Renewable Hydrogen in Fuel Cell Heavy Duty Trucking - Ramp-up towards 2030

JRC Workshop
Decarbonisation of Heavy Duty Vehicle Transport
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Agenda

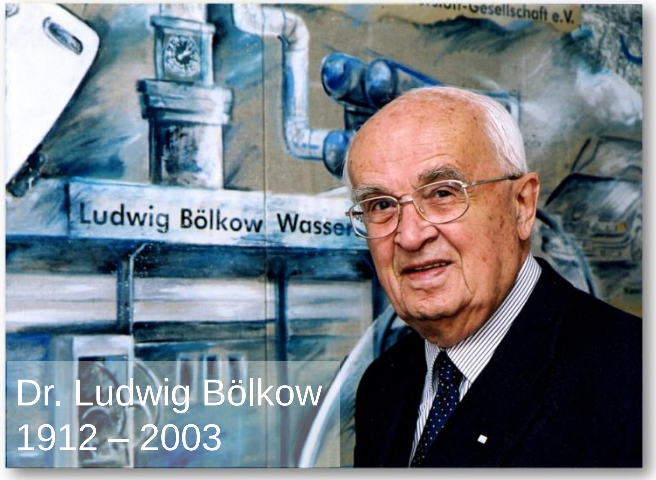
1. LBST
2. Challenging boundary conditions
3. Infrastructure implications
4. Fuel cell trucks coming to the market – a selection
5. Take-away

1 Ludwig-Bölkow-Systemtechnik GmbH – company profile

1 Ludwig-Bölkow-Systemtechnik GmbH (LBST)

Company profile

- Cutting edge competence
  - 35 years of continuous expertise
  - Interdisciplinary team
  - Independent expertise
- Bridging technology, markets, and policy
- Global and long term perspective
- Rigorous system approach – thinking outside the box
- Serving international clients in industry, finance, politics, and NGOs



German aeronautic engineer and industrialist, co-founder of Airbus Industries and founder of LBST

Selected references

- PRYHDE – *CGH_2 refuelling protocol for HDV*
- JRC – *Well-to-Tank studies*
- Tuck Foundation – *Future Fuel for Truck Freight*
- German Transport Ministry – *Mobility & Fuels Strategy*
- Automotive & energy industry – *Techno-economics / energy / GHG of fuel pathways*
- CertifHy – *EU-wide Certification System for Hydrogen*

1 Selected LBST clients

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Mobility

DAIMLER	BMW	AUDI	Volkswagen	MAN
Ford	Hyundai	Toyota	Honda	Nissan
BOSCH	Valeo	KEYOU	ALSET	
ProtonMotor	AIRBUS	ALSTOM		

Energy

Equinor	SHELL	REPSOL	uniper	Concawe
CAPEX	Innogy	RWE	Amprion	EDF
COFELY	TENNET	AXPO	EnBW	OGE
GAZPROM	Gasunie	Thyssengas		

Politics

European Parliament — European Commission — EC JRC

KfW — BMVI — Landesregierung NRW

Landesregierung Niedersachsen — Hessen Agentur

VDA — FCH JU — Hydrogen Europe — DWV

Industry

SIEMENS	NEL	here	TÜV SÜD
LINDE GROUP	REHAU	AngloAmerican	
Air Liquide	HEXAGON	HYDROGENICS	Marubeni
STILL	H2energy	Technova	

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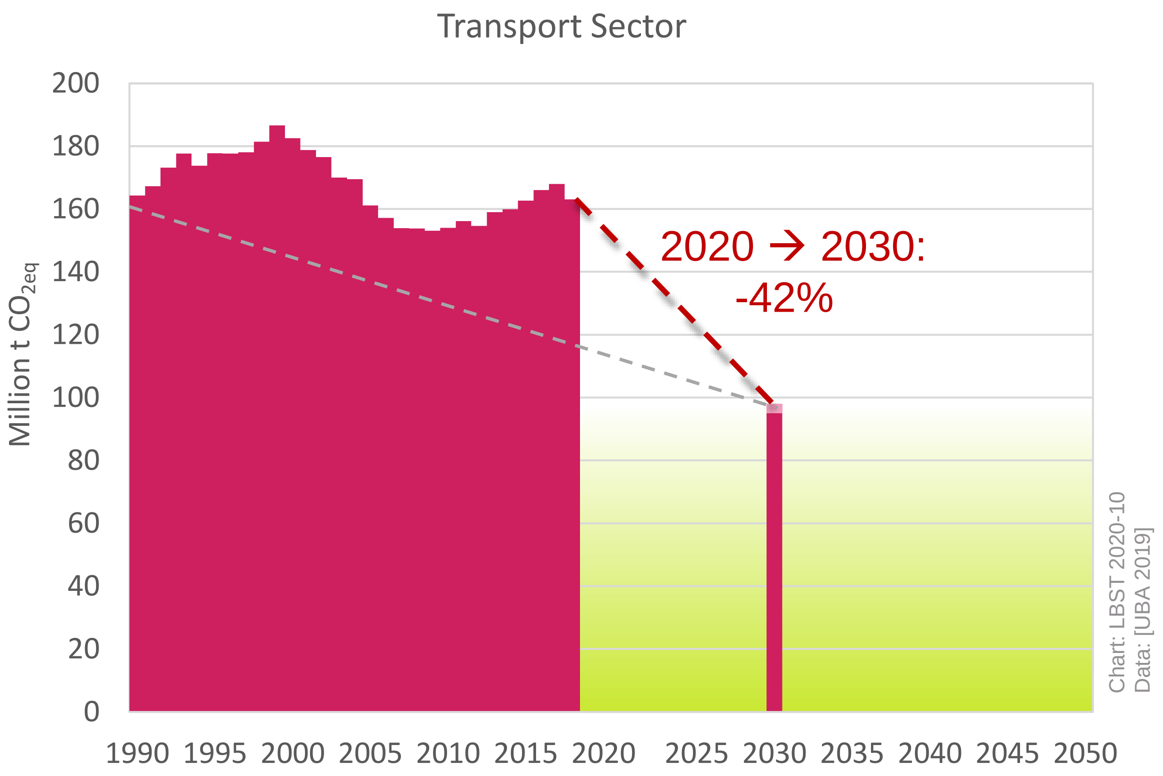
2 Challenging boundary conditions

2 Greenhous gas reduction goals in Germany: -42% by 2030

Since 30 years net GHG emissions from entire transport sector not reduced in Germany:



2 GHG reduction requirements for commercial vehicles > 3.5 t

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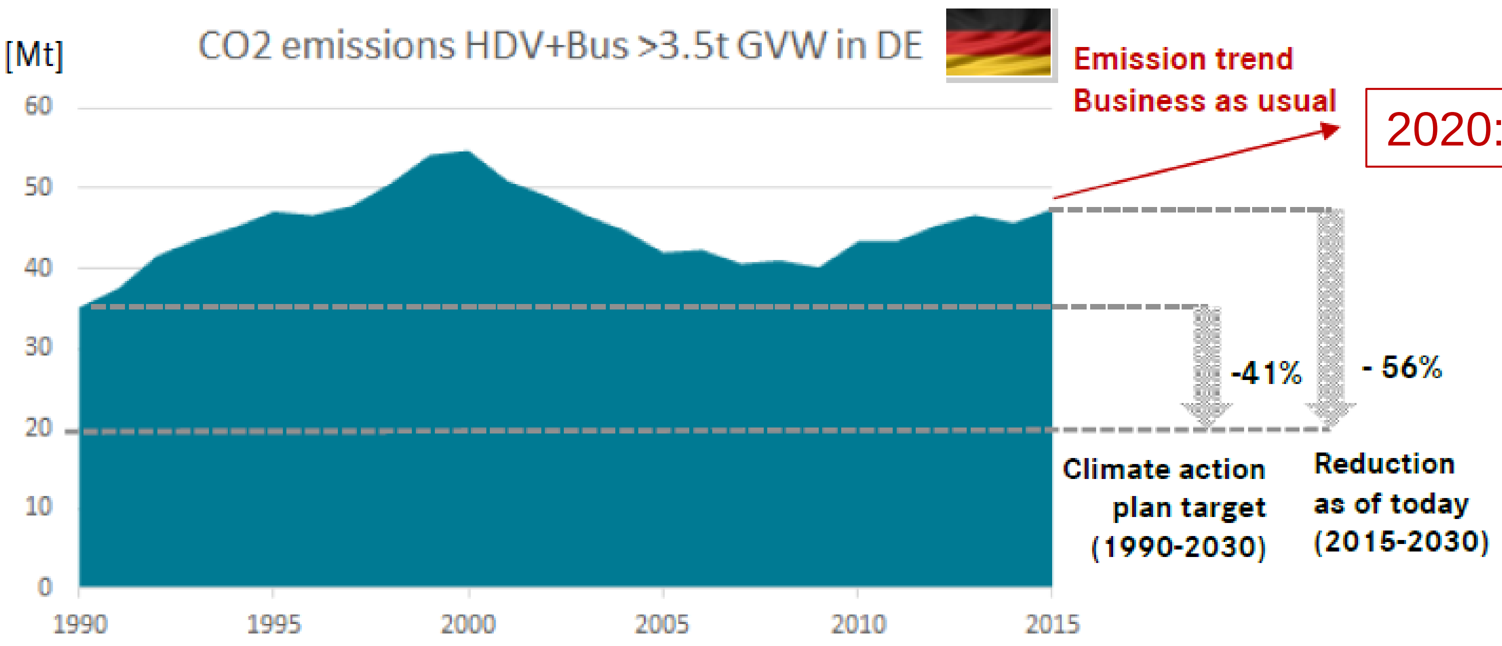
Official CO_2 emission inventory data, submitted to UNFCCC



2020: > -60% ?

LBST projection

> 50% of all fuel consumed by commercial vehicles today is consumed by 30 - 44 t trucks

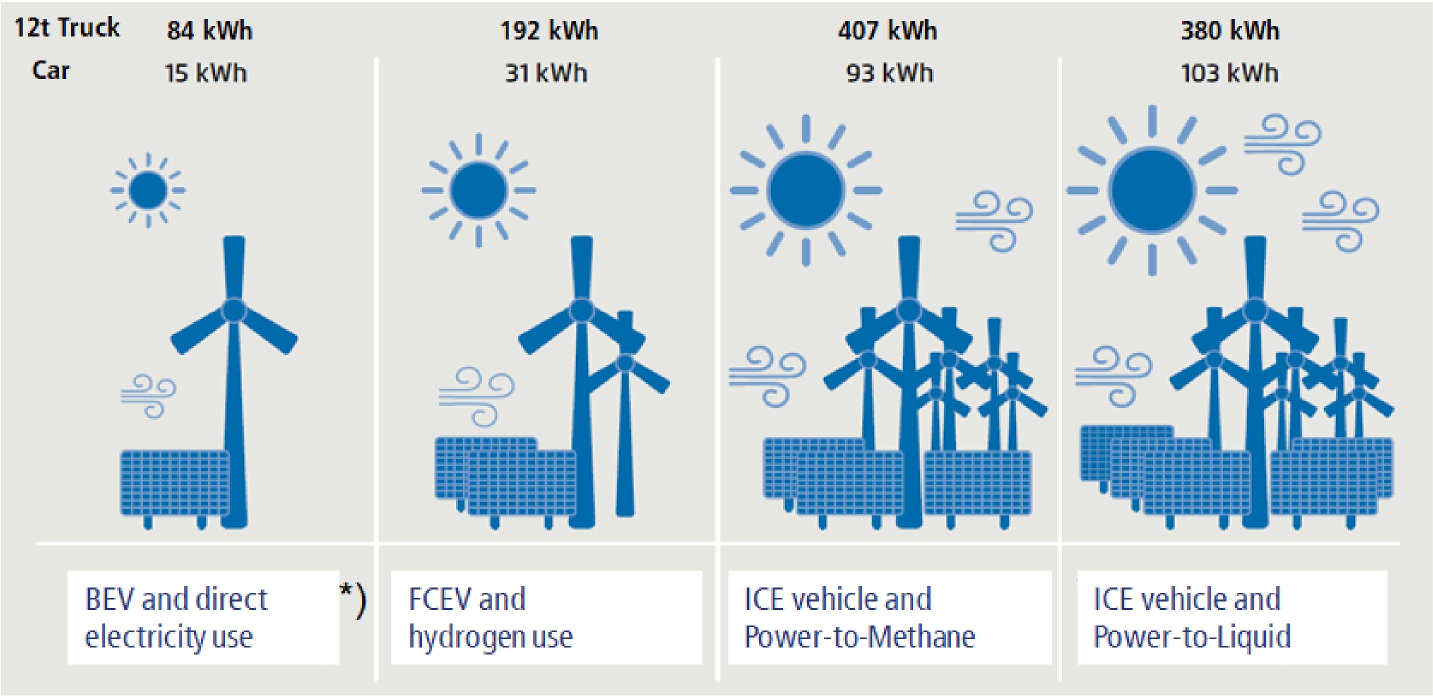
[1] KBA statistics on total traffic on German territory does not account HDV <6t GVW, were added separately under the assumption that in this case only vehicles with German registration have to be considered
[2] HDV with 2 axles subtracted for stringency due to changes in toll legislation
[3] Assuming 46% less fuel consumption for HDV 3.5-12t GVW

Sources: DIW 2015, EEA 2016, KBA, BAG, UNFCCC Emission Inventory Data

Source: Manfred Schuckert, Daimler Trucks, Berlin, 24 May 2018

2 Renewable electricity-based truck and car fuel/powertrain combinations

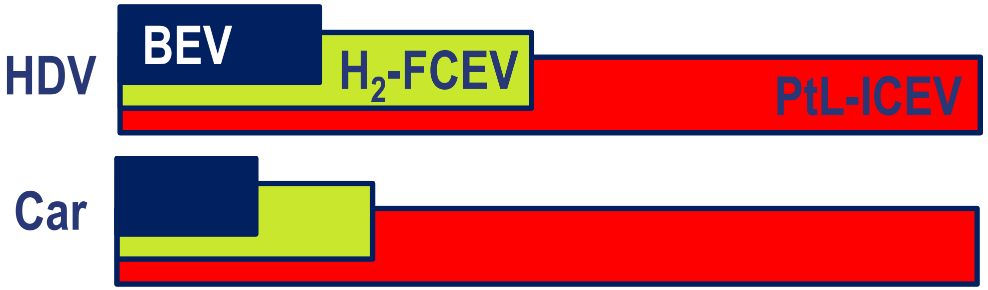
Renewable electricity demand for several fuel/powertrain combinations (per 100 km)



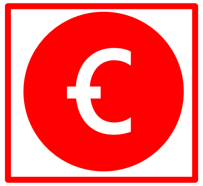
Source: Agora Verkehrswende 2017 auf Basis von DLR/ ifeu/ LBST/ DFZ 2015

H_2FC is 2-3 times more efficient than PtL
[+ zero emission + low noise]

Green Electricity Demand:



2 Existing access limits for urban centers in Europe



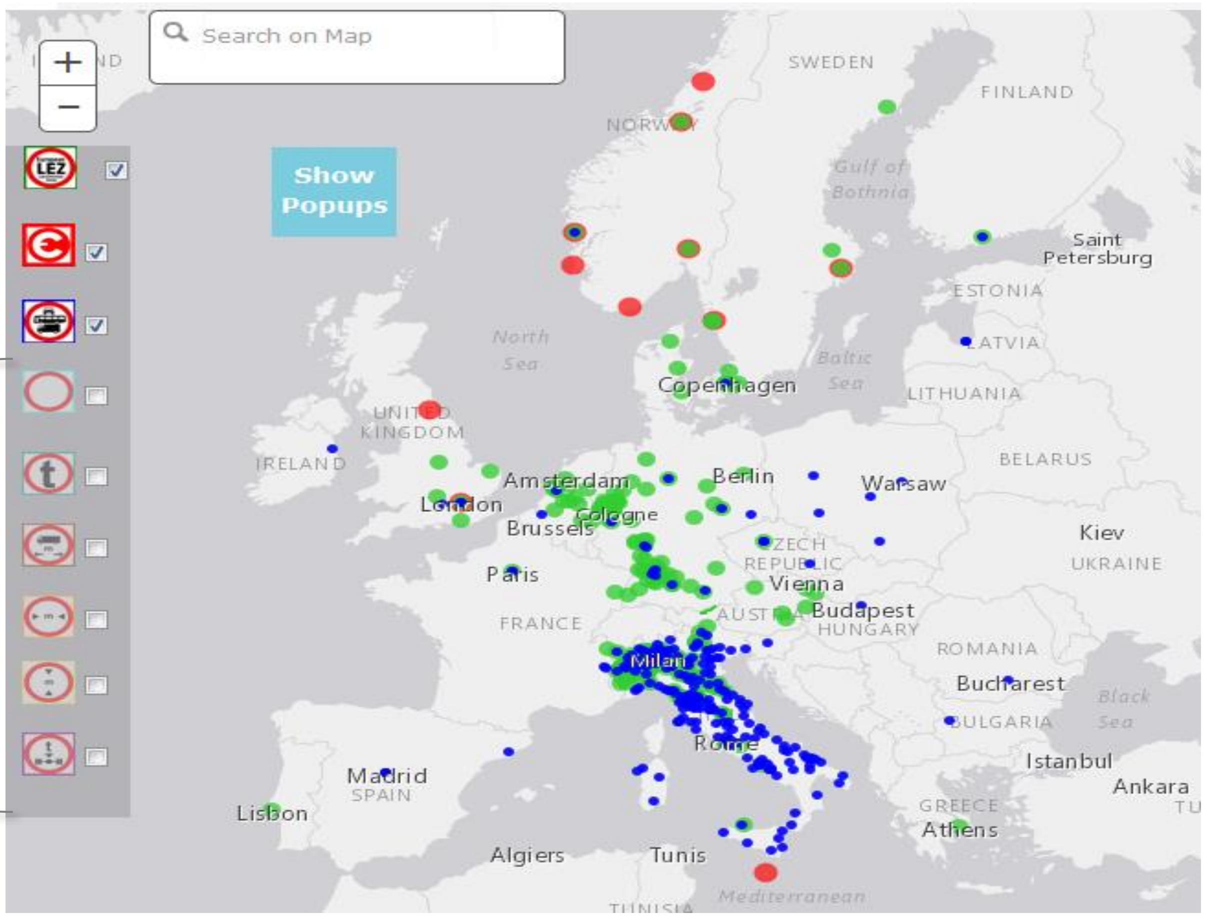
Urban Road Toll Schemes
(e.g. Northern Europe:)

Low Emission Zones (LEZs) implemented in areas where air pollution levels are dangerous to health
(e.g. Central Europe)

Key Access Regulation Schemes (Key-ARS)
(e.g. Southern Europe)

Others

Source: http://urbanaccessregulations.eu



Diesel drives will increasingly be banned from urban areas – in Paris as early as from 2025

Following pollutant emissions, limiting noise emissions is the next big issue for urban agglomerations → the end of the combustion engine is foreseeable
(of the >100 C40 cities [www.c40.org], for example, Paris will ban diesel from 2025, and e.g. Paris, Mexico City, Madrid and Athens, a total of 12 cities, will only use zero-emission buses from 2025)

2 Regulatory requirements favoring ZEVs incl. FCEVs

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Requirements (push)

RED II
2018/2001/EU
[14% renew. fuel]

HDV CO_2
2019/1242/EU
[-30% CO_2 by 2030]

EU emission standards
rev. 70/220/EEC
[Euro VII+ → ZEV]

AQD
2008/50/EU
[air pollutants limited]

CVD
2019/1161/EU
[15% clean vehicles 2026]

Fuel Cell Truck

Enablers (pull)

AFID
2014/94/EU
[H_2 infra mandatory]

Eurovignette
rev. 1999/62/EU
[-75% toll for ZEVs]

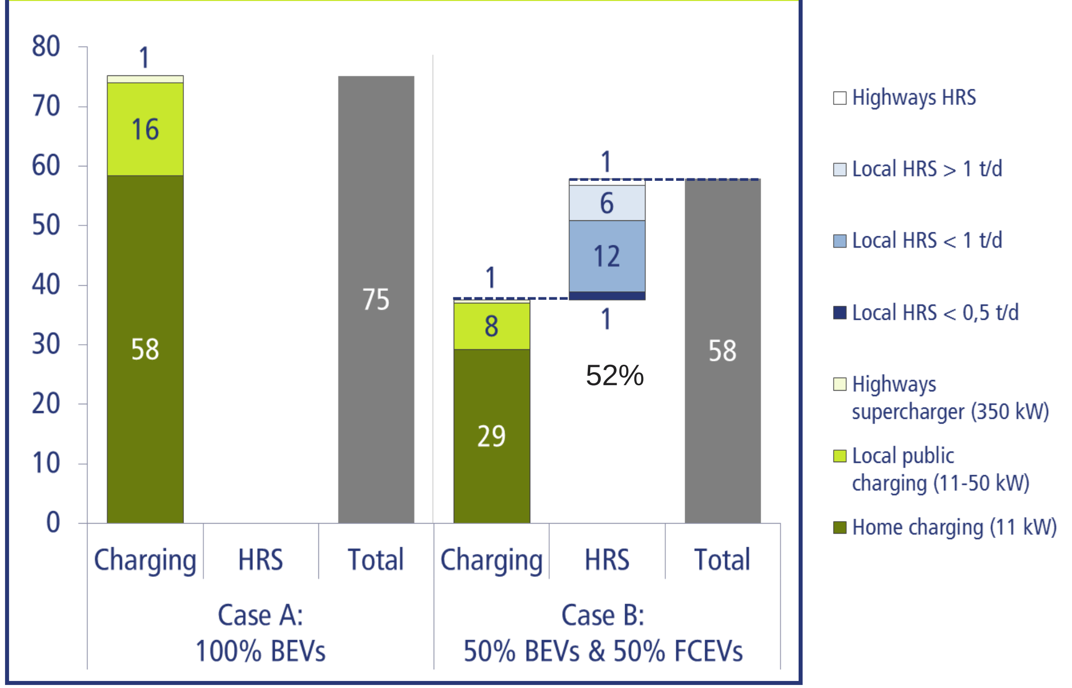
Extended urban delivery times
[noise → ZEVs]

C40 CITIES
www.c40.org
[stepwise ICE ban by cities}

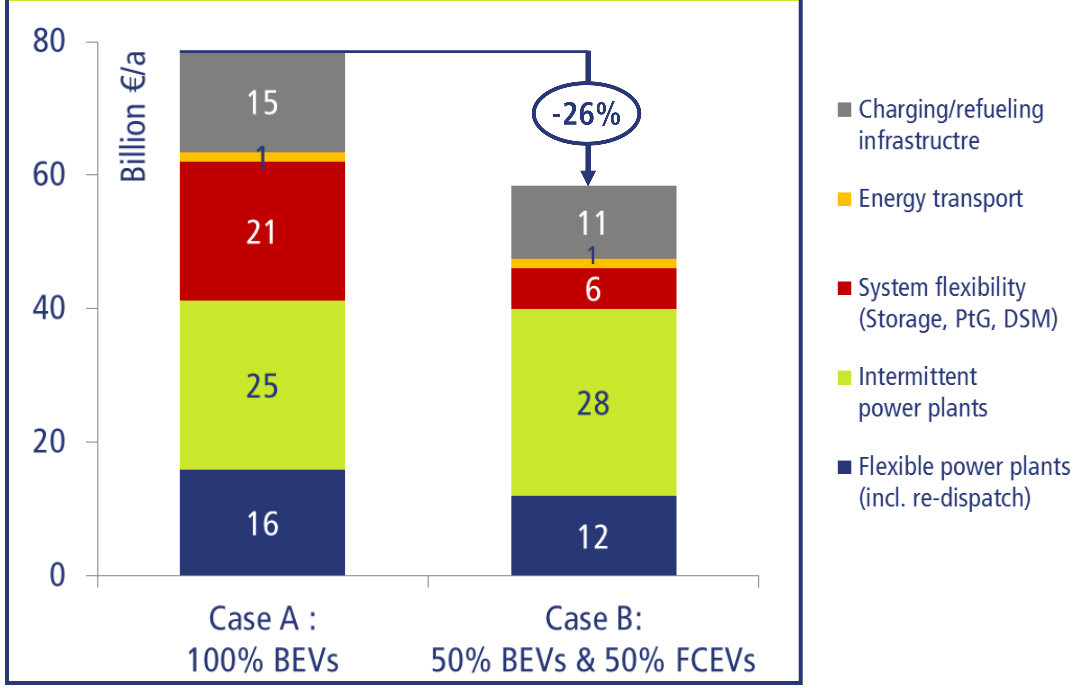
2 Lower cumulated investments already for a BEV+FCEV mix compared to BEV-only infrastructure

Case A: 45.8 million BEVs in 2050 | Case B: 22.9 million BEVs and 22.9 million FCEVs in 2050

Total investment needs in billion €

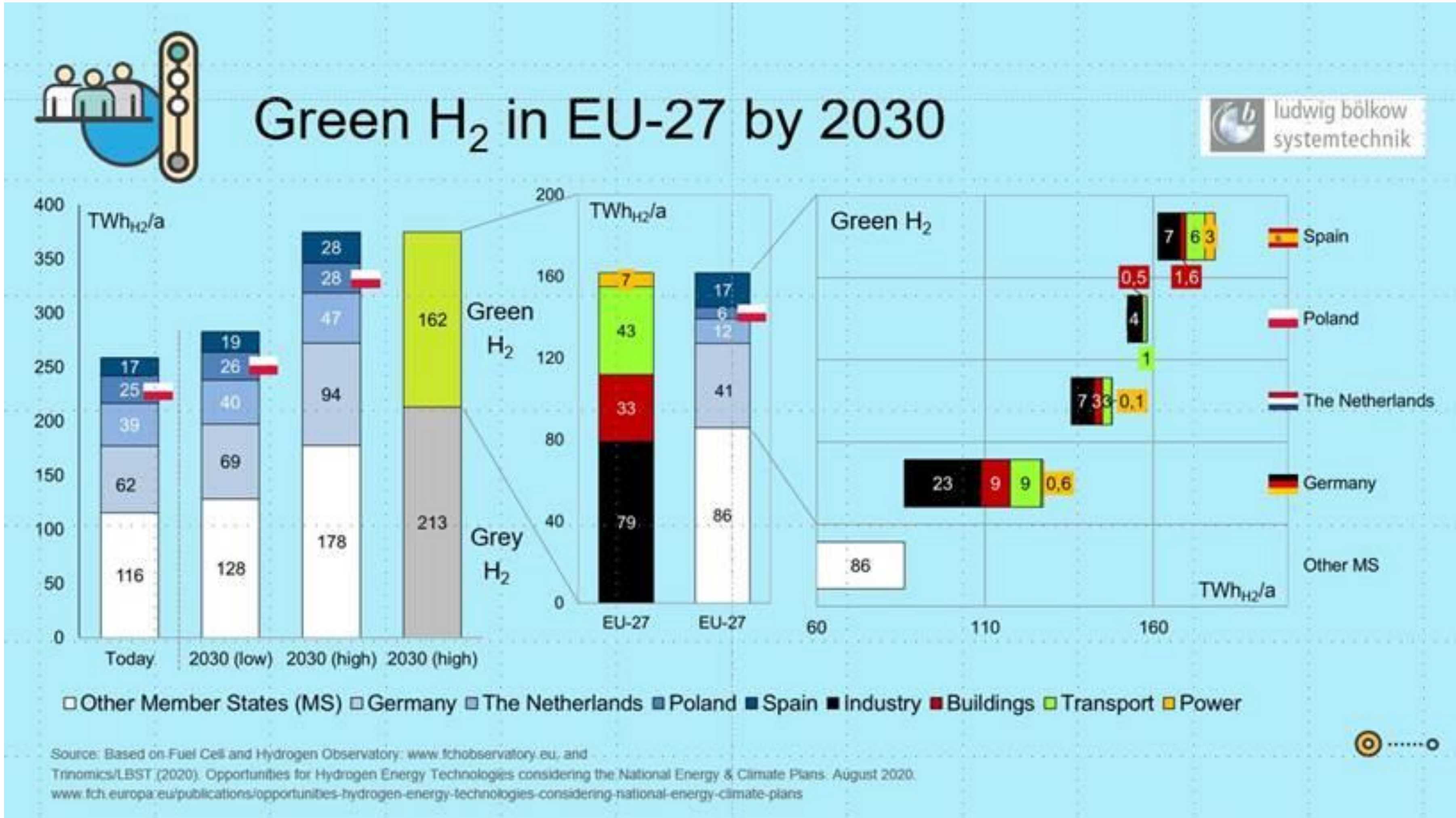


Scenario 2: 95% GHG reduction



Source: The impact of electro-mobility on energy supply in a future energy system dominated by renewable electricity | World Hydrogen Energy Conference 2018 | Rio de Janeiro 21 June 2018 | Jan Michalski, Ulrich Bünger, Reinhold Wurster

2 Significant near-term H_2 contribution for transport in EU-27



Forecast of H2 demand in EU-27 by 2030 depicted by EU Member State, application areas, and green vs grey H_2.

Figures are based on NECP study for FCH-JU (without UK) amended by recent demand data obtained from the Fuel Cell and Hydrogen Observatory.

3 Infrastructure implications

3 FCEV shows lowest infrastructure costs for EU coverage

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Cumulative infrastructure investments per ramp-up stage		BEV (*) truck	FCEV truck	CEV truck
1. Pilot network	Pilot projects with focus on areas with high traffic volumes (> 100,000 HDT annually)	0.7 B€ (35 HPCs) ------------------- First stations	0.6 B€ (20 HRSs) ------------------- First stations	2.7 B€ (1,600 km) ------------------- First catenary lines
2. Area-coverage network	Complete coverage of Europe as a consistent network	2.5 B€ (120 HPCs) ------------------- Increased network to enable pan-European trips	0.6 B€ (20 HRSs) ------------------- Increased network to enable pan-European trips	36.2 B€ (21,500 km) -------------------- Complete catenary network already required for pan-European trips
3. High-demand network	Complete coverage of Europe with sufficient capacity	29.5 B€ (1,400 HPCs) ------------------- Complete network with more stations to meet energy demand	29.4 B€ (920 HRSs) ------------------- Complete network with more stations to meet hydrogen demand	44.1 B€ (21,500 km) -------------------- More converter stations (increasing capacity) to meet energy demand

(*) Investments into system integration for short-/long-term electricity storage not included

Source: Making zero-emission trucking a reality, Strategy&, 21 September 2020

3 Only moderate H_2 refueling infrastructure required for Germany

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	2020	2025	2030	2035	2040	2045	2050
No. of FC trucks in Germany	0	15,500	48,700	77,400	135,000	188,100	221,300
Share of FC trucks of total HDV market	0 %	7 %	22 %	35 %	61 %	85 %	100 %
H_2 demand in M t							
No. of HRSs	0	50	70	90	110	124	137
Annual expenditure for the construction and operation of the HRSs in B € (*)	0	3.06	4.28	5.51	6.73	7.58	8.38

(*) Annuity of investments and expenditures for H_2 production excl. taxes and duties

Source: Wie könnte ein Tankstellenaufbau für Brennstoffzellen-Lkw in Deutschland aussehen? | Martin Wietschel, Till Gnann - FhG-ISI & Philipp Rose - PwC Strategy& (Germany) GmbH | 09/2020]

3 Full cost projections for fuel cell heavy duty trucks

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Strategy& (PWC):

- 2030 TCO(*) for

- Fuel Cell:	0.65 €/km
- Battery:	0.68 €/km
- CEV:	0.79 €/km-
- PtL-Diesel:	0.95 €/km
- Diesel	0.57 €/km

(*) Total Cost of Ownership/TCO:
energy cost, maintenance cost, depreciation of vehicles
@ 2.3 €/l PtL-Diesel | 0.29 €/kWh | 6.8 €/kg_{H2} |
@ > 50 €/t_{CO2} alternatives competitive with Diesel-ICE

Source: Making zero-emission trucking a reality, Strategy&, 21 September 2020

European infrastructure – minimum/sufficient

Minimum European infrastructure:

120 high power chargers:	2.5 B€
70 logistics HRSs	2.2 B€
21,500 km overhead catenary lines	36.2 B€
2,400 Diesel refueling stations	0 B€

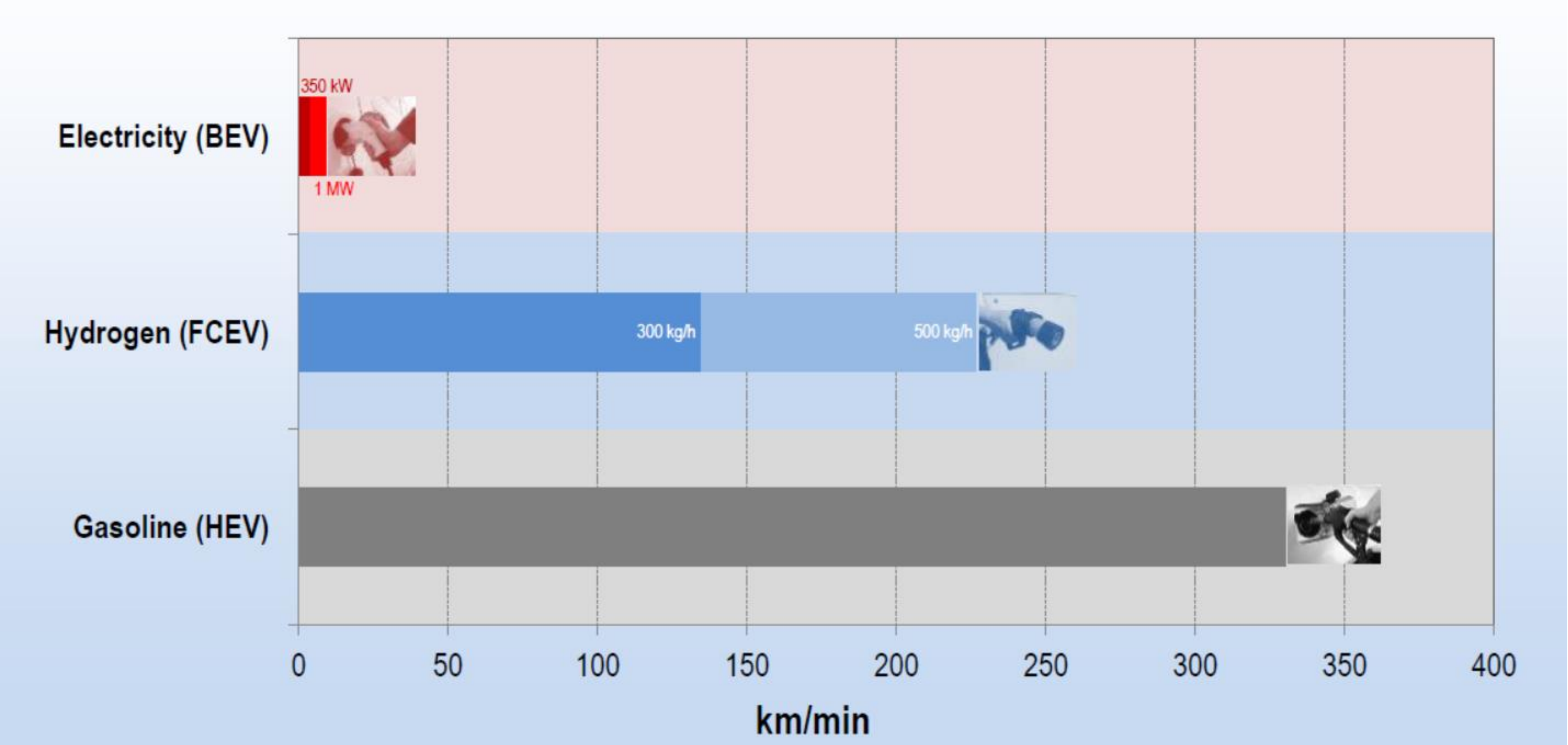
Sufficient European infrastructure:

1400 high power chargers:	2.5 B€
920 logistics HRSs	2.2 B€
21,500 km overhead catenary lines	44.1 B€
2,400 Diesel refueling stations	0 B€

3 Advantages of fuel cell trucks vs alternatives

- TCO by 2030 close to be competitive with fossil Diesel – competitive if CO_2 tax >50 €/t is imposed (planned EU toll to favor all zero emission alternatives)
- Longer operating range than BEV trucks while comparable payload as Diesel version
- Fast hydrogen refueling within 10-15 minutes for 800 km range
- Only realistic zero emission alternative for 30-44 t truck class (which in Germany represents almost 70% of all fuel use and GHG emissions in the > 7.5 t GVW class)
- Better flexibility in logistics than battery or catenary-electric alternatives
- Lowest infrastructure requirements w.r.t. number of units and investment cost and thus fastest to be implemented

3 Refueling speed in comparison



Source: Hynergy GmbH March 2020

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4 Fuel cell trucks coming to the market – a selection

4 First 10 Hyundai FC trucks from Korea to Switzerland of 50 to be delivered in 2020 and of 1,600 by 2025

Source:
Hyundai Hydrogen Mobility 2020

4 Toyota class 8 truck in California
(in the future to be realized on Hino XL Platform)

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36.24 t total operating weight (80,000 pound)

480 km operating range

60 kg hydrogen storage
@ 70 MPa (6 x 10 kg)

12 kWh hybridization battery

500 kW peak/
230 kW permanent power

1796 Nm

7 sec to 100 km/h

Tested @ 16t total weight – acceleration video:
https://www.youtube.com/watch?v=egK_fTcTZv4

Source: Toyota-Media website

The **PRHYDE** project (prhyde.eu) is developing a new HDV refueling protocol for high-throughput transfer of 35 & 70 MPa CGH_2 → up to 100 kg H_2 in ideally 10 minutes.

Project **duration**: until 12/2021. Subsequently a new ISO standard 19885 shall be developed for global harmonization.

PRHYDE **partners**: Air Liquide, CEA, Engie, ITM, LBST, MAN, NEL, Nikola, Shell, Toyota, ZBT

FCH2JU co-funded project

4 CSR example in the US: Anheuser-Busch

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Anheuser-Busch

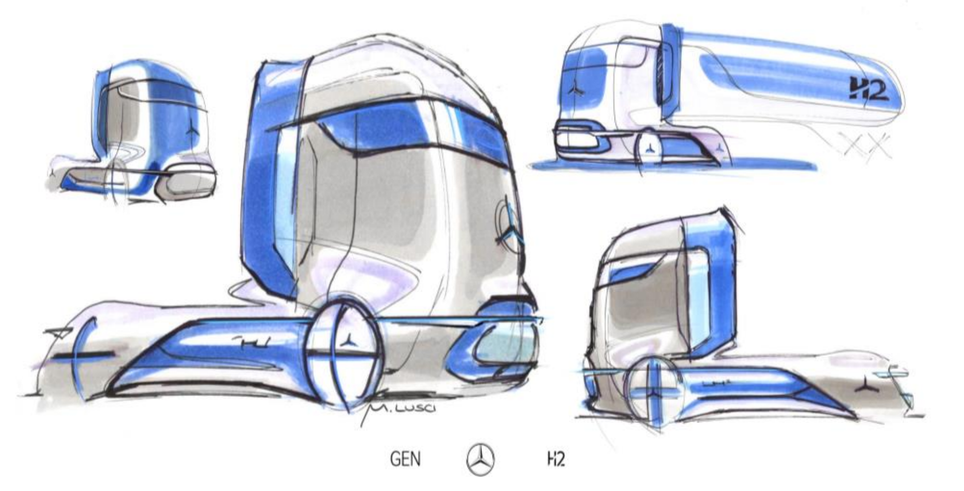
- 800 FC HD trucks ordered from Nikola Motor Company
- Delivery from 2021
- By 2026, AB will source all its vehicle fuels from renewable energy sources

Nikola Two

- Operating range: 750-1,200 km
- Battery: 250 kWh
- Fuel Cell: 240 kW
- H_2 storage: 60-80 kg H_2 @ 70 MPa
- Refueling time: < 20 min.
- HRS planning: 28 @ 8...32 t/d
- Pay for use modell (US$/mile)

Source: Jesse Schneider, Vice President Technology, Nikola, Berlin, 24.05.2018

4 Mercedes GenH2 Concept Truck

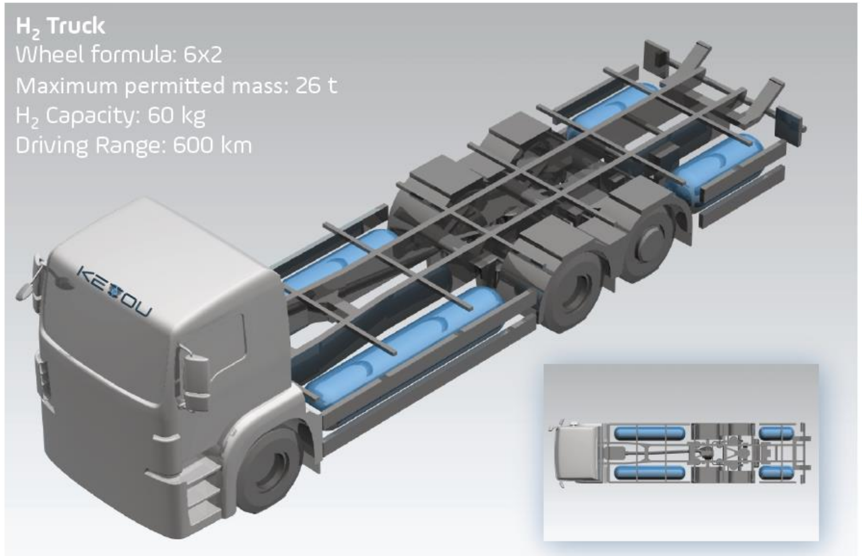


- First trucks at pilot customers from 2023
- Market rollout after 2025

Source: Daimler Truck AG
September 2020

4 KEYOU H_2 ICE near zero emission trucks – cost effective now

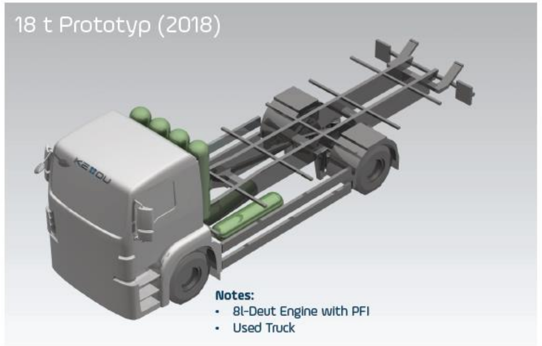
Example Truck: an optimized 350 bar CGH2-storage (horizontal) KEYOU

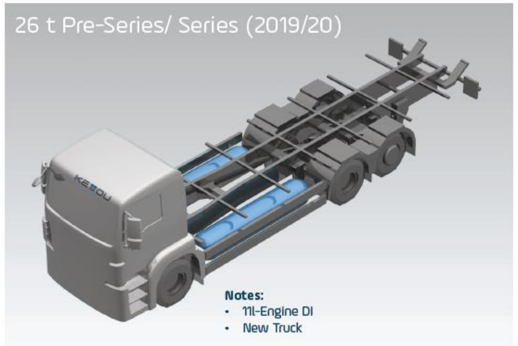


Source: : KEYOU GmbH | Copyright 2017

Example for a Pilot Project with a 18t / 26t Truck KEYOU

Performance data for a pilot Truck: Prototyp, Pre-series and Series



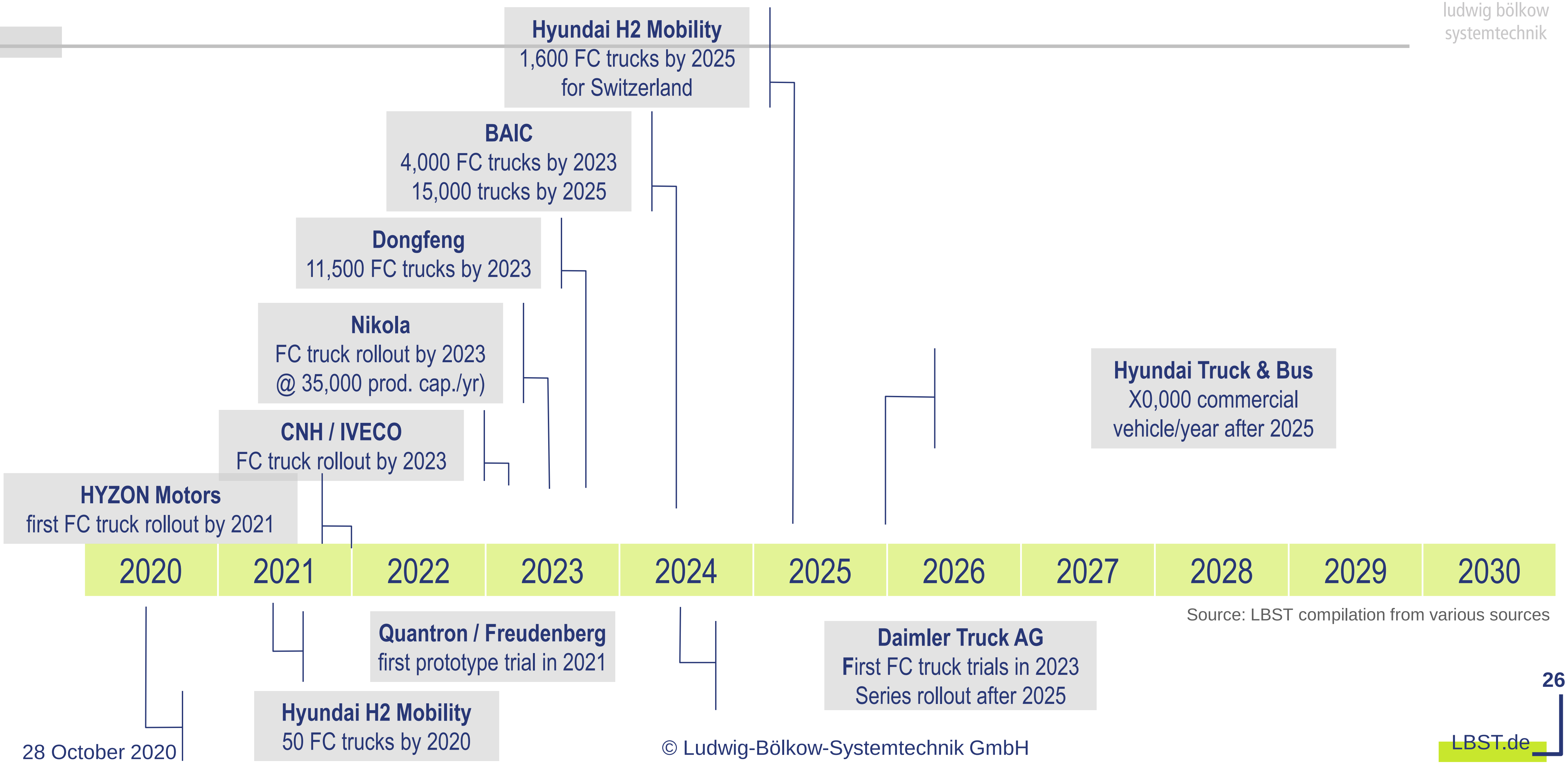


Prototyp	
Tank capacity	30 kg H_2
Driving range	300 km

Pre-Series	
Tank capacity	35 kg H_2
Driving range	370 km

Series	
Tank capacity	35 kg H_2
Driving range	410 km

4 Announcements on commercialization of fuel cell HD trucks



Source: LBST compilation from various sources

China, the 'hidden champion' with fuel cell HDVs by numbers

Examples of H_2 fuel cell van and delivery trucks in China

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SAIC Maxus FCV 80 Van with 100 kW_e propulsion power

Horizon 18 t truck with 120 kW_e FC

Foton 8.275 t truck with 60 kW_e FC

Dongfeng-ReFire 7.51 t truck with 30 kW_e REX-FC

Pictures: R. Wurster, Rugao, 26./27.09.2019

Year	Trucks/yr
2020	1,000
2021	2,000
2022	3,500
2023	5,000

Rollout planning by Dongfeng for fuel cell trucks of 9 / 12 / 18 t class
with operating ranges of 400 to 500 km

Source: Dongfeng Xiangyang Touring Car Co., Ltd., July 2019

5 Take-away

5 On the road to sustainability…

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- **Long-distance trucks** are the key segment to address GHG reductions in road freight
- **Renewable H_2** allows for deep GHG emission reductions at high pace
- **Zero emission** capability is increasingly decisive for continued access to urban areas
- Only moderate **H_2 refueling infrastructure** required for EU inter-operability
- Windows of opportunity exist for all zero emission options:
  - **BEV** for pure short-range logistics in moderate climates
  - **CEV** for dedicated fleets serving high-frequency point-to-point relations
  - **FCEV** for its versatility to serve all applications and to facilitate renewable/sector integration and thus is practically inevitable
- Today, patchy picture of push & pull **policy drivers** towards zero emission propulsion

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