



# Monetizing CO<sub>2</sub> – Technology strategies for NEV

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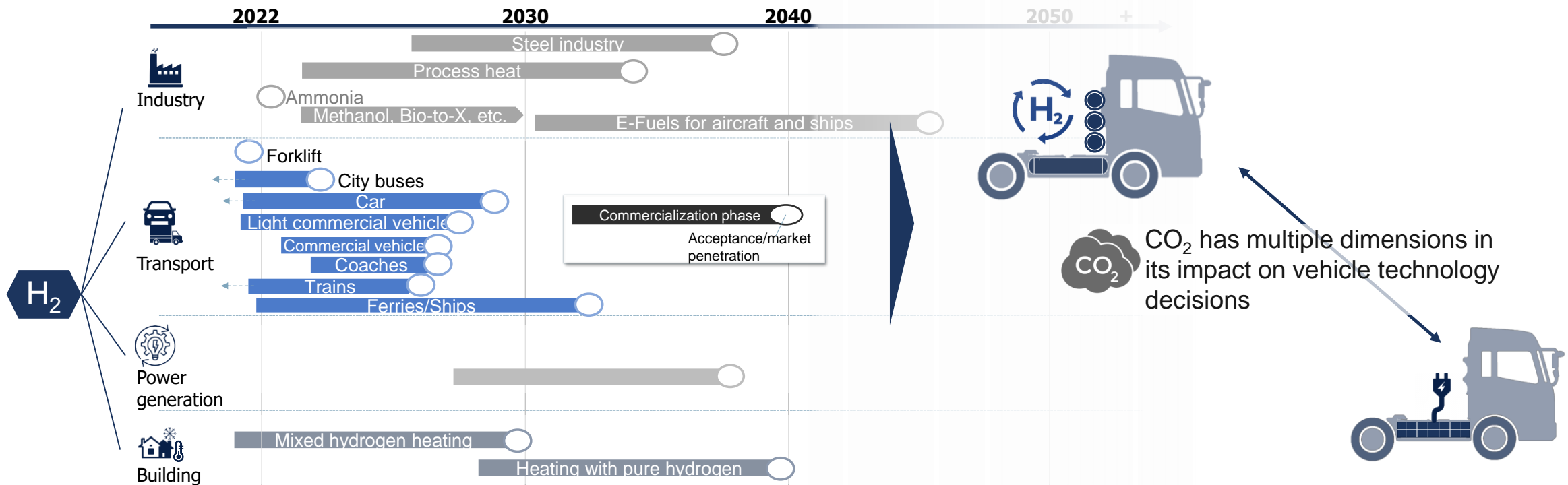
# What's the automotive perspective in ramping-up H<sub>2</sub> economy under the impression of multidimensional value of CO<sub>2</sub>?

## Drivers for the multidimensional value of CO<sub>2</sub>



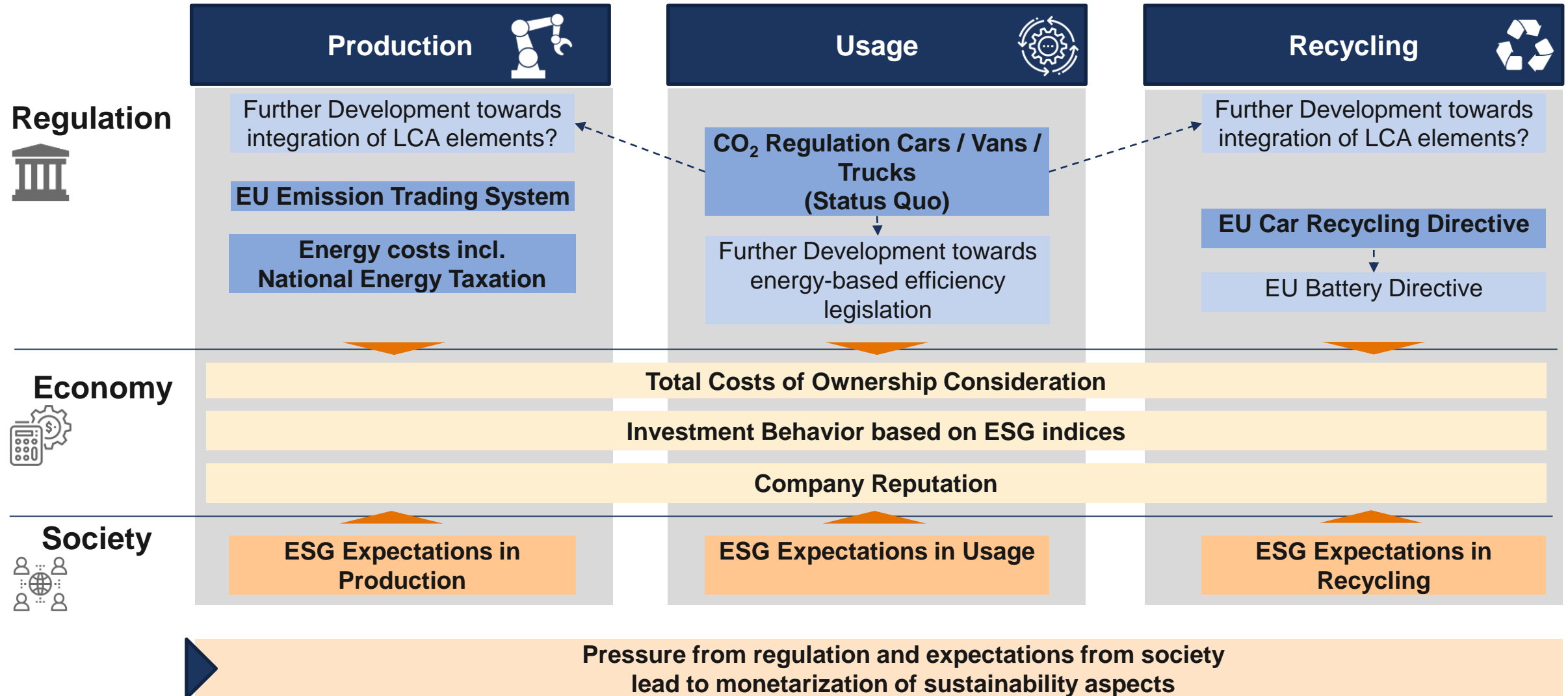
The hydrogen ecosystem will supply different industries in the transformation towards sustainability

Hydrogen automotive position is shaped by the strong competition with battery electric powertrains

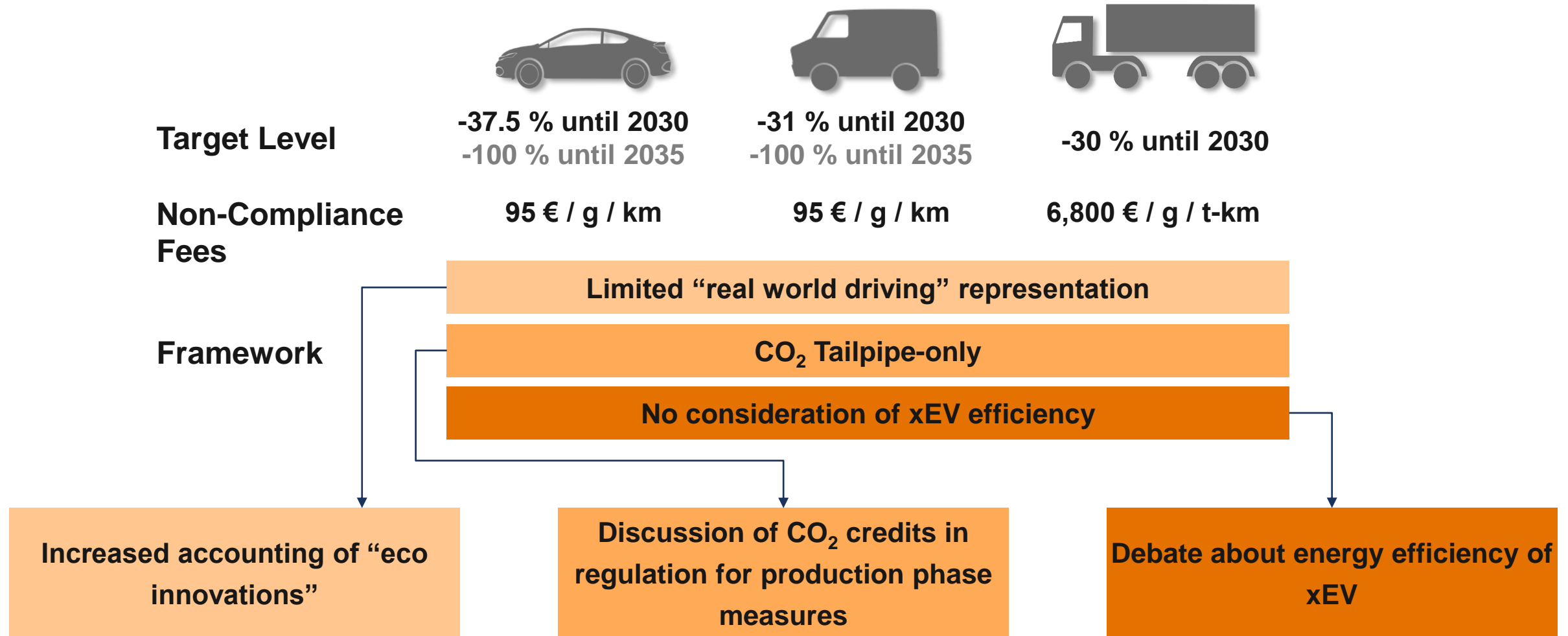


- » **The value of CO<sub>2</sub> in the automotive industry**
- » **Hydrogen as sustainable propulsion?**
- » **Technology and use-case perspective for hydrogen in vehicles**
- » **Implications of CO<sub>2</sub> on hydrogen vehicle technology decisions**
- » **Conclusion**

# The value of CO<sub>2</sub> is determined multidimensionally - and increasingly rising!



# Limitations of CO<sub>2</sub> regulation framework are increasingly addressed by initiatives



## Status Quo

### Industries covered

- » Electricity and heat generation
- » Energy intensive industries
- » Aviation as only mobility branch

### Relevant for automotive

- » Vehicle material concepts
- » Process heat generation & efficiency
- » Paint shops (CO<sub>2</sub> equivalents)
- » general electricity demand in production & recycling phase.

## Impact

### Drastic increase of price level

- » Record high in Aug. 2022: ~100 € / t
- » Price level until 2018: ~10 € / t
- » Further increase to 150 € / t expected! <sup>[1]</sup>



10 € / t equals to ca. 3 € / g CO<sub>2</sub> per km in usage phase\*

- neglectable price level compared to technological use phase measures

100 € / t equals to ca. 30 € / g CO<sub>2</sub> per km in usage phase\*

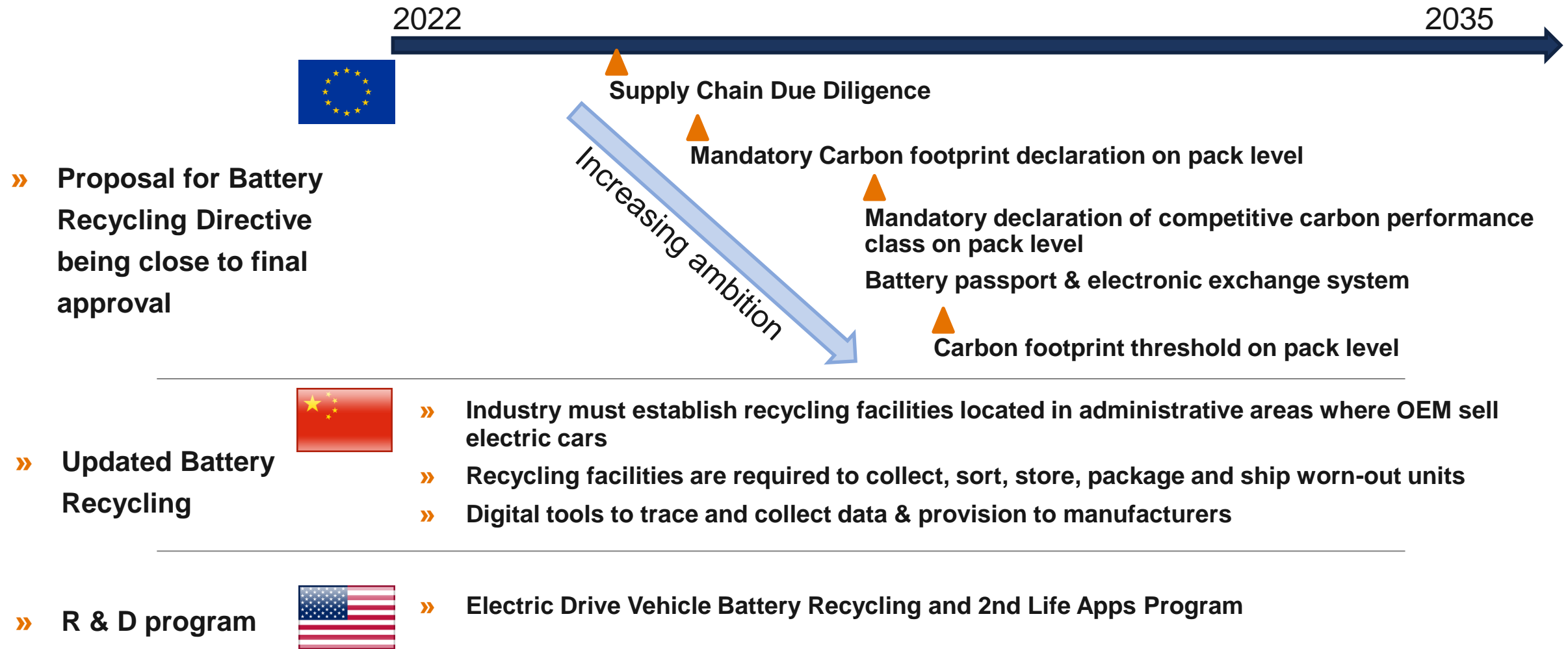
- price level in the range of **vehicle technology measures such as downsizing**

\* 1 g CO<sub>2</sub>/km reduction in vehicle creates overall savings of ca. 300 kg CO<sub>2</sub> in vehicle lifetime / lifetime mileage 300,000 km

[1] ClimateTrade (2022)

In recent years, production emissions have become a relevant factor also from a monetary perspective

# Recycling phased is increasingly relevant given carbon footprint of battery system, motivating legislative actions



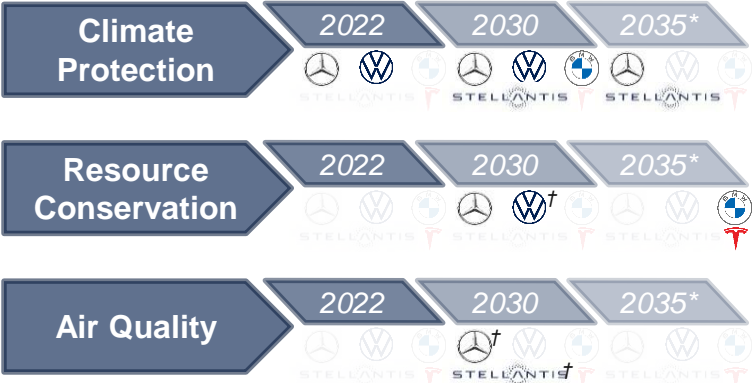
# Overview of ESG criteria by given timeframe



**Largest Focus**



## Environmental



**Climate Protection**

- Own vehicles and Service: Share of B/PHEV
- Supply Chain: Emissions/CO<sub>2</sub> targets
- Production: Recovered materials/CO<sub>2</sub> targets

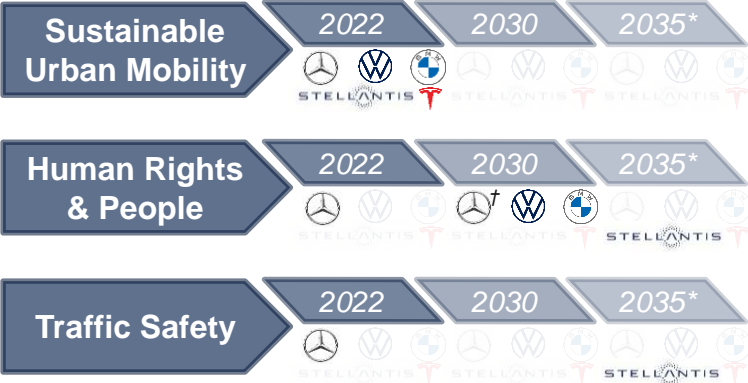
**Resource Conservation:** Raw material, energy and water usage, recycling

**Air Quality:** Emissions/Nitrogen based pollutants

Most OEMs are focusing on **environmental** targets to be implemented **within the next decade**



## Social



**Sustainable Mobility** to increase safety for all traffic

**Human Rights** is relevant for:

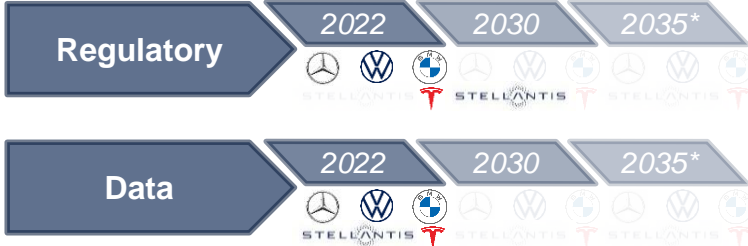
- Production and commodity sourcing

**Partnerships and People** to increase visibility

Activities are largely **ongoing**, new **safety technologies** to benefit society to be considered



## Governance



**Regulatory aspects** is relevant for:

- Integrity and compliance

**Data** is relevant for:

- Compliance management

Activities involve ethical decision making and fair competition

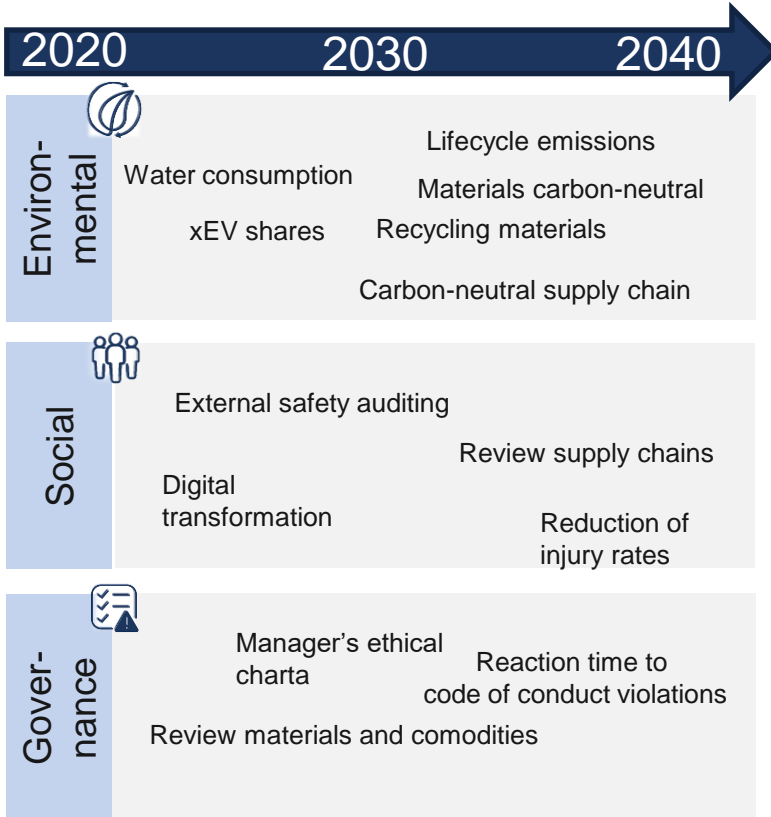
\* Includes goals which have been announced, but yet to be given a timeframe † Includes some goals planned for 2025



# Environmental, Social and Governance aspects monetize through investor's strategies

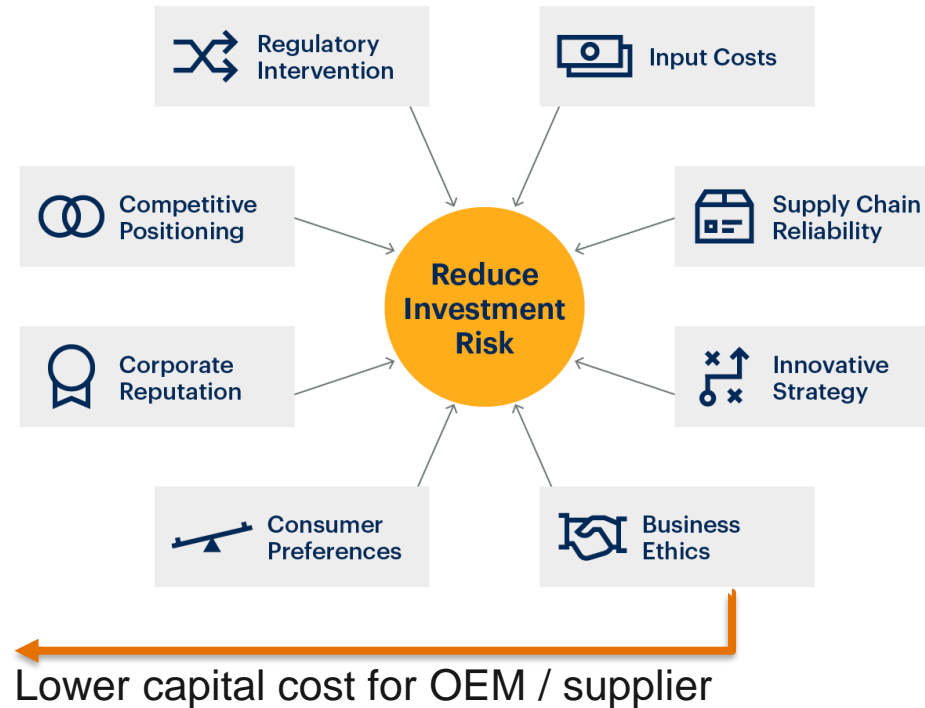
## Automotive player (OEM / Supplier)

### ESG strategy



## Benefit for Investor

### Risk reduction of portfolio



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**ESG Ratings**  
Measuring a company's resilience to long-term, financially relevant ESG risks

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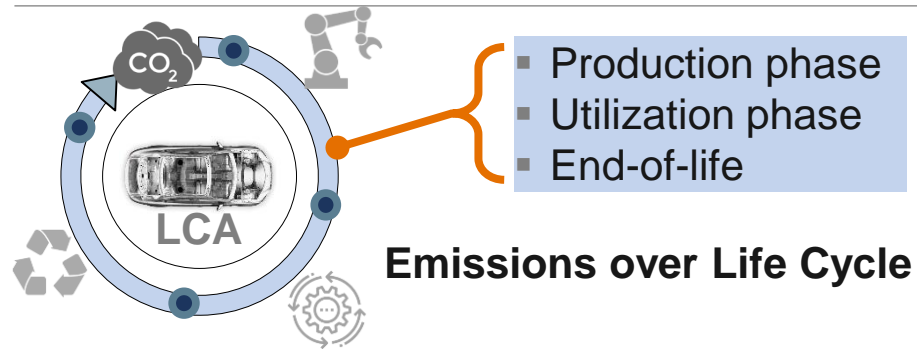
MOODY'S | ESG Solutions

ESG targets become a relevant factor in investment and have a direct impact on financing costs of OEM and suppliers

- » **The value of CO<sub>2</sub> in the automotive industry**
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# CO<sub>2</sub> in the sustainability perspective: Can Hydrogen compete with BEV?

## Life Cycle Assessment

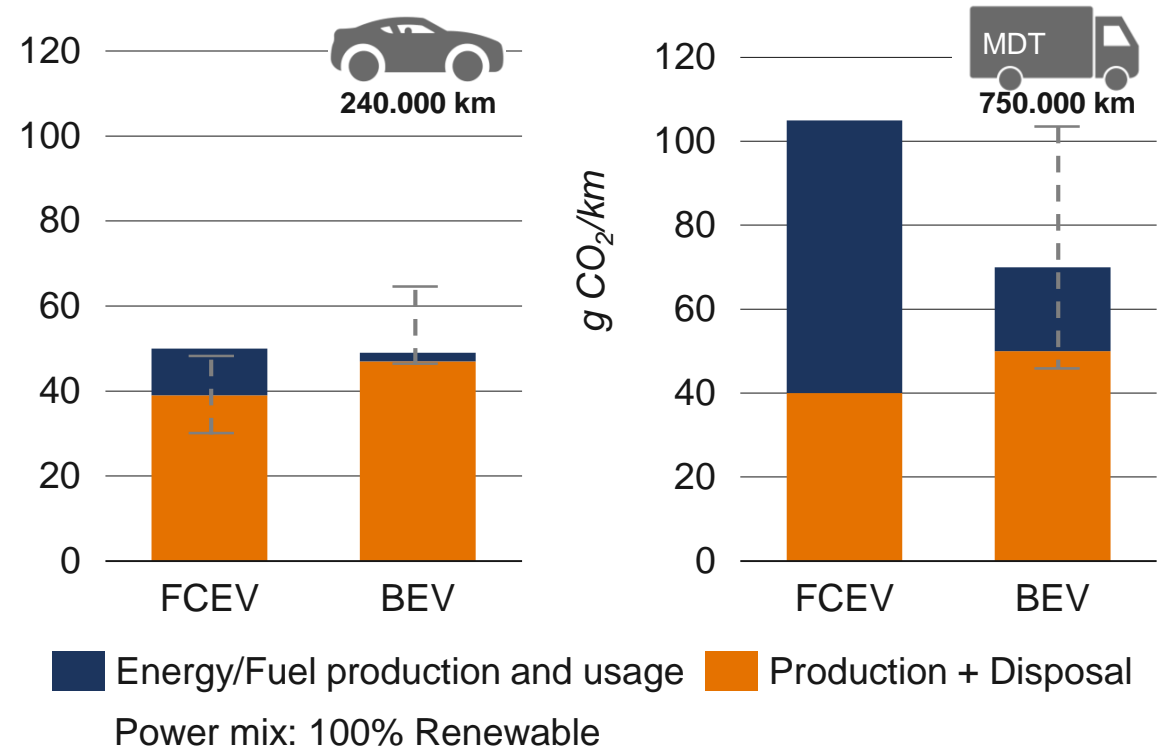


### Possible Parameters:

- Energy mix... (% of renewables)
- Driven mileage... (100.000-300.000km)
- Manufacturing location... (USA/Europe/China)
- Energy storage size (esp. battery)
- ...

⇒ *LCA Studies can come to different results, due to different boundaries and parameters*

## Passenger Car and Commercial Vehicle LCA



ICCT, Fraunhofer ISE

**FCEV can compete with BEV regarding life cycle CO<sub>2</sub> footprint especially with increasing battery size of BEV (or smaller buffer battery for FCEV)**

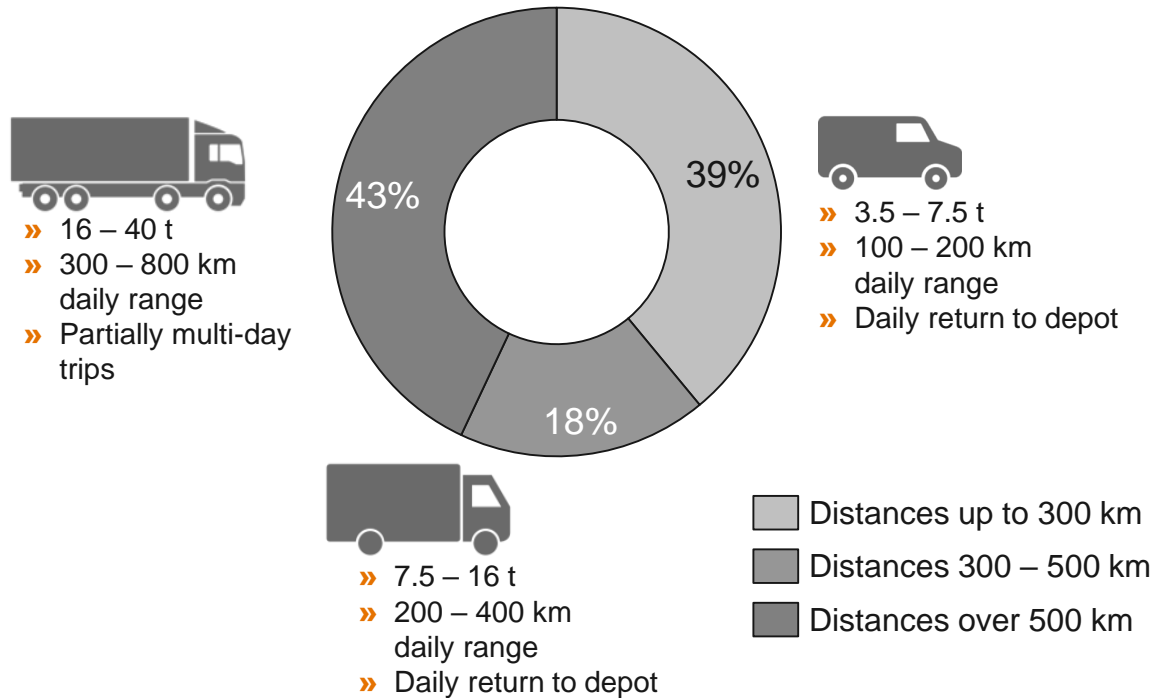
**However BEV outperform FCEV in use-phase due to higher efficiency and**

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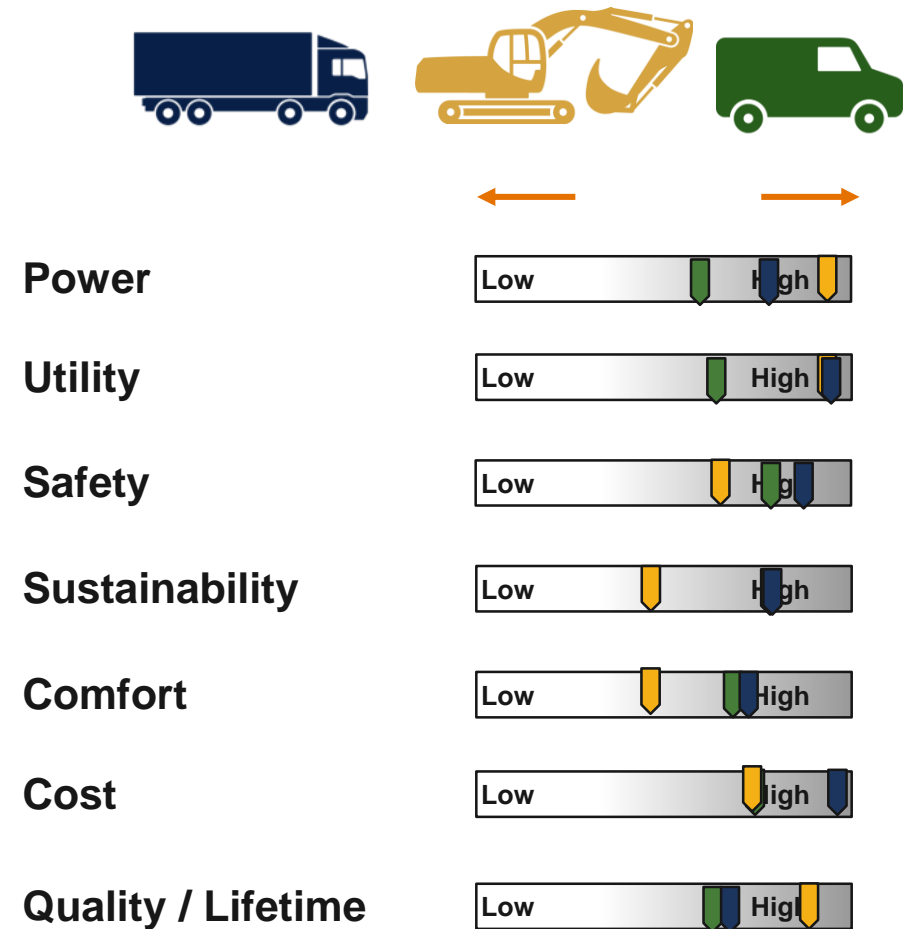
# Wide range of commercial vehicle applications and requirements provide market for multi-technology strategy

## Commercial Vehicles Application Fields

### Share of t-km in EU road freight transport – by distance class



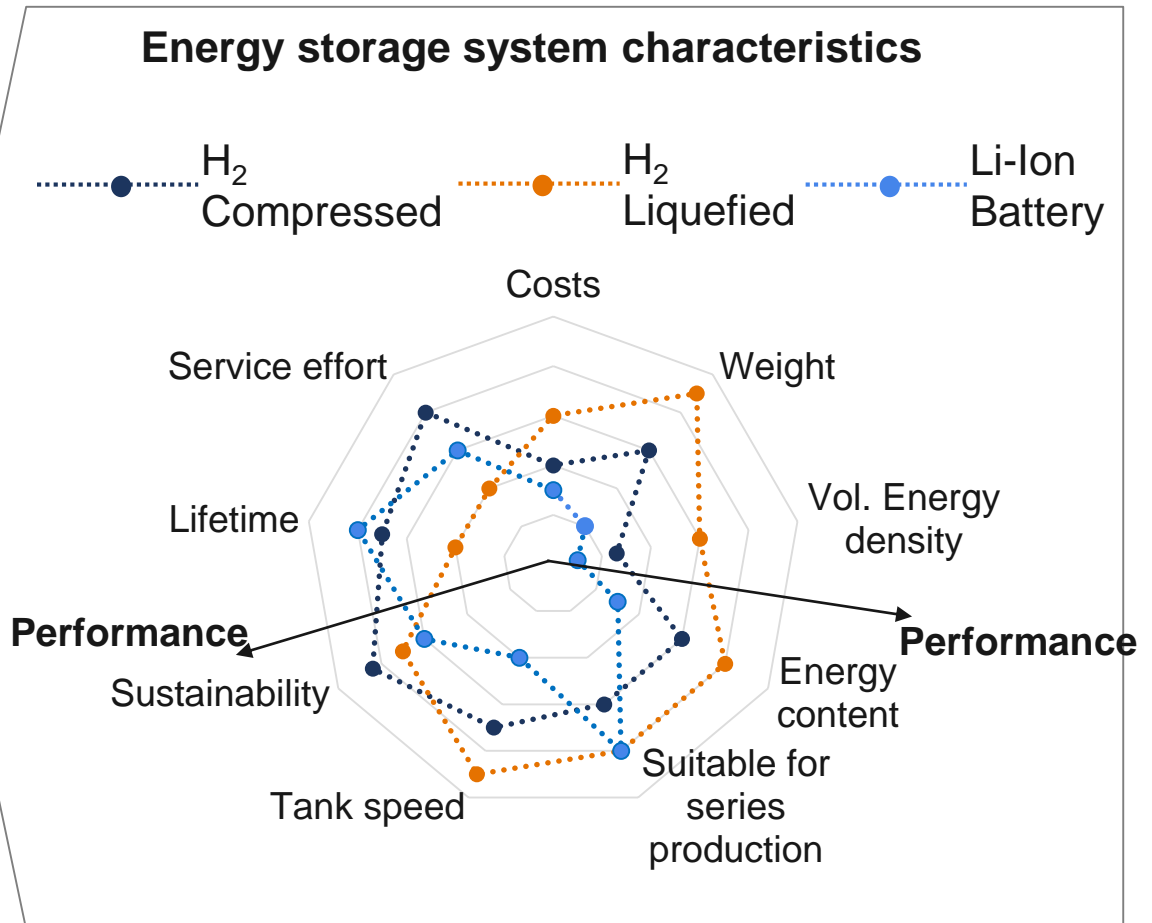
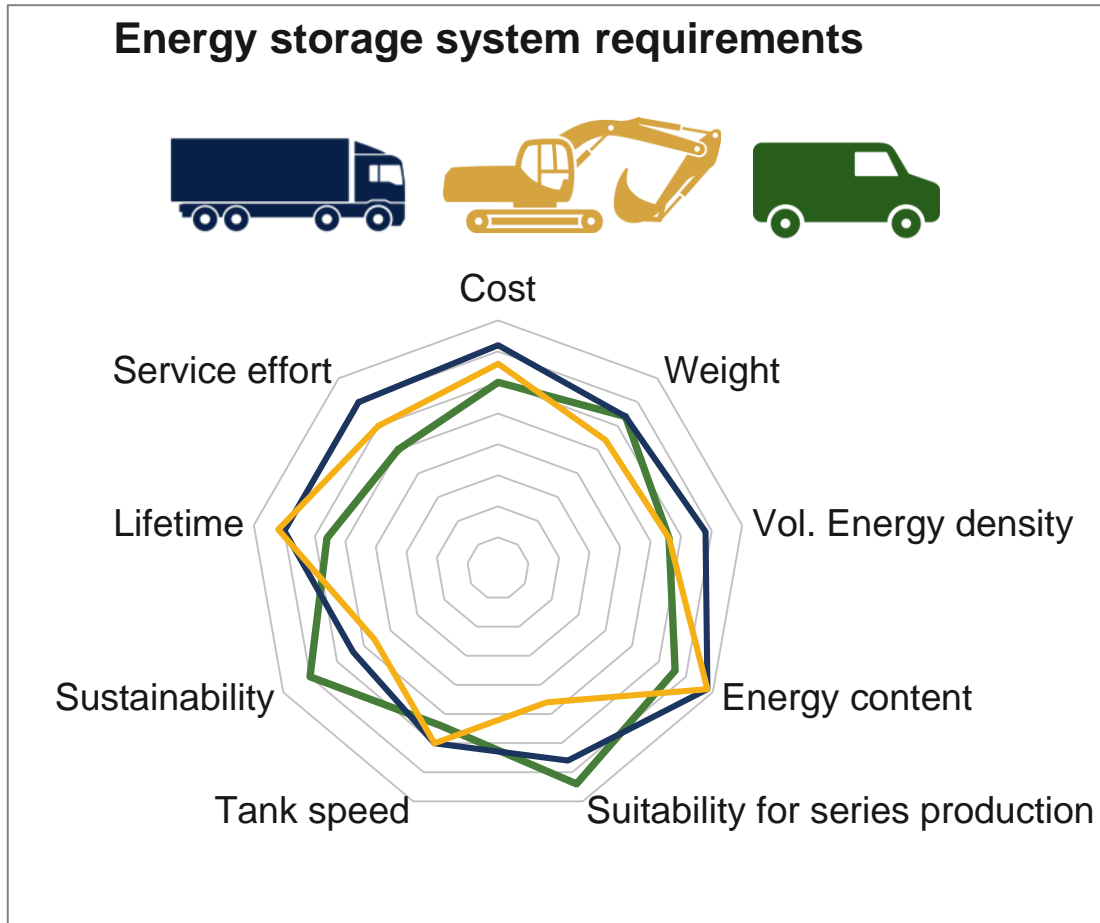
## Requirements at vehicle level



On-Highway

Off-Hwy.

# Vehicle application fields interrelate with the expectations formulated for energy storage options



▶ **Weight-sensitive use cases can create a significant advantage from using H<sub>2</sub> solutions**

# Voices of key-players regarding BEV and FCEV commercial vehicles: Hydrogen will be in the fleet

**Tesla**  
 Hydrogen "is not realistic"  
 "It's just crazy, basically."

**Daimler Truck**  
 "Battery electric and fuel-cell electric – both technologies needed"

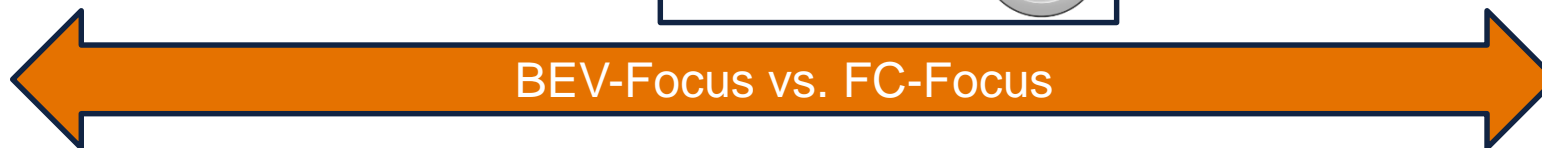
**FAW**  
 "Develop in the three technical routes: BEV, hybrid, and FC, to achieve global leadership in key core technologies by 2030"

**Hyundai**  
 "Hydrogen is the best suitable fuel for heavy duty trucks by ensuring a short refueling time and long-distance driving"







**VW Group**  
 "Scania favors battery-electric over hydrogen"  
 "MAN sees hydrogen as an interesting addition"

**Volvo Truck**  
 "Battery-electric vehicles and fuel cell electric vehicles with a longer range will be key on this journey"

**PACCAR**  
 "Hydrogen is certainly an option in the medium and long term for powering trucks"



# Relevance of hydrogen for different mobile applications is shaped by the energy-dependent use-cases

	Requirements	Energy carrier 2030+	H <sub>2</sub> Storage	H <sub>2</sub> Conversion	H <sub>2</sub> Potential 2050
 <b>PCs und LCVs</b>	Sustainability pressure, quantities, energy content (large seg.)	Battery, Hydrogen	CGH <sub>2</sub> @700 bar	Fuel Cell (FC)	 <span style="border: 1px solid gray; padding: 2px 10px;">Medium</span>
 <b>HDCVs and busses</b>	Cost, range (energy density & content)	Hydrogen, Battery, LNG	CGH <sub>2</sub> , LH <sub>2</sub>	FC / Hydrogen combustion engine (HICE)	 <span style="border: 1px solid blue; padding: 2px 10px;">High</span>
 <b>Construct. and agricult. machinery</b>	Utility, energy content, power	Hydrogen, Synfuel, Battery	CGH <sub>2</sub> @350 bar/ @700 bar LH <sub>2</sub>	FC/ HICE	 <span style="border: 1px solid blue; padding: 2px 10px;">High</span>

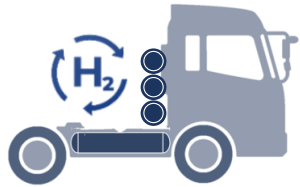
- Hydrogen has a relevance in weight-sensitive and / or range sensitive use cases
- ⇒ Commercial on- and off-highway vehicles do have a high hydrogen potential in the long-term
- Fuel cells will be the major energy converter in hydrogen vehicles, hydrogen combustion engines might have a potential in off-highway vehicle segments
- Compressed hydrogen (CGH<sub>2</sub>) will play major role as energy storage for hydrogen vehicles



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# Case study hydrogen storage: Alternatives towards lower CO<sub>2</sub> footprint of production phase realize cost advantages too

## Reference



- » Hydrogen long-haul tractor
- » Energy storage: 4\*CGH<sub>2</sub> à 15kg H<sub>2</sub>



### State-of-the-Art

Type 4 storage: non-metallic liner, CFRP wrapping

- » Specific costs system: 400 € / kg H<sub>2</sub>
- » Gravimetric storage density: 17 kg / kg H<sub>2</sub>

### + Gravimetric storage density

▷ 24.000 € ; 1020 kg

### Alternative material for liner: UHS Steel

Ultra high-strength steel tube

- » Specific costs system: 210 € / kg H<sub>2</sub> (\*Assumption)
- » Gravimetric storage density: ~45 kg / kg H<sub>2</sub> (\*Assumption)

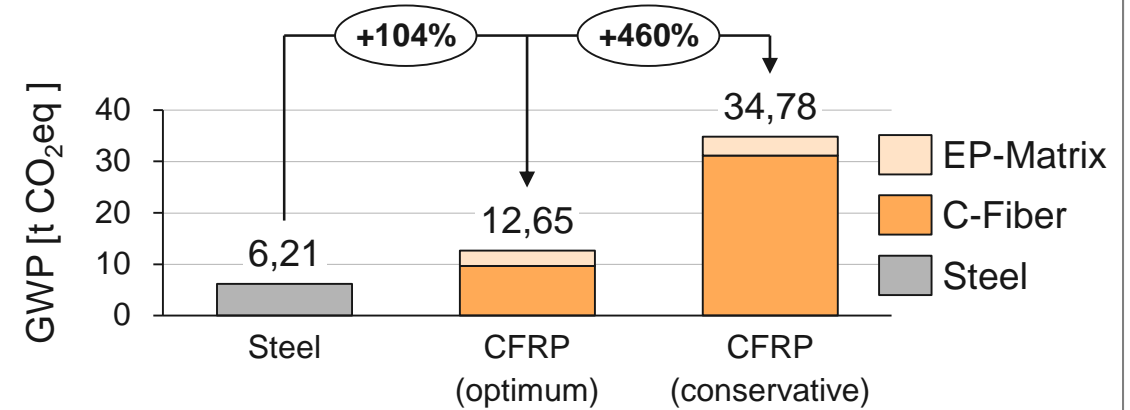
### + System costs + Sustainability, Recycling, LCA

▷ 12600 € ; 2700 kg

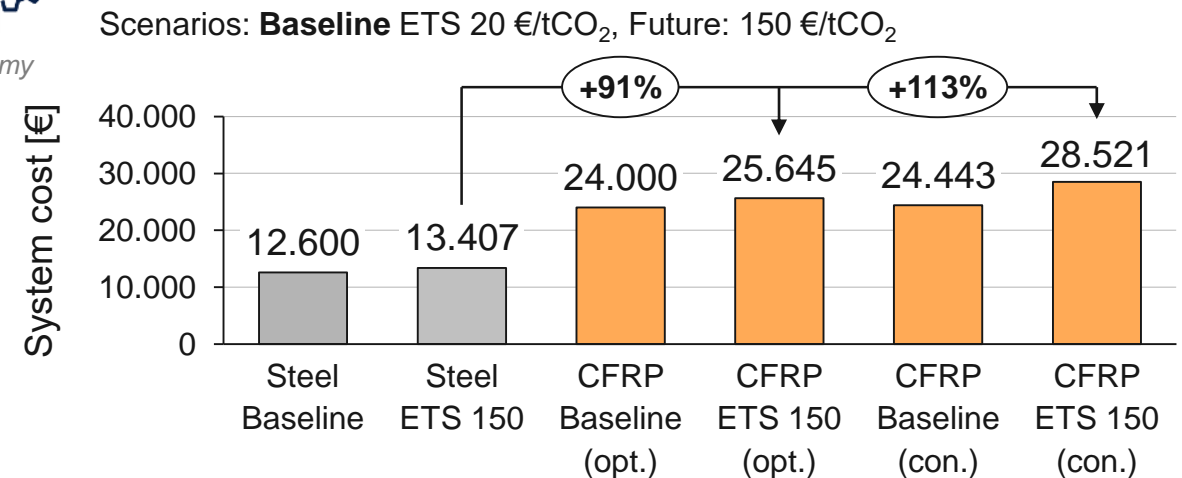
## Evaluation of production phase



Sustainability



Economy



▶ Emission trading could massively influence economy of production

# Case study hydrogen storage: Heavy alternatives show monetary drawbacks in potential future regulation schemes

## Reference

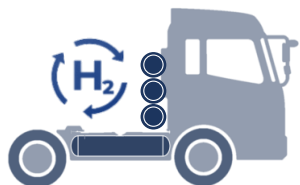


- » Tailpipe emission legislation only
- » No difference between technology options as TPE are always Zero

## Potential future scenario: Energy-based regulation



- » Accounts for the differences in energy consumption in use phase and the **CO<sub>2</sub> emission factor** of the respective fuel
- » Technology measures for BEV and FCEV become relevant for CO<sub>2</sub> regulation, e.g. lightweight design
- » State-of-the-Art saves ca. 0.35 kg H<sub>2</sub>/100 km in typical long-haul driving cycle (\*Assumption)



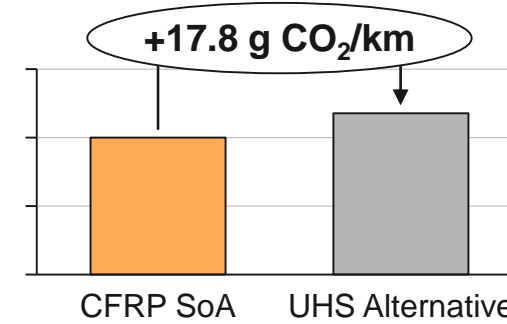
## Evaluation of use phase (based on regulation scenario)

Assumption: 5,04 kg CO<sub>2</sub> per kg Green Hydrogen, Avg. Payload 14 t.



Sustainability

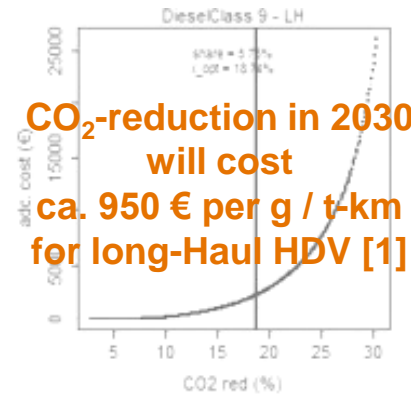
CO<sub>2</sub> emission attributed to H<sub>2</sub> storage tank [g CO<sub>2</sub>/km]



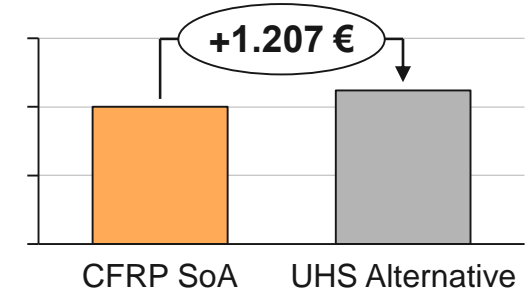
~ difference of 1.27 g CO<sub>2</sub> per t-km



Economy



CO<sub>2</sub> costs attributed to H<sub>2</sub> storage tank [€]



Evaluation of alternatives in use phase highlights efficiency impact of lightweight design

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## CO<sub>2</sub> Value



- » Strong push of legislation and society to reflect life cycle aspects
- » OEM have to force sustainability, esp. CO<sub>2</sub> footprint in the automotive value chain with ambitious ESG targets
- » Regulatory development combines GWP of life cycle with economic boundary conditions

## Technology Perspective



- » Hydrogen in vehicles is a promising technology option, LCA evaluation shows energy storage size (#battery) dependency in the sustainability perspective in the BEV-FCEV competition

## Implications



- » LCA/CO<sub>2</sub> importance in technology strategies and product development process rises significantly
- » New/alternative technologies and materials are becoming attractive and open up perspectives for suppliers/OEM in the ramping-up of xEV ecosystems

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