THE ROLE OF FUEL CELLS FOR THE ENERGY TRANSFORMATION IN MOBILITY

40 YEARS
FRAUNHOFER ISE
#CreatingTheEnergyFuture

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Fraunhofer Institute for Solar Energy Systems ISE
Freiburg, Germany

1st International VDI Conference Future of Fuel Cells

November 16th, 2021

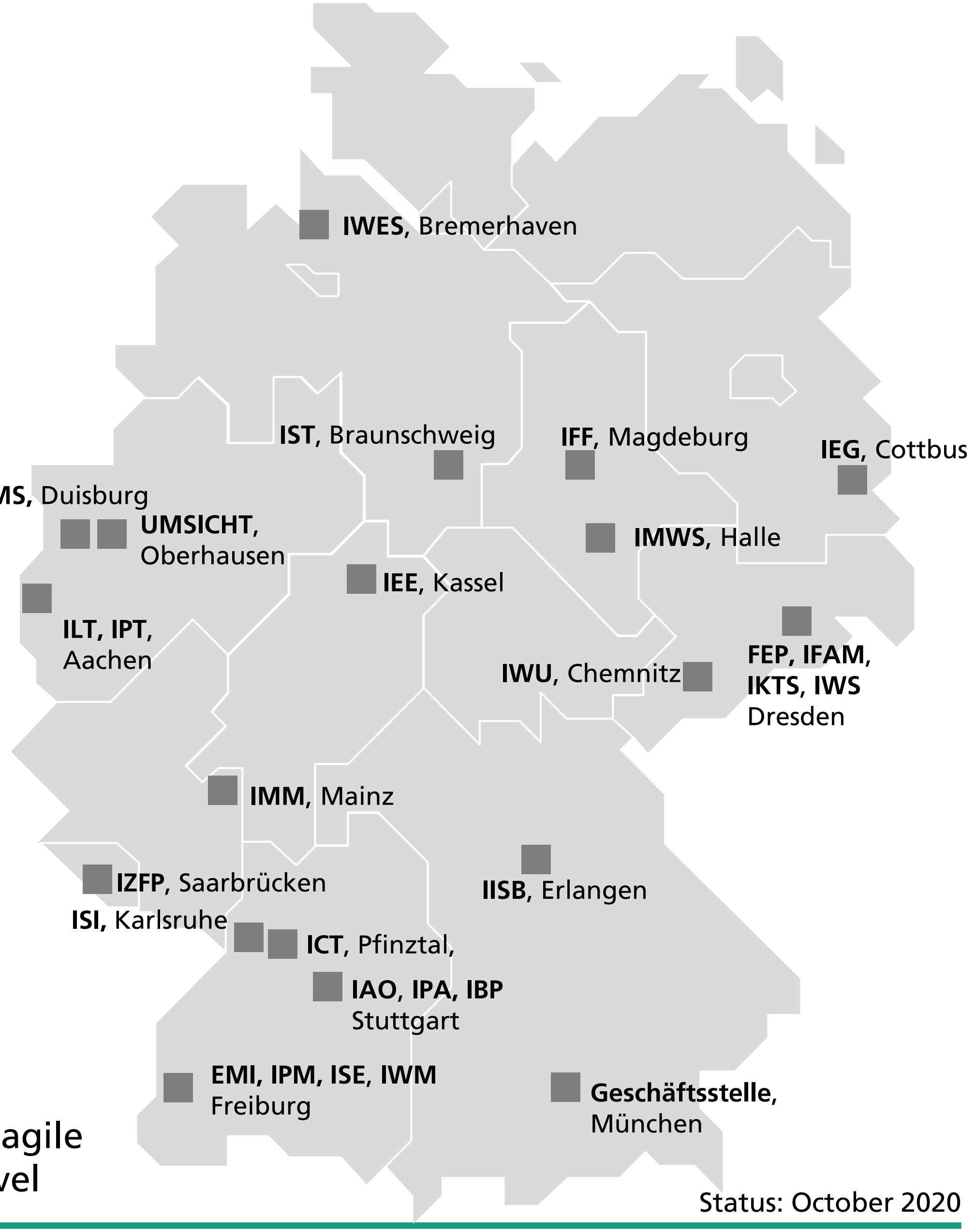
http://www.ise.fraunhofer.com
http://www.h2-ise.com

The Fraunhofer Hydrogen Network

Founded in February 2019

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

- **Profile sharpening** within the H_2 value chain
- **Exchange** and cooperation platform
- **Management:** Prof. Christopher Hebling (ISE), Prof. Mario Ragwitz (IEG)
- **Management Committee** as an agile operational decision-making level



Status: October 2020

Fraunhofer Institute for Solar Energy Systems ISE

Research for the Energy Transformation

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Directors

Prof. Dr. Hans-Martin Henning

Prof. Dr. Andreas Bett

Staff

ca. 1300

Scientists, engineers, students

Budget 2020

Operation	91,2 Mio. EUR
Investment	13,6 Mio. EUR
Total	104,8 Mio. EUR

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ISE

Hydrogen Technologies @ Fraunhofer Institute for Solar Energy Systems

Defossilization of Transport, Chemicals and Process Heat

Sustainable Mobility

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

Synthetic Fuels, energy carriers, and chemicals

Catalysts and processes incl. 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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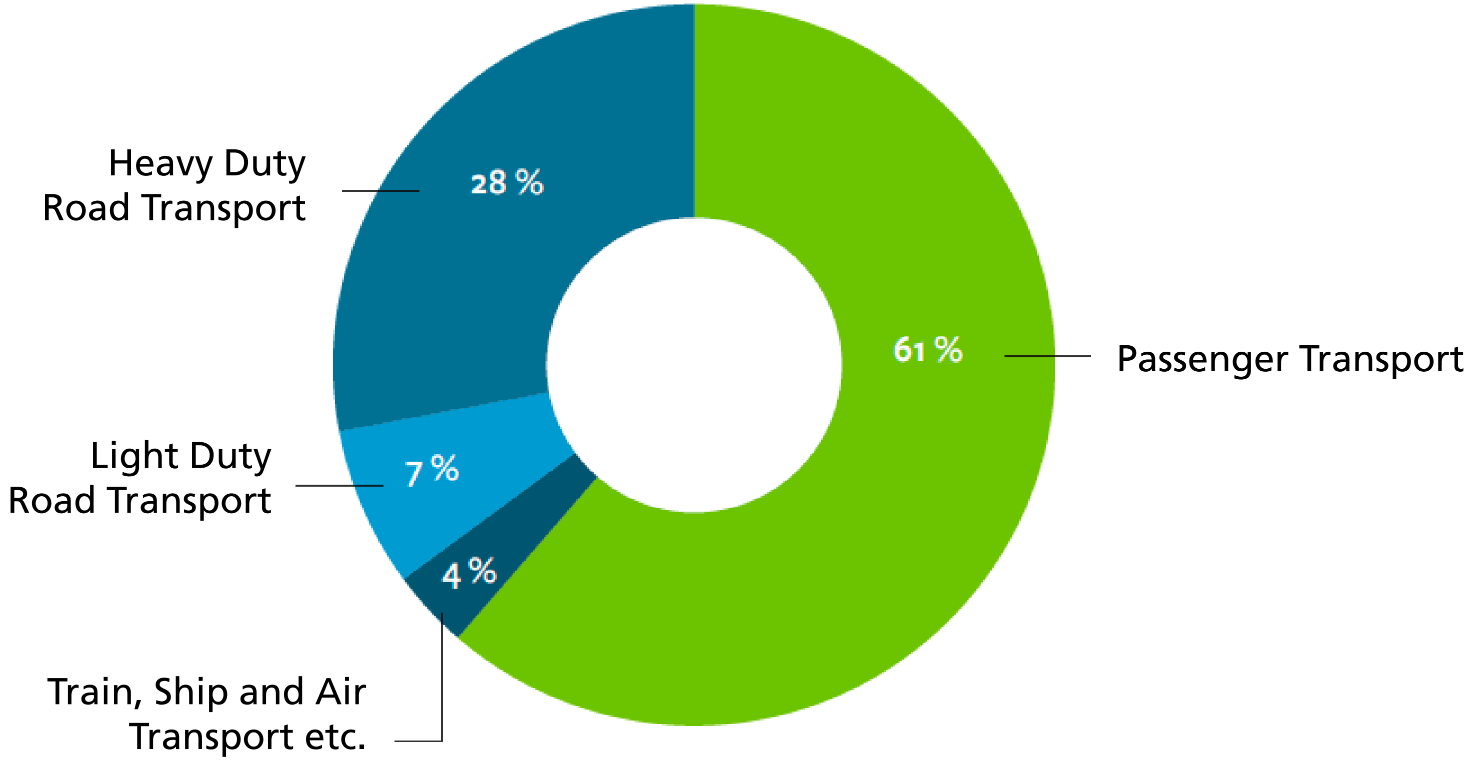
Zero Emission Mobility Needs Zero Emission Energy

Renewable Energy = Hydrogen will be Traded Globally

Hydrogen Refuelling is Economically and Technically Reasonable

Direct CO_2 Emissions from the Mobility Sector in Germany 2019



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

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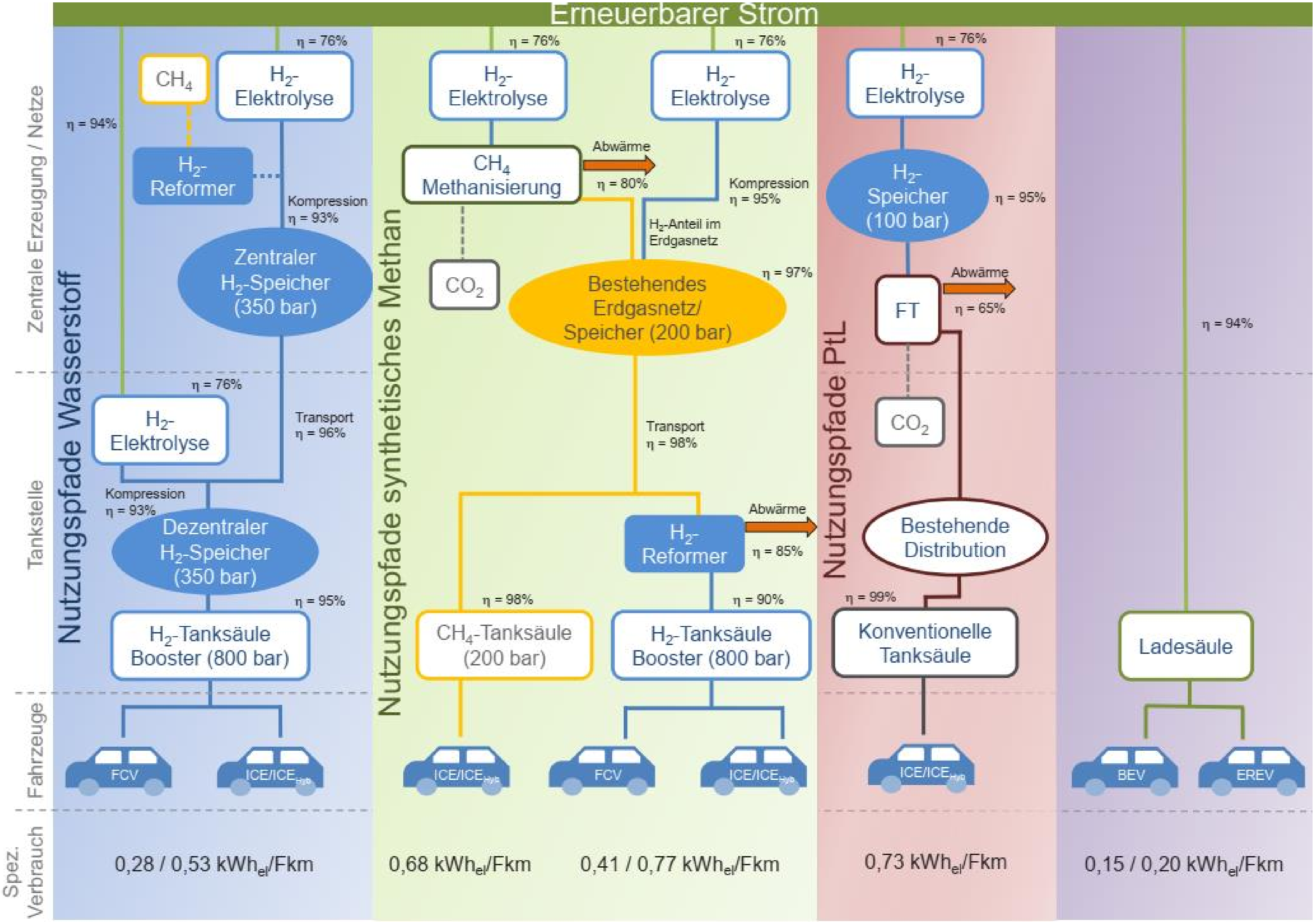
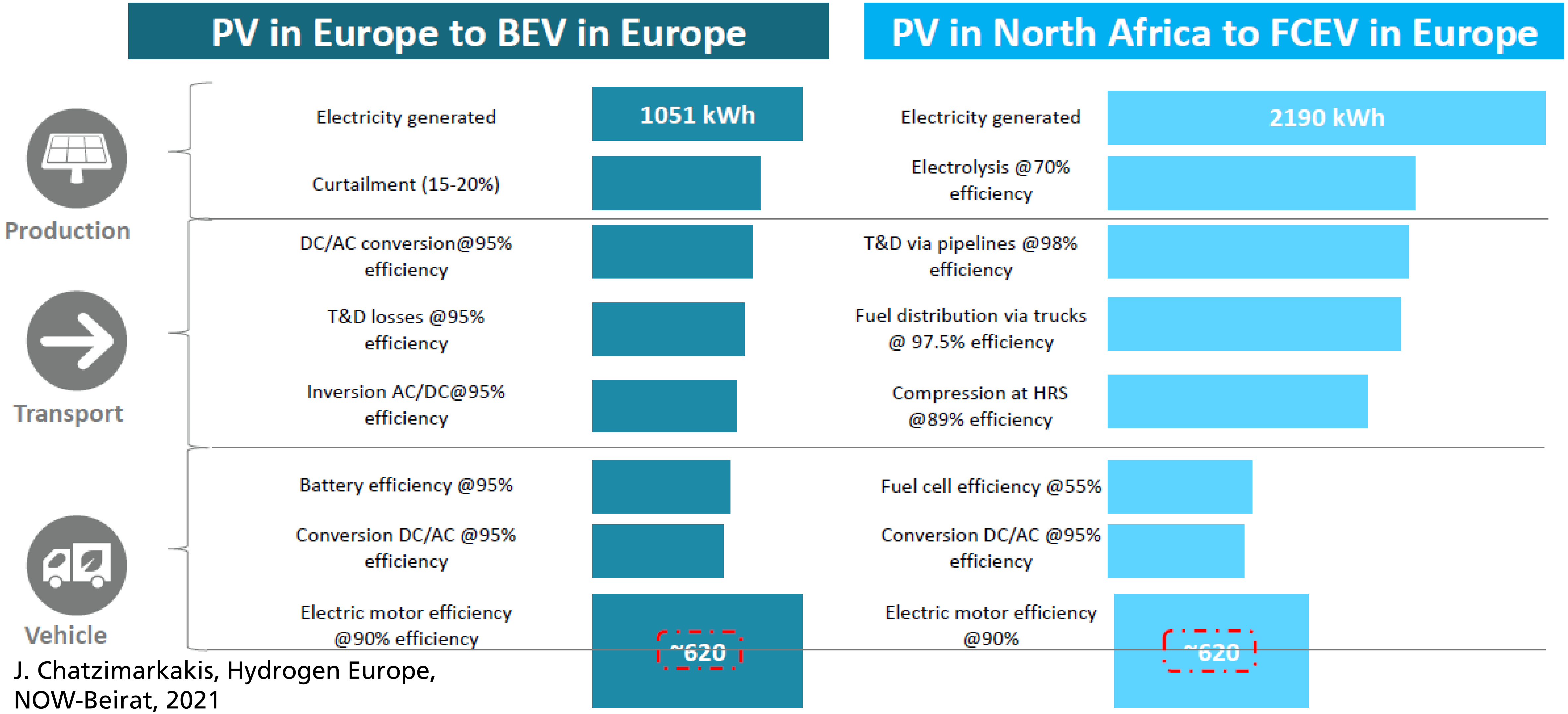
Regenerative Power Trains



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

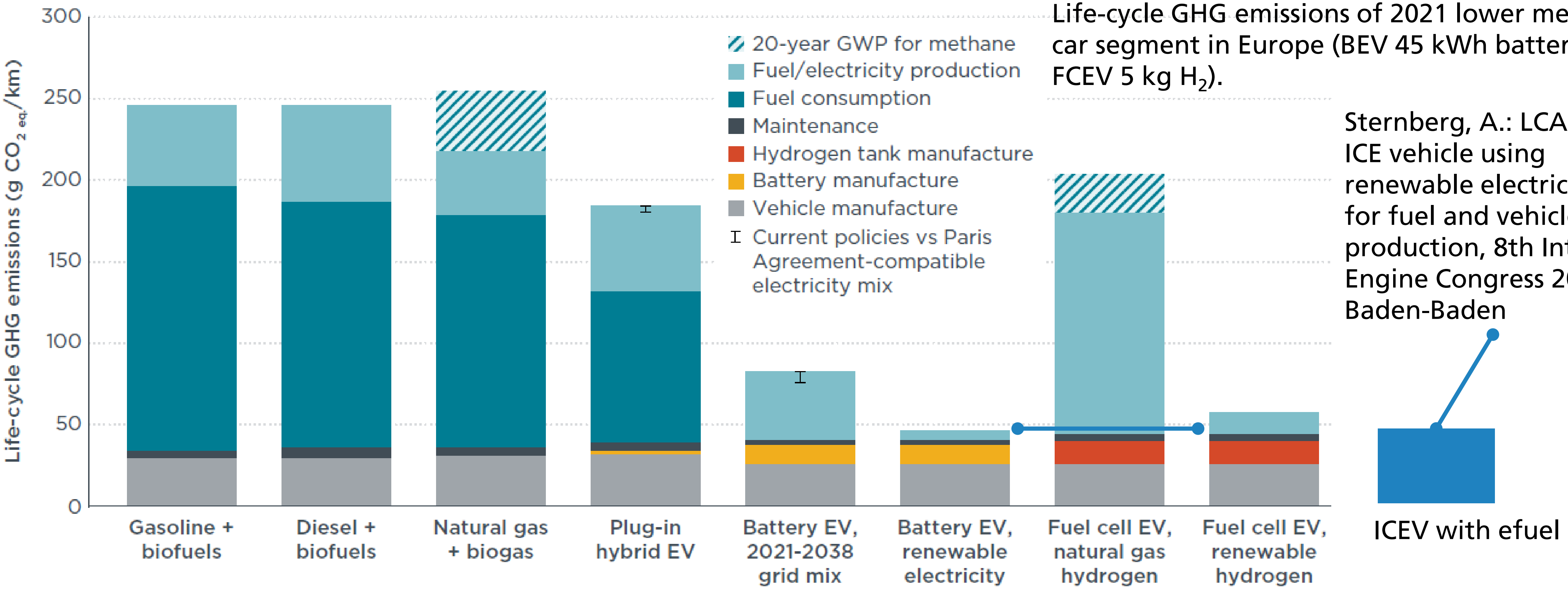
Well-to-Wheel Yields in Local/Global Perspectives



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

Green House 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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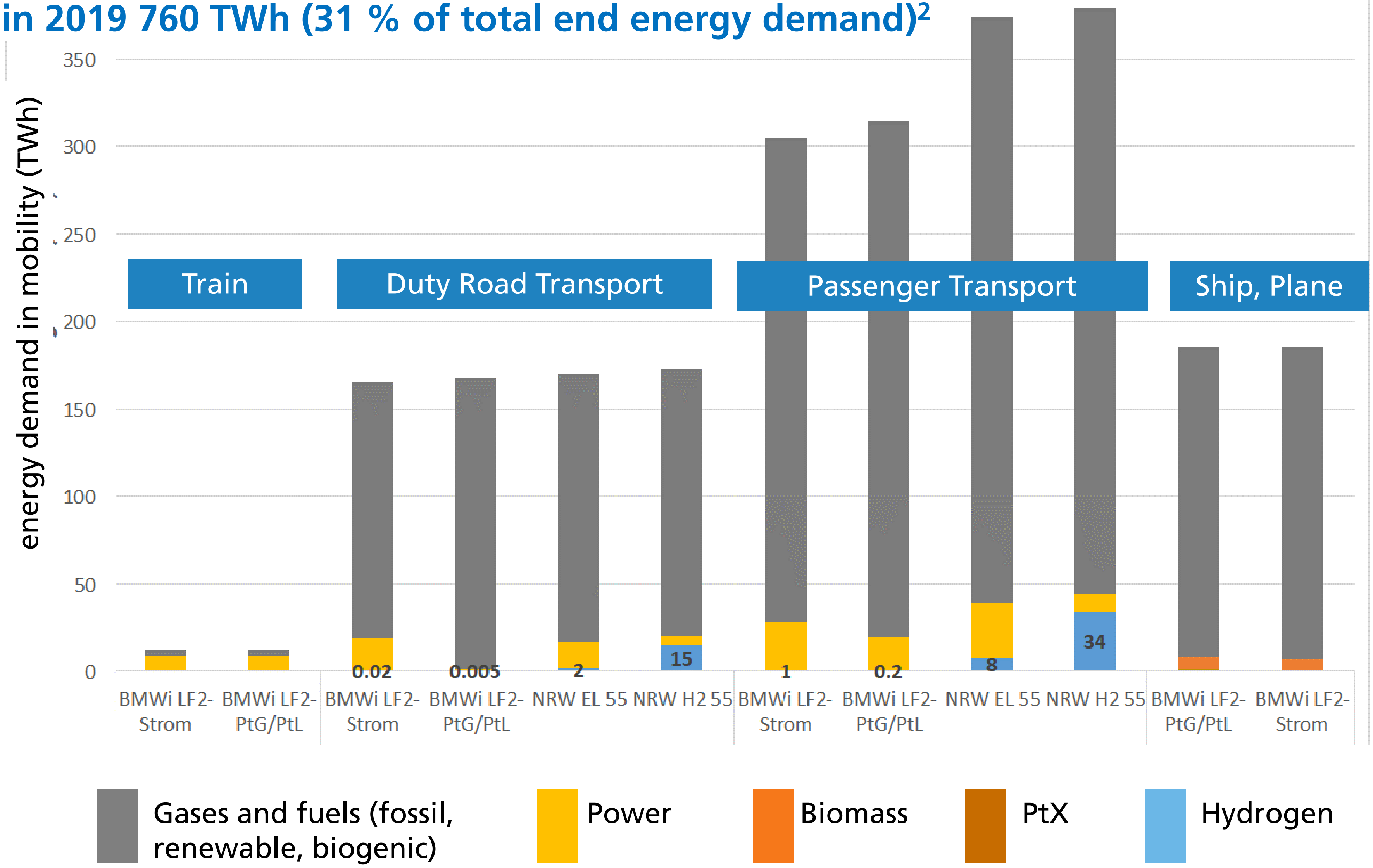
End Energy Demand in German Mobility 2030[1]

Total end energy demand in 2019 760 TWh (31 % of total end energy demand)[2]



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

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

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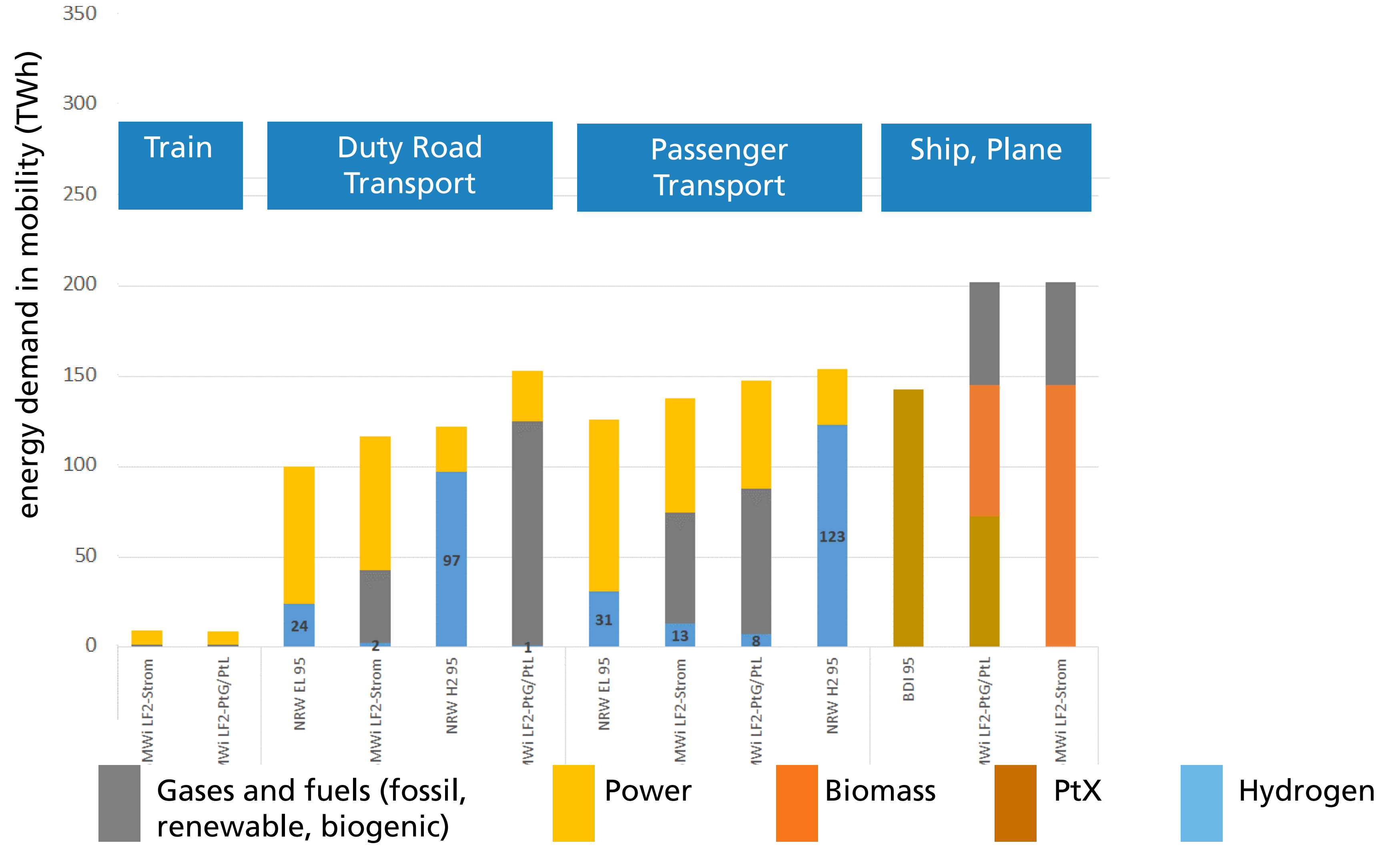
End Energy Demand in German Mobility 2050

End energy demand declines due to higher efficiency of e-mobility



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

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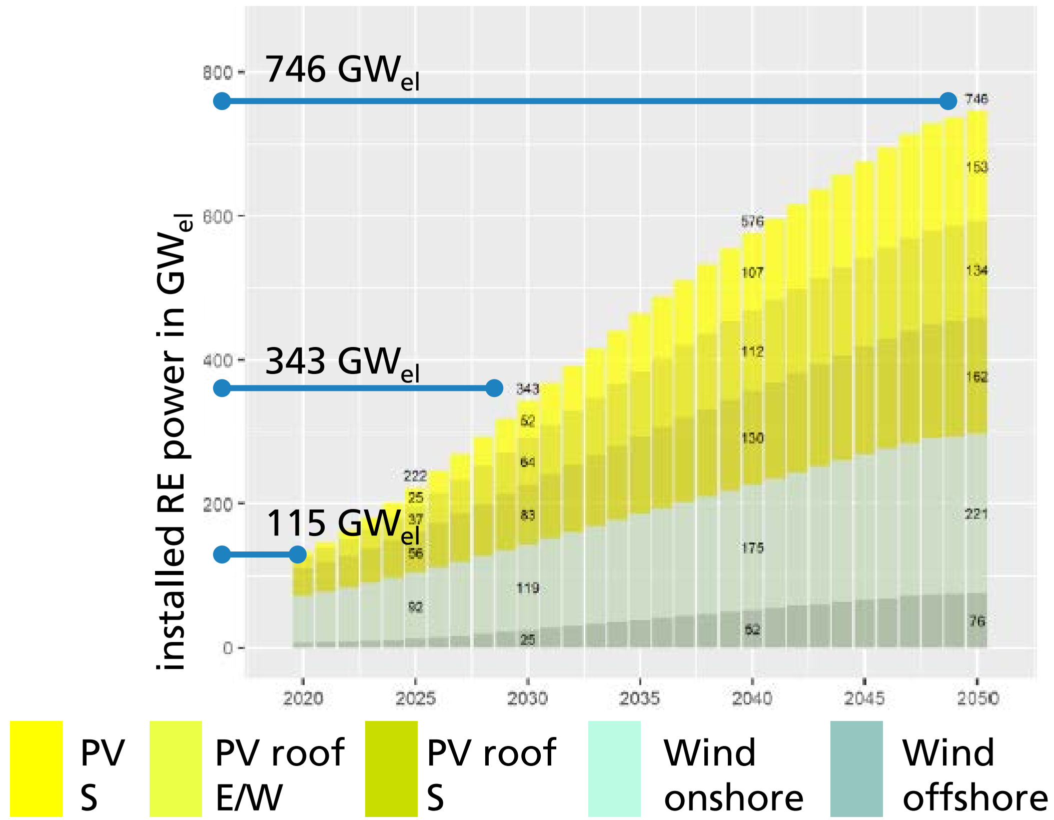
German Climate Targets Depend on Significant Growth of Renewable Energies

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}



Installed power of wind and solar for climate emission targets of 65% RE in 2030 and 100% RE in 2050 of German power consumption

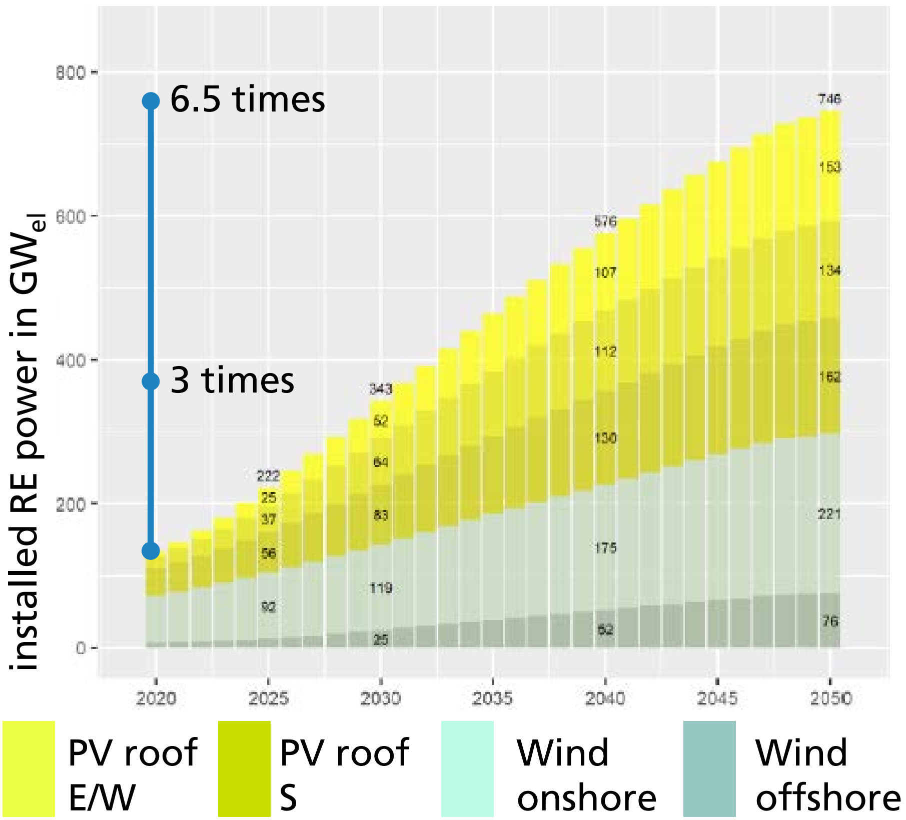
2: Wietschel, M. et al. (2021): Metastudie Wasserstoff – Auswertung von Energiesystemstudien. Studie im Auftrag des Nationalen Wasserstoffrats. Karlsruhe, Freiburg, Cottbus: Fraunhofer ISI, Fraunhofer ISE, Fraunhofer IEG (Hrsg.).

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

German Climate Targets Depend on Significant Growth of Renewable Energies

Growing power demand due to electrification

- Annual growth PV until 2030:
  10.5 – 14.8 GW_{el} (2020: 3.9 GW_{el})
- Annual growth wind on-/offshore until 2030 :
  7.4 – 8.4 / 1.4 – 1.7 GW_{el} (2020: 1.4 GW_{el})

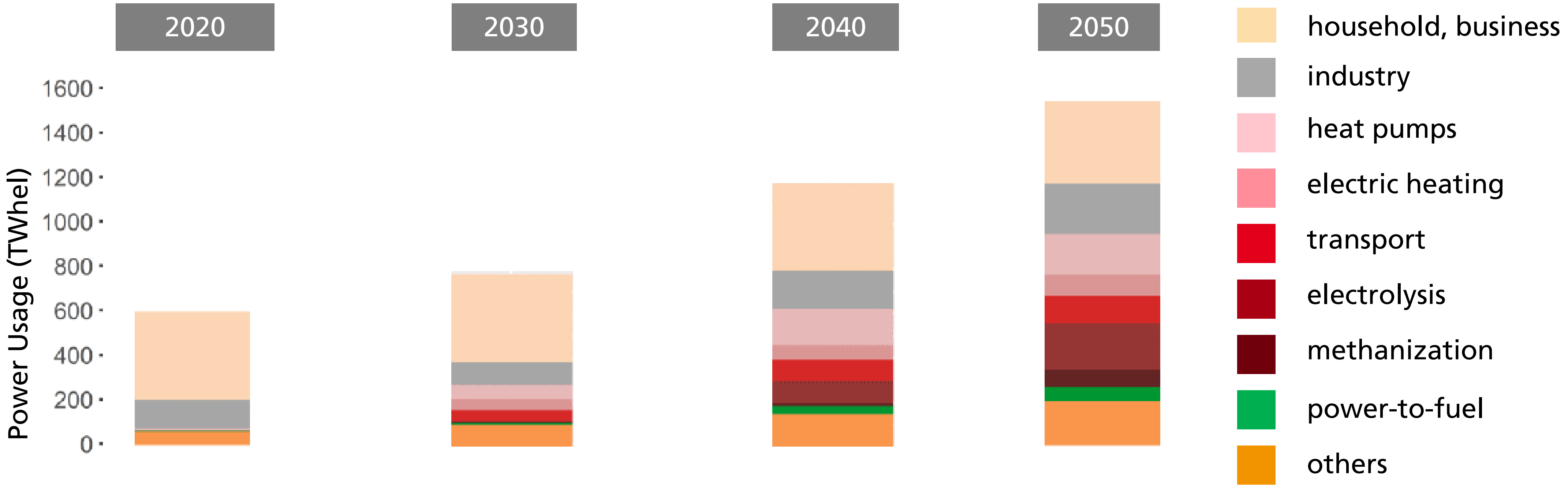


Installed power of wind and solar for climate emission targets of 65% RE in 2030 and 100% RE in 2050 of German power consumption

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

Our 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

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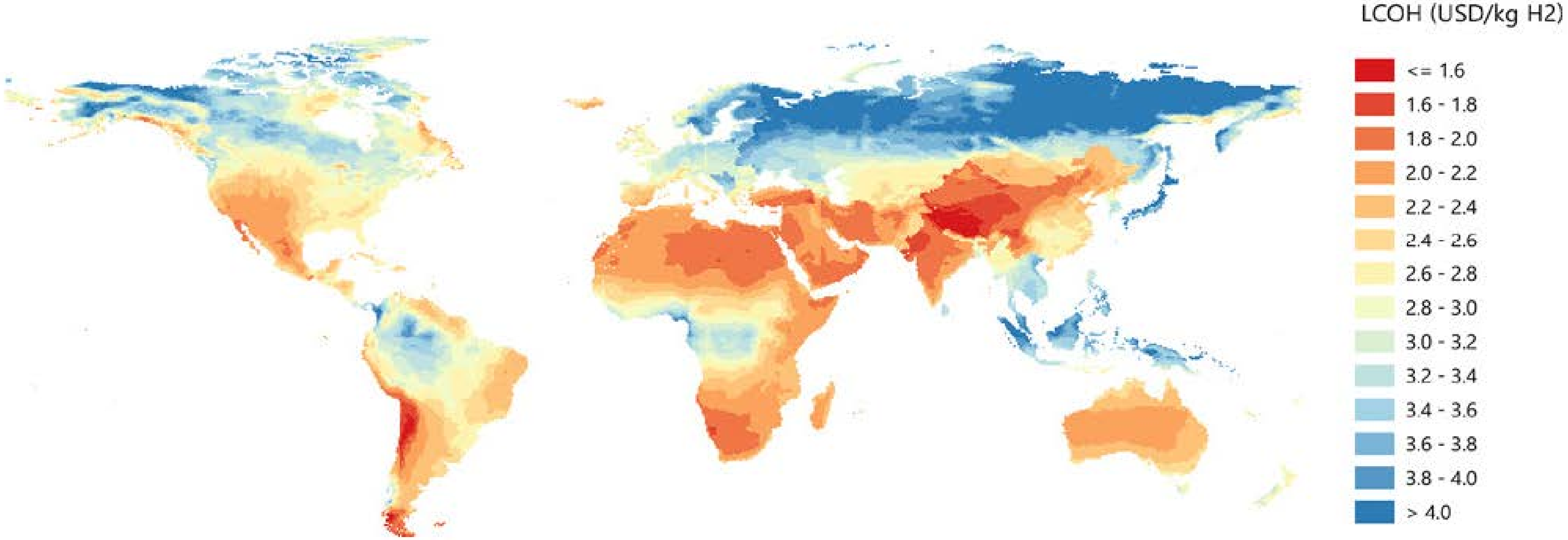
Zero Emission Mobility Needs Zero Emission Energy

Renewable Energy = Hydrogen will be Traded Globally

Hydrogen Refuelling is Economically and Technically Reasonable

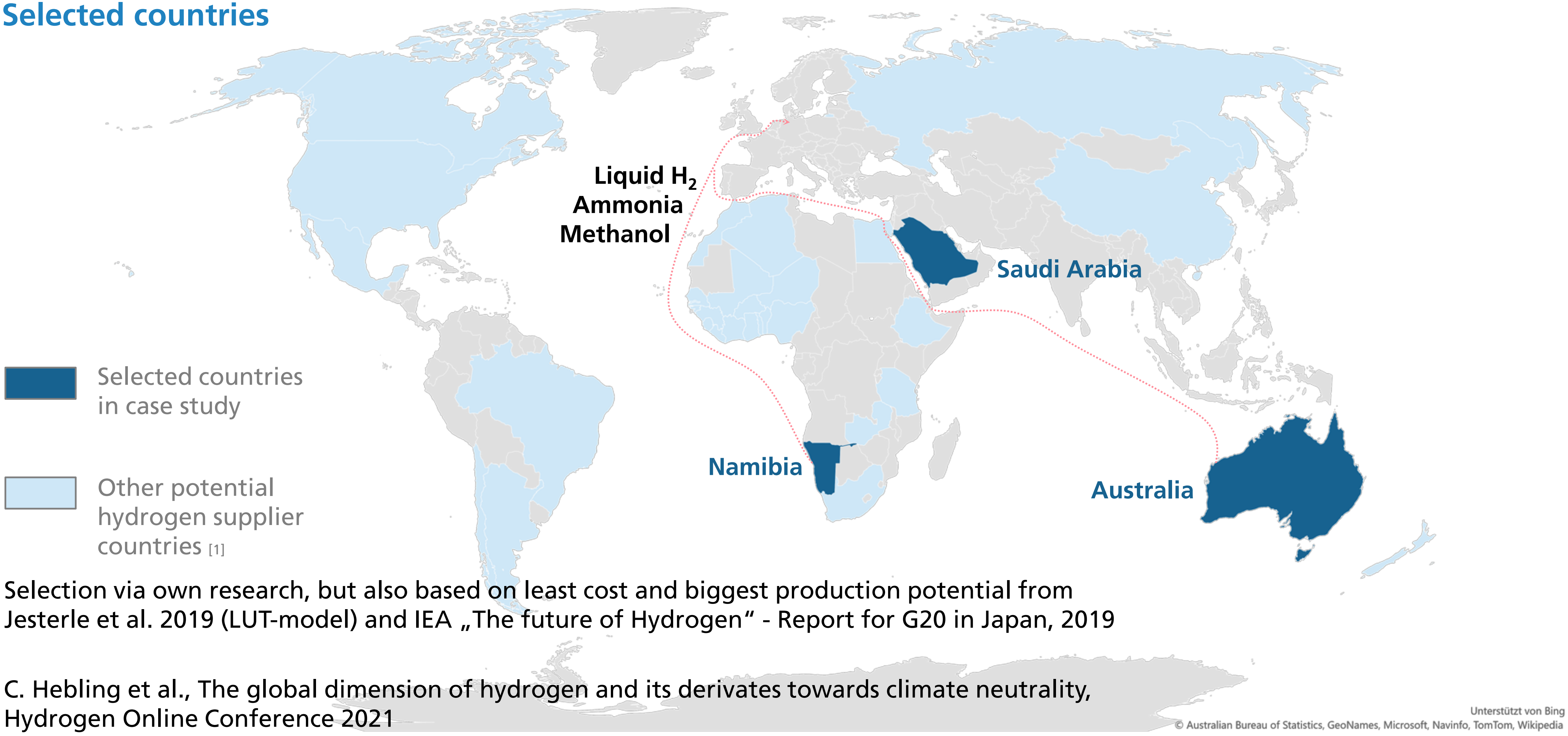
Global Hydrogen Generation Costs



IEA, The Future of Hydrogen, Seizing today's opportunities, Report prepared by the IEA for the G20, Japan, 2019

Production Cost and Long-Distance Import of Hydrogen and Derivates

Selected countries



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

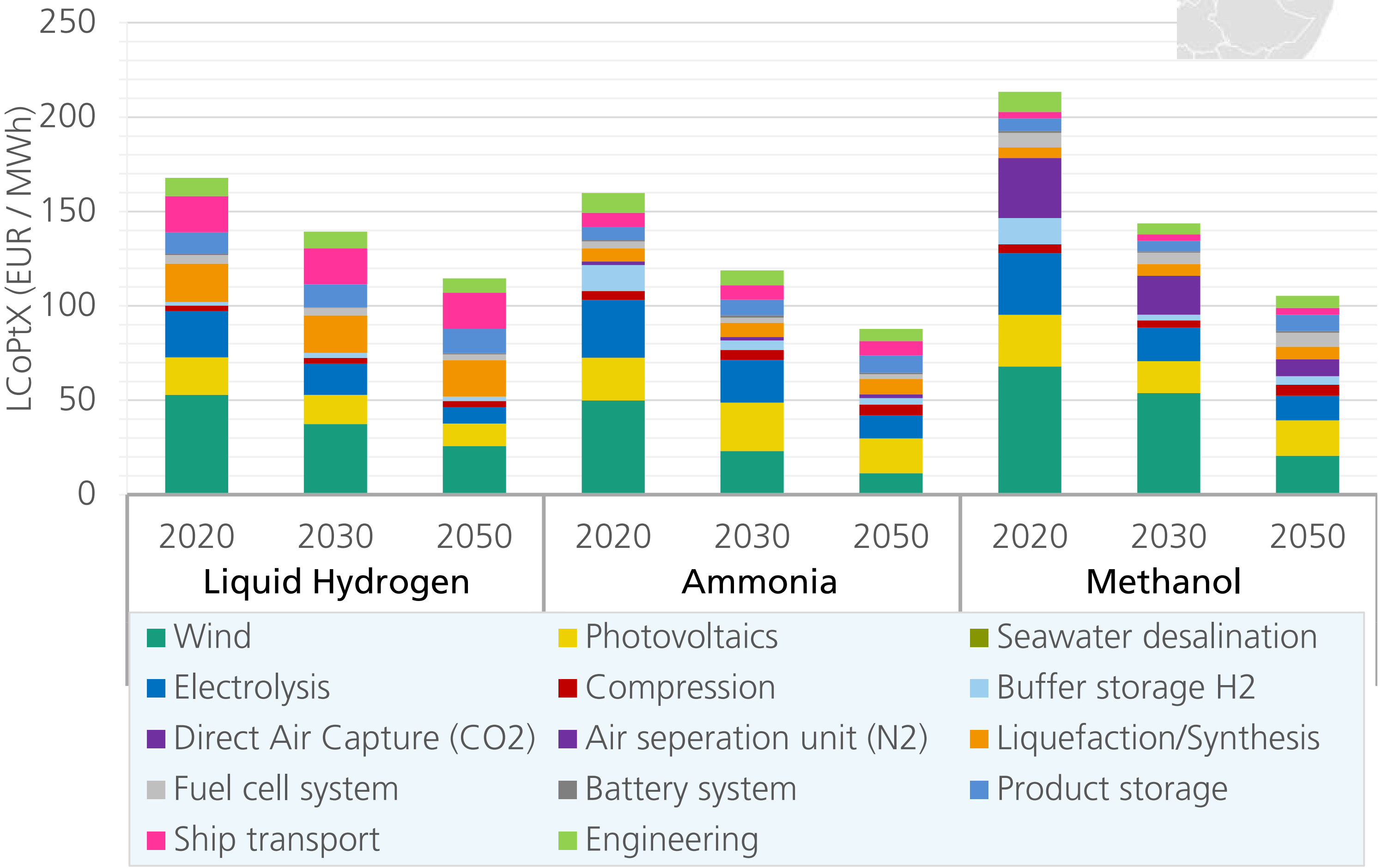
Production Cost and Long-Distance Import of Hydrogen and Derivates

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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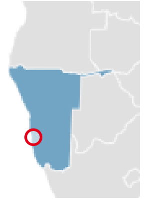
Production Cost and Long-Distance Import of Hydrogen and Derivates

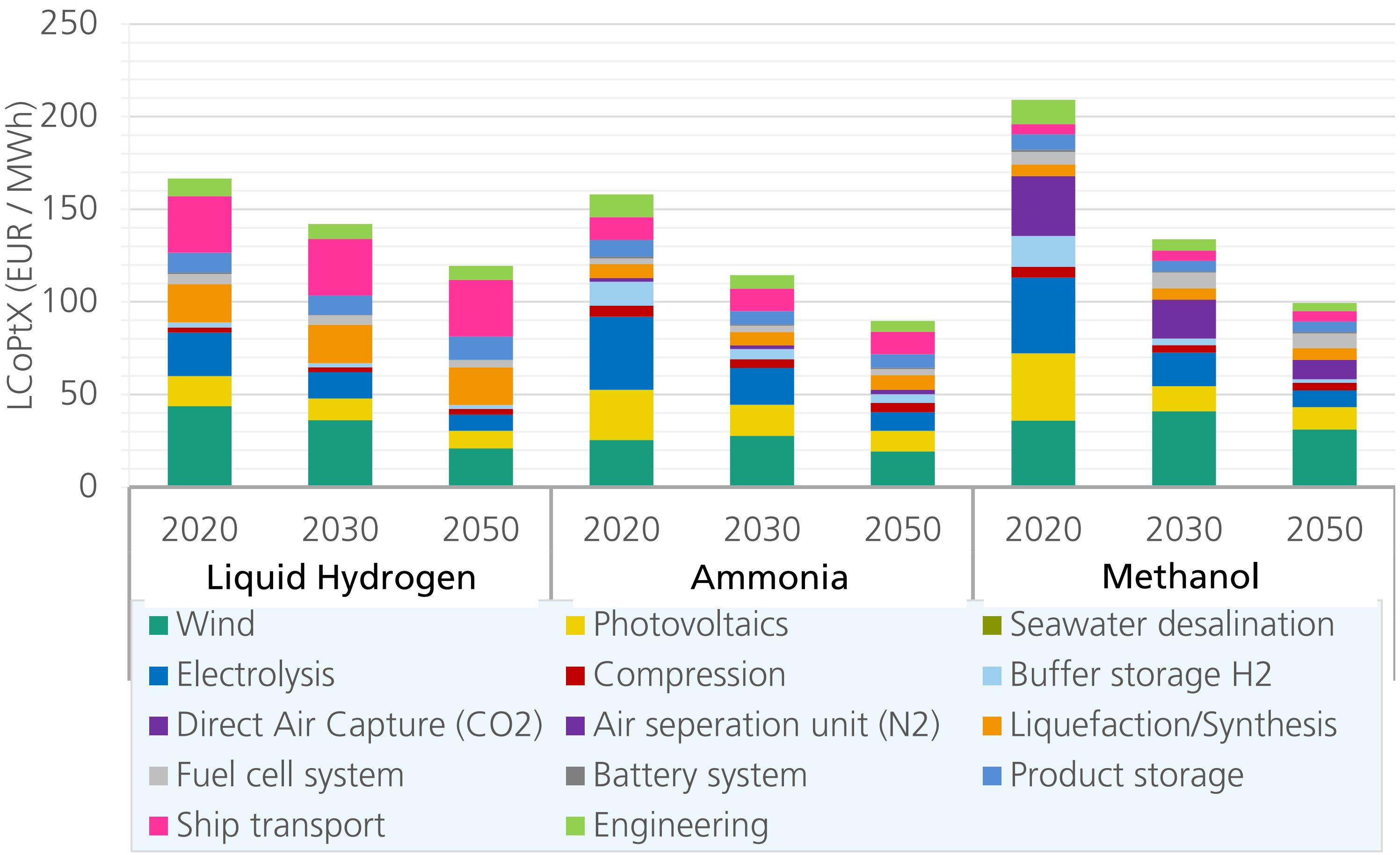
Namibia – South



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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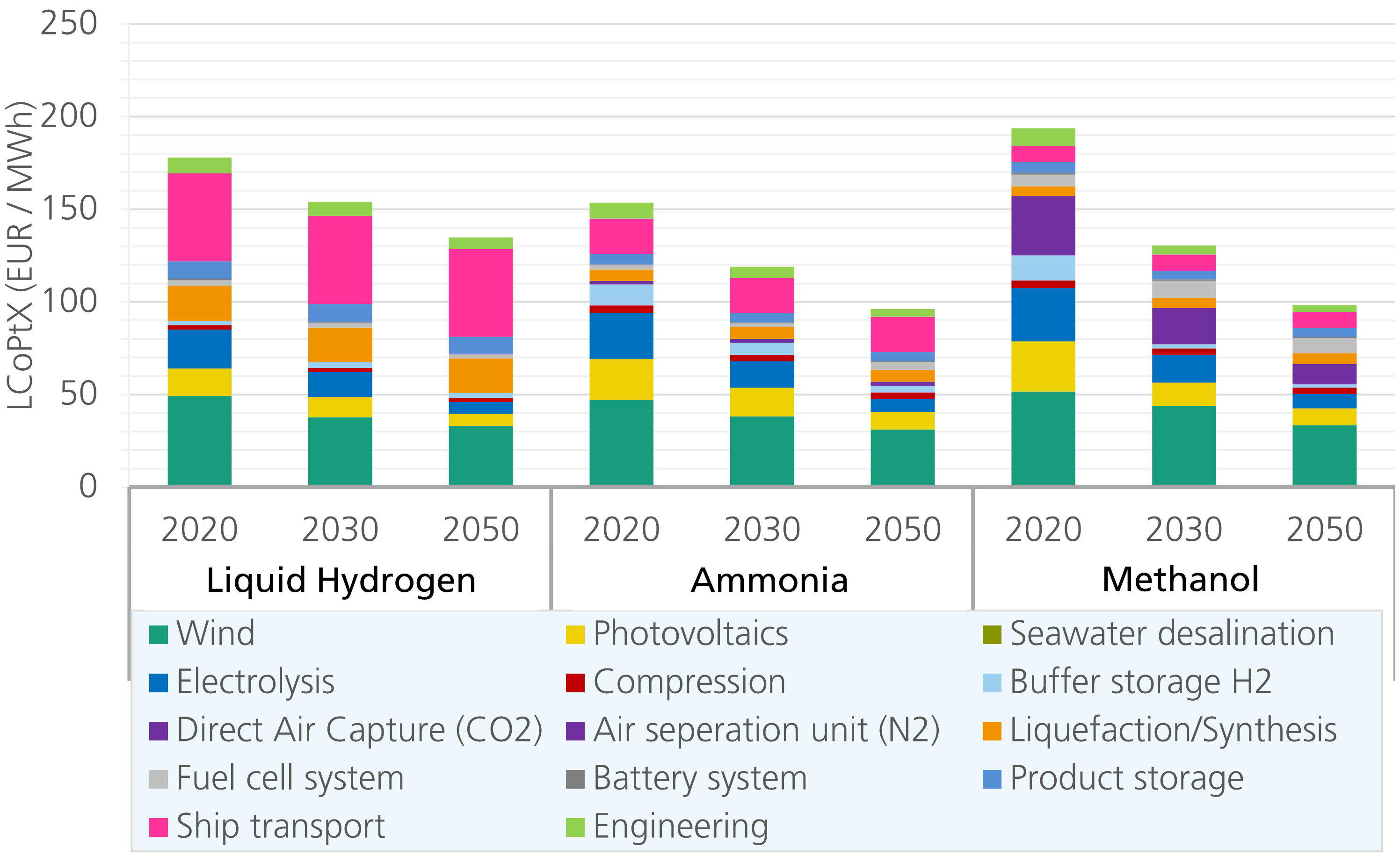
Production Cost and Long-Distance Import of Hydrogen and Derivates

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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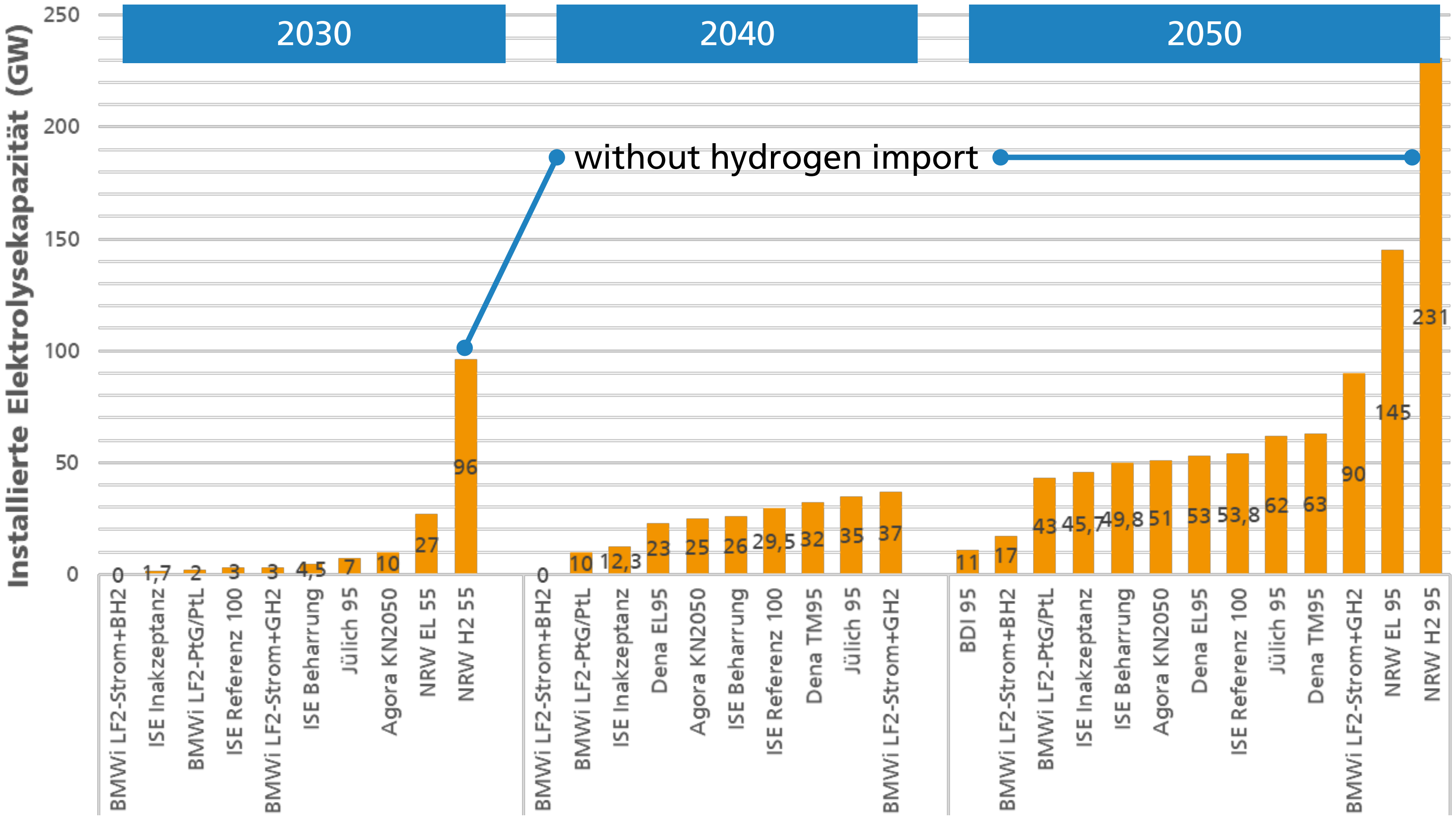
Demand for Electrolysis Capacity in Germany 2030 to 2050



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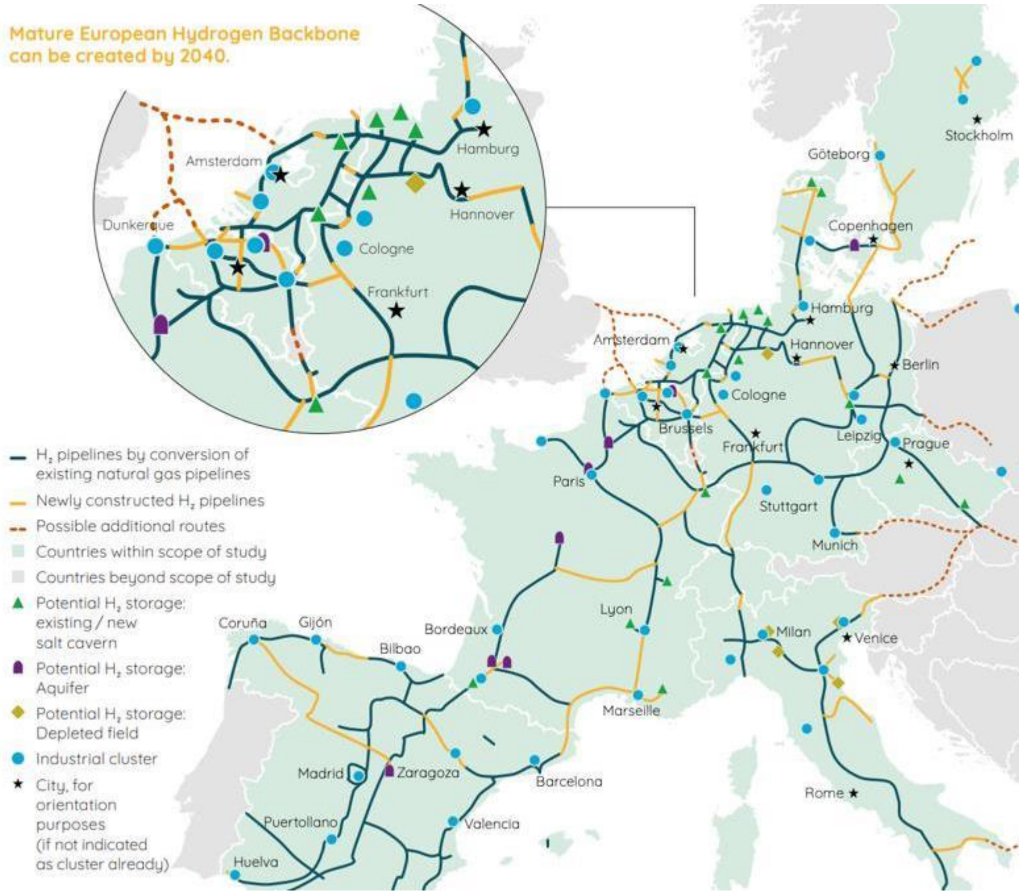
Hydrogen Pipeline Infrastructure is Cost Effective

6.800 km H_2-Pipelines until 2030
23.000 (40.000) km H_2-Pipelines 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

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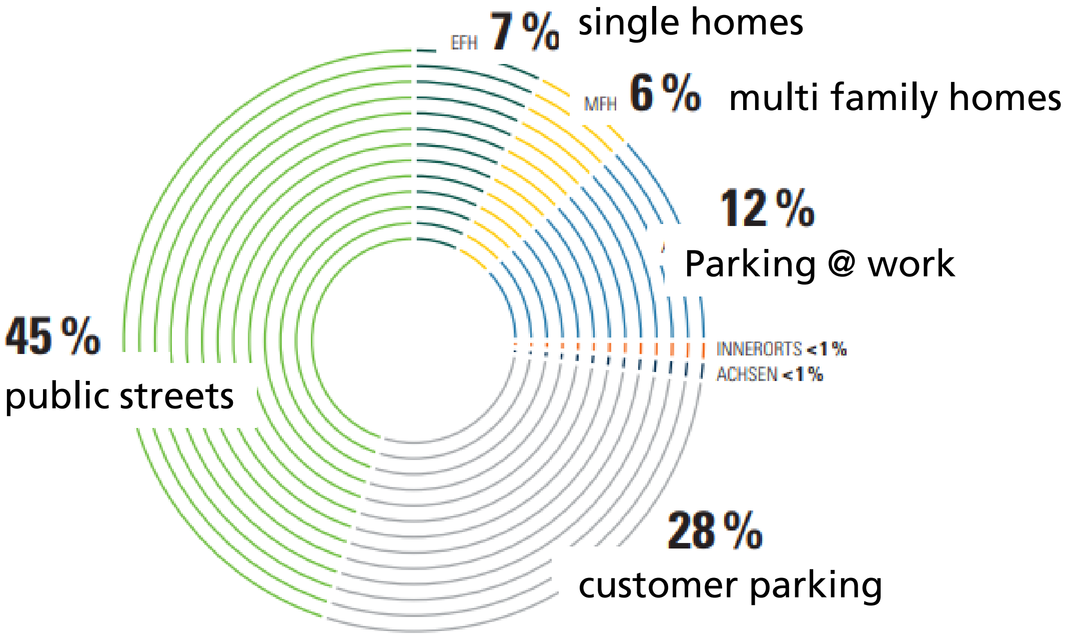
BEV: Most Important Use Case for Charging is Public Street

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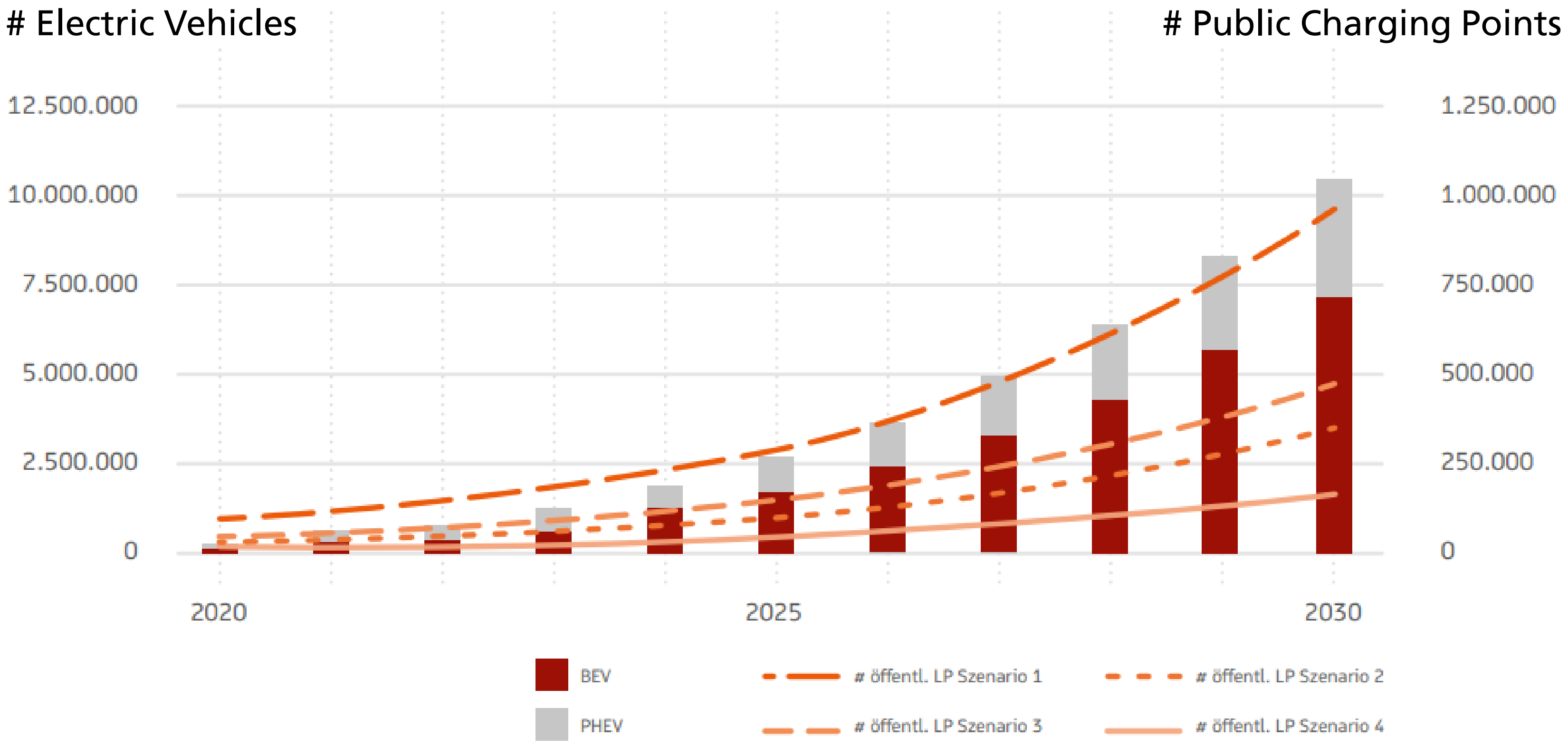
BEV: We Need up to 1 Mio. Public Charging Points in 2030

- 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

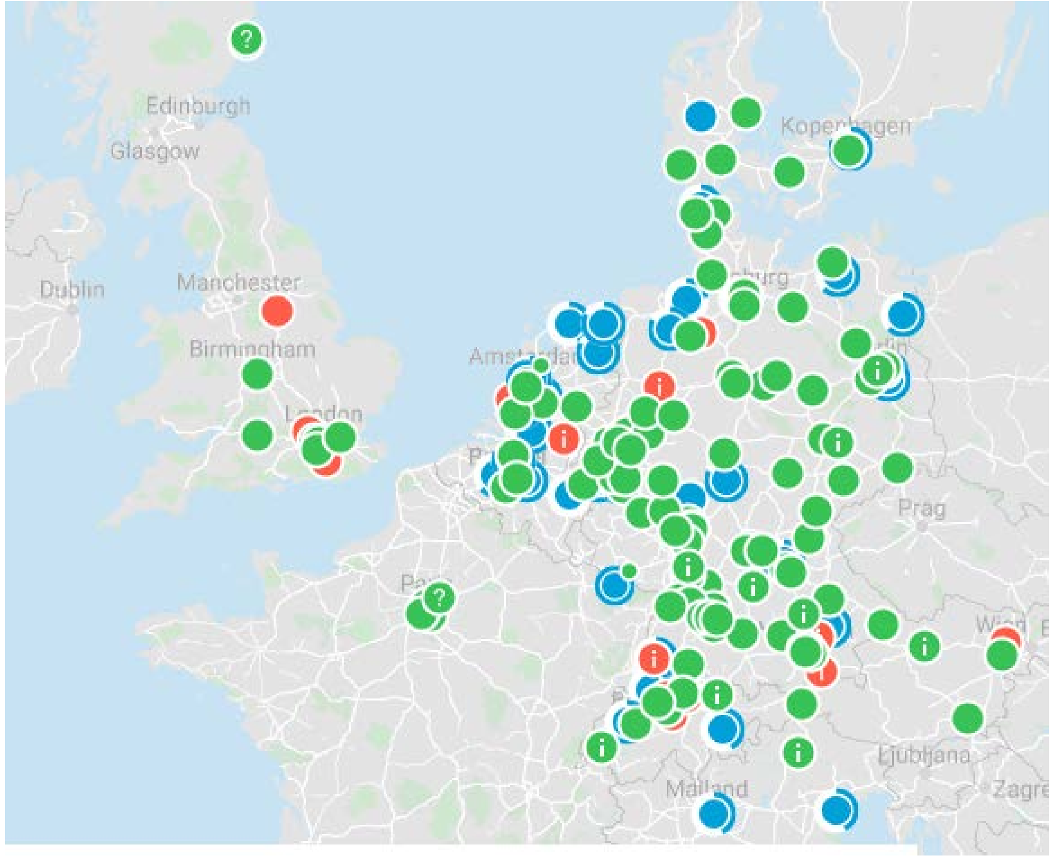
2 Nationale Plattform Zukunft der Mobilität, Arbeitsgruppe 5, Bedarfsgerechte und wirtschaftliche öffentliche Ladeinfrastruktur – Plädoyer für ein dynamisches NPM-Modell, 2020

Costs for HRS until 2030 are Economcially Feasable

But Infrastructure is more than refuelling stations

- Number of Hydrogen Refuelling Stations for cars: 1.000 to 3.000 in 2030 [1]
- Average CAPEX for HRS: 1.5 Mio. € [2] (1,67 to 1.34 M€ for a medium size HRS with 420 kg/d)

➢ CAPEX for public HRS: 1.5 to 4.5 billion €



h2.live (Oct 10, 2021)

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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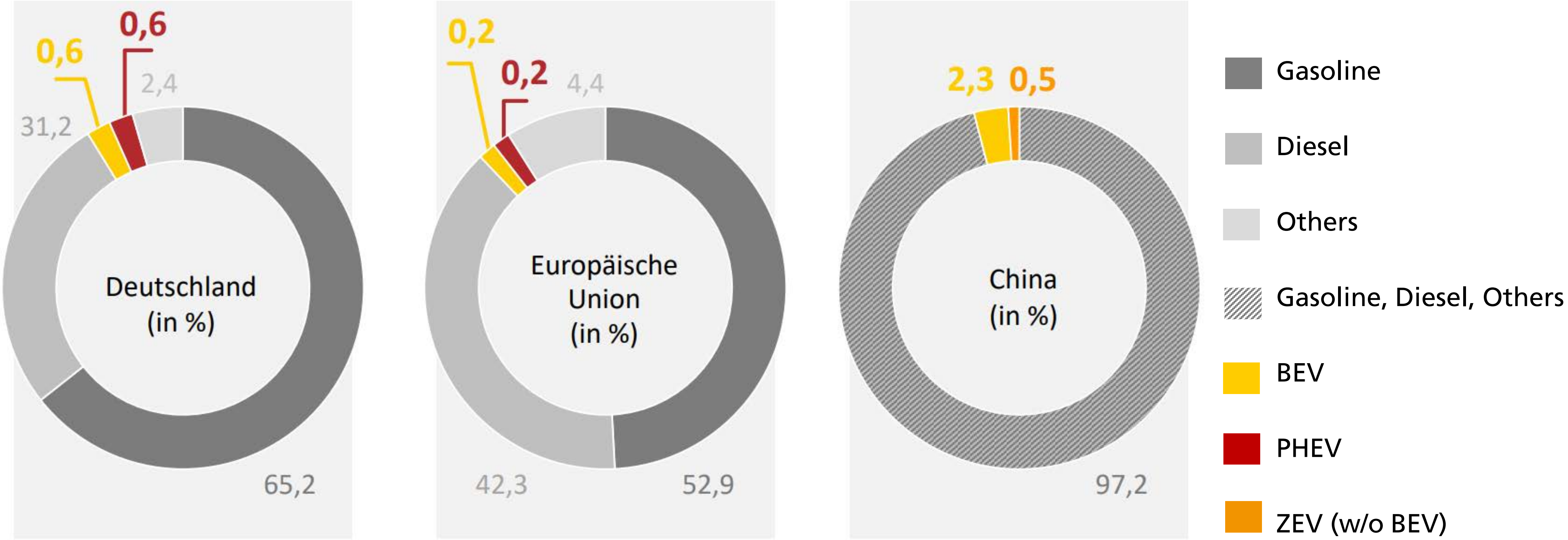
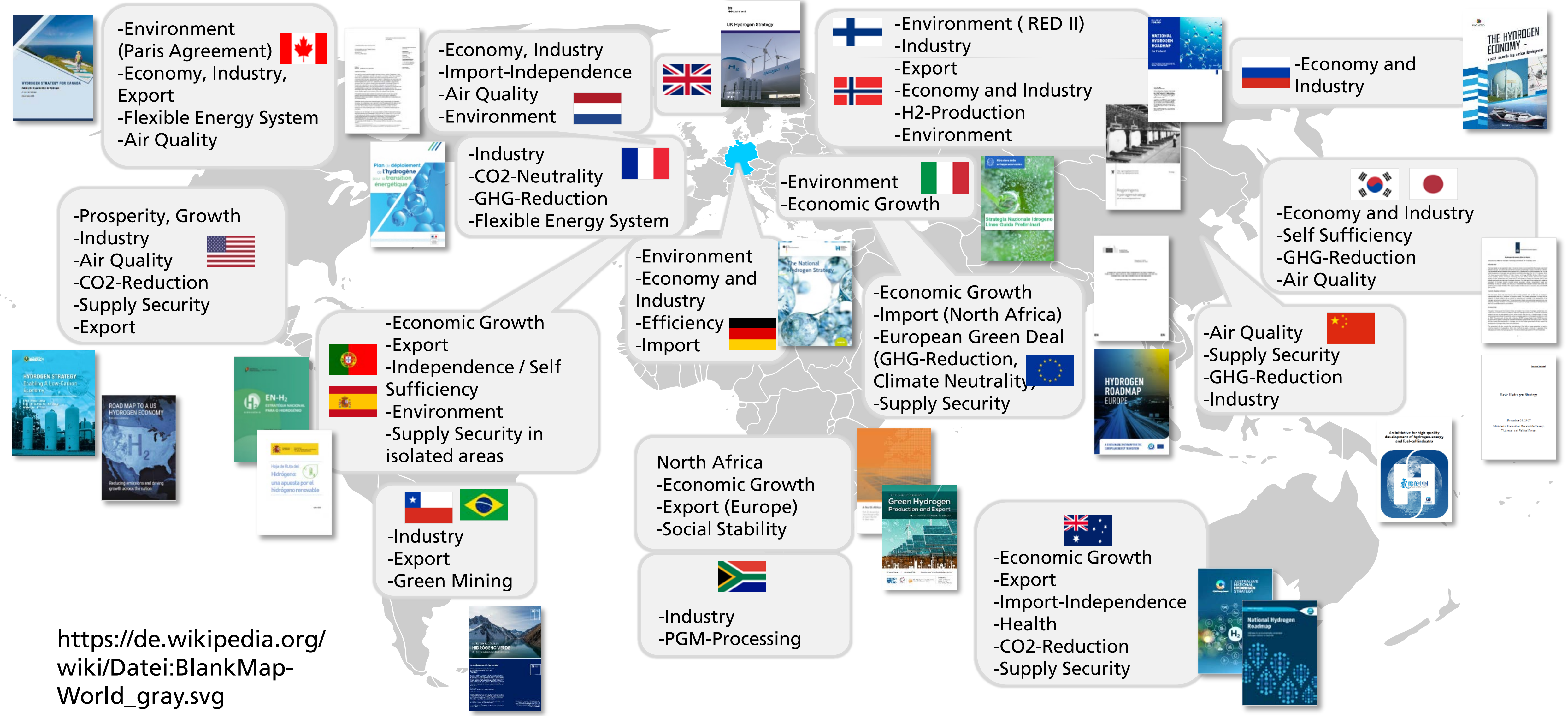
There is by far not Enough Experience with Electric Cars to Decide on Power Train Technologies: We Still Need (to Some Extend) Open Minds!



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

35 National Roadmaps, Strategy Papers, R&D Programms on Hydrogen



https://de.wikipedia.org/wiki/Datei:BlankMap-World_gray.svg

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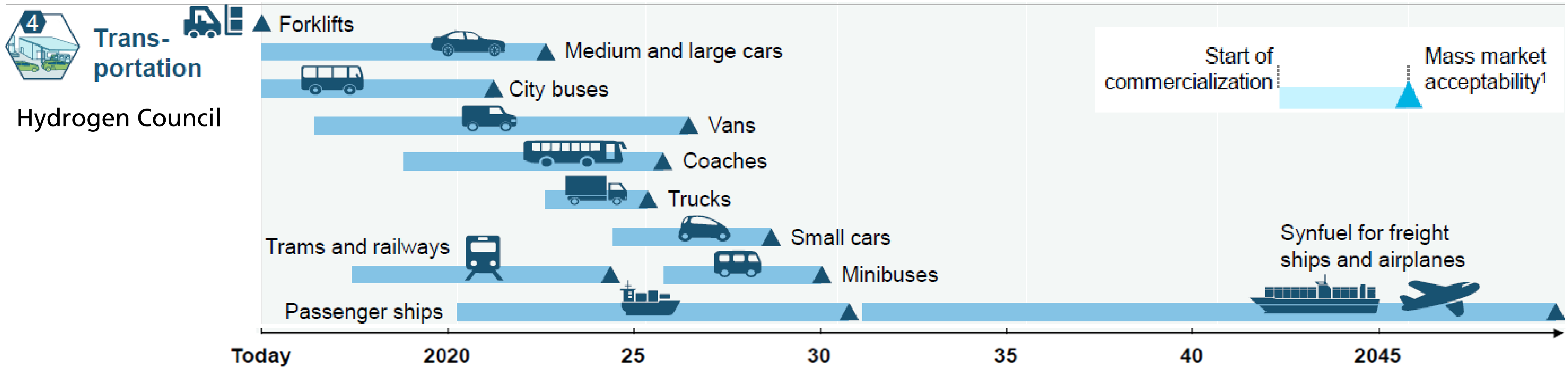
Roadmap for Fuel Cell Mobility



- Korea: 2030: **1,8 Mio** Fuel Cell Electric Vehicles (FCEV)
- Japan: 2030: **0,8 Mio** FCEV
- China: 2030: **1 Mio** FCEV
- California: 2030: **1 Mio** FCEV

https://www.electrive.net/2019/09/04/china-will-eine-million-brennstoffzellenfahrzeuge-bis-2030/ (Download 05.09.2020)

Take Home Messages

- **Zero emission mobility needs Renewable Energy**
- **Renewable Energy will be traded globally via hydrogen**
- **H_2 infrastructure is economically and technically reasonable**
- **H_2 refuelling of FCEV will supplement recharging of BEV**
- **At the very beginning of our learning curve we should consider alternative power train technologies which could supplement BEV**
- **International markets have strong commitments to FCEV and open export potentials**

Thank You for Very Much for Your Attention!

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