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CO2 Neutrality
PERSPECTIVE 20-50
Powertrain Innovation

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CONFIDENTIAL

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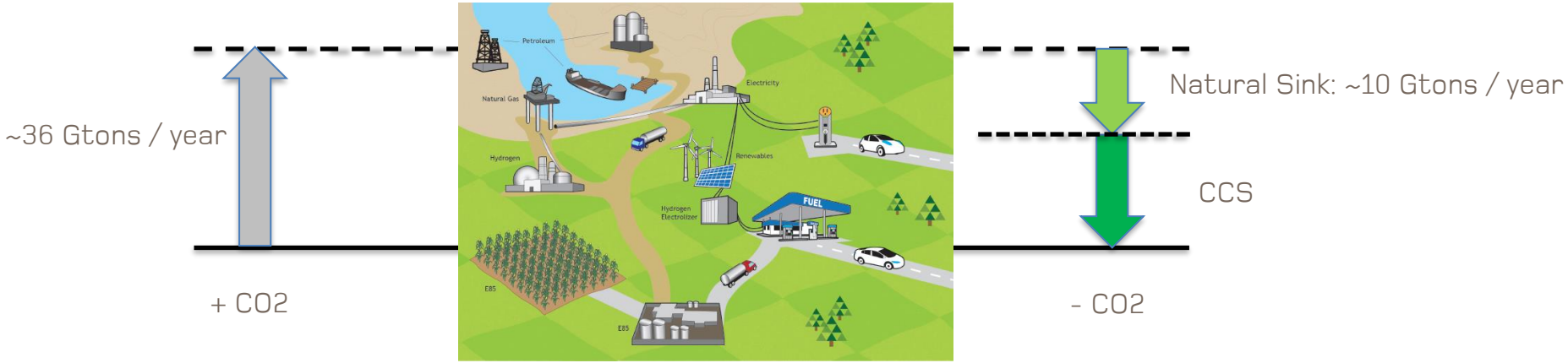
CO2 NEUTRALITY
WELL TO WHEEL APPROACH

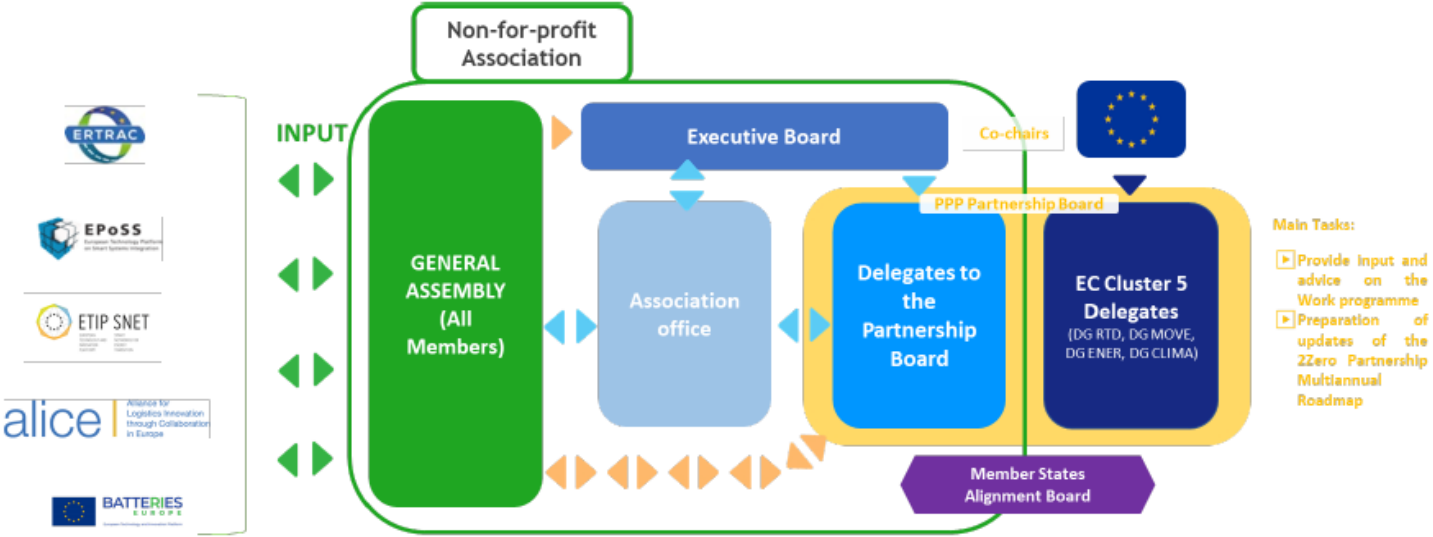
- **Balance** between **emitting** carbon and **absorbing carbon** from the atmosphere in **natural carbon sinks** (soil, forests and oceans) or via Carbon capture and storage (**CCS**) from Feedstock to Energy transmission and Use



- **Net zero emissions**: all worldwide greenhouse gas (GHG: carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, and F-Gases: HFCs, PFCs, SF_6, NF_3) emissions will have to be counterbalanced by carbon sequestration (Removing carbon oxide from the atmosphere and then storing it)

Association Composition

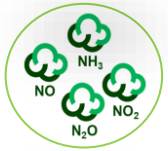
The Towards zero emission road transport (2Zero) is a co-programmed Partnership funded under the Horizon Europe programme and aiming at accelerating **the transition towards zero tailpipe emission road mobility** across Europe.



Source: https://www.2zeroemission.eu/who-we-are/2zero

CO2 NEUTRALITY
OBJECTIVES TOWARD 2030

2ZERO

2Zero 4 pillars	Legal (EURO 7)
BEV and FCEV	
Charging Infrastructure	Limit of PN10nm 
Zero Emissions Mobility	Non-regulated pollutants 
LCA and Circular Economy	Volatile Organic Compounds  Well-to-wheel

European Commission

- 35-45% better efficiency for BEV vs. ICE
- 10-15% better efficiency FCEV vs. ICE
- 20% vehicle mass based on Circular Economy
- Price diff. ZEV vs. Conv. reduction

- -55% CO2 transport emissions
- -20% development time via digitalization
- +50% ZEV (incl. HDV)
- -90% Price diff. ZEV vs. Conv.

Source: ERTRAC Working Group

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CO2 NEUTRALITY

CLIMATE NEUTRAL ROAD TRANSPORT SYSTEM IN 2050

- GHG neutral road transport system need contributions of:

Automotive Industry, Energy Providers, TSO and DSO's, public and private (Charging) Infrastructure, the Fuel Industry and Regulators

- WtW approach is needed in 3 areas:

Energy production, Vehicle fleet and efficient powertrains and traffic technology, Infrastructure (i.e. charging) and the use of renewable energies

- GHG neutral production of electricity is a prerequisite for:

production, storage and distribution system

- Total demand for electricity compared to 2019 increases between 20 and 160 % (for road transport only) in 2050, whilst the demand for liquid fuels in road transport decreases by between 55% and 98%WtW
- Mix of technologies is needed, where electrification is the key element for the reduction of the GHG emissions
- All vehicles in urban areas must use emission free powertrains by driving 100 km in electrical mode
- Changes in the infrastructure provision will be needed for charging together with retaining a sufficient part of liquid and gaseous fuels supply network

CO2 NEUTRALITY

ENERGY: FEEDSTOCK - PROCESS - ENERGY CARRIERS

- No single energy carrier has the best-in-class properties in each of phase of the process hence variety of energy carriers will be required for road transport in 2050 in three main categories:

  electricity, liquid and gaseous fuels

- Electricity: 83% RES (variable) in 2050: implies digitalization tools and upgrading electricity networks
- Liquid fuels are today mostly fossil based, biofuels are capped at 7% (on an energy basis) hence advanced biofuels are needed (biomass to liquids, cellulosic ethanol etc), need for Power to liquids fuels made from renewable electricity and CO2 capture
- Gaseous fuels: CNG and LNG can be produced from a variety of renewable, scalable and very low carbon intensity energy sources, such as organic waste and biomass or by directly converting CO2 into synthetic methane by using hydrogen produced from renewable electricity
- Hydrogen: today worldwide it is produced mainly from the thermochemical conversion of natural gas ("grey"). In a scenario with an increasing share of low cost renewable electricity green hydrogen production via electrolysis is a promising contribution to decarbonization

Fleet Composition (short-medium term)

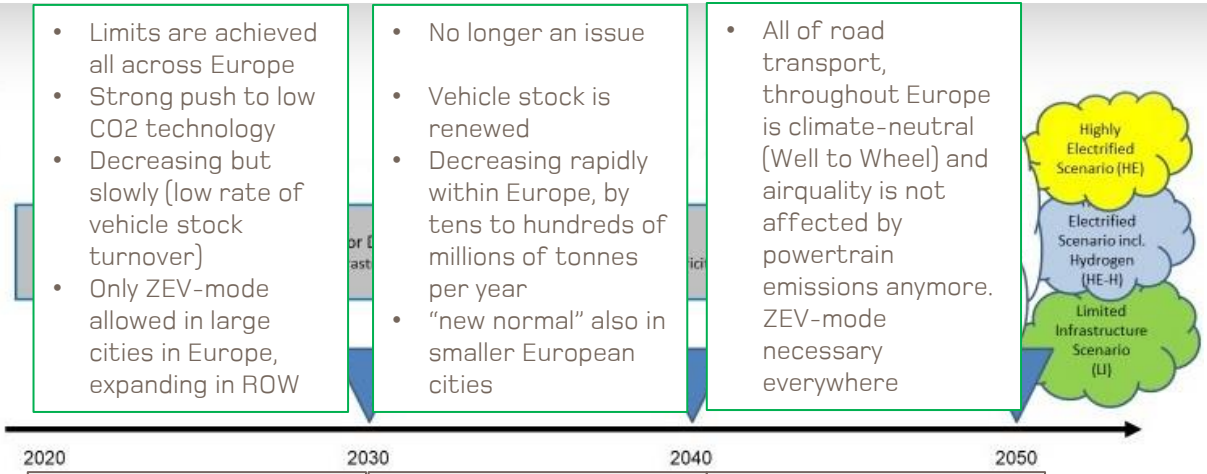
Energy Category	Aspect	2-Wheeler	PC	LDV	HDV/ Bus
Electricity	Battery	BEV	BEV	BEV	BEV
	ERS				ERS-xEV
Liquid Fuel	Diesel-like		PHEV	PHEV	ICE PHEV
	Gasoline-like	HEV	PHEV		
Gaseous Fuel	Methane		ICE PHEV	ICE PHEV	ICE PHEV
	Hydrogen		FCEV	ICE FCEV	ICE FCEV

Source: ERTRAC Working Group

CO2 NEUTRALITY

VEHICLE OPTIONS VS. TIMEFRAME

- Air quality
- Mobility
- CO2 emissions
- Cities "zero-emission-zones"



2020	2030	2040	2050
• Limits are achieved all across Europe • Strong push to low CO2 technology • Decreasing but slowly (low rate of vehicle stock turnover) • Only ZEV-mode allowed in large cities in Europe, expanding in ROW	• No longer an issue • Vehicle stock is renewed • Decreasing rapidly within Europe, by tens to hundreds of millions of tonnes per year • "new normal" also in smaller European cities	• All of road transport, throughout Europe is climate-neutral (Well to Wheel) and airquality is not affected by powertrain emissions anymore. ZEV-mode necessary everywhere	

Vehicles

- L-category vehicles
- Passenger cars (PC)
  - BEV
  - PHEV
  - ICE
  - FCEV
- MDT & Busses
- HDT & Coaches
  - ICE
  - FCEV
  - ERS

2020	2030	2040	2050
• Strong electrification • NVR: 50% is xEV Short/medium range 100 km electric-only Higher efficiency Niche market • Urban: BEV increases Non-urban: ICE based • xEV niche in the parc ICE are prevalent First applications Selected routes only	• Fully EVs in urban use • Parc: >50% is xEV Dominating urban use Only ICE application Niche and non-EU Commercial fleet • Urban: only xEV ICE for regional use • NVR: prevalent xEV Still prime mover Alternative in Corridors Expanding puntually	• Fully CO2 neutral • Parc: ~90% is xEV Dominating Consumer choice Net CO2 and non-EU Private use also • Generally xEV and net CO2 ICE • NVR: xEV dominating With synthetic fuel Major share Established puntually	

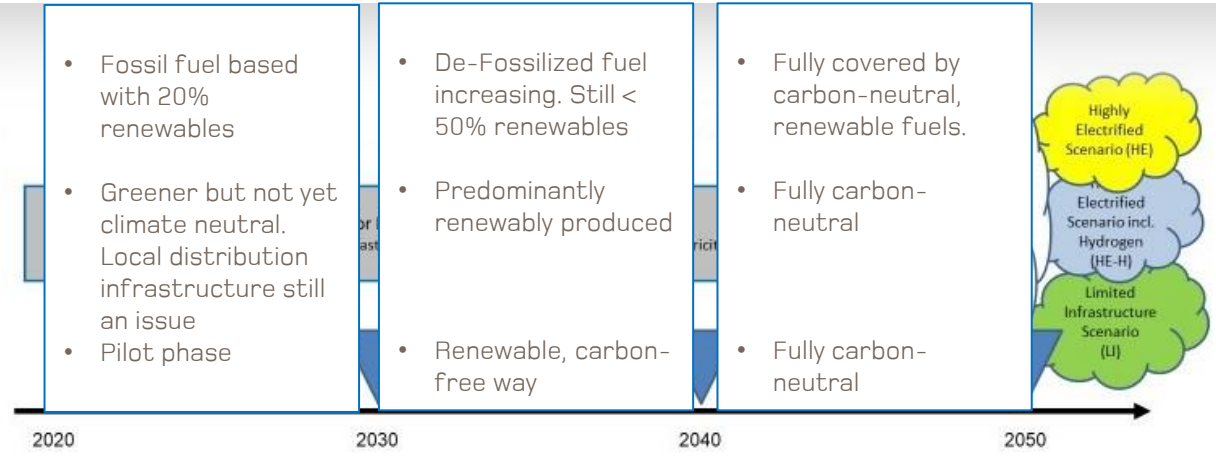
Source: ERTRAC Working Group

CO2 NEUTRALITY

ENERGY AND INFRASTRUCTURES VS. TIMEFRAME

Energy Production
- Fuel
- Electricity
- Hydrogen

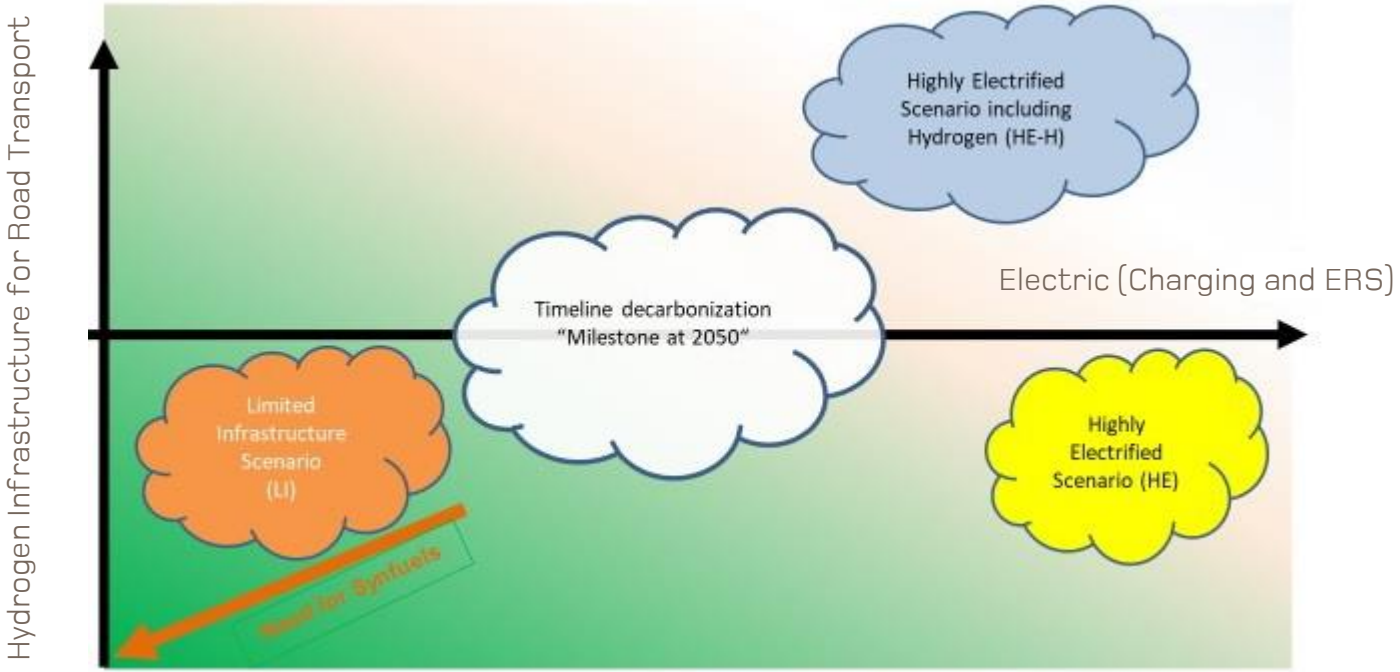
Infrastructure
- Charging System
- Hydrogen
- ERS



2020	2030	2040	2050
• Fossil fuel based with 20% renewables • Greener but not yet climate neutral. Local distribution infrastructure still an issue • Pilot phase	• De-Fossilized fuel increasing. Still < 50% renewables • Predominantly renewably produced • Renewable, carbon-free way	• Fully covered by carbon-neutral, renewable fuels. • Fully carbon-neutral • Fully carbon-neutral	
• Public & private for PC available but still limiting factor for EV market share. • It is available in corridors at specific filling stations. • On publicly funded test routes or specific (private) local operations.	• It is established in urban and most other areas, including smart and fast charging • main corridors are supplied with sufficient filling stations • some publicly funded corridors will be established.	• smart and fast charging infrastructure is available. • main corridors and local hot-spots are supplied with filling stations. • Local routes are also commercially viable	

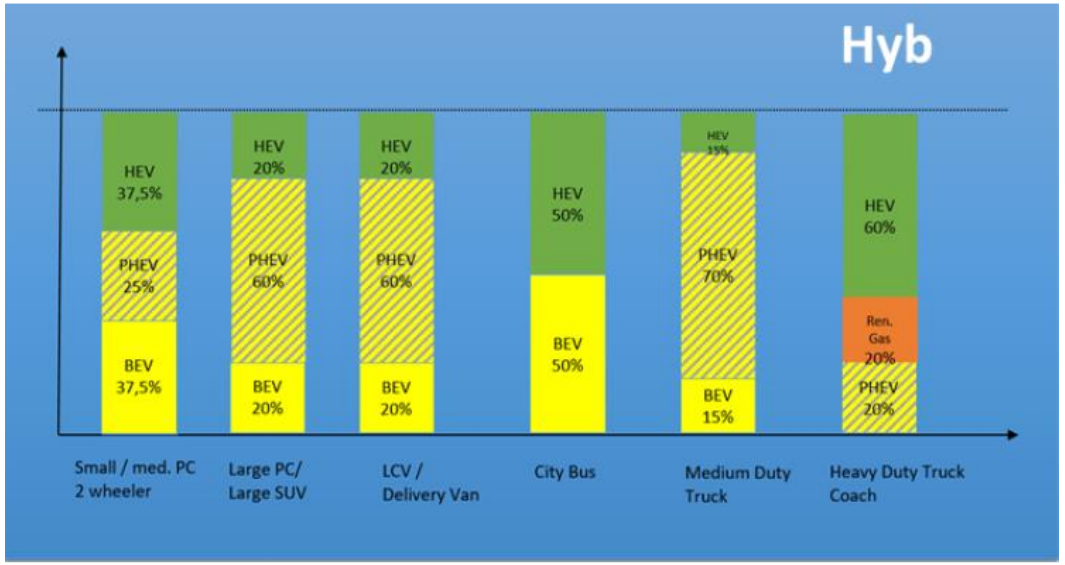
Source: ERTRAC Working Group

Possible Scenarios



Source: ERTRAC Working Group

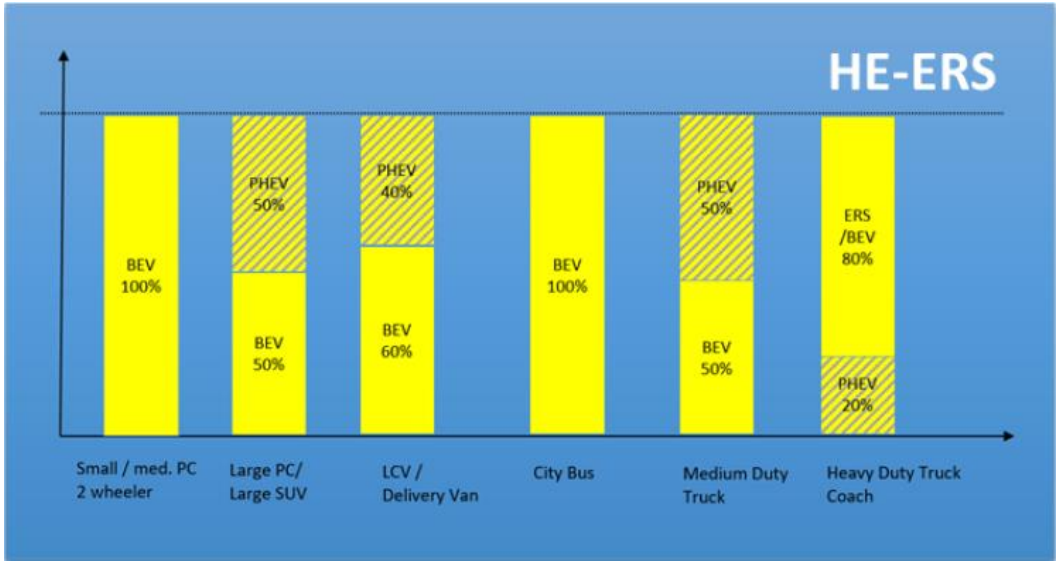
Vehicle categories - 2050



Sales % in case of hybrid scenario (limited infrastructure)

Source: ERTRAC Working Group

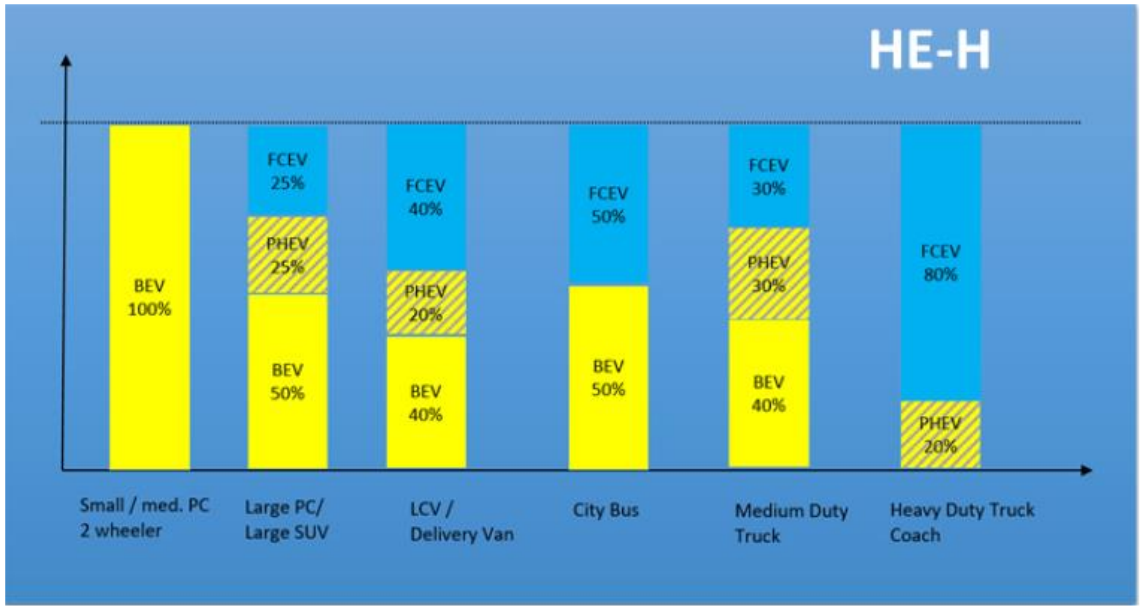
Vehicle categories - 2050



Sales % in case of hyghly electrified scenario

Source: ERTRAC Working Group

Vehicle categories - 2050



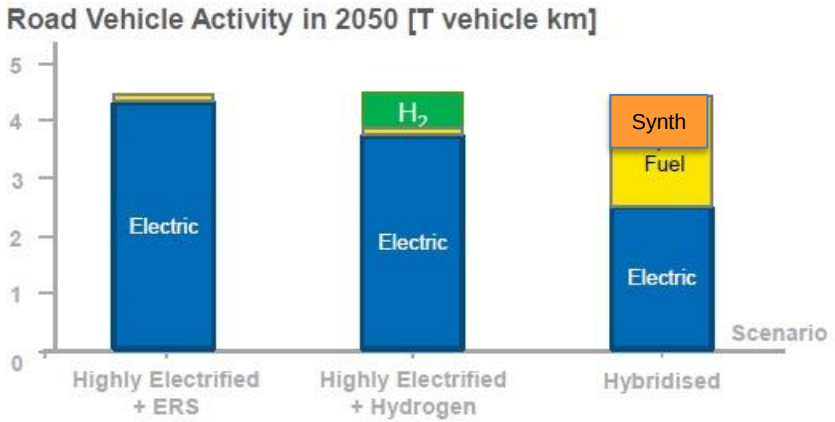
Sales % in case of electrified + Hydrogen scenario

Source: ERTRAC Working Group

Powertrain Options

Road activity - Different scenarios

- Simultaneous ambitious solution aimed at "Fit for 55 Package"
- Massive Electrification of road traffic
- Development of renewable fuels in each stage of life cycle, using LCA approach
- GHG neutrality in 2050 on a WtW basis
- Solution oriented choice of technologies and the use of renewable energies:
  - Traditional powertrain systems (PHEV)
  - Fuel cell powertrains
  - Battery Electric Vehicles

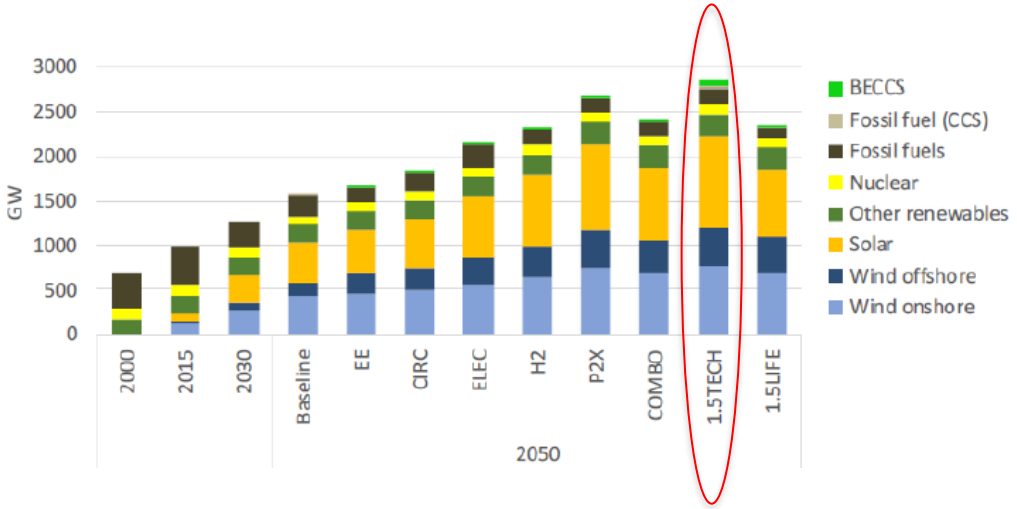


Source: ERTRAC Working Group

CO2 NEUTRALITY
1.5 TECH PROJECTIONS – ENERGY MIX

Power generation capacity

- Decarbonization of electricity, due to the massive introduction of competitive RES.
- Electrification of the demand in transport, buildings and industry allows a strong reduction in the primary and final energy demand
- Renewables (RES 83%)
  - Wind + Solar: 69%
  - Biomass with CCS: 10%
  - Hydro: 4%
- Nuclear (12%)
- CCS and others (5%)



Source: ERTRAC Working Group

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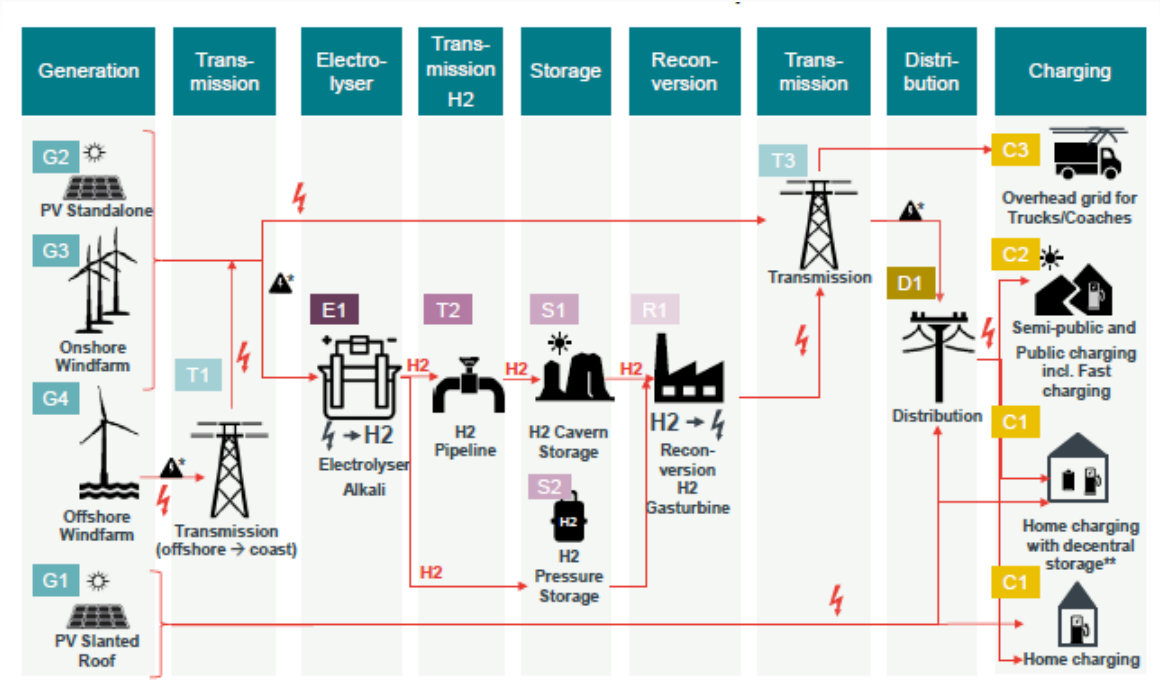
7 Energy possible pathways

- Electricity* : Battery / Catenary electric vehicles
- H2 produced via electrolysis from RES: Fuel cell or H2 ICE
- Power-to-X (PtX) fuels (from clean H2 and capturing CO2) for:
  - Methane
  - Methanol (MeOH)
  - Dimethylether (DME)
  - Fischer-Tropsch-fuels (FT)

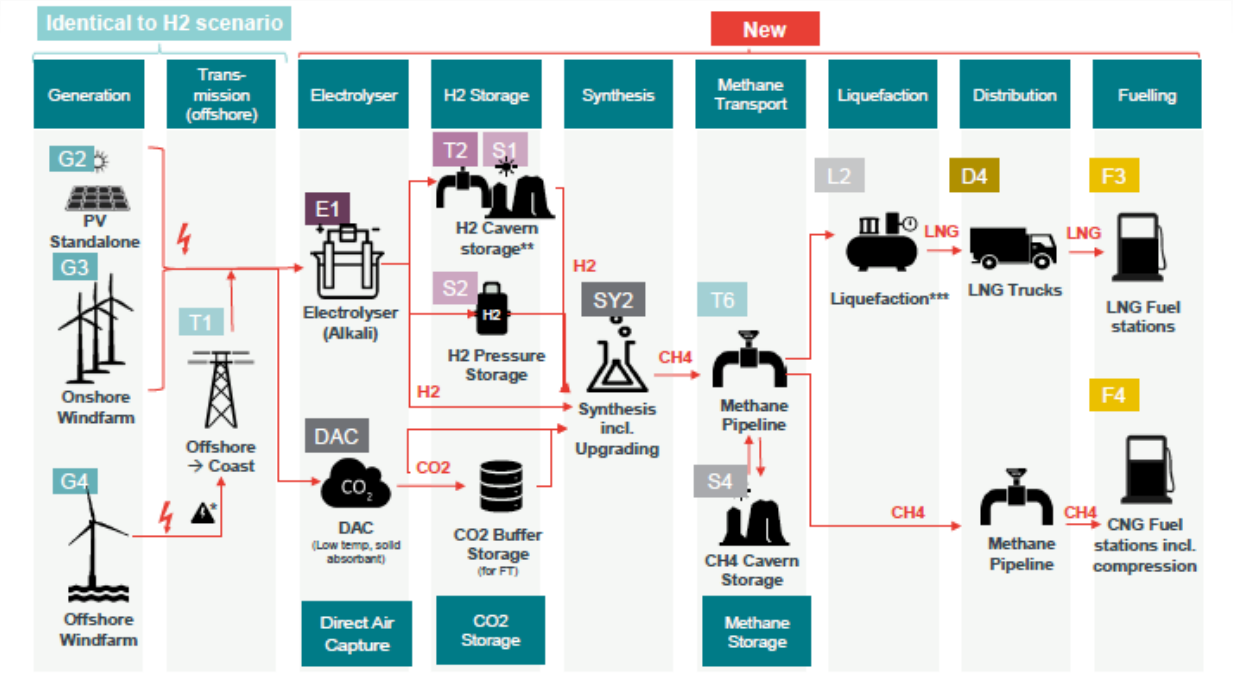
Roadmap 2020 - 2050



BEV / ERS & H2

Source: FVV Fuels Study IV

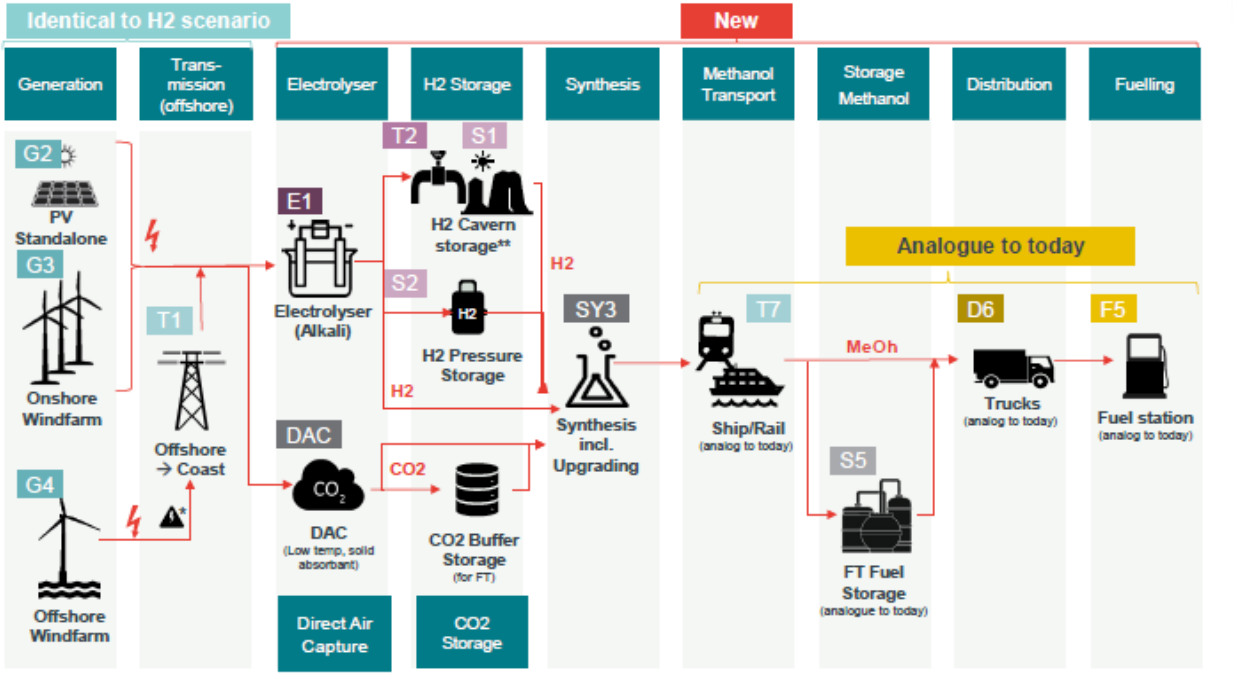
Roadmap 2020 - 2050



Methane

Source: FVV Fuels Study IV

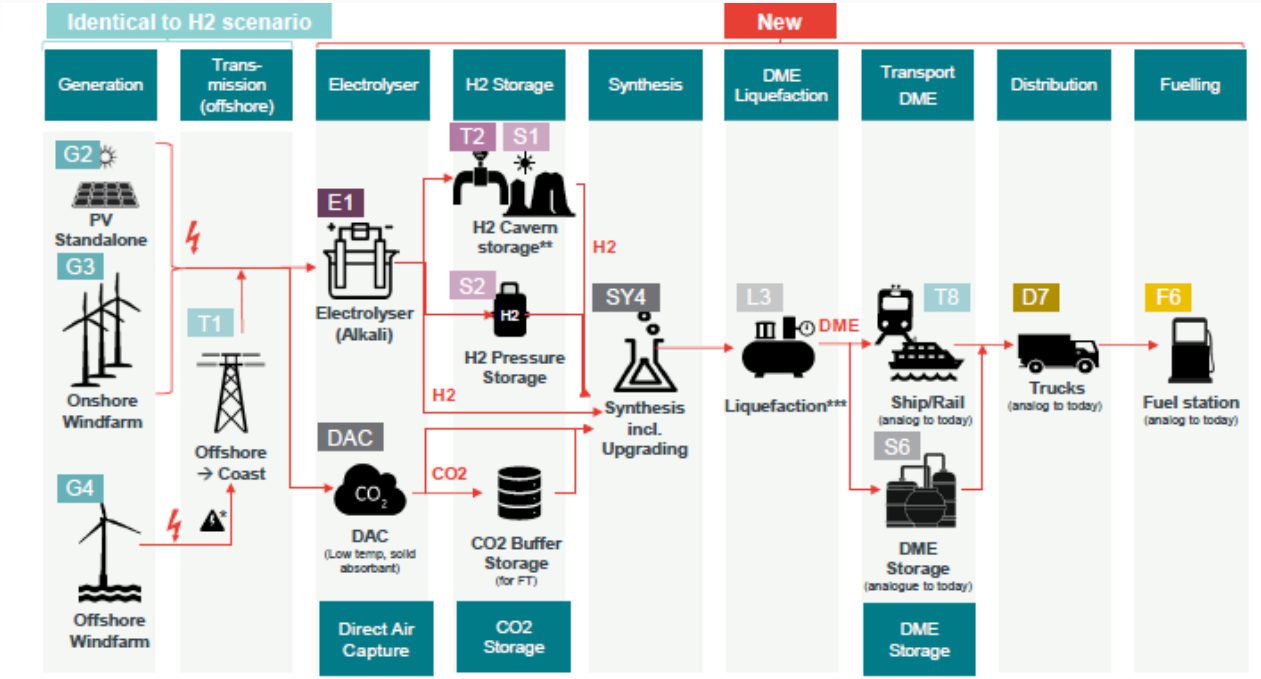
Roadmap 2020 - 2050



Methanol

Source: FVV Fuels Study IV

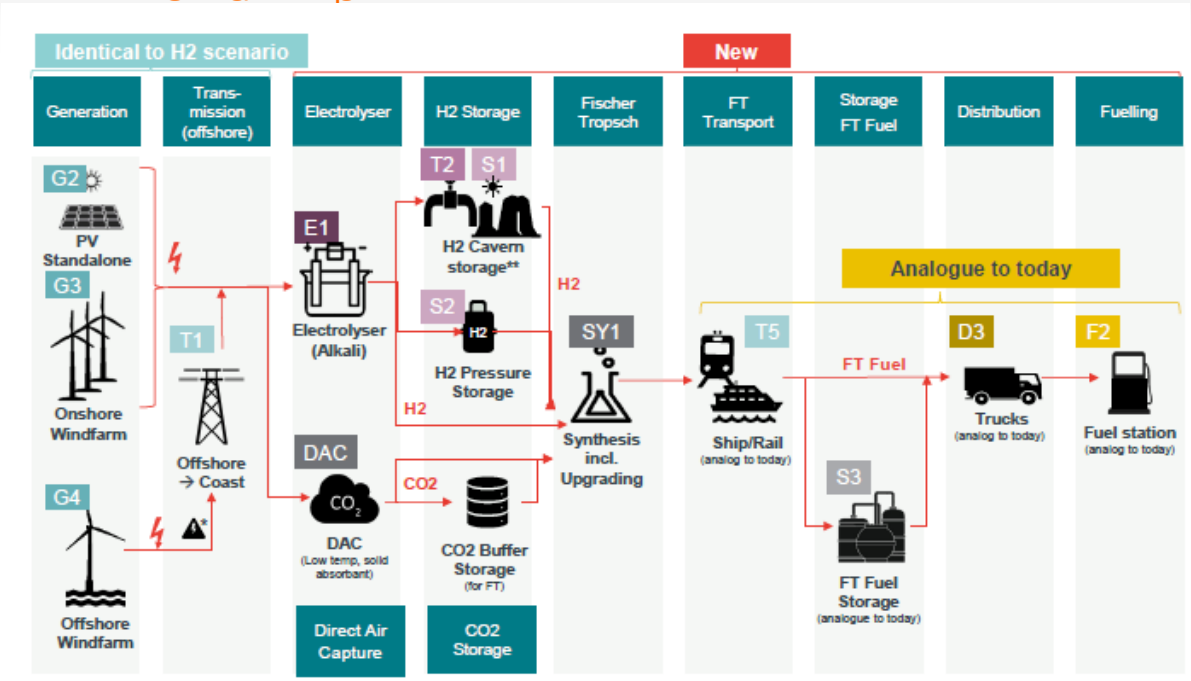
Roadmap 2020 - 2050



DiMethylEther

Source: FVV Fuels Study IV

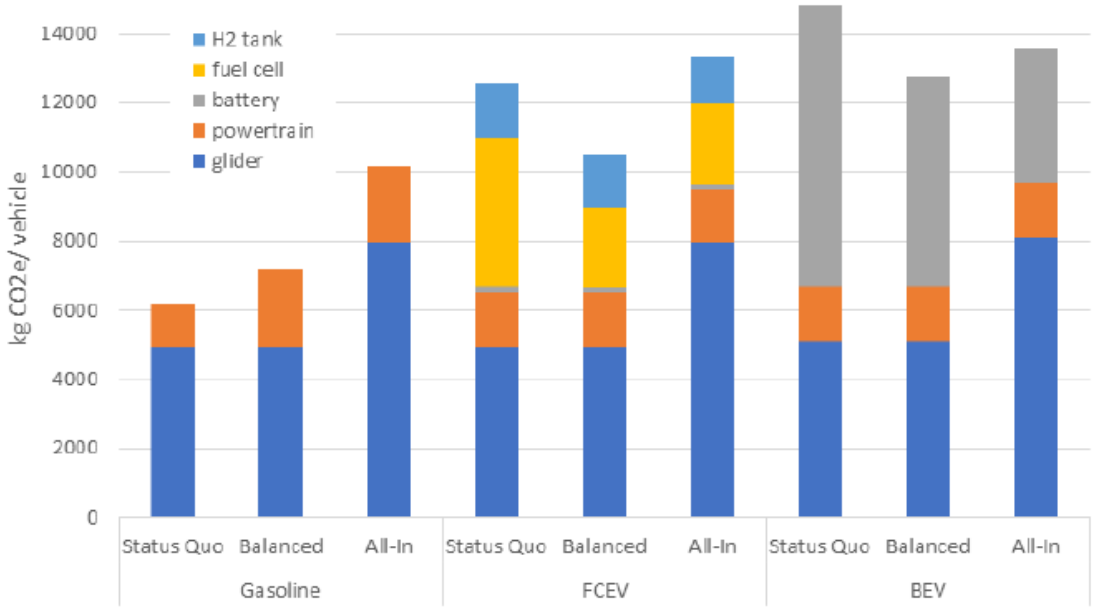
Roadmap 2020 - 2050



FT Fuel

Source: FVV Fuels Study IV

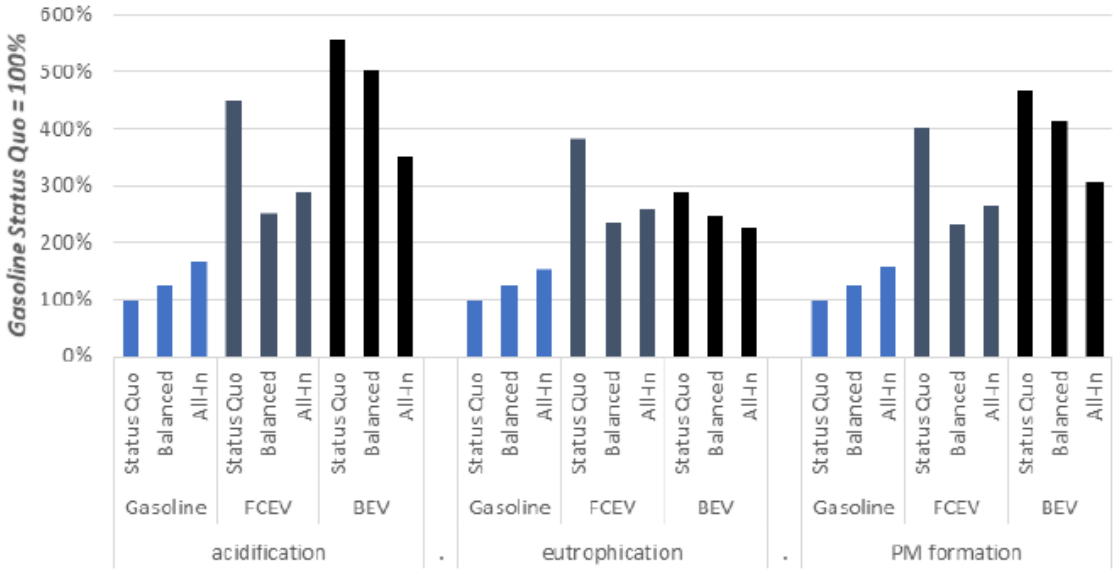
GHG emissions from manufacturing of selected C-segment in 2020



- **Status Quo**: all vehicle efficiencies remain unchanged
- **Balanced**: technological measures which are expected to have a positive cost-benefit balance are implemented
- **All-in**: all available measures to decrease the fuel consumption are integrated into the vehicle

Source: FVV Fuels Study IV

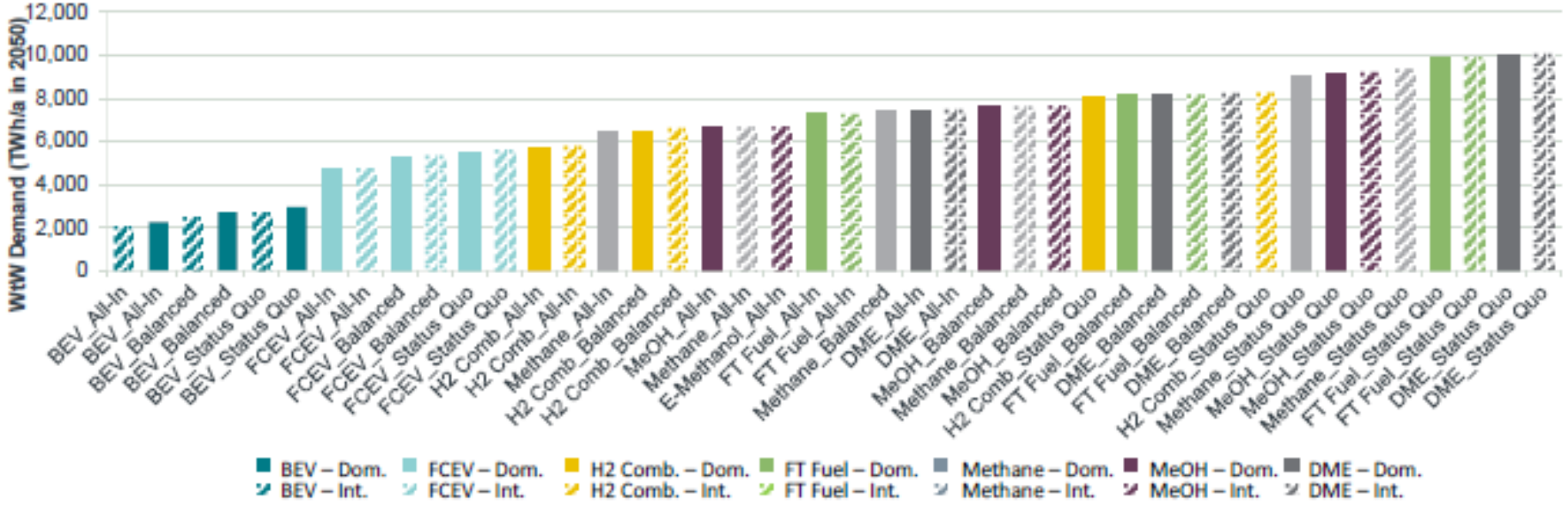
Other environmental impact indexes



- **Status Quo**: all vehicle efficiencies remain unchanged
- **Balanced**: technological measures which are expected to have a positive cost-benefit balance are implemented
- **All-in**: all available measures to decrease the fuel consumption are integrated into the vehicle

Source: FVV Fuels Study IV

WtW Demand in TWh/a in 2050

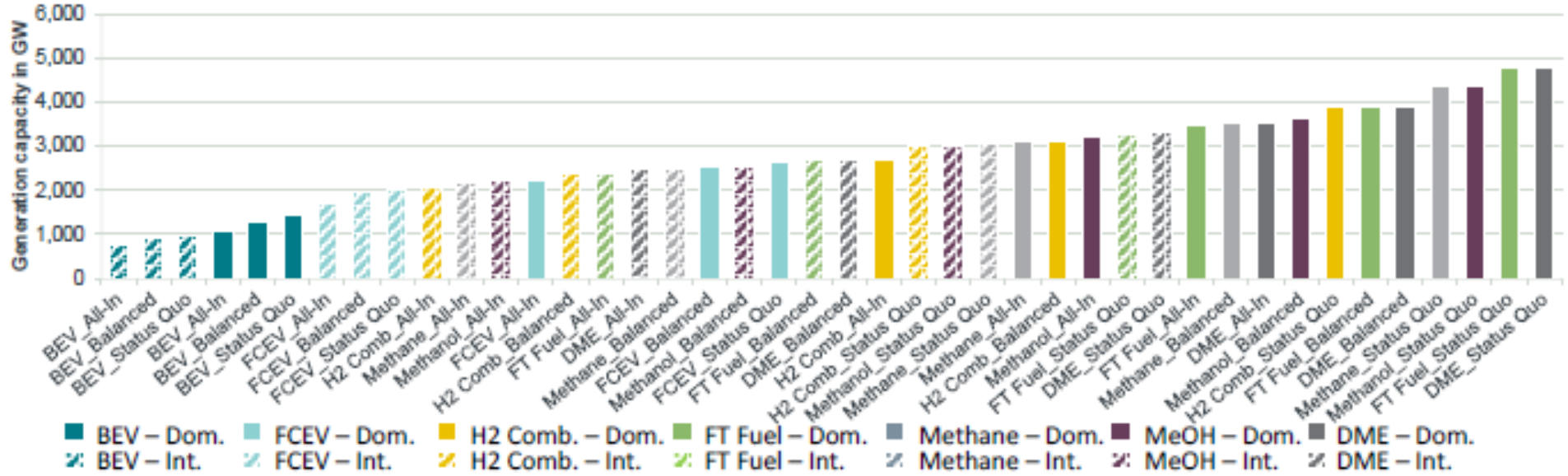


- **Domestic:** Europe can become energy independent
- **International:** energy is also sourced from regions outside of Europe such as MENA or further abroad

Source: FVV Fuels Study IV

CO2 NEUTRALITY FORECAST

Generation Capacity in GW in 2050



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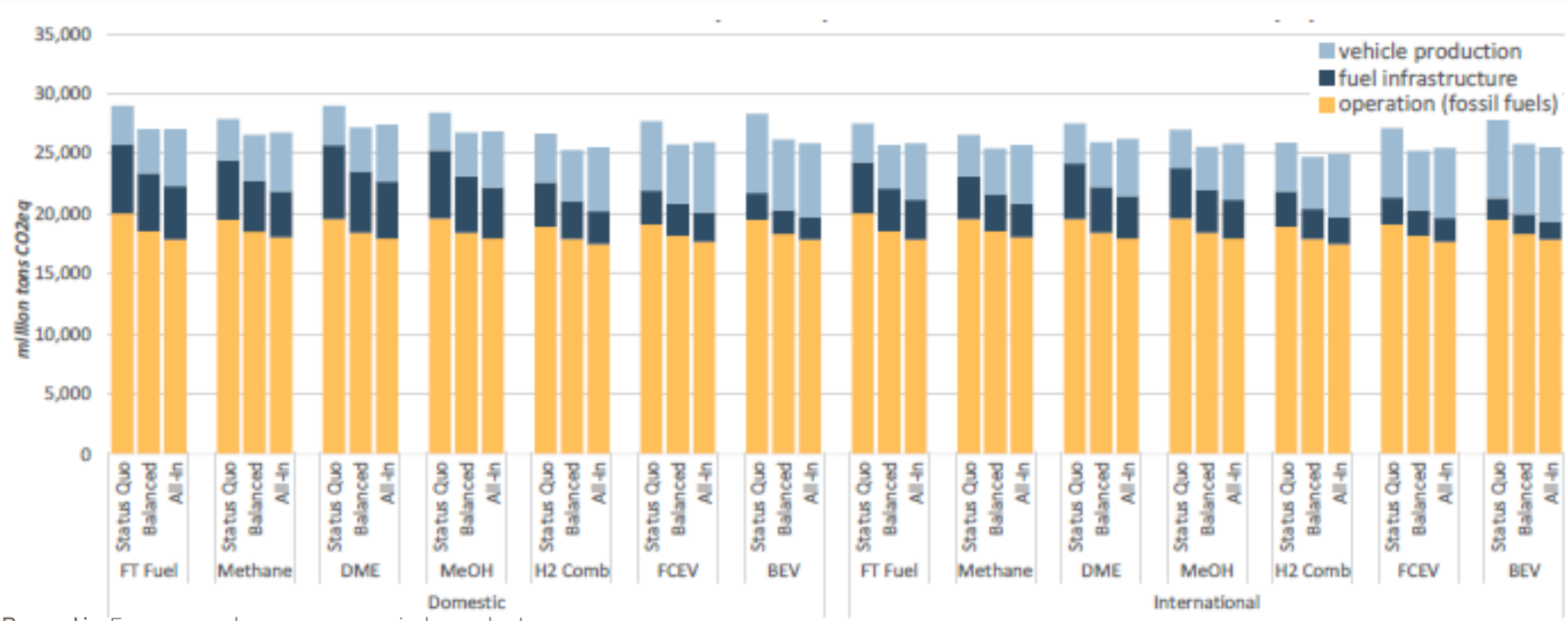
Source: FVV Fuels Study IV

Cumulative GHG Emissions in 2050



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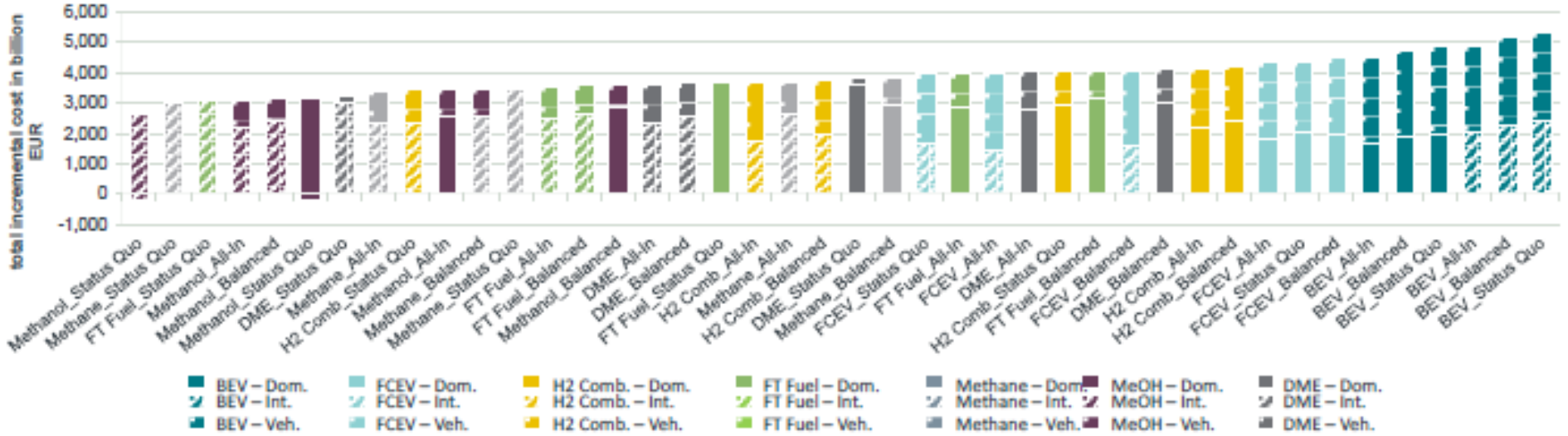
Source: FVV Fuels Study IV

Total (energy/fuel supply chain + vehicles) incremental costs in 2050



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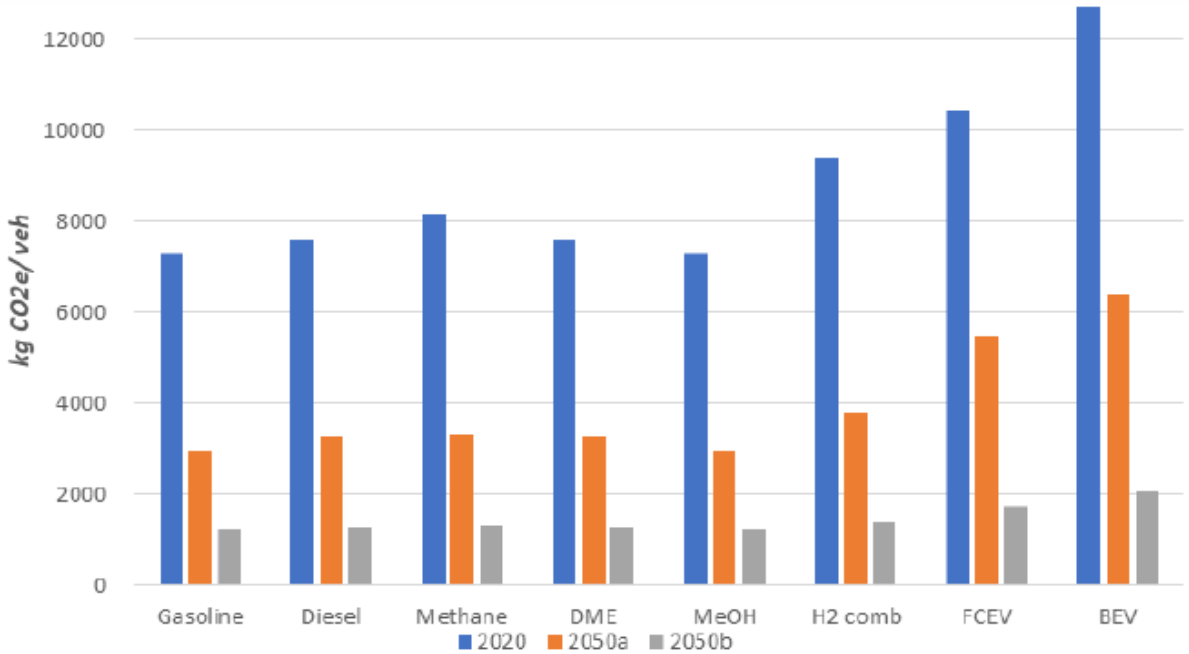
Source: FVV Fuels Study IV

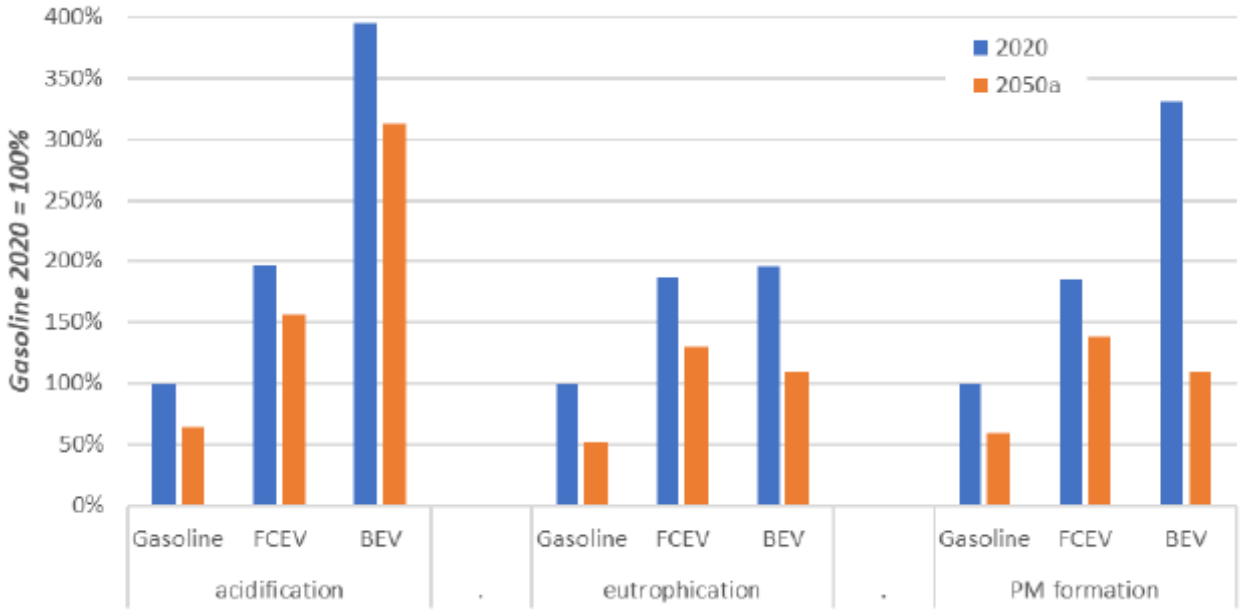
GHG emissions from manufacturing of balanced C-segment



- **2050a scenario**: defossilisation of car manufacturing in Europe (also for pre-chains of car materials like steel, aluminium and copper)
- **2050b scenario**: background system defossilisation where no fossil GHG emissions from any part of the worldwide process chain remain

Source: FVV Fuels Study IV

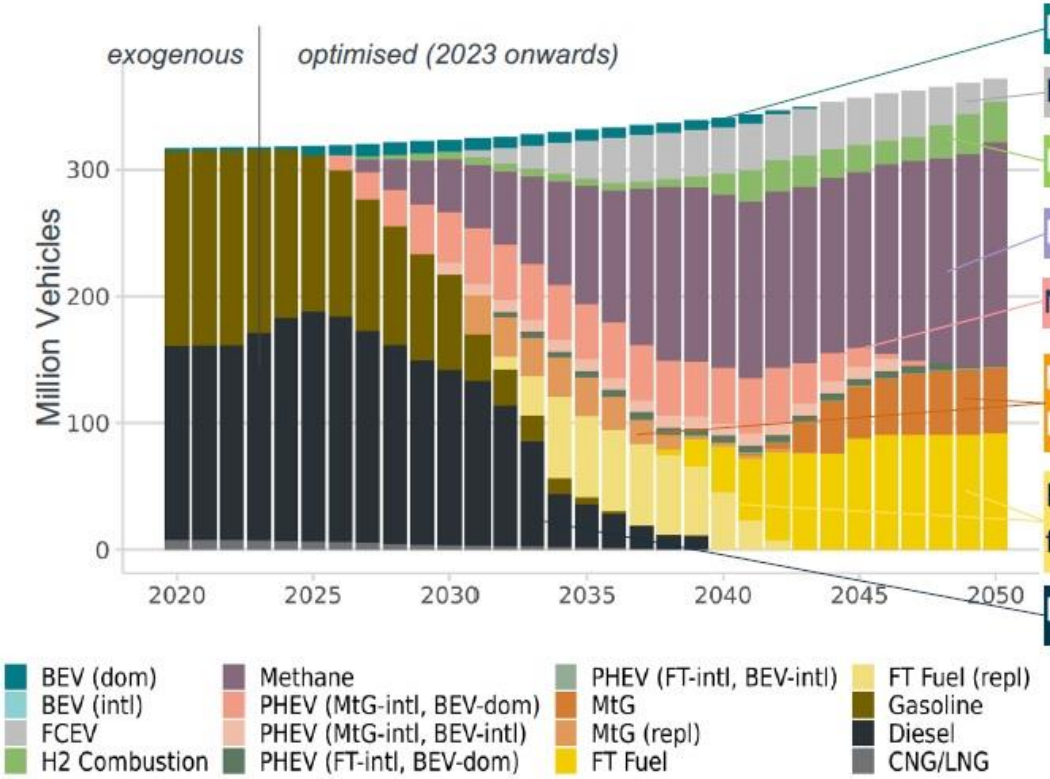
Other environmental impact indexes in 2050



- **2050a scenario**: defossilisation of car manufacturing in Europe (also for pre-chains of car materials like steel, aluminium and copper)

Source: FVV Fuels Study IV

Mixed Technology Scenario - Roadmap 2020 - 2050



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)

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

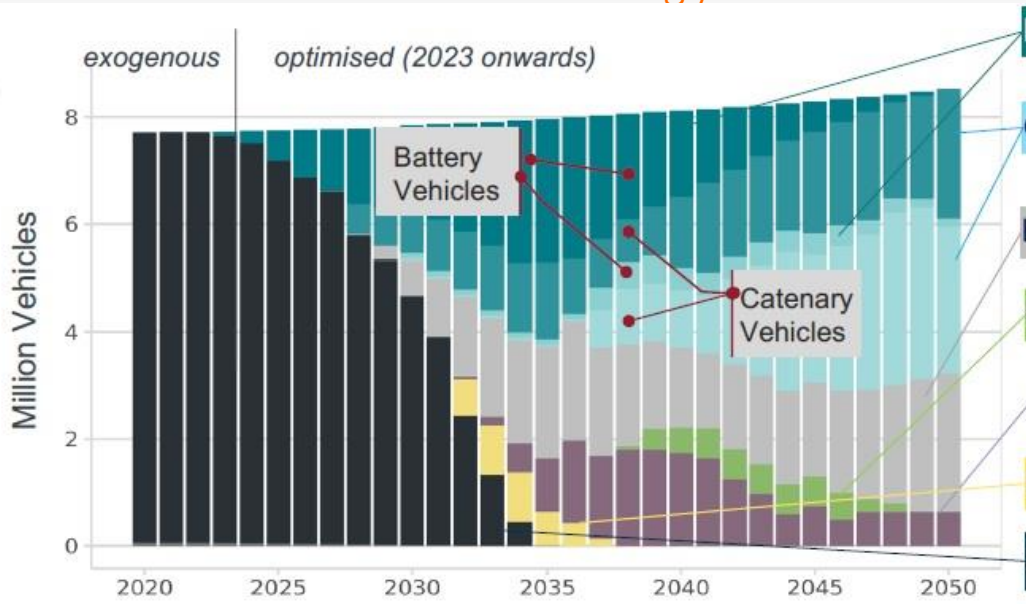
Fossil gasoline phase out 2036, fossil diesel 2039

Dominating:

- Methane-ICEV
- FT- & MTG-ICEV
- H2-ICEV

Source: FVV Fuels Study IV

Mixed Technology Scenario - Roadmap 2020 - 2050



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

BEV (dom)
BEV (intl)
FCEV
H2 Combustion
Methane
PHEV (MtG-intl, BEV-dom)
PHEV (MtG-intl, BEV-intl)
PHEV (FT-intl, BEV-dom)
PHEV (FT-intl, BEV-intl)
MtG
MtG (repl)
FT Fuel
FT Fuel (repl)
Gasoline
Diesel
CNG/LNG

Dominating:

- Catenary BEV (for HDV > 7.5t)
- H2-FCEV (for HDV < 7.5t)

Source: FVV Fuels Study IV

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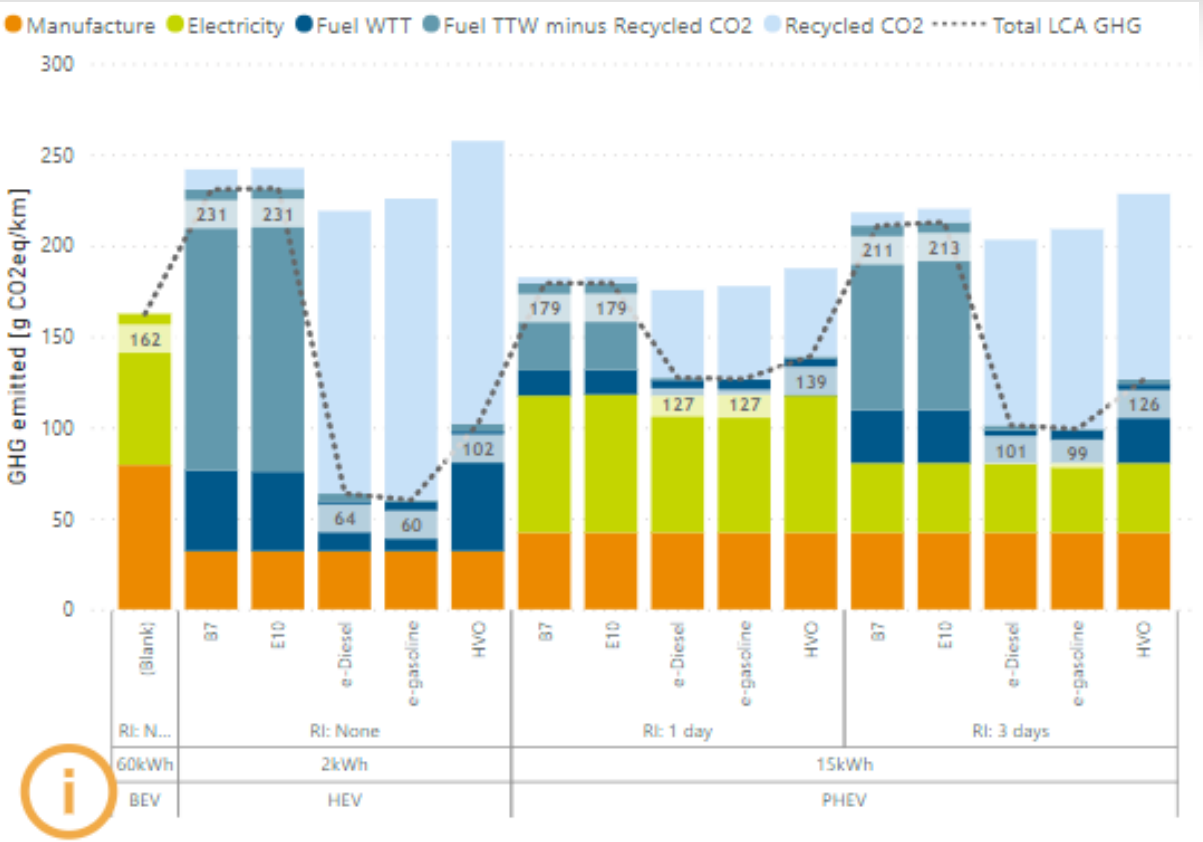
CO2 NEUTRALITY

ADVANCED BIO FUEL – GHG COMPARISON

- B7: blended with 7% renewable biodiesel
- E10: blended with 10% renewable ethanol
- HVO: hydrotreated renewable vegetable oil and waste cooking oil
- e-Diesel: ren. El. and captured CO2
- e-gasoline: ren. El. and captured CO2
- Battery prod.: 120 kg CO2eq / kWh
- Electricity prod.: 335 kg CO2eq / kWh

Use case

- Passenger cars
- Total lifetime mileage: 150000 km
- Daily mileage: median daily trip (20%: < 25km & > 100 km, 60%: 25-100 km)
- Climate: temperate
- Recharge interval: 1 and 3 days



Source: CONCAWE - https://www.carsco2comparator.eu

CO2 NEUTRALITY
CONCLUSIONS

- Timeline for the **decarbonisation of Road Transport** can only be achieved through **cooperation between the public and private sectors** with significant investment into new vehicle, energy production and infrastructure technologies
- To achieve **Well-To-Wheel carbon neutrality goal in 2050** different scenarios are possible
- The route is **complex** and requires the contributions from **many stakeholders** and investment.
- The **negative impacts** of making possibly **wrong decisions**, too early, are significant.
- A **mix of carbon neutral pathways** can speed up the transition to GHG neutrality significantly compared to single technology scenarios with lowest cumulative GHG emissions.
- BEV has the lowest energy requirements*
- Carbon Neutral Transportation scenarios must be **affordable** (i.e. 1% EU GDP per year for 30 years*)
- Synthetic hydrocarbon fuels are the least expensive option*
- **Life Cycle Assessment** approach based on all Indicators (Acidification, Eutrophication, PM formation, Land use,…) to be used for technical-ecological evaluation
- Availability of **critical raw materials** is a key factor for enabling 100% BEV or 100%FCEV pathways*

*Source: FVV Fuels Study IV

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THANK YOU FOR YOUR KIND ATTENTION

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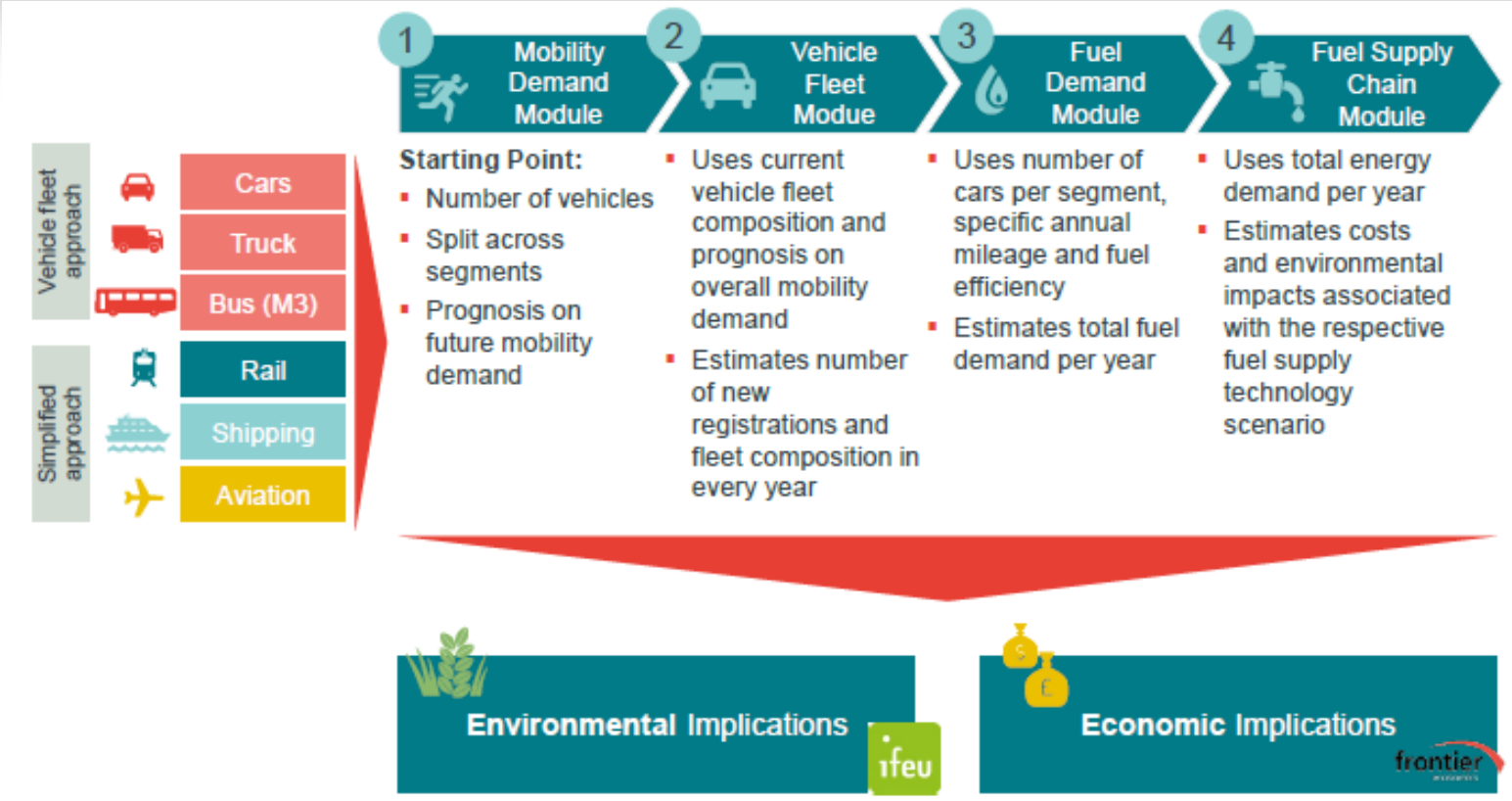
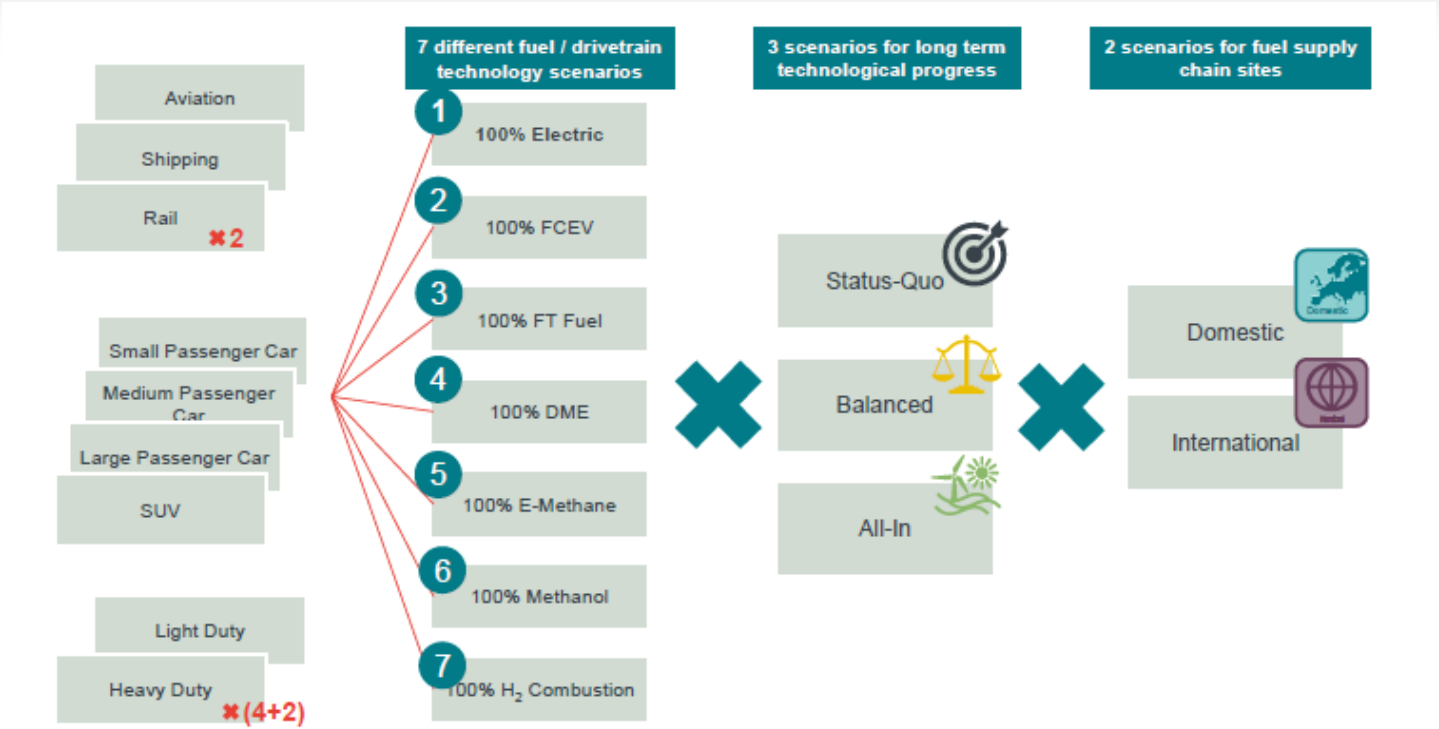
FFV TANK-TO-WHEEL MODEL APPROACH



Schematic overview of the modelling approach

Source: FVV Fuels Study IV

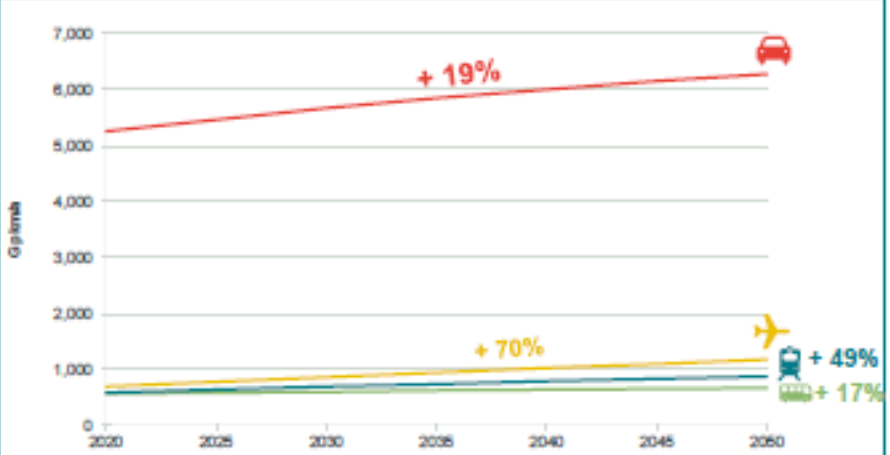
FFV TANK-TO-WHEEL MODEL APPROACH



Schematic overview of scenarios and assumptions

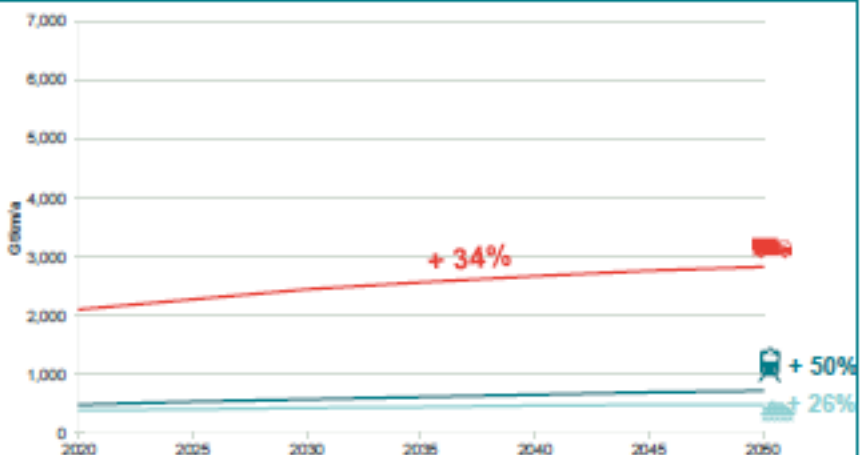
Source: FVV Fuels Study IV

Mobility Demand – Passenger Transport



Total: + 27%

Mobility Demand – Freight Transport



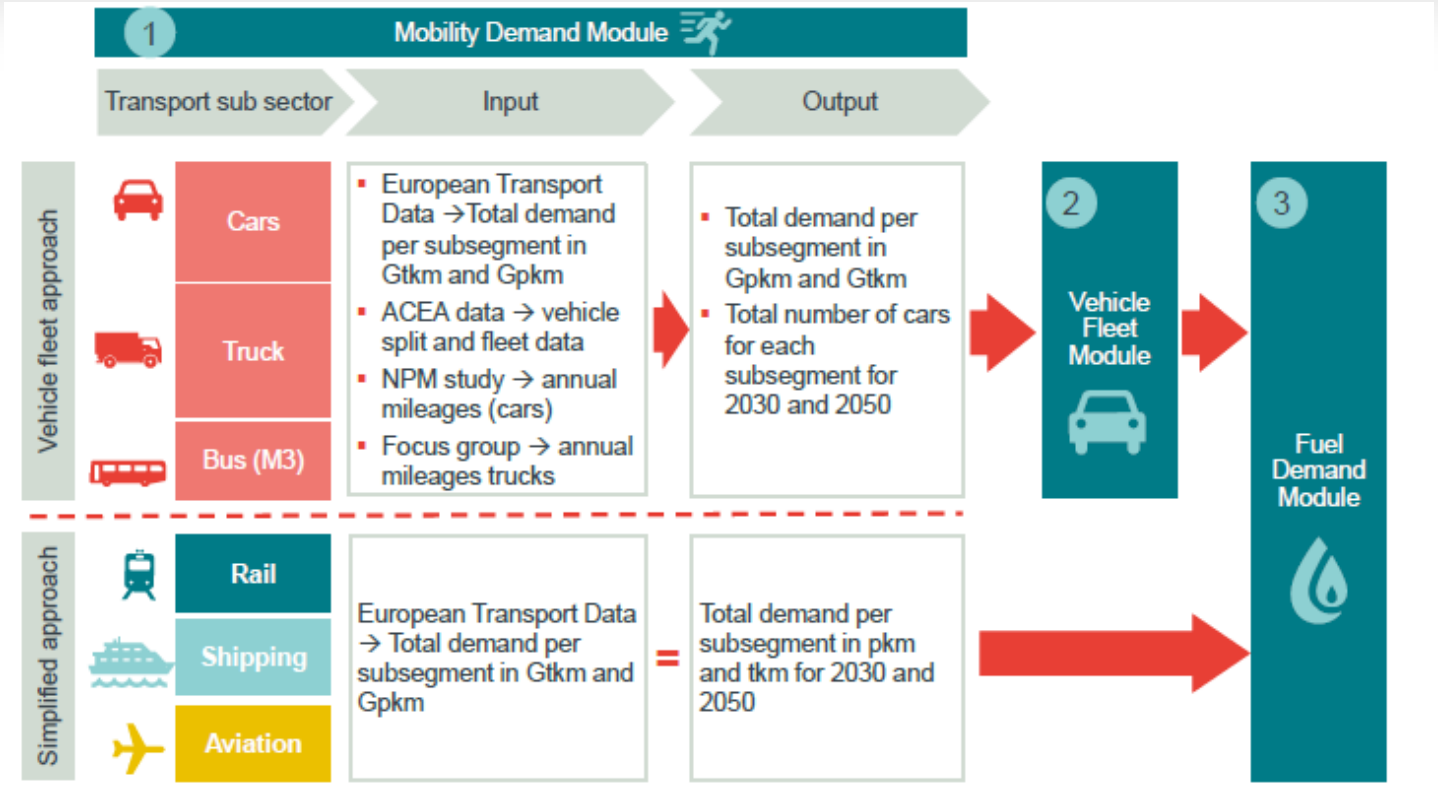
Total: + 36%

Share of global mobility demand

Source: FVV Fuels Study IV

CO2 NEUTRALITY - ANNEX

FFV TANK-TO-WHEEL MODEL APPROACH

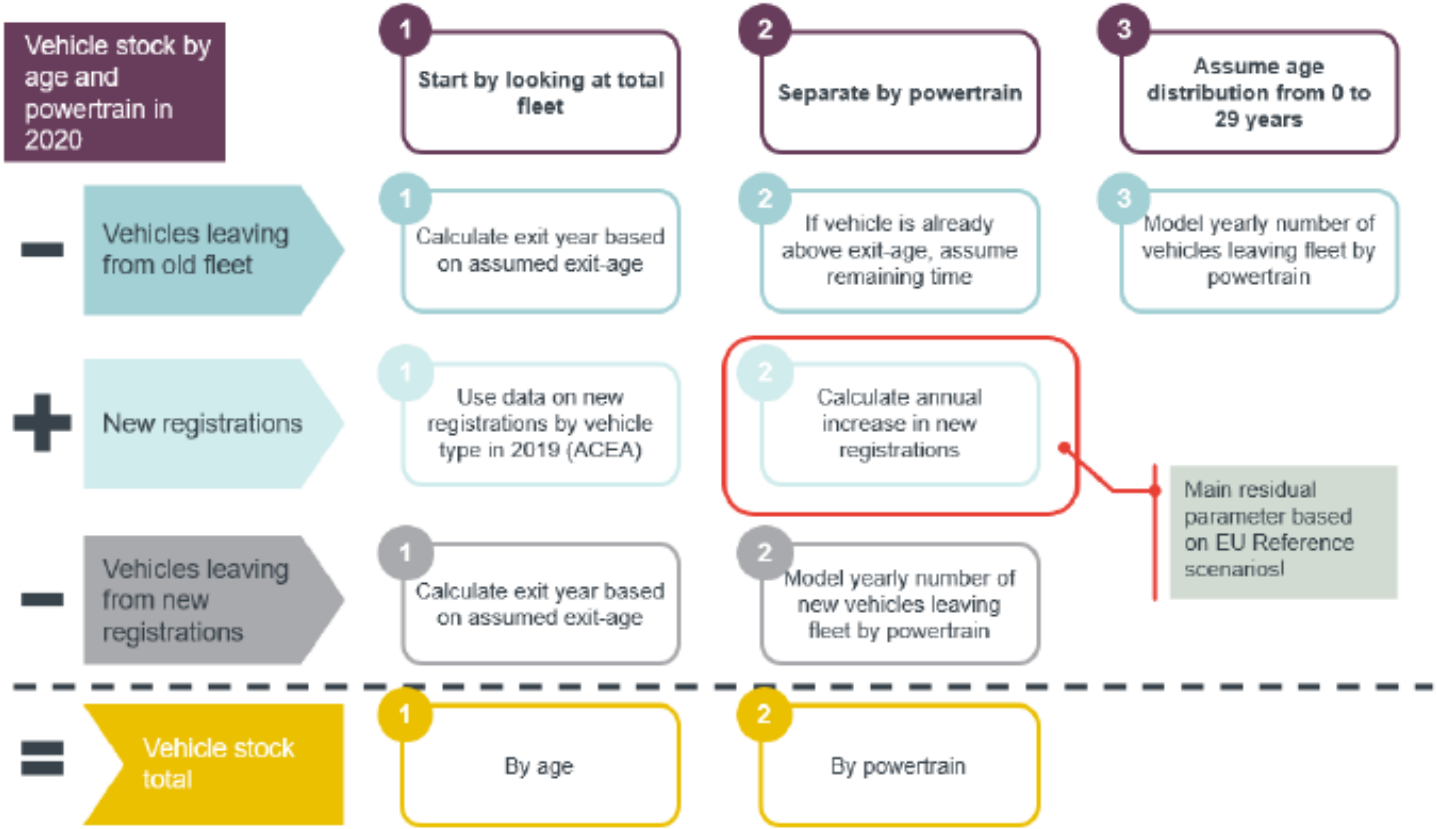


Mobility demand Module

Source: FVV Fuels Study IV

CO2 NEUTRALITY - ANNEX

FFV TANK-TO-WHEEL MODEL APPROACH

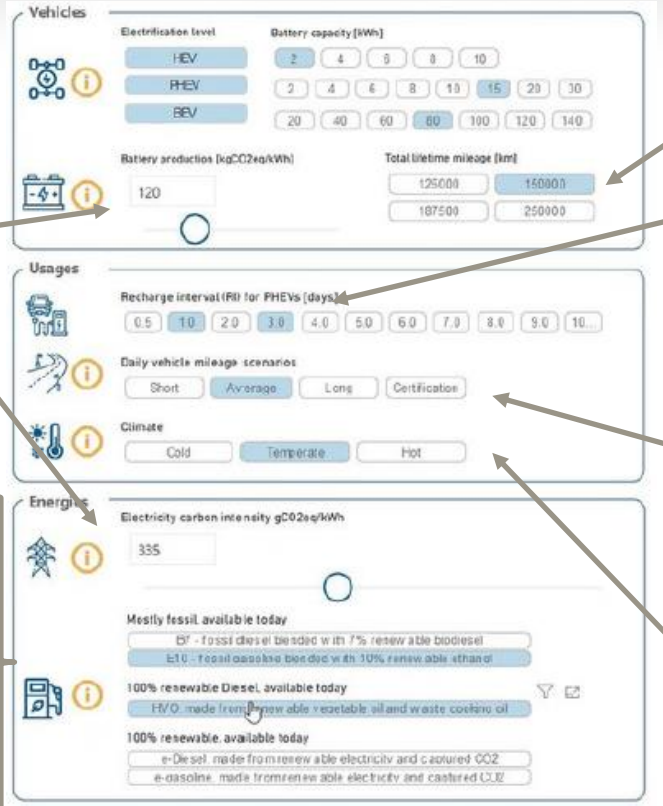


Schematic overview of vehicle fleet modelling

Source: FVV Fuels Study IV

CONCAWE LCA MODEL APPROACH

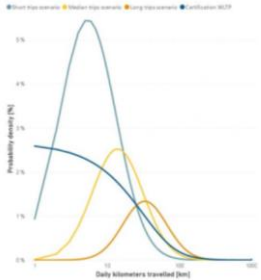
- Battery prod.: 120 kg CO2eq / kWh
- Electricity prod.: 335 kg CO2eq / kWh



Schematic overview of interactive tool

- B7: blended with 7% renewable biodiesel
- E10: blended with 10% renewable ethanol
- HVO: hydrotreated renewable vegetable oil and waste cooking oil
- e-Diesel: ren. El. and captured CO2
- e-gasoline: ren. El. and captured CO2

- Passenger cars
- Total lifetime mileage: 150000 km
- Recharge interval: 1 and 3 days



- Daily mileage: median daily trip (20%: < 25km & > 100 km, 60%: 25-100 km)
- Climate: temperate

Source: CONCAWE - https://www.carsco2comparator.eu