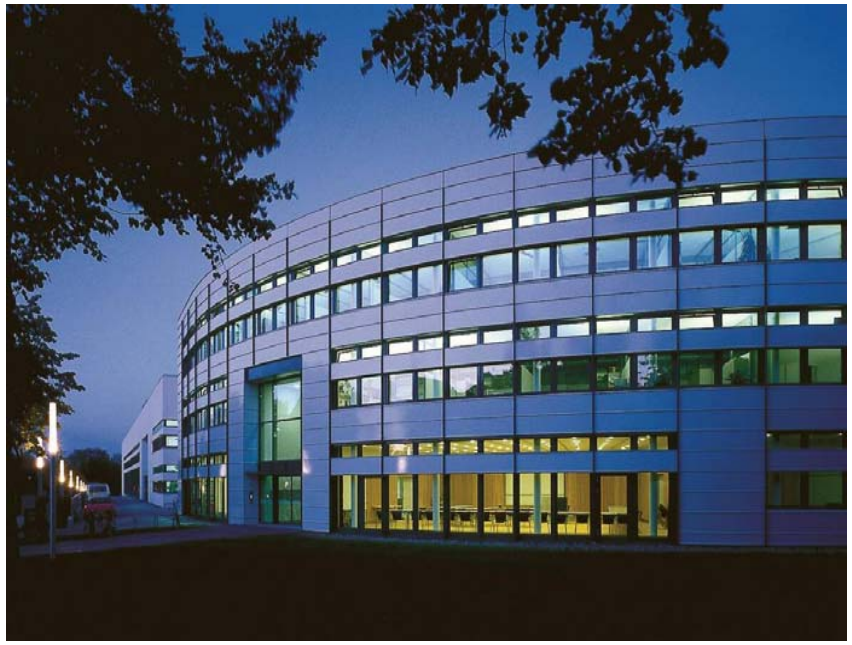
The Need for Large Scale Electrolyzers

Hydrogen as Part of the Energy System

2nd International Workshop

Durability and Degradation Issues in PEM Electrolysis Cells and its Components



Christopher Hebling

Freiburg, February 16th - 17th 2016

Fraunhofer Institute for
Solar Energy Systems, ISE
Freiburg, Germany

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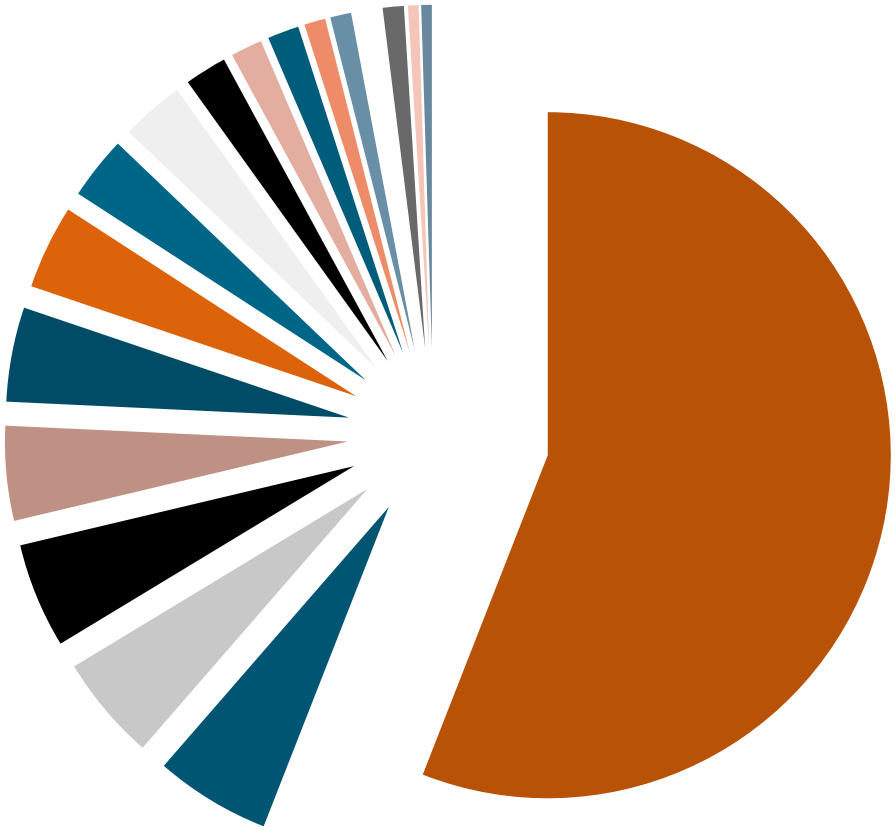
Welcome at Fraunhofer ISE in Freiburg

Foto Joscha Feuerstein

Nationalities of Participants



- Germany (113)
- France (11)
- Denmark (10)
- Netherlands (10)
- Belgium (9)
- United Kingdom (9)
- Japan (8)
- Switzerland (6)
- South Africa (6)
- Unites States (4)
- Italy (3)
- South Korea (3)
- Czech Republic (2)
- Sweden (2)
- Norway (2)
- Canada (2)
- Finland (1)
- Island (1)

Total number of participants: 202

Fraunhofer Institute for Solar Energy Systems ISE
Research for the Energy Transformation

- About 1250 members of staff (incl. students)
- € 83.7 M budget in 2015
- 14 % basic financing, 86 % contract research
- Largest European Solar Energy Research Institute

- Over 1000 ongoing R&D projects in the fields of
  - energy conversion
  - energy efficiency
  - energy distribution
  - energy storage

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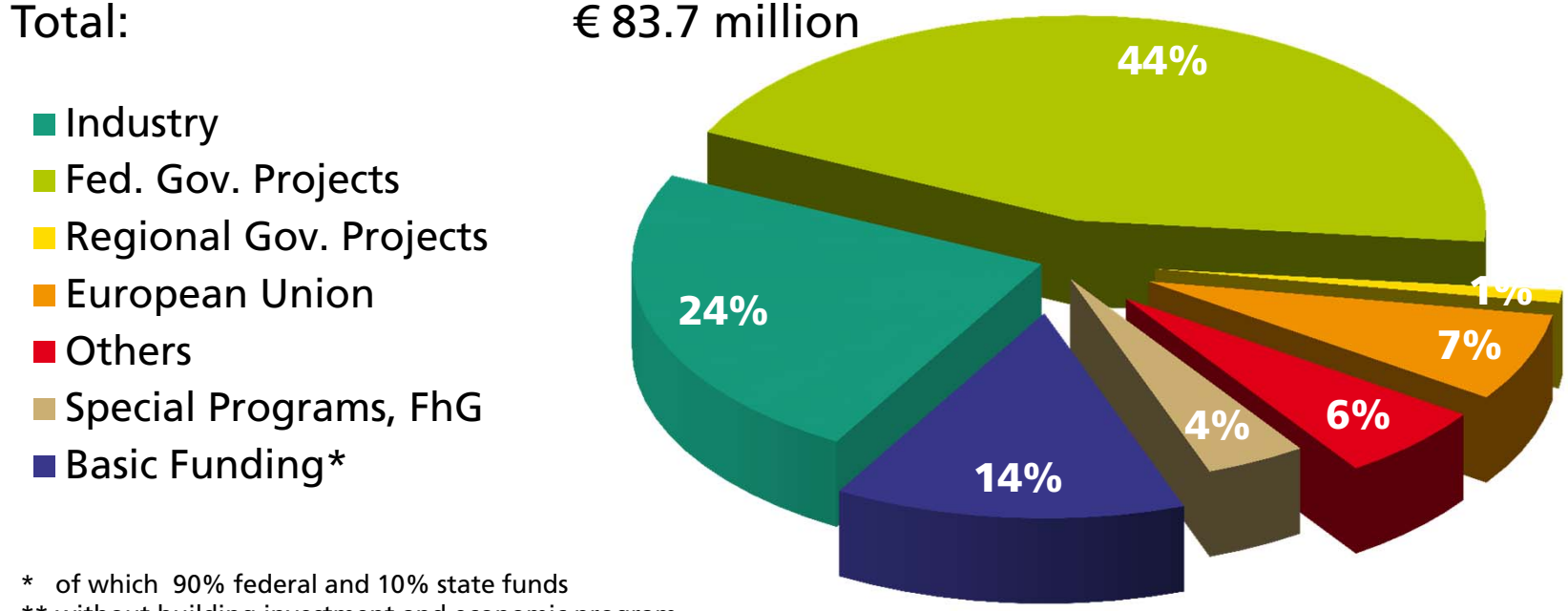
Revenue Structure, Operation 2015

Operation:	€ 73.1 million
Investment**:	€ 10.6 million
Total:	€ 83.7 million



* of which 90% federal and 10% state funds
** without building investment and economic program

Status : January 2016

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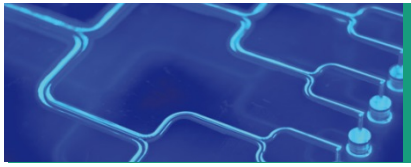
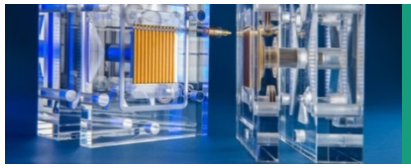
Our Areas of Business

PHOTOVOLTAICS

SOLAR THERMAL TECHNOLOGY



BUILDING ENERGY TECHNOLOGY



HYDROGEN TECHNOLOGIES

ENERGY SYSTEM TECHNOLOGY

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Division Hydrogen Technologies H_2T

- Synthesis of H_2 and CO_2 to liquid energy carriers/fuels (PtL)
- Thermochemical H_2-generation from hydrocarbons
- Catalytic evaporation of liquid hydrocarbons

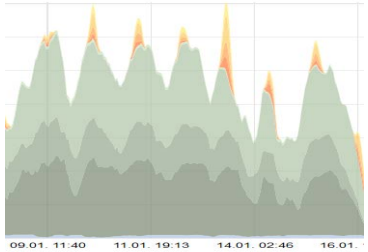
- H_2-generation by means of PEM-electrolysis
- Energy storage in H_2-Systems and Redox-Flow-Batteries
- Interconnection of the power and gas grid, Power-to-Gas

- Scientific characterization of Fuel Cell components
- Degradation research (load profile, various climates)
- Customer specific, self-sufficient complete systems up to 20 kW

Which are the main drivers for fuel cell and hydrogen technologies ?

Energy security-
Independency
from fossil fuels

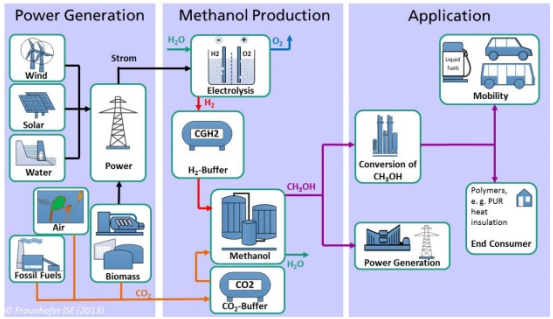
**CO_2 Reduction -
Decarbonization of
the Energy System**



Integration of intermittant renewable energy into the energy system

Securing the economy -
new markets and new jobs
through innovations

Power-to-X



Zero emission mobility

Global energy-related CO_2 emissions over the last century

Increase by a factor of ten

CO_2 emissions
35.8 Gt (2015)

Source: thinkprogress.com

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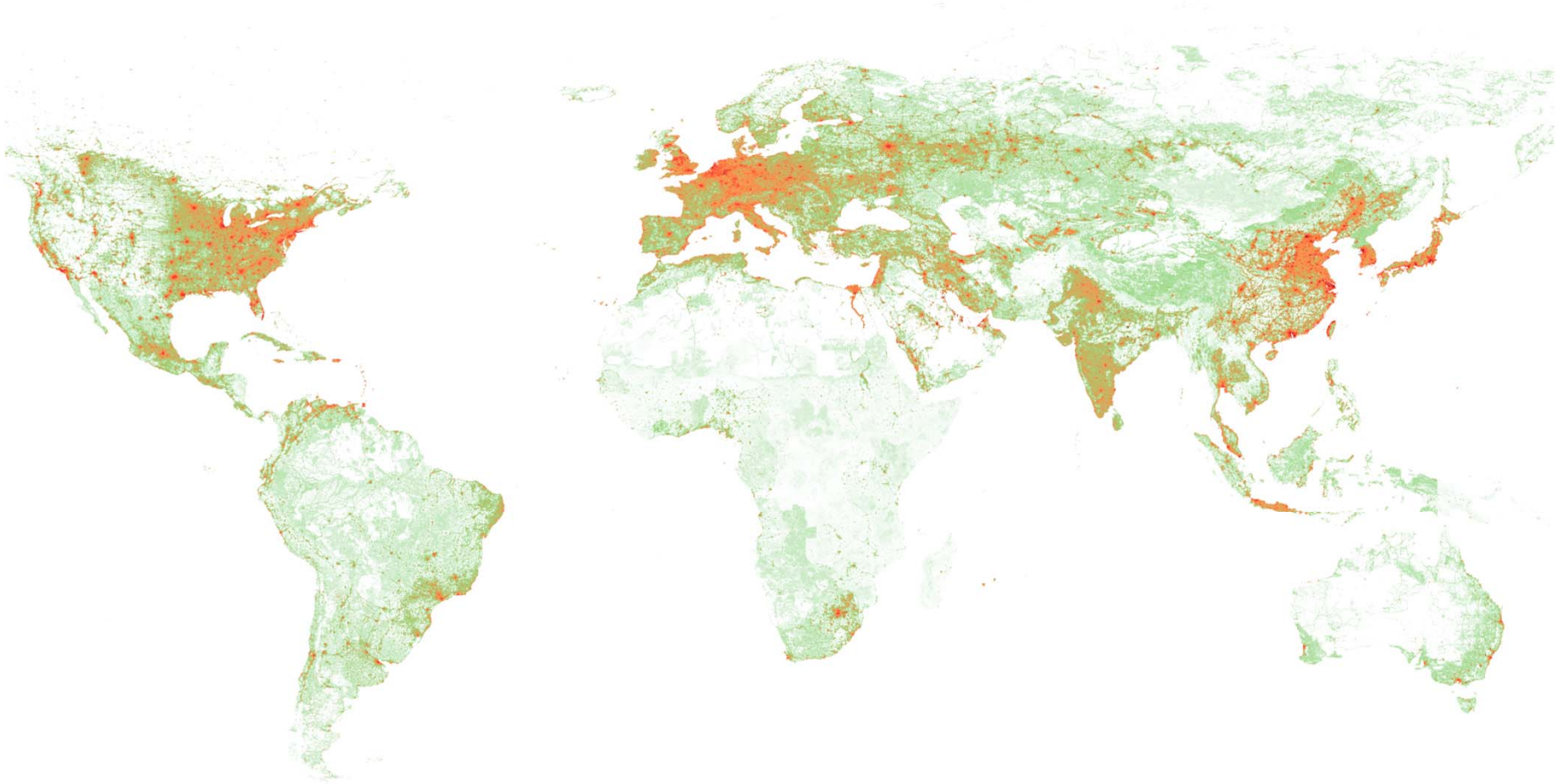
Global fossil fuel CO_2 emissions

2010 data



Source: http://hpcg.purdue.edu/FFDAS/index.phpl

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Current CO_2 emissions in millions of metric tons

Fourteen nations and Europe account for about 80 percent of world greenhouse gas emissions

Source: http://environment.nationalgeographic.com/environment/energy/great-energy-challenge/global-footprints/

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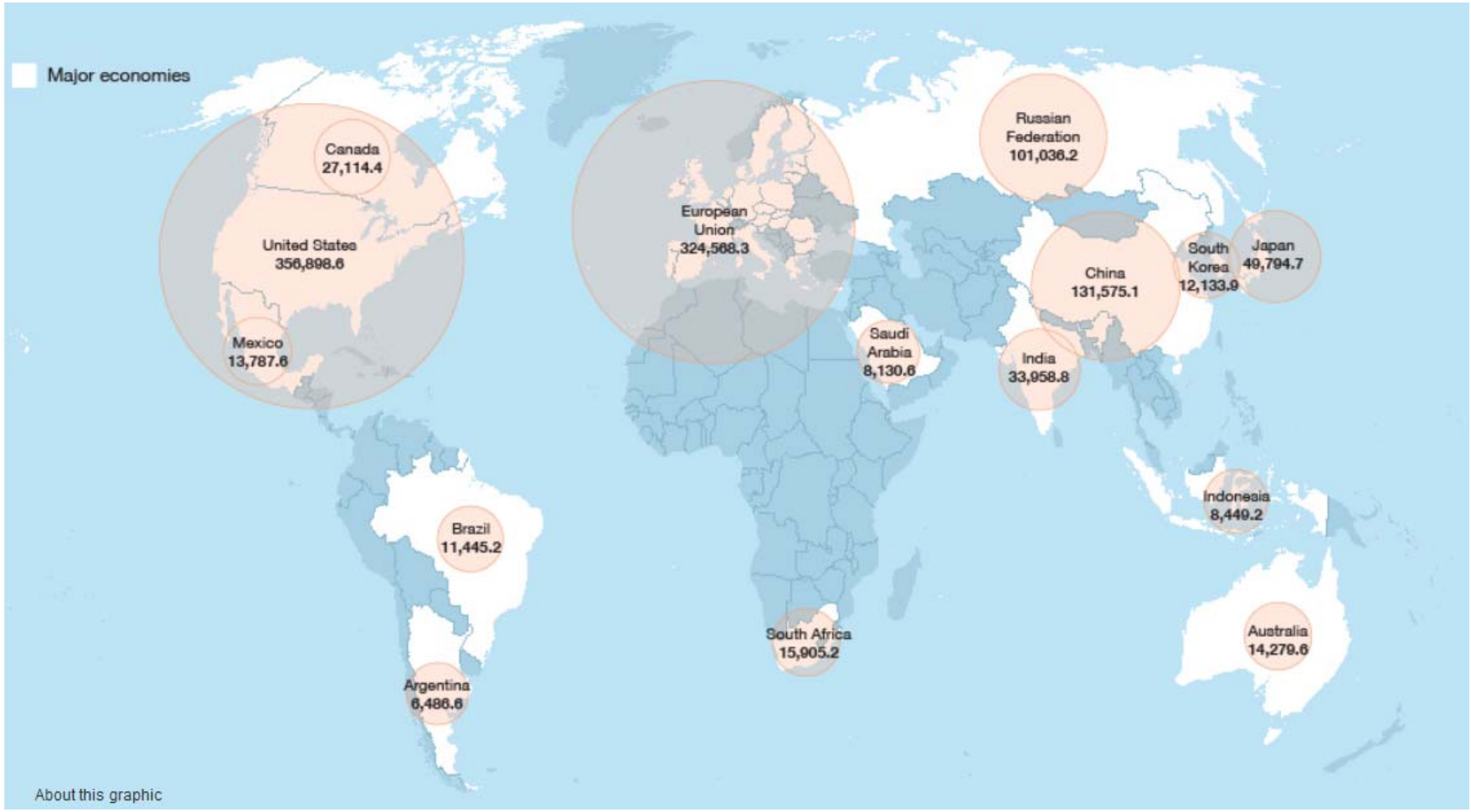
Cumulative emissions in metric tons since 1850



Source: http://environment.nationalgeographic.com/environment/energy/great-energy-challenge/global-footprints/

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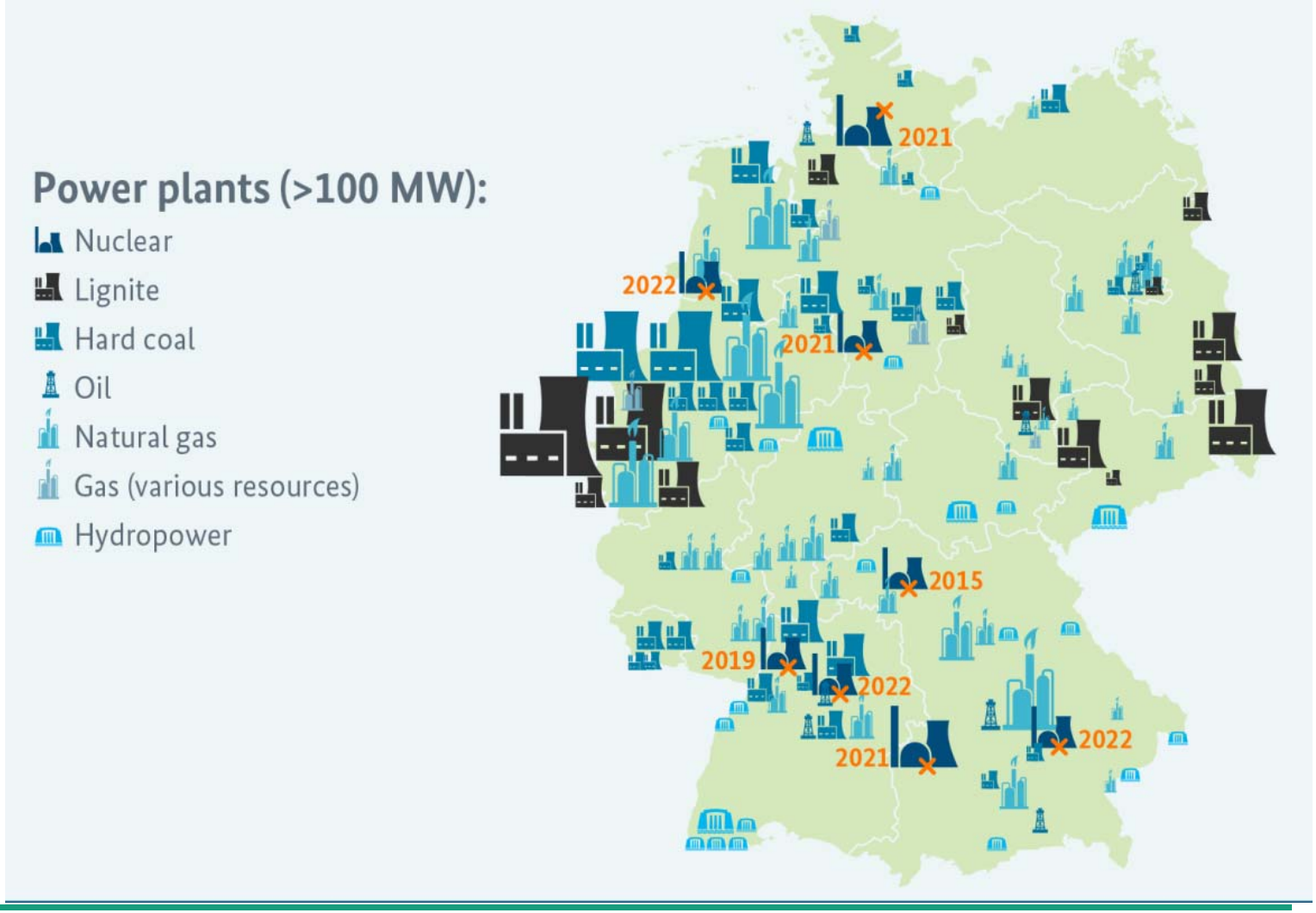
Regional distribution of power capacities in Germany



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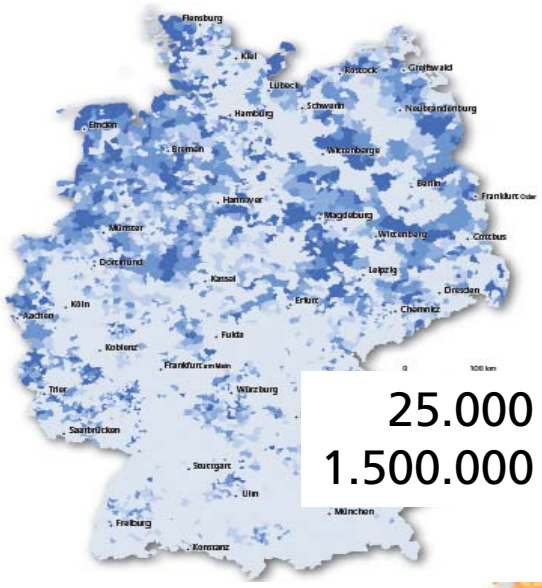
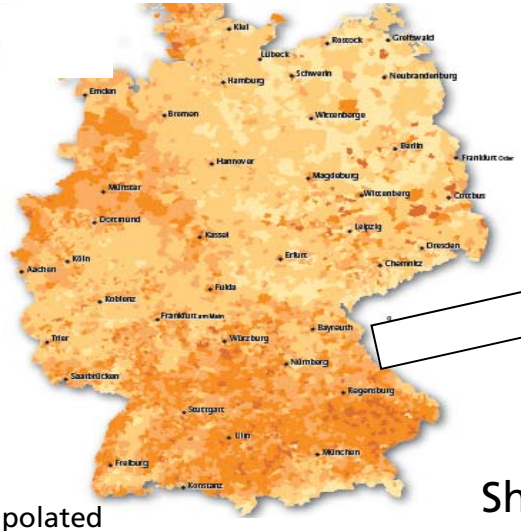
Wind and photovoltaic power generation in Germany

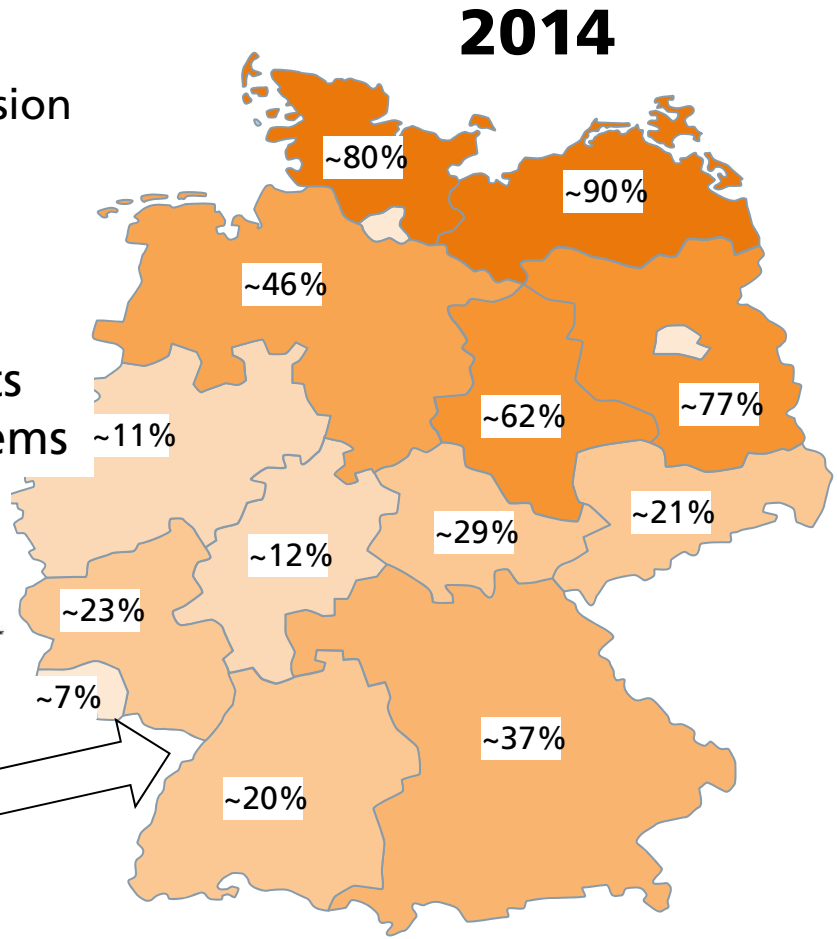


Wind power expansion
mainly in the North

25.000 wind power plants
1.500.000 photovoltaic systems



Solar power
expansion mainly
in the South



Share of Renewable generation in regions *

* Source: AGEE-Stat, LAK, extrapolated

AGENTUR FÜR ERNEUERBARE ENERGIEN

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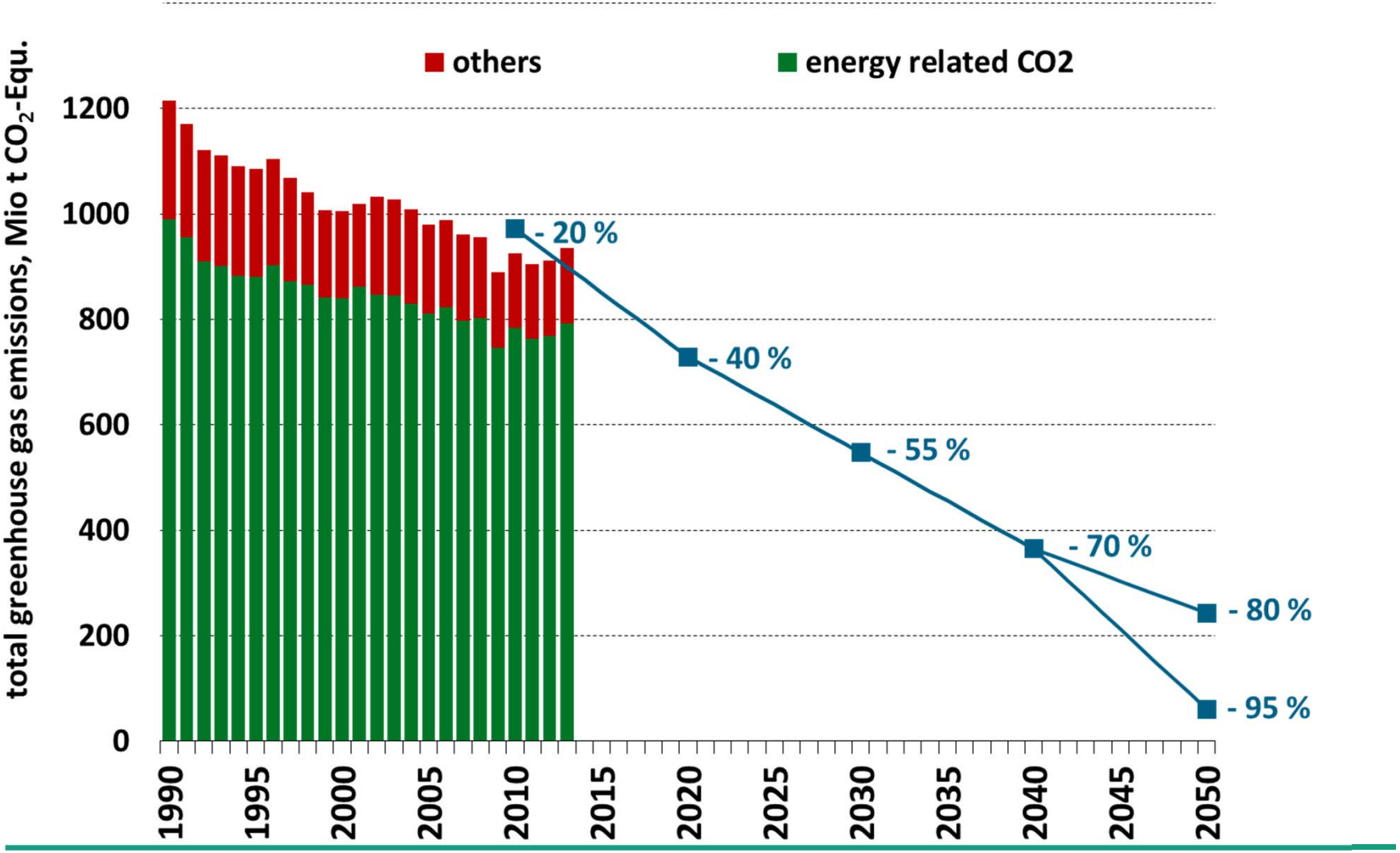
Development of german GHG Emissions 1990 – 2013 and target values until 2050 (The Energy Concept of Germany)



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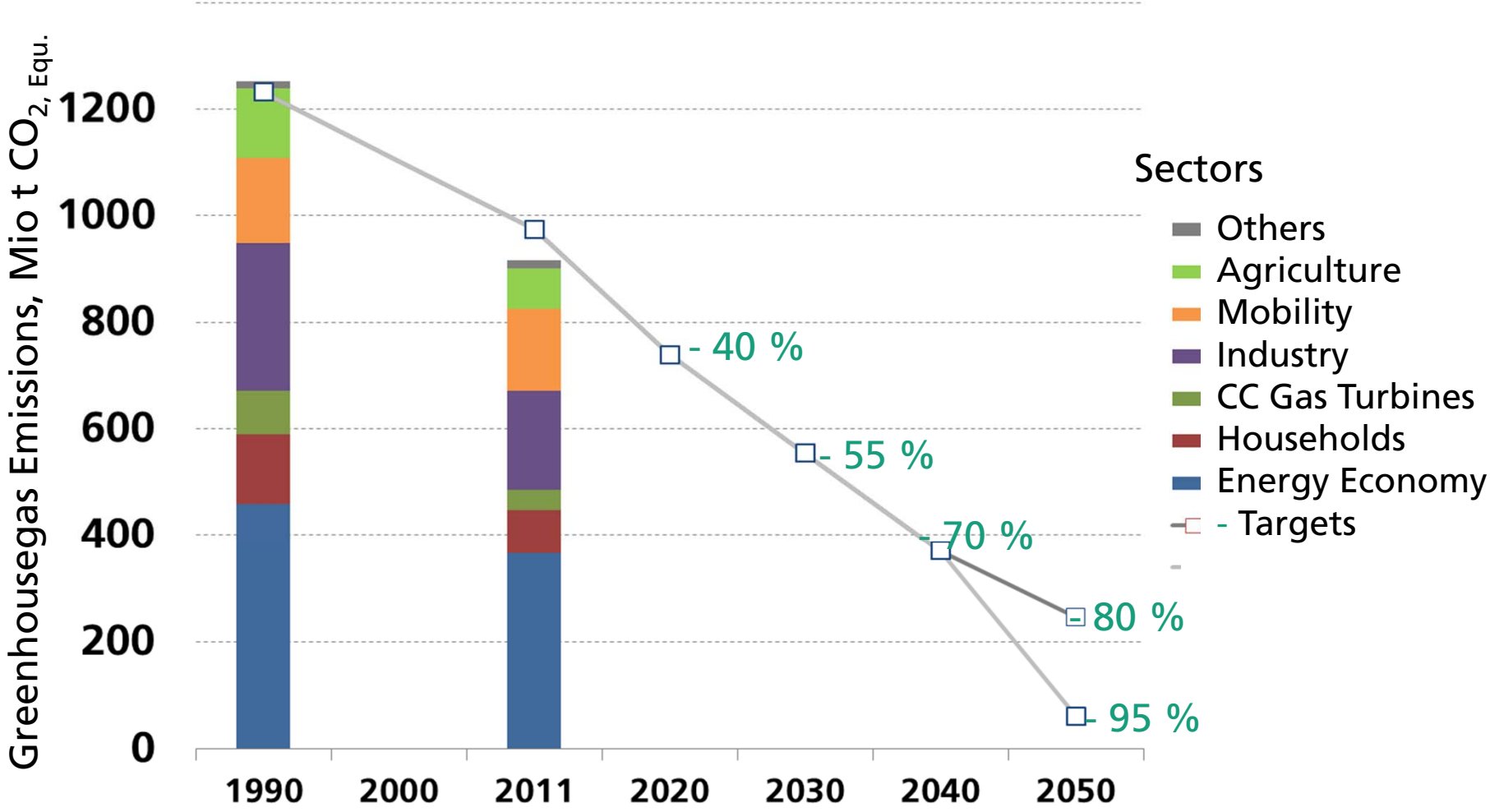
Development of german GHG emissions 1990 – 2013 and the target values until 2050



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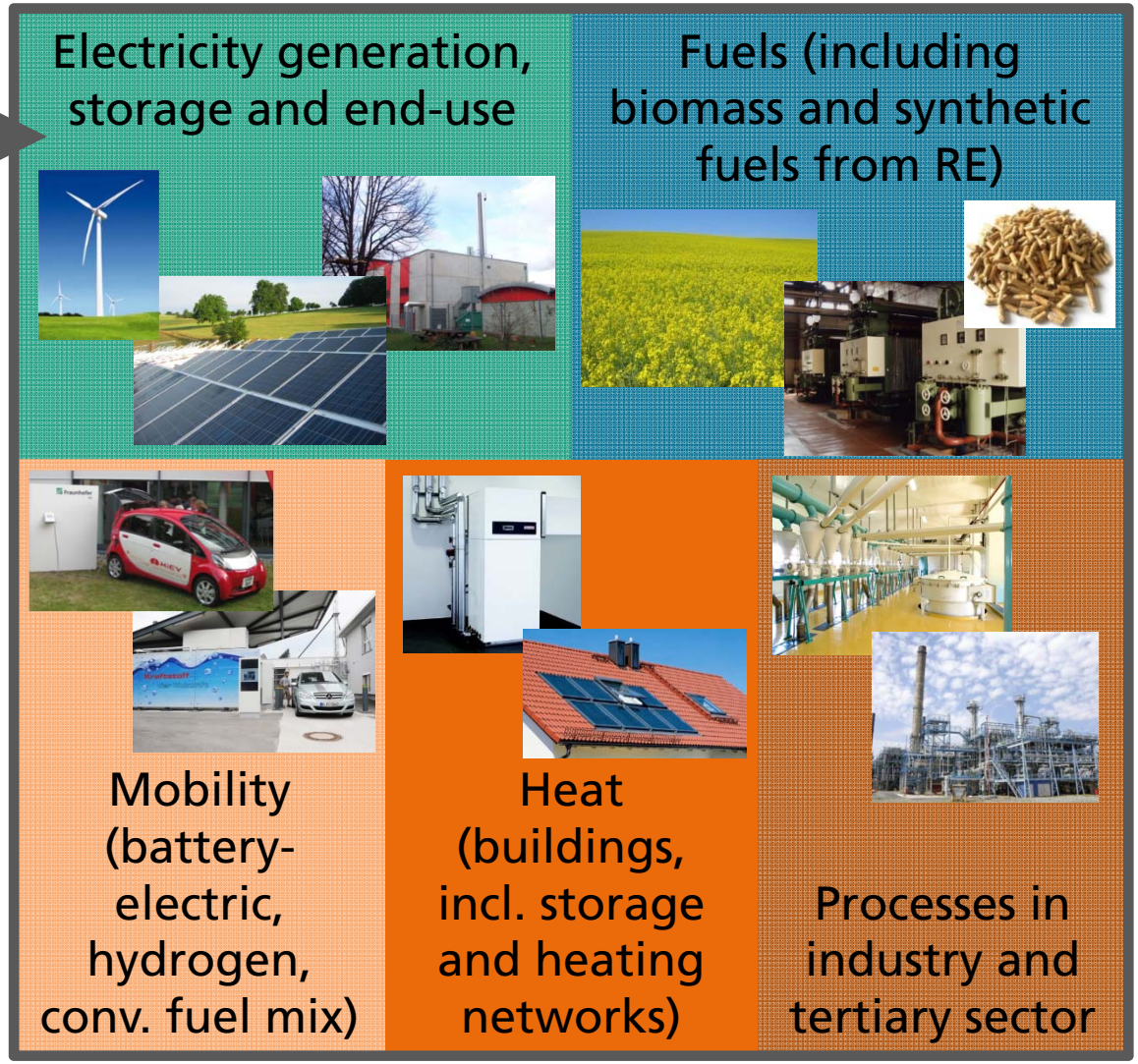
Optimization of germany's future energy system

Mimimize total annual cost (operation, maintenance, …)

REMod-D

Renewable Energy Model – Deutschland

Techno-economic optimization based on comprehensive simulation (hourly time scale)



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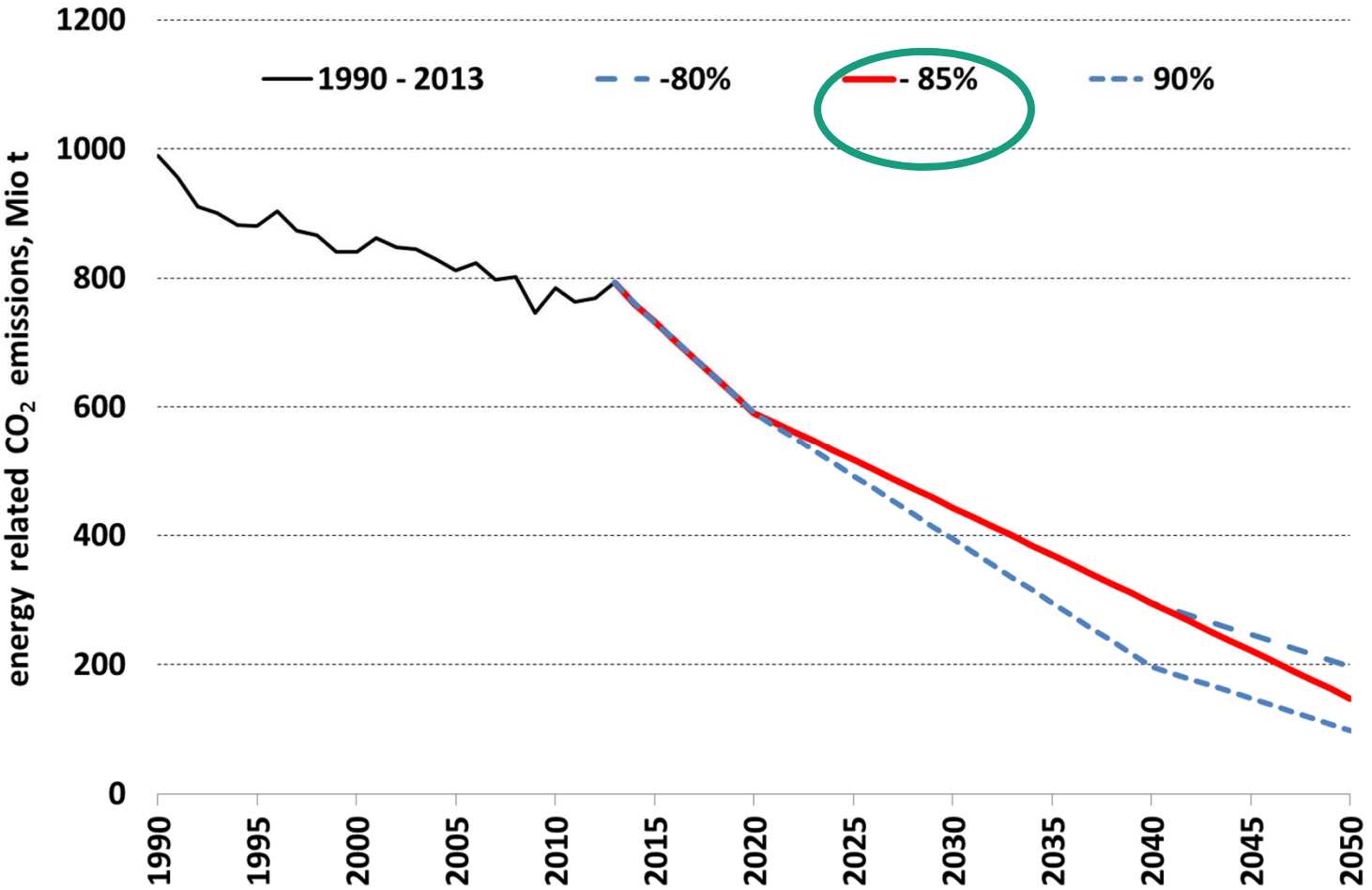
What will the energy transformation cost

- What is the cost-optimal transformation pathway for the German overall energy sytem including all end-use sectors
- Boundary condition: The political goals of reducing greenhouse gas emissions are fulfilled – the target value and in each single year?

Further boundary conditions

- Fade-out of nuclear energy until 2022
- No large scale implementation of CCS technology in fossil power plants

Boundary condition – CO_2 reduction pathway



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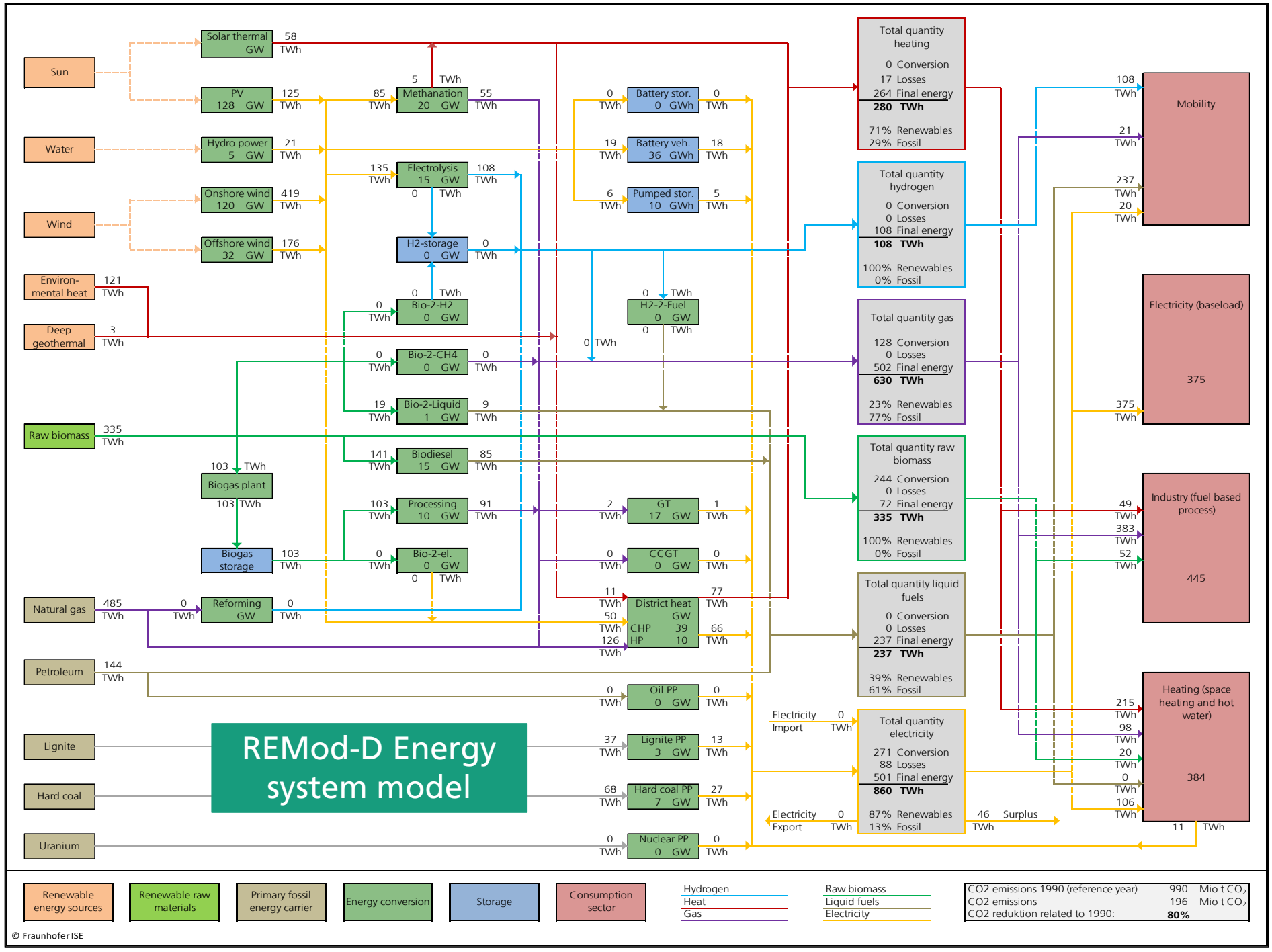

REMod-D Energy system model
Sun
Water
Wind
Environ-mental heat
121 TWh
Deep geothermal
3 TWh
Raw biomass
335 TWh
Natural gas
485 TWh
Petroleum
144 TWh
Lignite
Hard coal
Uranium
Solar thermal 58 GW TWh
PV 125 TWh 128 GW
Hydro power 21 TWh 5 GW
Onshore wind 419 TWh 120 GW
Offshore wind 176 TWh 32 GW
Methanation 85 TWh 20 GW 55 TWh
Electrolysis 135 TWh 15 GW 108 TWh
H2-storage 0 GW
Bio-2-H2 0 GW
Bio-2-CH4 0 GW
Bio-2-Liquid 19 TWh 1 GW 9 TWh
Biodiesel 141 TWh 15 GW 85 TWh
Biogas plant 103 TWh
Biogas storage 103 TWh
Processing 103 TWh 10 GW 91 TWh
Bio-2-el. 0 GW
Reforming 0 TWh GW 0 TWh
Battery stor. 0 TWh 0 GWh 0 TWh
Battery veh. 19 TWh 36 GWh 18 TWh
Pumped stor. 6 TWh 10 GWh 5 TWh
H2-2-Fuel 0 GW
GT 2 TWh 17 GW 1 TWh
CCGT 0 TWh 0 GW 0 TWh
District heat 11 TWh 77 TWh
CHP 50 TWh 39 GW 66 TWh
HP 126 TWh 10
Oil PP 0 TWh 0 GW 0 TWh
Lignite PP 37 TWh 3 GW 13 TWh
Hard coal PP 68 TWh 7 GW 27 TWh
Nuclear PP 0 TWh 0 GW 0 TWh
Total quantity heating
0 Conversion
17 Losses
264 Final energy
280 TWh
71% Renewables
29% Fossil
Total quantity hydrogen
0 Conversion
0 Losses
108 Final energy
108 TWh
100% Renewables
0% Fossil
Total quantity gas
128 Conversion
0 Losses
502 Final energy
630 TWh
23% Renewables
77% Fossil
Total quantity raw biomass
244 Conversion
0 Losses
72 Final energy
335 TWh
100% Renewables
0% Fossil
Total quantity liquid fuels
0 Conversion
0 Losses
237 Final energy
237 TWh
39% Renewables
61% Fossil
Total quantity electricity
271 Conversion
88 Losses
501 Final energy
860 TWh
87% Renewables
13% Fossil
Electricity Import 0 TWh
Electricity Export 0 TWh
46 TWh Surplus
11 TWh
Mobility
108 TWh
21 TWh
237 TWh
20 TWh
Electricity (baseload)
375
375 TWh
Industry (fuel based process)
445
49 TWh
383 TWh
52 TWh
Heating (space heating and hot water)
384
215 TWh
98 TWh
20 TWh
0 TWh
106 TWh
Renewable energy sources
Renewable raw materials
Primary fossil energy carrier
Energy conversion
Storage
Consumption sector
Hydrogen
Heat
Gas
Raw biomass
Liquid fuels
Electricity
CO2 emissions 1990 (reference year) 990 Mio t CO2
CO2 emissions 196 Mio t CO2
CO2 reduktion related to 1990: 80%
© Fraunhofer ISE

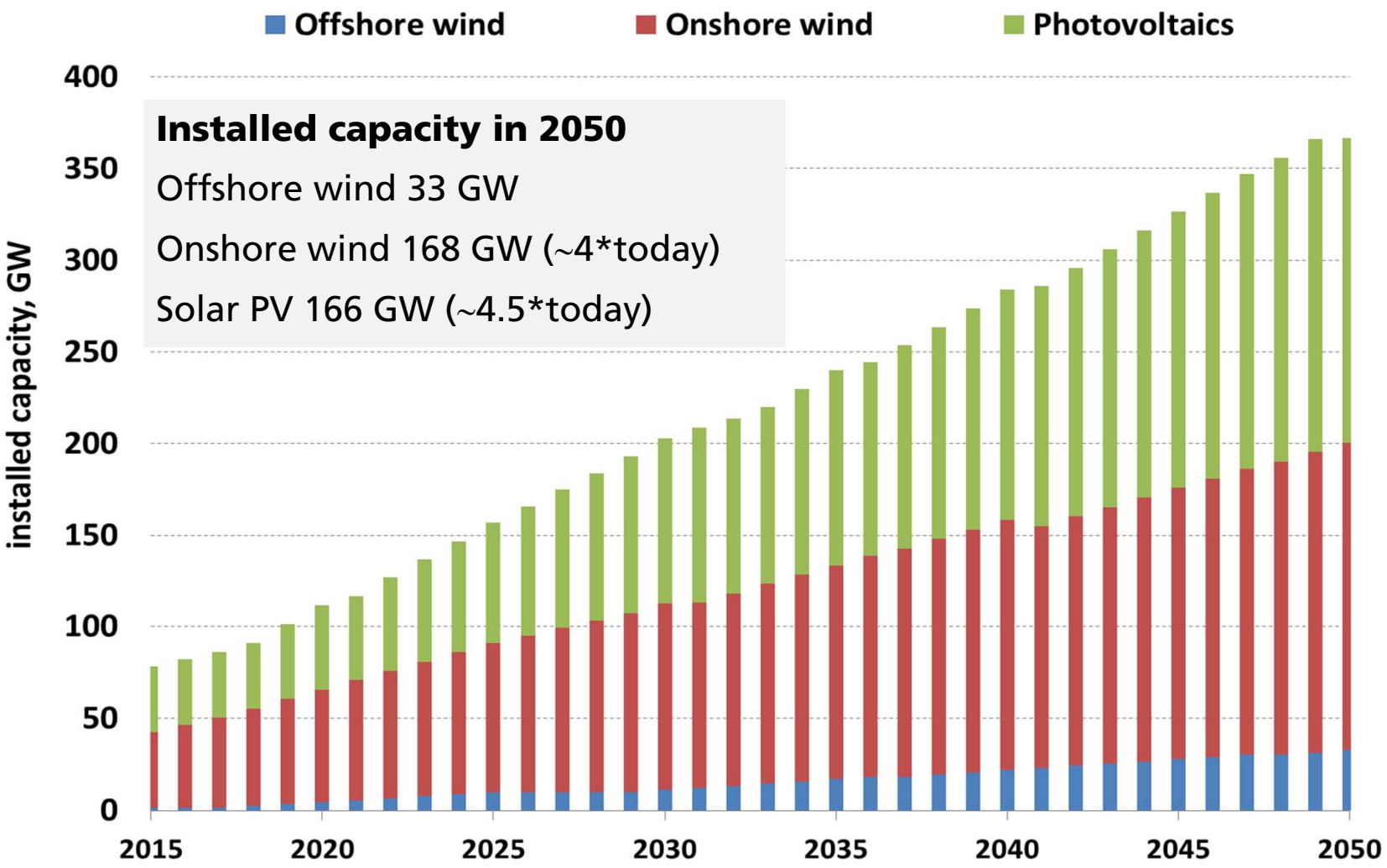
Methodology

- Hourly simulation of the total energy system Jan 1, 2014 until Dec 31, 2050
- Optimization of of the system composition including all future options
- Renewables
- Storage and power-to-gas, fuel and heat technologies
- Energy retrofit of building sector

Goal function: minimal overall transformation cost

➔ **Results of a scenario with a reduction energy related CO_2-emissions by 85 % compared to 1990 (Kyoto protocol reference value)**

Fluctuating renewable energies: solar, wind



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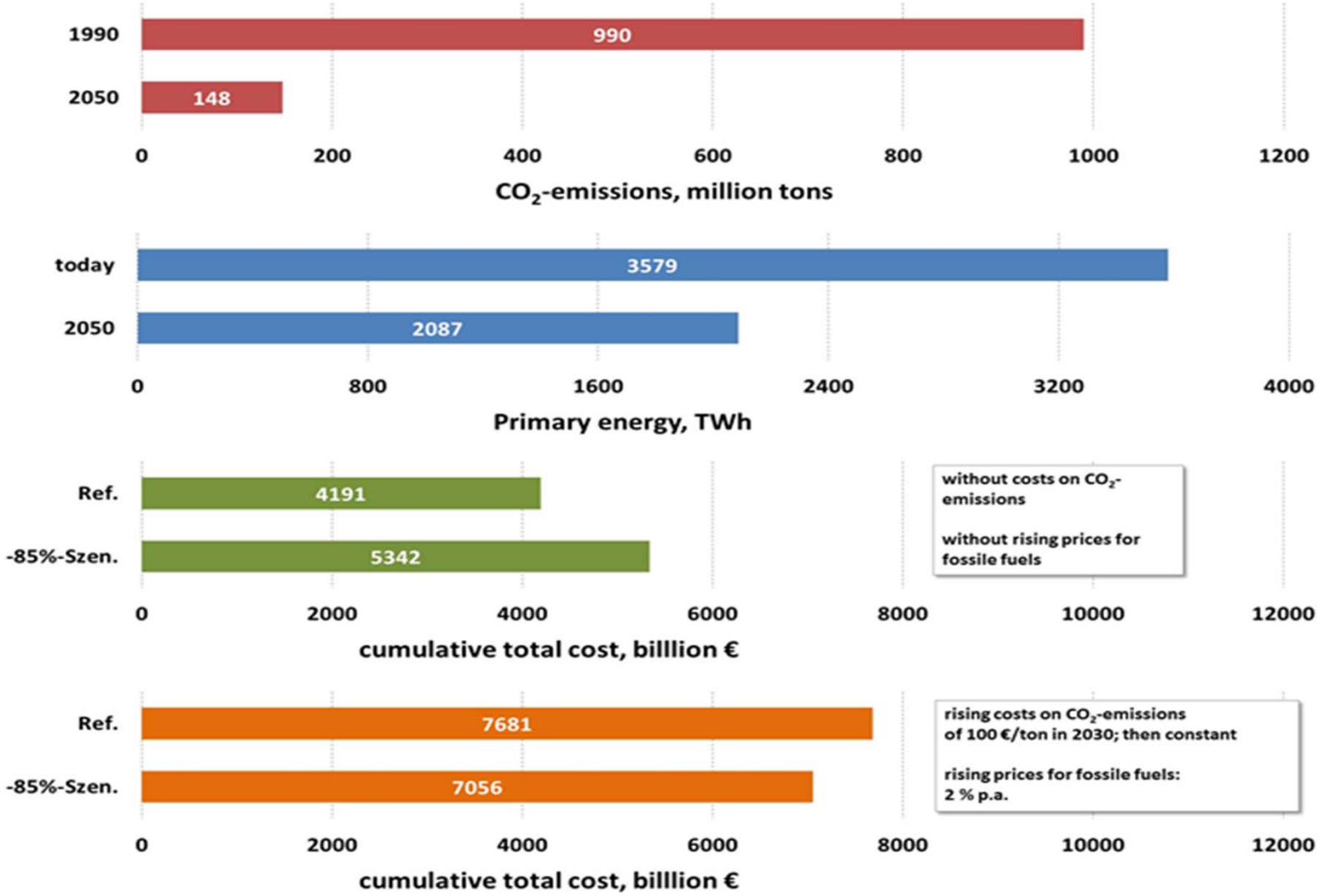
Costs of energy system reference vs. -85% CO_2 scenario



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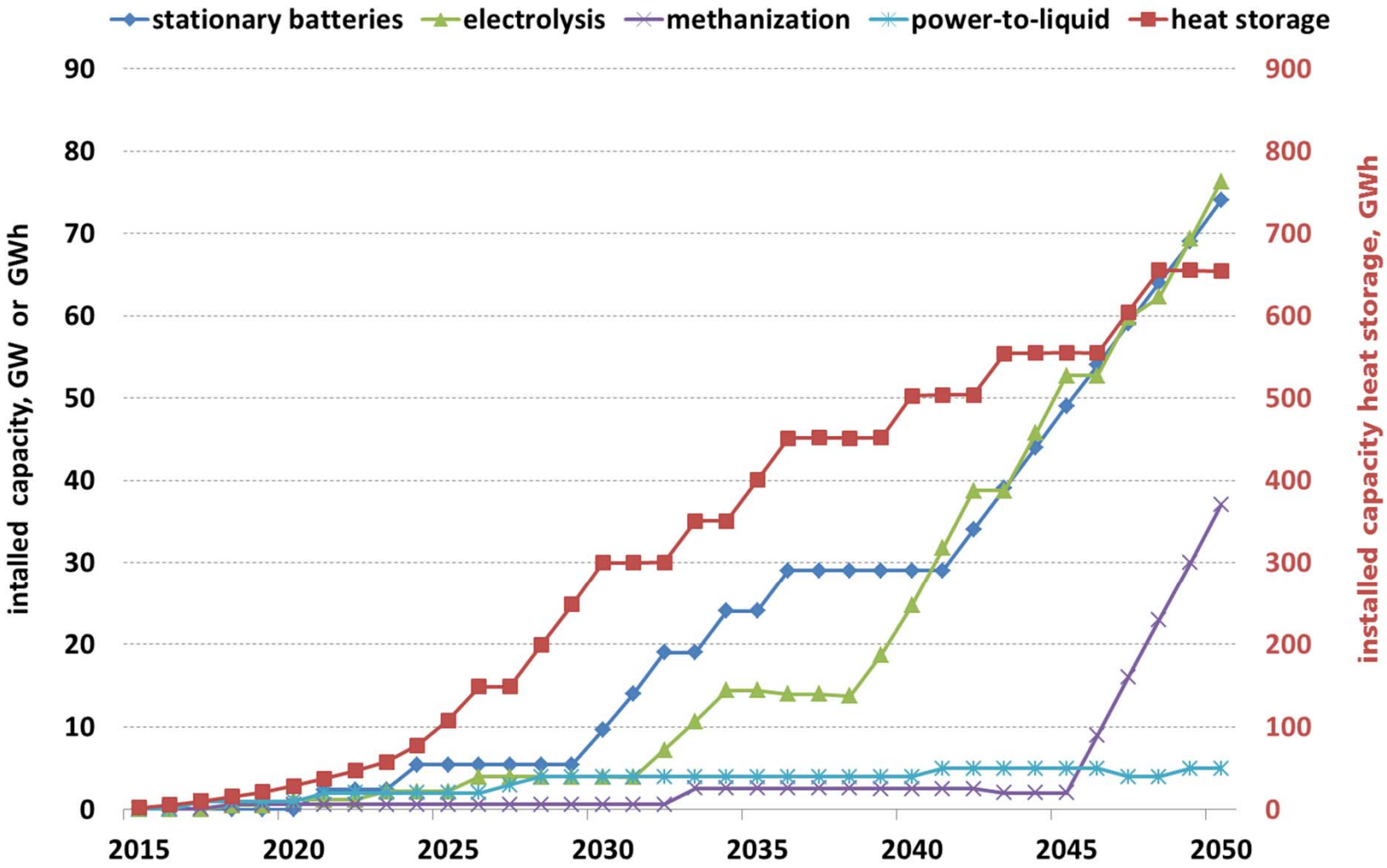
Storage and power-to-gas/fuel technologies



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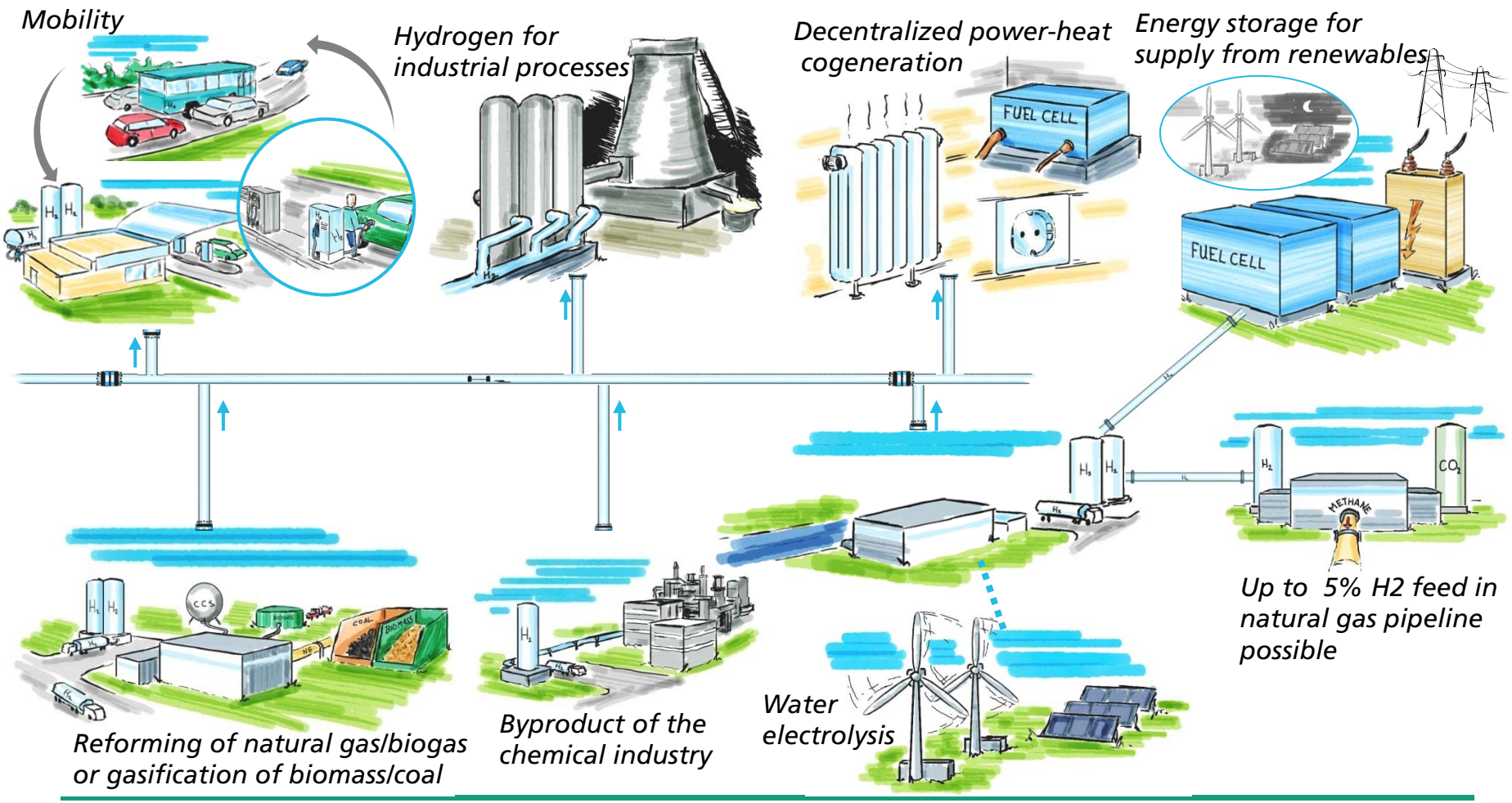
Hydrogen is an Energy Carrier to Facilitate the Energy Transition in Germany



H2-Mobility action plan until 2023

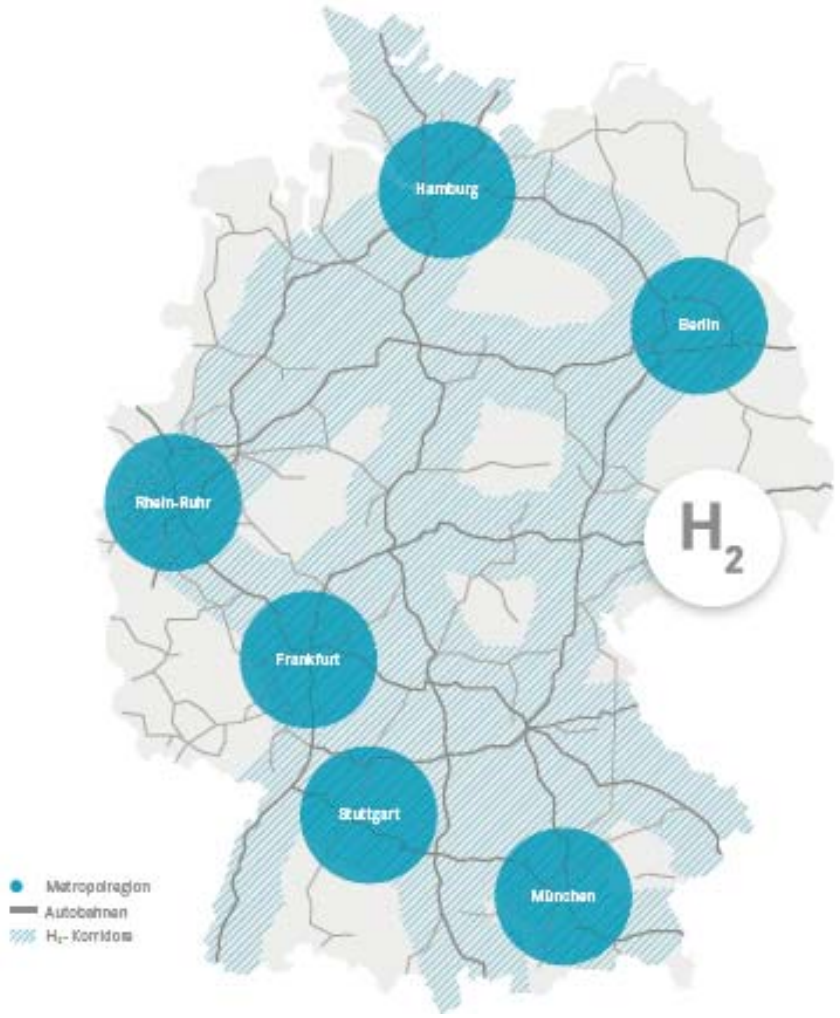
H2 MOBILITY
WASSERSTOFF TANKEN

DAIMLER TOTAL AIR LIQUIDE OMV Linde SHELL

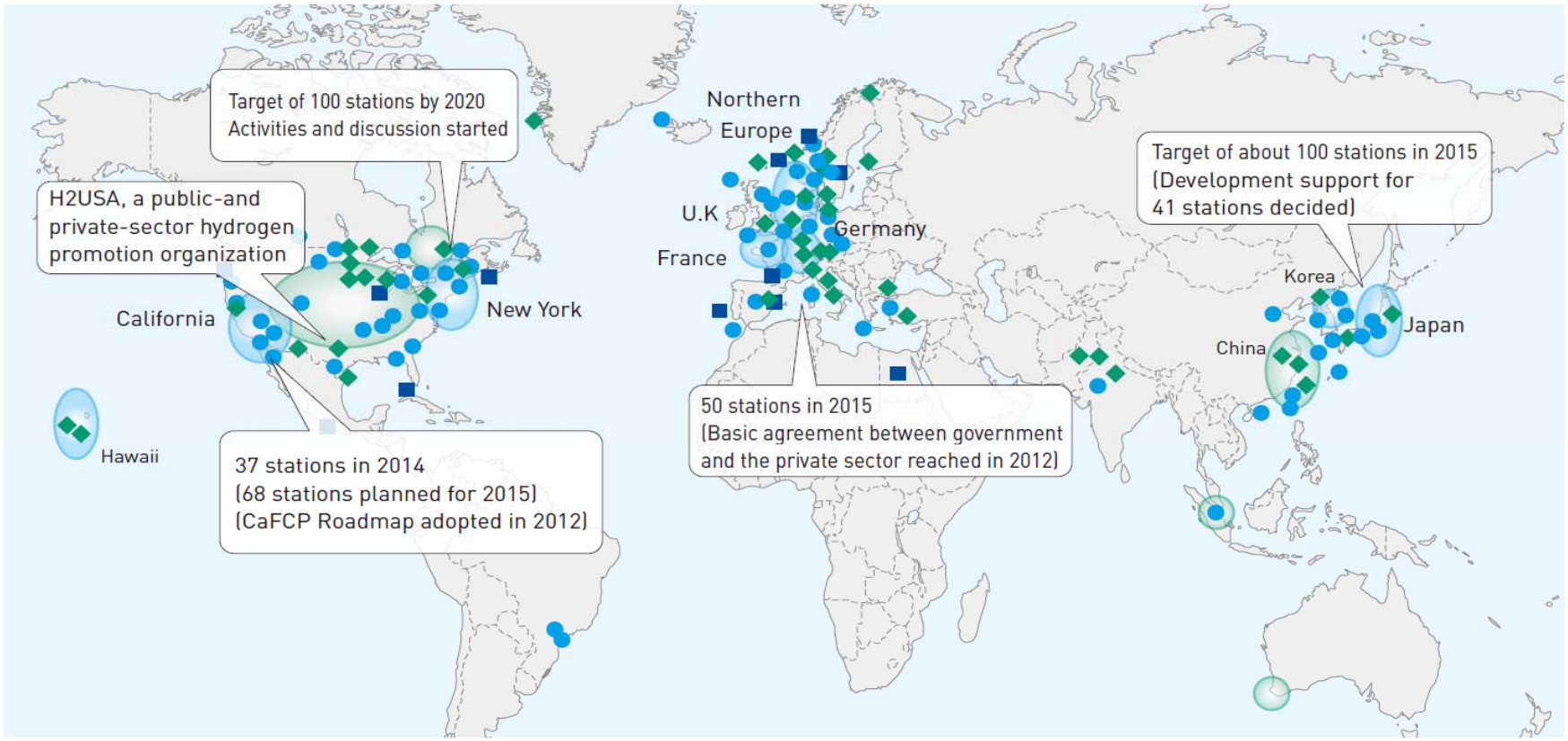
In January 2015 Air Liquide, Daimler, Linde, OMV, Shell and Total founded a joint venture to realize the action plan for the construction of a hydrogen refueling network in Germany.

Targets:

- **400 HRS** until **2023** (100 HRS until 2017).
- **350 mio. €** investment.
- Max**. 90 km** distance between two HRS at the motorway.
- **10 HRS** in each metropolitan area.



Worldwide hydrogen infrastructure activities



Development of several hundred hydrogen stations worldwide is expected between 2015 and 2020

Quelle: Toyota Global

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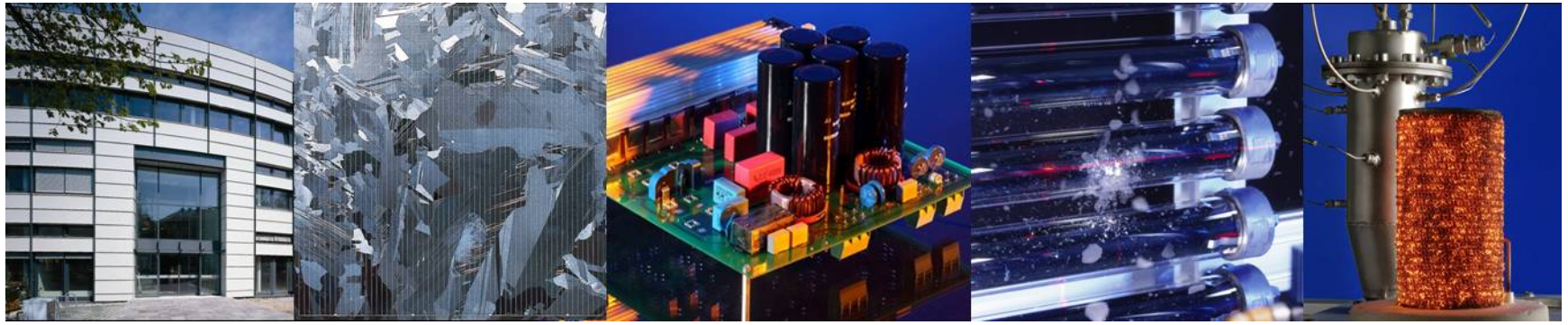
Conclusions

- The global energy transformation towards sustainability is **the** challenge of our generation. A decarbonized, renewable energy system is possible, at similar cost as today's energy system
- Most hydrogen and fuel cell technologies are still in an early stage of commercialization and have to compete with technologies which themselves are moving targets in terms of costs and efficiency (batteries, internal combustion engines, diesel generators, etc.)
- A stable policy and regulatory framework (like carbon pricing, feed-in-tarifs, fuel economy standards, zero-emission vehicle mandates) is required for raising market certainty for investors and create a self-sustaining market
- Electrolyzers combined with renewable energy sources will strongly support the climate change and energy security goals in sectors such as the transport, industry and power sector

Thank you



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