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Hydrogen and Fuel Cells for Zero-Emission Power Trains

Ulf Groos, Head of Department Fuel Cell Systems
Fraunhofer Institute for Solar Energy Systems ISE
ADAC Symposium 2023, Freiburg
www.h2-ise.com
www.ise.fraunhofer.com

Hydrogen Enables Our Energy Transition

1. Fraunhofer ISE
2. German Energy Transformation
3. Global Role of Hydrogen
4. Fuel Cell Mobility


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01

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The Fraunhofer Hydrogen Network

- Materials
- Systems
- Technology Production
- Energy Sector and Power Economy
- Applications in Industry
- Applications in Mobility and Transport
- Safety and Life Cycle

- **Management:**
  Prof. Christopher Hebling (ISE),
  Prof. Mario Ragwitz (IEG)

Status: October 2020

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Budget 2021 (118,1 M€ with investments)

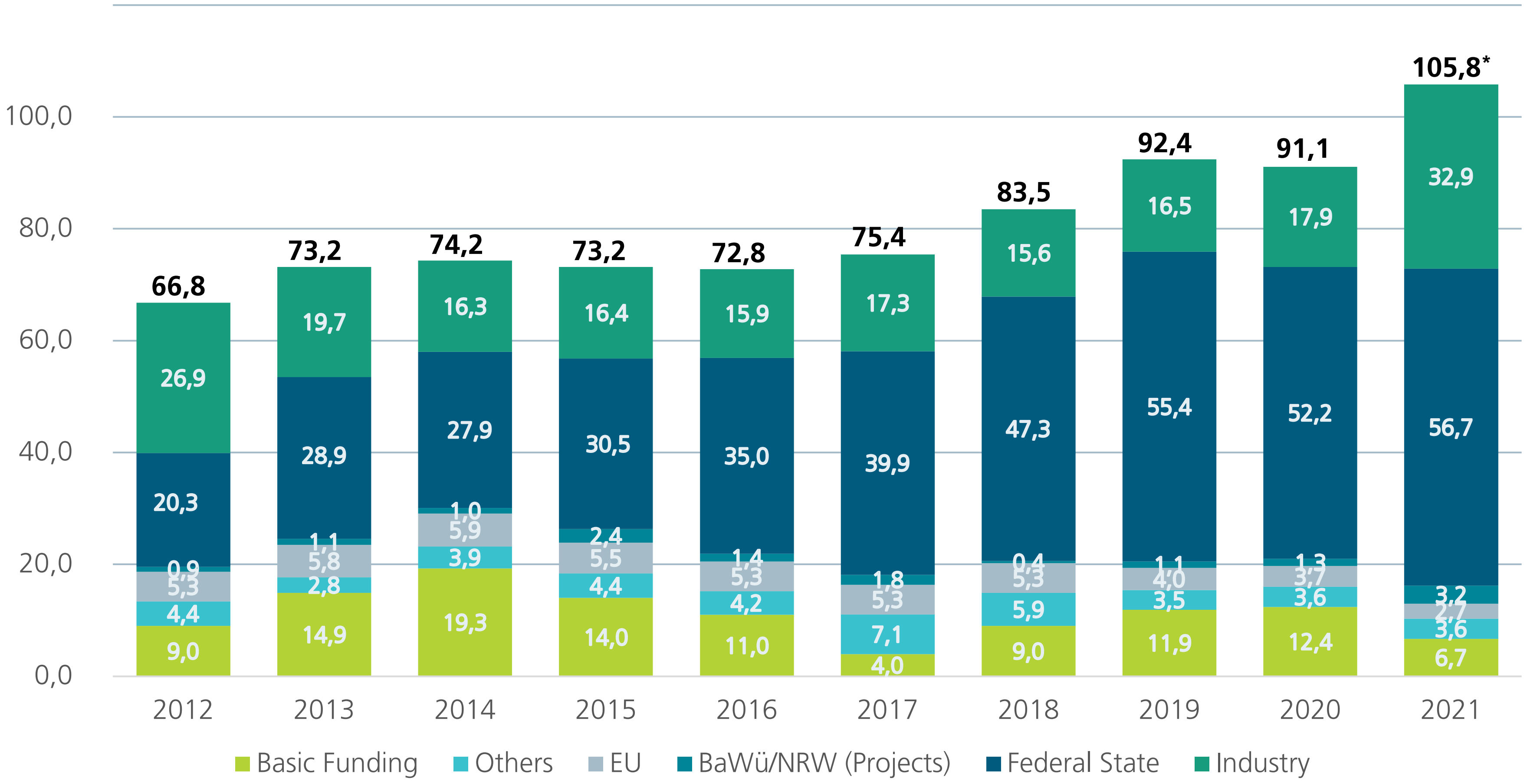
Photovoltaics
- Silicium-PV
- III-V- & Concentrator PV
- Perowskite- & Organic PV
- PV Modules & Power Plants

Energy Efficient Buildings

Solarthermal Power Plants & Industrial Processes

Hydrogen Technologies
Electrical Energy Storage

Power Electronics, Grids & Intelligent Systems



 16.02.2023

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Hydrogen Technologies @ Fraunhofer Institute for Solar Energy Systems ISE

Defossilization of Transport, Chemicals and Process Heat

Sustainable Mobility

Fuel cell cars at our solar hydrogen filling station; PEM fuel cell characterization, modelling, manufacturing, research and development

Synthetic Fuels, energy carriers, and chemicals

Catalysts and processes including LCA analyses for Power-to-Liquid processes

Power-to-X Technologies

PEM water electrolysis as basic technology for renewable fuels; hydrogen injection; Power-to-Gas simulations and techno-economical assessments

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Scientifically Sound R&D Services

Our customers rely on our results

Department Fuel Cell Systems

1. > 26 researchers plus students
2. 4.6 Mio € annual budget (w/o investments) and 40% direct revenue by industry contract research (2022)
3. >500 m² laboratory area with 12 single cell test stations, 4 short stack test stations, 1 system test site, 2 climate chambers (all fully automated for 24/7 operation)
4. Focus on transport application (LT PEMFC)

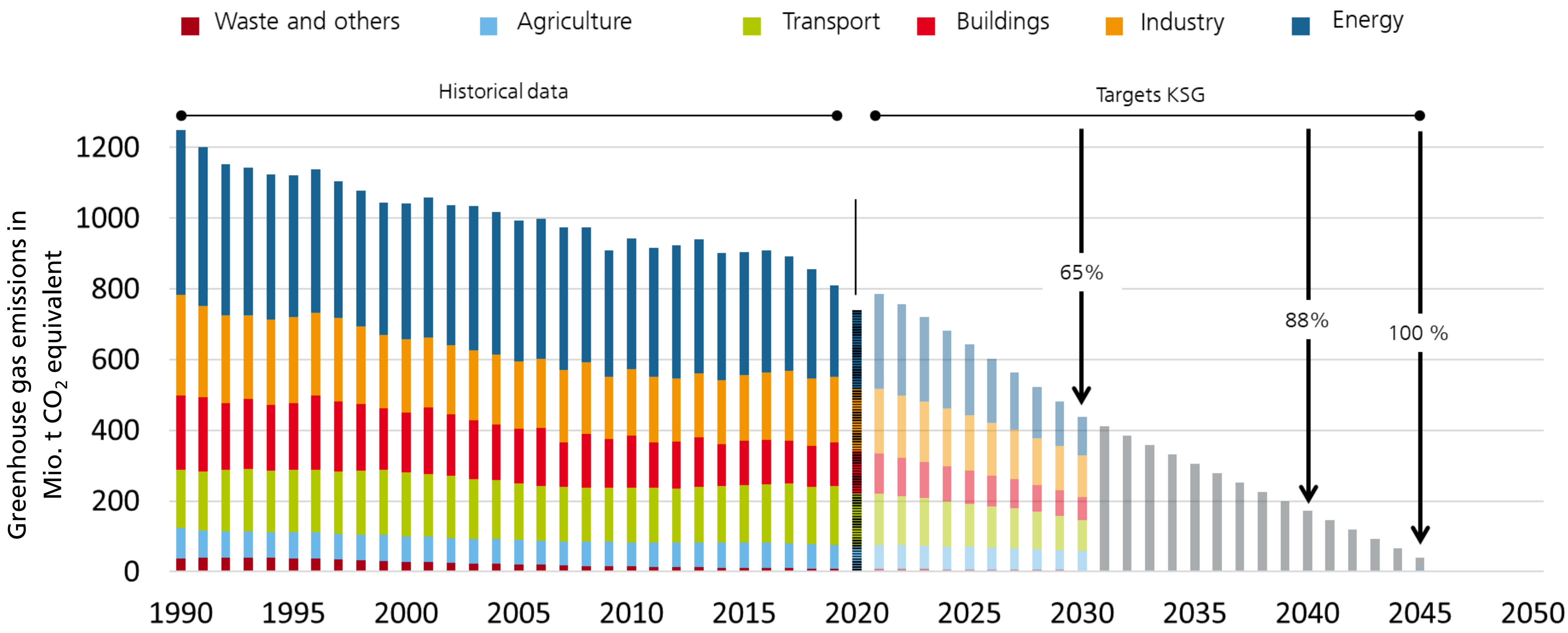
Enjoy our virtual lab tour:
https://www.ise.fraunhofer.de/en/business-areas/hydrogen-technologies-and-electrical-energy-storage/fuel-cell-systems.html

02

German Energy Transition

Greenhouse Gas Emissions in Germany

History and Targets according to Climate Protection Law

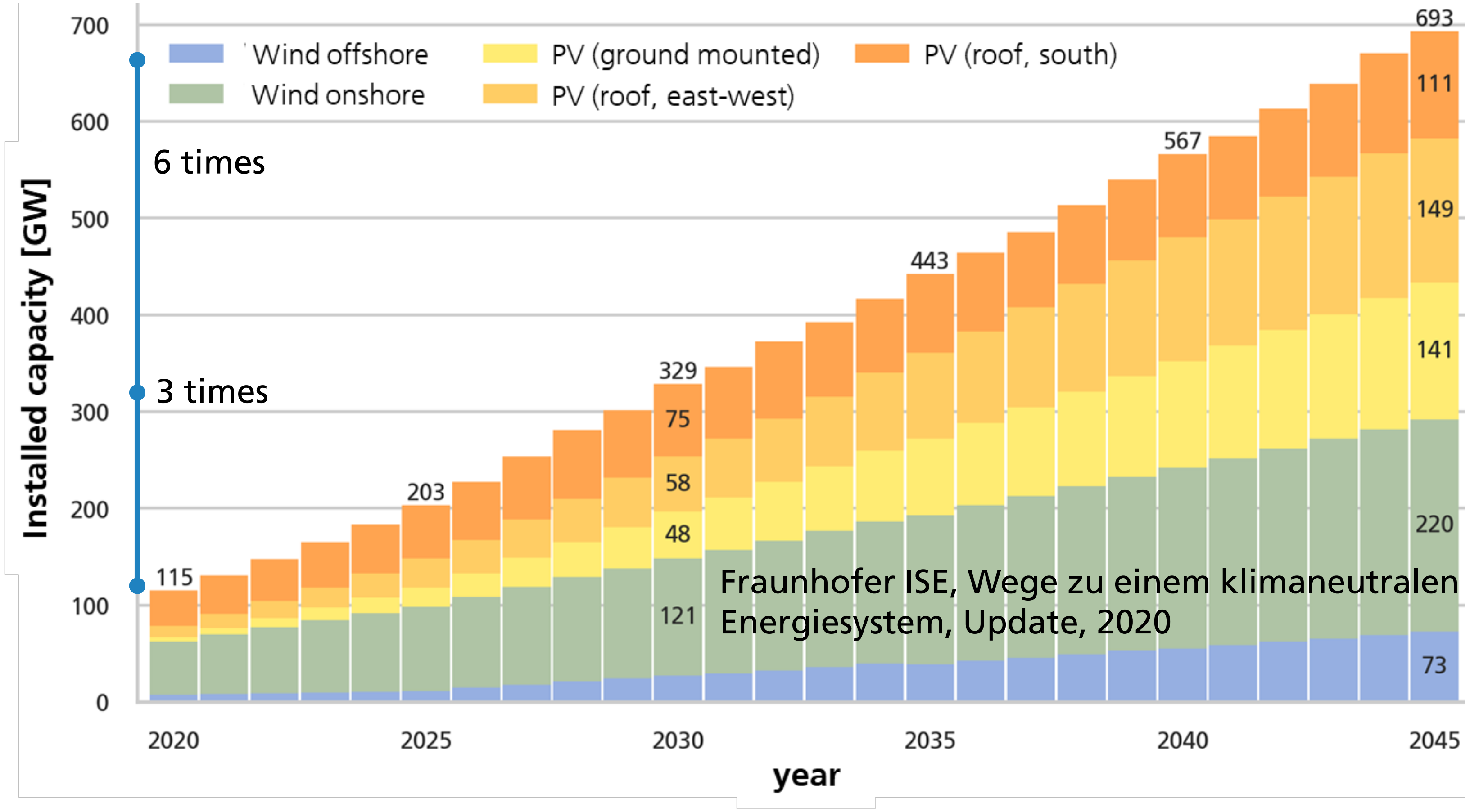


Historische Daten und VJS: Vorjahreschätzung (VJS) der deutschen Treibhausgas-Emissionen für das Jahr 2020. Umweltbundesamt, 15.3.2021

Significant Growth of Renewable Energies

Growing power demand due to electrification

- Power consumption 2019: 577 TWh_{el}
- Power consumption 2030: 700 – 780 TWh_{el}
  - End energy demand for mobility: 500 - 740 TWh [2]
- Power consumption 2050: 1.250 – 1.570 TWh_{el}
  - End energy demand for mobility: 200 - 650 TWh [2]
- Energy import necessary:
  - 2030: 40 – 80 TWh_{el}
  - 2050: 140 – 300 TWh_{el}



2: Wietschel, M. et al. (2021): Metastudie Wasserstoff – Auswertung von Energiesystemstudien. Studie im Auftrag des Nationalen Wasserstoffrats. Karlsruhe, Freiburg, Cottbus: Fraunhofer ISI, ISE, IEG (Hrsg.).

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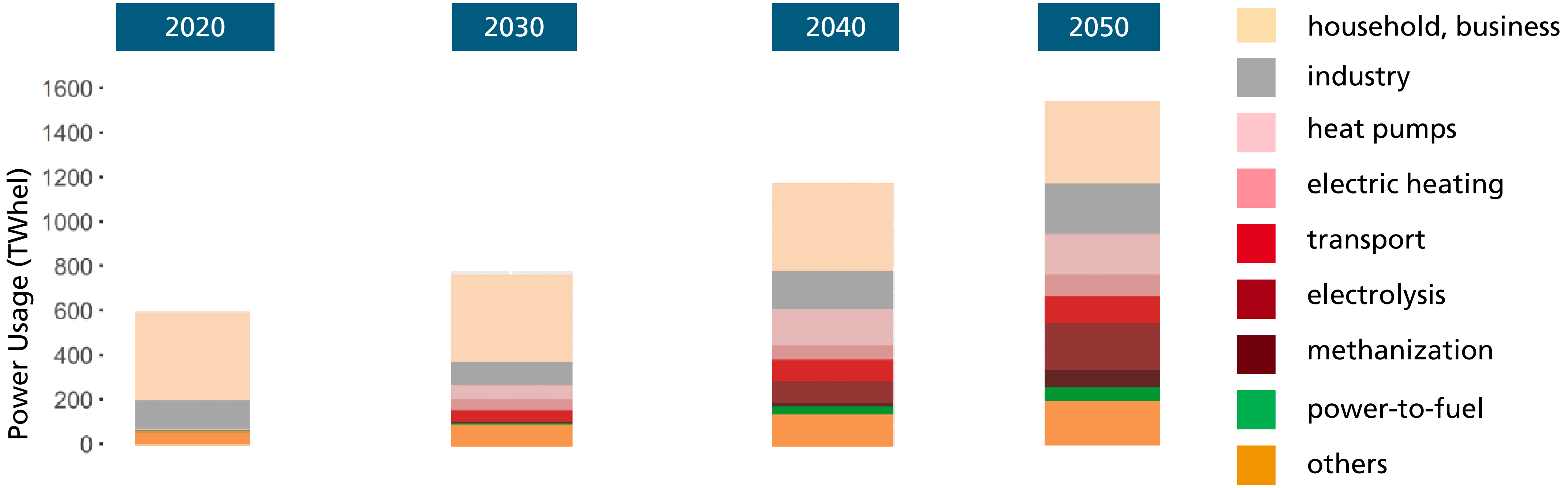
German Power Demand is Significantly Based on Household and Industry

Power supply for these sectors is mandatory



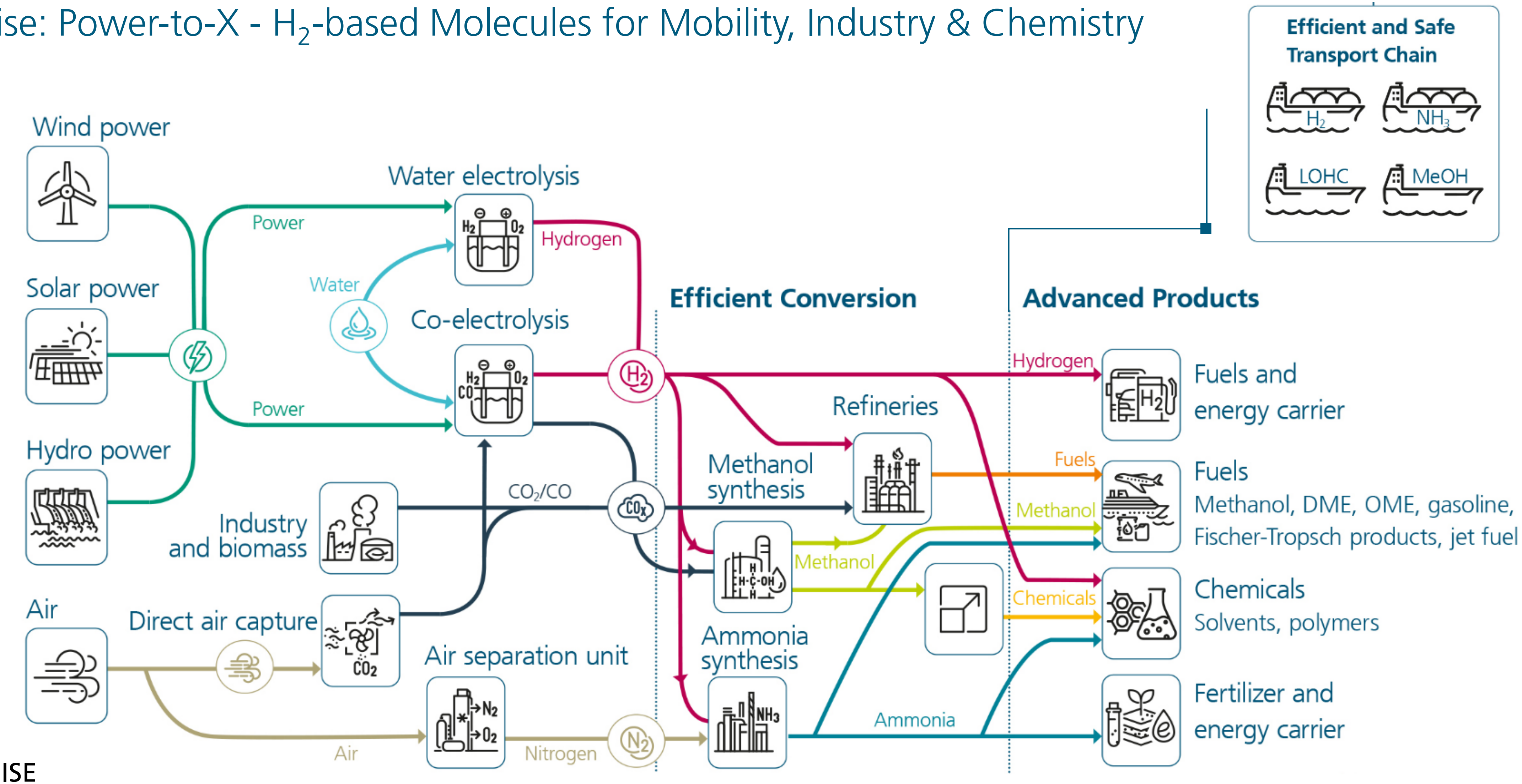
Fraunhofer ISE, Wege zu einem klimaneutralen Energiesystem, Update, 2020

03

Global Role of Hydrogen

Sustainable Energy Carriers, Fuels and Base Molecules

The Promise: Power-to-X - H_2-based Molecules for Mobility, Industry & Chemistry



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40 National Roadmaps, Strategy Papers, R&D Programms on Hydrogen (2023)

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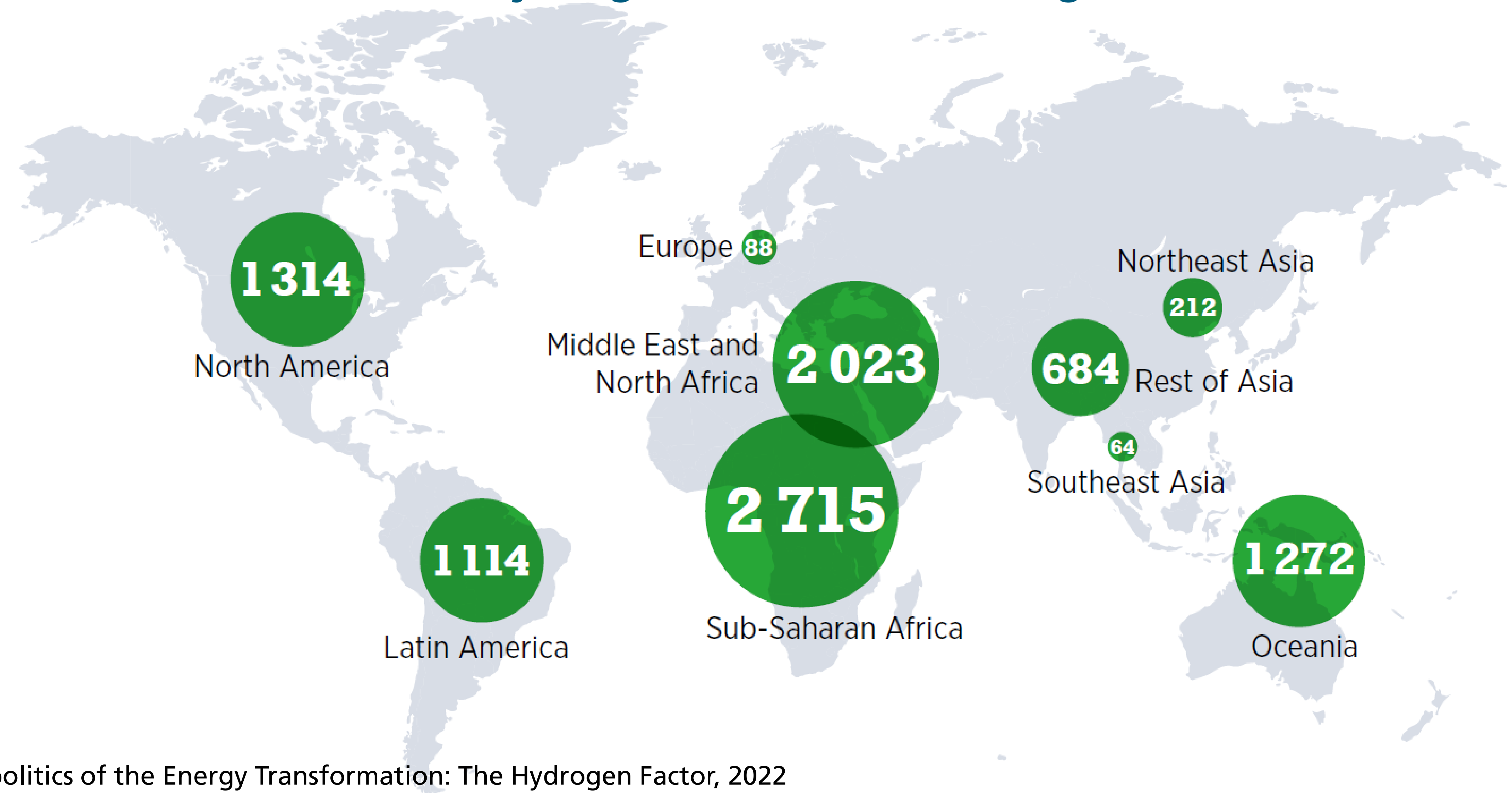
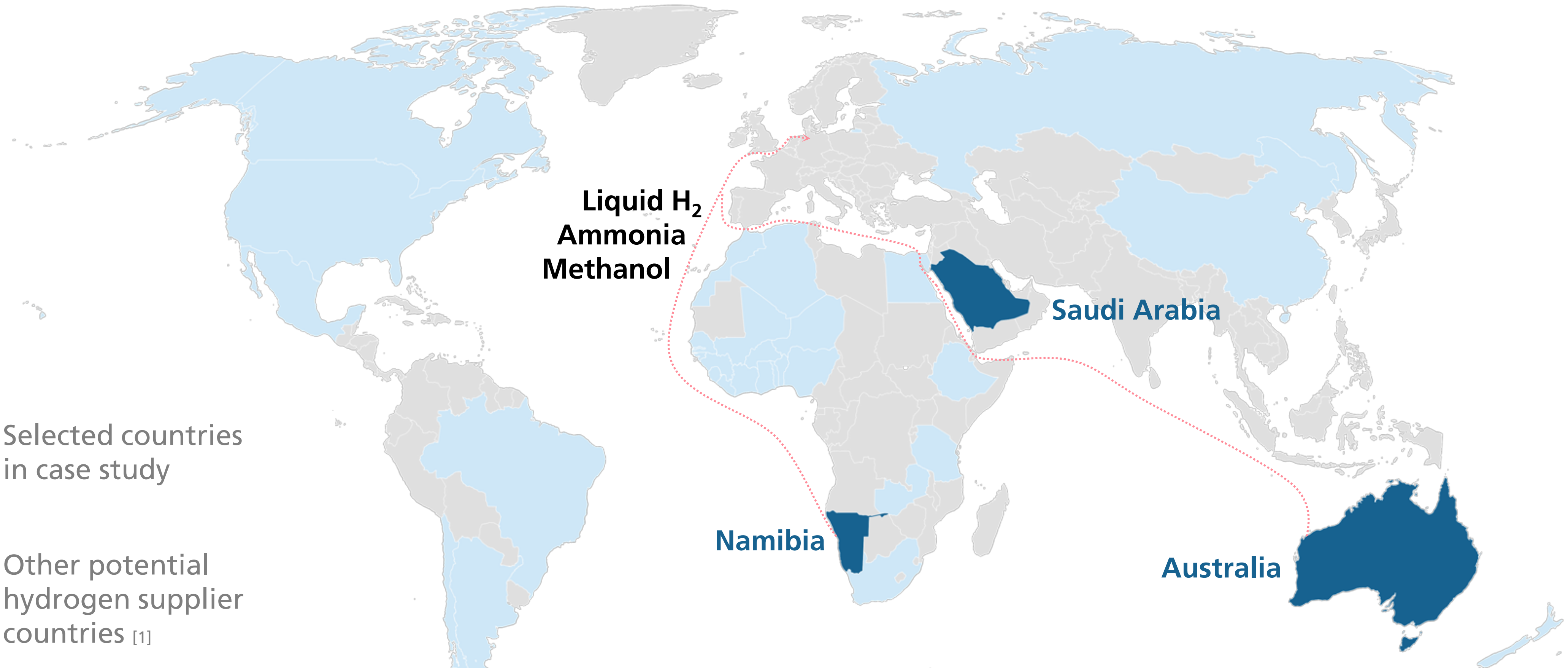
Technical Potentials for Green Hydrogen below USD 1.5/kg (2050, EJ)



IRENA, Geopolitics of the Energy Transformation: The Hydrogen Factor, 2022

Production Cost and Long-Distance Import of Hydrogen and Derivates



Selected countries in case study

Other potential hydrogen supplier countries [1]

Selection via own research, but also based on least cost and biggest production potential from Jesterle et al. 2019 (LUT-model) and IEA „The future of Hydrogen" - Report for G20 in Japan, 2019

C. Hebling et al., The global dimension of hydrogen and its derivates towards climate neutrality, Hydrogen Online Conference 2021

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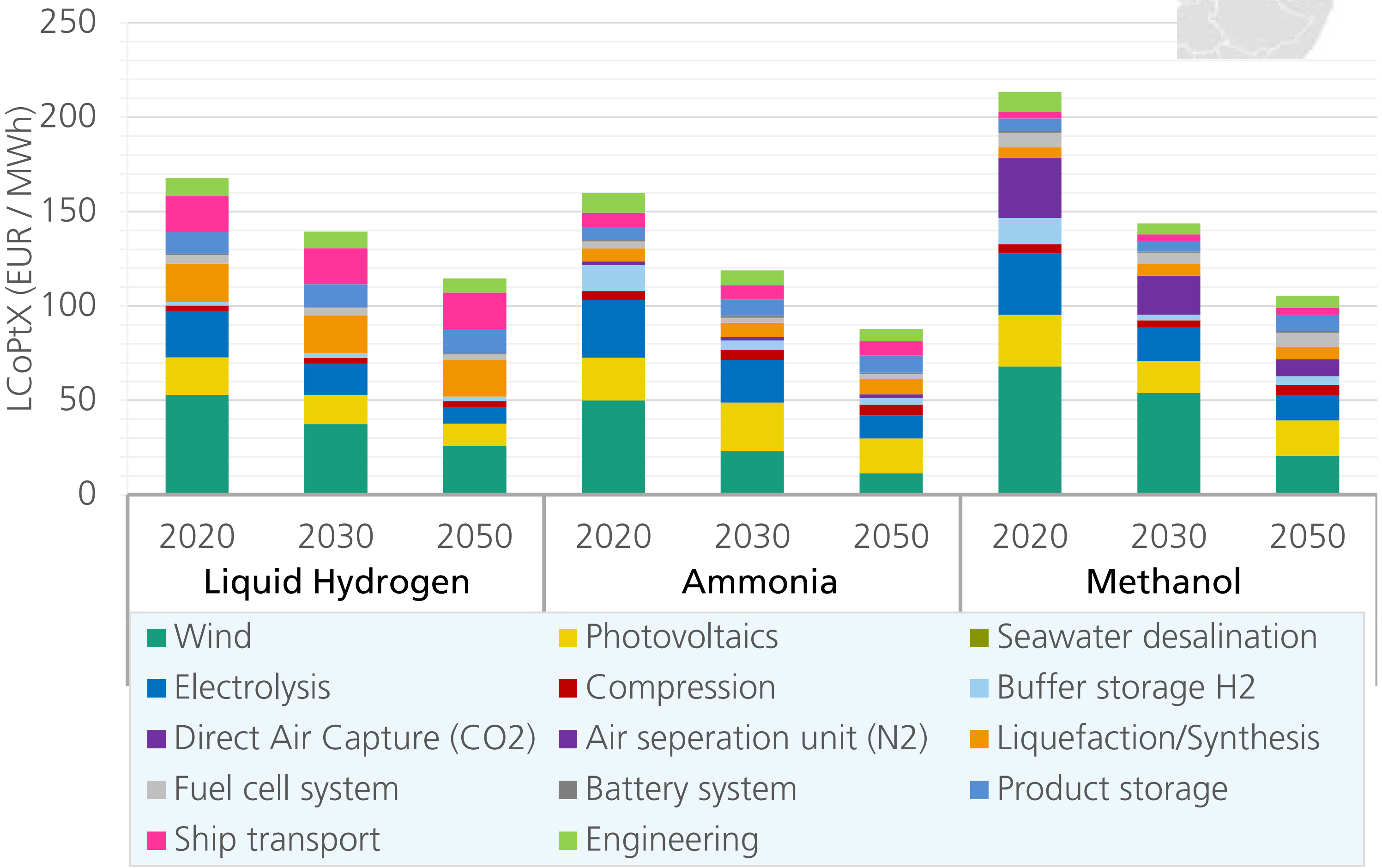
Production Cost and Long-Distance Import of Hydrogen and Derivates

Saudi Arabia – North-West (Neom)

Component Sizing	LH_2	NH_3	MeOH
Wind (GW)	1.8	1.4	1.7
PV (GW)	2.0	1.8	2.0
H_2 Liquefaction / NH_3- / MeOH- Synthesis (tpd)	388	1,614	1,353
Battery (MWh)	53	42	60
LCoPtX (EUR/MWh)	168	160	213
LCoPtX (EUR/ton)	5,587	828	1,180
Exported Energy (TWh)	3.6	2.9	2.7
Full load hours electrolysis	5,755	5,192	5,005

All values apply to the optimal cost

C. Hebling et al., The global dimension of hydrogen and its derivates towards climate neutrality, Hydrogen Online Conference 2021



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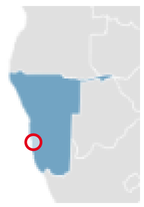
Production Cost and Long-Distance Import of Hydrogen and Derivates

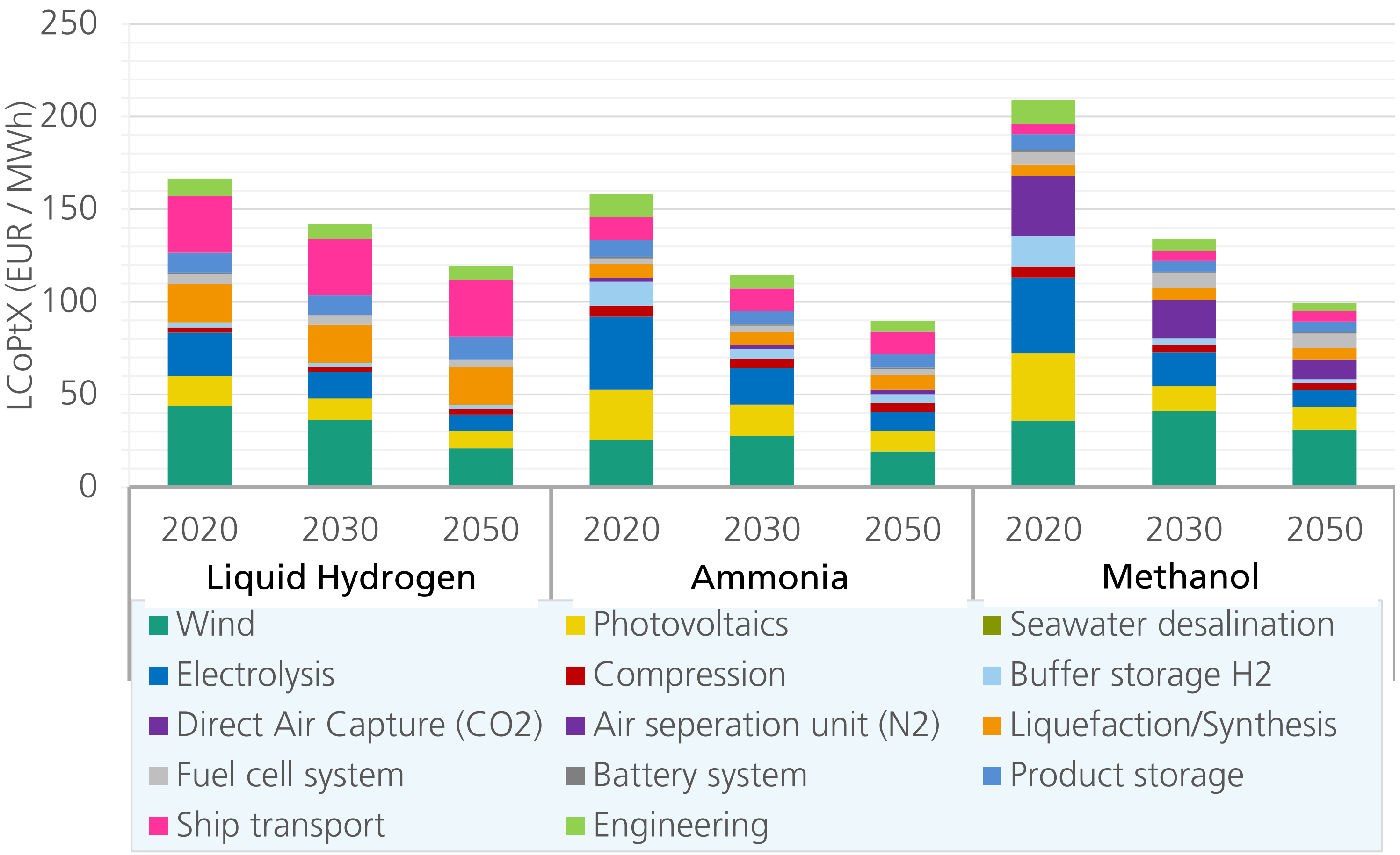
Namibia – South



Component Sizing	LH_2	NH_3	MeOH
Wind (GW)	1.6	0.5	0.7
PV (GW)	1.7	1.7	2.1
H_2 Liquefaction / NH_3- / MeOH- Synthesis (tpd)	410	1,236	1,086
Battery (MWh)	61	44	51
LCoPtX (EUR/MWh)	167	158	209
LCoPtX (EUR/ton)	5,549	819	1,157
Exported Energy (TWh)	3.8	2.2	2.1
Full load hours electrolysis	6,079	4,017	4,069

All values apply to the optimal cost

C. Hebling et al., The global dimension of hydrogen and its derivates towards climate neutrality, Hydrogen Online Conference 2021



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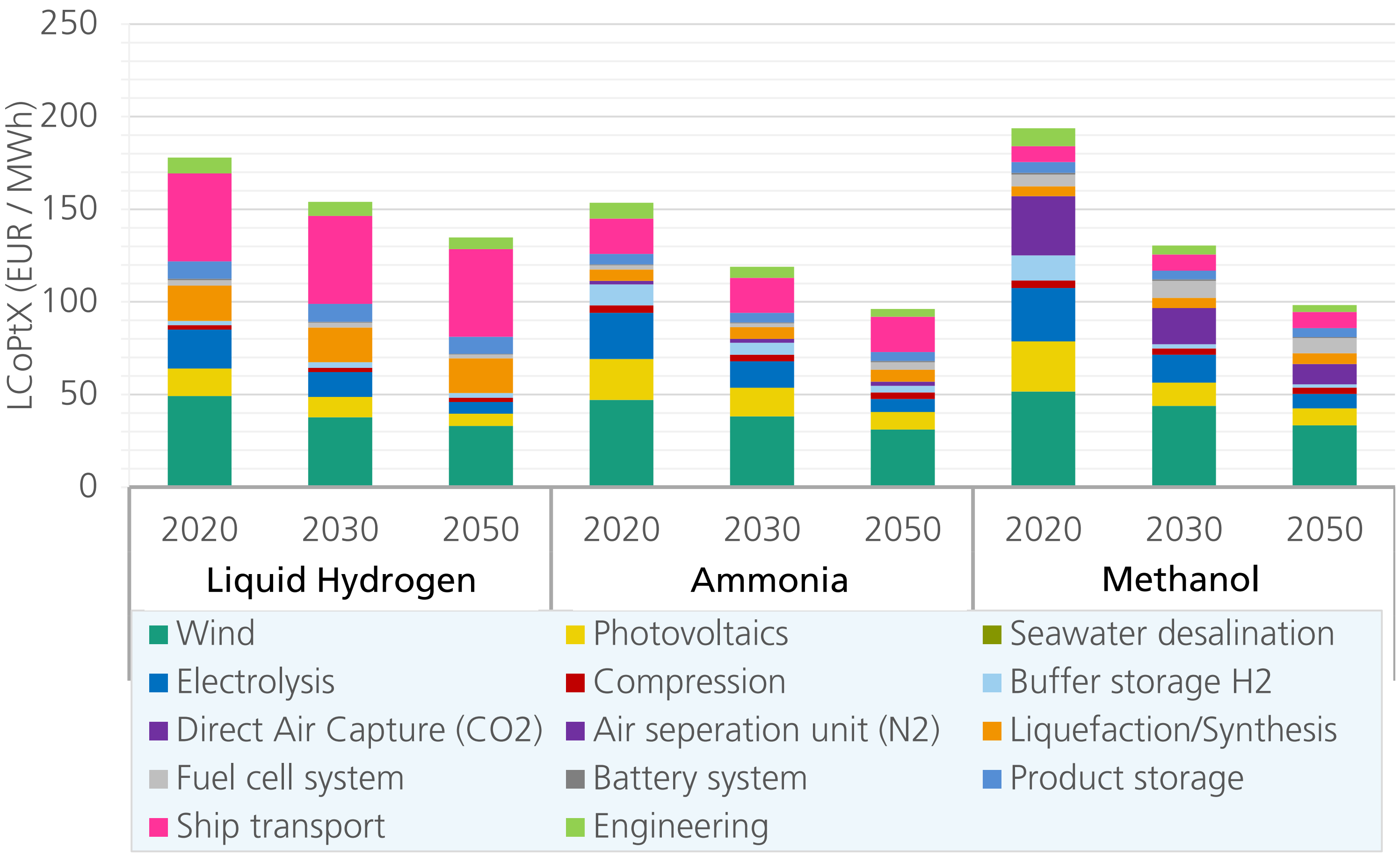
Production Cost and Long-Distance Import of Hydrogen and Derivates

Australia – West

Component Sizing	LH_2	NH_3	MeOH
Wind (GW)	2.0	1.6	1.5
PV (GW)	1.8	2.2	2.3
H_2 Liquefaction / NH_3- / MeOH- Synthesis (tpd)	429	1,960	1,552
Battery (MWh)	66	42	66
LCoPtX (EUR/MWh)	178	154	194
LCoPtX (EUR/ton)	5,925	795	1,072
Exported Energy (TWh)	4.3	3.5	3.0
Full load hours electrolysis	6,895	6,431	5,690

All values apply to the optimal cost

C. Hebling et al., The global dimension of hydrogen and its derivates towards climate neutrality, Hydrogen Online Conference 2021



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Hydrogen Pipeline Infrastructure is Cost Effective

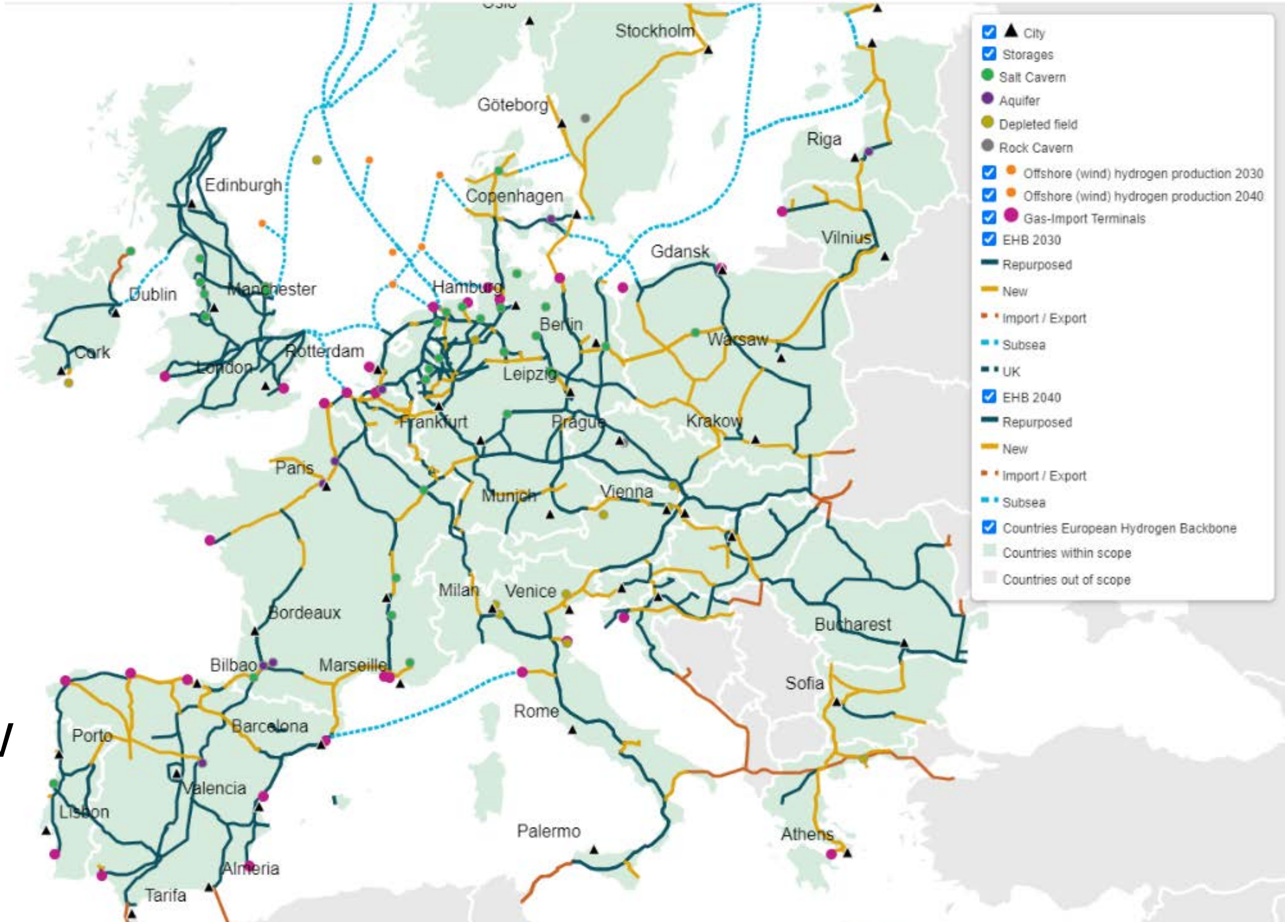
6,800 km H_2-Pipelines until 2030 and 23,000 km until 2040

- 75% rededication of existing gas pipelines
  25% construction of new H2-pipelines

CAPEX on-shore transmission:

- H_2 pipelines retrofit: 275 €/m (20 inch, 1.2 GW): 229 €/m/GW
- H_2 pipelines new: 2,750 €/m (48 inch, 16.9 GW): 163 €/m/GW
- Overhead HVAC: 532 €/m (2.8 GW): 190 €/m/GW
- Overhead HVDC: 2,040 €/m (8.0 GW): 255 €/m/GW
- Underground HVDC: 3,179 €/m (2.0 GW): 1.590 €/m/GW

Gas for Climate, European Hydrogen Backbone, Analysing future demand, supply, and transport of hydrogen, 2021



Download:01.02.2023
https://ehb.eu/maps/202209/index.html#5/48.323/-0.439, 01.02.2023

04

Fuel Cell Mobility

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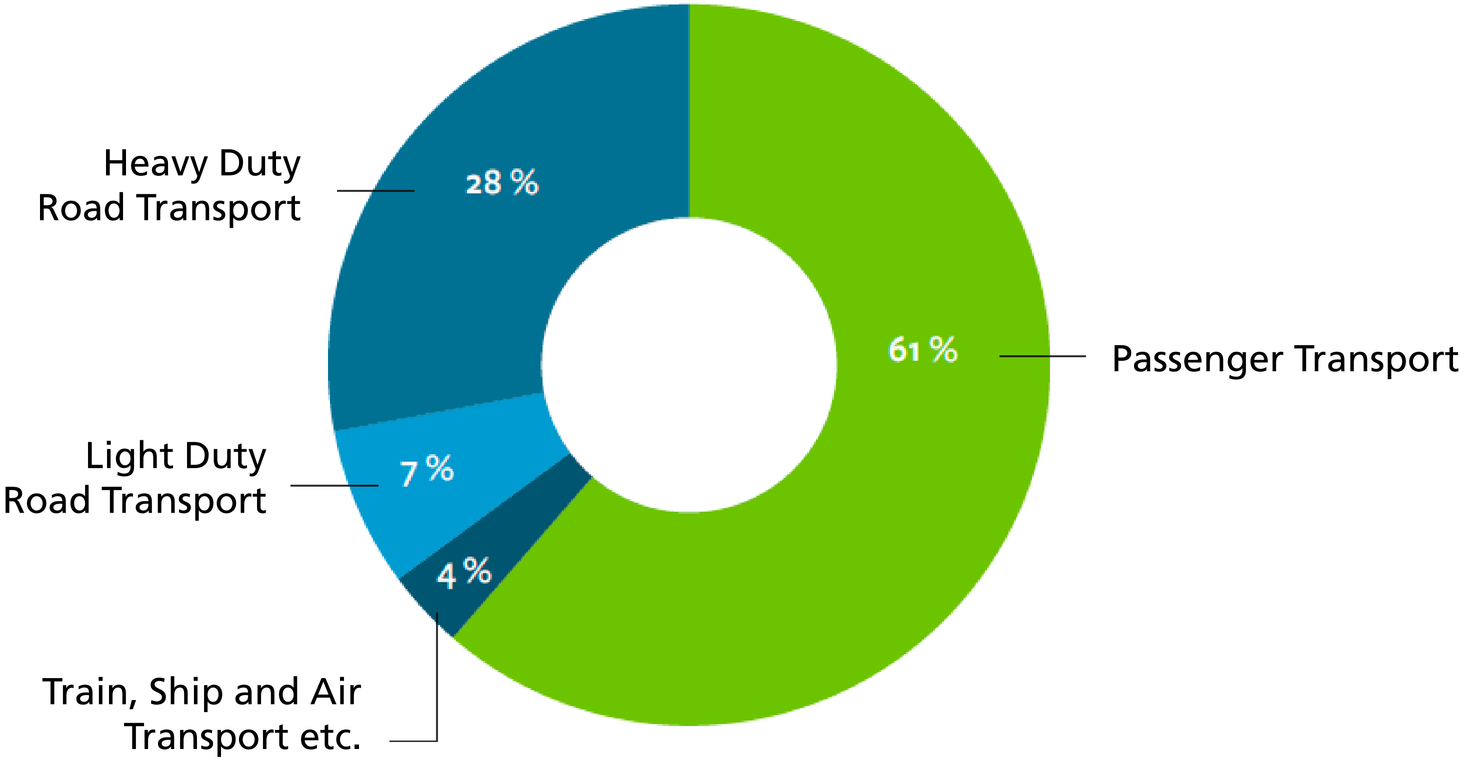
Direct CO2 Emissions from the Mobility Sector in Germany 2019



SRU, Wasserstoff im Klimaschutz: Klasse statt Masse, Stellungnahme, 06.2021

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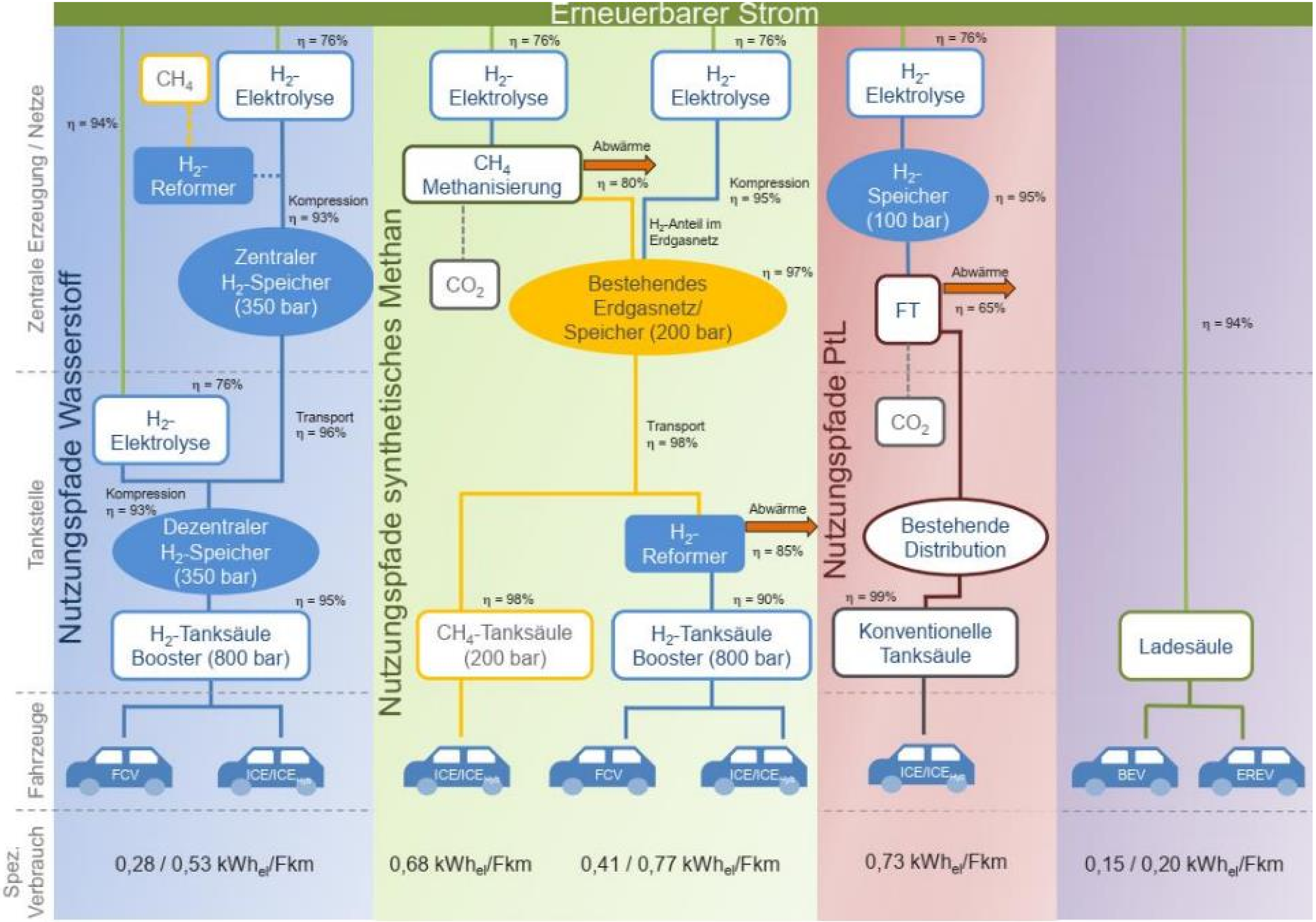
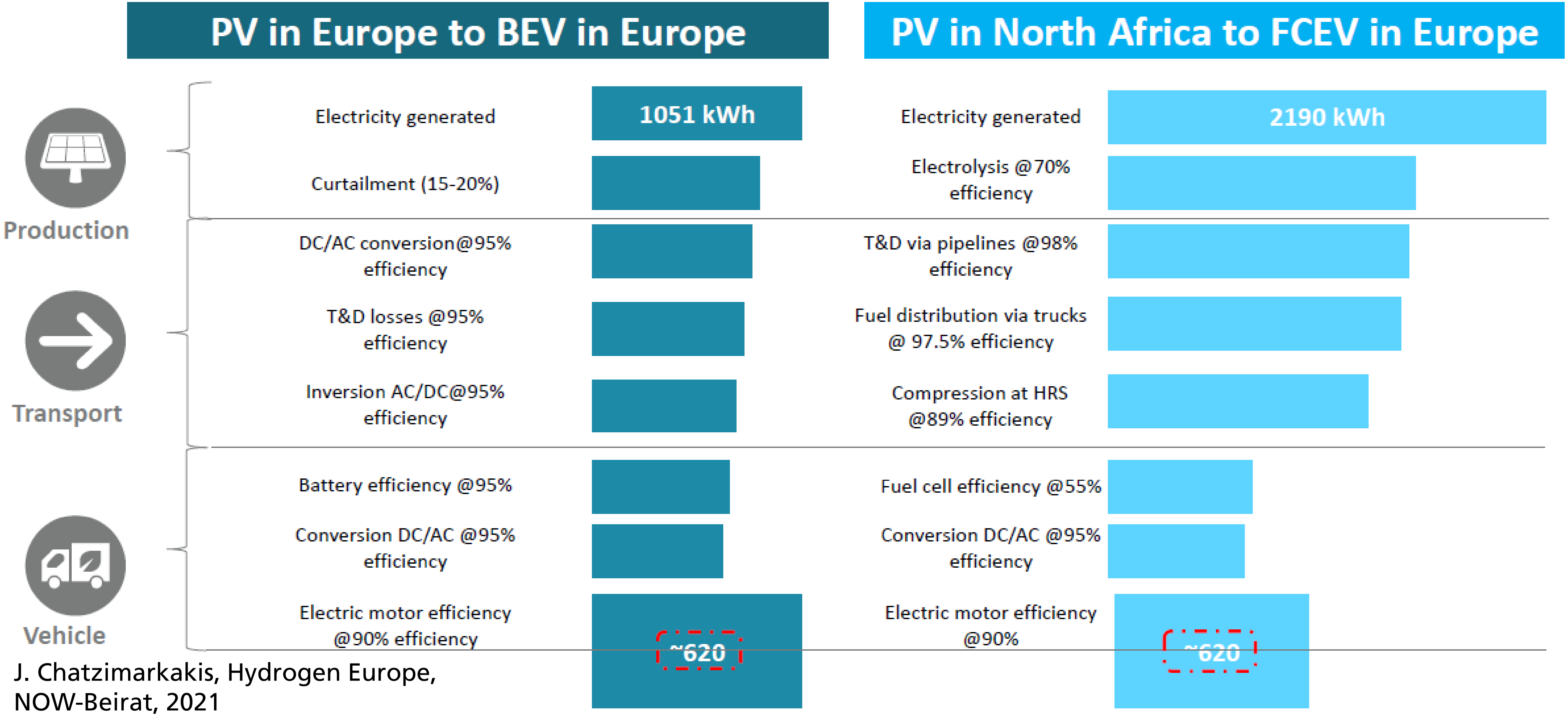
Regenerative Power Trains



DLR, Wasserstoff als ein Fundament der Energiewende – Teil 2, 2020

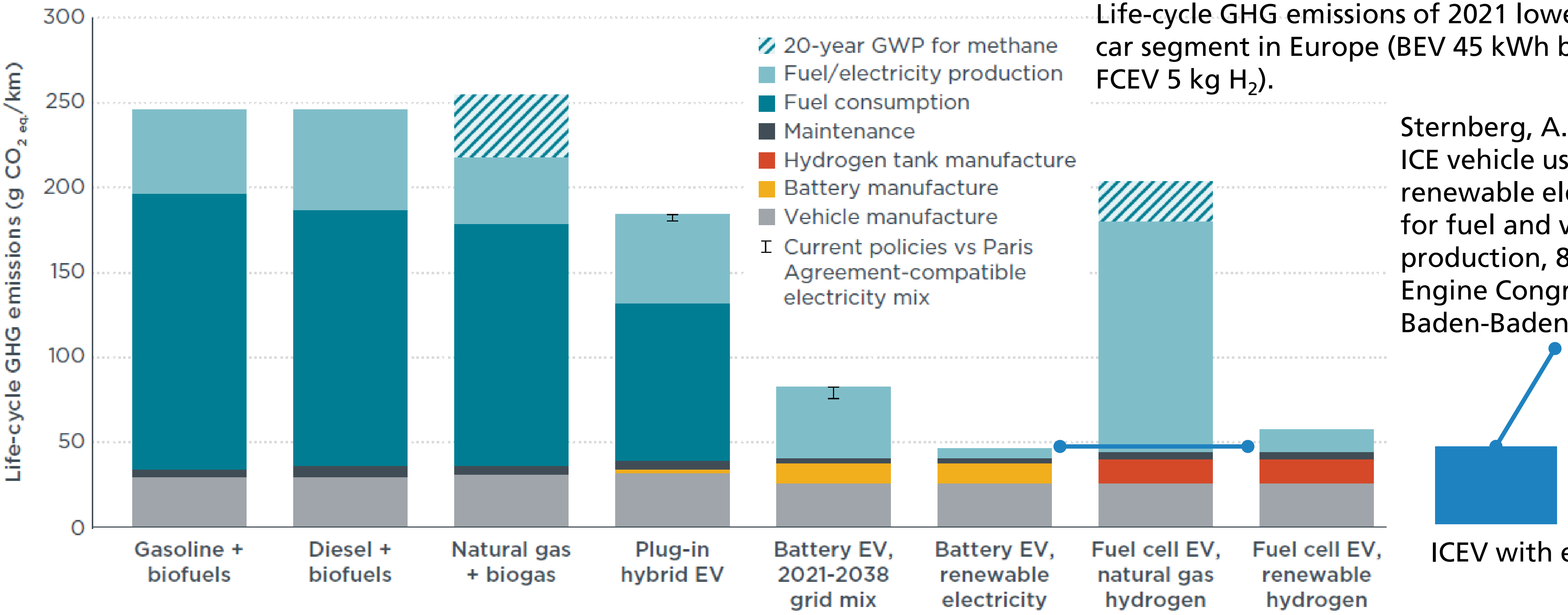
Well-to-Wheel Yields in Local/Global Perspectives



J. Chatzimarkakis, Hydrogen Europe, NOW-Beirat, 2021

Greenhouse Gas Emissions of BEV and FCEV are comparable

Cradle-to-Grave Emission is the Key Indicator: Renewable Energy Supply is Essential



Life-cycle GHG emissions of 2021 lower medium car segment in Europe (BEV 45 kWh battery, FCEV 5 kg H_2).

Sternberg, A.: LCA of an ICE vehicle using renewable electricity for fuel and vehicle production, 8th Int. Engine Congress 2021, Baden-Baden

ICCT, A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars, 2021

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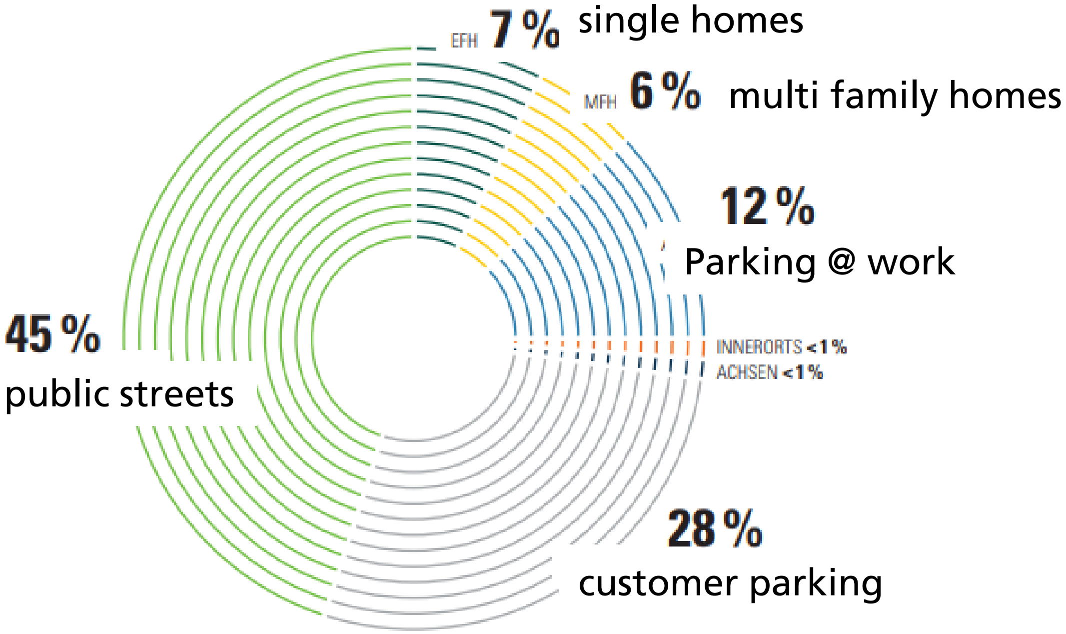
Battery Electric Vehicles: Most Important Use Case for Charging is Public Street

Parking in Freiburg, photo Ulf Groos



Nationale Leitstelle Ladeinfrastruktur, Ladeinfrastruktur nach 2025/2030: Szenarien für den Markthochlauf, Studie im Auftrag des BMVI, 2020

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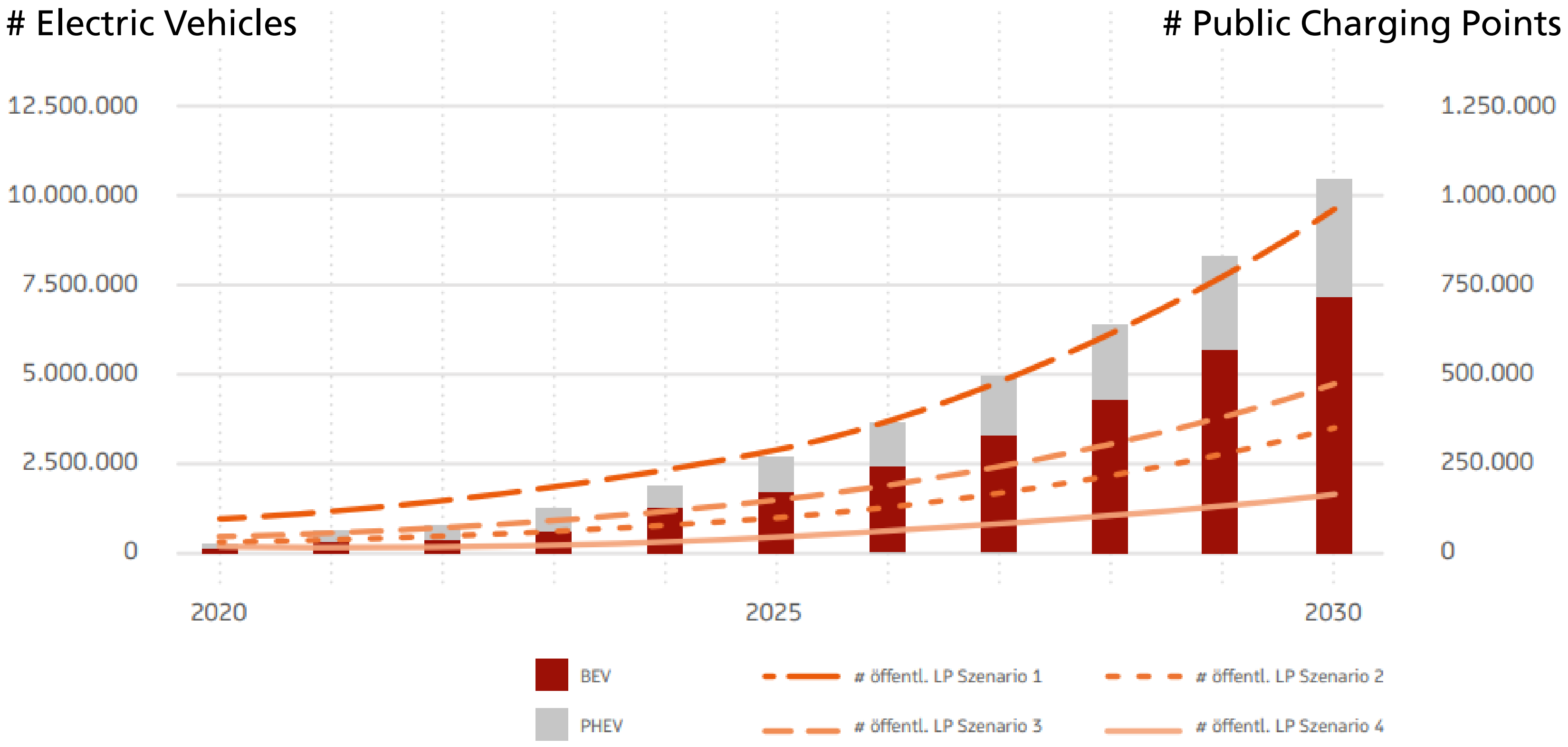
BEV: We Need up to 1 Mio. Public Charging Points in 2030

- 2020 47,7 Mio. cars in Germany [1]
- 2020 14.089 refueling stations at roads and 358 at motorways in Germany [2]
- Number of public charging points needed in 2030: 437,000 to 843,000 [3]



1 Statistisches Bundesamt (Destatis), 2021

2 Statista, 2021

3 Nationale Leitstelle Ladeinfrastruktur, Ladeinfrastruktur nach 2025/2030: Szenarien für den Markthochlauf, 2020

Nationale Plattform Zukunft der Mobilität, Arbeitsgruppe 5, Bedarfsgerechte und wirtschaftliche öffentliche Ladeinfrastruktur – Plädoyer für ein dynamisches NPM-Modell, 2020

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Costs for Public Charging Points

Infrastructure is more than charging points

- Average CAPEX for charge point (11 kW) 3,000 Euro [2] (up to 7,000 € [1])
- Number of public charging points needed in 2030: 180,000 to 1 Mio.

➢ CAPEX public charging points: 0.54 to 3 billion € (w/o high power charging and infrastructure)

➢ CAPEX private charging points: 19.2 billion € (11 kW: 2,000 Euro | 9.6 Mio. charging points) [1]

1 Nationale Leitstelle Ladeinfrastruktur, Ladeinfrastruktur nach 2025/2030: Szenarien für den Markthochlauf, Studie im Auftrag des BMVI, 2020

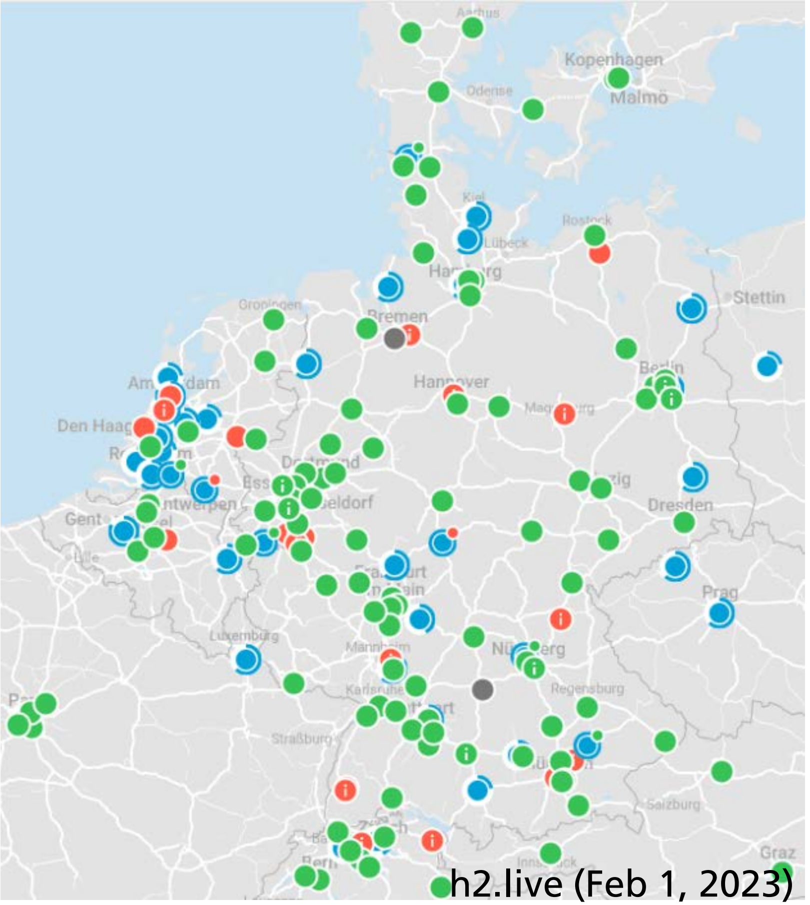
2 Nationale Plattform Zukunft der Mobilität, Arbeitsgruppe 5, Bedarfsgerechte und wirtschaftliche öffentliche Ladeinfrastruktur – Plädoyer für ein dynamisches NPM-Modell, 2020

Costs for Hydrogen Refueling Stations until 2030 are Economically Feasible

But Infrastructure is More than Refueling stations

- Number of HRS for cars:
  1,000 to 3,000 in 2030[1]
- Average CAPEX for HRS: €1.5 million [2]
  (€1.67 to €1.34 million for a medium size HRS with 420 kg/d)

➢ CAPEX for public HRS network: €1.5 to €4.5 billion



h2.live (Feb 1, 2023)

1 LBST, Infrastrukturbedarf E-Mobilität, Analyse eines koordinierten Infrastrukturaufbaus zur Versorgung von Batterie- und Brennstoffzellen-PKW in Deutschland, 2020

2 Roland Berger, Potenzial der Wasserstoff- und Brennstoffzellen-Industrie in Baden-Württemberg, 2020

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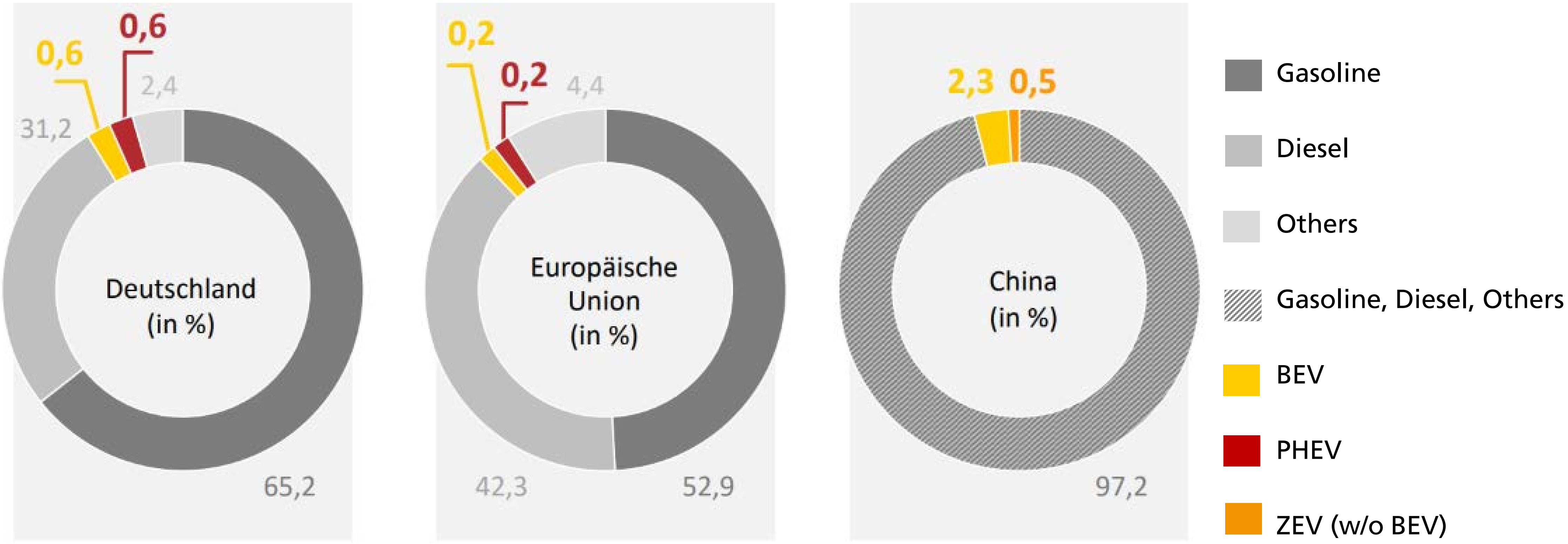
There is by far Not Enough Experience with Electric Cars to Decide on Power Train Technology: We Still Need Open Minds!



Percentage of electric cars on the road today for Germany, Europe and China, NOW, Wasserstoffmobilität in der Verkehrswende, Deutsch-Schweizer Wasserstoff-Forum, 2021

Fuel Cell Electric Vehicles Today


https://media.daimlertruck.com/marsMediaSite/de/instance/ko/GenH2-Truck.xhtml?oid=47469461

https://www.media.stellantis.com/de-de/opel/press/stellantis-prasentation-zur-brennstoffzellen-technologie-1632575435


https://www.bosch.com/de/stories/brennstoffzellen-lkw-nikola-two/

https://www.hzwei.info/blog/2022/12/30/hyzon-motors-neuigkeiten-erst-im-februar-2023/

Downloads: Feb 1, 2023

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Fuel Cell Electric Vehicles Today

Downloads: Feb 1, 2023

Take Home Messages

- We need vast amounts of Renewable Energy
- Renewable Energy will be traded globally via hydrogen
- H_2 infrastructure is economically and technically reasonable
- At the very beginning of our learning curve we should consider all zero-emission technologies
- International markets have strong commitments to hydrogen and fuel cells and open export potentials

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