HYDROGEN AS PART OF AN INTEGRATED ENERGY SYSTEM IN GERMANY

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Division Energy Technologies and Systems
and
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IPHE Universities/Research Institutions Outreach Event: FCH R&D Status & Focus

SANLAM Auditorium, University of Pretoria
December 04th, 2018

The Fraunhofer-Gesellschaft
Joseph von Fraunhofer (1787 – 1826)

Researcher

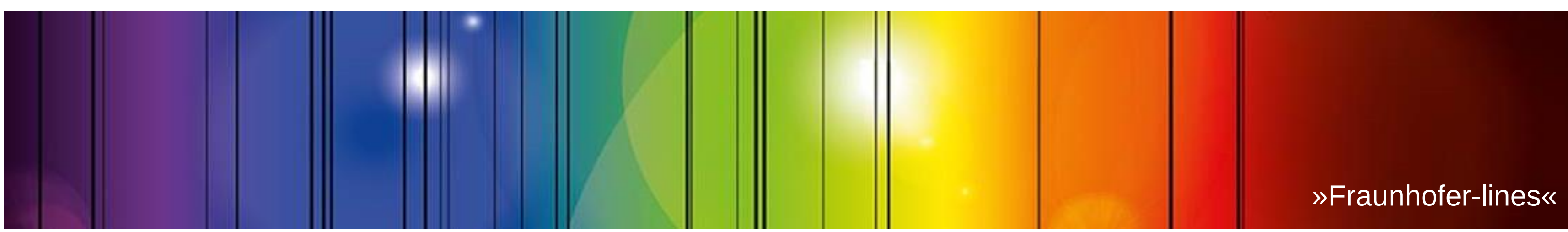
➔Discovery of the “Fraunhofer lines” in the solar spectrum

Inventor

➔New methods for processing lenses

Entrepreneur

➔Director and partner in a glassworks



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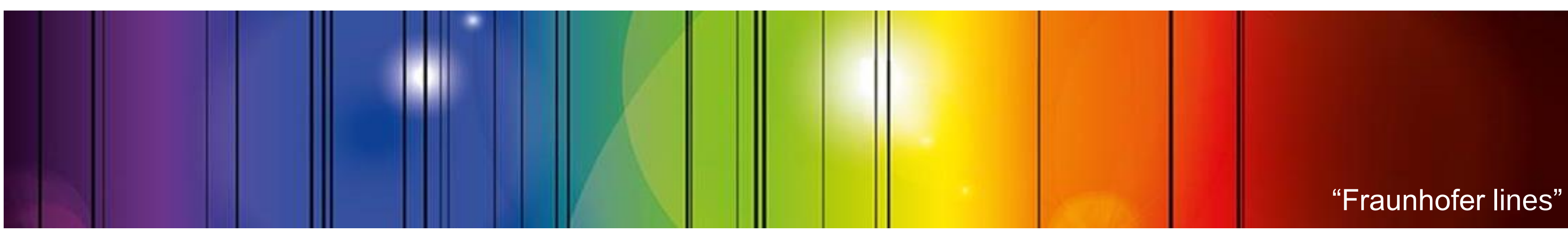
The Fraunhofer-Gesellschaft

Largest Organization for Applied Research in Europe

- 72 institutes and research units with a total staff of ca. 25,000
- More than € 2.3 billion annual research budget, of which around € 2 billion is generated through contract research
  - Roughly 75 percent of contract research is generated on behalf of industry and publicly funded research projects.
  - Roughly 25 percent is contributed by the German federal and state governments in the form of base funding.
- International cooperation throughout the world



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Vision of Fraunhofer Institute for Solar Energy Systems ISE

Performing Research for the Energy Transformation

- Our driving motivation is to secure the livelihood of present and future generations and protect our natural resources.
- With our pioneering research and development work, we hold a leading role internationally in the field of renewable energy systems and technologies. This enables us to contribute significantly to creating a sustainable, economic, secure and socially just energy supply worldwide, paving the way for an energy supply based exclusively on renewable energy sources.

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Fraunhofer Institute for Solar Energy Systems ISE

95 Mio € Budget in 2018 (1.5 bn Rand), 1280 Employees

Energy Technologies and Systems

Solar Thermal Technology

Building Energy Technology

Hydrogen Technologies

Energy System Technology

Photovoltaics

Silicon Photovoltaics

III-V- and Concentrator Photovoltaics

Emerging Photovoltaic technologies

Photovoltaic Modules and Power Plants

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Business Area Hydrogen Technologies

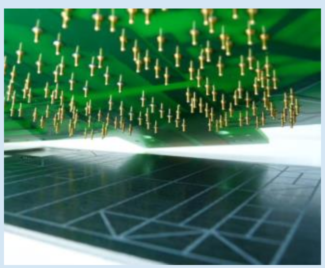
Research topics

H_2O

Department Chemical Energy Storage

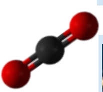
- Hydrogen generation by PEM water electrolysis
- Energy storage in H_2 systems and redox flow batteries
- Power-to-Gas: Interconnection of the power and gas grid

H_2



Department Fuel Cell Systems

- Scientific characterisation of fuel cell components
- Degradation research (load profile, various climates)
- Customer specific, self-sufficient PEM systems



CO_2

Department Thermochemical Processes

- Synthesis of H_2 and CO_2 to liquid fuels and chemicals (PtL)
- Thermochemical H_2 generation from fuels
- Catalytic evaporation of liquid fuels

Paradigm Shift towards Sustainable Energy Systems
Defossilization - as Opposed to Decarbonization

- Climate protection is a key topic on the global political agenda
- Target:
  Energy systems with dramatically reduced fossil CO_2 emissions
- A technical carbon cycle in analogy to the natural carbon cycle is needed (like Photosynthesis / Breathing)
- Cost minima: retain as much from old fossil infrastructure as possible such as pipelines, ships, airplanes, heavy duty applications, incl. internal combustion

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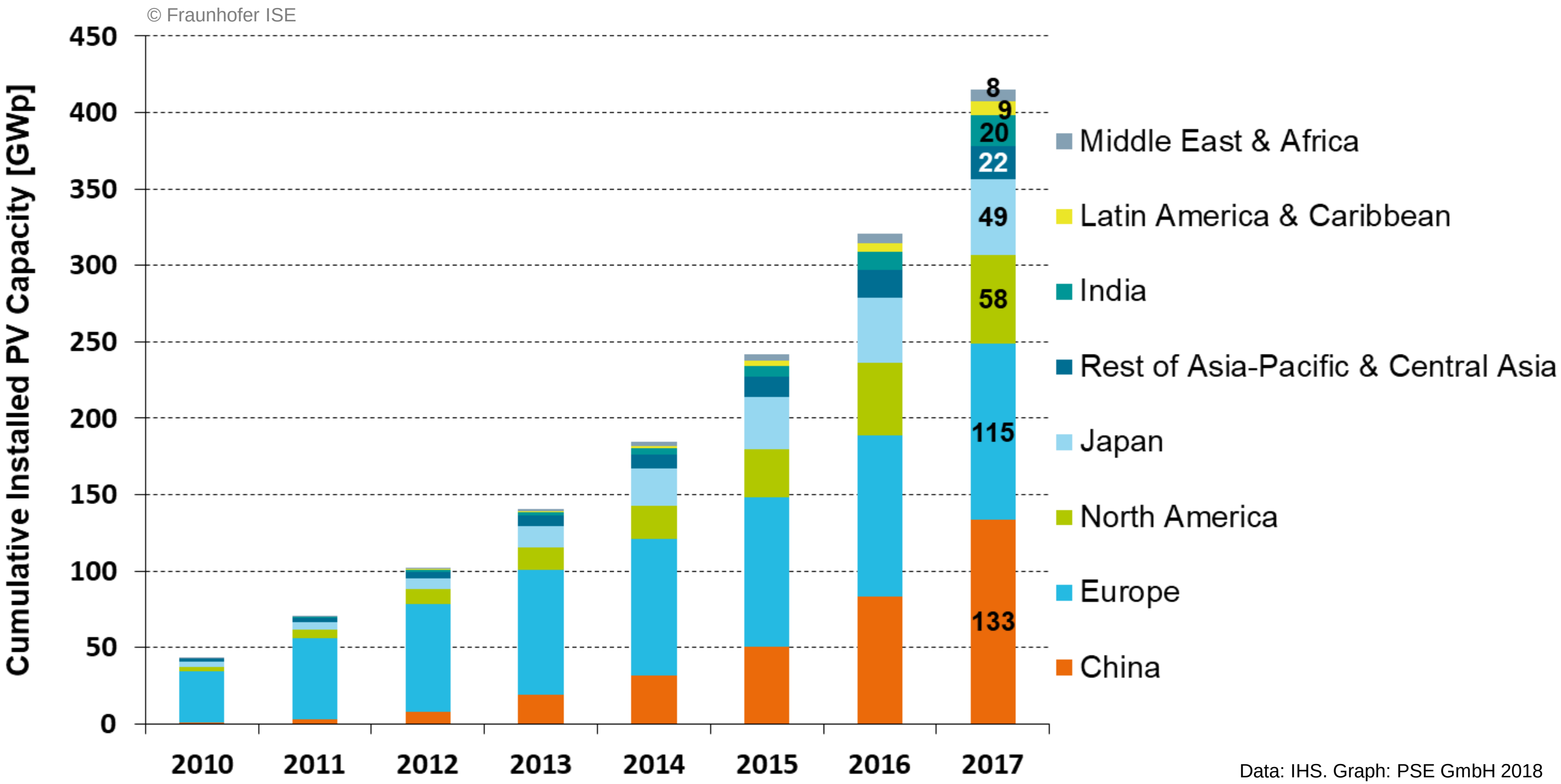
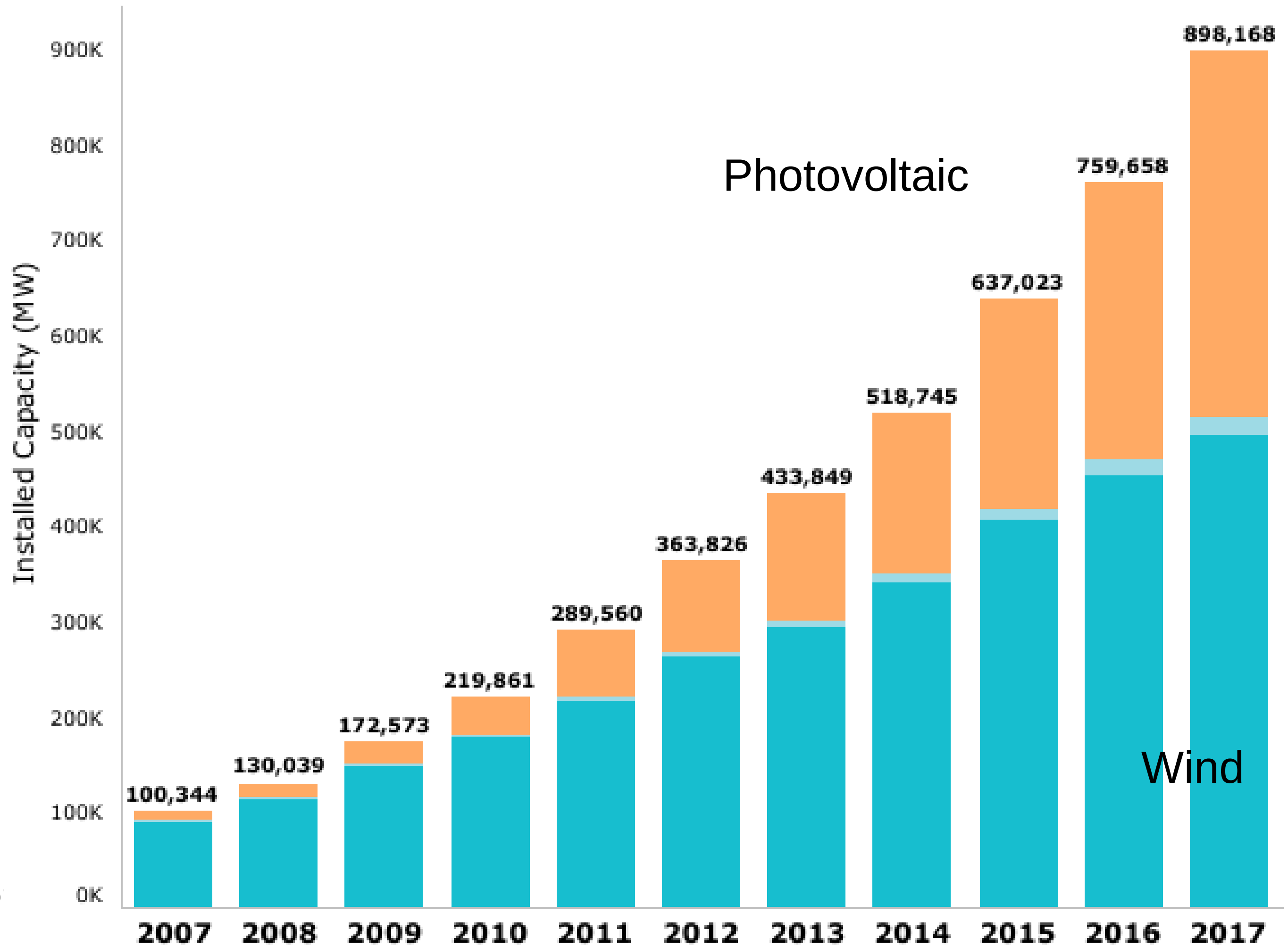
Global Cumulative Photovoltaic Installations (incl. off-grid)



Data: IHS. Graph: PSE GmbH 2018

Growing Renewables: Cumulated Global Wind and PV Installations reached 1 TW total Capacity (August 2018)



Source: IRENA, 2018, http://resourceirena.irena.o ay/dashboard/

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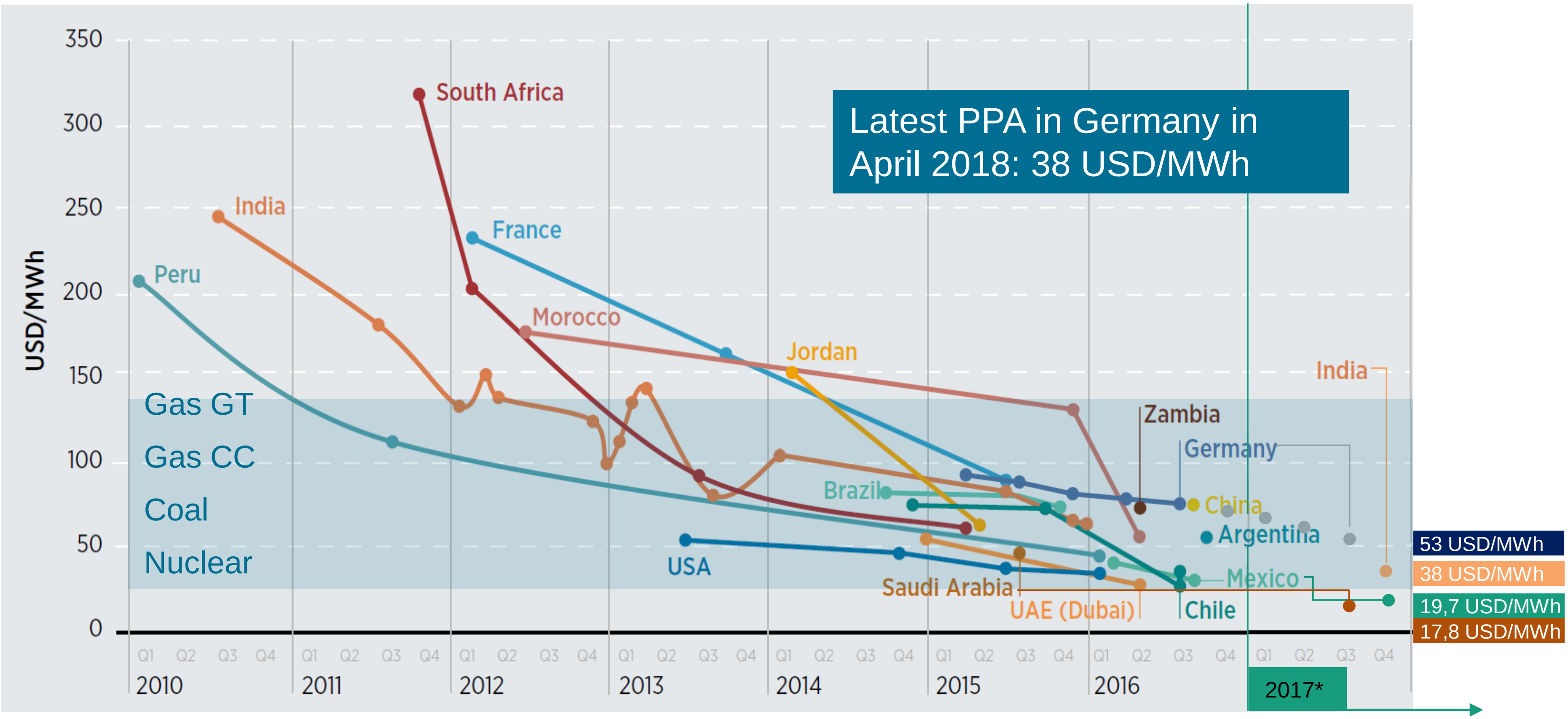
Photovoltaic Electricity in Power Purchase Agreements
January 2010 - December 2017



Source: Renewable Energy Auctions 2016, IRENA

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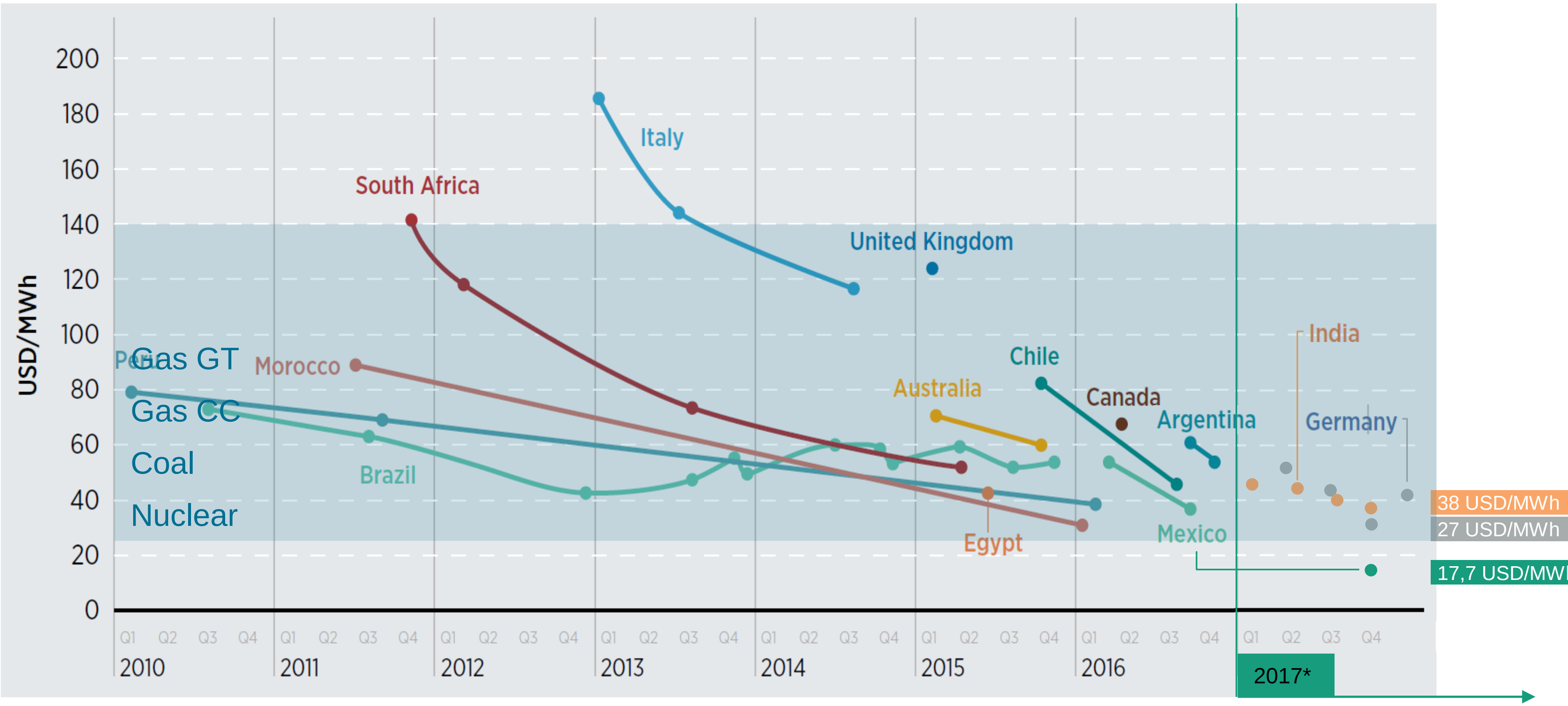
Onshore-Wind Electricity in Power Purchase Agreements

January 2010 - December 2017



Source: Renewable Energy Auctions 2016, IRENA

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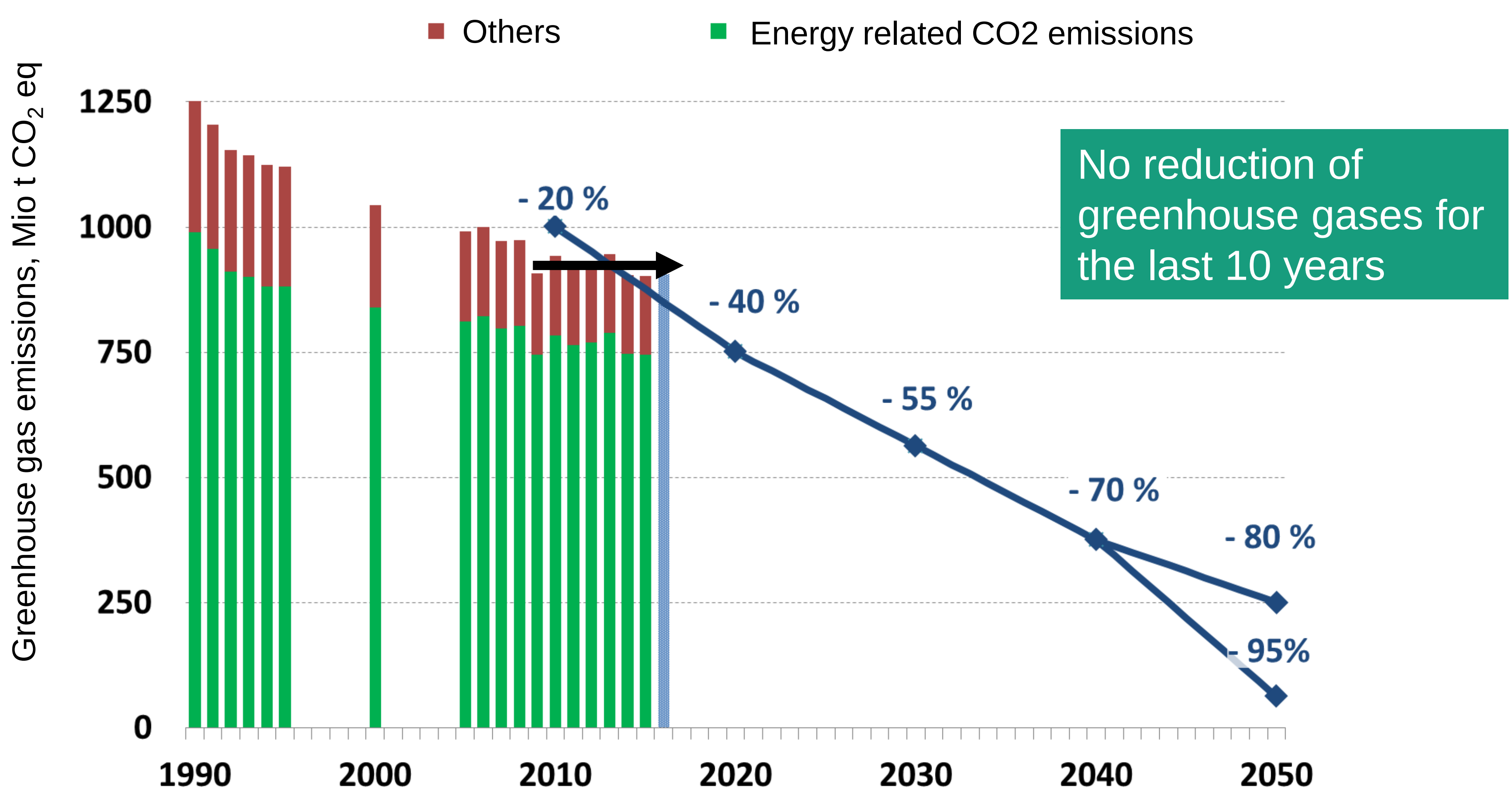
Greenhouse gas emissions in Germany

Historical Values 1990-2017 And Target Values Until 2050



Based on: Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen. Umweltbundesamt (UBA) Dessau, März 2017

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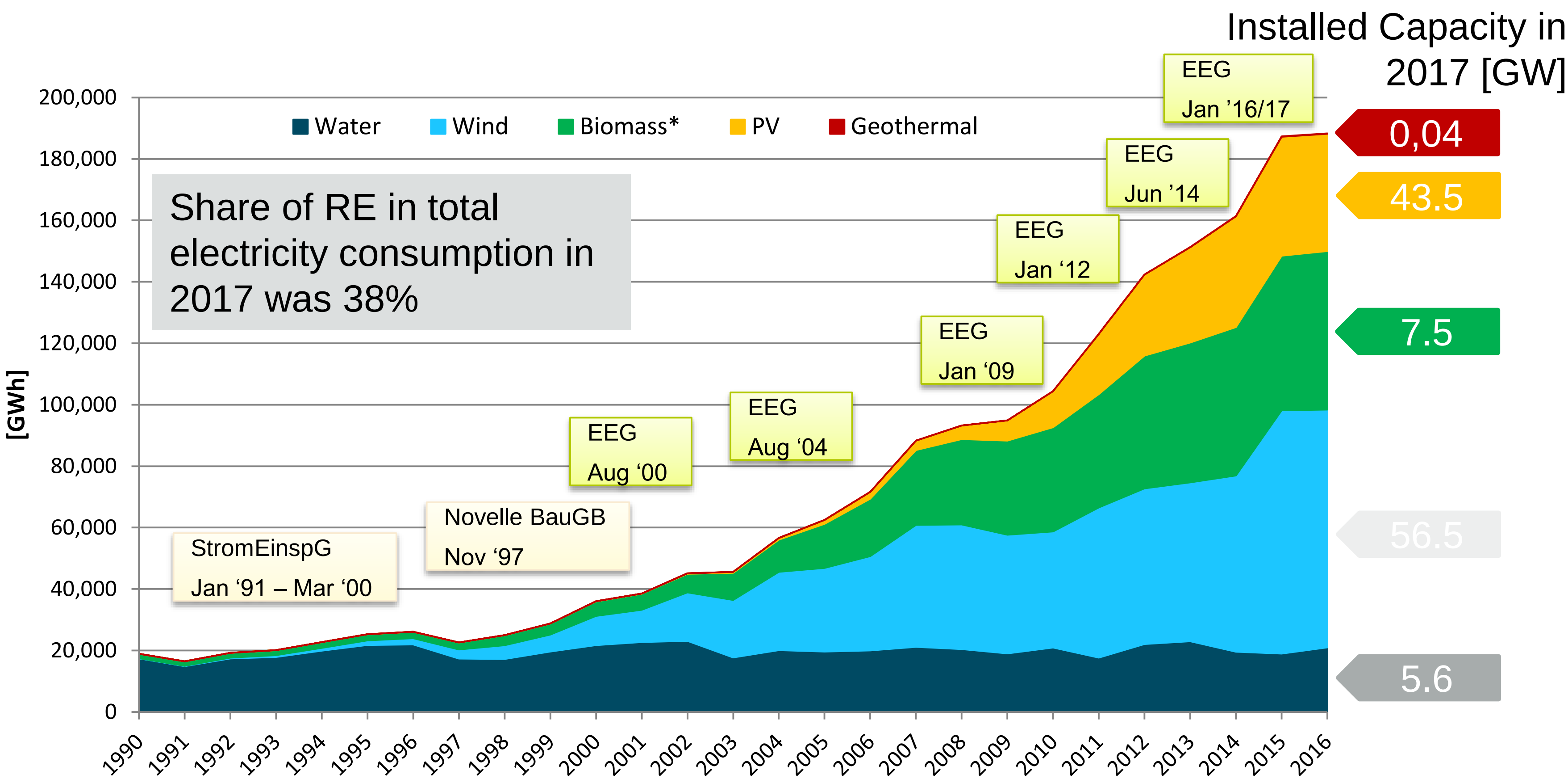
Power Generation from Renewable Energy Sources

Produced Power from Renew. Energy in 2017: 217,9 TWh



* Solid and liquid biofuels, biogas, landfill gas, sewage gas and biogenic waste

Data source: BMWi – Arbeitsgruppe Erneuerbare Energien – Statistik (AGEE-Stat); Feb. 2017

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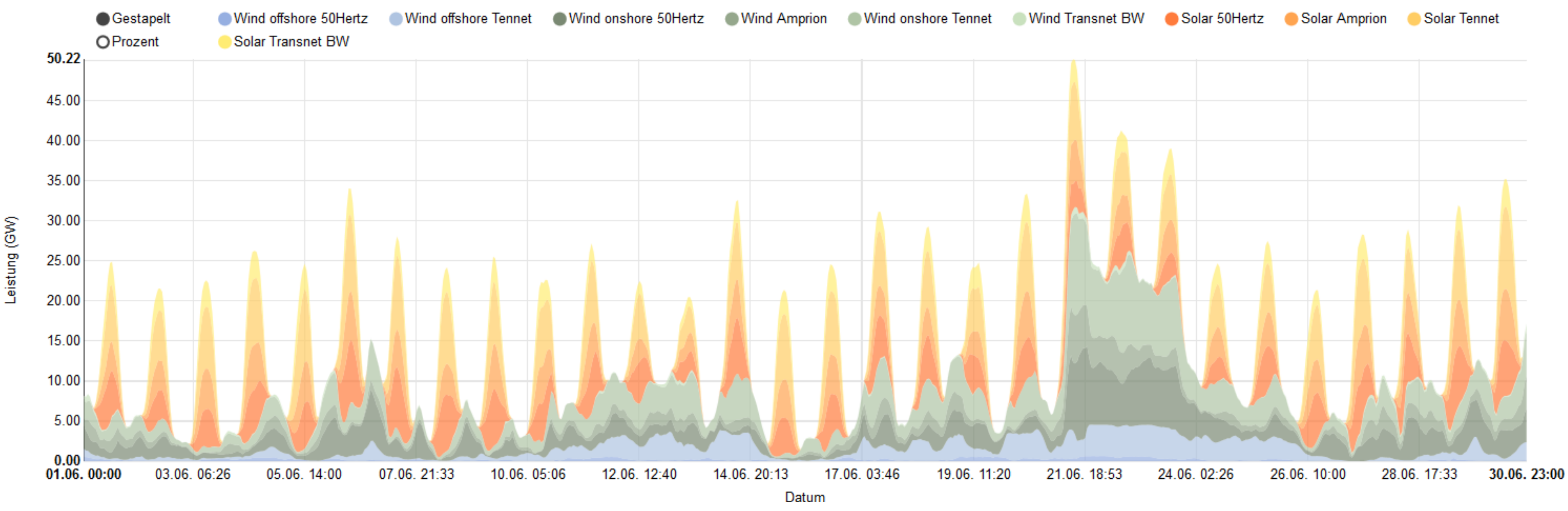
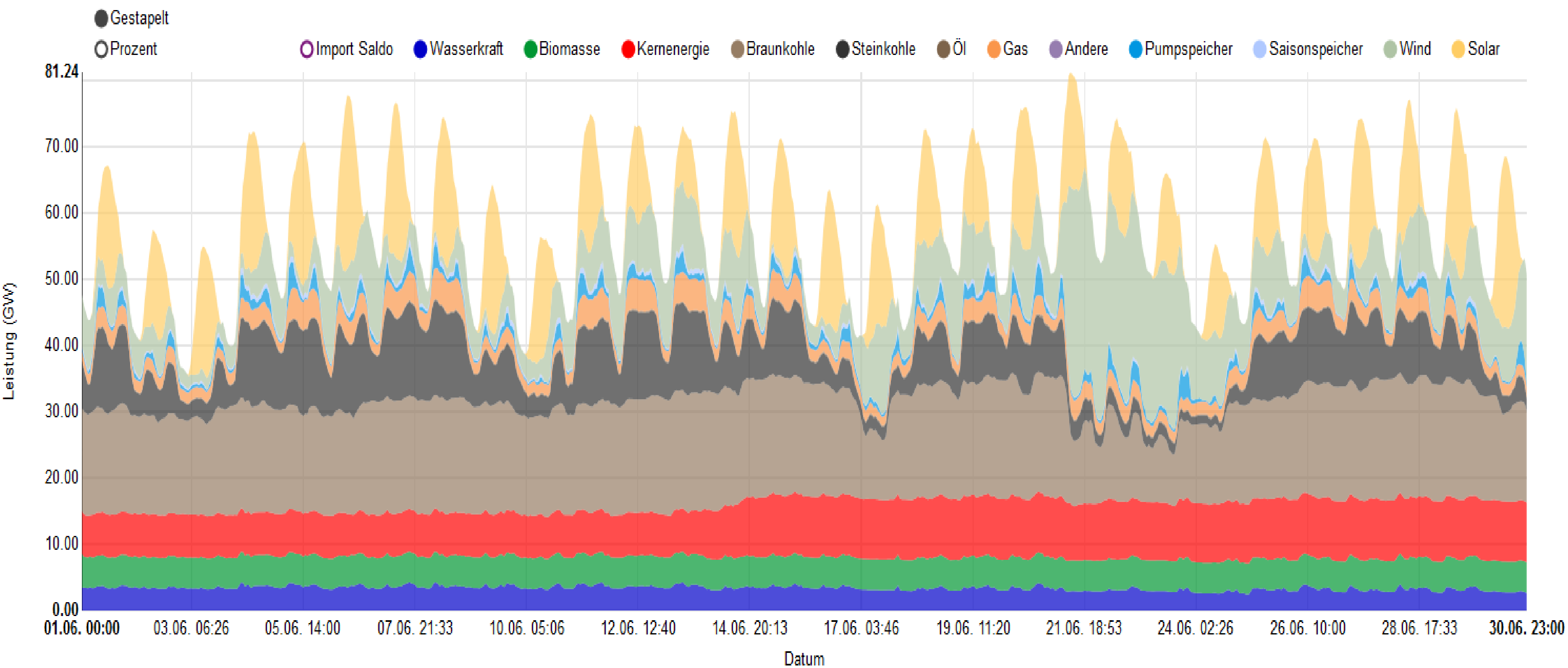
Power Generation by Photovoltaic and Wind June 2018



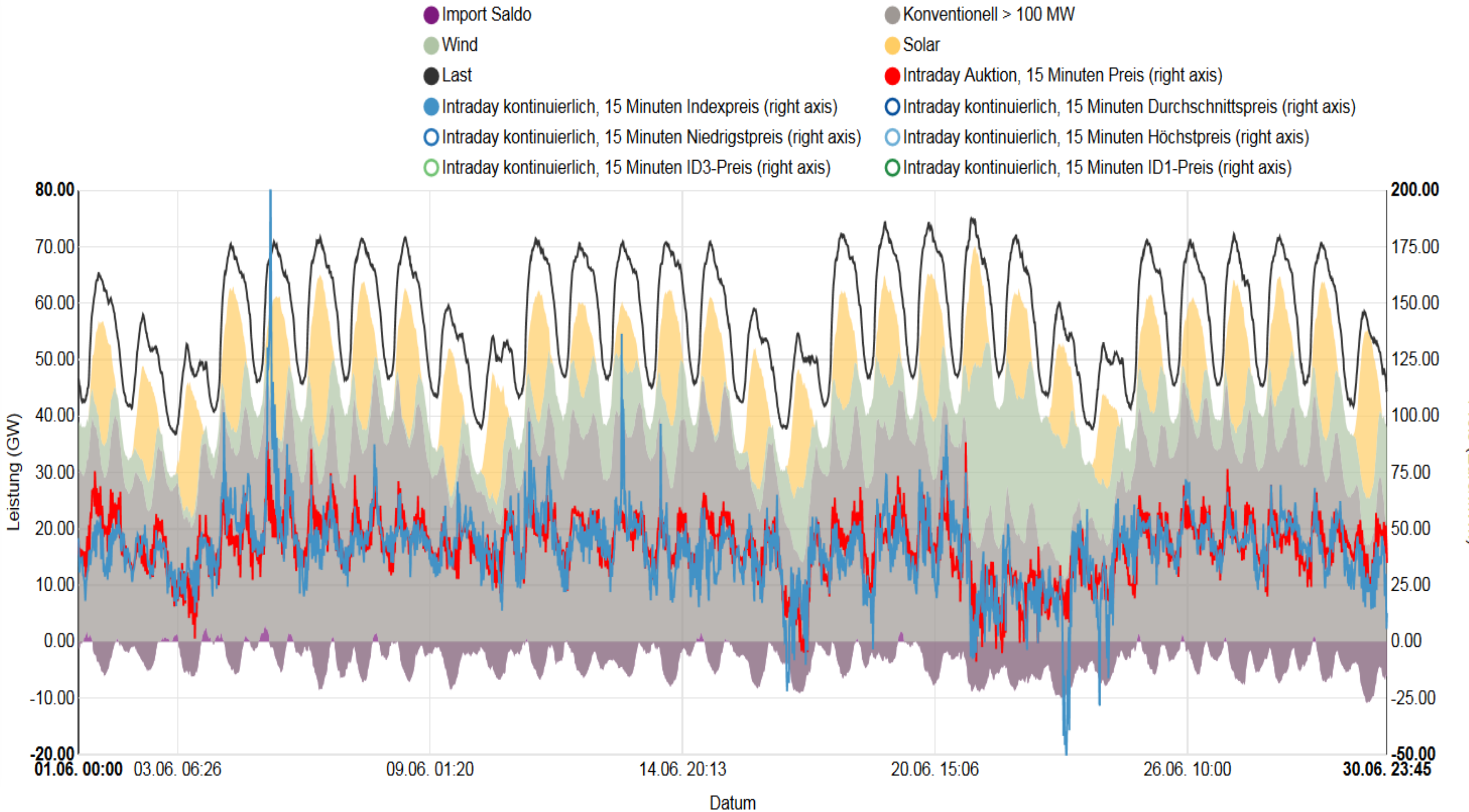
Quelle: Energy Charts, Fraunhofer ISE

Cumulated Power Generation by PV, Wind, Hydro, Bio & all Nuclear and Fossile Energy Power Plants in June 2018



Quelle: Energy Charts, Fraunhofer ISE

Power Generation and Market Prices in June 2018



Datenquelle: EEX, EPEX

Quelle: Energy Charts, Fraunhofer ISE

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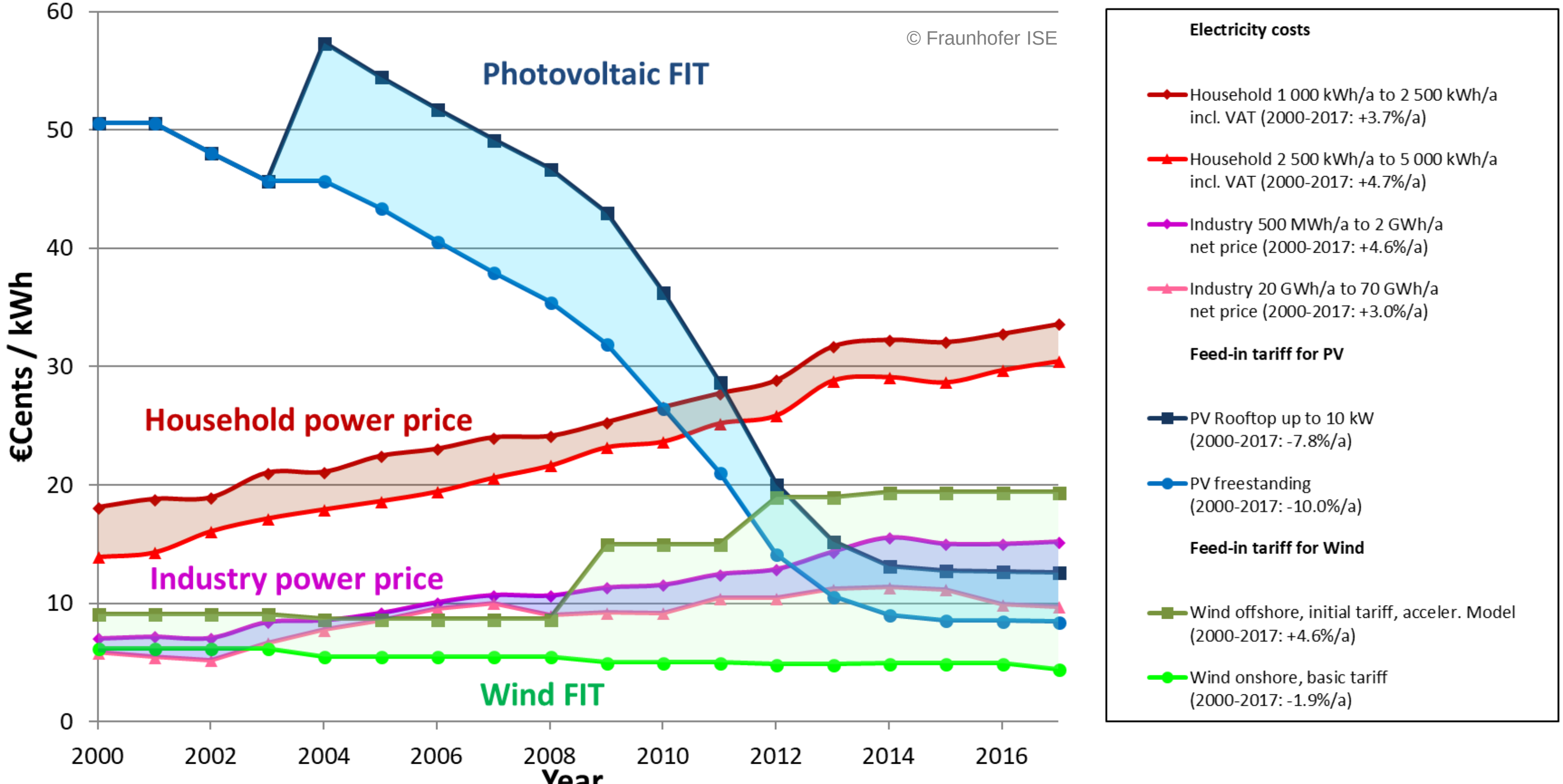
Power Prices and Feed-In Tariffs (FIT) in Germany

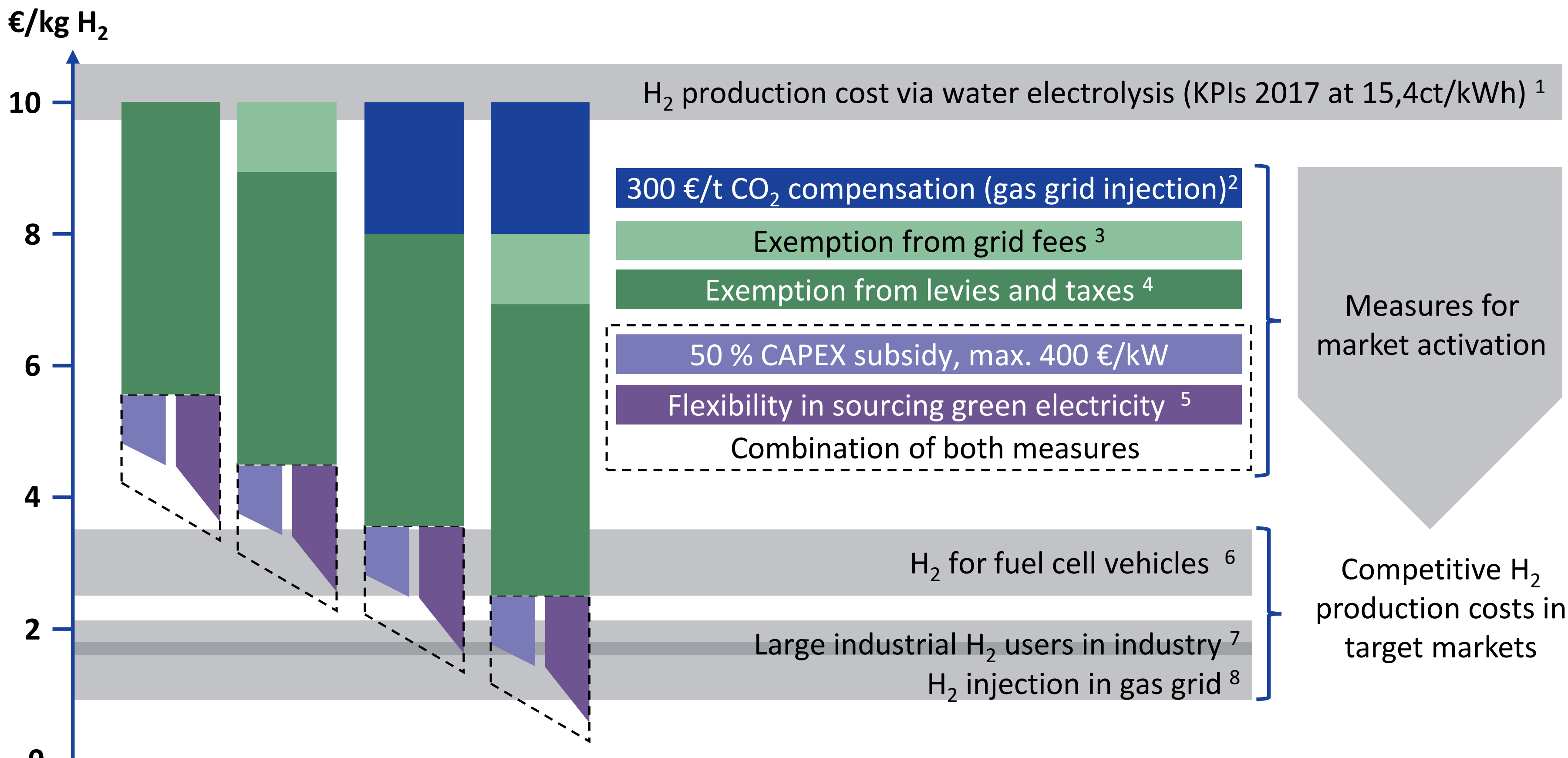
€ 220 bn cumulated costs since the year 2000 in Germany (€ 24 bn in 2018)



Data: BMU, EEG 2017 and BMWi Energiedaten. Design: B. Burger - Fraunhofer ISE , Update: 14 June 2018

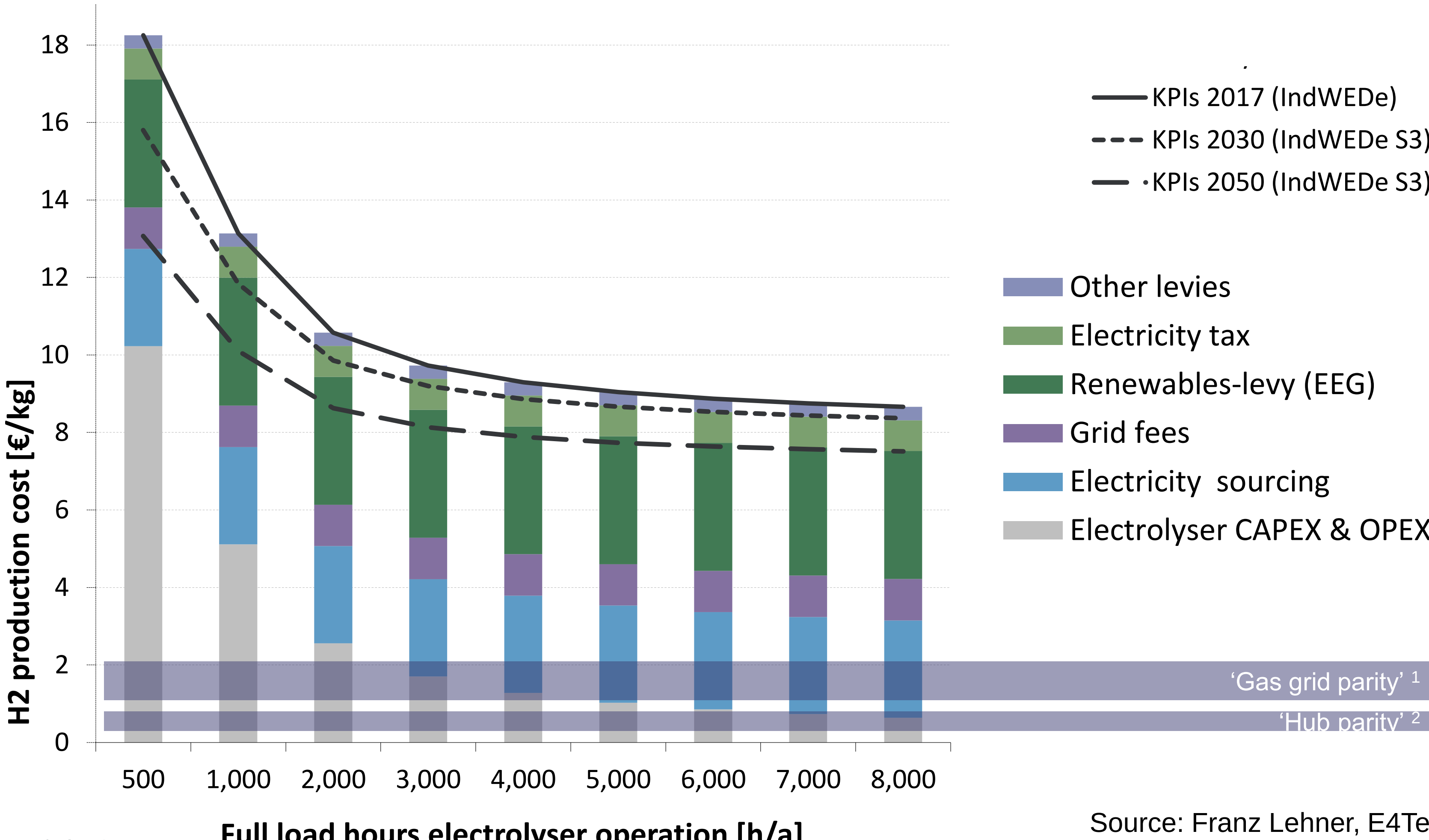
Measures for Market Activation of Hydrogen Production

A Combination of Actions is Needed



[1] KPIs of scenario S3 2017, range results from 2,000 to 3,000 full-load hours [2] Compensation payments for CO_2 savings (204g CO_2-Äq/kWh LHV natural gas) Comparison based on substitution LHV of natural gas with hydrogen (33,3kWh/kg LHV, assumption 100% CO_2 free hydrogen) [3] 2,06ct/kWh electricity grid fees (Bundesnetzagentur/Bundeskartellamt (2016): „Monitoringbericht 2016“, industrial consumers with 24 GWh/a) [4] 8,55ct/kWh electricity levies and taxes („BDEW Strompreisanalyse 2018”, industrial consumers up to 20 GWh) [5] If electrolyser operations are not coupled to PV- and Wind generation profiles or to the negative residual load in the network, 8,000 full load hours (instead of assumed 2,000-3,000) per year become possible, implying that (during a transition period) guarantees of origin can be provided from, e.g., hydro power plants. [6] Assumption: Competitive hydrogen prices at the pump 6 €/kg (Diesel passenger car 5l/100km at 1.20 €/l, fuel cell passenger car 1 kg_{H2}/100km), of which 3 €/kg deducted for distribution and station costs. Prerequisite: Roll-out of fuel cell vehicles and refuelling stations and continued tax exemption for hydrogen as a fuel. [7] Cost of steam methane reforming at 100t/day hydrogen production based on FCHJU „Study on Development of Water Electrolysis in the EU“ 2014 [8] Substitution of natural gas with hydrogen based on LHV, natural gas prices private customers in Germany 2016 6,5ct/kWh, large customers 3,4ct/kWh (Eurostat), LHV hydrogen: 33,3kWh/kg; Results in a value of hydrogen in gas grid between 1,13 and 2,16 €/kg

Can hydrogen from renewables reach 'fossil parity' ?



Source: Franz Lehner, E4Tech

[1] 1.13 and 2.16 EUR/kg based on natural gas prices for private customers in Germany 2016 6,5ct/kWh, large customers 3,4ct/kWh (Source: Eurostat)

[2] 0.30-0.80 EUR/kg based on natural gas Henry Hub 2017: 3 USD/MMBtu and Japan LNG cif: 8 USD/MMBtu (Source: BP)

[3] Assumption: Competitive hydrogen prices at the pump 6 €/kg (Diesel passenger car 5l/100km at 1.20 €/l, fuel cell passenger car 1 kgH2/100km), of which 2-3 €/kg deducted for distribution and station costs. Prerequisite: Roll-out of fuel cell vehicles and refuelling stations and continued tax exemption for hydrogen as a fuel.

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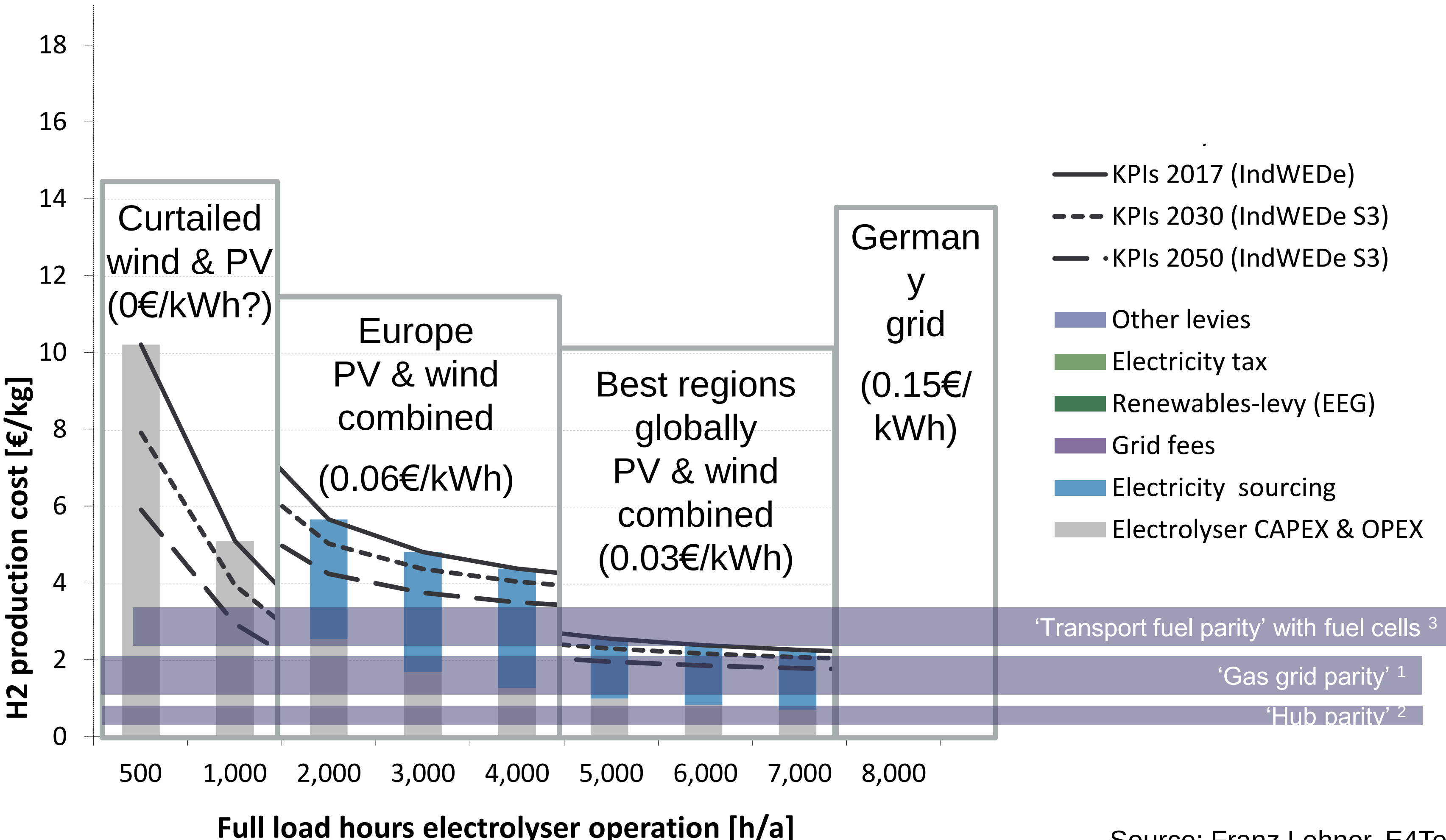
Can hydrogen from renewables reach 'fossil parity' ?

… yes, and fuel cells can help to reach it even earlier



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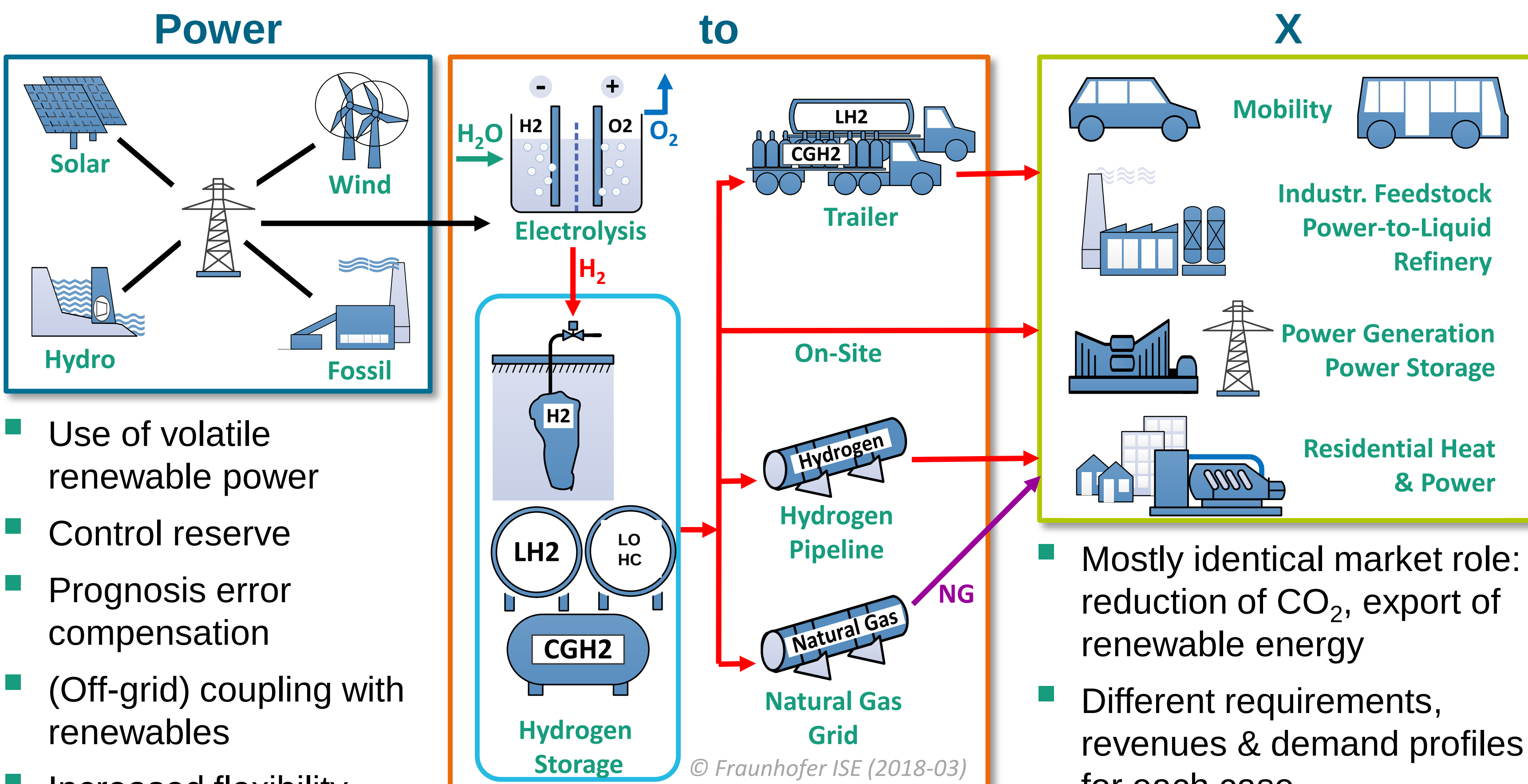
Business Models of Power-to-X

PtH_2 Plant has Market roles on Both Sides



- Use of volatile renewable power
- Control reserve
- Prognosis error compensation
- (Off-grid) coupling with renewables
- Increased flexibility

- Mostly identical market role: reduction of CO_2, export of renewable energy
- Different requirements, revenues & demand profiles for each case

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Future Hydrogen Demand in Germany REMod-D

Scenario Based Analysis with Techno-economic

Input

Weather data

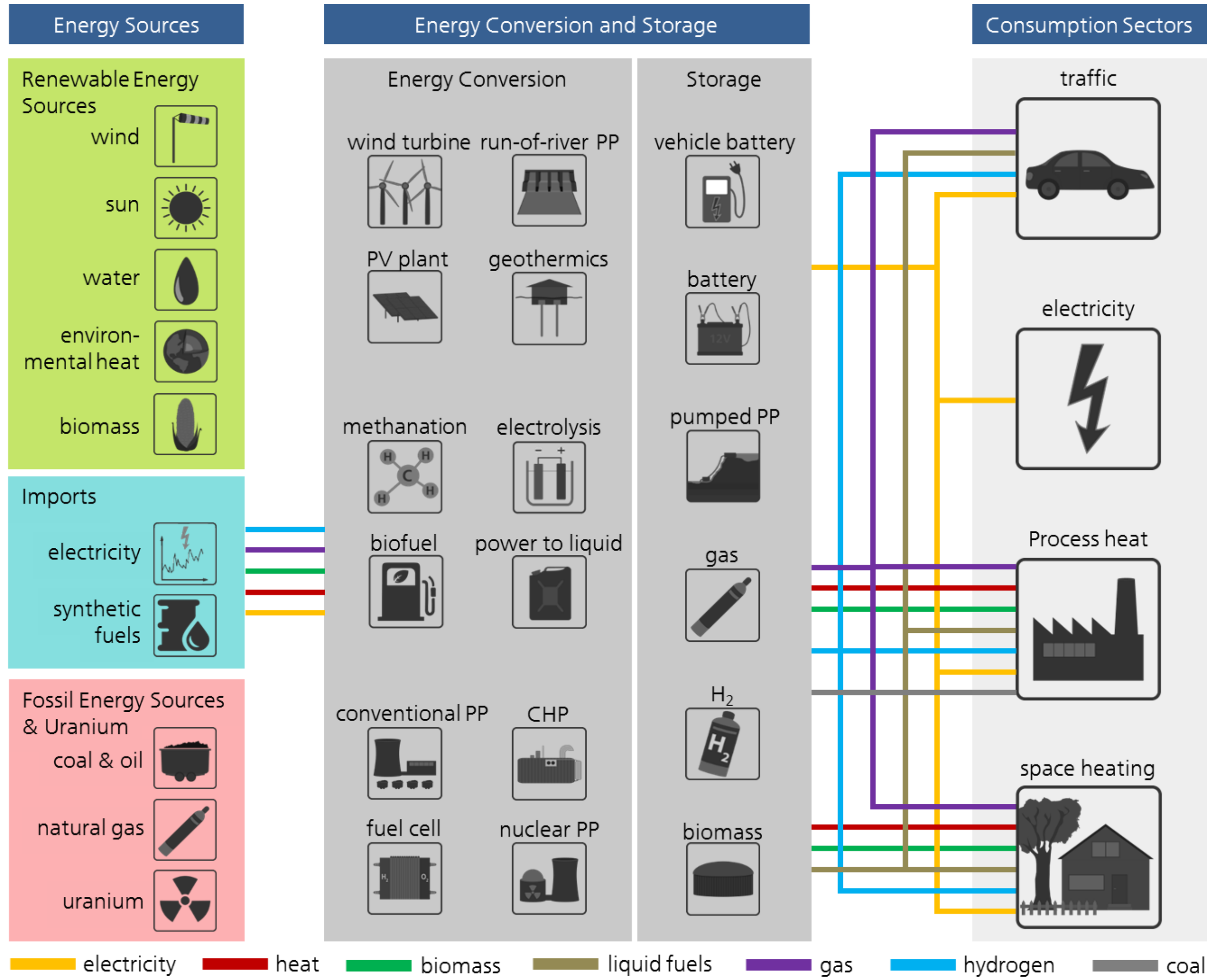
- Temperature
- Radiation
- VRE feed in profile (Germany and neighbors)

Technology Parameters

- Existing stock
- Efficiency
- Available potential

Economic parameters

- Technology cost projections
- Fuel costs
- CO_2 price
- Service time



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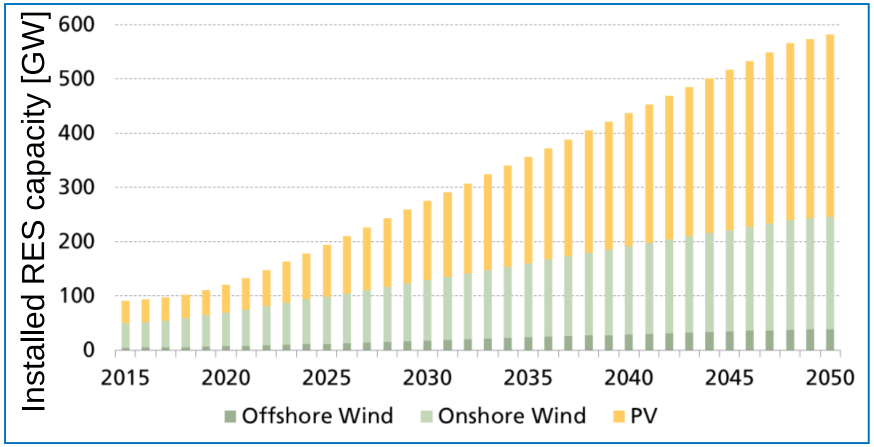
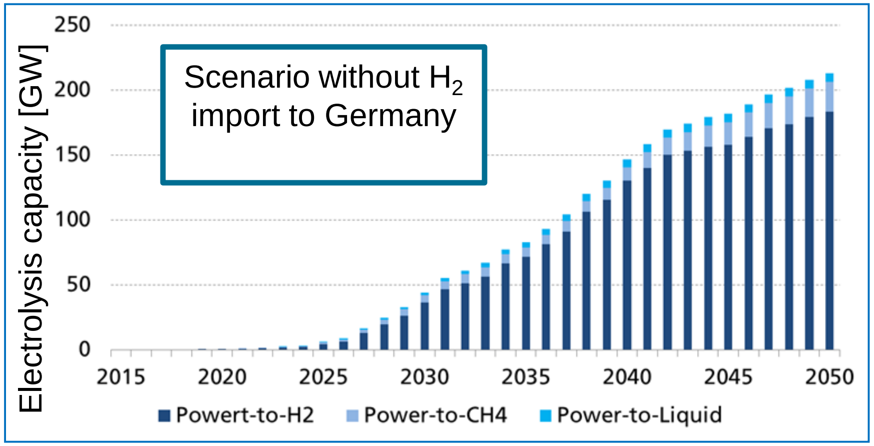
Future Hydrogen Demand in Germany
Exemplary Results for the Central Case

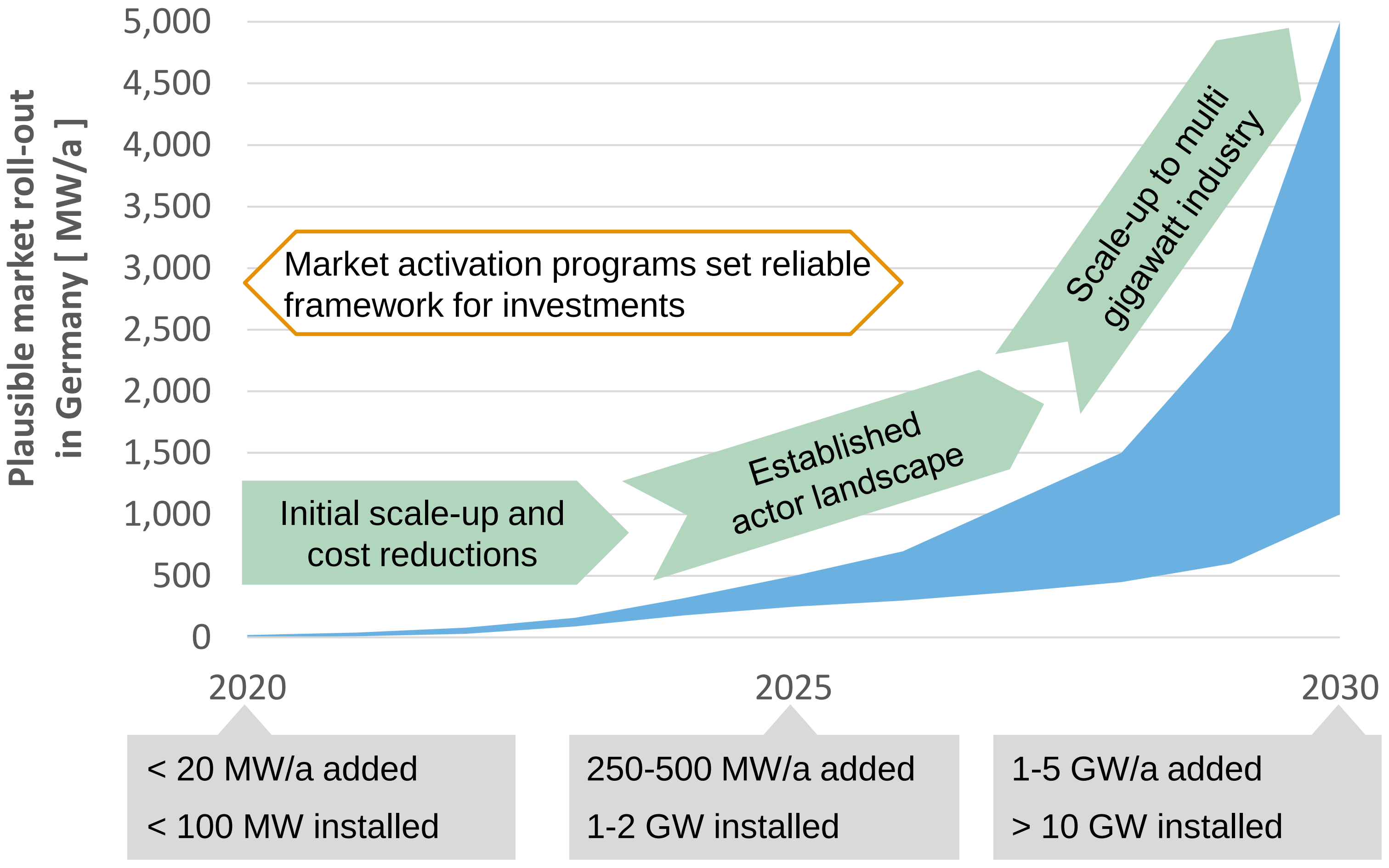
- Substantial expansion of wind and solar to achieve CO_2 reduction target in 2050
  - 600 GW installed wind and solar
  - Electricity demand 800-1200 TWh (depending on the scenario)
  - BUT: Results sensitive to import settings for electricity or fuels
- H_2 from electrolysis and further derivatives essential in all scenarios

S3 (EL mix)	2030	2050
Installed EL capacity [GW]	44 (7-71)	213 (137-275)
Ø installation rate [GW/a]	3.4 (0.5 – 5.4)	6.4 (4.2 – 8.3)



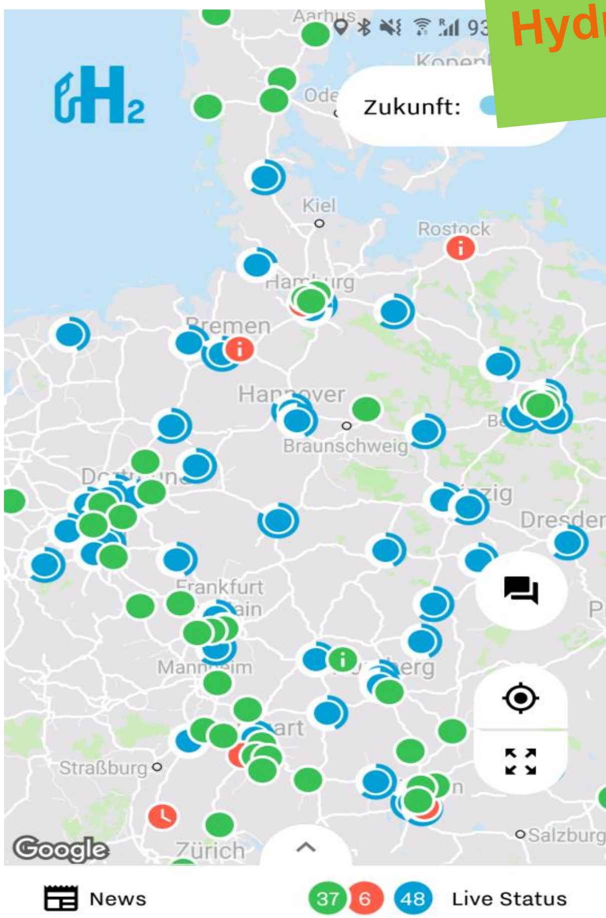


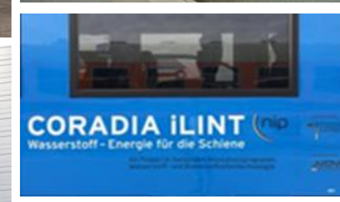
To Reach 2030 Targets, Roll-out Needs to Start Now
Clear Frameworks for Investments are needed



Setting up the Scene

November 2018: 55
Hydrogen Fueling Stations

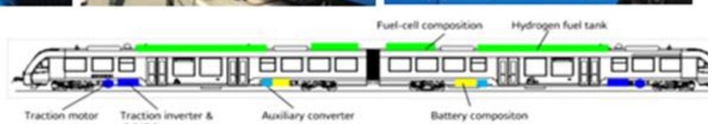


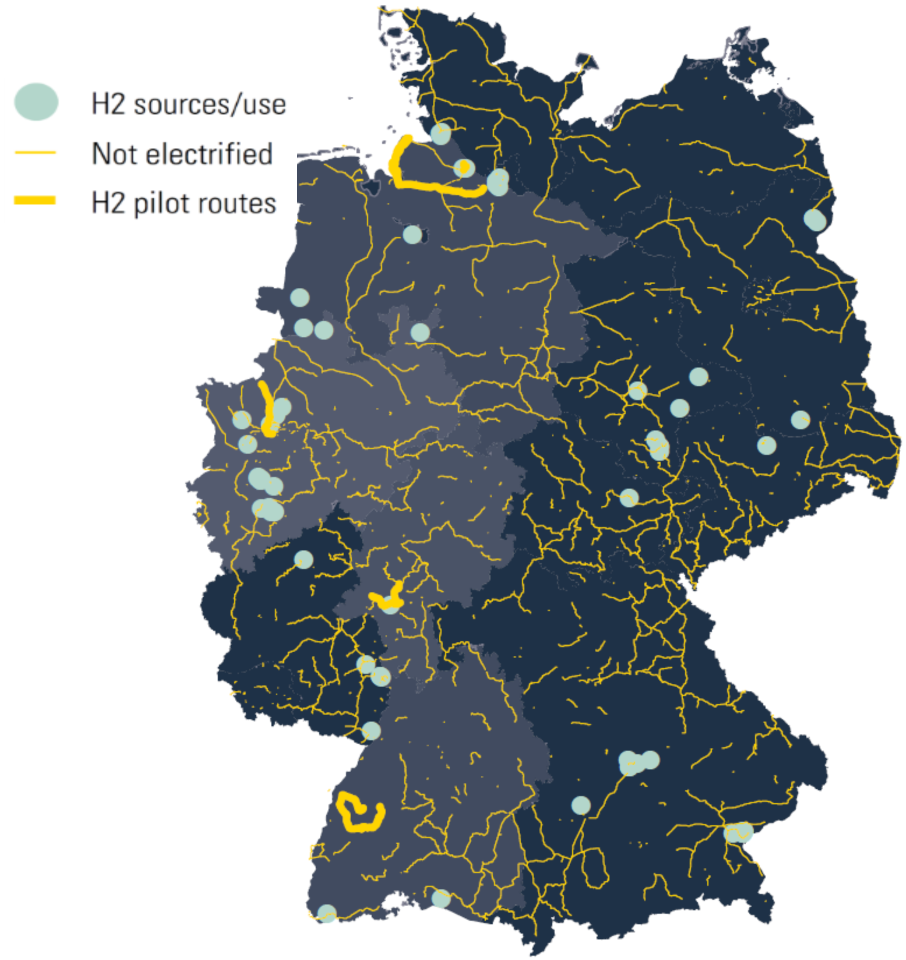


Public Transportation: Railway Vehicles with Fuel Cells

59 % of the German rail network is not electrified

~30 % less energy demand with fuel cell trains





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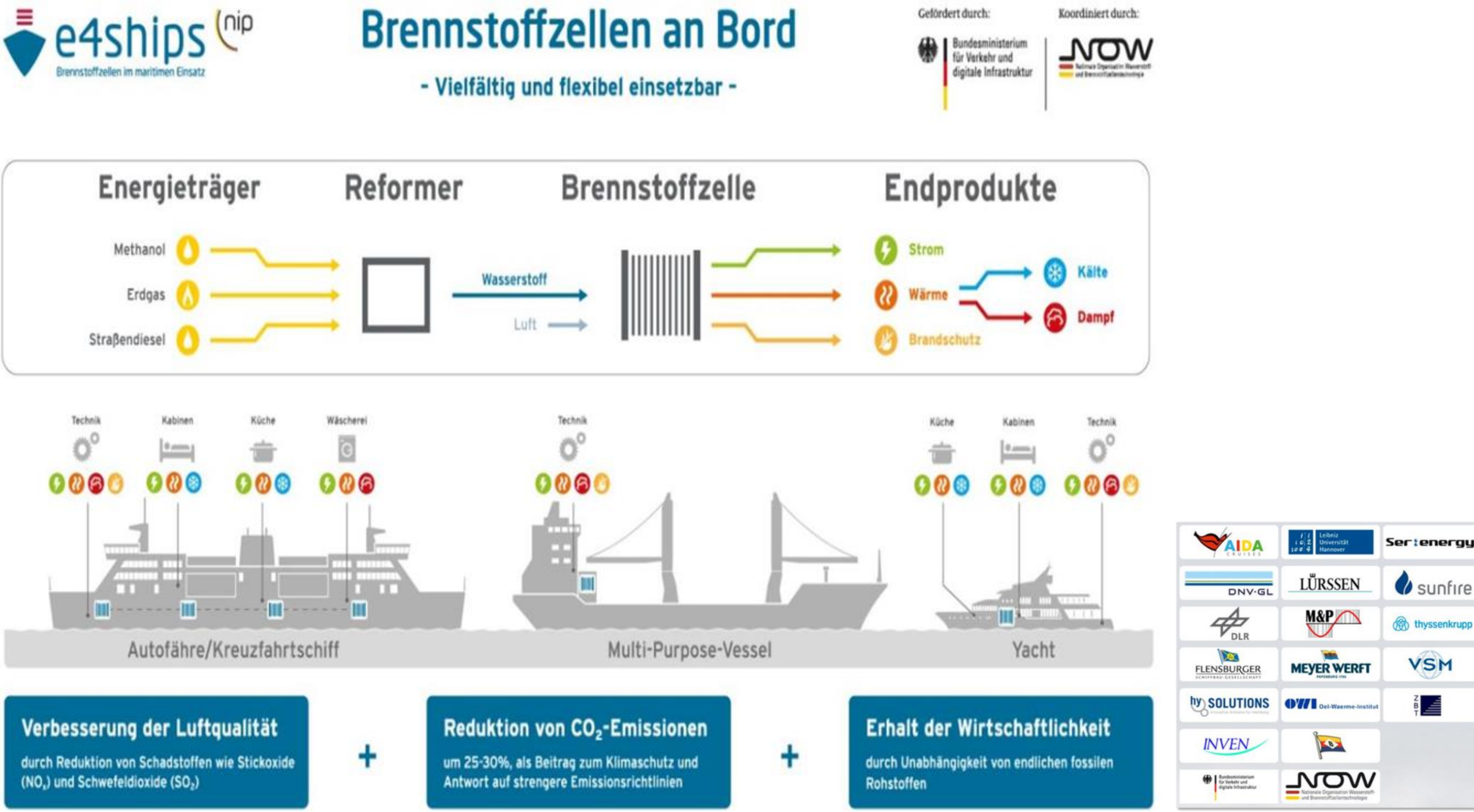
E4ships: Industry Network for Maritime FC Applications



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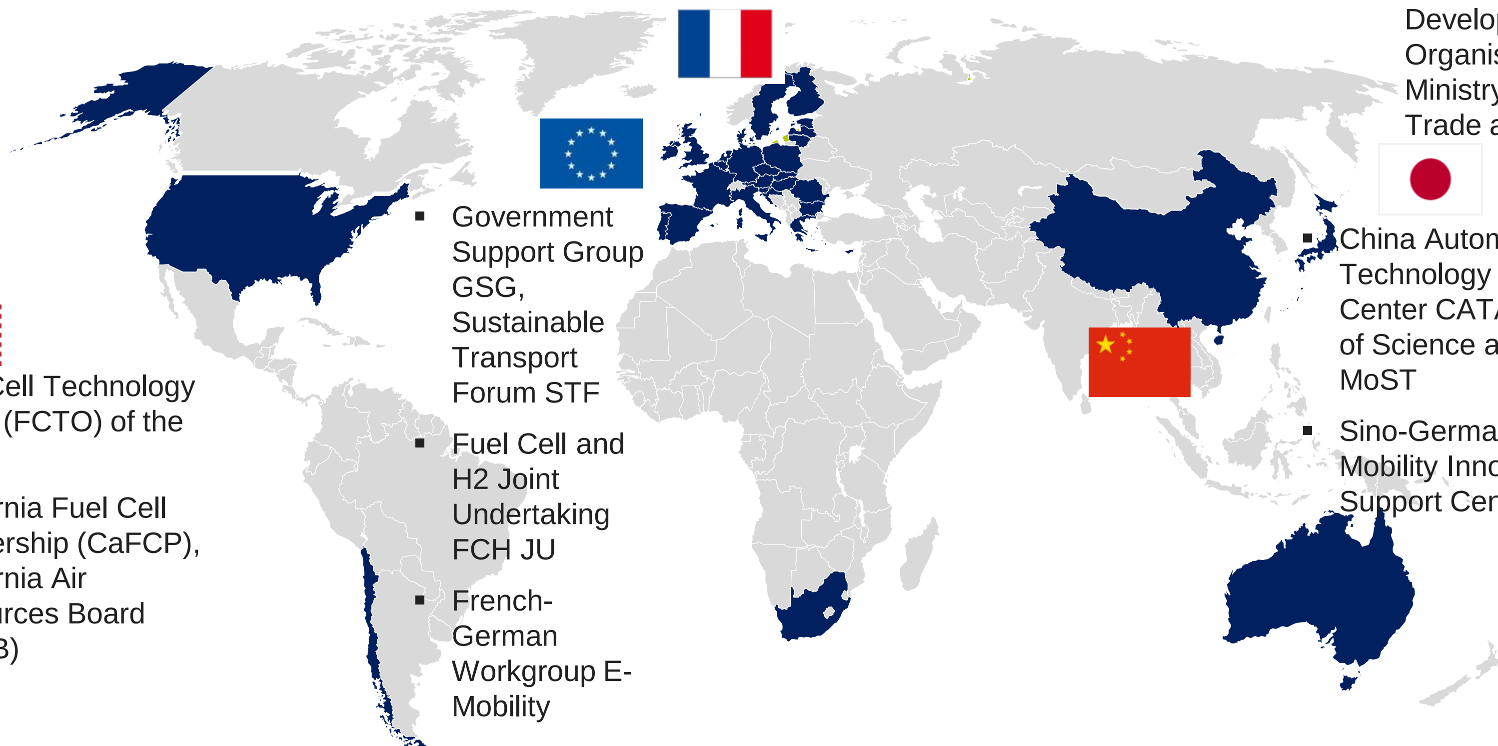
Renewable hydrogen production –
Collaboration Needed on a Global Scale



- Fuel Cell Technology Office (FCTO) of the DoE
- California Fuel Cell Partnership (CaFCP), California Air Resources Board (CARB)

- Government Support Group GSG, Sustainable Transport Forum STF
- Fuel Cell and H2 Joint Undertaking FCH JU
- French-German Workgroup E-Mobility

- New Technology Development Organisation NEDO & Ministry of Energy, Trade and Industry

- China Automotive Technology and Research Center CATARC & Ministry of Science and Technology MoST
- Sino-German Electro Mobility Innovation and Support Center SGEC

Summary & conclusions

Think big !

- Transformation of energy systems in line with GHG emission reduction targets are in principle technically feasible
- Renewable energies (solar, wind) will be dominant and the importance of electric energy increases ➔ electricity demand doubles
- Increased conversion efficiencies and consumption reduction is important
- Large scale hydrogen production will be starting globally in the early 2020s
- About 40% of Renewable Electricity in Power-to-X Applications
  - Coupling of sectors ➔ electricity use (directly, indirectly) for heat and mobility
  - Large scale conversion of renewable electricity into synthetic energy carriers (hydrogen, liquids, chemicals, methane) ➔ needed for transportation
  - Transformation cost competitive if CO_2 emissions appropriately penalized
- New market frameworks to stimulate flexible load and generation -> level playing field
- Comprehensive, effective CO_2 pricing covering all energy sectors
- Global transport and trade is required

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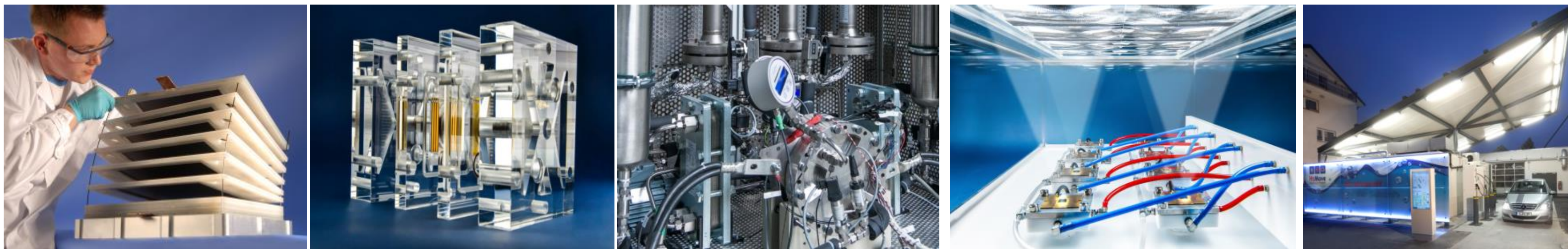
Thank you for your kind attention!



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