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CREATING IDEAS &
DRIVING INNOVATIONS

Monetizing CO_2 – Technology strategies for NEV

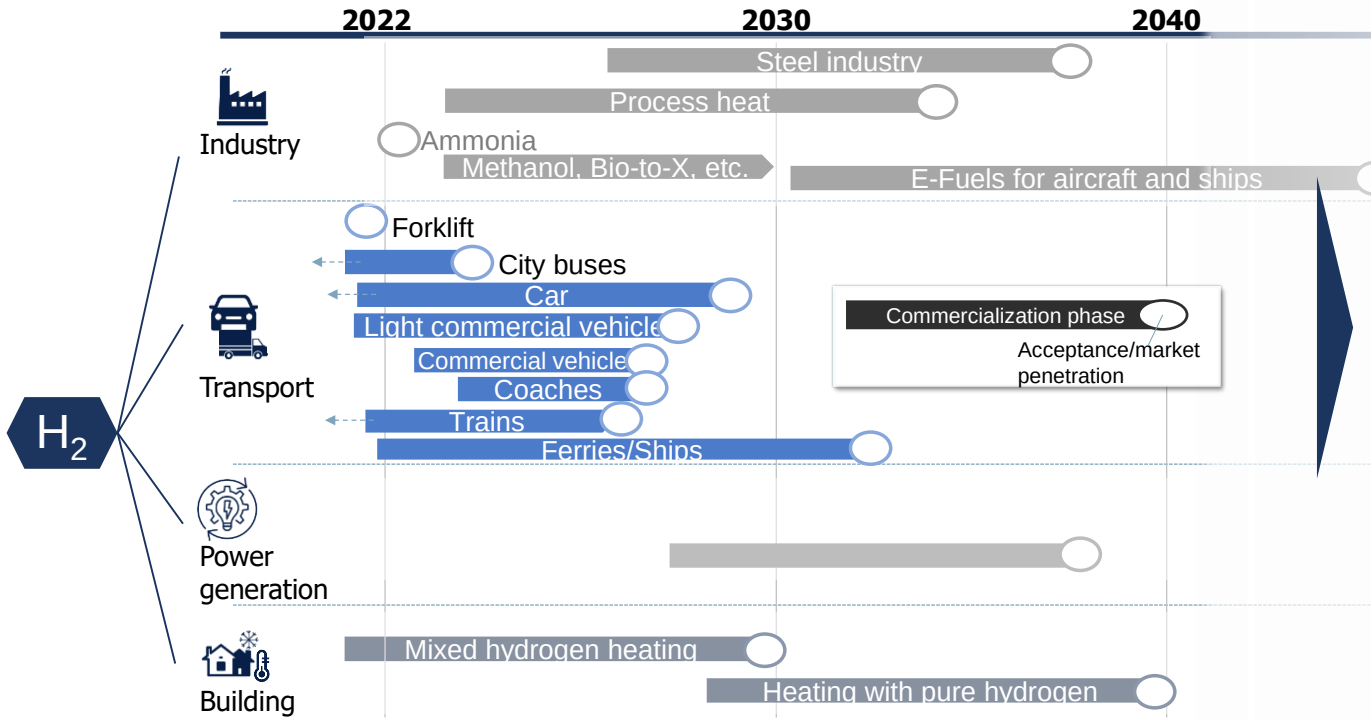
Alexander Busse, Christian Harter

What's the automotive perspective in ramping-up H_2 economy under the impression of multidimensional value of CO_2?

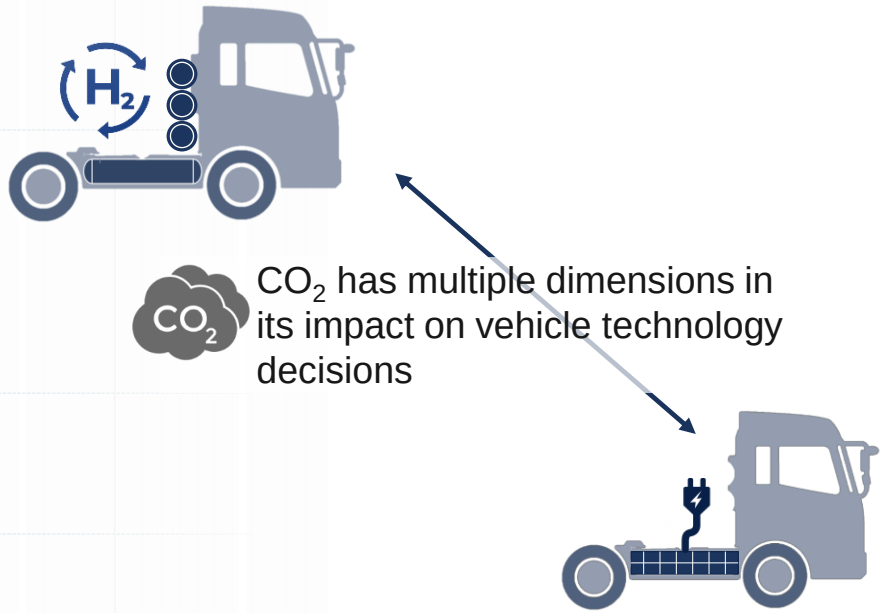
Drivers for the multidimensional value of CO_2

Society *Legislation* *Economy* *User*

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



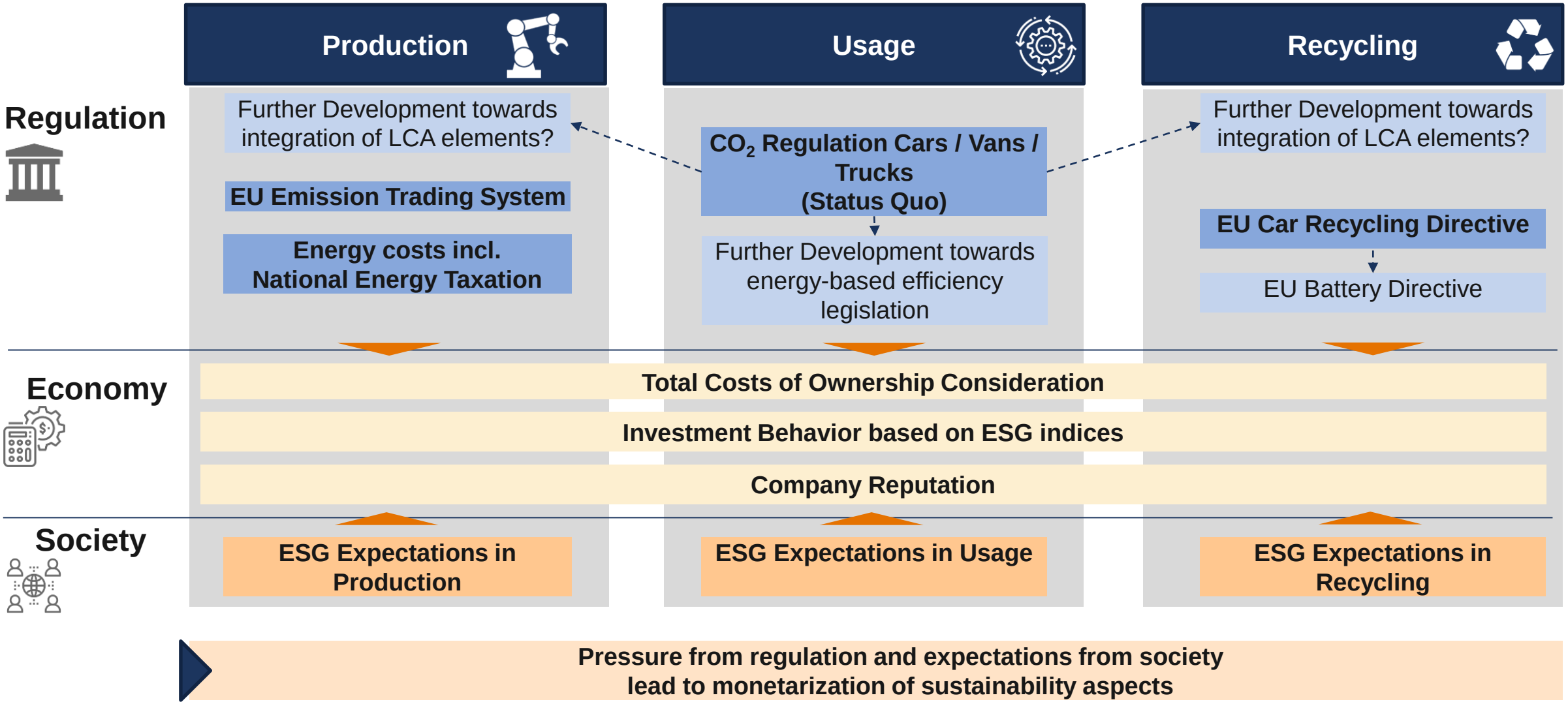
Hydrogen automotive position is shaped by the strong competition with battery electric powertrains



Agenda

- **The value of CO_2 in the automotive industry**
- **Hydrogen as sustainable propulsion?**
- **Technology and use-case perspective for hydrogen in vehicles**
- **Implications of CO_2 on hydrogen vehicle technology decisions**
- **Conclusion**

The value of CO_2 is determined multidimensionally - and increasingly rising!



Limitations of CO_2 regulation framework are increasingly addressed by initiatives

Target Level	**-37.5 % until 2030** -100 % until 2035	**-31 % until 2030** -100 % until 2035	**-30 % until 2030**
Non-Compliance Fees	**95 € / g / km**	**95 € / g / km**	**6,800 € / g / t-km**

Framework

- **Limited “real world driving” representation**
- **CO_2 Tailpipe-only**
- **No consideration of xEV efficiency**

Increased accounting of “eco innovations”

Discussion of CO_2 credits in regulation for production phase measures

Debate about energy efficiency of xEV

EU Emission Trading System and its impact on automotive industry

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_2 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! [1]

[1] ClimateTrade (2022)

10 € / t equals to ca. 3 € / g CO_2 per km in usage phase*

➢ neglectable price level compared to technological use phase measures

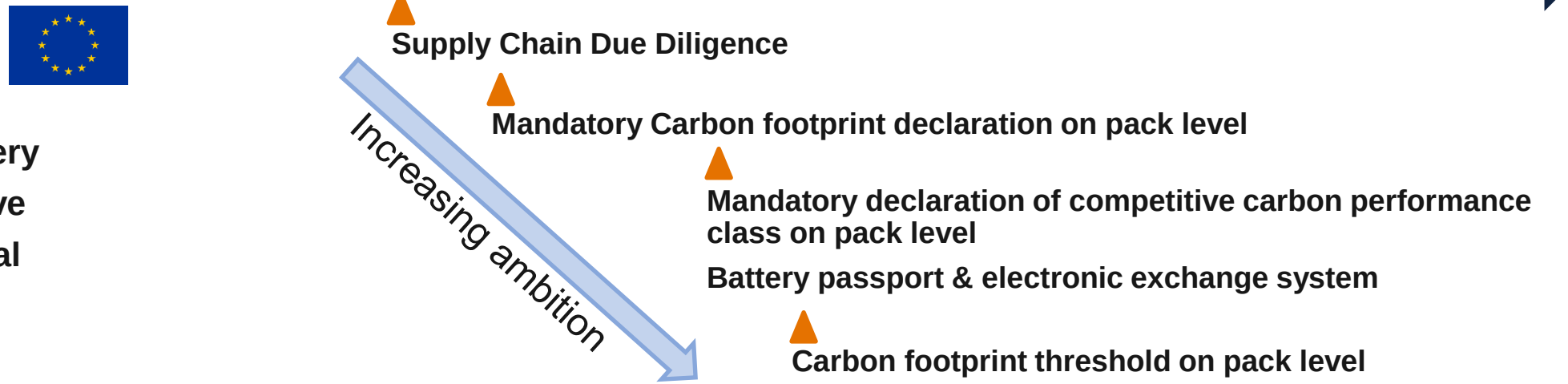
100 € / t equals to ca. 30 € / g CO_2 per km in usage phase*

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

* 1 g CO2/km reduction in vehicle creates overall savings of ca. 300 kg CO_2 in vehicle lifetime / lifetime mileage 300,000 km

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



- Proposal for Battery Recycling Directive being close to final approval

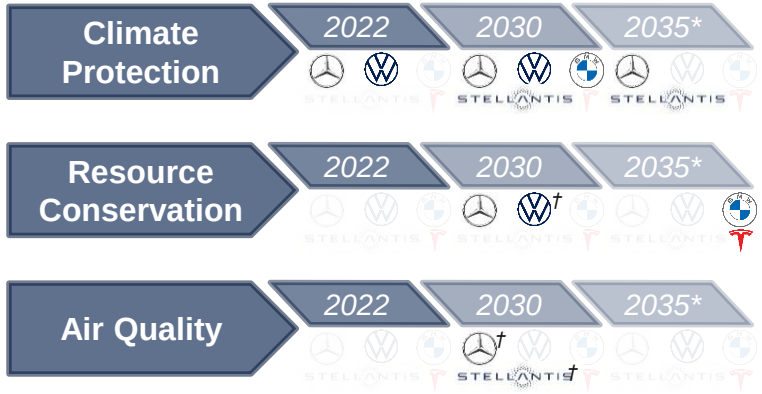
- Updated Battery Recycling
  - Industry must establish recycling facilities located in administrative areas where OEM sell electric cars
  - Recycling facilities are required to collect, sort, store, package and ship worn-out units
  - Digital tools to trace and collect data & provision to manufacturers

- R & D program
  - Electric Drive Vehicle Battery Recycling and 2nd Life Apps Program

Overview of ESG criteria by given timeframe

Largest Focus

Environmental



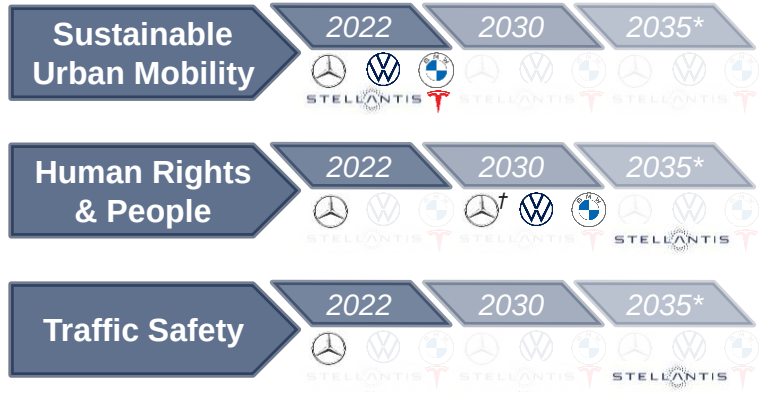
Climate Protection
- Own vehicles and Service: Share of B/PHEV
- Supply Chain: Emissions/CO_2 targets
- Production: Recovered materials/CO_2 targets

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



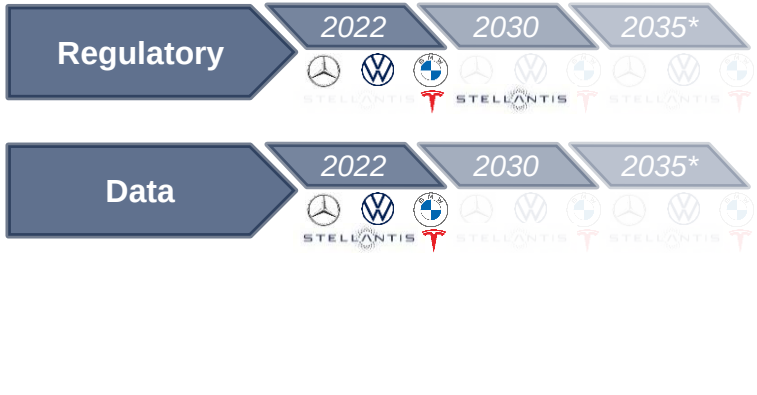
Sustainable Mobility to increase safety for all traffic

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

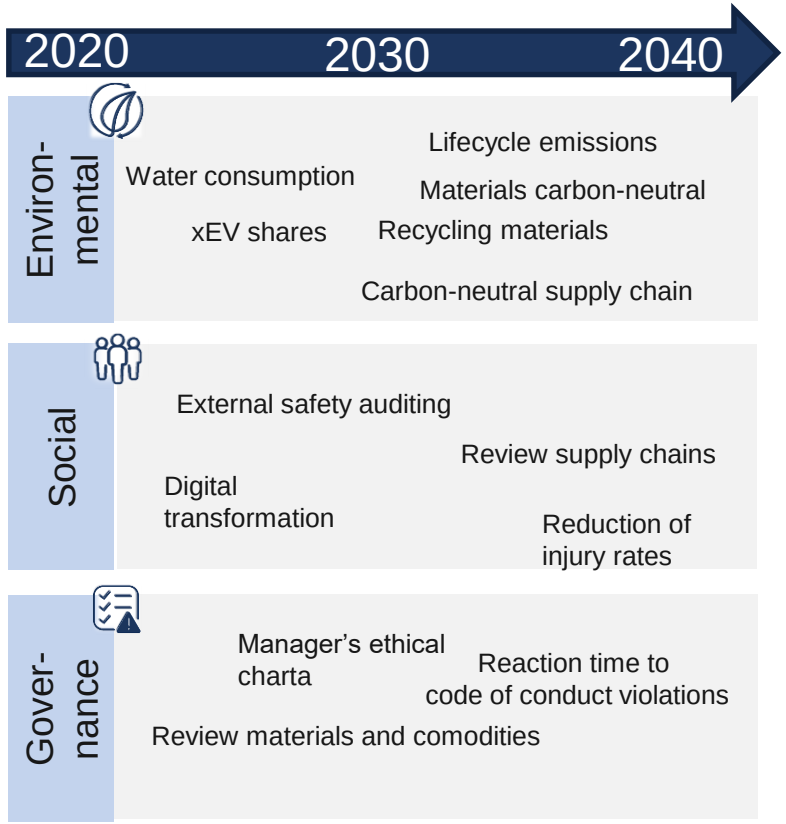
Activities involve ethical decision making and fair competition

** 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

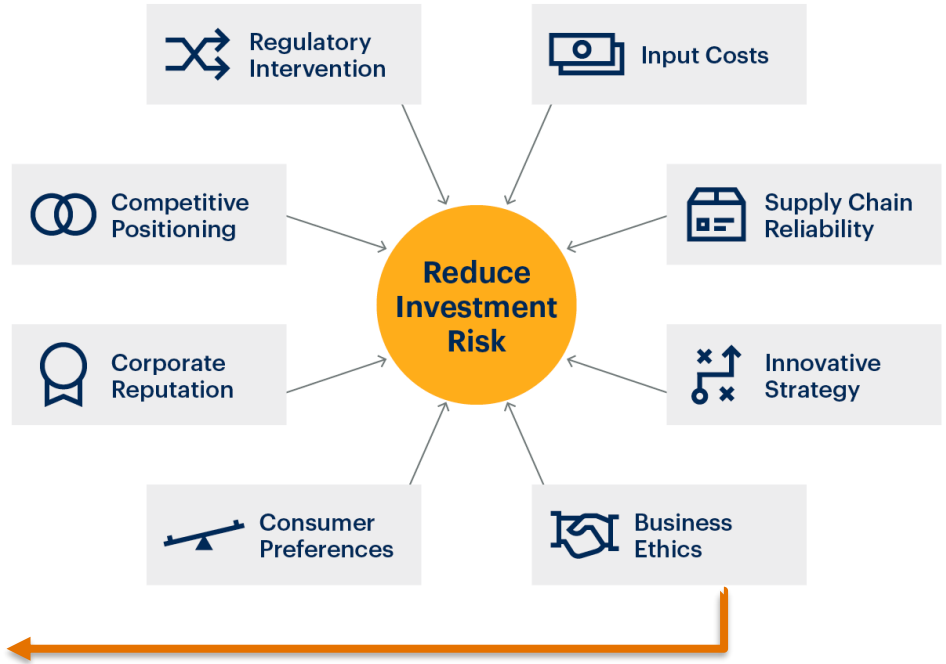
Automotive player (OEM / Supplier)

ESG strategy



Benefit for Investor

Risk reduction of portfolio



MSCI Our Clients Our Solutions Research & Insights

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

MORNINGSTAR | SUSTAINALYTICS

MOODY'S | ESG Solutions

Transparency to stakeholders

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

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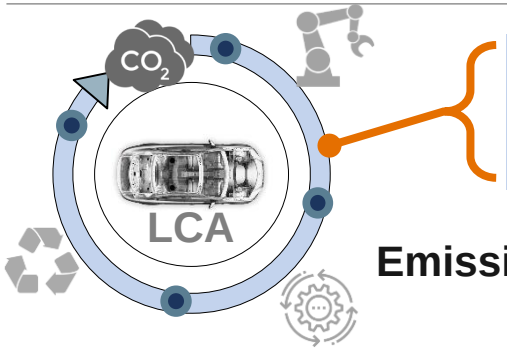
CO_2 in the sustainability perspective: Can Hydrogen compete with BEV?

Life Cycle Assessment



- Production phase
- Utilization phase
- End-of-life

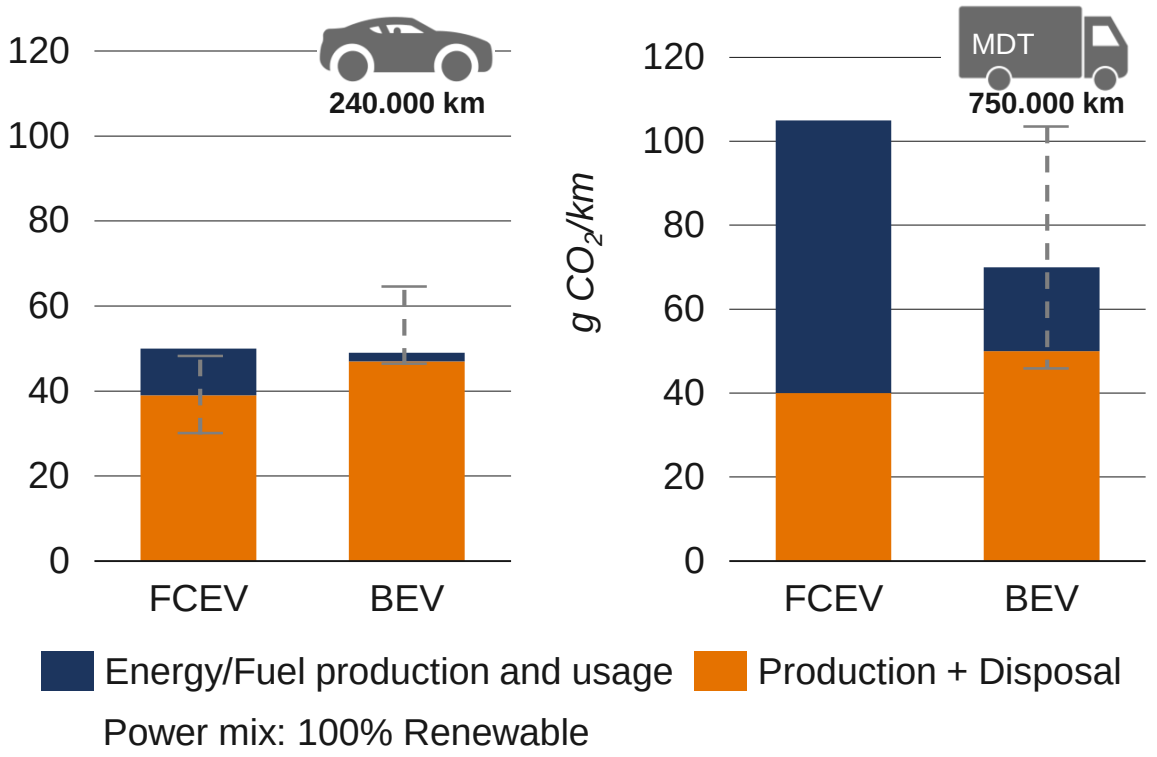
Emissions over Life Cycle

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_2 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

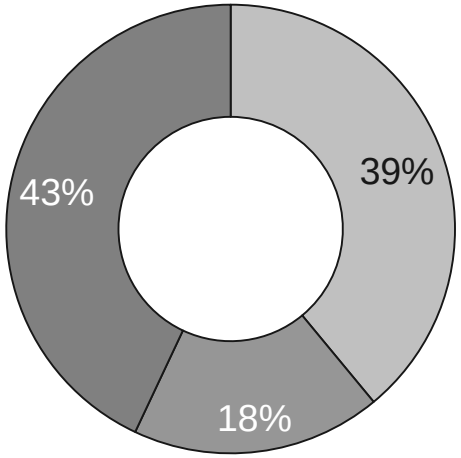
Commercial Vehicles Application Fields

On-Highway

Off-Hwy.

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

- 16 – 40 t
- 300 – 800 km daily range
- Partially multi-day trips



- 3.5 – 7.5 t
- 100 – 200 km daily range
- Daily return to depot

- 7.5 – 16 t
- 200 – 400 km daily range
- Daily return to depot

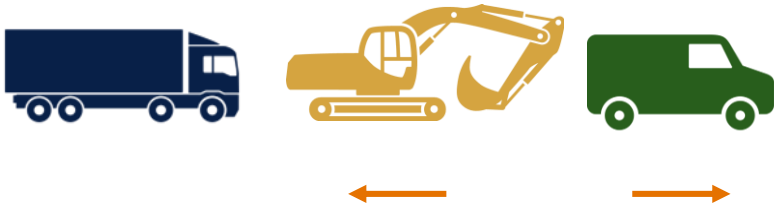
- Distances up to 300 km
- Distances 300 – 500 km
- Distances over 500 km

Construction

Agriculture

Mining

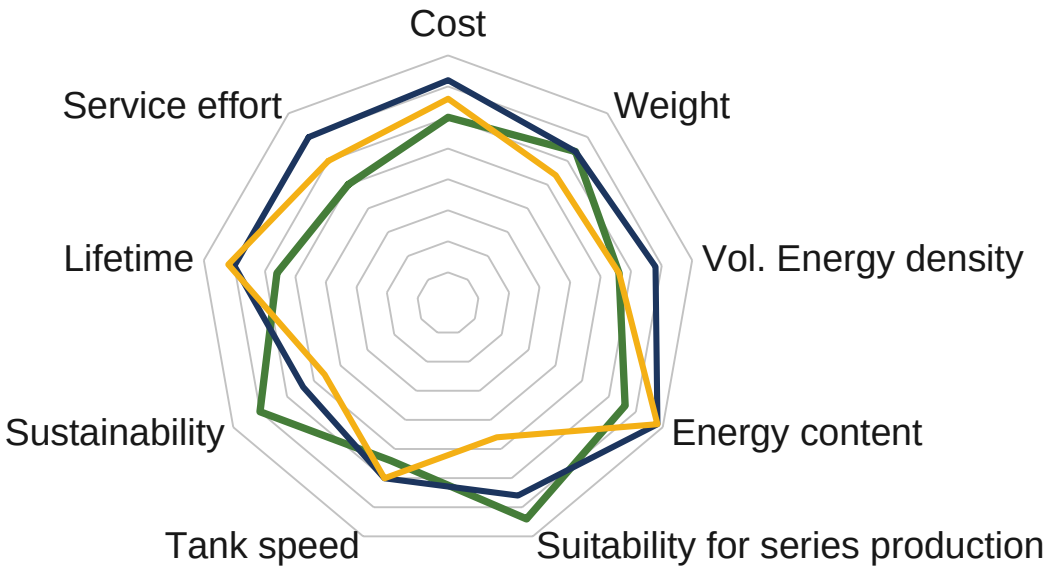
Requirements at vehicle level



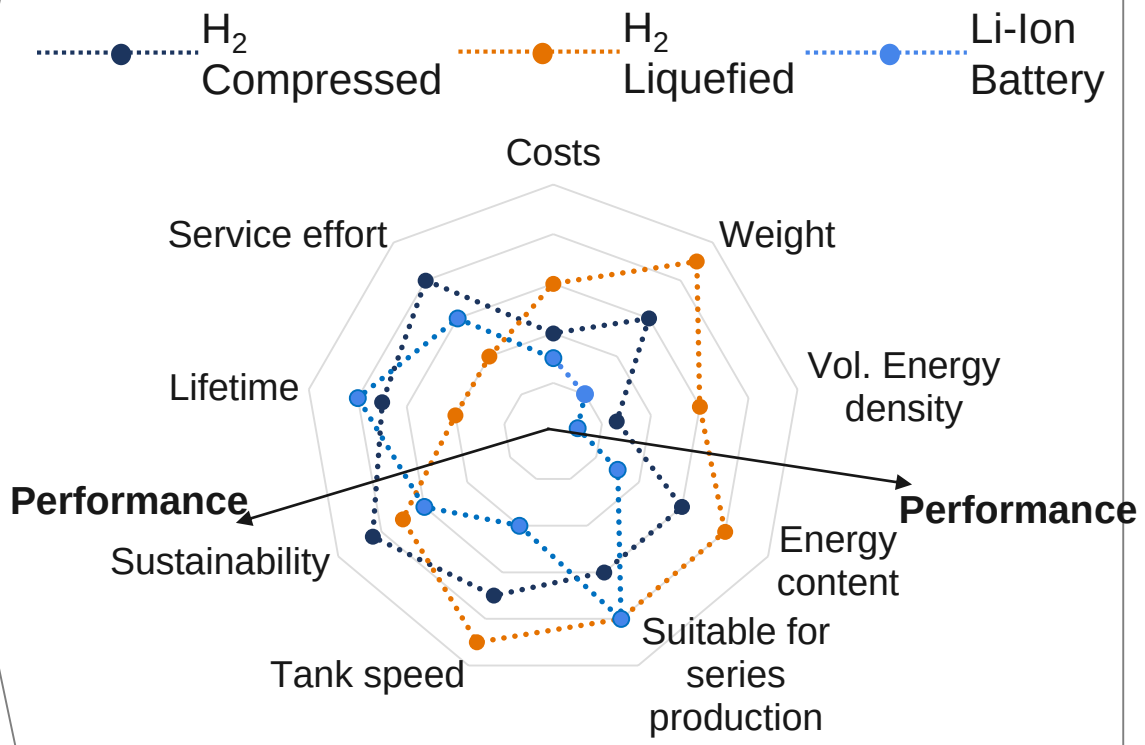
Power	Low – High
Utility	Low – High
Safety	Low – High
Sustainability	Low – High
Comfort	Low – High
Cost	Low – High
Quality / Lifetime	Low – High

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

Energy storage system requirements



Energy storage system characteristics



Weight-sensitive use cases can create a significant advantage from using H_2 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**"

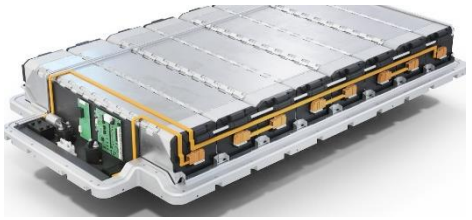
"MAN sees **hydrogen** as an **interesting addition**"

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"



BEV-Focus vs. FC-Focus

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

	Requirements	Energy carrier 2030+	H_2 Storage	H_2 Conversion	H_2 Potential 2050
 **PCs und LCVs**	Sustainability pressure, quantities, energy content (large seg.)	Battery, Hydrogen	CGH_2@700 bar	Fuel Cell (FC)	**Medium**
 **HDCVs and busses**	Cost, range (energy density & content)	Hydrogen, Battery, LNG	CGH_2, LH_2	FC / Hydrogen combustion engine (HICE)	**High**
 **Construct. and agricult. machinery**	Utility, energy content, power	Hydrogen, Synfuel, Battery	CGH_2@350 bar/ @700 bar LH_2	FC/ **HICE**	**High**

- **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_2) will play major role as energy storage for hydrogen vehicles**

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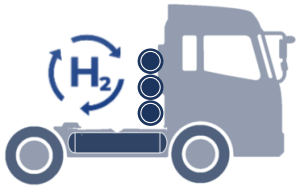
Case study hydrogen storage: Alternatives towards lower CO_2 footprint of production phase realize cost advantages too

Reference



- Hydrogen long-haul tractor
- Energy storage: 4*CGH_2 à 15kg H_2


Image source: ECS Composite

State-of-the-Art

Type 4 storage: non-metallic liner, CFRP wrapping

- Specific costs system: 400 € / kg H_2
- Gravimetric storage density: 17 kg / kg H_2

\+ **Gravimetric storage density**

24.000 € ; 1020 kg

Alternative material for liner: UHS Steel

Ultra high-strength steel tube

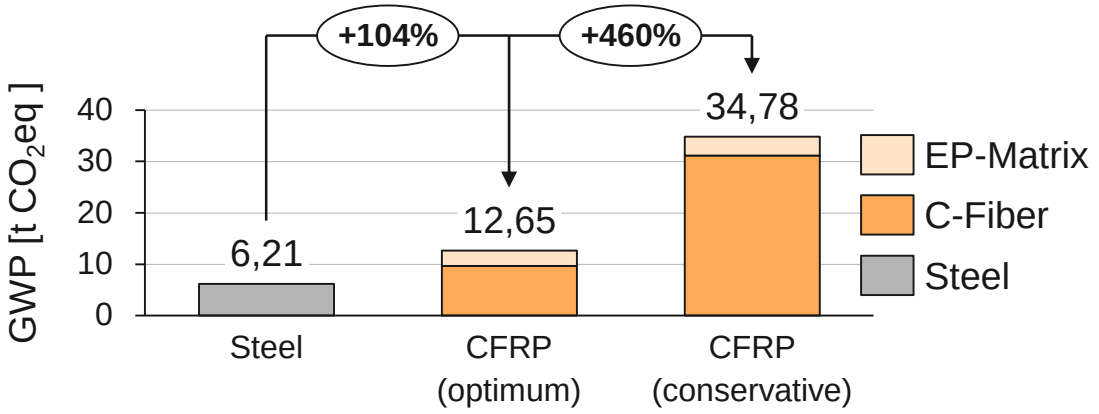
- Specific costs system: 210 € / kg H_2 (*Assumption)
- Gravimetric storage density: ~45 kg / kg H_2 (*Assumption)

\+ **System costs** \+ **Sustainability, Recycling, LCA**

12600 € ; 2700 kg

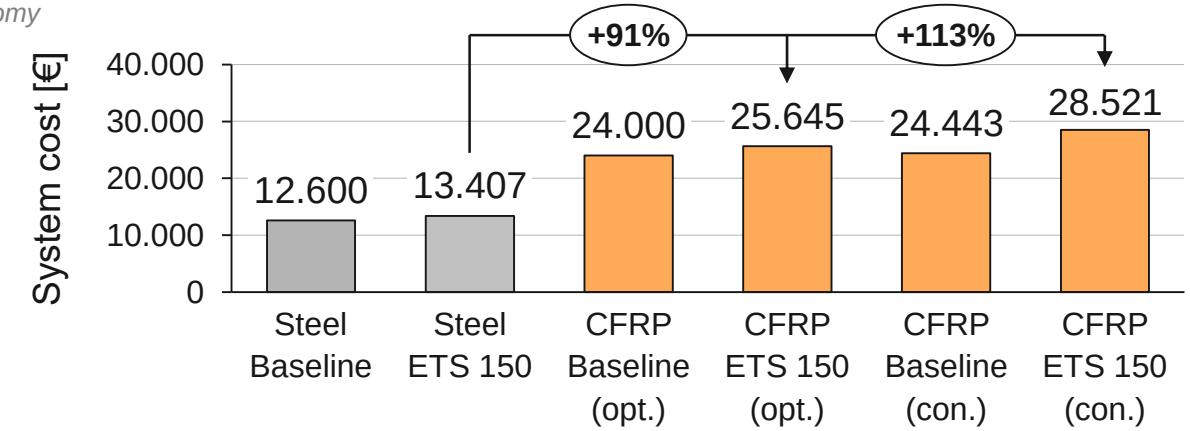
Evaluation of production phase

Sustainability



Economy

Scenarios: **Baseline** ETS 20 €/tCO_2, Future: 150 €/tCO_2



Emission trading could massively influence economy of production

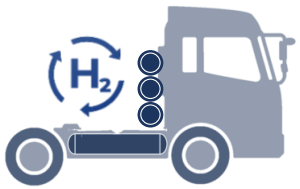
Case study hydrogen storage: Heavy alternatives show monetary drawbacks in potential future regulation schemes

Reference

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

Potential future scenario: Energy-based regulation

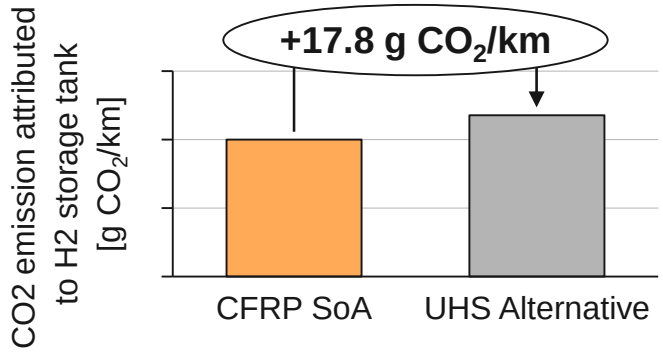
- **Accounts for** the differences in energy consumption in use phase and the **CO_2 emission factor of** the respective **fuel**
- **Technology measures for BEV and FCEV become relevant for CO_2 regulation,** e.g. lightweight design
- State-of-the-Art saves ca. 0.35 kg H_2/100 km in typical long-haul driving cycle (*Assumption)



Evaluation of use phase (based on regulation scenario)

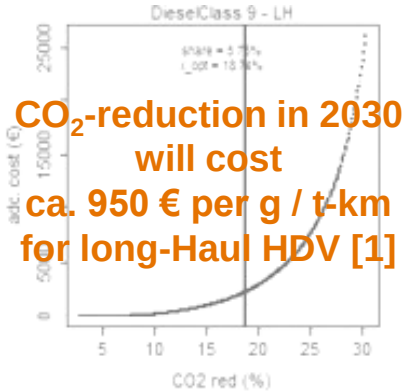
Assumption: 5,04 kg CO_2 per kg Green Hydrogen, Avg. Payload 14 t.

Sustainability

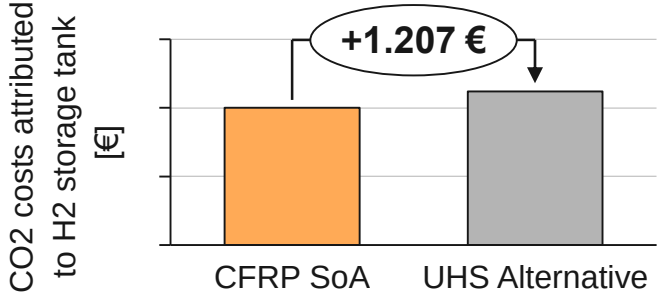


~ difference of 1.27 g CO_2 per t-km

Economy



CO_2-reduction in 2030 will cost ca. 950 € per g / t-km for long-Haul HDV [1]



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

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Conclusion – strategic implications of multidimensional value of CO_2

CO_2 Value

- Strong push of legislation and society to reflect life cycle aspects
- OEM have to force sustainability, esp. CO_2 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_2 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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