Zero-Emission Transport

Fairy tale or realistic pathway forward?

M. Rothbart, R. v Helmolt

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Today's Presenters

Martin Rothbart

Master of Business

Senior Product Manager
Energy & Sustainability

Energized for driving the
green revolution of renewables!

> than 20 years with AVL

Dr. Rittmar von Helmolt

Physicist

Director Business Development

Actively shaping the industry's
transformation towards a
sustainable mobility

> 20 years in automotive and
energy industry

Facts and Figures

AVL

Global Footprint

Represented in 26 countries

45 Affiliates at over 93 locations

45 Global Tech and Engineering Centers (including Resident Offices)

1948
Founded

10,700
Employees Worldwide

12%
Of Turnover Invested in Inhouse R&D

70+
Years of Experience

68%
Engineers and Scientists

2,500
Granted Patents in Force

97%
Export Quota

Content

1 **Approaches to bring CO_2 to zero**

2 **Example of public bus fleet defossilization**

3 **The lifecycle perspective**

4 **Outlook**

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What are the biggest challenges on our path to reduce CO_2?

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We are in the Middle of a Transformation

We strive for two Goals: Climate-Neutrality and Energy Security

EU wants to become the 1st carbon neutral continent by 2050

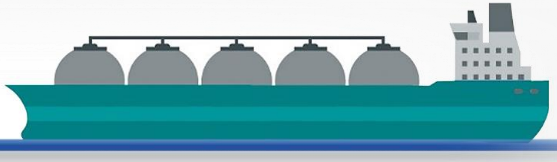
United States to achieve a 50-52 percent reduction from 2005 GHG levels in 2030

China will peak emissions before 2030 and aims to achieve carbon neutrality before 2060

Japan aims for zero emissions, carbon neutral society by 2050

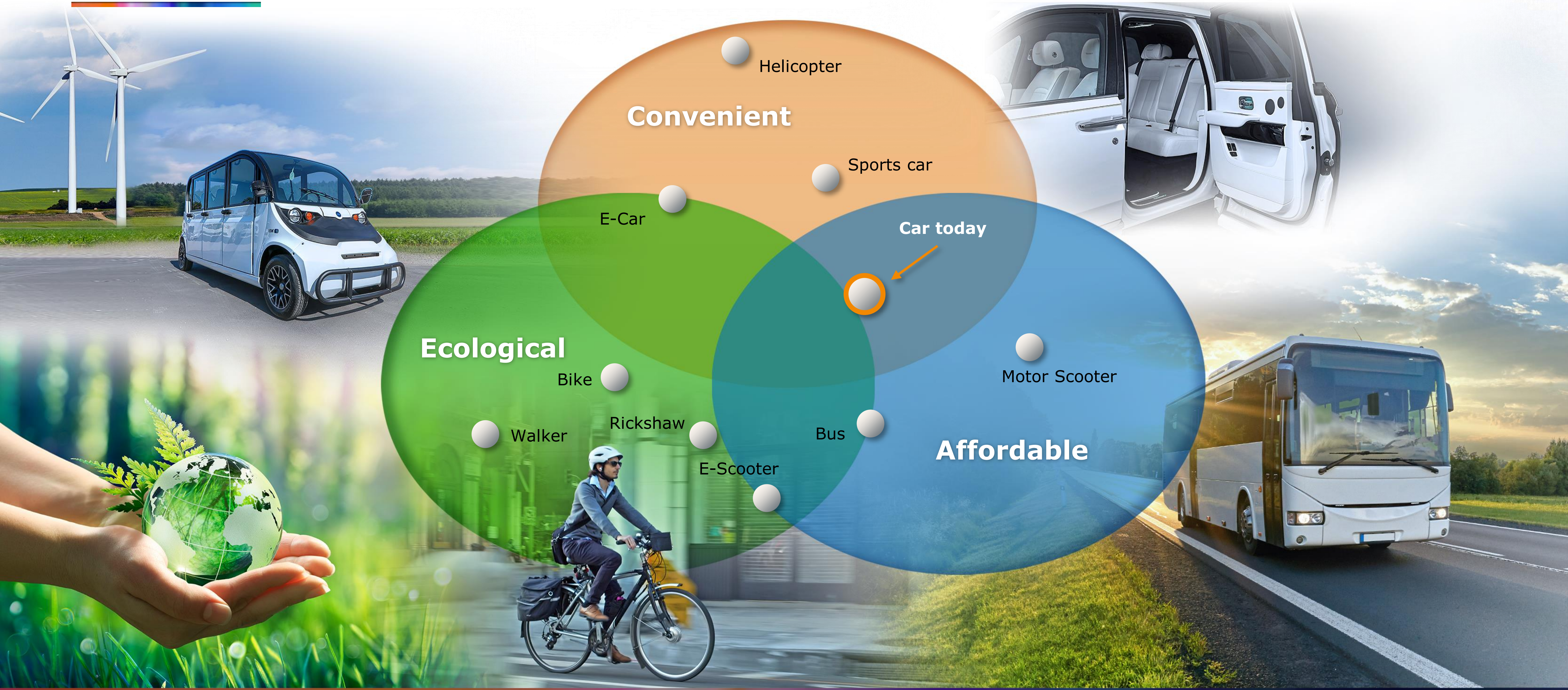
Energy Security

Energy Trade

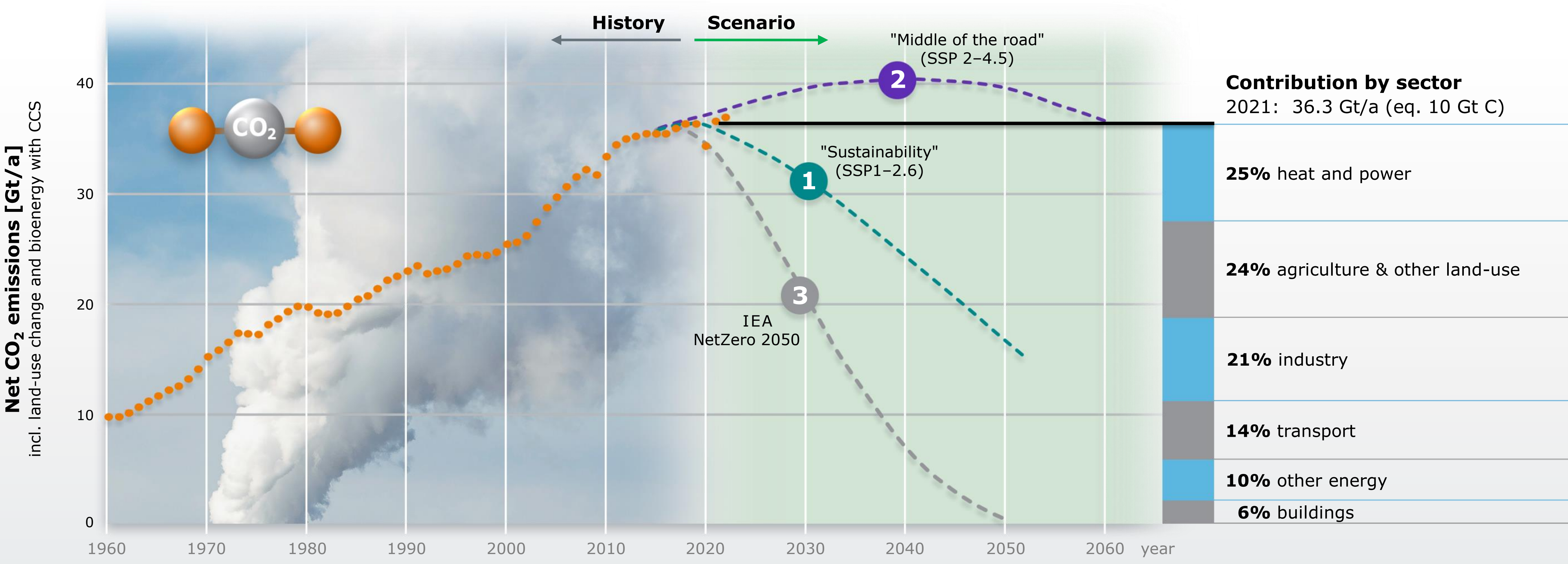


Sustainable Energy

Transport and Energy



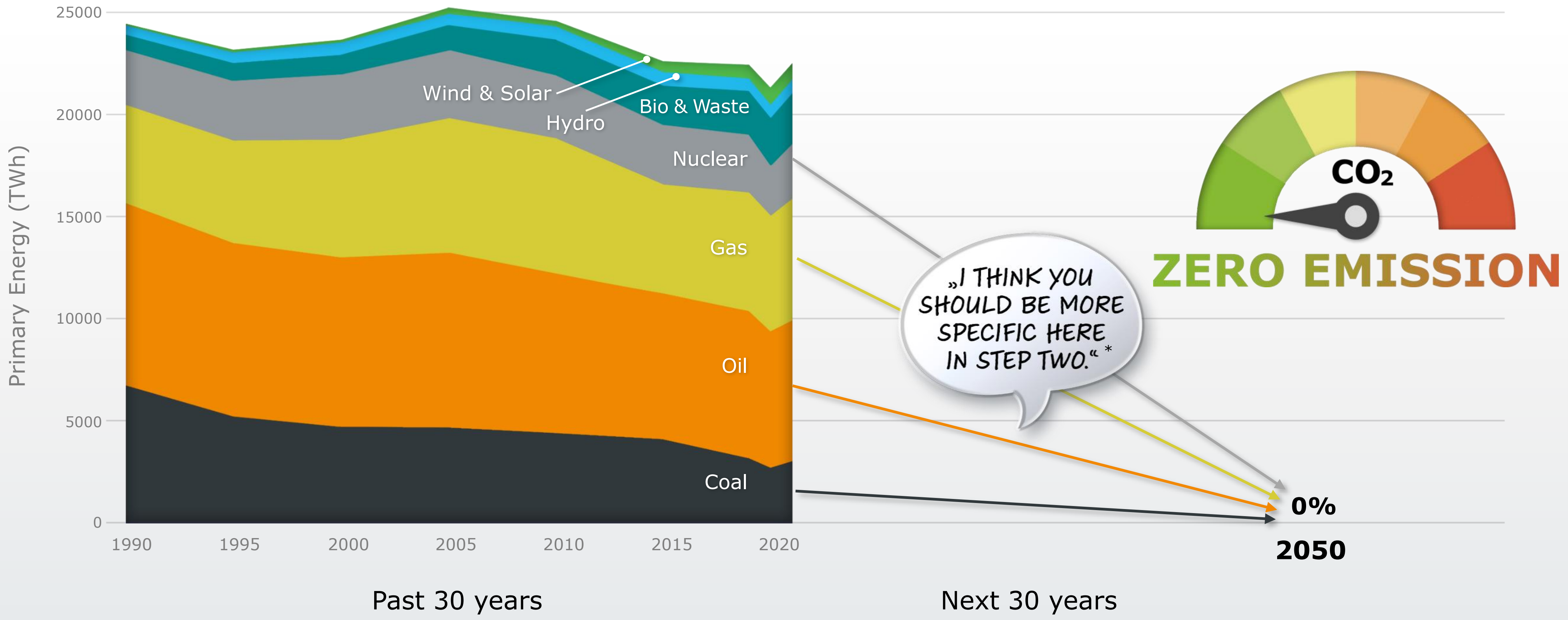
History of Global Human-Made CO_2 Emissions



- Growth of population and prosperity have been and still are the main drivers for GHG emissions.
- Technology progress in all sectors needed for the entire lifecycle including production.

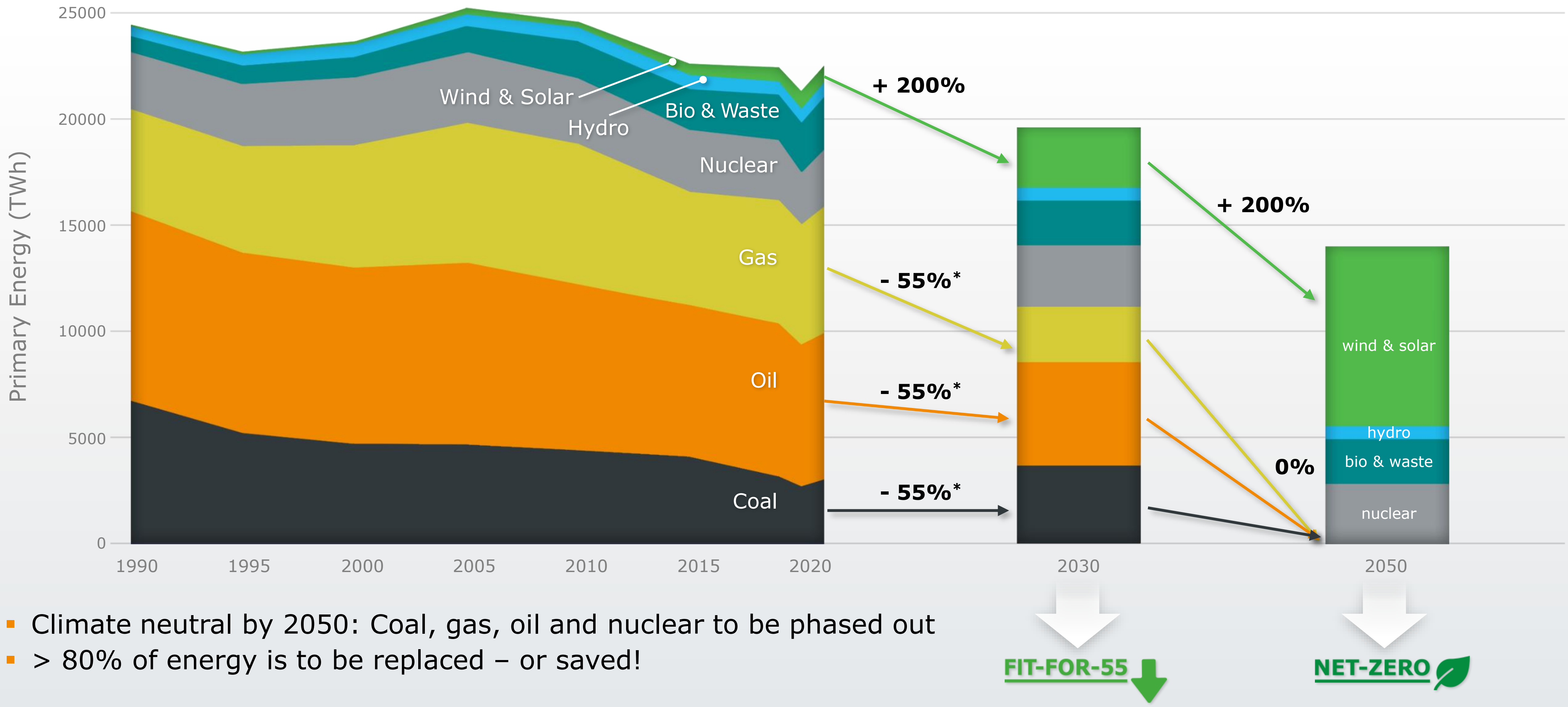
Source: The Global Carbon Budget, Friedlingstein et al. 2020 (Historic Data), SSP Public Database (Scenarios), IEA 2014/IPCC (2010 sector split), IEA 2021, Net Zero by 2050, IEA Global Energy Review 2022

Primary Energy Supply Europe



Source: Historic Data: IEA 2022 2030 and 2050: Own illustration *Sidney Harris

Primary Energy Supply Europe: History and "Targets"



- Climate neutral by 2050: Coal, gas, oil and nuclear to be phased out
- > 80% of energy is to be replaced – or saved!

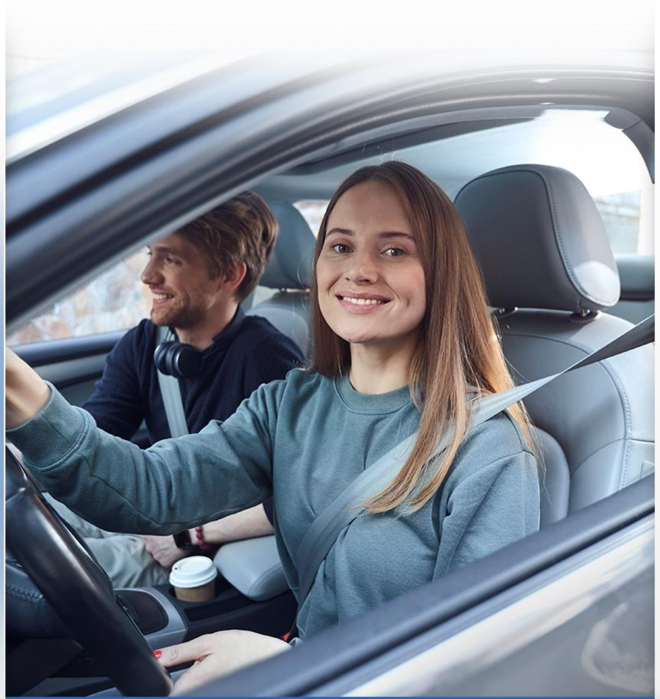
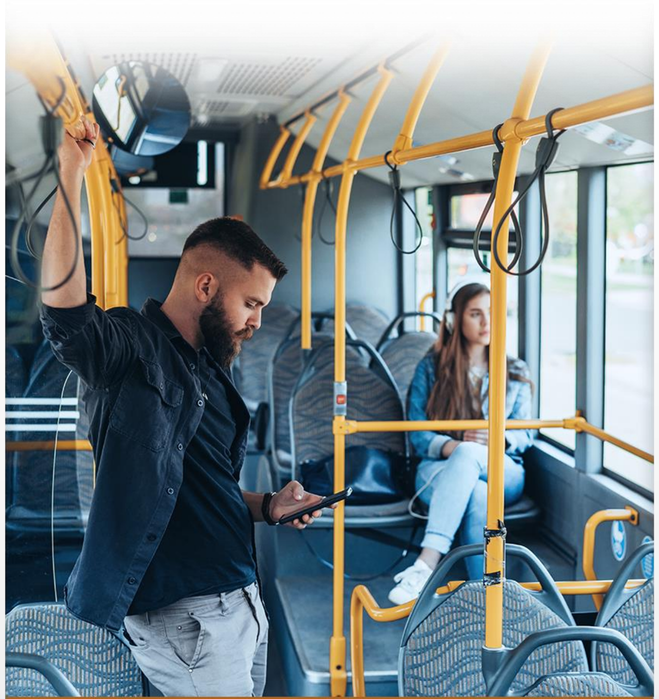
Source: Historic Data: IEA 2022 2030 and 2050: Own illustration *CO_2 compared to 1990 level

Evolution of Tank-to-Wheel CO_2 Emissions

	Horse	Cars	E-Cars
Fuel Type	Biomass	Fossil, Biofuel, E-Fuel	Electricity (fossil, renewable, nuclear, …)
CO_2 Emissions	**120 g/km** plus some methane	**95 g/km***	**0,0 g/km***

* acc. to EU regulatory framework

It Depends on the Use Case: Emissions per Vehicle km → per Passenger km


	Car	Bus, nearly empty	Bus, nearly filled
Use Case	Car, 2 persons	Bus, 2 persons	Bus, a lot of persons
CO_2 Emissions	**48 g/Pkm**	**> 600 g/Pkm**	**< 30 g/Pkm**

More detailed analysis e.g. on UK department for Transport, Transport and environment statistics: Autumn 2021
https://www.gov.uk/government/statistics/transport-and-environment-statistics-autumn-2021/transport-and-environment-statistics-autumn-2021

Three Major Options for Emission-Free Propulsion

Electricity

Battery Electric

Hydrogen

Fuel Cell

Hydrogen ICE

E-Fuel

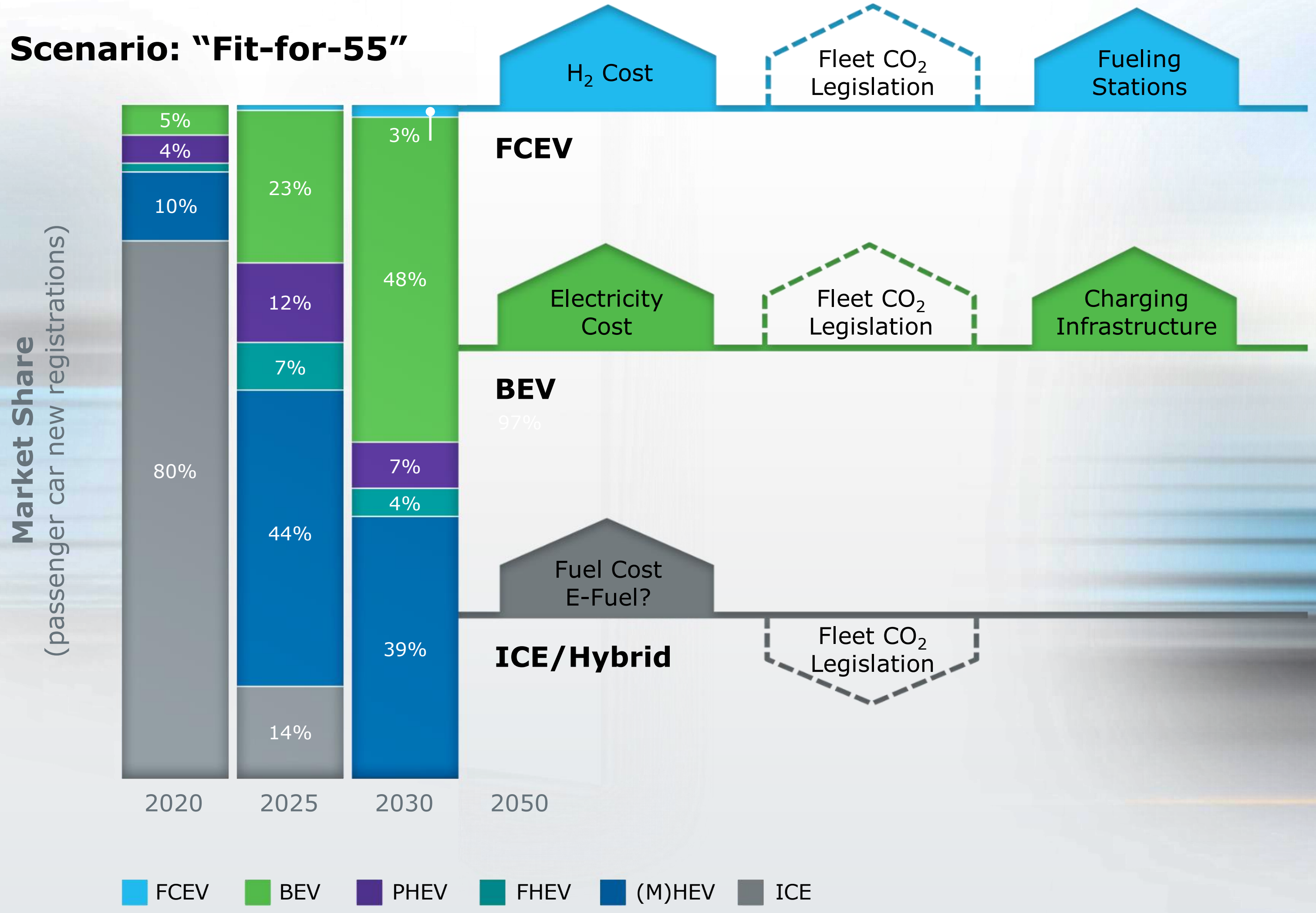
Hybrid ICE

TTW Zero-CO_2

In the EU currently not possible due to "Zero-Tailpipe" Regulation

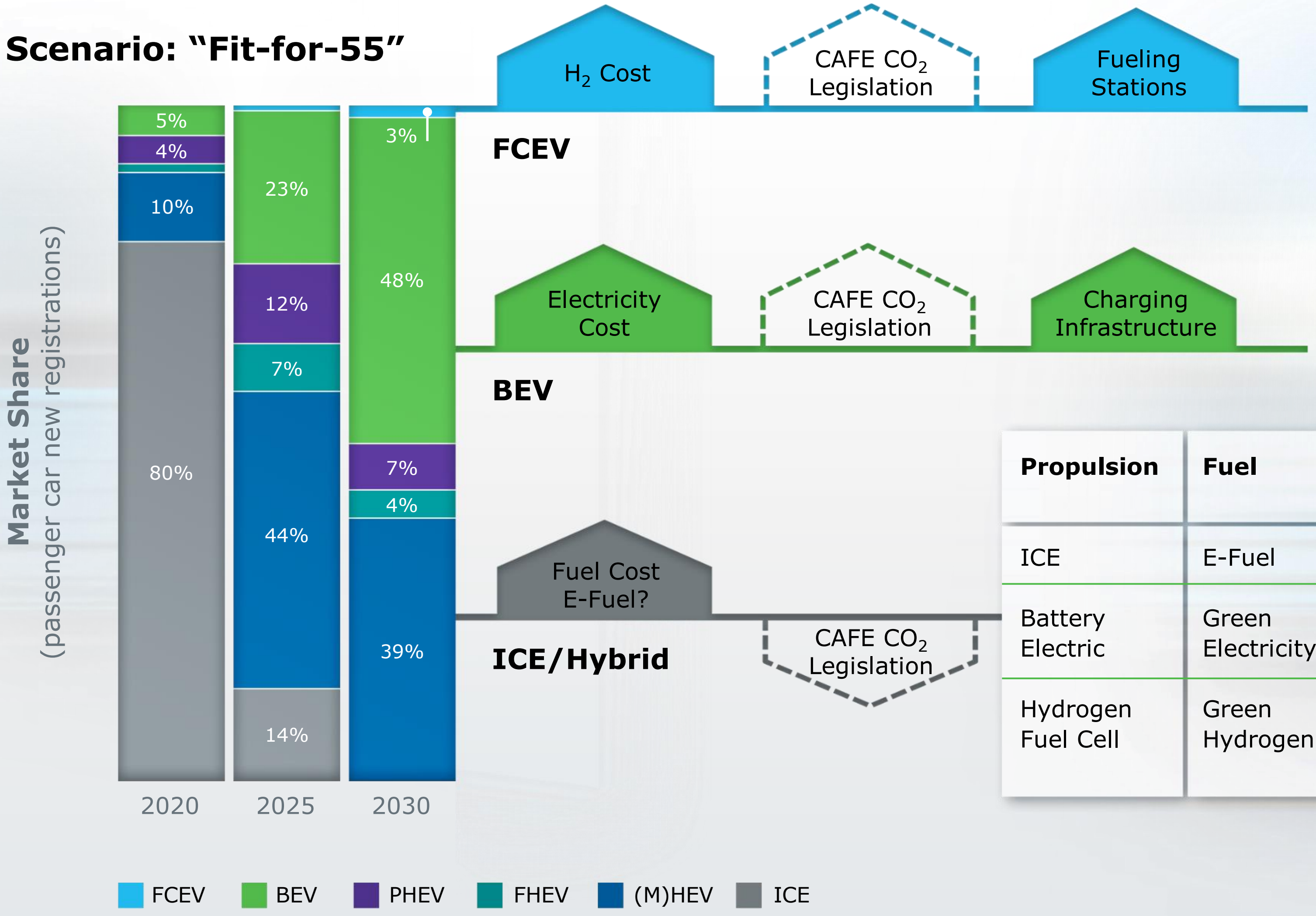
Fuel Cost and Availability: Major Market Driver & Scenario

Scenario: "Fit-for-55"



Source: AVL, Synthesis from various industry and market research data

Fuel Cost and Availability: Major Market Driver & Scenario

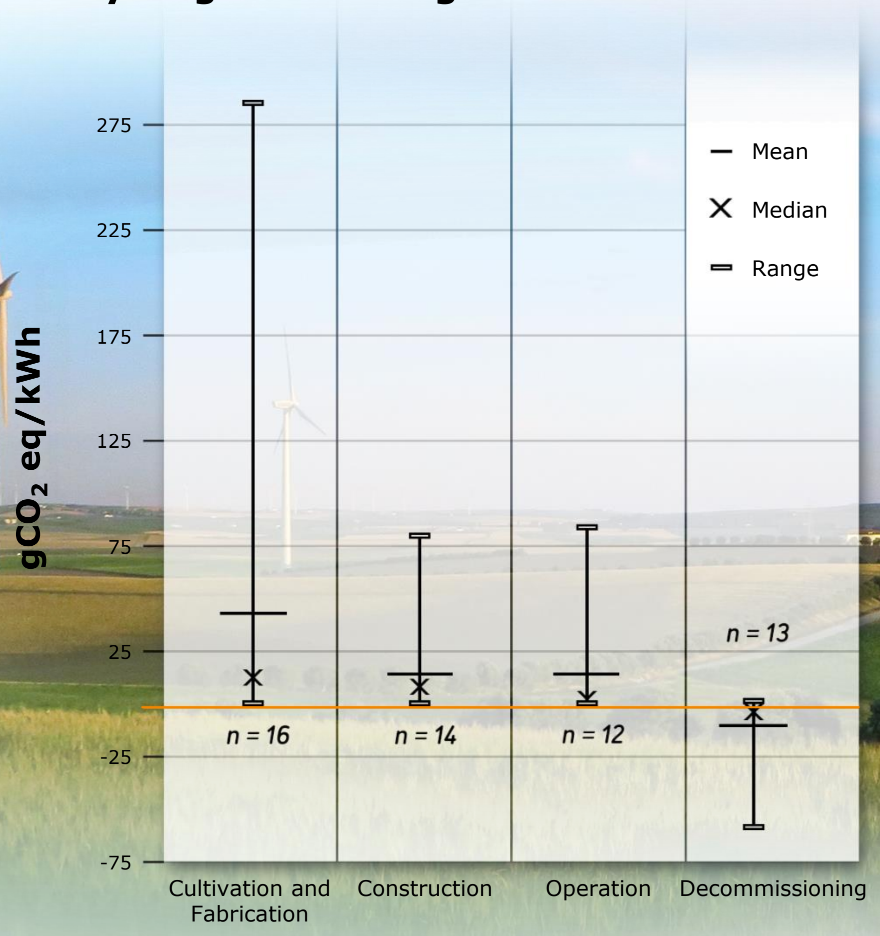


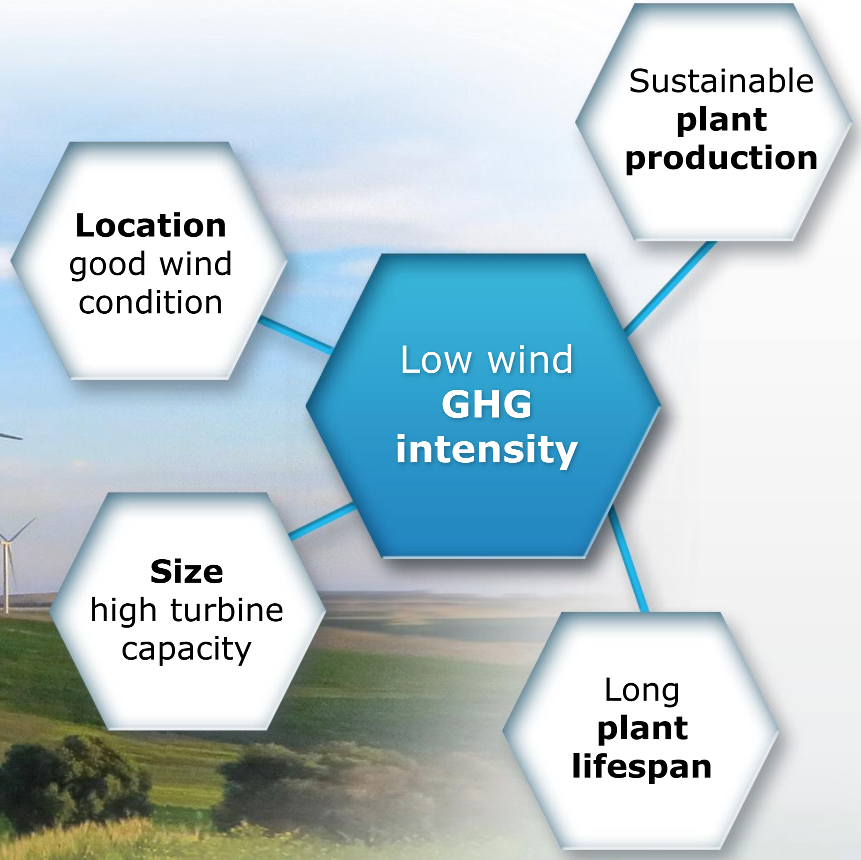
Propulsion	Fuel	Fuel Cost (w/o tax)	Fuel /100 km	CO_2 Emission	Energy Cost /100 km
ICE	E-Fuel	1 – 2 EUR/Liter	5 Liter	Zero	5 – 10 EUR
Battery Electric	Green Electricity	20 – 40 ct/kWh	25 kWh	Zero	5 – 10 EUR
Hydrogen Fuel Cell	Green Hydrogen	4 –8 EUR/kg	1.25 kg	Zero	5 – 10 EUR

Source: AVL, Synthesis from various industry and market research data

GHG Emissions from Renewables? – LCA for Wind Power

Lifecycle greenhouse gas emissions for wind energy by lifecycle stage*





Average total GHG emissions wind turbine: **34 g/kWh**

* Meta-Survey, D. Nugent, B.K. Sovacool, EnergyPolicy (Elsevier, 2013)

Adding the Backup Power

CartoonStock.com

To be included for a fair evaluation:

System Integration

Incl. backup and storage systems:

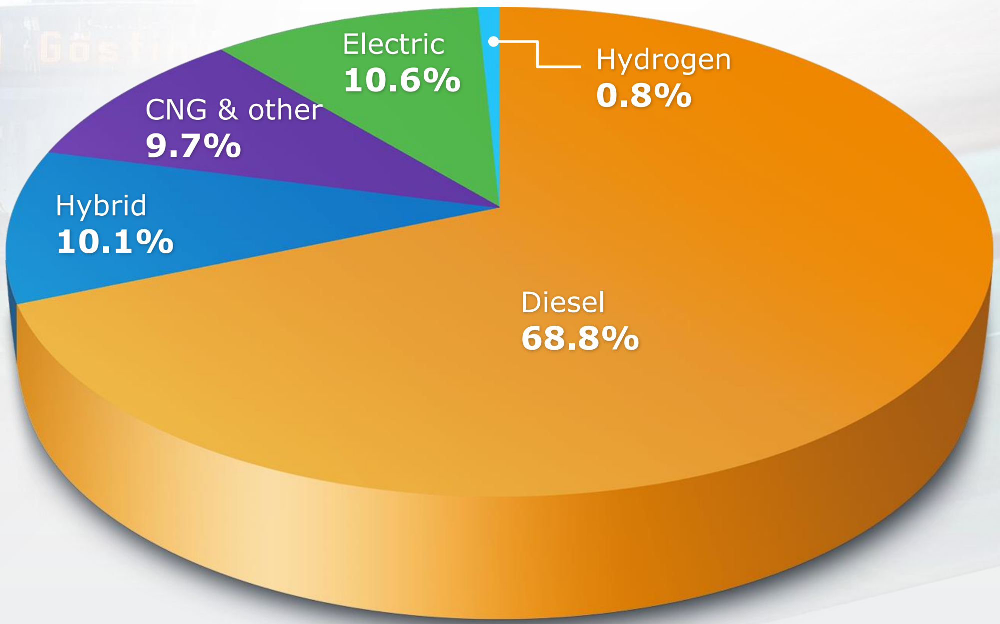
- Fossil (gas, coal, lignite, waste)
- Nuclear
- Biomass
- Hydropower
- Geothermal
- Battery
- Hydrogen

Public Transit: Bus Electrification

Graz, Austria
- 328,000 inhabitants
- 120,000 daily commuters

Public transport
- 107 M trips (2014)
- Bus: 37 lines, 130 km
- Tram: 4 lines, 36 km

Europe: New busses by fuel type (2021)



EU clean vehicles directive
City bus procurement
- Since 8/2021: **45%** "clean", thereof 50% zero emission
- From 2026+: **65%** "clean", thereof 50% zero emission

Parameters for TCO Bus Study

City Bus: overview technology and net-investment[1] of different drive systems

[12m City bus]

Diesel

Fuel consumption:	40.1 l/100 km
Engine power:	220 kW
Range:	648 km
Mileage:	68000 km/yr

2021: **230.000 Euro**

CNG

Fuel consumption:	28.3 kg/100 km
Engine power:	230 kW
Range:	812 km
Mileage:	68000 km/yr

2021: **276.000 Euro**

BEV

E-engine power:	245 kW
Energy consumption:	190 kWh/100 km
Range:	232 km
Mileage:	68000 km/yr

2021: **430.000 Euro**

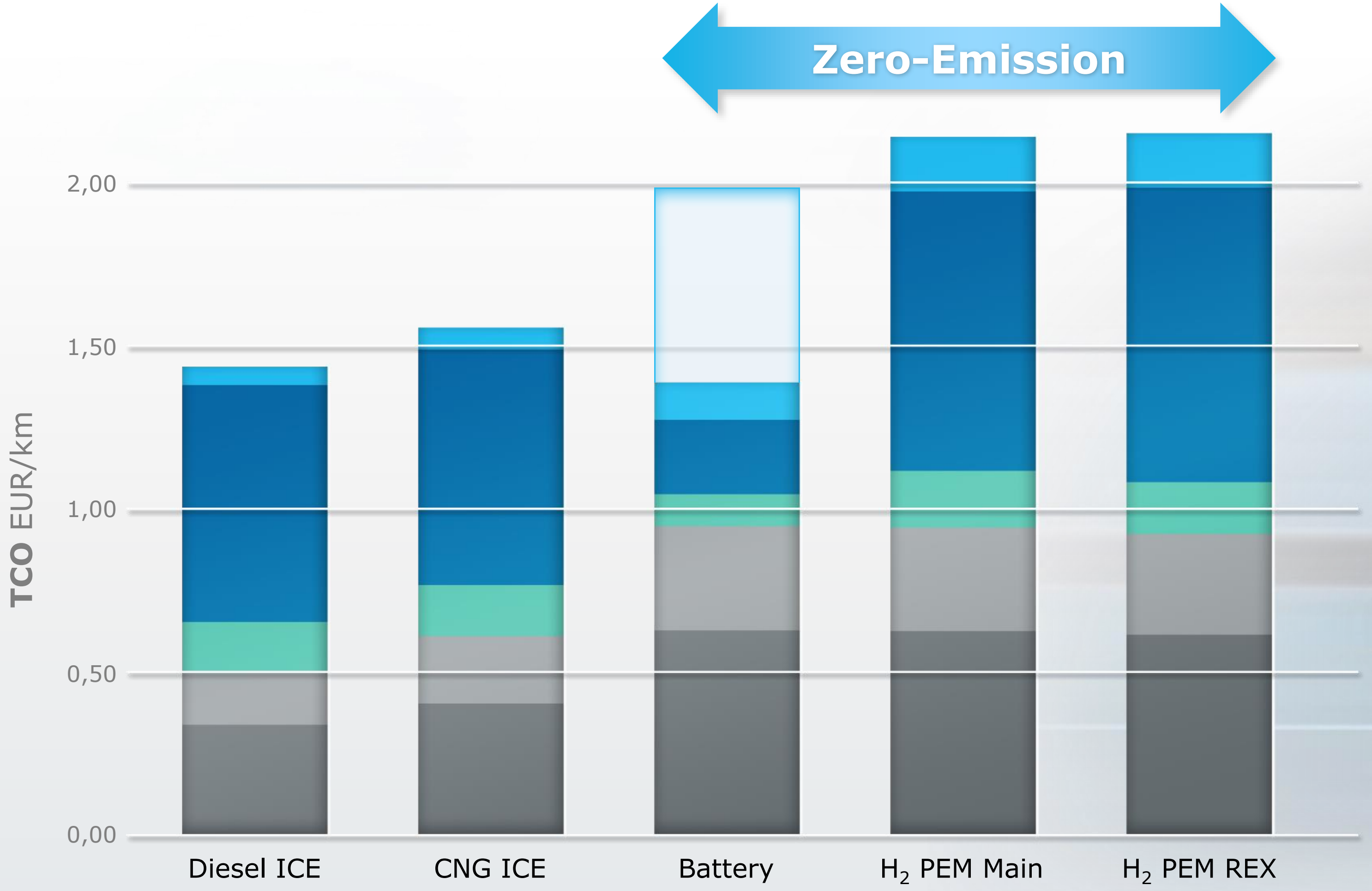
H_2 FCEV

E-engine power:	245 kW
Fuel cell system power:	120 kW (REX: 60 kW)
Hydrogen consumption:	10.2 kg/100 km
Range:	367 km
Mileage:	68000 km/yr

2021 – 2025: **426.000 Euro** [2]

Source: 1) AVL Estimate. Specified cost structure valid for an investment in 2021, for vehicles on the market
2) AVL cost estimate for specified powertrain

TCO Bus Study: City Bus, Graz Scenario 2025



Out-of-scope in this figure:

- Battery recharging infrastructure
- Backup vehicles (e.g. in case of range limitation)

Fuel price 2025	
Electricity	0.18….0.50 kWh
Diesel	1.95 €/L
CNG 0.81 kg/m^3	2.79 €/kg
H_2 PEM	10.10 €/kg

M. Rothbart, R. v Helmolt | AVL Energy Consulting | 10 November 2022 |

Electricity and Heat
Model Concept of the Energy System

Tools

Application test case:
Small community (300 households)
Scale-up for medium-size city (300k pop.)

Residential household module

- Seasonal electricity & heat load demand
- Self energy supply by PV with small-size battery storage

Commercial building module

- Seasonal electricity & heat load demand
- Self energy supply by PV with small-size battery storage

Public transport module (e-bus fleet)

- Electricity demand from electric bus lines
- Self energy supply by PV with large-size battery storage

Energy source module

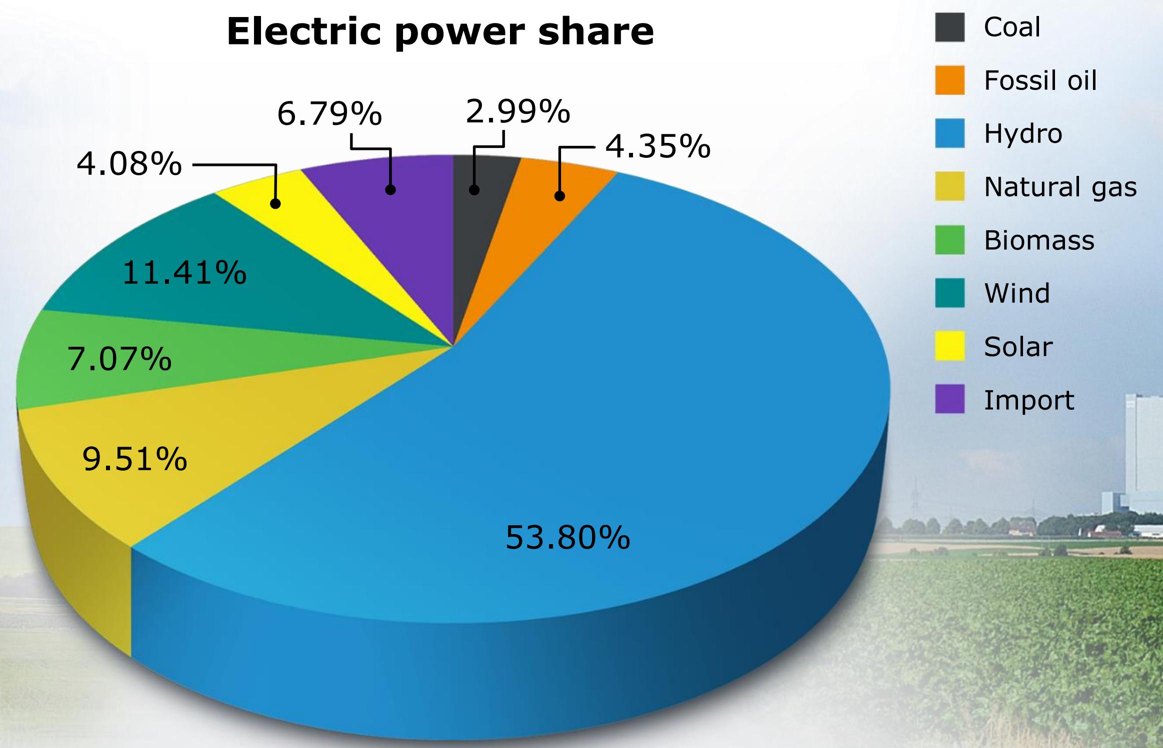
- Conventional/renewable energy supply
- CO_2 (and Finance) assessment

Energy storage module

- Energy storage for excess production
- Output during peak load demand

AVL tool uses python

"Graz-like" City Showcase: Electricity Production (Supply)

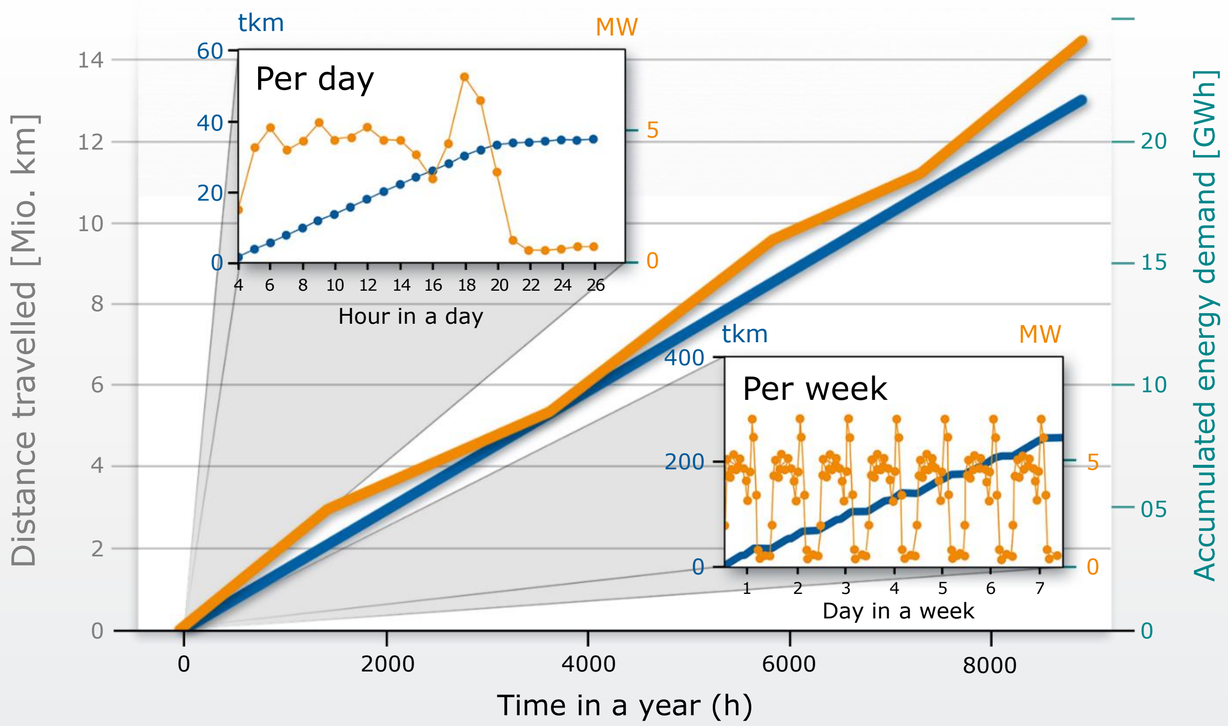


- Electricity generation structure according to **country average (IEA)***
- **28 different virtual power plants** to create the mix
- Individual **ramp rates** for each power plant to illustrate the power outputting flexibility

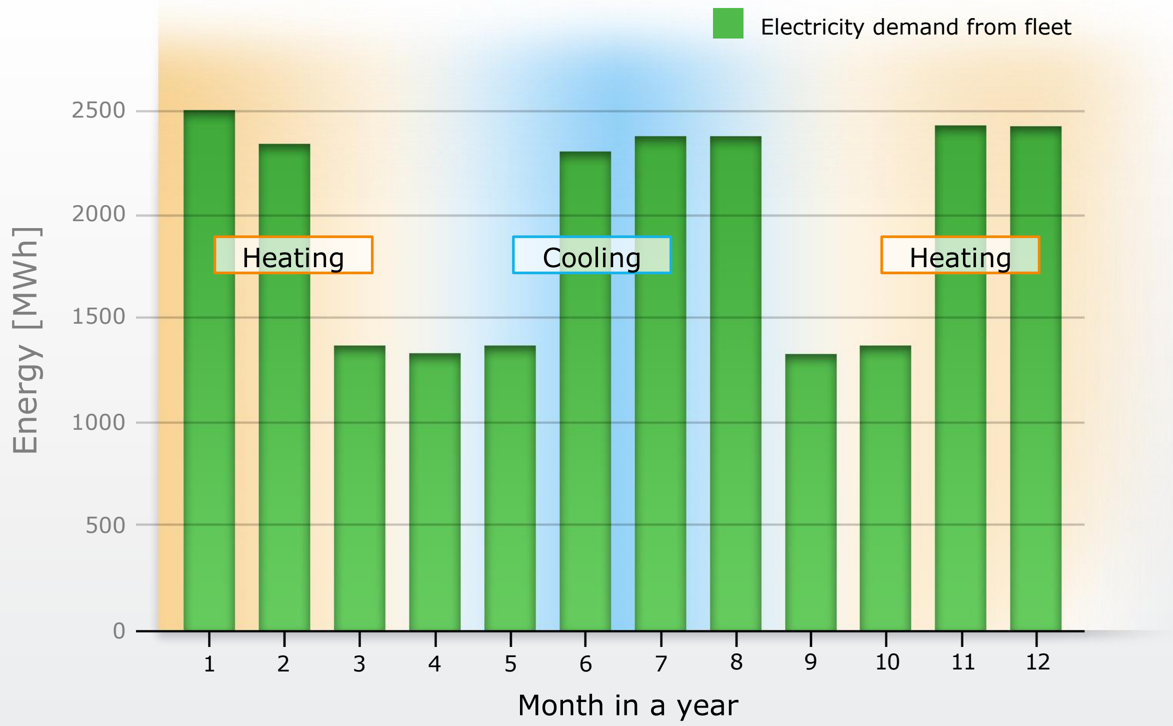
* https://www.iea.org/fuels-and-technologies/electricity

Energy Requirement of Bus Fleet

Driven distances & energy demand



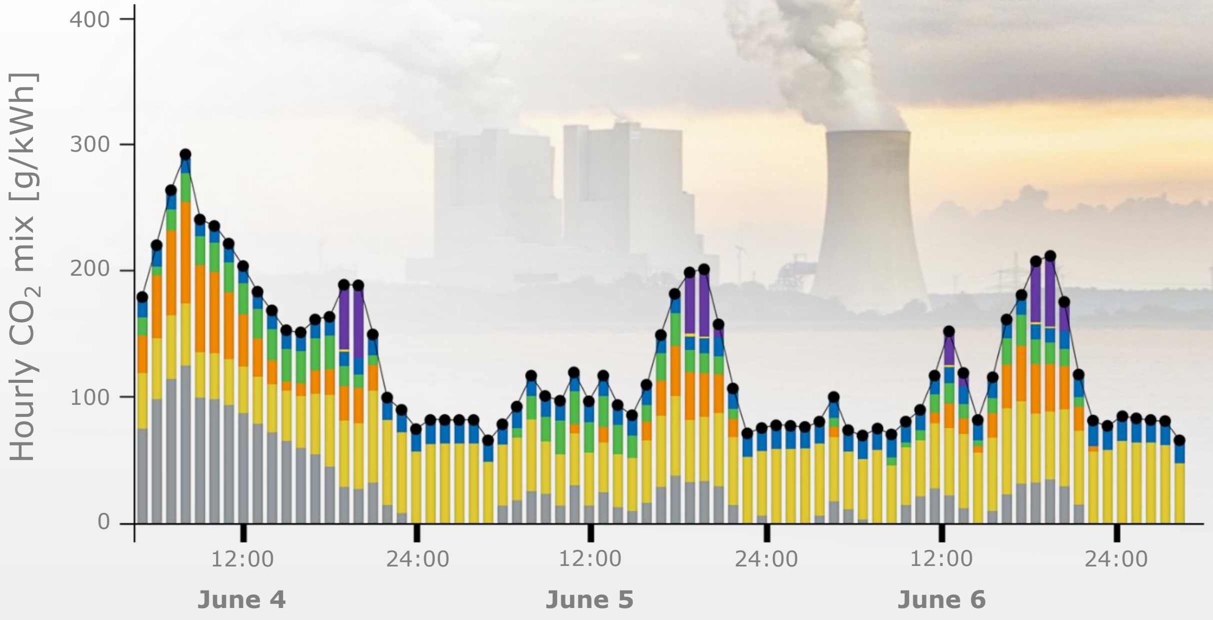
Monthly energy demand



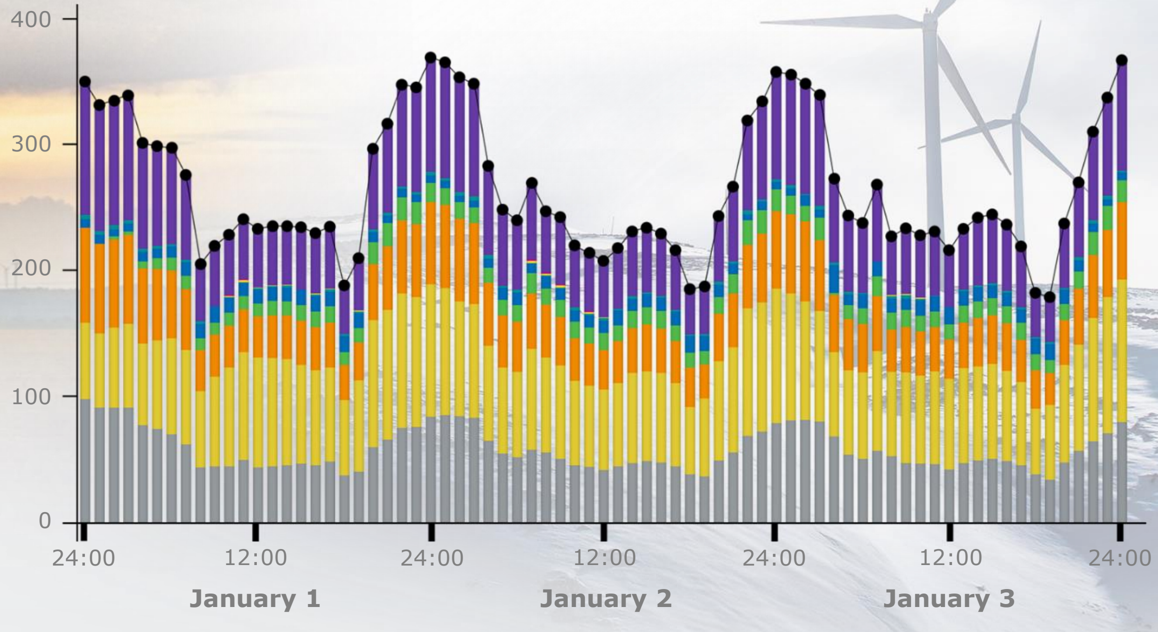
- Size of the e-bus fleet: **170 buses**
- Total travel distance: **12.8 x 10^6 km/year**
- Total electricity demand: **23.6 GWh/year**
- Averagely **1.8 kWh/km** for an e-bus

City Showcase (Graz): Electricity Production (Supply)

CO_2 mix of electricity by energy source
CO_2 mix in summer days



CO_2 mix of electricity by energy source
CO_2 mix in winter days



- CO_2 mix
- Import
- Bio
- Wind
- Oil
- Hydro
- NG
- Nuclear
- Coal

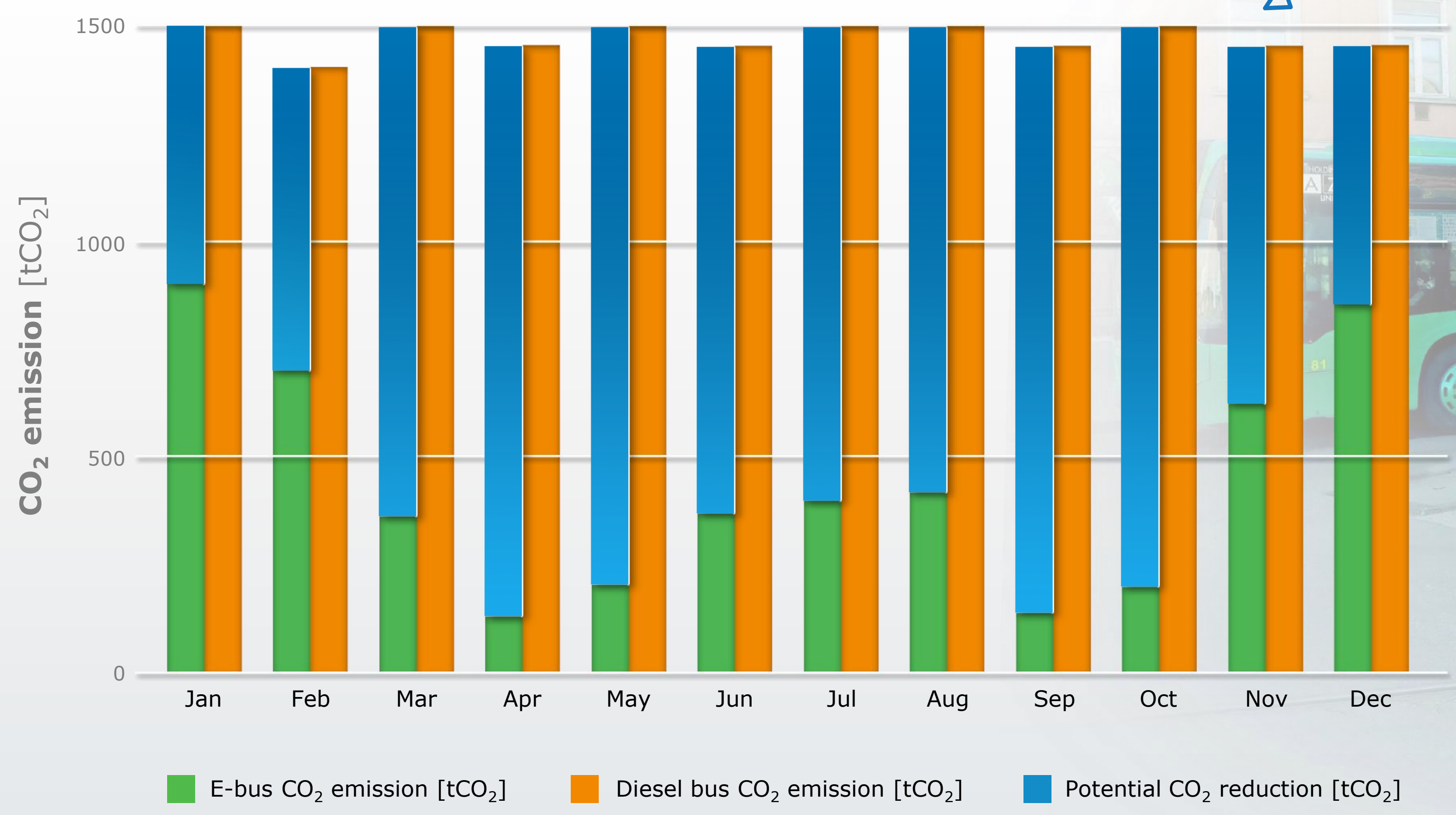
- Electricity generation structure according to **country average (IEA)***
- 28 different **virtual power plants** to create the mix
- Individual **ramp rates** for each power plant to illustrate the power outputting flexibility

E-bus emission based on hourly electricity mix
CO_2 value from power plant model

* https://www.iea.org/fuels-and-technologies/electricity

City Bus Fleet: CO_2 Emissions

Monthly CO_2 emission



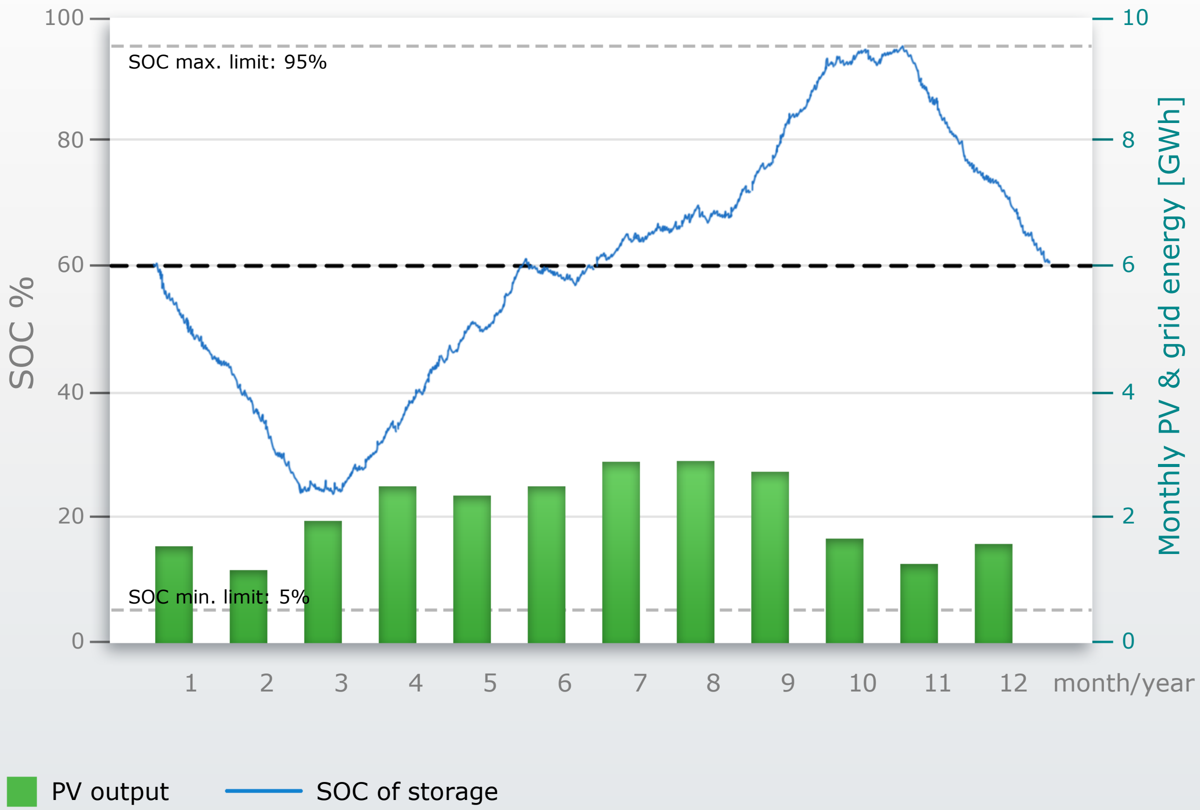
CO_2-emission by e-bus fleet:
5,280 tCO_2/year

CO_2-emission by diesel bus fleet:
17,665 tCO_2/year

How to Further Reduce City Bus Fleet CO_2 Emission? Solar Operation, Grind Independent

Case A: Solar sufficiency

- PV 20.4 MWp (102,000 m^2)
- Storage 6.5 GWh



E-Bus charging*:

- 30 GWh/year (2.2% of city electricity demand)
- Max charging power: 6.6 MW
- Assumed charging power: 600 kW
- Maximum allowed number of buses plugged into the grid: 11

* 78% overall efficiency; for E-bus fleet consumption of 23.6 GWh/year

Required invest:

- Solar 20 MW: invest ca. 25 Mio EUR
- Battery 6.5 GWh: (300 EUR/kWh) EUR 2 Bn.

CO_2 footprint of battery:

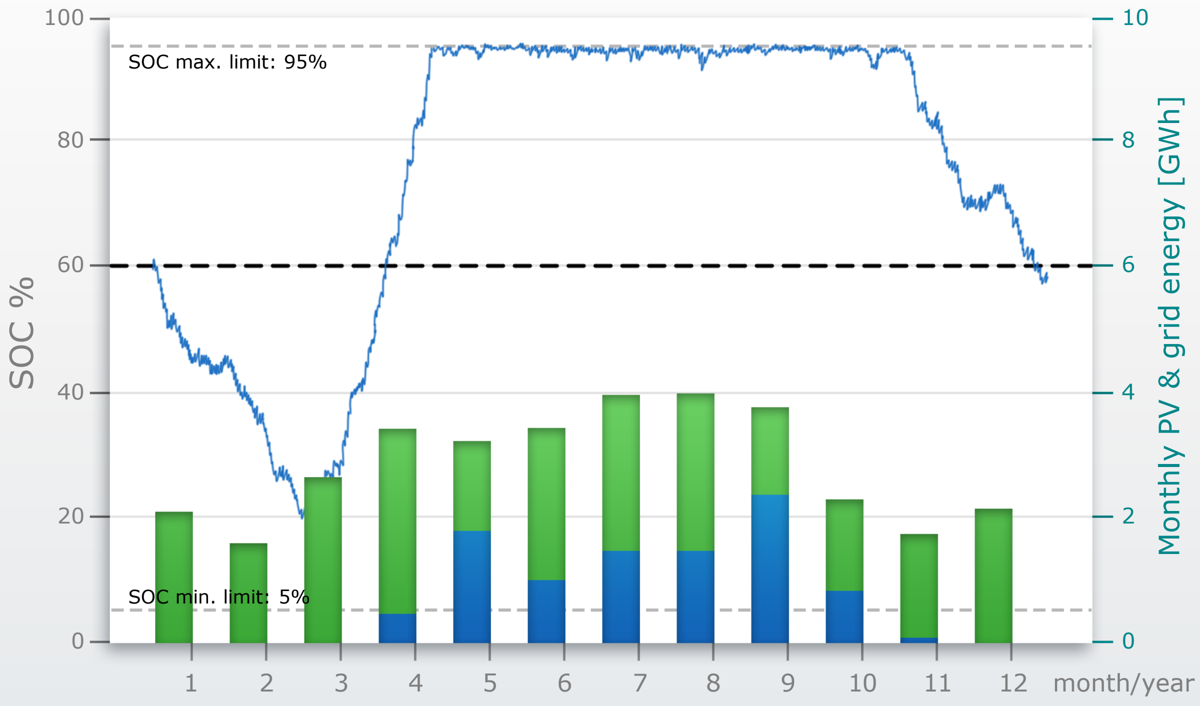
- Production: 500,000 t CO_2 eg.
- ➢ Over 25 vs. diesel bus operation

City Bus Fleet: Variation of Parameters to Reduce Storage Requirements

Case B: Oversize PV

- PV 28 MWp (140,000 m²)
- Storage 3.5 GWh

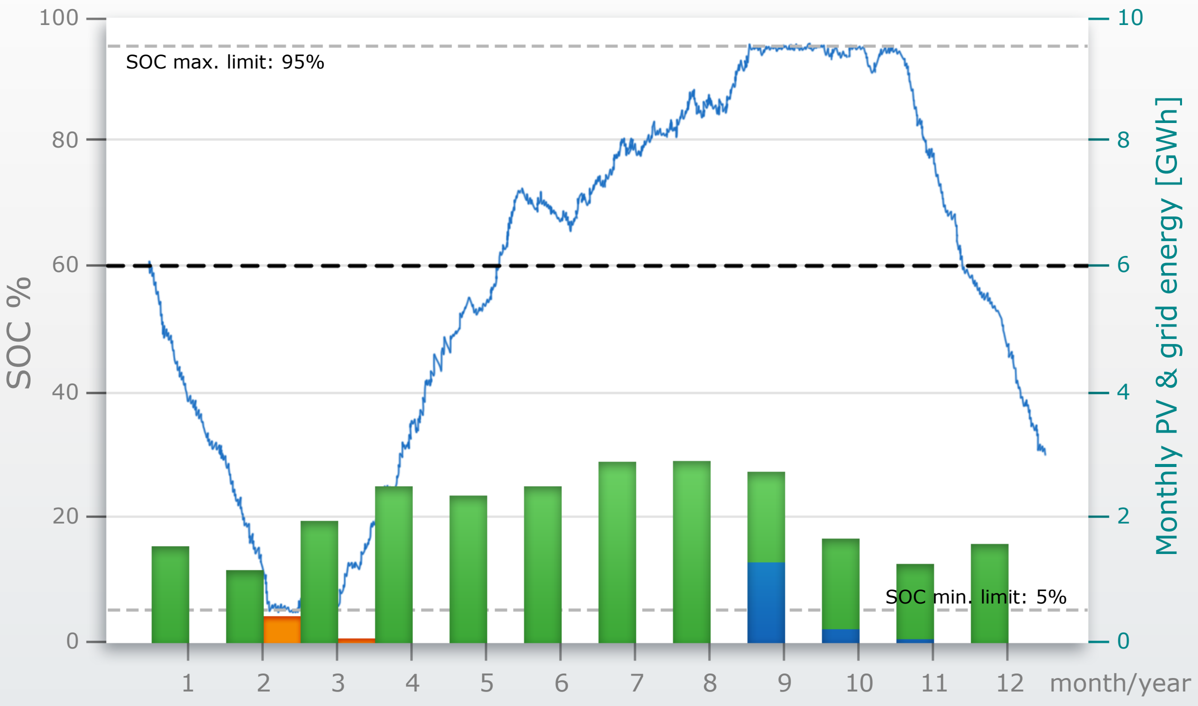
➡ **Solar export to grid in summer**



Case C: Winter deficit

- PV 20.4 MWp (102,000 m²)
- Storage 3.5 GWh

➡ (small) **Export to grid in summer**
(small) **Import from grid in winter**



PV output | Grid export | Grid import | SOC of storage

Graz City Bus Fleet – Summary

- EU Directive mandates for electric bus*
  – independent of origin of energy
- Thought experiment: solar bus operation
  for a true „green" transport system
- Large storage for seasonal balancing required
  – even if various system are coupled

➡ Beyond batteries – what other types of storage do we have?

How to deal with the annual cycle. The nature provides the successful example.

* or Hydrogen

Necessary Energy Storage-Scenarios 2050

E.g. Germany: 30 TWh for all Sectors (DENA-Study)

30 TWh

required in 2050*

- 40 million vehicles
- 30% of it usable
- 12 kWh available per vehicle

0.14 TWh
Possible contribution BEV Fleet Germany 2050

0.038 TWh
All Germany energy storage today

Image: HaSe

0.008 TWh
Largest energy storage Germany today

Image: Propriété Neoen

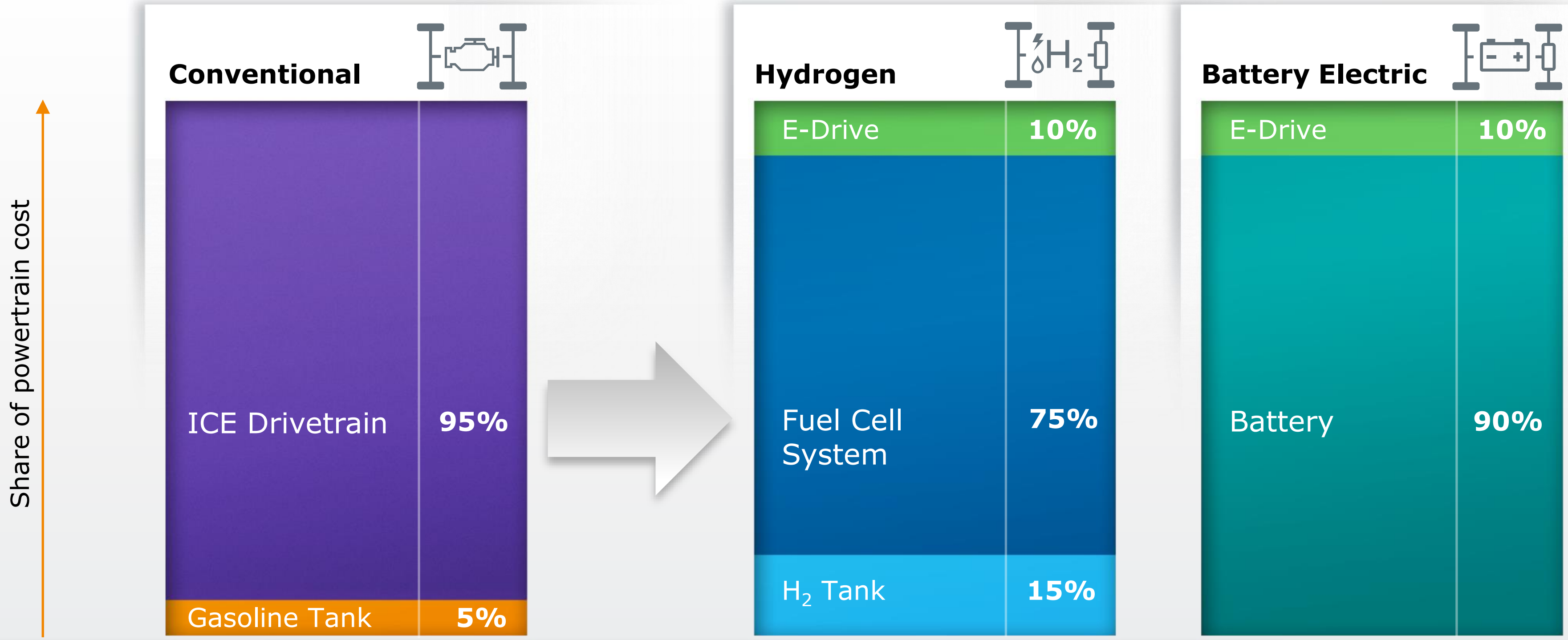
0.0005 TWh
A large battery storage (Victoria AUS, Tesla)

Propriété Neoen - Propriété Neoen, CC BY-SA 4.0 https://commons.wikimedia.org/w/index.php?curid=122680920
HaSe, CC BY-SA 4.0 https://commons.wikimedia.org/wiki/File:Pumpspeicherwerk_Goldisthal_Luftaufnahme_(2020).jpg

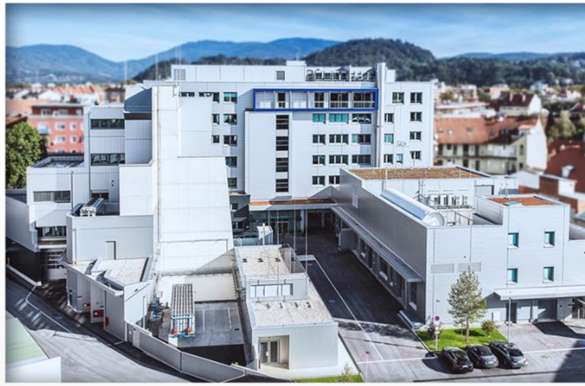
* DENA Leitstudie Integrierte Energiewende, 7/2018 Wissenschaftlicher Dienst des Bundestages, 01/2021 other (partly silmilar): Ariadne scenario report, 10/2021

Powertrain Value Share:
Significant Shift to Energy Storage

100 kW, 500 km range



Specific cost: **0.45 €/kWh** **12 €/kWh** **140 €/kWh**



AVL Fuel Cell Test Center

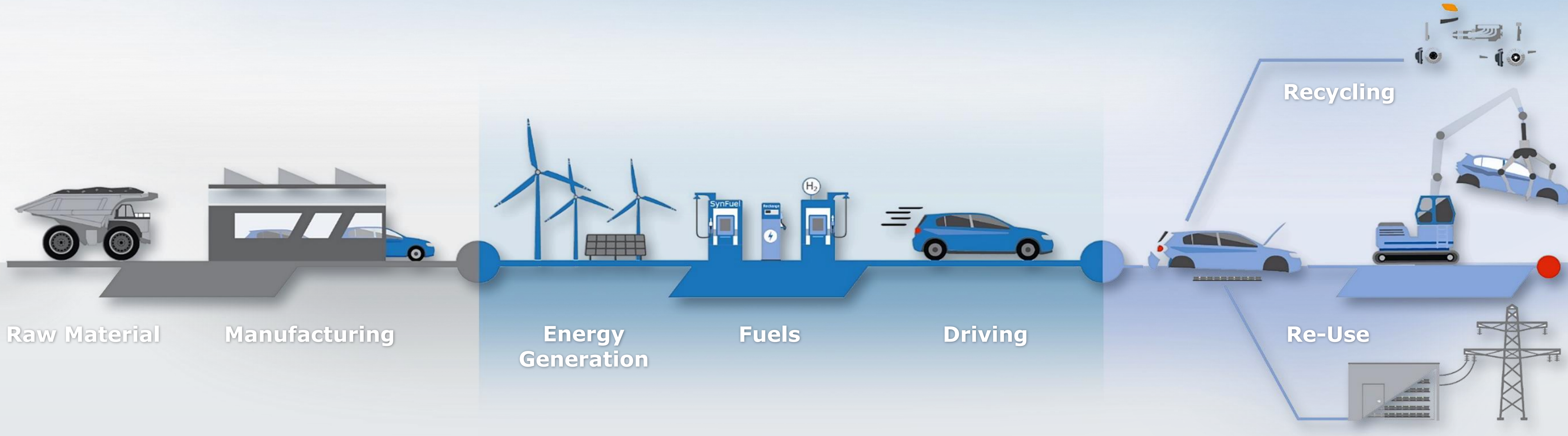
AVL Battery Innovation Center

AVL own cost estimates and neutralized customer projects, other sources include

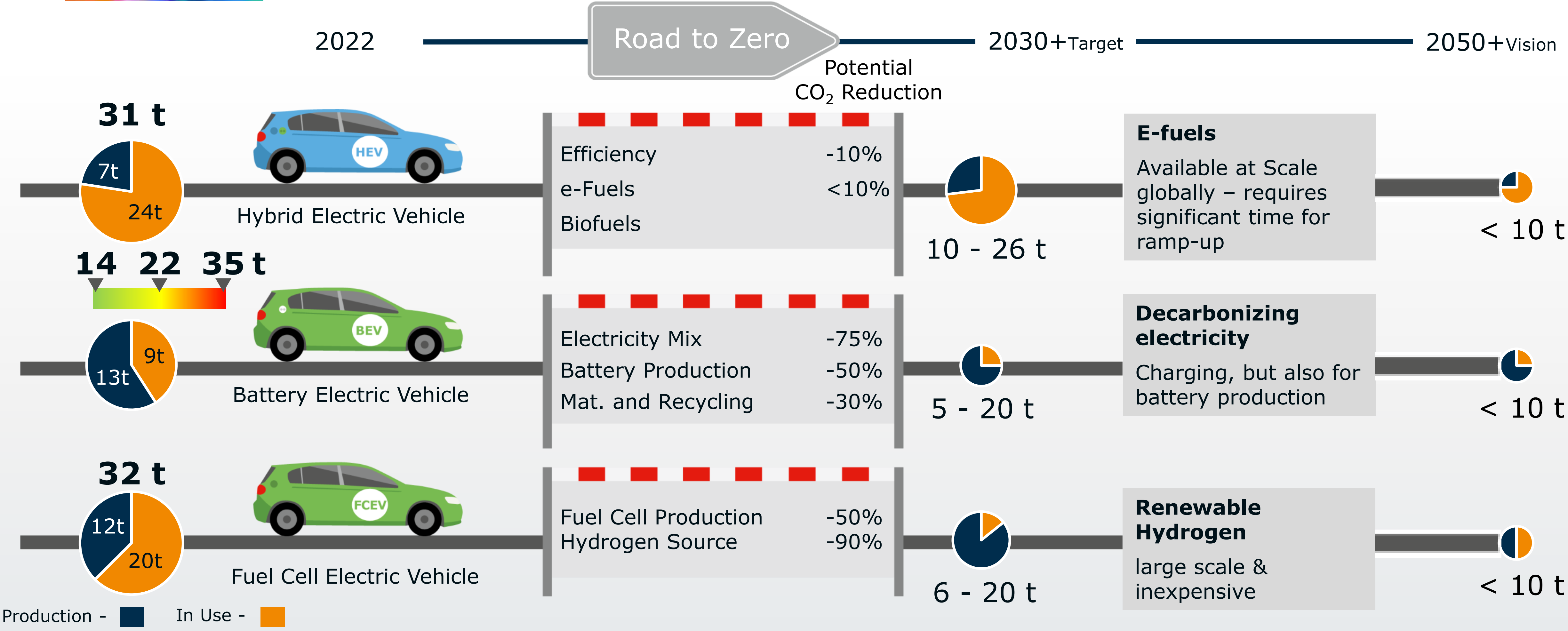
- Final Report: Hydrogen Storage System Cost Analysis, September 2016
- Hydrogen Storage Cost Analysis, https://www.hydrogen.energy.gov/pdfs/review21/st100_james_2021_o.pdf
- US DOE, https://www.energy.gov/eere/vehicles/articles/fotw-1206-oct-4-2021-doe-estimates-electric-vehicle-battery-pack-costs-2021

CO_2 Reduction as Major Business Driver

Green energy (wind & solar) and fuel	WtW	Choice of powertrain	Vehicle competitiveness
CO_2-lean material and production process	LCA	Product design	Corporate reporting, future regulations, B2B, product competitiveness
Product, process, business model	LCA+	Business & portfolio planning	Corporate bankability

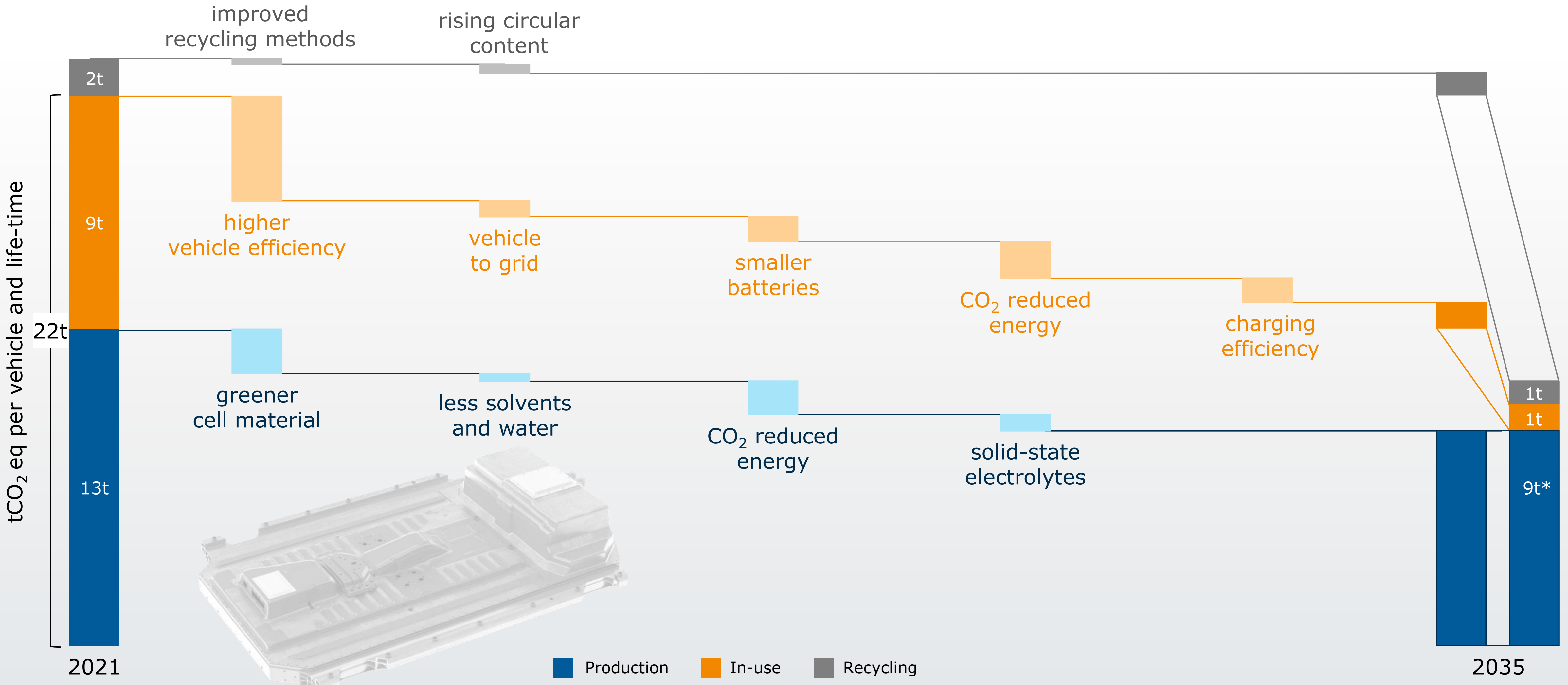


Competition of Powertrains
Automobile Roadmap to Zero CO_2



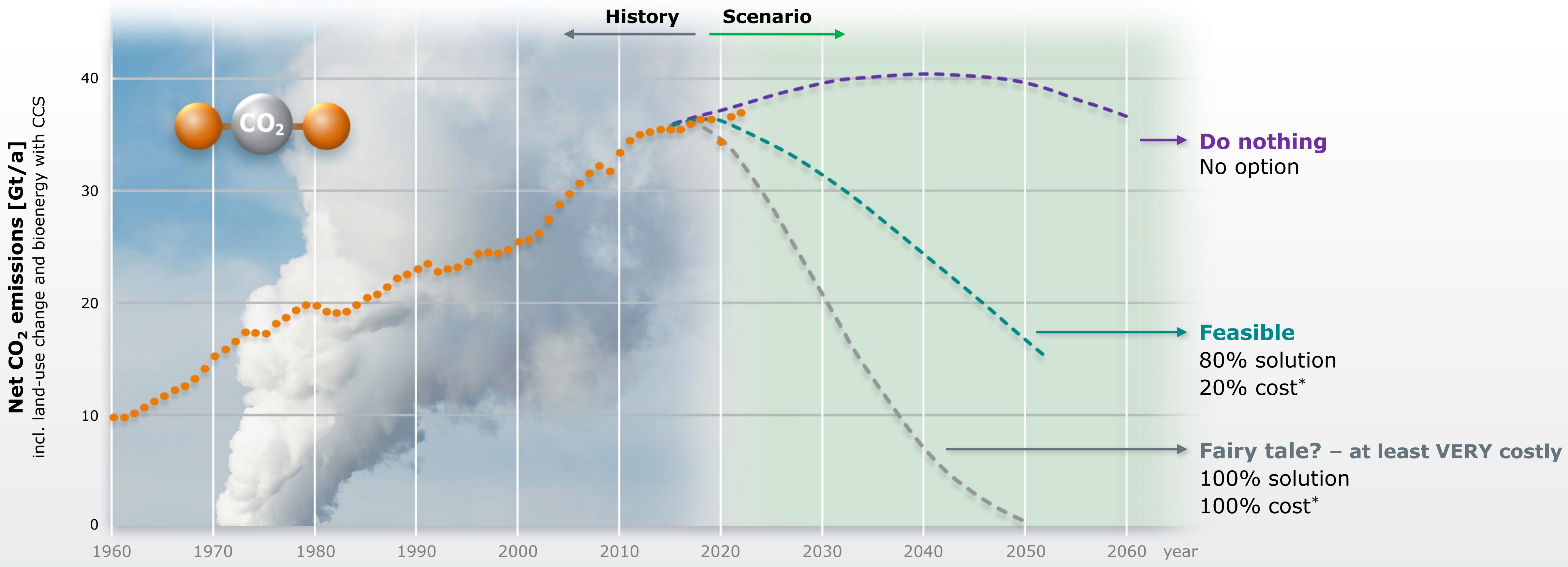
While there is no “zero emission” path, lifecycle emissions below 8 t $CO_{2\ eq}$ can be achieved on different ways
There is more than one way to skin a cat

BEV CO_2 Walk Life-Cycle – Battery Improvements Over Time



*PT w/o battery (glider) constant CO_2eq over time assumed

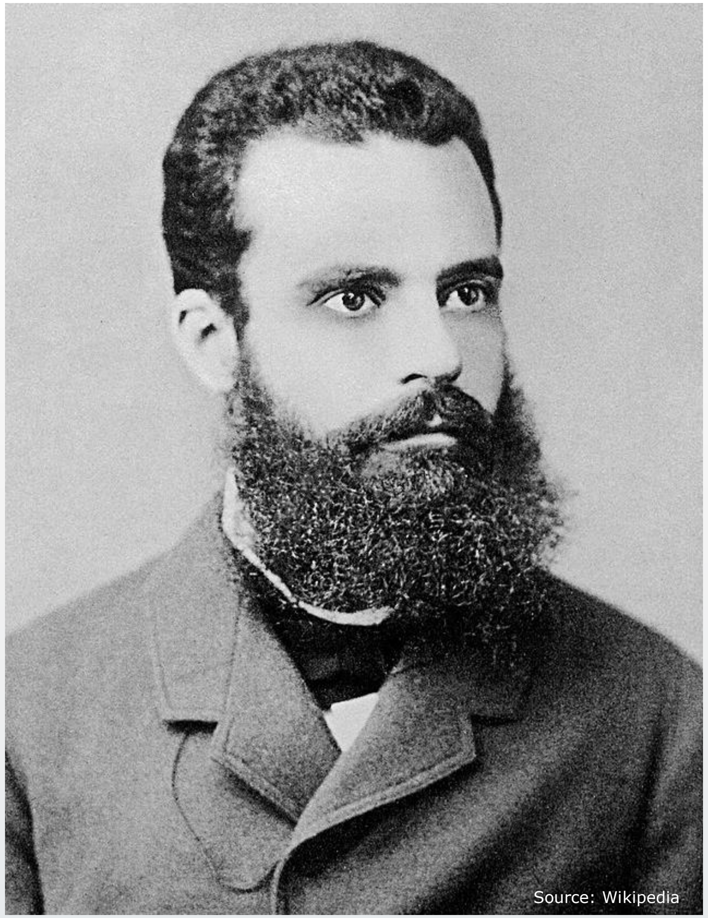
History of Global Human-Made CO_2 Emissions



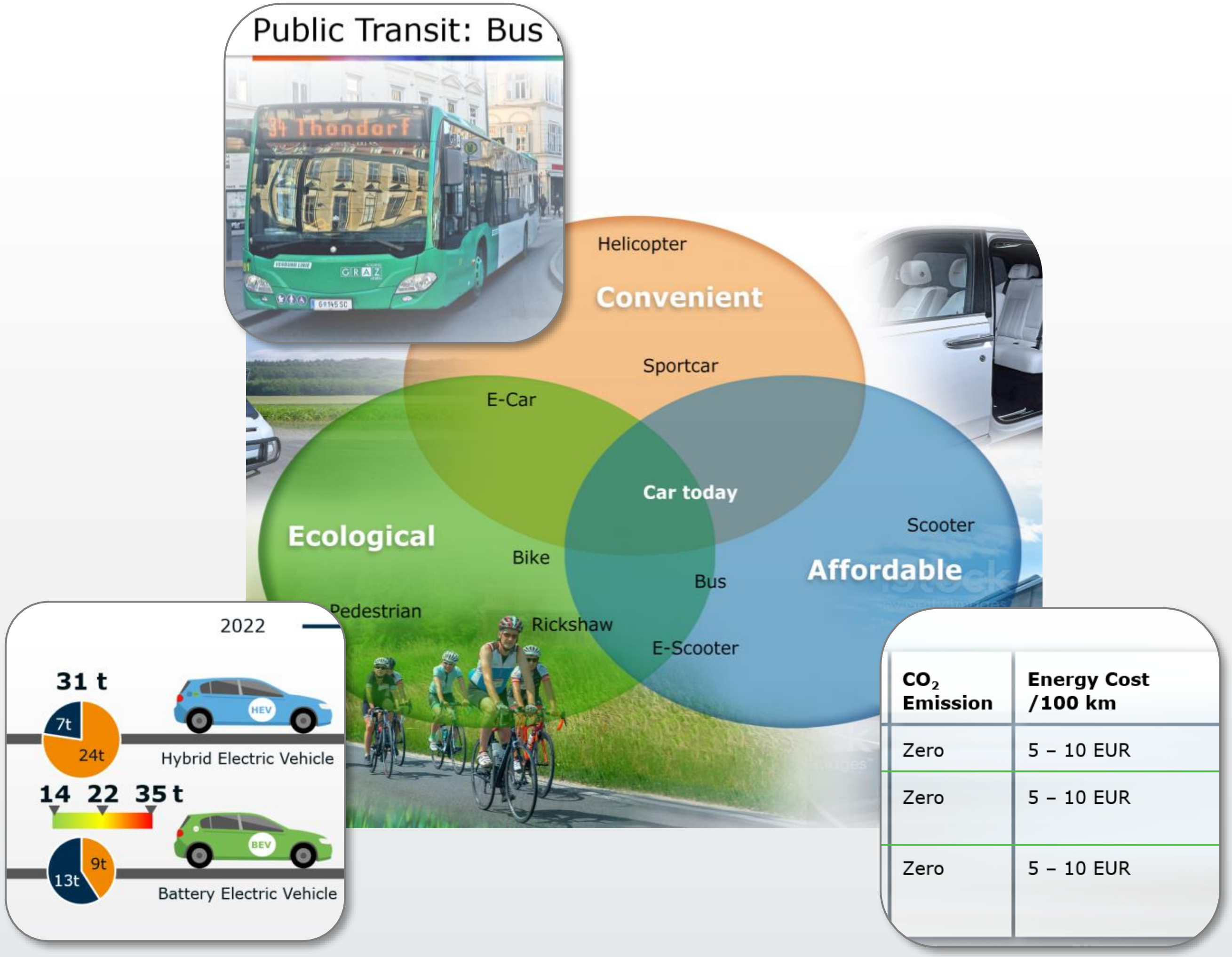
*monetary, but also environmental impact

Source: The Global Carbon Budget, Friedlingstein et al. 2020 (Historic Data), SSP Public Database (Scenarios), IEA 2014/IPCC (2010 sector split), IEA 2021, Net Zero by 2050, IEA Global Energy Review 2022

Not Perfect But Efficient



Vilfredo Federico Damaso **Pareto**
1848 - 1923



CO_2 Emission	Energy Cost /100 km
Zero	5 – 10 EUR
Zero	5 – 10 EUR
Zero	5 – 10 EUR

Conclusion

1. There is no "Zero" option

First things first
- Each step is important & better than waiting for an entirely green technology which might never come

Competing pathway towards GHG reduction exist
- Technology openness (despite current regulations dilemma)
- Green Electricity and green Hydrogen are increasingly relevant energy vectors

Key for relevant solutions: Acceptance!
- Feasible & available, affordable, accessible & convenient

2. The task of the century: Affordable transition

Getting out of fossil fuels is possible, but neither fast nor easy
- AVL is supporting planning and implementation for solutions on efficient energy conversion and storage

It's on us – Engineers and Scientists – to advance the necessary technologies for energy conversion, and support the implementation in mobility and energy

Sneak Preview 2023 Webinar Series

More detail will be provided in our next session

And you are invited to select the topic!

Vote 1 for

- The Energy Trilemma:
  Affordable, sustainable and available

Vote 2 for

- Taxation on CO_2: Accelerator to net-zero
  or new protectionism of local economies?

Vote 3 for

- News and insights on selected energy storage
  and energy transport technologies

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Sneak Preview 2023 Webinar Series - What should be next?

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