AVL

From Tank-to-Wheel to Life Cycle Emissions

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May 20, 2019

Prof. Dr. Uwe Dieter Grebe


" We came all this way to explore the moon, and the most important thing is that we discovered the Earth. "
William Anders, Apollo 8
December 24, 1968
Source: NASA

Example: Li-Ion Battery Materials

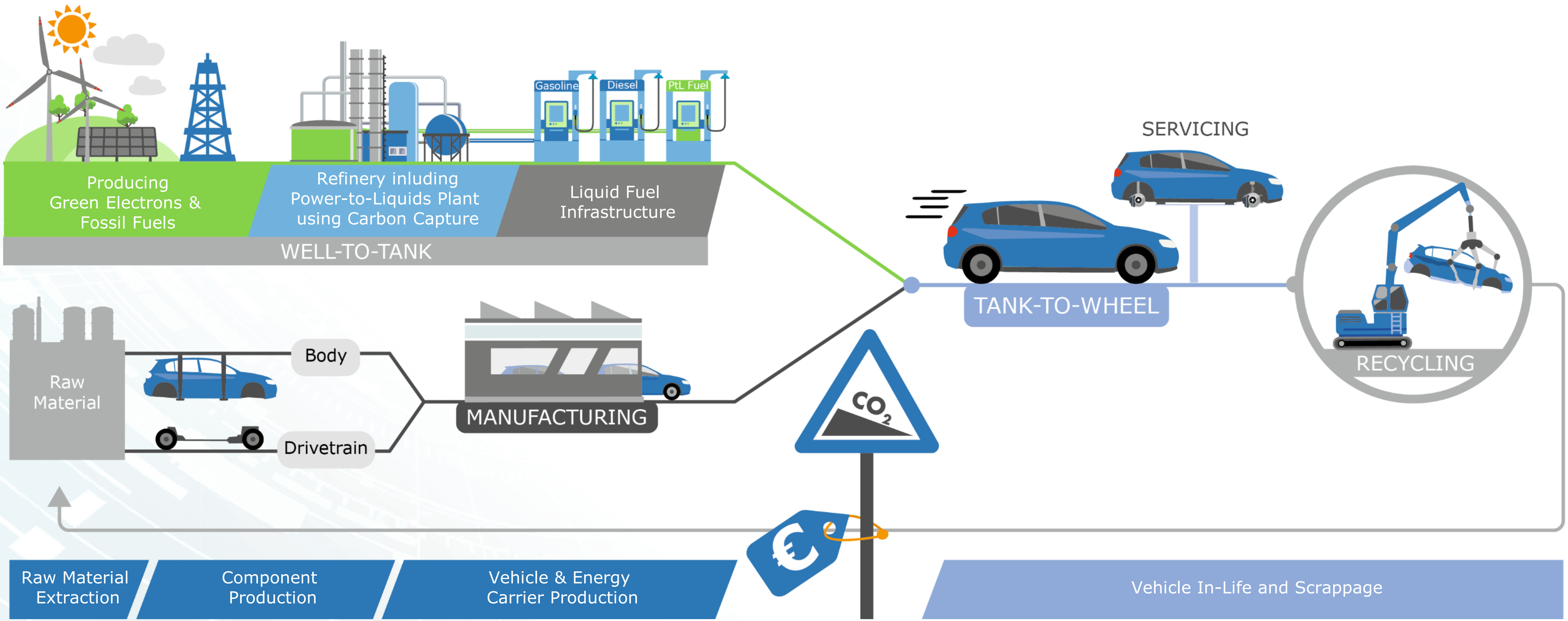
Challenges:
- Destruction of sensible Ecosystems
- Hazardous Emissions
- Substandard working conditions

Cobalt washing at a small mine, Kongo

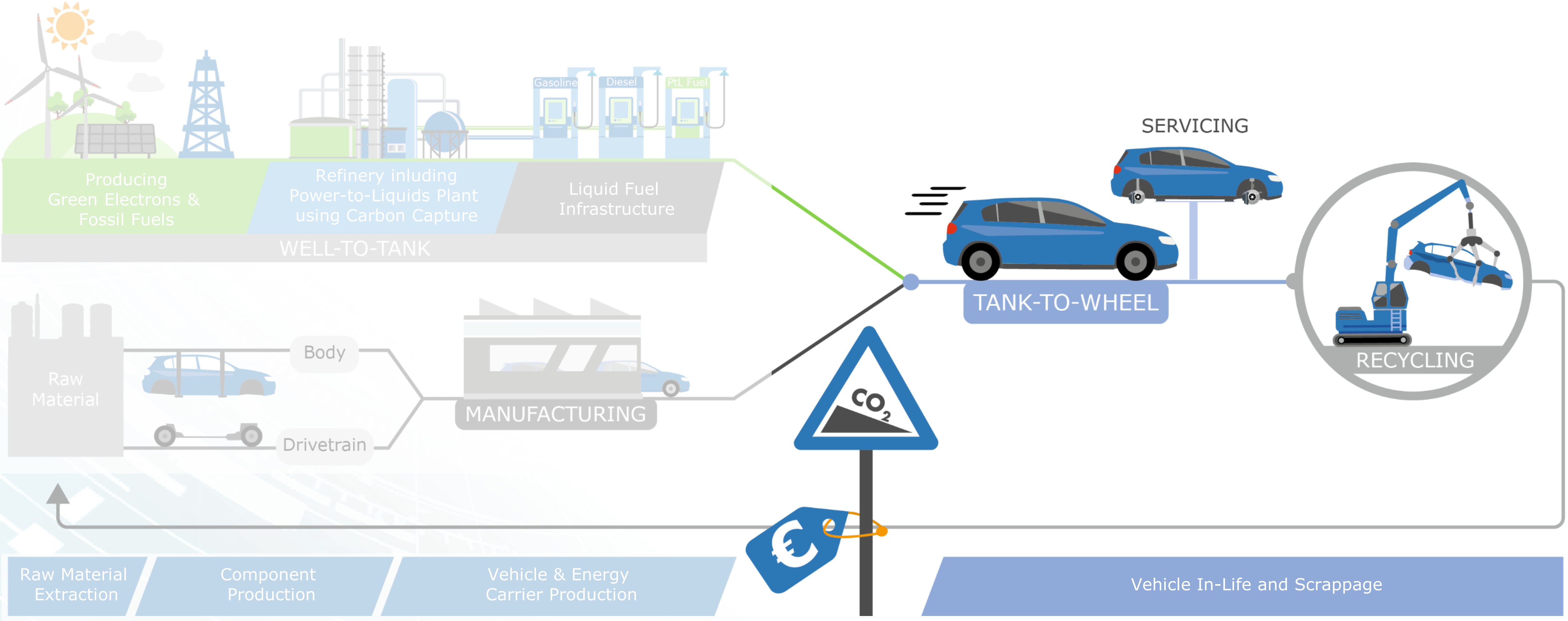
Actions for Sustainability:
- Ensure State-of-the-art process engineering
- Study & minimize ecosystem impact
- Implement EoL strategies & Material Recycling

Matanda Copper & Cobalt Mine, Kongo

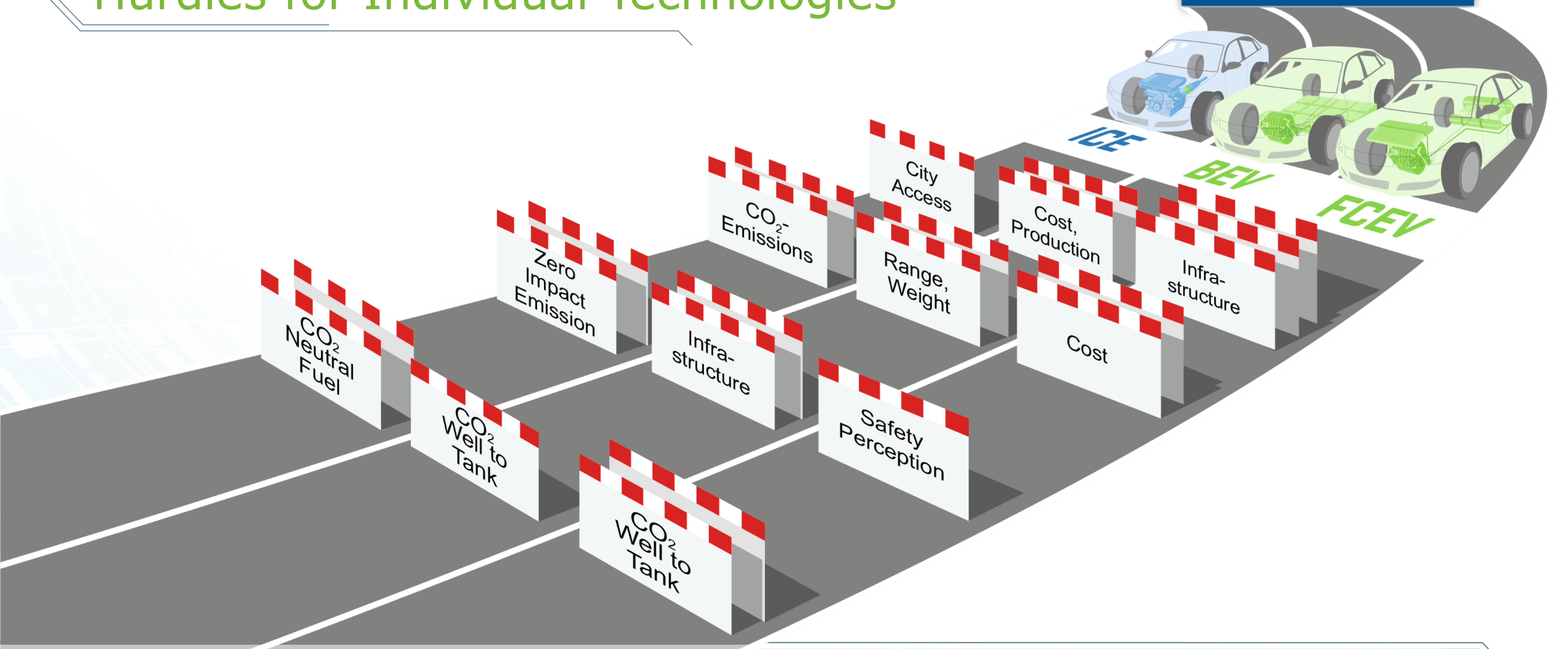
Life Cycle CO_2



Life Cycle CO_2



Powertrain Competition
Hurdles for Individual Technologies



The need for individual mobility will lead to a coexistence of different propulsion systems

ICE-based Powertrain with Zero Impact Emission

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Affordable Mobility with unlimited Driving Range

RDE

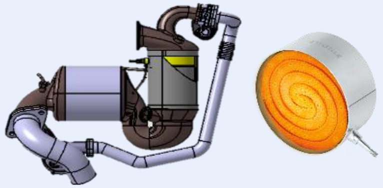
REAL DRIVING EMISSIONS

Compliance in all Driving Situations

Severity
- EU
- China
- India
- US

TECHNOLOGY EVOLUTION

Combustion

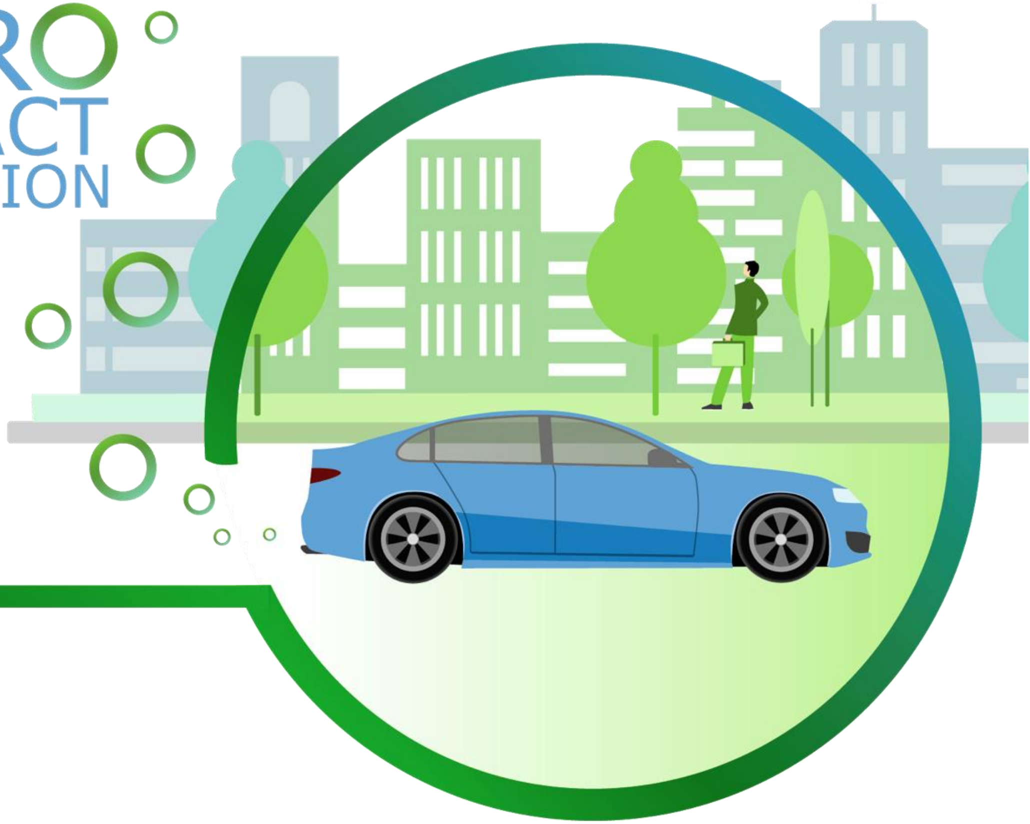


Aftertreatment

Process and Thermal Control

Hybrid

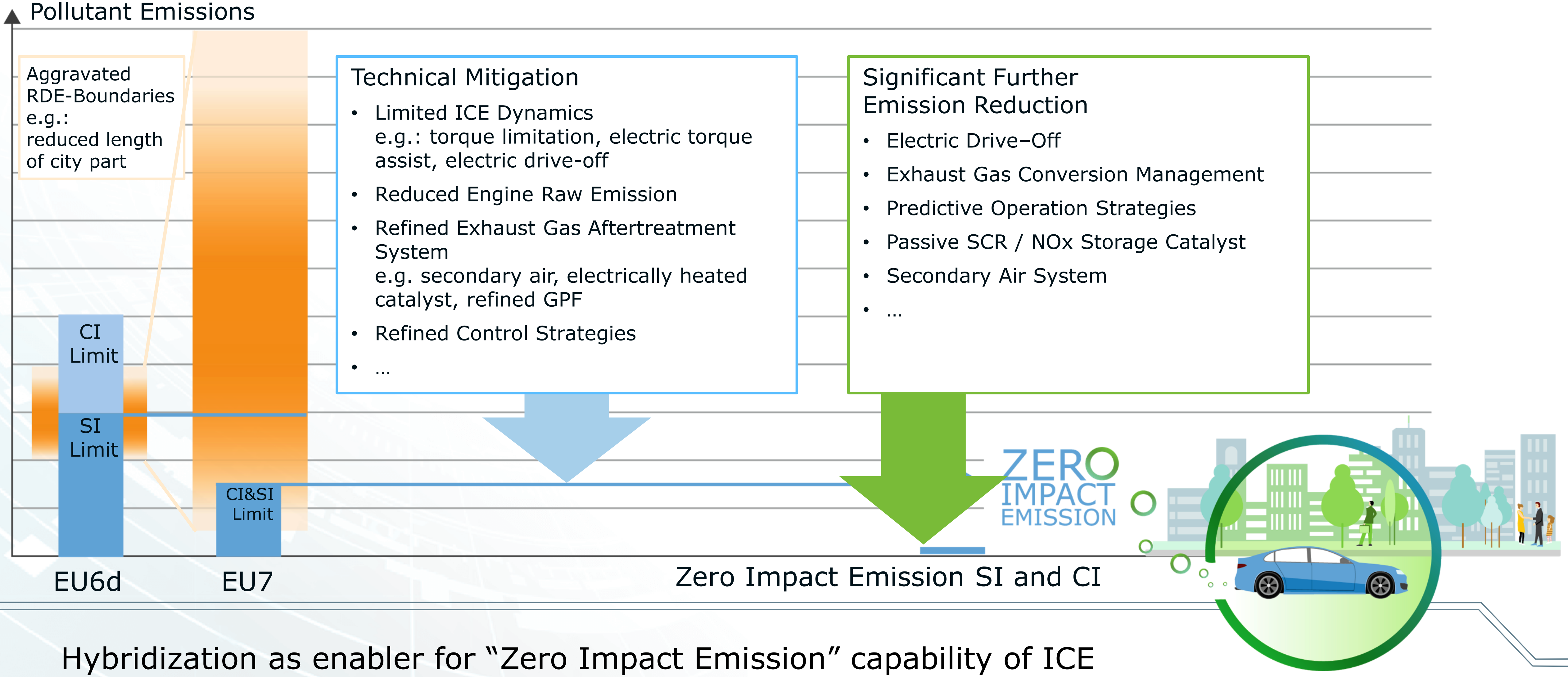
ZERO IMPACT EMISSION



Reasonably low product cost increase allows for local air quality without impact to human health

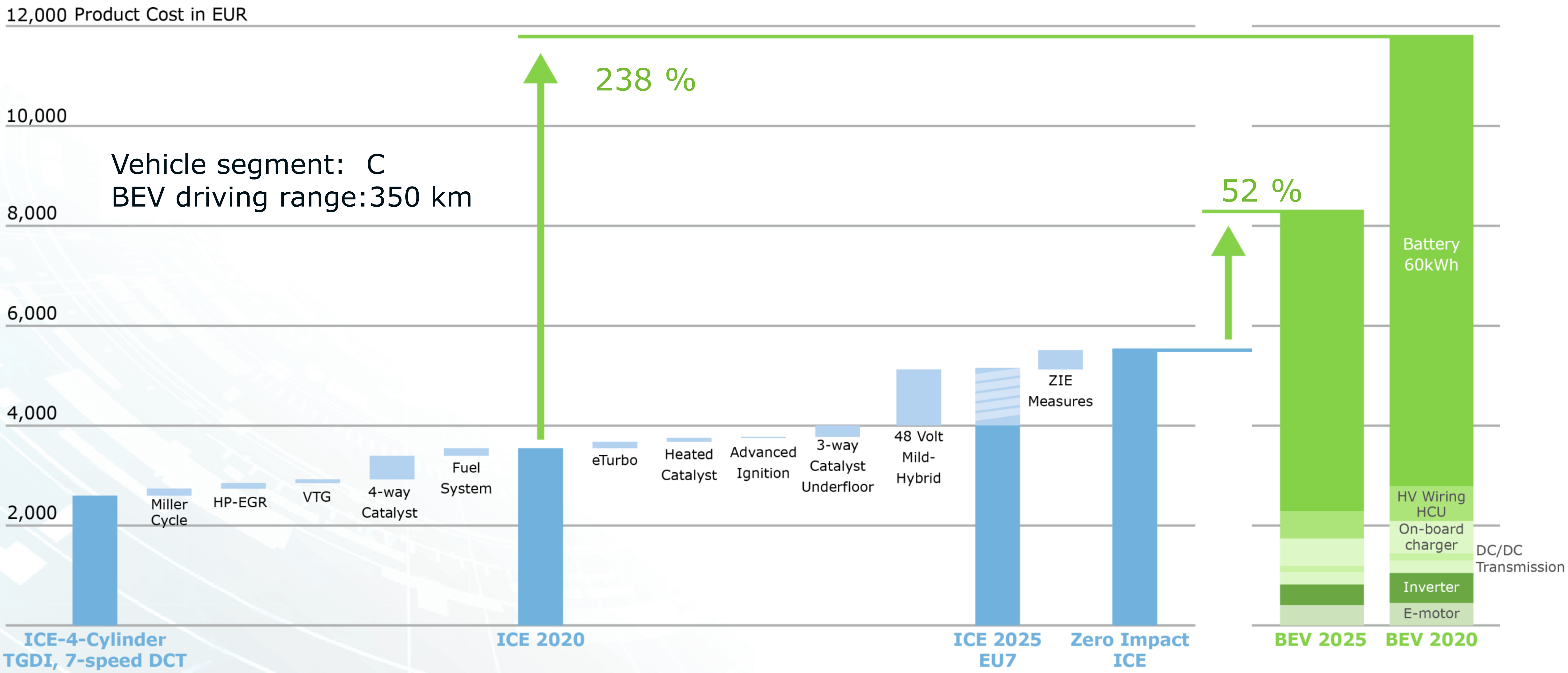
Internal Combustion Engines with zero impact on the air quality in cities are possible and reasonably affordable

On the way to Zero Impact Emissions



Hybridization as enabler for “Zero Impact Emission” capability of ICE

Cost Walk
Zero Impact Emission ICE and BEV



Global CO_2 Reduction – CAFE / CAFC

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2015–2030
-30-40% ?

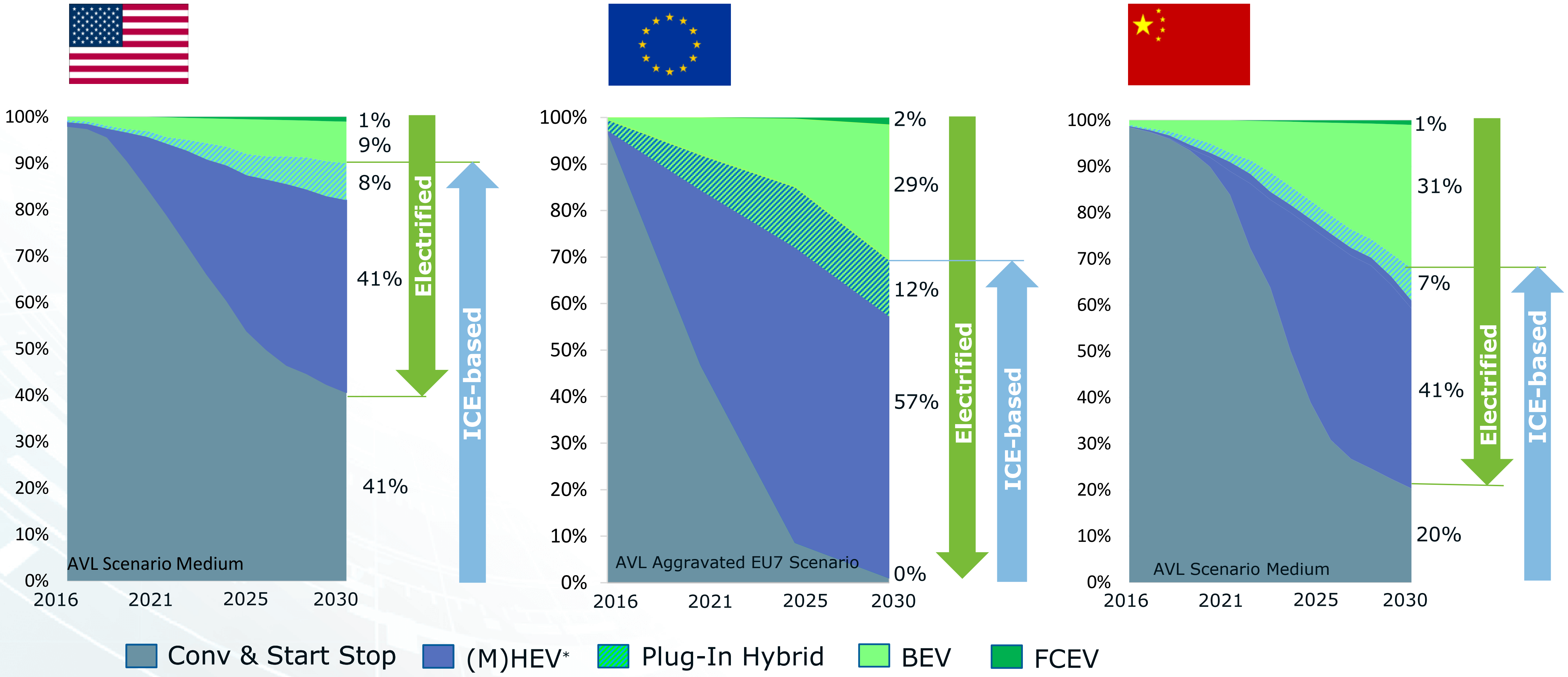
2015 – 2030
-56%

2015 – 2030
-50-60% ?

USA	EU	China
Freezing 2020 targets until 2026 ?	NEDC → WLTP -15% $_{2025}$, - 37,5% $_{2030}$	NEV share mandatory
ZEV requirements in CA	Zero Level Emission Vehicles 15% $_{2025}$, 35% $_{2030}$	License plate restrictions
Accounting for CO_2 from electricity 2025 ?	Real World CO_2 ?	NEDC → WLTP (CATC) ?

Significant aggravation of CAFE targets especially in EU and China

Technology Forecast - LD Vehicles 2030
New Vehicle Production – AVL "Most Likely "



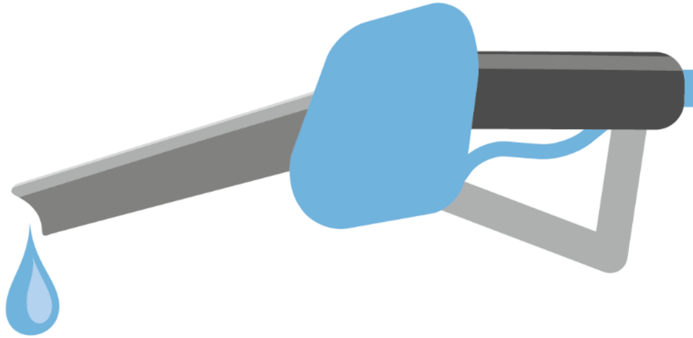
AVL prediction 04/2019

*) incl. 48V with e-Drive

What if Synthetic Fuels are available?

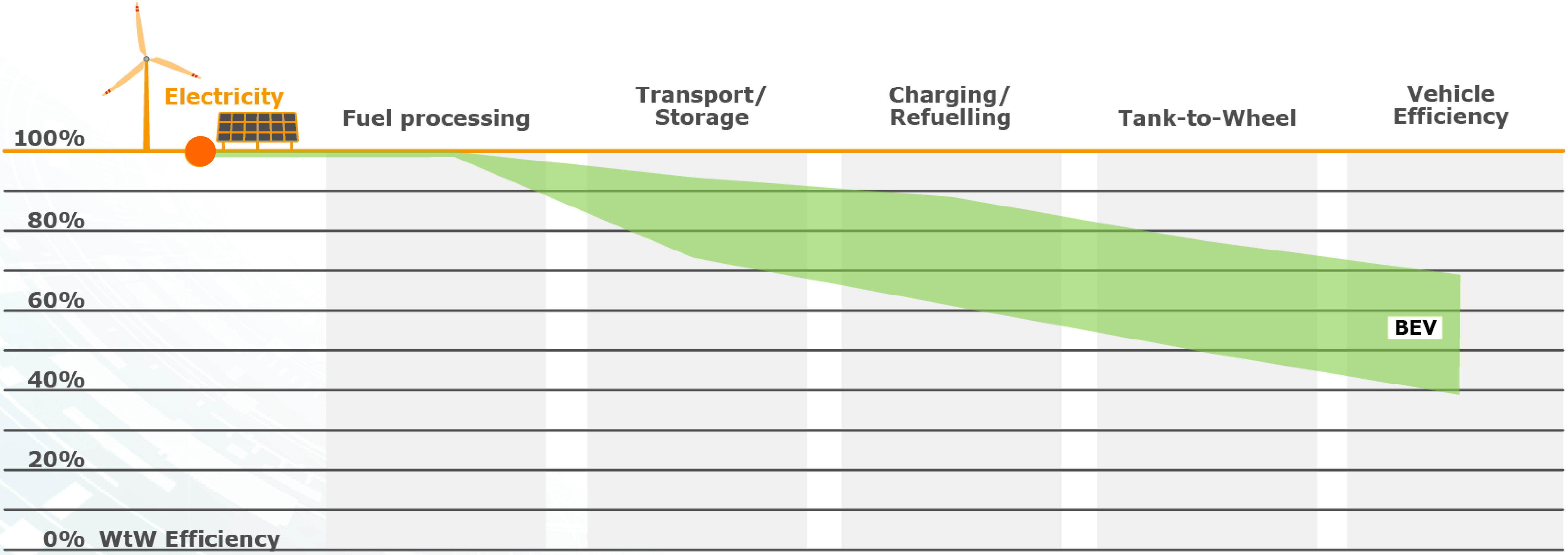
Power-to-X (E-Fuels)

- Feasible scenario –
  Technologies are fundamentally established
- Storage to balance fluctuations from wind and solar
- Scale-up and infrastructure built-up need to be started soon to enable sizable volumes mid-term
- Will be in competition to other alternative renewable routes
  (Hydrogen, Battery Electric)
- Aviation and ocean-going marine likely to be first in line for any liquid fuels



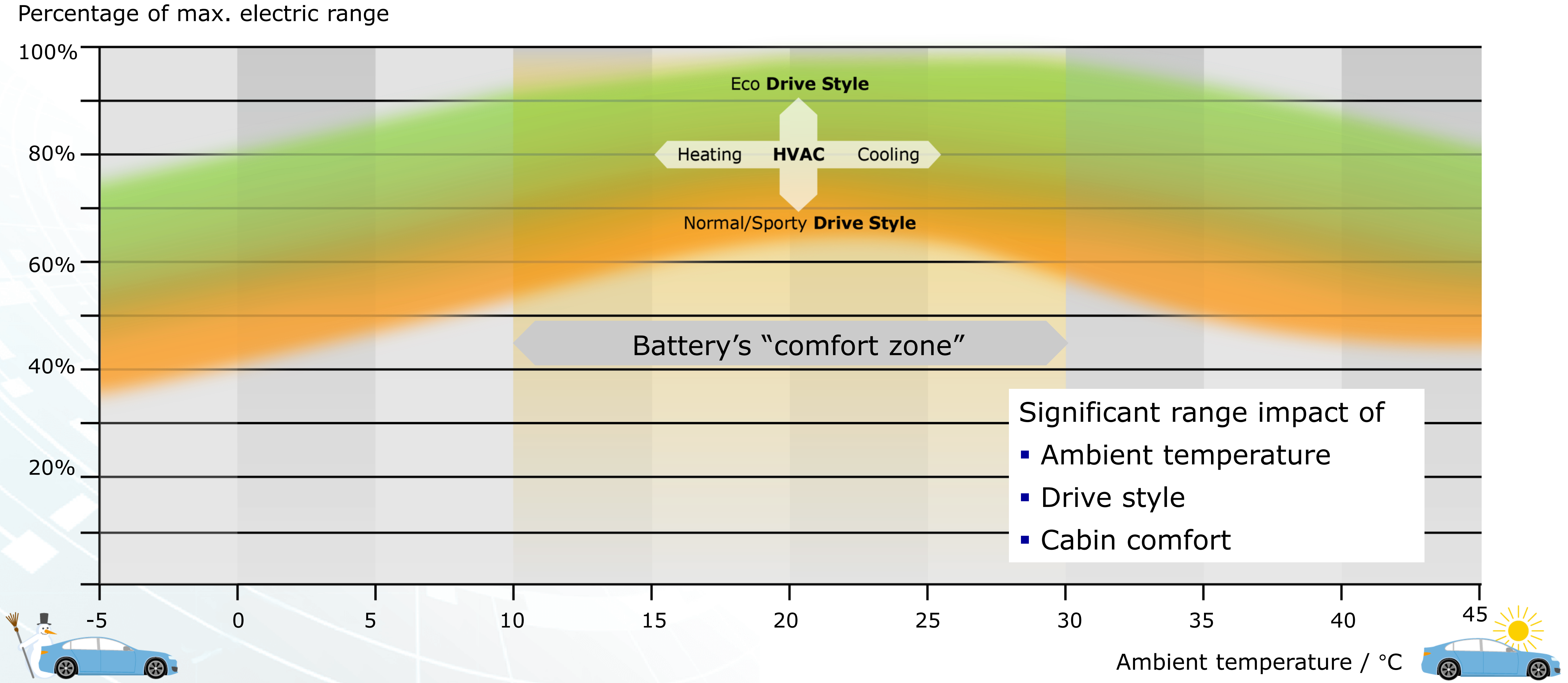
PtX Fuels are a favorable option to use as drop-in for existing fleet

Efficiency Chain: from Source to Wheel

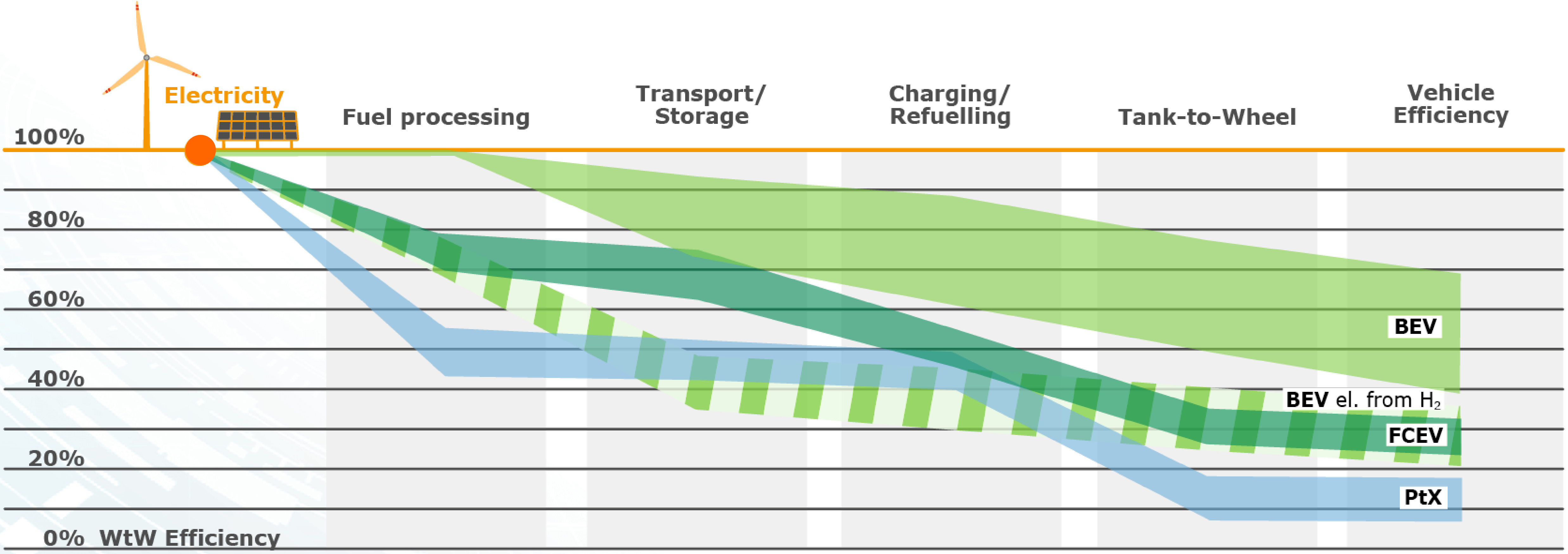


Source: AVL

Real World EV Driving Range: A reliable Uncertainty

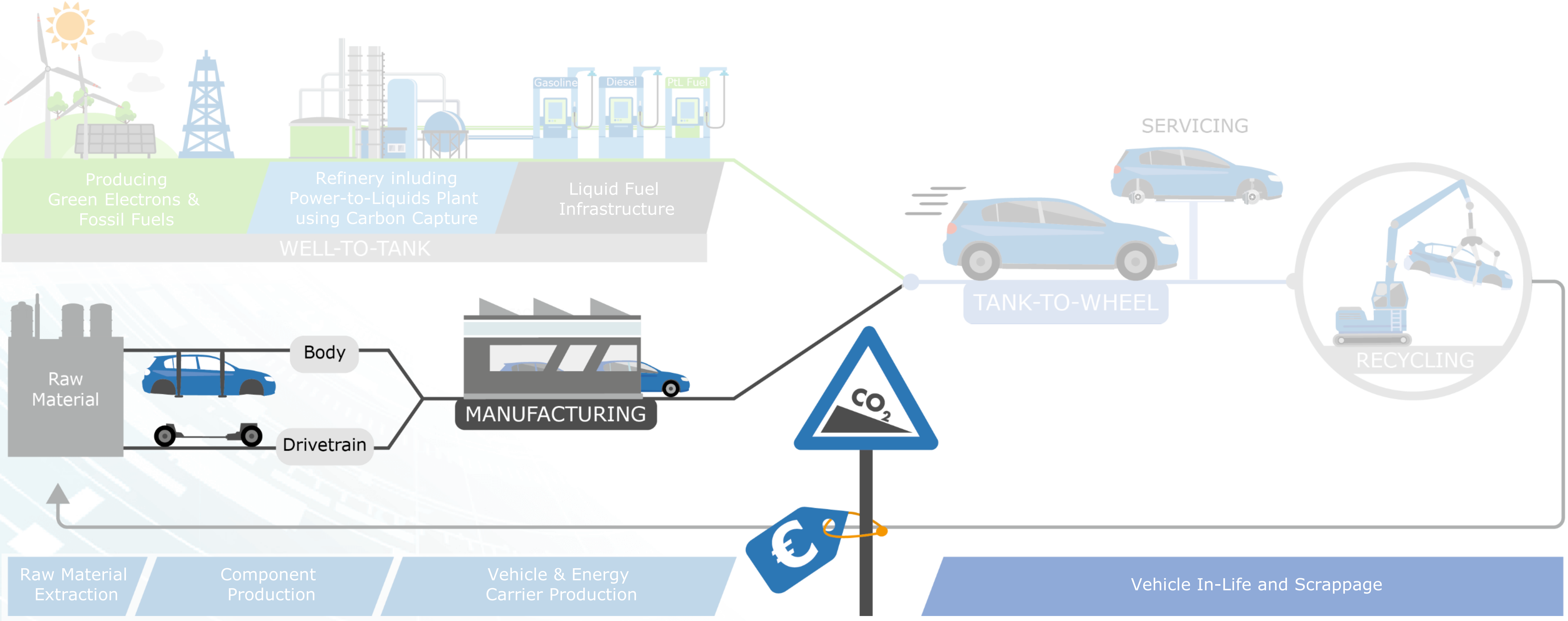


Efficiency Chain: from Source to Wheel

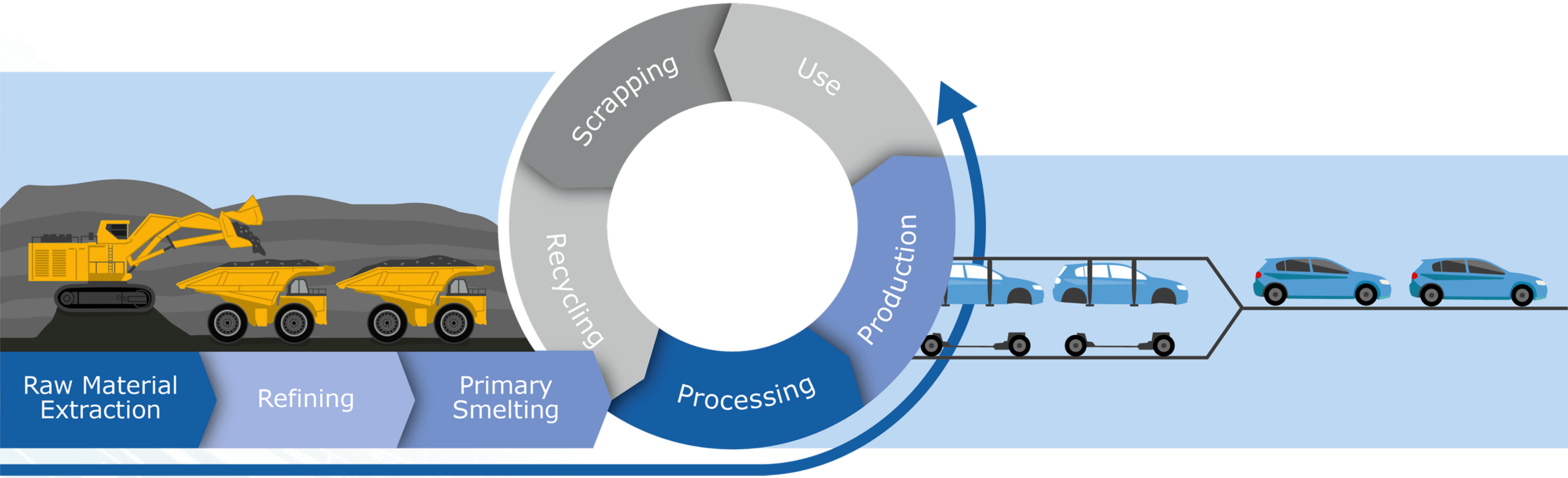


Source: AVL

Life Cycle CO_2

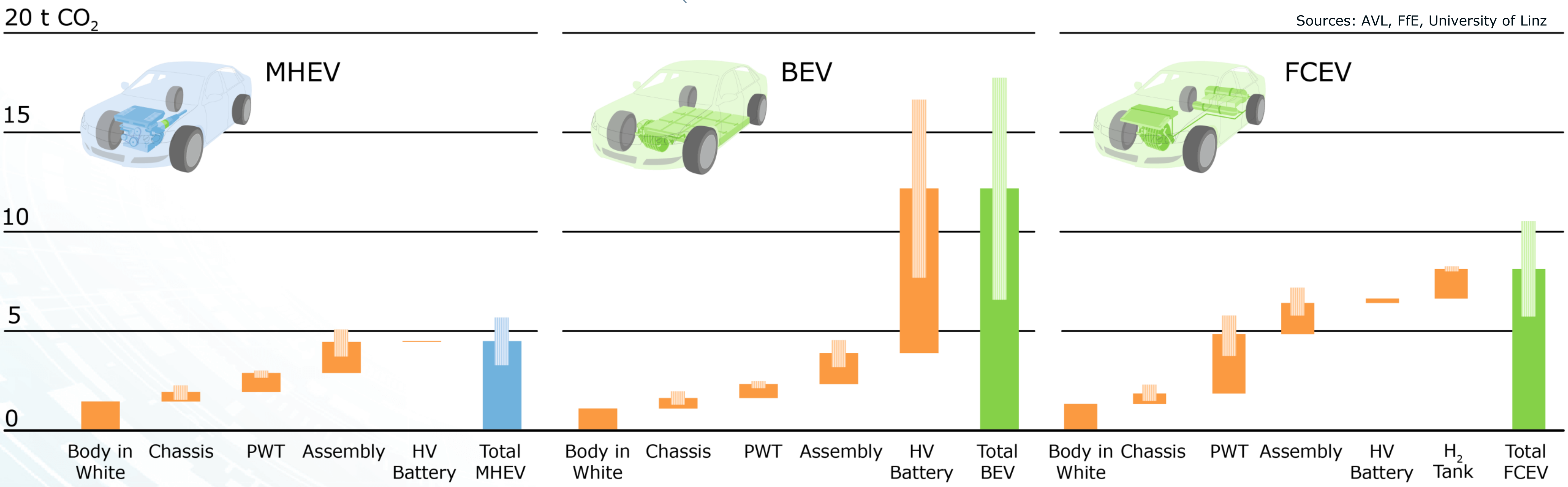


Vehicle Production GHG Emissions



Raw Material Extraction, Refining and Smelting needs to be included into assessment of Vehicle GHG Emissions. Recycling is a potential for GHG Reduction.

Vehicle Production GHG Emissions



C-Segment Vehicle
Values largely dependent on boundary conditions:

MHEV

"GHG lean" production for base Vehicle and ICE. Today "real world" values vary largely (up to 8 t/veh.)

BEV

Battery 60 kWh, US MI Electricity Mix, Production Best-Practice (140 kg CO_2/kWh)

Battery-related: Variation 62 to 212 kg CO_2/kWh, depending on battery manufacturing

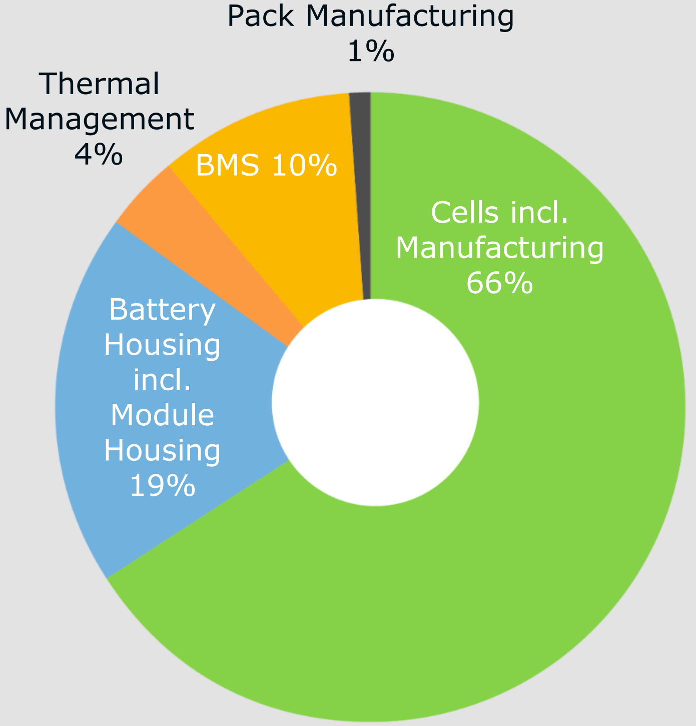
FCEV

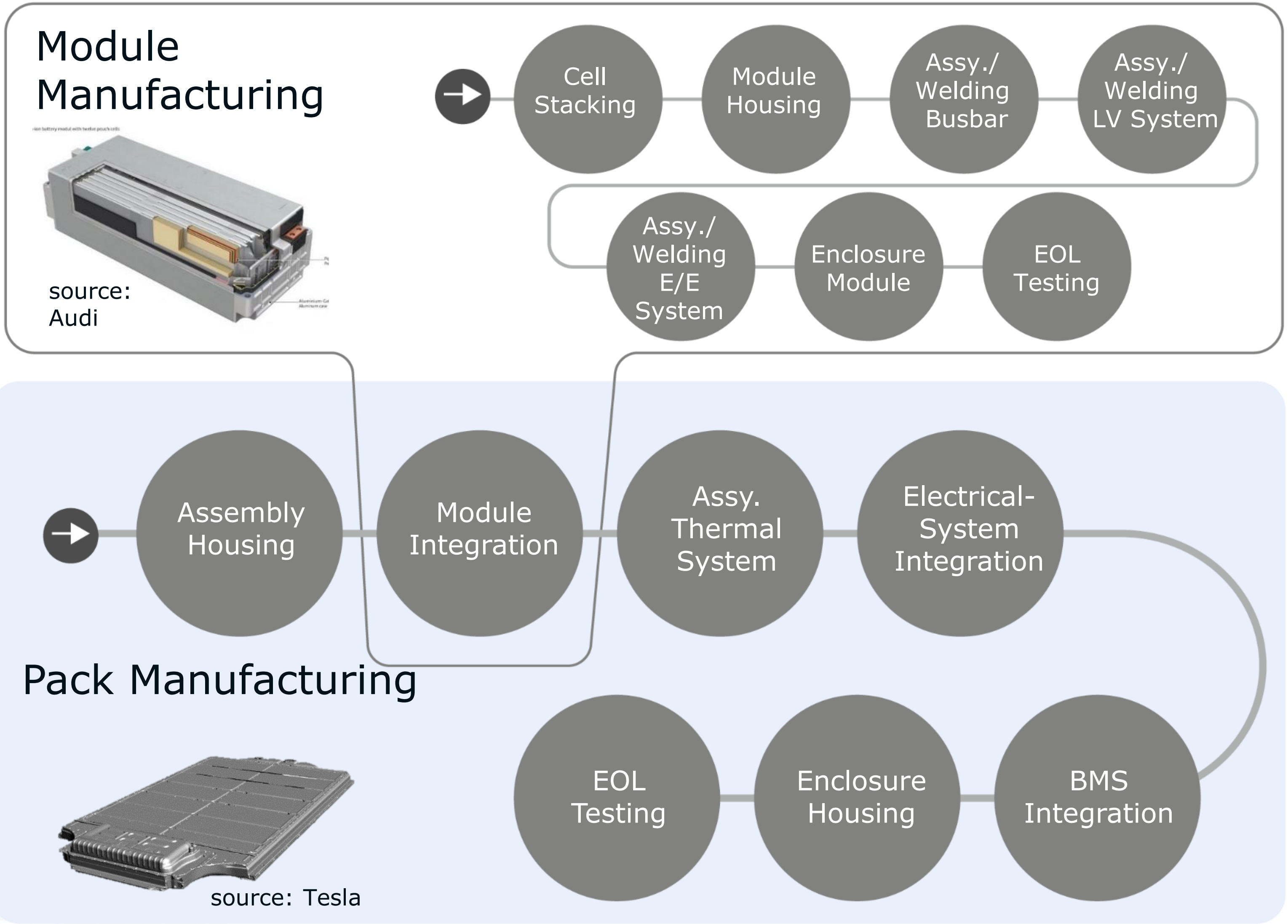
Fuel Cell Stack: 80kW

Carbon Fiber Hydrogen Storage, 5 kg capacity. Carbon Fiber Production Footprint 25 kg CO_2/kg (range is 20…31)

Battery Pack Production GHG Emissions

GHG Share of Battery Pack

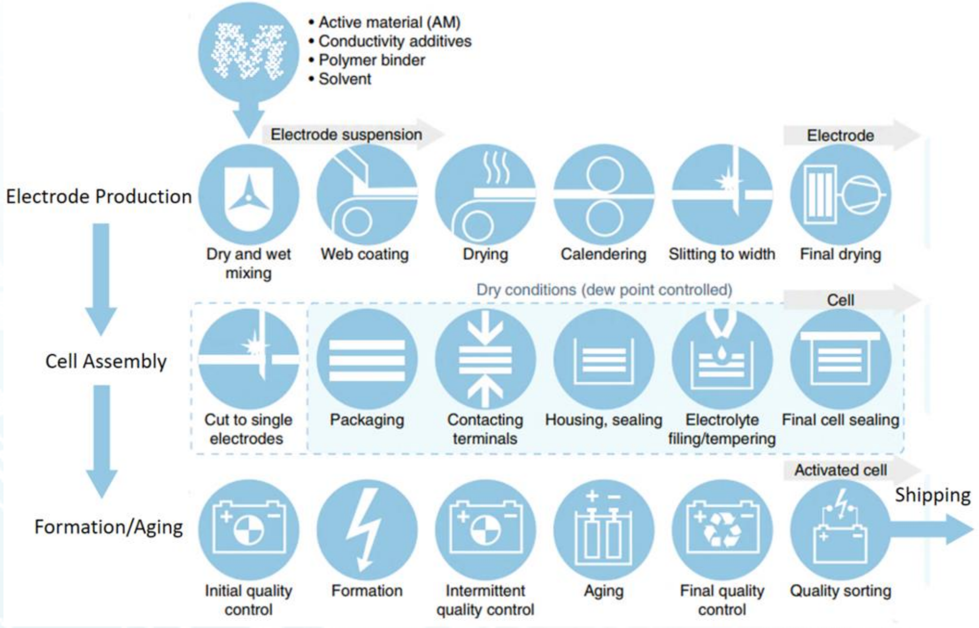


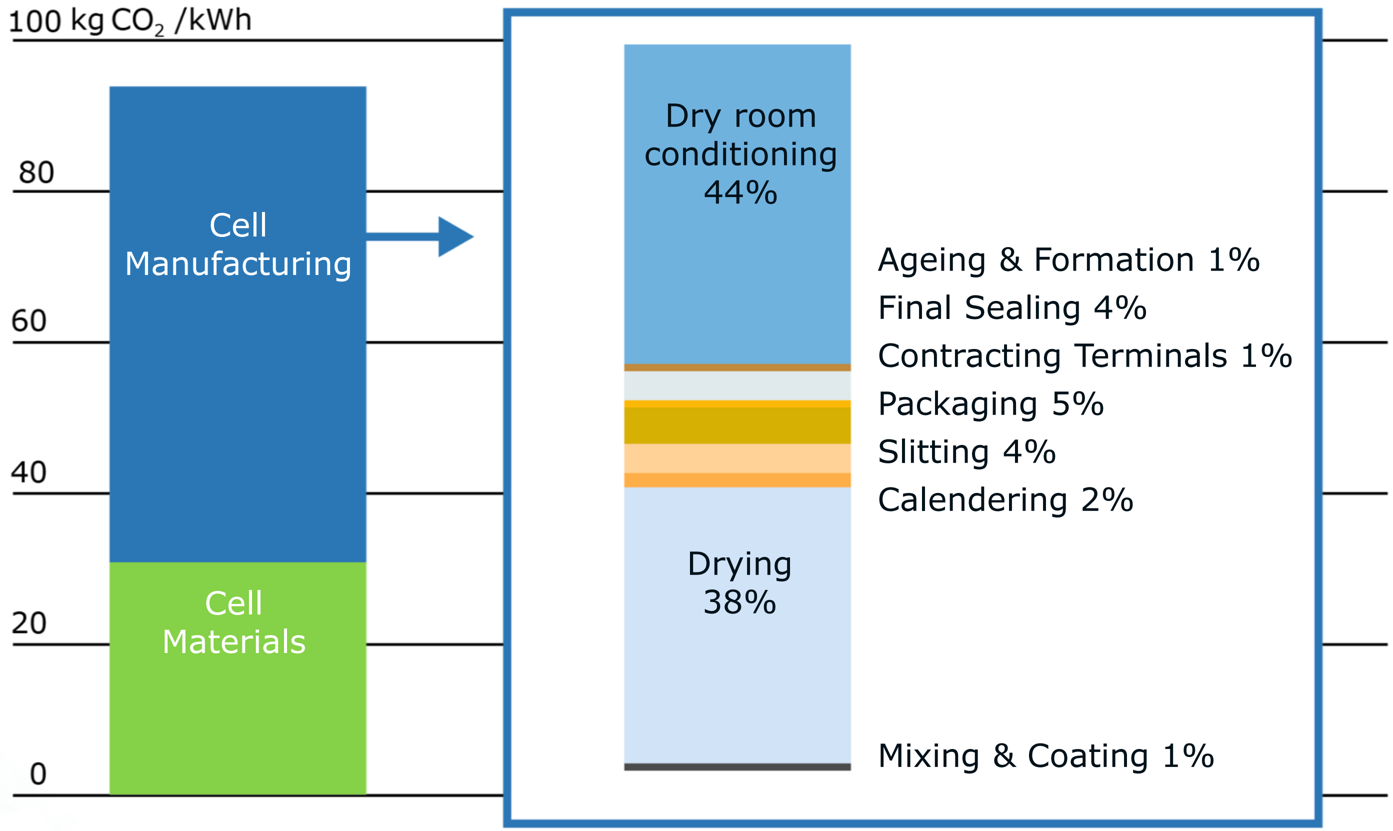


source: Audi

source: Tesla

Battery Cell Production GHG Emissions





References:
Kwade et al., Nature Energy (2018)
H. C. Kim et al. Env. Sci. (2016)
C. Yuan et al. Manuf. Tech. (2017)
L. Janschitz, AVL, Master Thesis (2018)

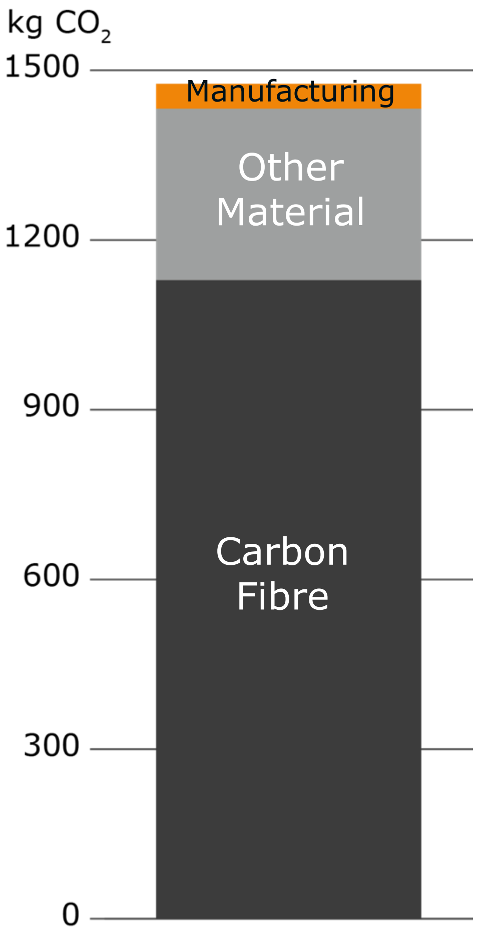
Fuel Cell Tank Production GHG Emissions

Type 4 Hydrogen Storage Vessel
(AVL / OEM Specimen)

Manufacturing Steps

	Material Input	Manuf. Step
1	Plastic Liner	Injection Molding
2		Thermal Treatment
3	Silicon	Coating
4	Plastic Liner	Laser Welding
5	Carbon Fiber	Winding
6	Glass Fiber	Winding
7		Hardening
8	PU Foam	Protectors
9		Cleaning
10		End of Line Test

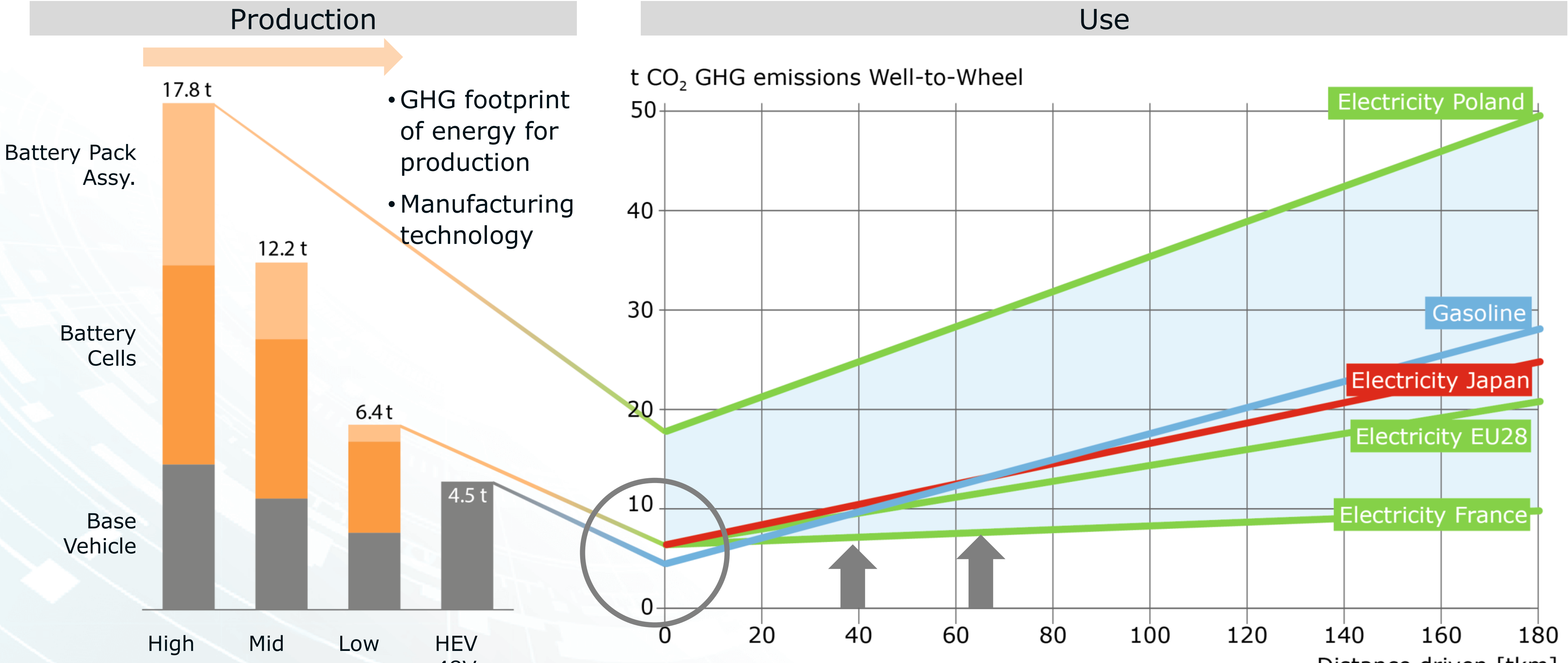
GHG Emissions for Vessel Manufacturing



2-vessel system, capacity 5 kg (usable)
Vessels only, i.e. w/o valves, receptacle, PRD.

References
AVL Benchmark Data
J.J. Cook, NREL Technical Report (2017)
Toray technical data (T700 Fiber)

Production and Well-to-Wheel
A long Use Phase to offset for Production



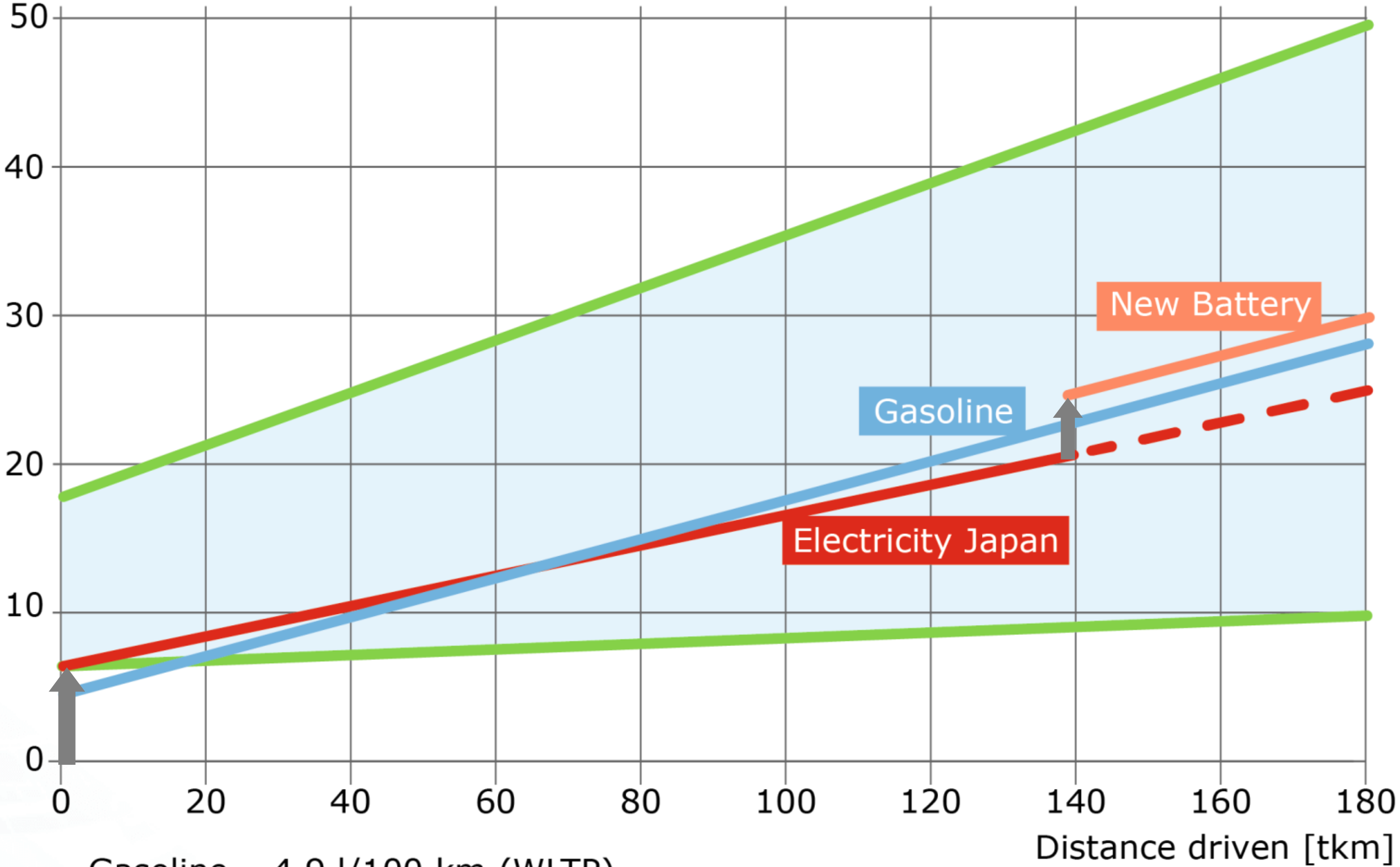
- GHG footprint of energy for production
- Manufacturing technology

Gasoline – 4.9 l/100 km (WLTP)
BEV – 18 kWh/100 km (WLTP)

*Electricity Low Voltage, 2013 data, from A. Moro, L. Lonza, Transp. Res. D64, 5ff (2018)

Use Phase and battery calendar life

German Car Fleet*:
- Average Age – 9.4 y
- Annual Mileage – 13922 km
- Many Cars (>28%) older than 15 years at EoL



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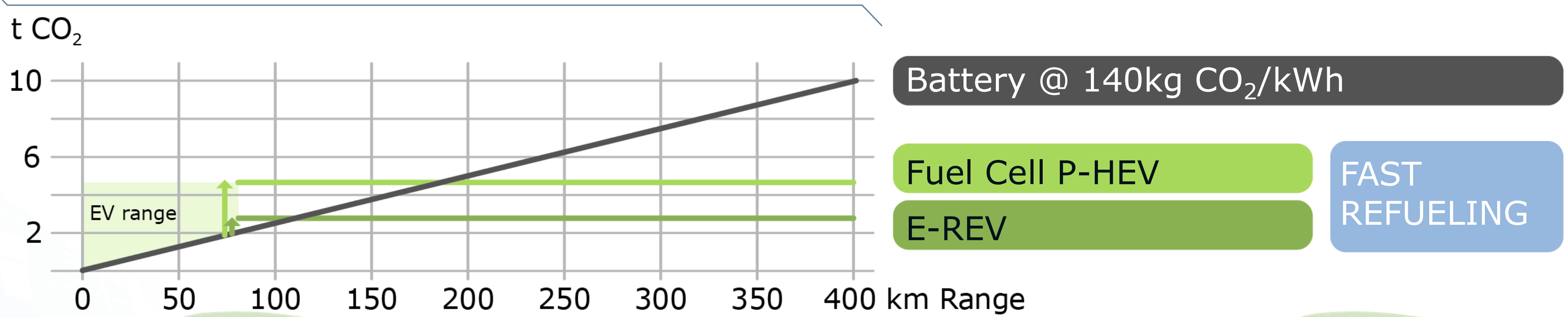
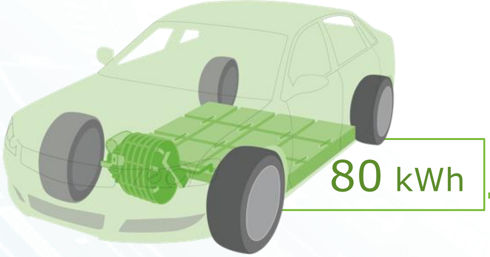
*Electricity Low Voltage, 2013 data, from A. Moro, L. Lonza, Transp. Res. D64, 5ff (2018)

*Kraftfahrt-Bundesamt, 03/2018

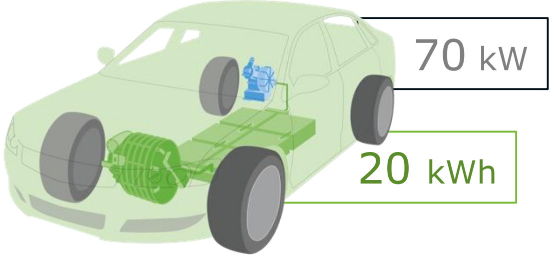
Modular Powertrain System





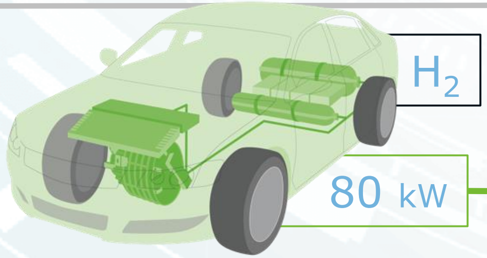
BEV 400 km range

Take out: 60 kWh Battery Cap.
Add: 70 kW Range Extender



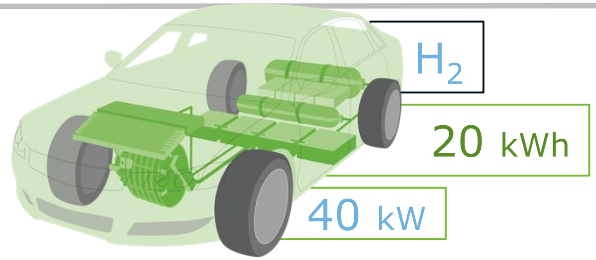
100 km EV range / Gasoline: Unlimited

+ Flexibility
Weight: -240 kg
Product Cost: -5500 €



FCEV 80 kW, H2 Refueling

Take out: 40 kW Fuel Cell
Add: Battery 20 kWh



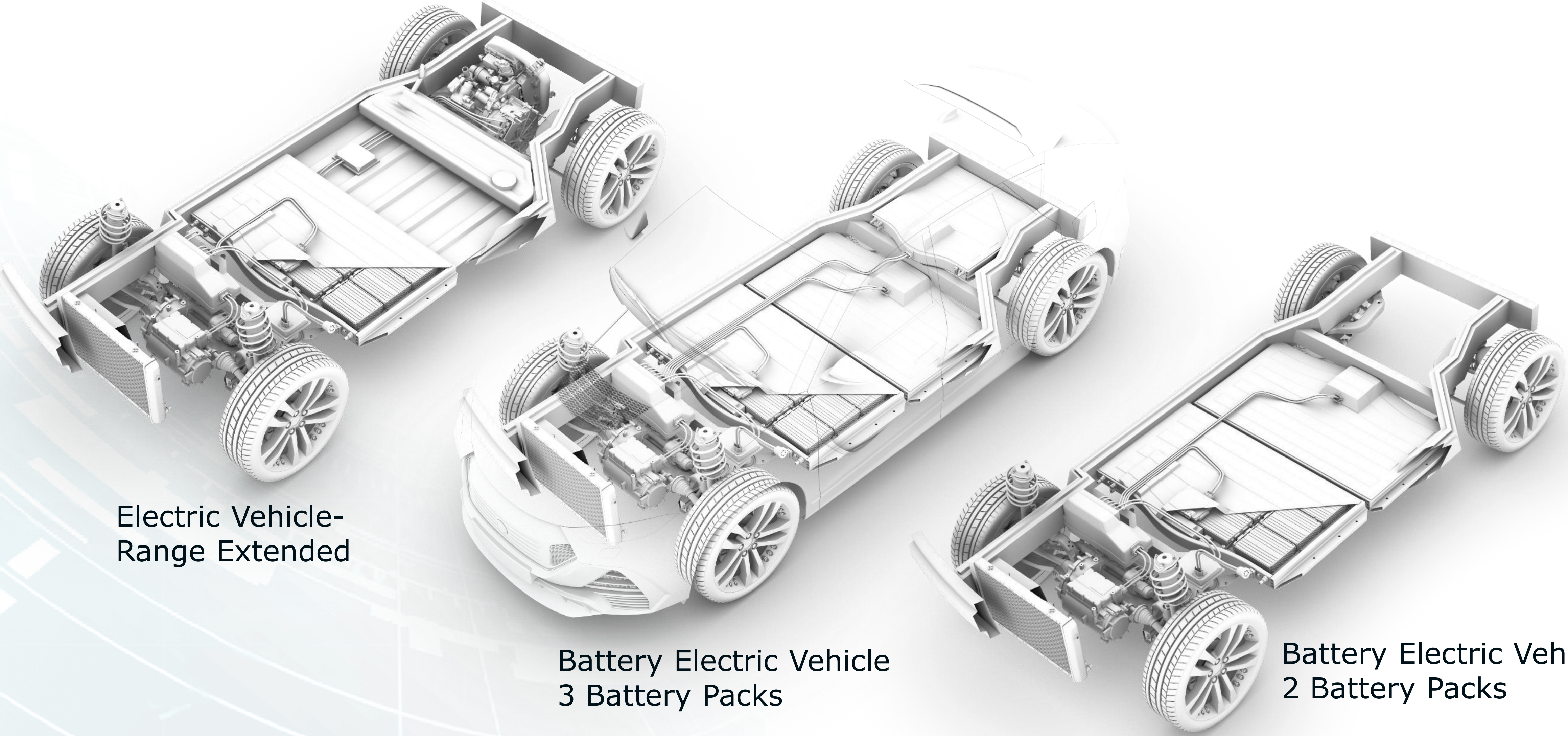
Plug-In 100 km range, H2 Refueling

+ Plug-In Capability
Weight: +60 kg
Product Cost: -1500 €

Note: Simplified Scenario. Implications e.g. on performance & efficiency

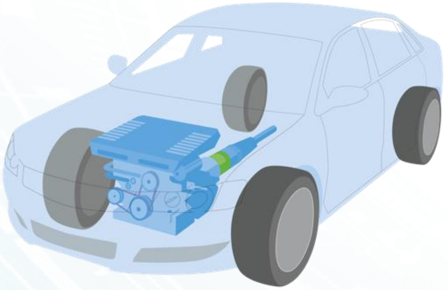
Optimizing for low CO_2 in production requires a rethinking of the configuration of the propulsion system

Modular Plattform
Battery Electric and Range Extender Vehicle



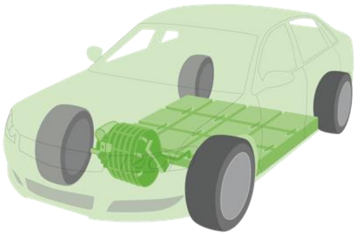
Evolution of Car Ownership (Scenario)

Gasoline or Diesel
Main vehicle for
universal use

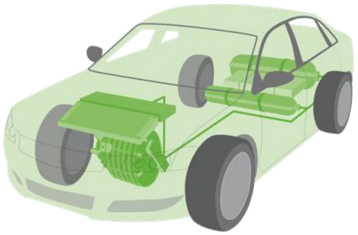


Multi-Purpose
ICE Vehicle

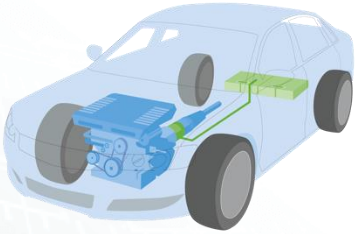
Variants of Electrification



400 km BEV
(with limitations)

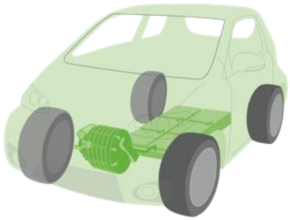


FCEV
(Infrastructure
& Cost issue)



E-REV/PHEV
(Might still suffer
from city bans)

Main Vehicle
tailored to use case
(e.g. commute)



200 km BEV
= 99% of trips

+

Shared Car, bus, train, plane…
= 1% of trips

Owned

Owned
(with some shortfalls)

Owned + Shared

Summary

Sustainability in ecology, economy and society as the guiding principle

Zero impact emissions for internal combustion engines is reasonably affordable

GHG regulations drive a significant share electrification –
however, the ICE plays an important role in the propulsion of future vehicles

PtX enables the use of renewable energy with ICE – drop-in capability preferred

GHG emissions from the production of batteries determined by energy used to manufacture

Minimized WtW GHG emissions can be achieved with smaller batteries –
combined with range extenders, fuel cells or future intermodal mobility concepts

Thank You

Source: NASA