_2

Coal-fired electricity

BEV

Battery-electric vehicle

Fossil CO_2 Natural Gas Combustion

CO_2

Grey H2

Hydrogen from natural gas

FCEV

Fuel cell vehicle

Fossil CO_2 Oil Combustion

Gasoline and diesel from crude oil

ICEV

CO_2

Vehicle with an internal combustion engine

Atmosphere

* WTW: Well-To-Wheel

** GHG: Green House Gas (mainly <u>fossil</u> CO_2)

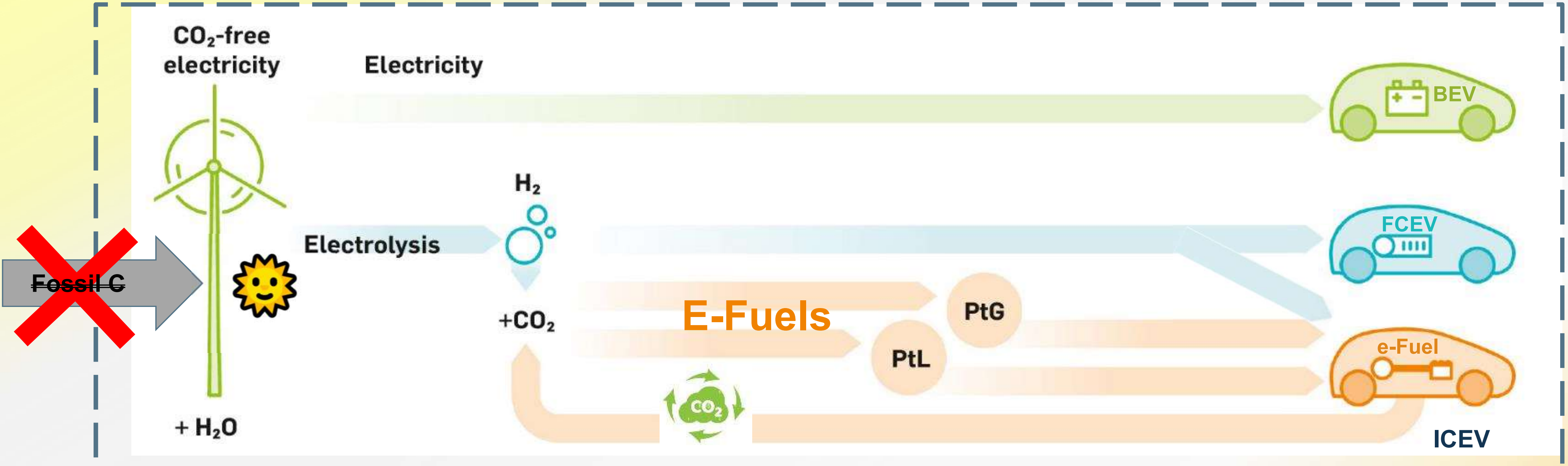
BEV: Battery Electric Vehicle

FCEV: Fuel Cell Electric Vehicle

ICEV: Internal Combustion Engine (ICE) Vehicle

Motivation: Target: “Climate-neutral” mobility (net zero GHG) in 2050

„ Climate-neutral“ → GHG-neutral : No enrichment of the atmosphere with GHG (mainly fossil CO2))



Closed carbon cycle → no GHG (fossil CO2) enrichment in atmosphere → „climate-neutral “

Atmosphere

BEV:	Battery Electric Vehicle
FCEV:	Fuel Cell Electric Vehicle
ICEV:	Internal Combustion Engine Vehicle

* WTW: Well-To-Wheel

** GHG: Green House Gas (mainly fossil CO_2)

History: FVV Fuel Studies I .... IVb / Outlook: FVV Energy Study

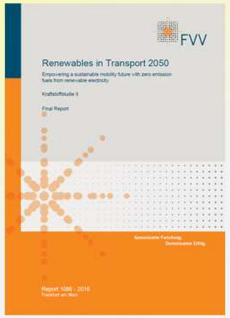
13 years lessons learned

2013
Fuel Study I

Kraftstoffstudie

Heft 1031 - 2013

2016
Fuel Study II



Renewables in Transport 2050

Final Report

Well-to-Wheel,
German (2050)
Transport Sector,
Arbitrary scenarios

2018
Fuel Study III

Defossilizing the transportation sector

Well-to-Wheel
German (2050)
Transport Sector,
Single
Technologies

2021
Fuel Study IV

FINAL REPORT

Zukünftige Kraftstoffe: FVV-Kraftstoffstudie IV
Future Fuels: FVV Fuels Study IV

LCA
EU (2030/2050)
Transport Sector,
Single
Technologies

2022
Fuel Study IVb

FINAL REPORT

Zukünftige Kraftstoffe: FVV-Kraftstoffstudie IVb
Future Fuels: FVV Fuel Study IVb

LCA
EU **(ramp-up)**
Transport sector,
Mixed
Technology Ramp-Up

Outlook Q4/2026
Energy Study

LCA
EU (ramp-up)
Complete Economy,
Mixed
Technology Ramp-Up

Research Partners	LBST	none *(FVV's own study)*	Frontier Economics, ifeu	Frontier Economics	Frontier Economics, ESU, IAEW, DVGW EBI
Chair (FVV)	FVV Board	U. Kramer (Ford)	U. Kramer (Ford)	U. Kramer (Ford)	Study Design & Start-up: U. Kramer (Ford) Meanwhile: Continuation with new FVV chairmen

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    - Reference Ramp-Up
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  - Costs

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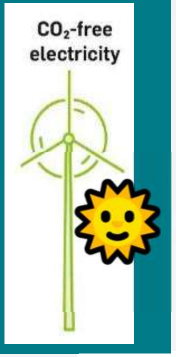
Research Approach

FVV Fuel Studies IV / IVb

GHG neutral transport EU27+UK **in 2050 …**

Only solar-/ wind power



2 regions of "solar/wind energy harvesting": Domestic vs. Global

Powertrains & Energy Carriers

- Electric (BEV) >7.5t catenary line
- e-H_2 (ICEV, FCEV)
- e-FT Diesel/Gasoline (ICEV)
- e-CH_4 (ICEV)
- e-MtG (Gasol.)* (ICEV)
- e-MtG/FT* (PHEV)
- *e-Methanol***
- *e-DME***

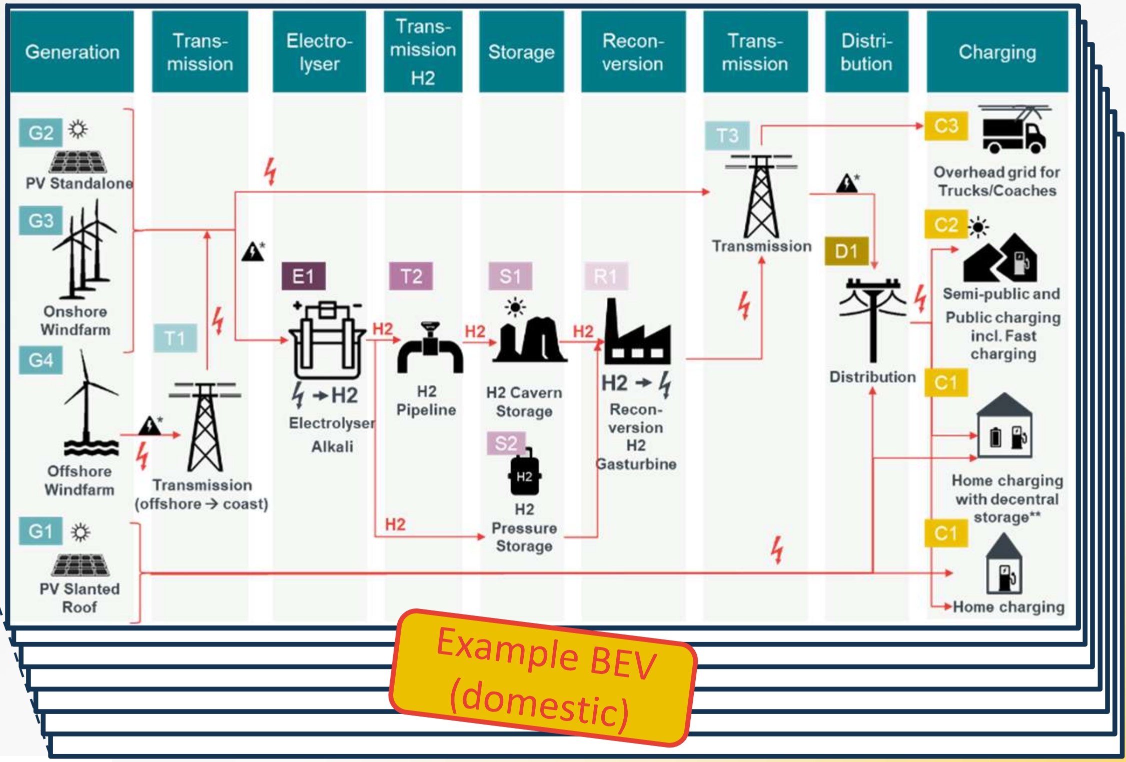
* Only FVV FS IVb; **Only FVV FS IV

3 Vehicle Efficiency Classes

- **Status Quo****
- **Balanced**
- **All-In****

- **FVV FS IV: Step 1: Single Technology Scenarios; Reference Ramp-Up**
- **FVV FS IVb: Step 2: Realistically achievable technology ramp-ups,** assuming **ideal regulatory and financial conditions** (similar to "COVID 19 vaccine introduction")
  + Step 3: GHG-optimized Mixed Technology Scenario

Simulation of the entire energy system for each "powertrain-energy combination". Considering all Life Cycle GHG emissions, including vehicle manufacturing / disposal, and the installation of the entire energy supply system.



Example BEV (domestic)

Comparison of:

- Cumulated GHG emissions
- Costs
- Energy demand
- Raw material demand
- Other environmental aspects (land use, etc.…)

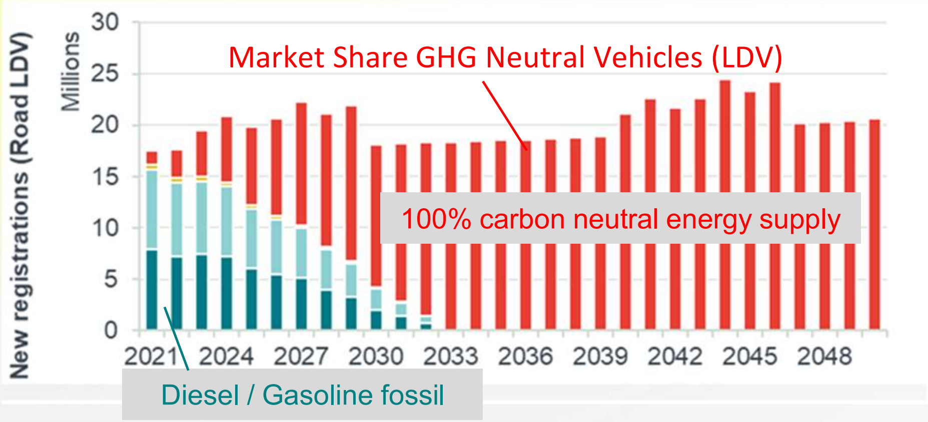
Research Approach: FVV Fuel Study IV - <u>Reference Ramp-Up</u> (GHG neutral in 2050)

limited solely by the fleet exchange rate (vehicle lifetime)

Example: Light Duty Vehicles (LDV) (which includes Passenger Cars)

Vehicle Sales: Market Sales Share

100% GHG Neutral Vehicle Sales Share in 2033



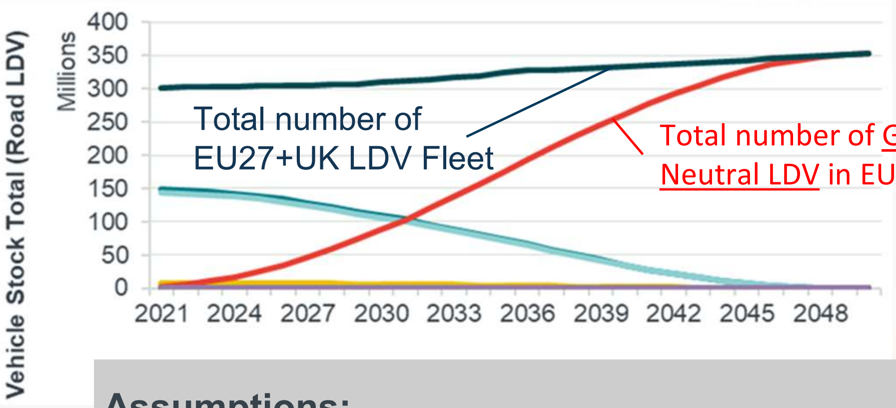
Market Share GHG Neutral Vehicles (LDV)

100% carbon neutral energy supply

Diesel / Gasoline fossil

Fleet Composition

100% GHG Neutral Vehicle Market Penetration in 2050



Total number of EU27+UK LDV Fleet

Total number of <u>GHG Neutral LDV</u> in EU27+UK

🟩 Vehicles of out-phasing fleet, operated with fossil diesel

🟦 Vehicles of out-phasing fleet, operated with fossil gasoline

🟥 New carbon neutral vehicles, operated with defossilized fuel/energy

⬛ Total number of vehicles (fleet stock)

<u>Assumptions:</u>

- **GHG neutral transport in 2050**
- **<u>Theoretical ramp-up</u> for all pathways, determined <u>solely</u> by historical fleet replacement rates**

- **<u>Assumption:</u> All new vehicles will be powered exclusively by GHG-neutral energy!**

Research Approach: FVV Fuel Study IV - Reference Ramp-Up (GHG neutral in 2050)

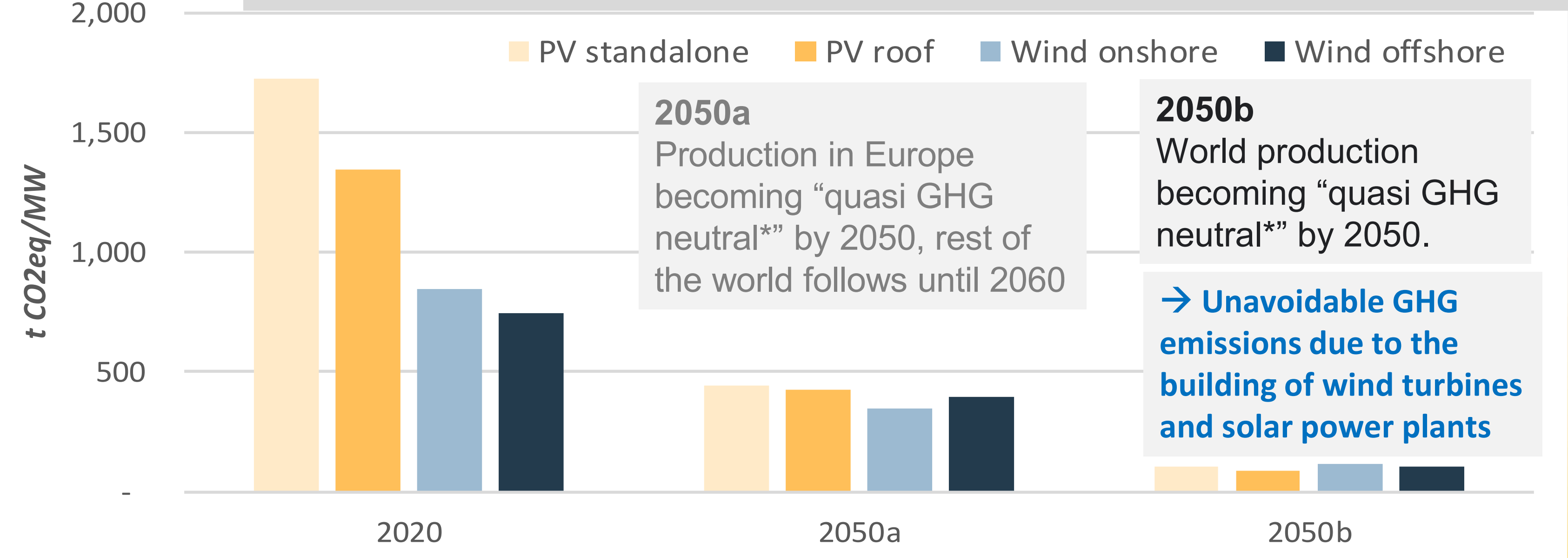
Future defossilization of the background system: **GHG of building energy supply (wind/solar)**

→ Defossilization of background system, i.e., powering all production processes with wind and solar energy by 2050 *(Scenario 2050b)*.

→ Minimizing GHG emissions to build up of energy supply infrastructure (solar/wind power) by 2050

→ **There will always be unavoidable GHG emissions** (in reality, GHG-neutral processes are almost unavailable)

Specific GHG emissions from building-up solar and wind power plants



2050a
Production in Europe becoming “quasi GHG neutral*” by 2050, rest of the world follows until 2060

2050b
World production becoming “quasi GHG neutral*” by 2050.

→ Unavoidable GHG emissions due to the building of wind turbines and solar power plants

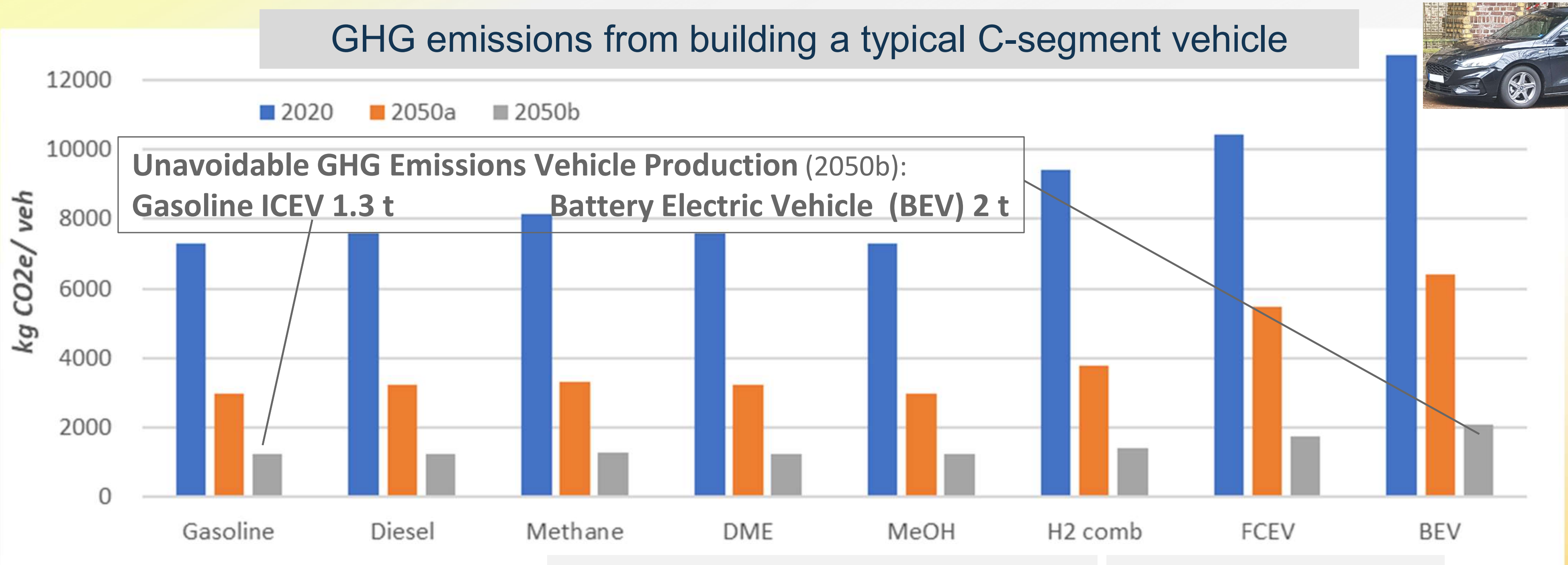
* only unavoidable GHG emissions remain

Research Approach: FVV Fuel Study IV - Reference Ramp-Up (GHG neutral in 2050)

Future defossilization of the background system: **GHG of vehicle production**

→ Defossilization of background system→ **Minimizing GHG Emissions in Vehicle Manufacturing**

→ **There will always be unavoidable GHG emissions** (in reality, GHG-neutral processes are almost unavailable)


GHG emissions from building a typical C-segment vehicle

Unavoidable GHG Emissions Vehicle Production (2050b):
Gasoline ICEV 1.3 t **Battery Electric Vehicle (BEV) 2 t**

2050a
Production in Europe becoming “quasi GHG neutral*” by 2050, rest of the world follows until 2060

2050b
World production becoming “quasi GHG neutral*” by 2050

* only unavoidable GHG emissions remain

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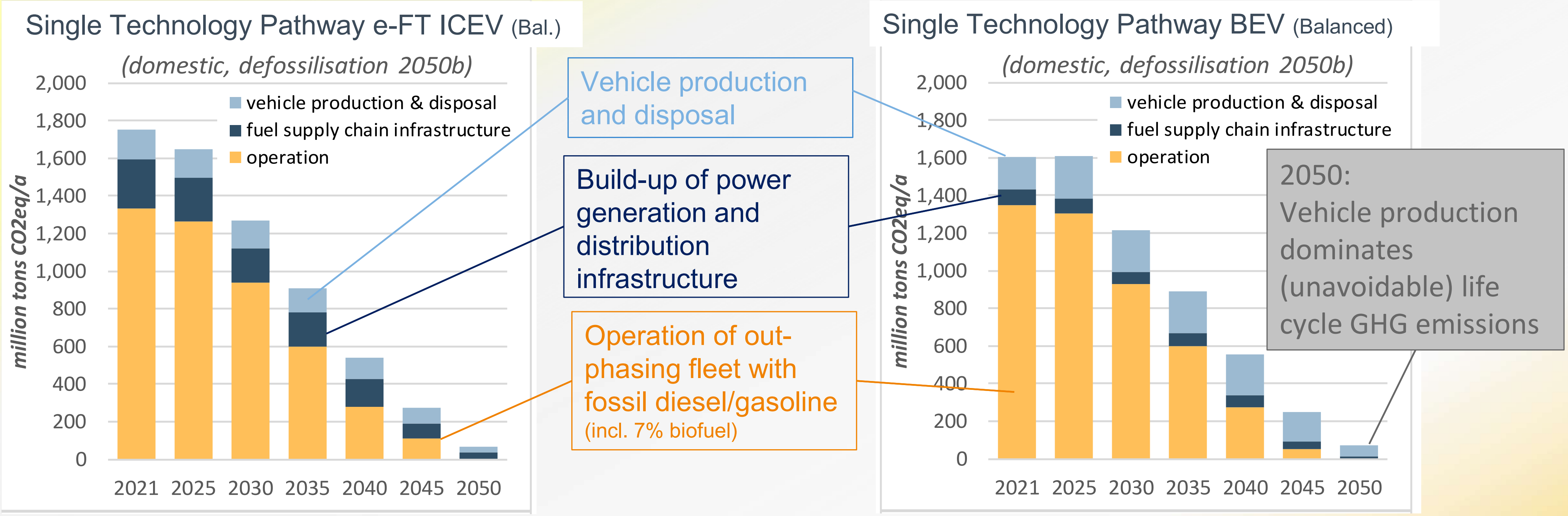
GHG Results: FVV Fuel Study IV - Reference Ramp-Up: 2 Single Technology Pathways

Annual GHG-Emissions: “ICEV w/ e-Fischer-Tropsch-Diesel” vs. “BEV w/ green electricity“



Vehicle production and disposal

Build-up of power generation and distribution infrastructure

Operation of out-phasing fleet with fossil diesel/gasoline (incl. 7% biofuel)

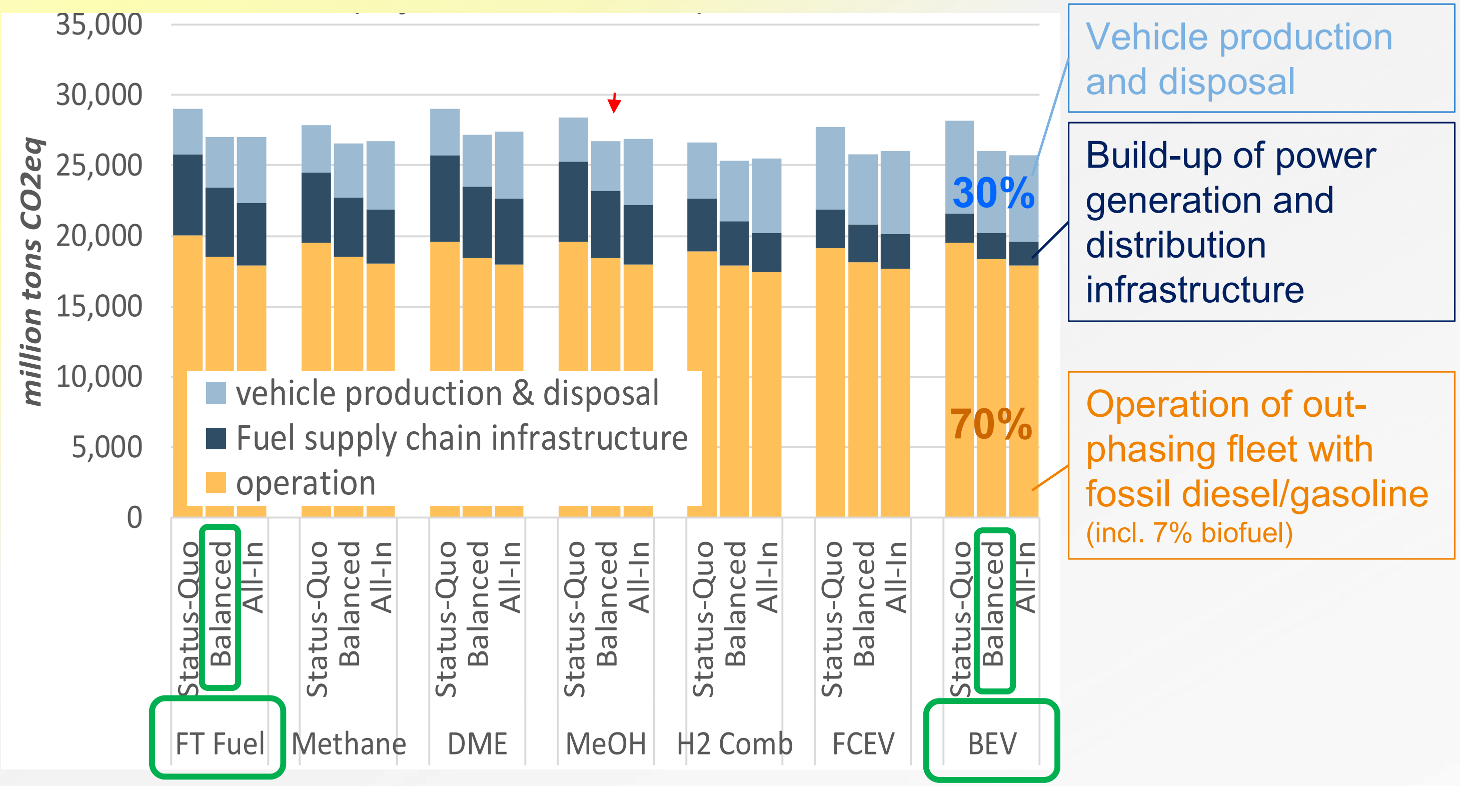
2050: Vehicle production dominates (unavoidable) life cycle GHG emissions

- **Annual GHG emissions in 2050: 95-97% lower than in 2020 for all Single Technology Pathways**
- **Operation of existing fleet, still running on fossil diesel & gasoline, will account for the majority of GHG emissions until around 2040**

** By 2050, only unavoidable GHG emissions will remain, primarily from background processes (e.g., the use of concrete for wind turbine foundations, methane leakage)*

GHG Results: FVV Fuel Study IV - Reference Ramp-Up: 2 Single Technology Pathways

The Key Factor in Global Warming: Cumulative GHG Emissions (2020 – 2050)



Vehicle production and disposal

Build-up of power generation and distribution infrastructure

Operation of out-phasing fleet with fossil diesel/gasoline (incl. 7% biofuel)

- ≈ **70%** of cumulative GHG by **vehicle operation of out-phasing fleet with fossil fuels independent of future powertrain technology**
- ≈ **30%** of cumulative GHG emissions by **vehicle production/disposal + building up the complete renewable (wind/solar based) energy infrastructure**

→ **Not the choice of powertrain technology, but the achievable ramp-up speed of completely defossilised pathways** (BEV, e-fuel, …) **determines the GHG reduction potential !**

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.....taking real-world bottlenecks into account
(FVV FS IV b)

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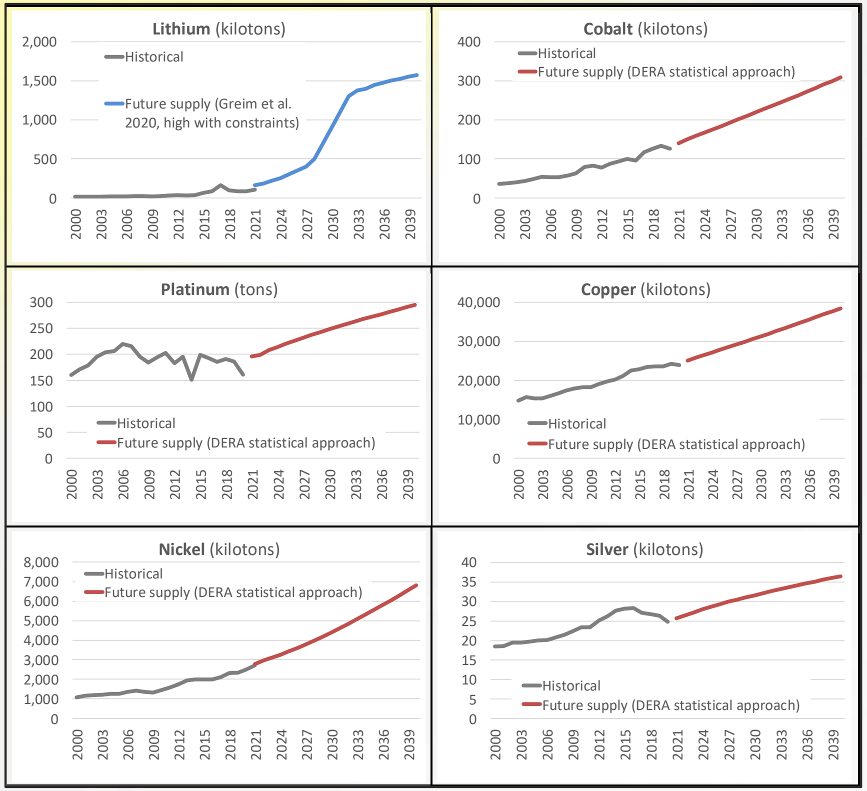
GHG: FVV FS IVb - Exemplary Technology Ramp-ups with real, technical bottlenecks*:

(e.g., „Critical Materials“, „Electrolysis“ and „Fuel Synthesis“)

At best, available raw materials

Max. material supply determined with the help of DERA ***

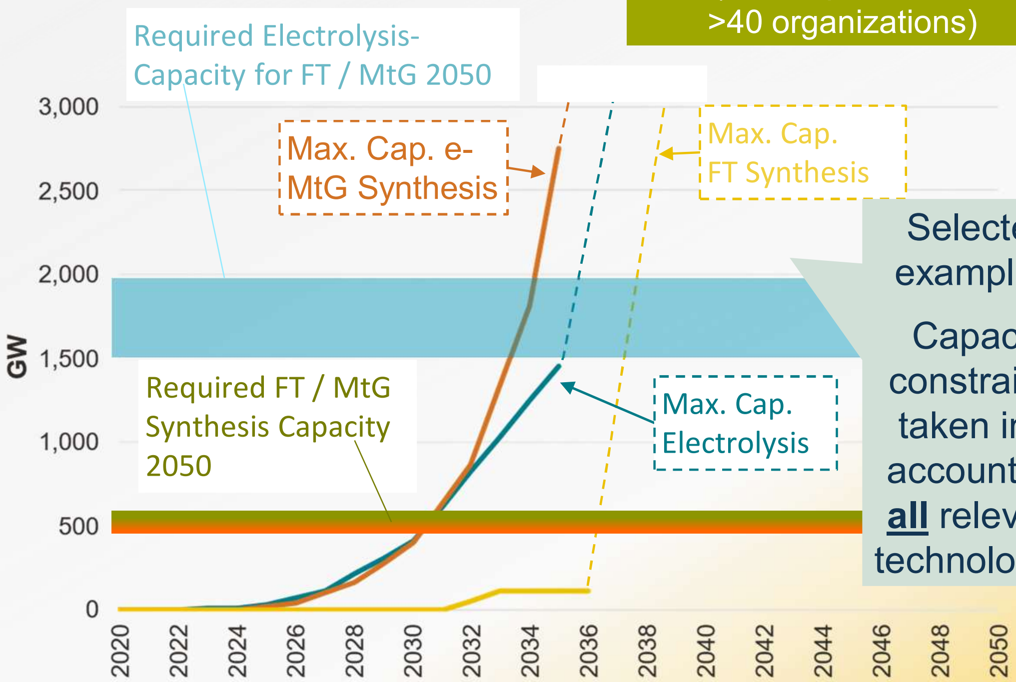
***Source: DERA (Deutsche Rohstoff Agentur), Greim et al. 2020



**90 % Recycling collection rate Recycling
Material specific recycling rates: 55 … 90 %

… Electrolysis, MTG and FT Synthesis

Determined in
7 Working Groups
(>50 Experts from
>40 organizations)



Required Electrolysis-Capacity for FT / MtG 2050

Max. Cap. e-MtG Synthesis

Max. Cap. FT Synthesis

Required FT / MtG Synthesis Capacity 2050

Max. Cap. Electrolysis

Selected examples!

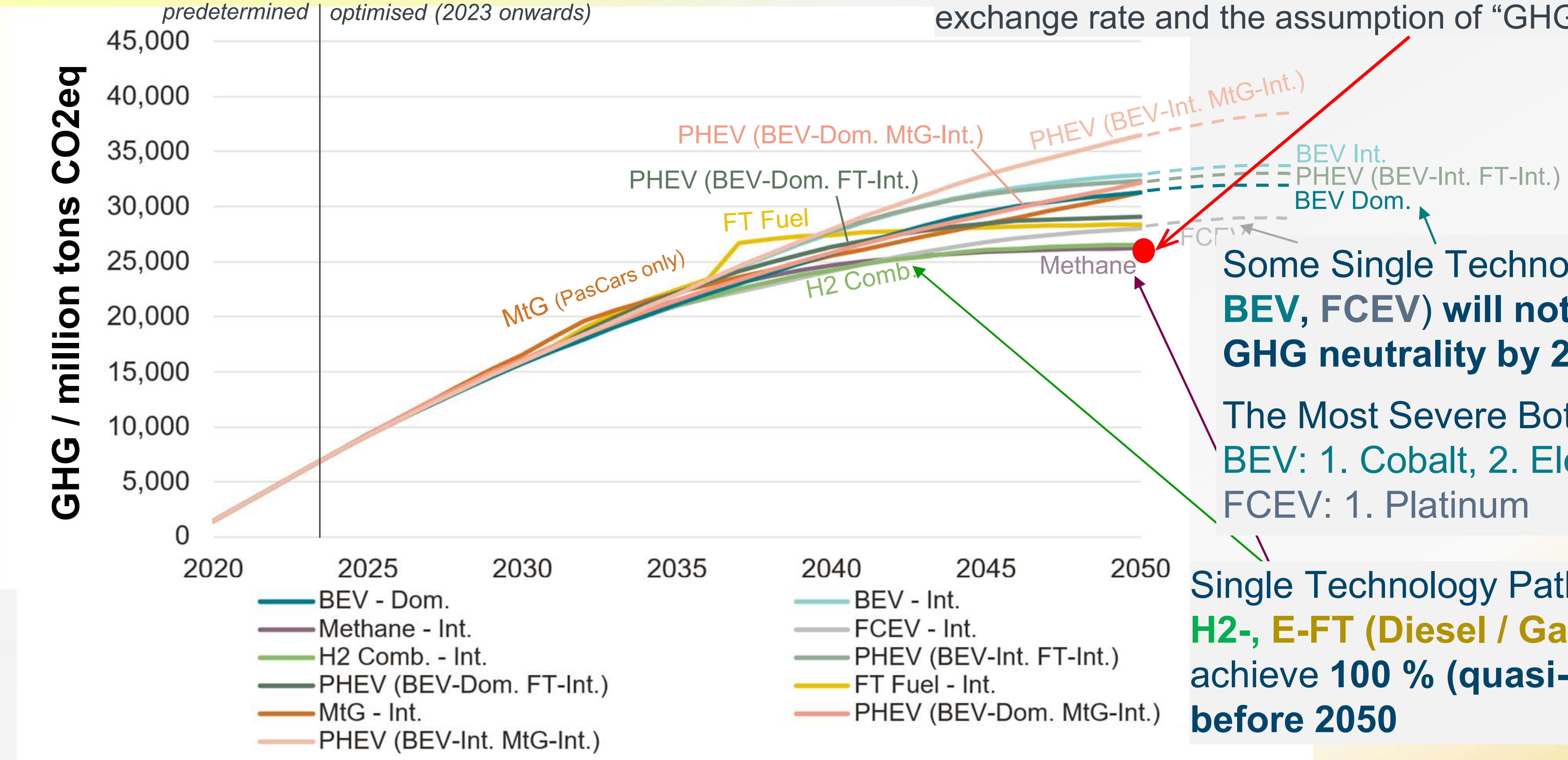
Capacity constraints taken into account for **all** relevant technologies

* Focus solely on “**technical bottlenecks**”, assuming **ideal regulatory and investment conditions**
(“COVID 19 vaccine development” scenario))

GHG: FVV FS IVb - Single Technology Pathways – cumulative GHG emissions

Taking into account actual technical bottlenecks

Reference Ramp-up FVV FS IV (limited only by the fleet exchange rate and the assumption of “GHG neutrality by 2050”)



Some Single Technology Pathways (e.g., **BEV**, **FCEV**) **will not achieve (quasi-) GHG neutrality by 2050**.

The Most Severe Bottlenecks:
BEV: 1. Cobalt, 2. Electricity grid expansion
FCEV: 1. Platinum

Single Technology Pathways **E-Methan-**, **E-H2-**, **E-FT (Diesel / Gasoline)** – ICEV* can achieve **100 % (quasi-) GHG-neutrality before 2050**

Higher cumulative GHG for all Single Technology Scenarios vs. Reference Scenario

**ICEV: Internal Combustion Engine Vehicles*

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.... Not a hypothetical scenario,
but the results of a mathematical optimization!

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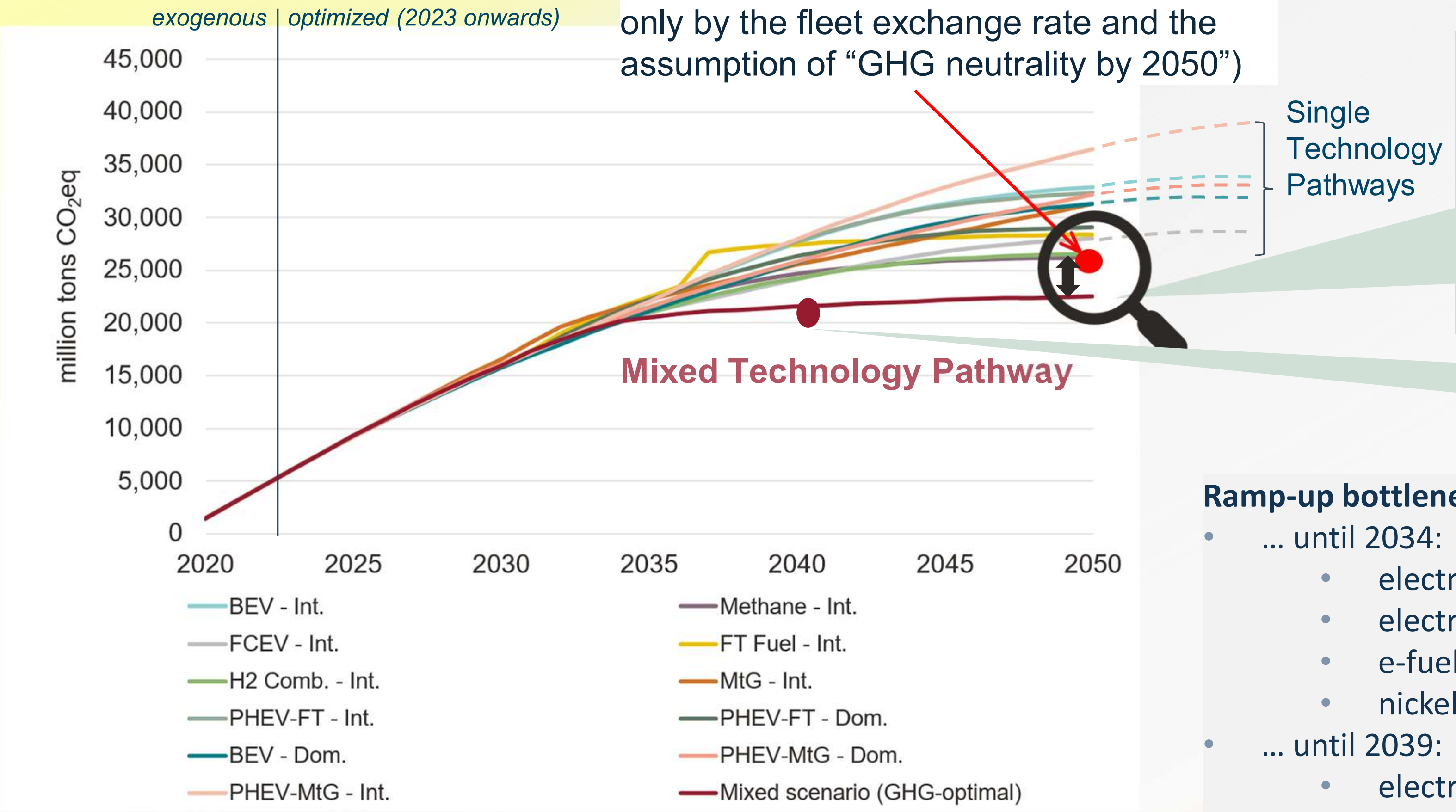
GHG: FVV FS IVb - GHG Optimized Mixed Technology Pathway

Minimum cumulative GHG emissions (no hypothetical scenario, **results of a mathematical optimization)**



Reference Ramp-up (FVV FS IV, limited only by the fleet exchange rate and the assumption of “GHG neutrality by 2050”)

Mixed Technology Pathway

Cumulated GHG emissions until 2050 ≈**3,700 Mt CO_2eq lower** than best single technology pathway (e-Methane), equivalent to app. 5 years of **total** German GHG emissions (all sectors)

“Quasi”* **GHG neutrality** can be achieved **before 2040**

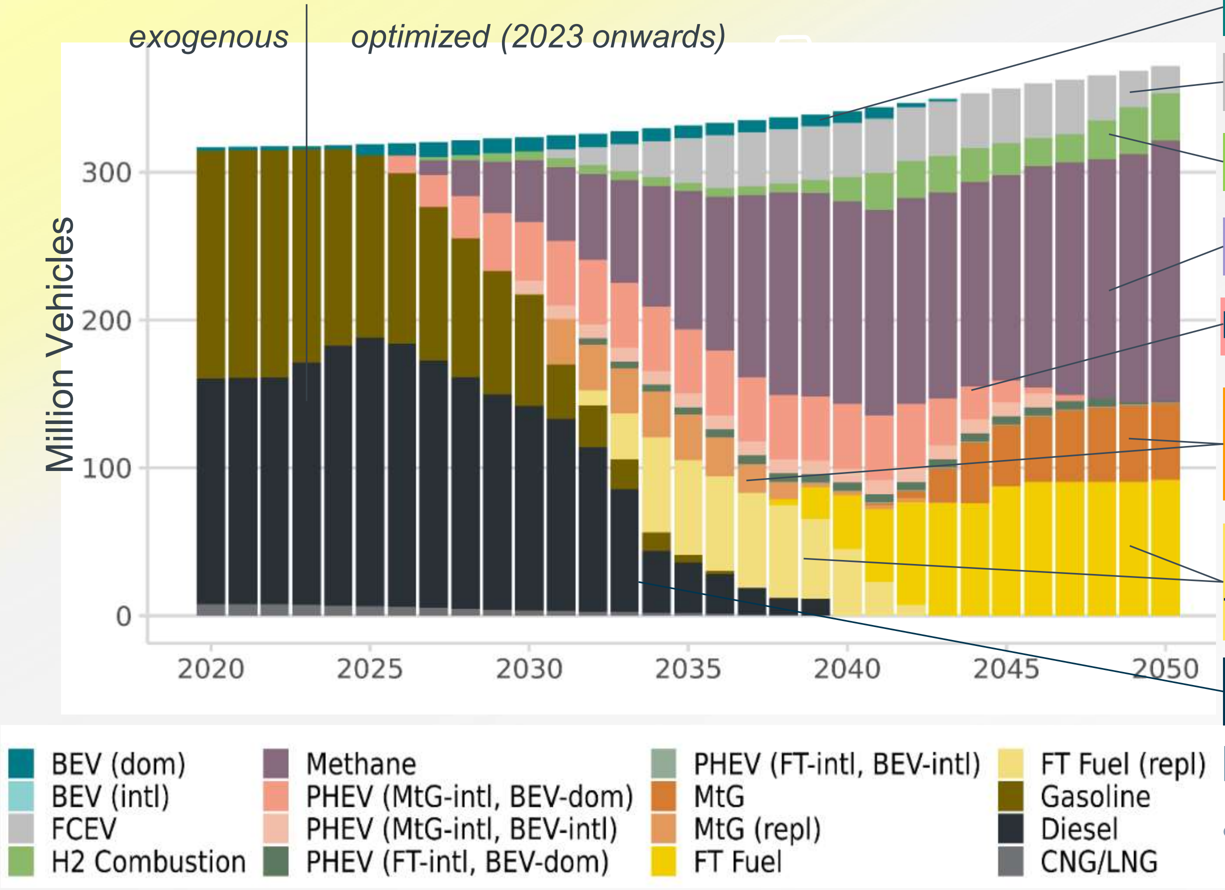
Ramp-up bottlenecks (GHG opt. mix):

- … until 2034:
  - electricity grid
  - electrolysis
  - e-fuel synthesis
  - nickel
- … until 2039:
  - electricity grid
- … after 2039:
  - no restrictions

GHG: FVV FS IVb - GHG Optimized Mixed Technology Pathway (min. cum. GHG)

Fleet Development **LDV*** (Passenger Cars + small (N1) vans / trucks)

**LDV: Light Duty Vehicles*
https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types



BEV phase out in 2042

H2-FCEV introduced in 2031, share in 2050 ≈ 5% (declining)

H2-ICEV introduced in 2027, share in 2050 ≈ 8 % (rising)

Methane introduced in 2027, share in 2050 ≈ 50% (rising)

MtG PHEV introduced in 2026, phase out 2047

MtG introduced in 2031 (use in existing fleet), new MtG ICEV from 2039, share of MtG ICEV in 2050 ≈ 10%

(rising(zunehmend)

FT introduced in 2032 (use in existing fleet), new FT ICEV from 2039, share of FT vehicles in 2050 ≈ 25% (rising)

Fossil gasoline phase out 2036, fossil diesel 2039

Dominating LDV pathways 2050

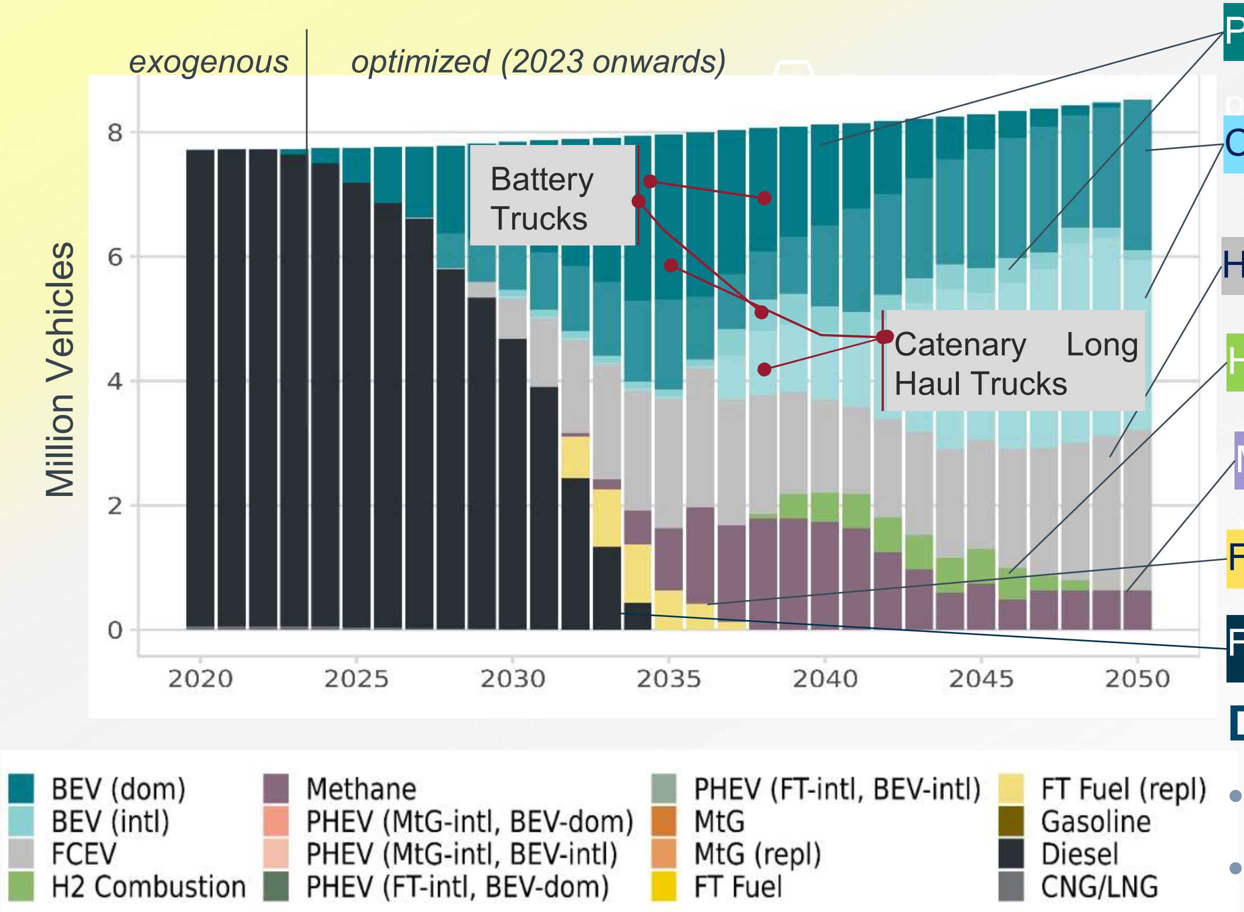
- e*-Methane-ICEV
- e*-FT & MTG-(Diesel/Gasoline) ICEV
- e*-H2-ICEV

**all e-fuels*

GHG: FVV FS IVb - GHG Optimized Mixed Technology Pathway (min. cum. GHG)

Fleet Development **HDV*** (large (N2/N3) trucks)

**HDV: Heavy Duty Vehicles*
https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types



Pure BEV (for < 7.5 t HD) phasing out until 2050

phase out in 2042

Catenary BEV (for > 7.5 t HD) > 50% share in 2050 (rising)

H2-FCEV introduced in 2028, share in 2050 ≈ 35% (rising)

H2-ICEV 2038 … 2048

Methane introduced in 2024, share in 2050 ≈ 5% (declining)

FT in ICEV (existing fleet) 2032 … 2037

Fossil diesel phase out 2034

Dominating HDV pathways 2050

- Catenary BEV* (for Long Haul HDV > 7.5t)
- H2-FCEV (for Delivery Trucks < 7.5t)

Reminder: Long haul truck (>7.5t) electrification assumed only with catenary (overhead) line, not with pure BEVs. Changed in "FVV Energy Study".

**Please note, this is the result of a GHG optimization. Optimizing to other constraints (costs, feasibility, etc.) may lead to different results.*

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Well-to-Wheel Energy Demand 2050 (2,000...10,000 TWh/a)

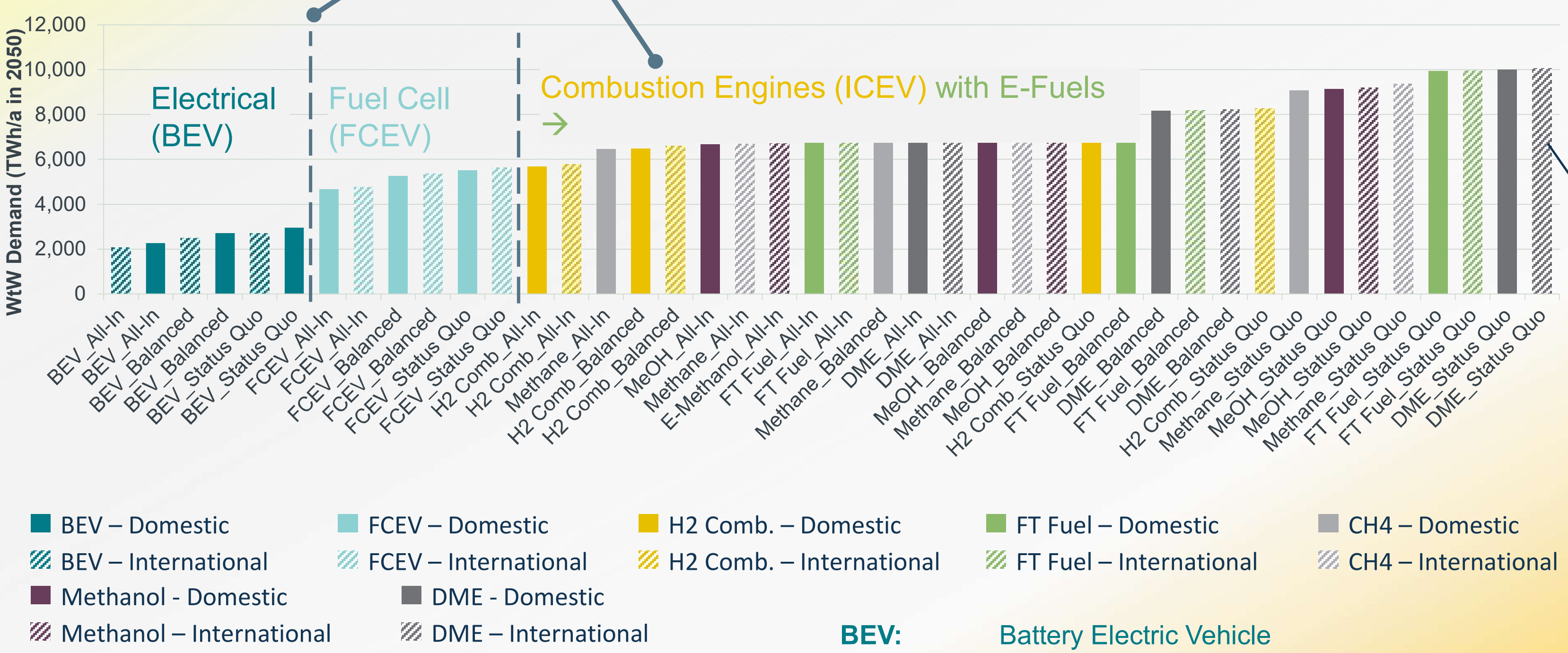
Calculation for the entire production chain: 42 Pathways (FVV FS IV)

Energy Demand
FCEV ≈ 2 x BEV

Energy Demand
ICEV (E-Fuel: H2) ≈ 2.5 … 3 x BEV
ICEV (E-Fuel: FT-Diesel/Gasoline) ≈ 3.5 … 4 x BEV

Road segment only

Well-to-Wheel Energy Demand 2050 / TWh/a



Solid bar: domestic energy sourcing

Dashed bar: global energy sourcing

BEV: Battery Electric Vehicle
FCEV: Fuel Cell Electric Vehicle
ICEV: Internal Combustion Engine Vehicle

Power Generation Capacity in 2050 → Environmental factors and costs are determined not only by **energy demand**, but also by **the location of the wind turbines and solar panels** (FVV FS IV)

BEV: needs locally generated grid-connected energy

E-Fuels: can be harvested & produced in sunny/windy prime regions of the entire world

Demand Wind Turbines / Solar Panels

FCEV (global) ≈ **1.5 x BEV** (domestic)

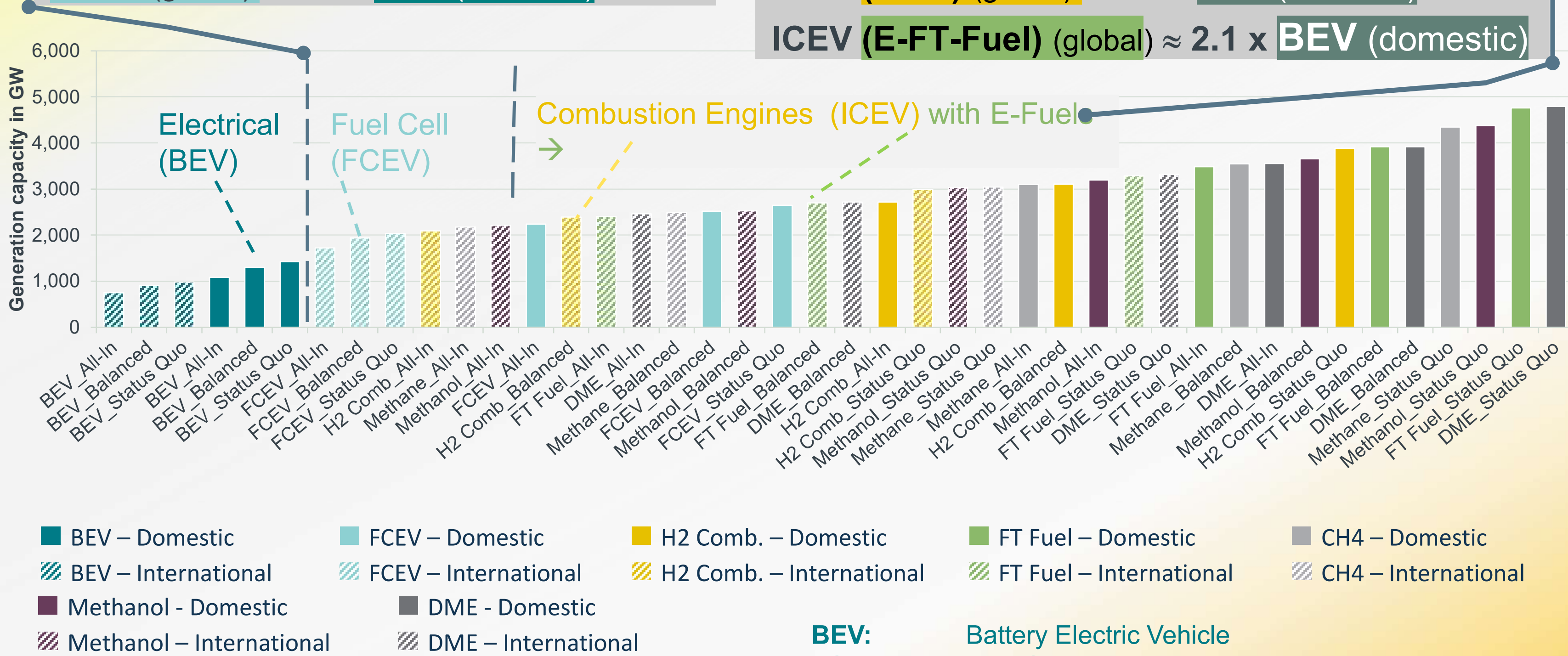
Demand Wind Turbines / Solar Panels

ICEV **(E-H2)** (global) ≈ **1.7 x BEV** (domestic)

ICEV **(E-FT-Fuel)** (global) ≈ **2.1 x BEV** (domestic)

Road segment only

Required installed Power Generation Capacity in 2050 / GW



Solid bar: domestic energy sourcing

Dashed bar: global energy sourcing

BEV:	Battery Electric Vehicle
FCEV:	Fuel Cell Electric Vehicle
ICEV:	Internal Combustion Engine Vehicle

Content

- Motivation, History of FVV Fuel Studies
- FVV Fuel Studies IV & IVb – Research Approach
- FVV Fuel Studies IV & IVb - Results
  - Green-House-Gas Emissions (GHG)
    - Reference Ramp-Up
    - Realistically achievable Ramp-Ups of Single Technology Pathways
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  - Costs
- Summary
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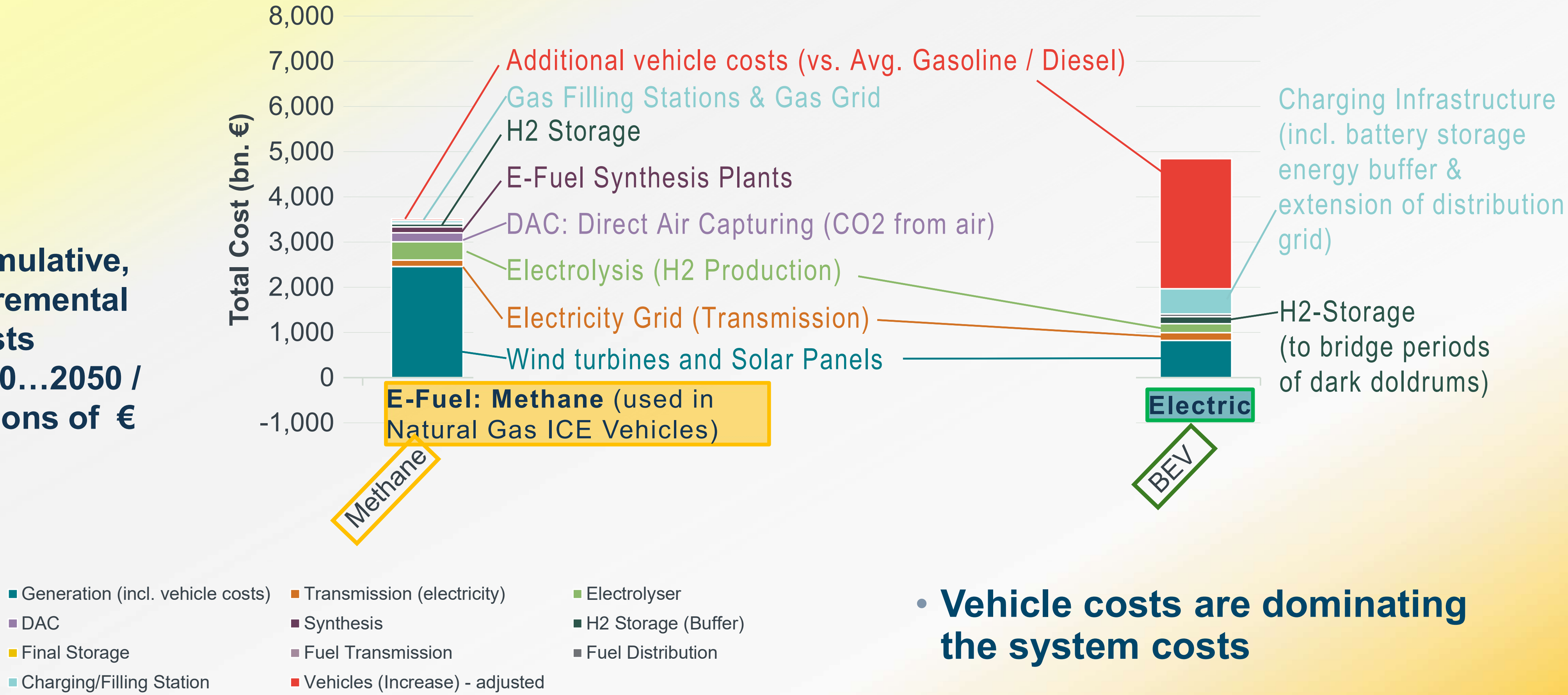
Costs: Depending on the powertrain / energy pathway, the main costs are generated in different areas (sectors) (FVV FS IV)

Status Quo domestic pathway

Cumulative, Incremental Costs 2020…2050 / billions of €



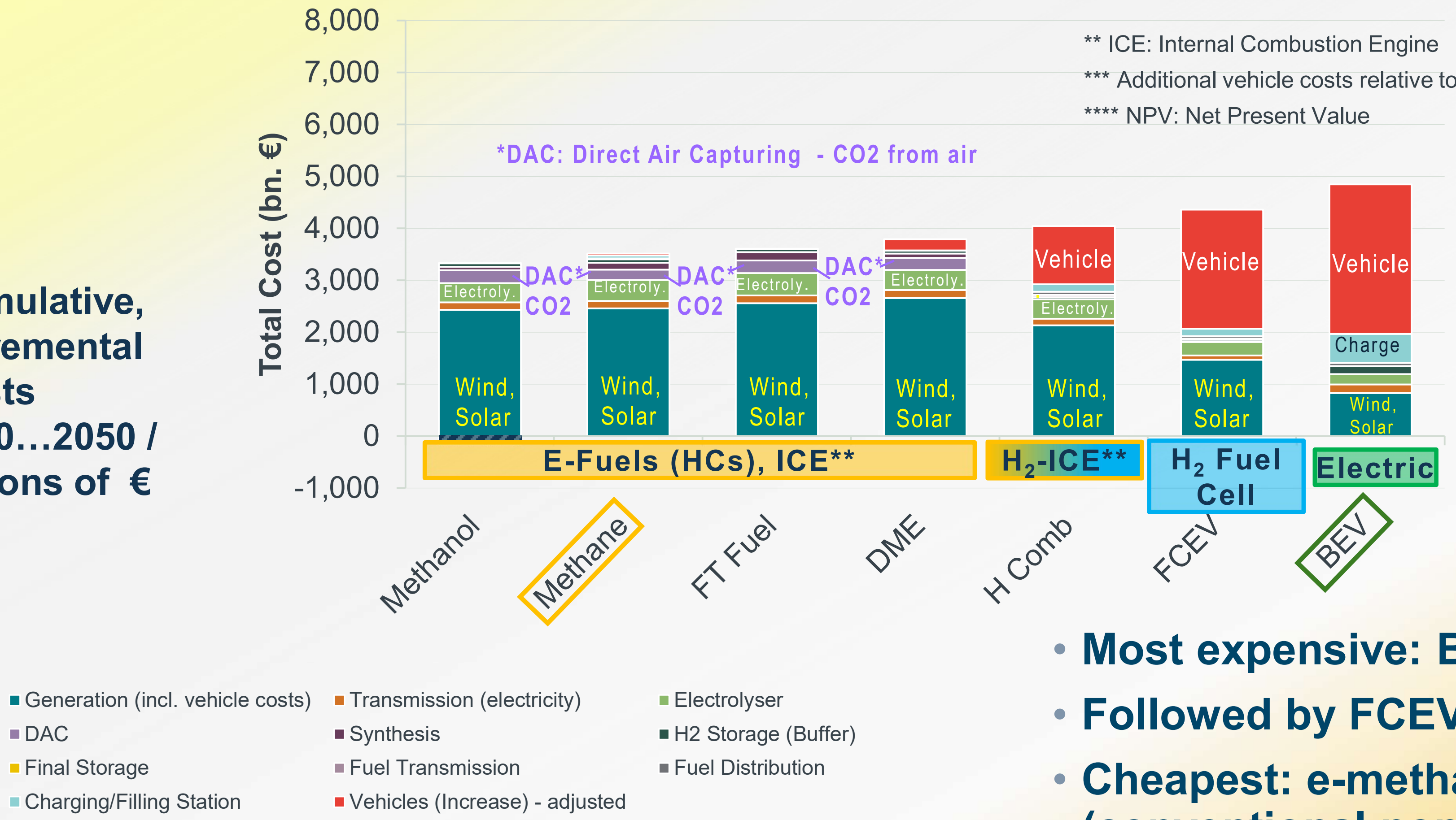
- **Vehicle costs are dominating the system costs**

Cumulative, incremental*** costs (NPV****)

2.600 … 5.300 billions of € (FVV FS IV)

Status Quo
domestic
pathway

Cumulative, incremental Costs 2020…2050 / billions of €



** ICE: Internal Combustion Engine

*** Additional vehicle costs relative to e-FT diesel/gasoline

**** NPV: Net Present Value

- **Most expensive: BEV**
- **Followed by FCEV**
- **Cheapest: e-methanol ICEV (conventional non-hybrid)**

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Summary

GHG Emissions

- → **Climate change** caused by transportation **is largely** (min. ≈70%) **the result of the operation of the out-phasing vehicle fleet** using fossil fuels.
- → The **key to limiting global warming** is **not the choice of powertrain technology**, **but the ramp-up speed** at which the entire sustainable technology chain is implemented
- → **Relying solely on BEVs is absolutely inadequate to achieve GHG neutrality* by 2050.**
- → **Under ideal regulatory and financial conditions, Europe can achieve GHG neutrality* with an optimized technology mix by 2040.**
- → **A technology-neutral legislation framework is required** to support such a development.
- → GHG-neutral, fleet-compatible **e-fuels (including for passenger cars) are essential and a necessary building block of such an optimized technology mix**.
- → Building a comprehensive e-fuel infrastructure over the next 10 to 15 years is crucial to achieving greenhouse gas reduction targets

* "Quasi"-GHG-neutral: only unavoidable GHG emissions remain

Summary

Energy Demand (Efficiency) & Costs

→ **Energy consumption (i.e., energy efficiency) is a parameter of only minor importance in terms of a technology's GHG reduction potential and costs.** → When it comes to limiting global warming, it is not "best powertrain efficiency" (i.e., BEVs) that makes the difference).

→ **E-fuel production only makes sense in countries with significant wind and solar potential** that can meet many times today's energy demand with wind and solar energy alone.

→ **Importing energy in a chemically bound form is essential** (ideally hydrocarbons ➞ e-fuel)

→ **GHG-neutral* European mobility is more expensive than today's options, but affordable:**

- 0.5 …1.1 % of GDP per year over 30 years

→ **Highest Cumulative Costs: BEV** (4.500 … 5.300 bil. €) **ahead of FCEV** (3.900 … 4.500 bil. €)

- Vehicle Costs dominate the Total Costs* **

→ **Lowest costs** (≈ 3.000 bil. €) **are achieved with conventional vehicles equipped with combustion engines that run on e-fuels** (e-Methanol, e-Methane, e-Gasoline/Diesel)

* Assumption: 300 – 500km range (LDV) ** Specific battery system costs: 160 €/kWh for 2020, 120 €/kWh for 2030, 80 €/kWh for 2050

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Policy Recommendations

to reduce further global warming in an effective and cost-efficient manner

→ **Immediate & complete deletion of all bureaucratic and inefficient GHG (CO_2) sector targets**

→ **In particular: Immediate deletion of the EU CO_2 regulation for motor vehicles**, **which limits CO_2 emissions only at the exhaust** (”so-called internal combustion engine ban”)

Along with the removal of EU CO_2 sector tagets (→ to minimize global warming):

→ Implementation of an (at least EU-wide) **sufficiently high carbon price, applied exclusively to the exploration of fossil fuels** (oil, natural gas, coal)

Need to Protect the EU Economy (maintain European competitiveness):

- **Careful Introduction of a Carbon Price** (alignment with EU economic strength)
- **GHG-based import duties on products from countries that do not impose a carbon price**, to protect the European economy from low-cost, GHG-intensive imports
- If necessary, **export subsidies for low-GHG European products to countries that do not impose a carbon tax** (must be affordable) → **need for a sufficiently large economic area with carbon price**

Thank you very much for your attention.

Questions?

BACKUP

Information Basis - FVV Fuels Studies IV & IVb

Cross-disciplinary studies, steering committee composed of many advisors from industry and research

Future Fuels
FVV Fuel Study IV

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FINAL REPORT

Zukünftige Kraftstoffe: FVV-Kraftstoffstudie IV
Future Fuels: FVV Fuels Study IV

+ >27 Further Consultants

Publication: Oct. 2021

Download Studie:
https://www.fvv-net.de/fileadmin/Transfer/Downloads/Publikationen/FVV__Future_Fuels__StudyIV_The_Transformation_of_Mobility__H1269_2021-10__EN.pdf

Transformation of mobility to
the GHG neutral post fossil age
FVV Fuel Study IVb

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FINAL REPORT

Zukünftige Kraftstoffe: FVV-Kraftstoffstudie IV
Future Fuels: FVV Fuels Study IV

+ >45 Further Consultants

Publication: Dec. 2022

Download Studie:
https://www.fvv-net.de/fileadmin/Storys/Wie_schnell_geht_nachhaltig/FVV_H1313_1452_Future_Fuels_FVV_Fuel_Study_IVb_2022-12.pdf

FVV Fuels Studies IV

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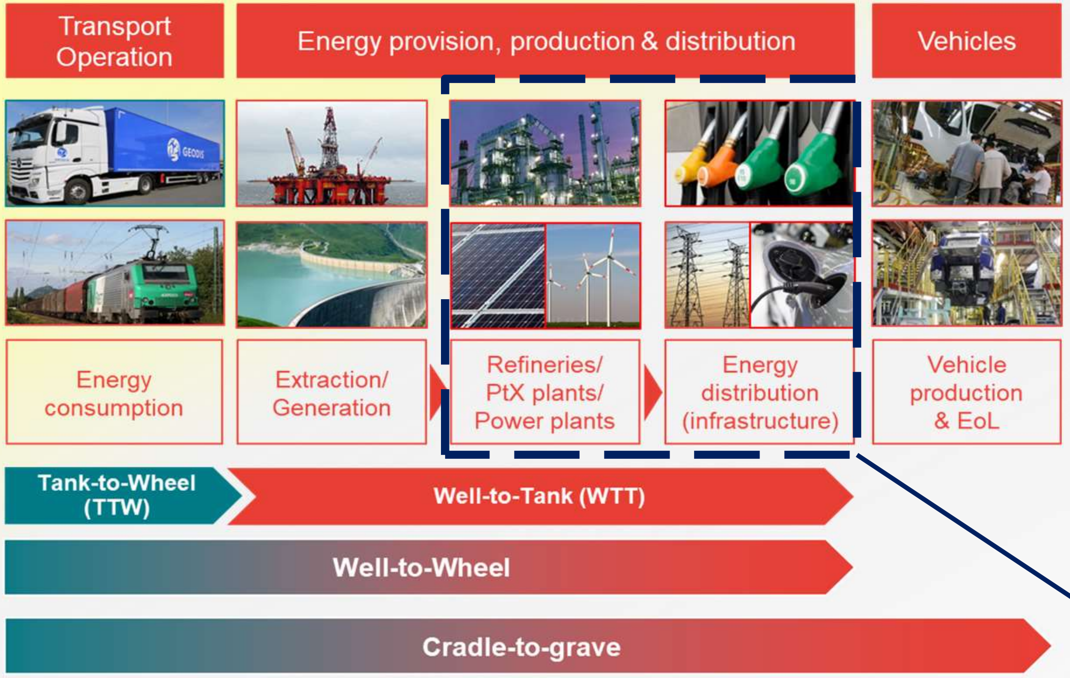
FVV Fuels Studies IV & IVb - Cradle-to-Grave (C2G) Analysis Approach

Separate report of GHG for Energy infrastructure Installation



Transport Operation | Energy provision, production & distribution | Vehicles

Energy consumption

Extraction/ Generation

Refineries/ PtX plants/ Power plants

Energy distribution (infrastructure)

Vehicle production & EoL

Tank-to-Wheel (TTW)

Well-to-Tank (WTT)

Well-to-Wheel

Cradle-to-grave

Separate disclosure of **building-up** the power generation and energy/ fuel distribution infrastructure

Total environmental impacts per year

Environmental impacts vehicle operation + Environmental impacts FSC build-up + Environmental impacts vehicle production & disposal = **Total environmental impacts**

Environmental databases and studies

- LCA databases and models: e.g. EcoInvent, Umberto, eLCAr
- Emission factor databases: HBEFA 4.1, TREMOD
- ifeu scientific studies: e.g. SYSEET, RESCUE
- Scientific literature research

Cradle-to-grave (C2G) approach

includes GHG emissions of
- fossil fuels consumption (wtw)
- building-up defossilised energy supply and distribution infrastructure
- vehicle production and disposal

→ GHG emissions are accounted **in the year they occur**, **not depreciated over lifetime** (and then added to the WtT emissions)

FVV Fuels Studies IVb - Ramp-up Bottlenecks

Technologies, Ramp-Up Bottlenecks

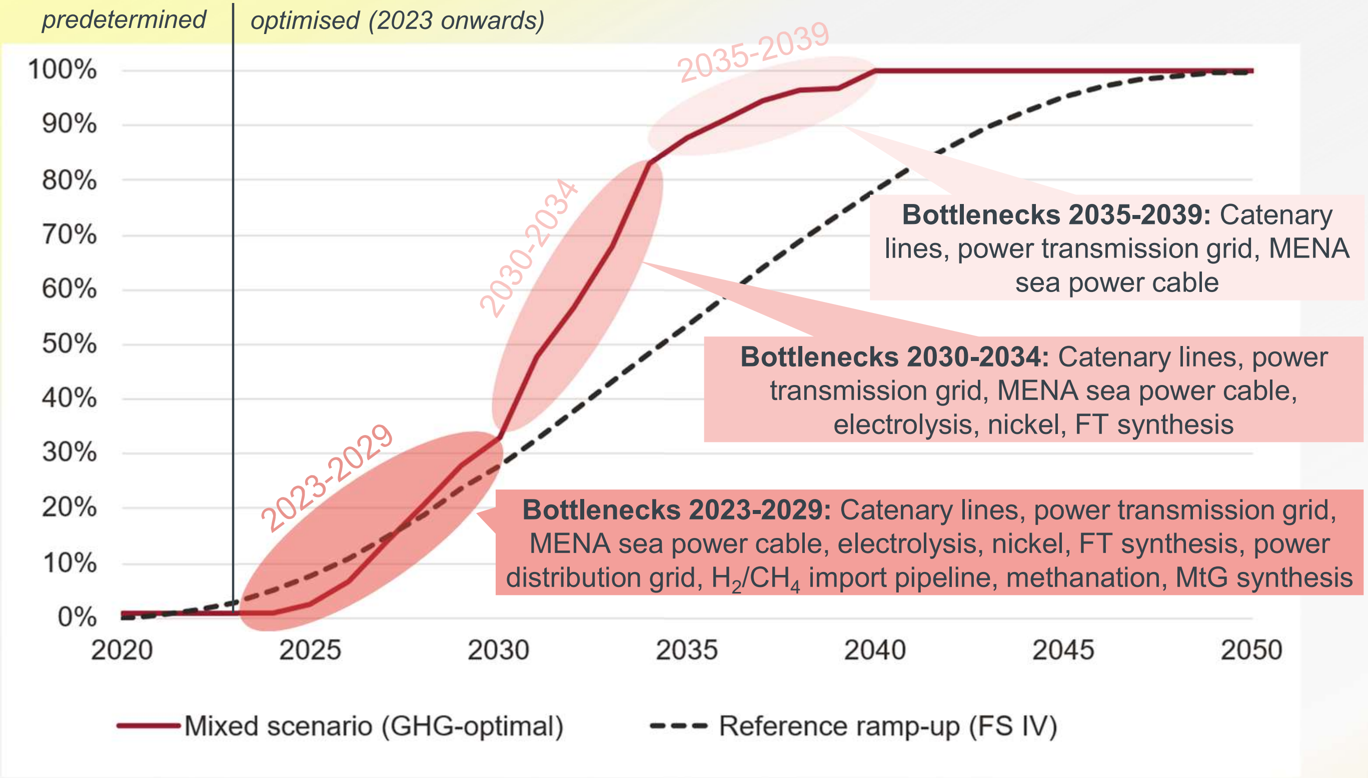
Fair share of other sectors and other areas than EU considered.

- Ramp-up times, limited only by technical bottlenecks!
- Appropriate representation of sectors and regions other than the EU

			2020-2029	2030-2039	2040-2049
BEV (Battery Electric Vehicles) (Long Haul > 7.5t: Catenary HDV)		Domestic	Power transm. grid, catenary lines, cobalt, battery prod., wallboxes	Power transm. grid, catenary lines, cobalt, battery prod., wallboxes	Power transm. grid, cobalt
		International	Sea power cable, catenary lines, cobalt, power transmission grid	Sea power cable, catenary lines, cobalt, power transmission grid	Cobalt, **power transm. grid**
FT (Fischer Tropsch)		International	FT synthesis, nickel, electrolysis	FT synthesis, nickel, electrolysis	
MtG (Methanol-to-Gasoline, **only LDV** (Passenger Cars+ N1)			Electrolysis, **renewable electr. generation**, MtG synthesis	Electrolysis, **renewable electricity generation**	
Synthetic Methane			Methanation, CH_4 import pipelines, electrolysis	Methanation, electrolysis	
H2 Comb. (Hydrogen Combustion)			H_2 import pipeline, electrolysis	H_2 import pipeline, electrolysis	H_2 import pipeline
FCEV (Fuel Cell Electric Vehicles)			H_2 import pipeline, platinum, battery production,	H_2 import pipeline, platinum	Platinum
PHEV (Plug-In Hybrid Electric Vehicles)	BEV + FT	Dom. (BEV-share)	FT synthesis, battery prod., electrolysis, wallboxes	FT synthesis	
		Int. (BEV+E-Fuels)	FT synth., sea power cable, batt. prod., electrolysis, wallboxes	FT synthesis, sea power cable	
	BEV + MtG (**only LDV**)	Dom. (BEV-share)	Wallboxes, public chargers, electrolysis	Wallboxes, public chargers	
		Int. (BEV+E-Fuels)	Sea power cable, wallboxes, public chargers	Sea power cable, wallboxes, public chargers	

FVV Fuels Studies IVb - Ramp-up Bottlenecks

Main technical bottlenecks of **“Min GHG Mixed Technology Scenario”** restricting the ramp-up



Bottlenecks 2035-2039: Catenary lines, power transmission grid, MENA sea power cable

Bottlenecks 2030-2034: Catenary lines, power transmission grid, MENA sea power cable, electrolysis, nickel, FT synthesis

Bottlenecks 2023-2029: Catenary lines, power transmission grid, MENA sea power cable, electrolysis, nickel, FT synthesis, power distribution grid, H_2/CH_4 import pipeline, methanation, MtG synthesis

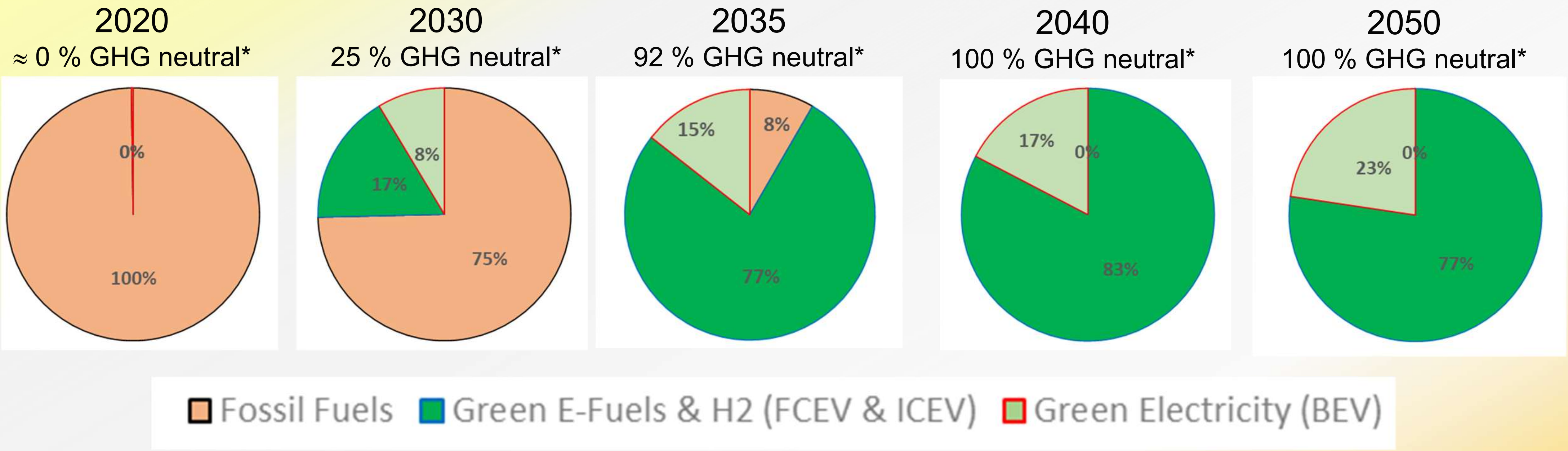
Main ramp-up bottlenecks of GHG opt. mixed scenario:

- … 2034:
  - electric supply network
  - electrolysis
  - e-fuel synthesis
  - nickel
- … 2039:
  - electric supply network
- … after 2039:
  - no restrictions

FVV Fuels Studies IVb - Minimum GHG - Mixed Technology Scenario

Energy Distribution (Road Transport)

Theoretically achievable maximum ramp-up gradients, assuming **ideal regulatory and investment conditions**
(similar to "COVID 19 vaccine introduction")



- **Theoretically** *(ideal regulatory and investment conditions)*, up to **92 % GHG neutral* energy** in European road transport **achievable by 2035 (77% e-fuels and H_2)** *(other sectors and worldwide demand considered)*
- Benefits of e-fuels: - Short-term: applicable to the existing vehicle legacy fleet (drop-in)
  - Long-term: lowest **unavoidable GHG** emissions (C2G)

FVV Fuels Studies IV - Single Technology Pathway e-FT-Diesel

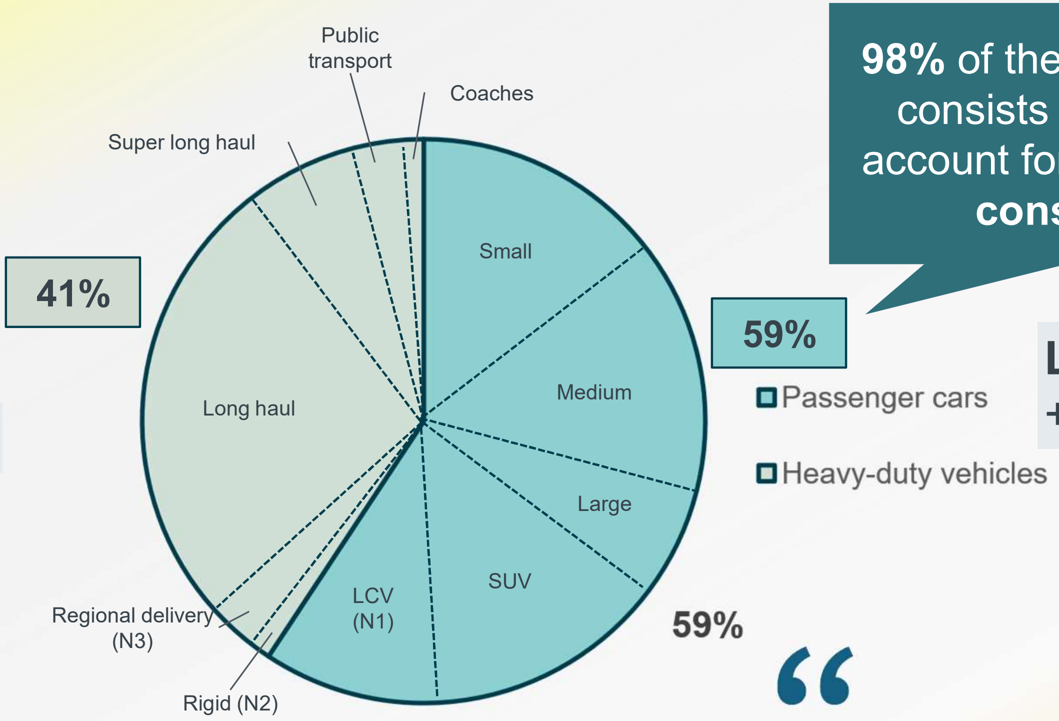
Share of energy consumption: HDV and LDV

Trucks account for **2%** of the European vehicle fleet. Yet they **consume 41% of the energy!**

98% of the EU vehicle fleet consists of **LDV**. These account for **59% of energy consumption!**

HDV

LDV (Passenger cars + light N1 vans)



“

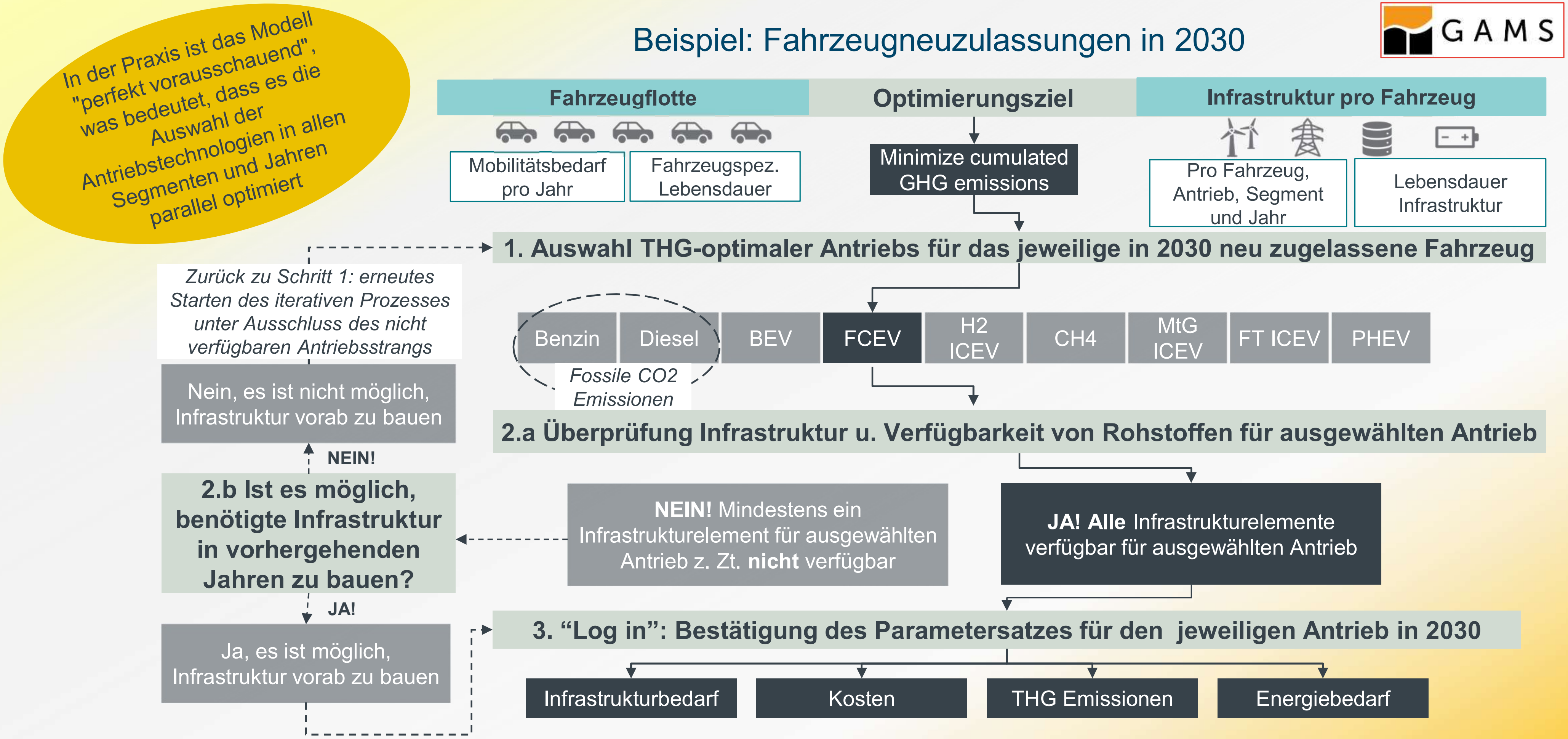
Trucks: relatively
- low CO_2 during manufacturing
- high CO_2 during operation

“

Passenger cars: relatively
- high CO_2 during manufacturing
- low CO_2 during operation

FVV Fuels Studies IVb –Technology Mix Optimizer for min cumulative GHG

Optimizer (by Frontier Economics) - Functional Scheme (simplified)



In der Praxis ist das Modell "perfekt vorausschauend", was bedeutet, dass es die Auswahl der Antriebstechnologien in allen Segmenten und Jahren parallel optimiert

Beispiel: Fahrzeugneuzulassungen in 2030

GAMS

Fahrzeugflotte

- Mobilitätsbedarf pro Jahr
- Fahrzeugspez. Lebensdauer

Optimierungsziel

- Minimize cumulated GHG emissions

Infrastruktur pro Fahrzeug

- Pro Fahrzeug, Antrieb, Segment und Jahr
- Lebensdauer Infrastruktur

1. Auswahl THG-optimaler Antriebs für das jeweilige in 2030 neu zugelassene Fahrzeug

Benzin	Diesel	BEV	FCEV	H2 ICEV	CH4	MtG ICEV	FT ICEV	PHEV

Fossile CO2 Emissionen

2.a Überprüfung Infrastruktur u. Verfügbarkeit von Rohstoffen für ausgewählten Antrieb

NEIN! Mindestens ein Infrastrukturelement für ausgewählten Antrieb z. Zt. **nicht** verfügbar

JA! Alle Infrastrukturelemente verfügbar für ausgewählten Antrieb

2.b Ist es möglich, benötigte Infrastruktur in vorhergehenden Jahren zu bauen?

NEIN!

Nein, es ist nicht möglich, Infrastruktur vorab zu bauen

Zurück zu Schritt 1: erneutes Starten des iterativen Prozesses unter Ausschluss des nicht verfügbaren Antriebsstrangs

JA!

Ja, es ist möglich, Infrastruktur vorab zu bauen

3. "Log in": Bestätigung des Parametersatzes für den jeweiligen Antrieb in 2030

- Infrastrukturbedarf
- Kosten
- THG Emissionen
- Energiebedarf