Hydrogen Storage and Transportation at 50MPa

Johannes Lorenz

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Workshop Objectives

"Identify areas of hydrogen infrastructure wherein early-stage R&D is necessary to reduce cost and improve reliability."

"Facilitate collaboration between laboratory researchers and industry stakeholders to inform R&D projects."

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Company Background

About EMS

- EMS' origins are based upon decades of high-tech, precision engineering in the emission free energy sector
  - We have more than 40 years experience in both sophisticated R&D and series manufacture of CFRP vessels and other products (HT and UHM fibers)
  - EMS is a world-leading CFRP manufacturer in terms of precision, quality and output
  - EMS is part of the ETC Group of companies
- EMS operates on two main manufacturing sites
  - Almelo (Netherlands) approx. 200 FTE
  - Jülich (Germany) approx. 200 FTE
- Our Group has sites in the UK, US and France
  - Capenhurst (UK) approx. 30 FTE
  - Eunice (NM, USA) approx. 30 FTE
  - Tricastin (France) approx. 30 FTE

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Vision - Type 4 Pressure Vessels

- We focus on development, precision design & engineering, manufacturing, testing & documentation of pressurized gas systems
- We believe in emission free and/or emission reducing technology
- We aim for applications with high quality standards and documentation requirements
- We are a series manufacturing company (in K units)



Applications - Type 4 Pressure Vessels

Markets

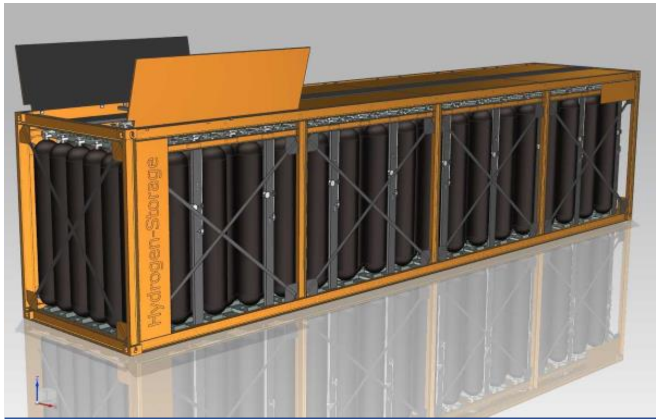
- Transport & Storage Systems
- Heavy Duty Vehicle Systems
- Automotive Systems
- Aviation & Special Applications

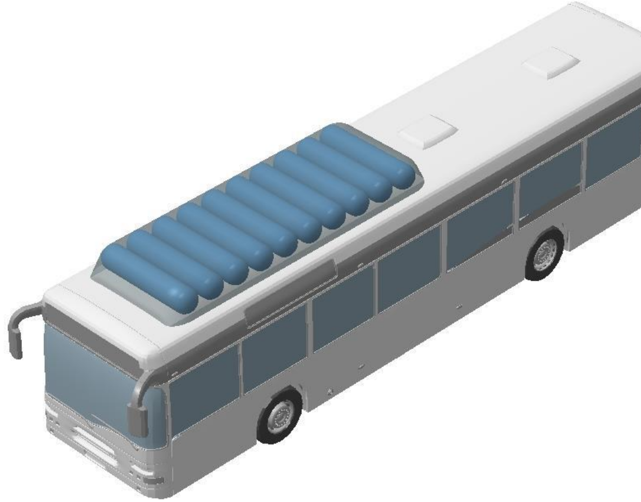
Relationship & Collaboration

- via development projects
- to series manufacturing

We improve total cost of ownership

- Know-how in PV Type 4 applications
  - Increase volume and save weight. Increase output and save waste
- Innovative series manufacturing solutions and scale effects





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Theory

"Identify areas of hydrogen infrastructure wherein early-stage R&D is necessary to reduce cost and improve reliability."

Comparative Analysis of Infrastructures

Hydrogen Fueling and Electric Charging of Vehicles

GRAZ, FEBRUARY 15, 2018

JOCHEN LINSSEN, MARTIN ROBINIUS, THOMAS GRUBE, MARKUS REUSS, PETER STENZEL, KONSTANTINOS SYRNANIDIS, DETLEF STOLTEN

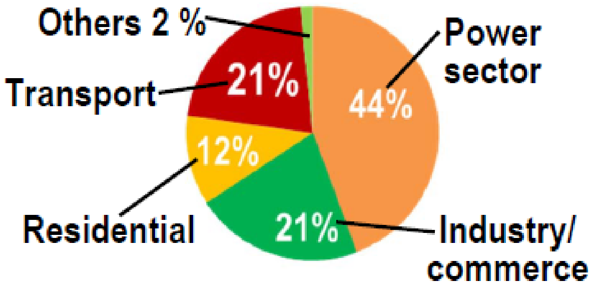
Institute of Energy and Climate Research

IEK-3: Electrochemical Process Engineering

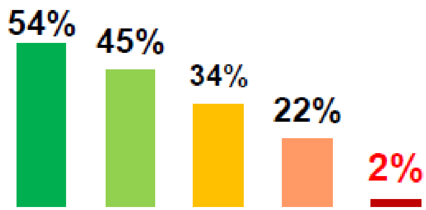
EnInnov2018, Graz, Austria 2018 February 14th to 16th

MOTIVATION

CO_2 emissions for Germany in 2015 (total: 762 Mt)



CO_2 emission reduction per sector 1990 to 2015



- Transport sector essential for reaching the ambitious climate protection goals
- Electric drivetrains key elements of low carbon, clean and energy-efficient transport based on renewable energy

Fuel Cell Electric Vehicles (FCEV) and Battery Electric Vehicles (BEV) require new energy supply infrastructures

Research Question

What are the investments, costs, efficiencies and emissions for an infrastructure capable of supplying hundred thousand or several million vehicles with hydrogen or electricity?

STATUS QUO OF INFRASTRUCTURE

Hydrogen Fueling

- Approx. 2,500 FCEV in operation worldwide
- End of 2016, 213 public Hydrogen Fueling Station (HRS) in operation worldwide: Japan (44%), the USA (17%) and Germany (13%)
- Germany: HRS network reached 30 stations by mid June 2017. At present, 27 HRS are under construction or being planned in Germany, with a goal to build up to 400 HRS before 2023
- pipeline systems for the transportation and distribution of hydrogen concentrated for the chemical uses of hydrogen

Existing Hydrogen Pipelines (by 2017-05)	
The USA	2,608 km
Europe	1,598 km
of which in Germany	340 km
Rest of world	337 km
World total	4,542 km

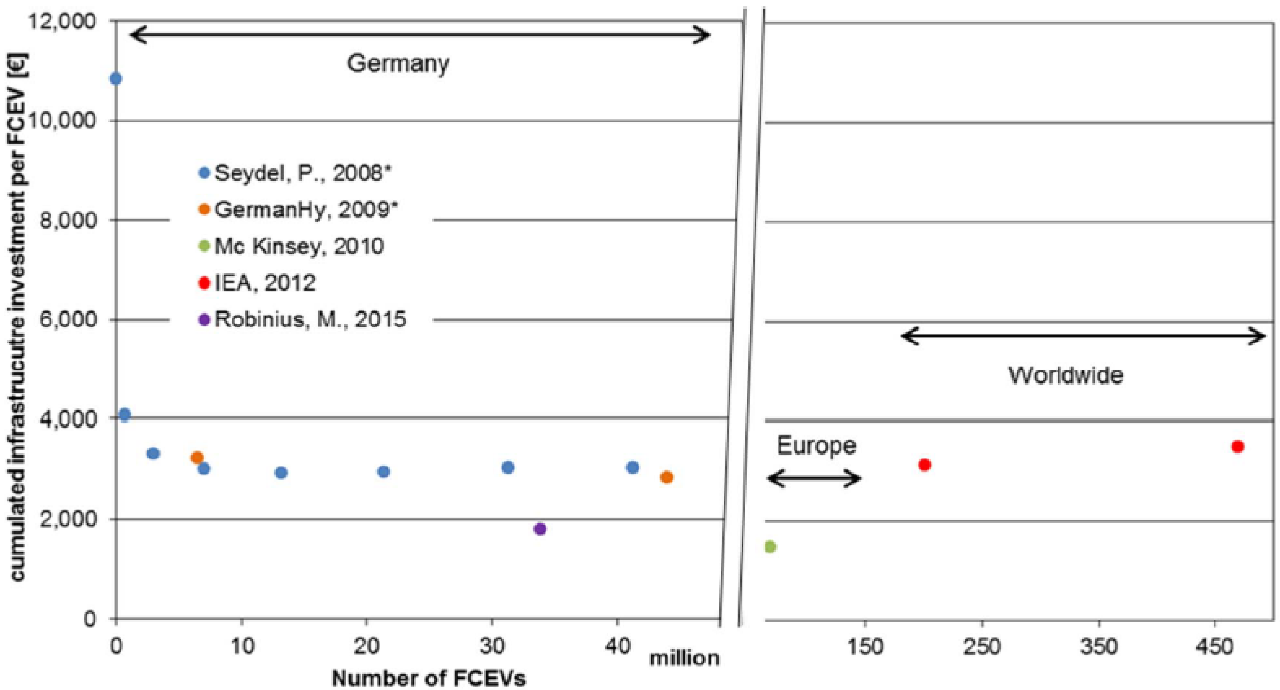
Sources: [9], [10], [14], [15]

Roadmap for hydrogen refueling stations in Germany

Sources: [12]

META ANALYSIS

Hydrogen Infrastructure – Vehicle Specific Cumulative Investment



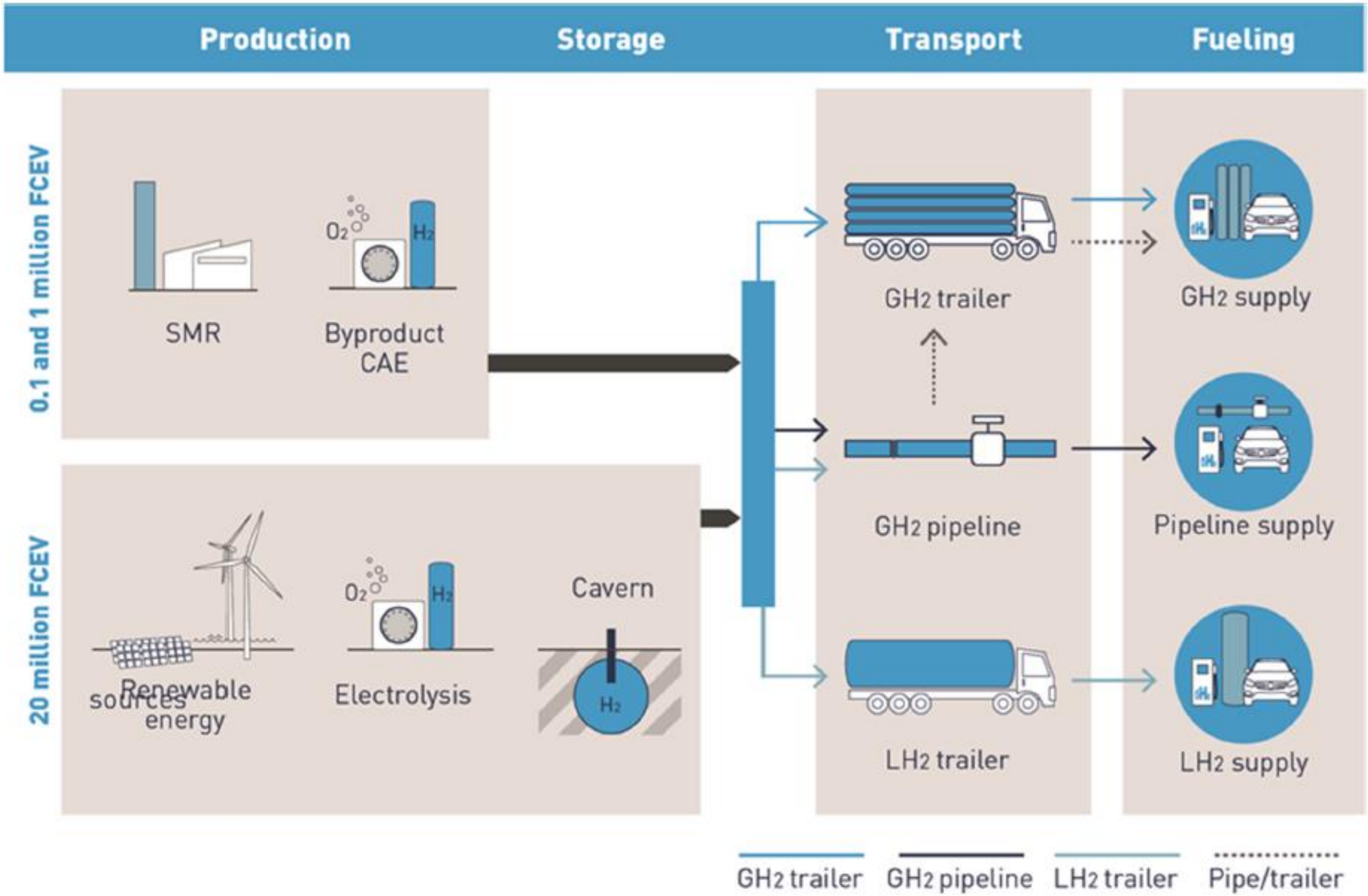
- Cumulative investment differs significantly due to different assumptions e.g. consideration of power plant investment or number of fueling stations
- Specific cumulative investment per FCEV in the range of € 2,000 to 4,000 per FCEV
- Expected decreasing specific investment per FCEV with increasing FCEV stock (due to learning curve and economy of scale) is not observed

INFRASTRUCTURE DESIGNS

Ramp up → Mass market

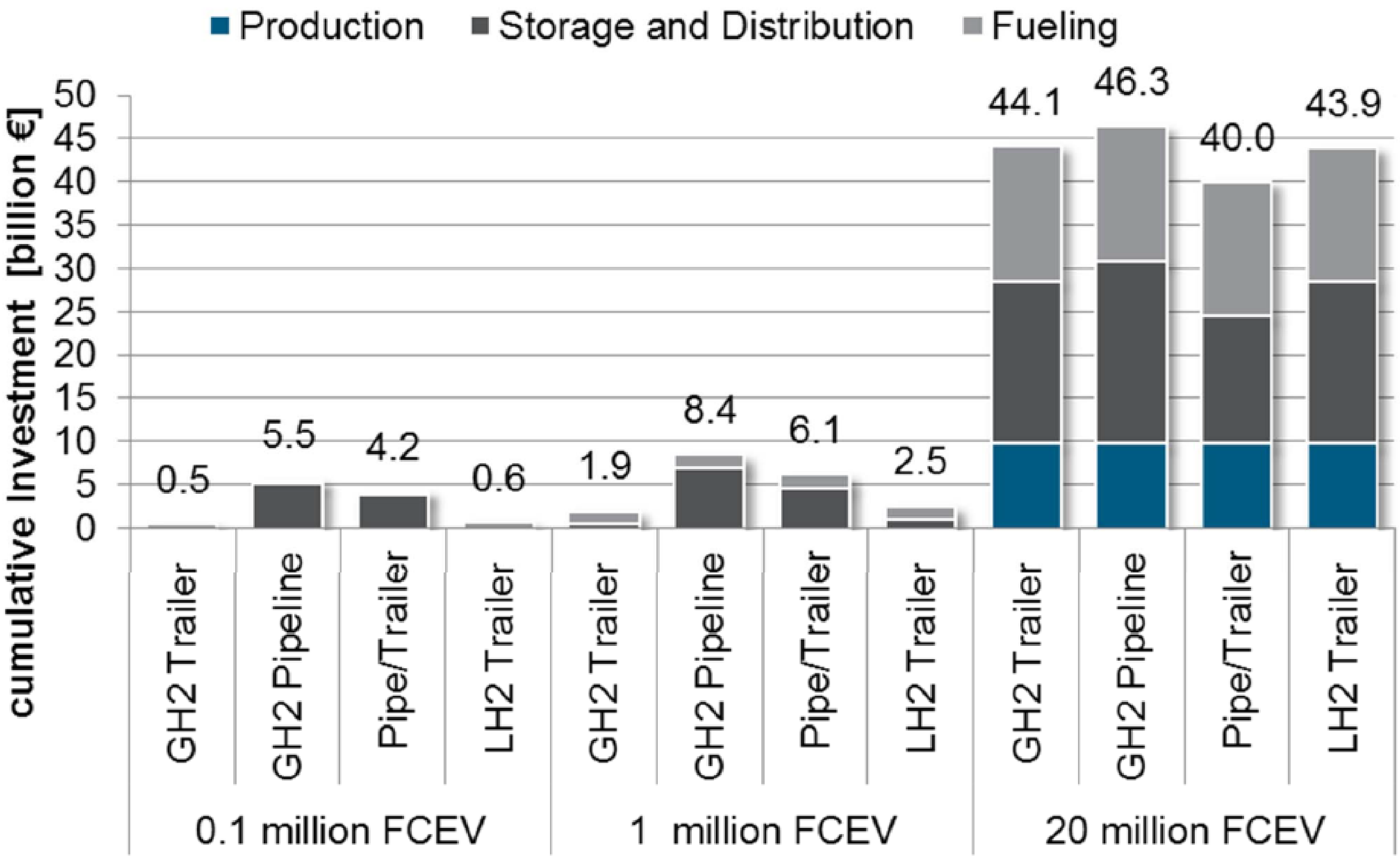
	0.1 million	3 million	10 million	20 million
cable length		1,800 km	28,000 km	183,000 km
transformer		6,100	55,000	187,000
slow chargers	100,000 @ 3.7 kW	2.8 million	6.5 million	11 million @ 22 kW
fast chargers	6,000 @ 150 kW	81,000	175,000	245,000 @ 350 kW
storage capacity		2 TWh	5 TWh	10 TWh
electrolysis		3 GW	10 GW	19 GW
truck trailer	42	730	1,500	3,000
pipeline		12,000 km	12,000 km	12,000 km
fueling	400	1,500	3,800	7,000

HYDROGEN SUPPLY PATHWAYS



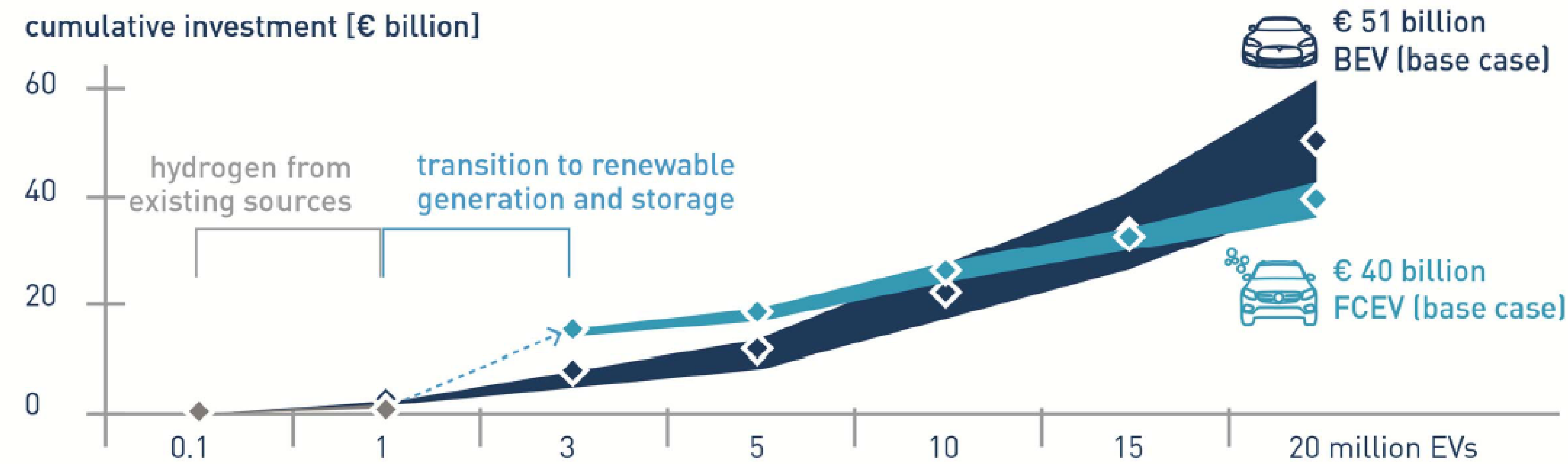
TOTAL CUMULATIVE INVESTMENT

Hydrogen Infrastructure



CUMULATIVE INVESTMENT

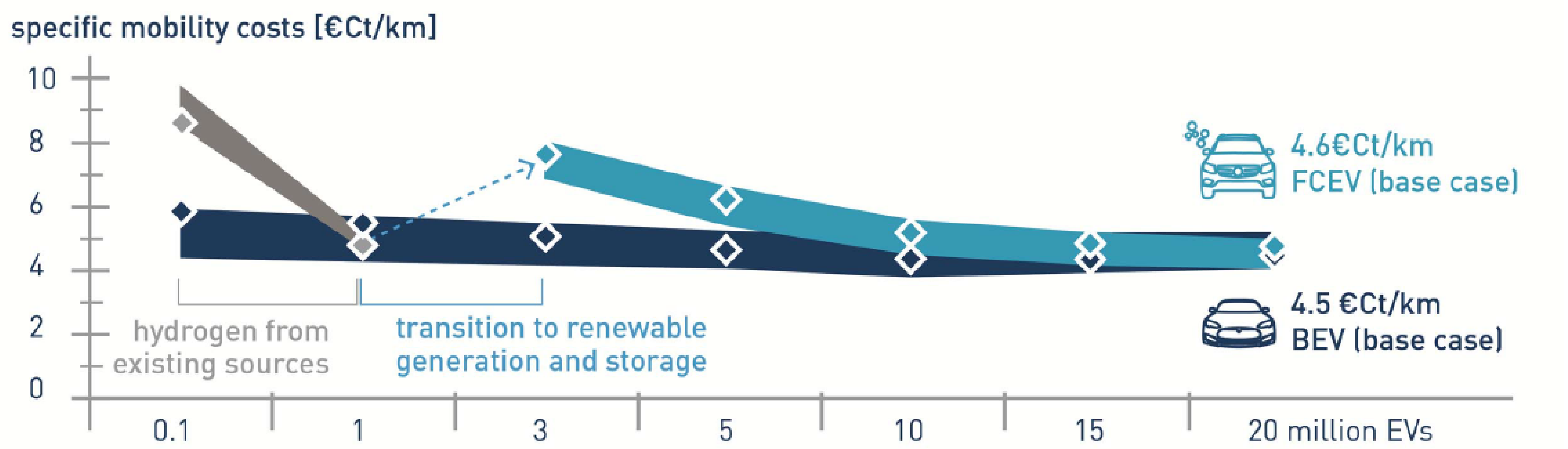
Infrastructure Roll-Out



- Hydrogen more expensive during the transition period to renewable electricity-based generation
- High market penetration: battery charging needs more investment than hydrogen fueling
- For both infrastructures investment low compared to other infrastructures

	Investment [€ billion]
Renewable electricity generation scenario	374
Electric grid enhancement plan 2030	34
Federal transport infrastructure plan 2030	265
Hydrogen fueling infrastructure	40
Electric charging infrastructure	51

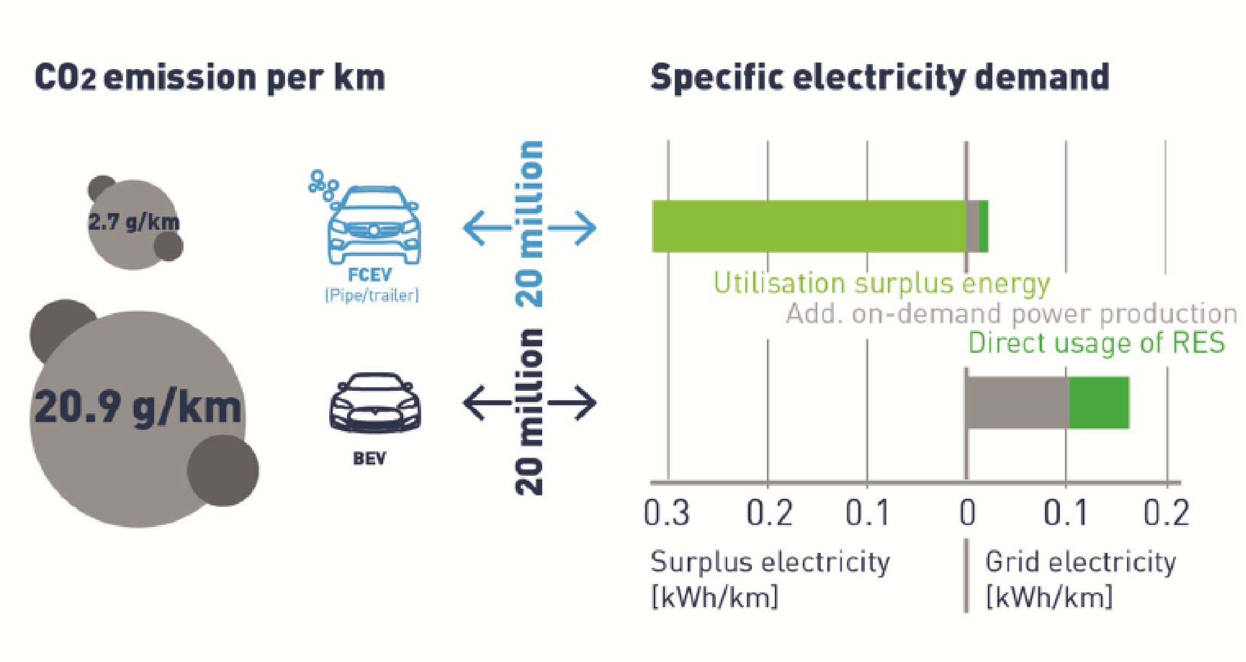
COMPARISON MOBILITY COSTS



vehicle purchase and operation costs excluded

- For small vehicle fleets, i.e. 0.1 million cars, BEV fuel costs are significantly lower compared to FCEVs.
- Increase for hydrogen between 1 and 3 million cars results of switching to exclusive utilization of renewable energy for hydrogen production via electrolysis
- Mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km => the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.

CO_2 EMISSIONS & ELECTRICITY DEMAND



- **Efficiency** of **charging** infrastructure is **higher**, but **limited in flexibility** and use of surplus electricity
- Fueling infrastructure for **hydrogen** with **inherent seasonal storage** option
- **Low** specific CO_2 **emissions** for **both options** in high penetration scenarios with advantage for hydrogen, **well below the EU emission target** after 2020: 95 g_{CO2}/km

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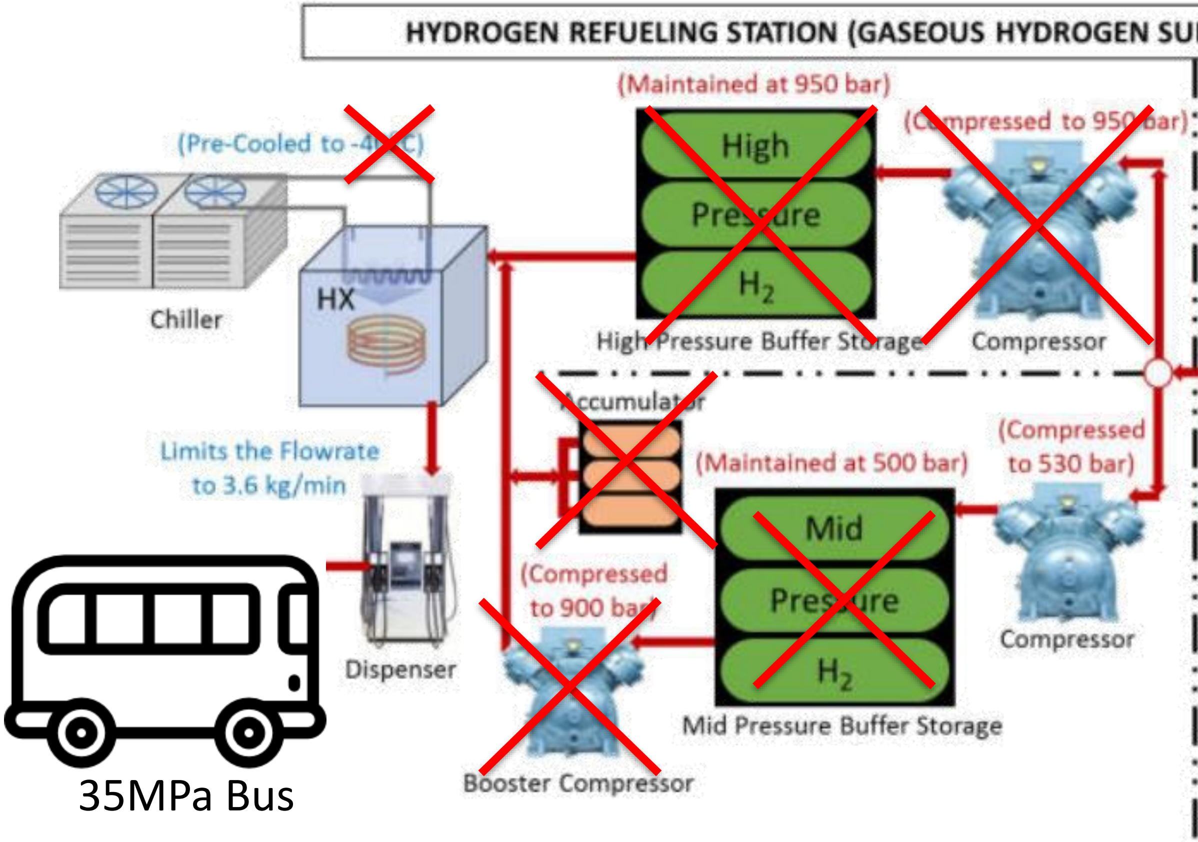
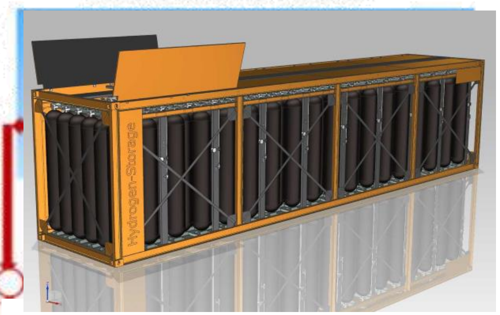
Advantage: 50MPa Trailer for 35MPa Busses



Hydrogen Supply Source



Main Advantages:

- Less Compressors
- Minimized compressor operation
- Lower maintenance and power costs
- Less cooling
- Reduced Noise

Sources: https://hdsam.es.anl.gov/index.php?content=hrsam
Designed by Flaticon

Test Site

- Public funded project to set up infra-structure
- Meckenheim (hydrogen storage)
- EMS will produce and certify the hydrogen storage

Fuel Station

Project Milestones

Jan 2019 → Installation

Feb 2019 → Commissioning

Feb 2019 until 2021 → Monitoring / Operational Behaviour

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Overview H² Transport & Storage System

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Thank you for your attention!

Appendix

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