Pathway and Technologies for the Transformation of the Energy System

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Fraunhofer Institute for Solar Energy Systems ISE

Sustainability Summit

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www.ise.fraunhofer.de

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Energy Supply and Climate -Today
Example Germany

1990: 1000 million tons CO_2-Equ. (as reference point)
2015: 800 million tons CO_2-Equ. energy related greenhouse emissions

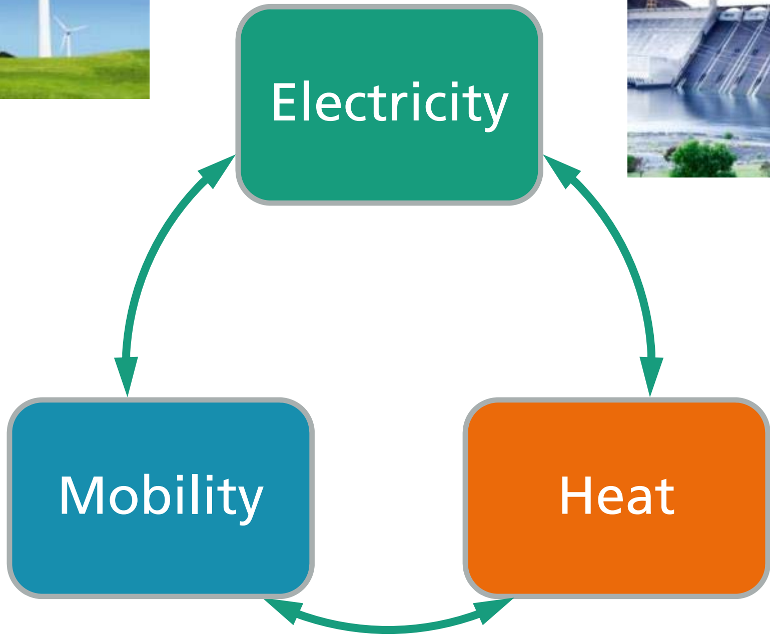
Photos: https://de.wikipedia.org/wiki/Kraftwerk_Boxberg; https://de.wikipedia.org/wiki/Schaufelradbagger

Energy Supply and Climate -Future
Example Germany

1990: 1000 million tons CO_2-Equ. (as reference point)
2015: 800 million tons CO_2-Equ. energy related greenhouse emissions
2050: 200 miillon tons CO_2-Equ. (as political goal, i.e. 80 % of 1990)

Photos: 18 MW-Solarpark Senftenberg, ©Phoenix Solar AG,
http://images02.kurier.at/40086867-46-55825557/620x340/40.086.868

How Will the Energy System Look Like in 2050?



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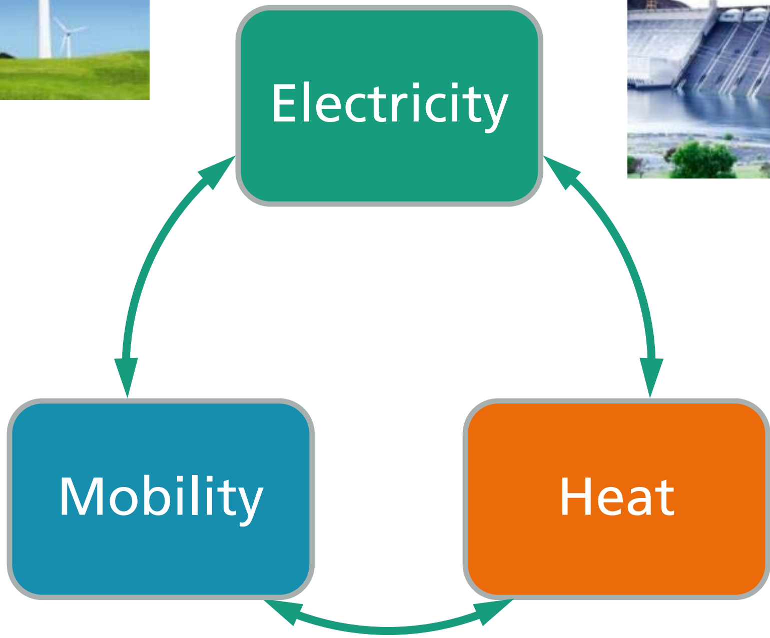
How Will the Energy System Look Like in 2050?



→ Develop a model to simulate the transformation of the energy system

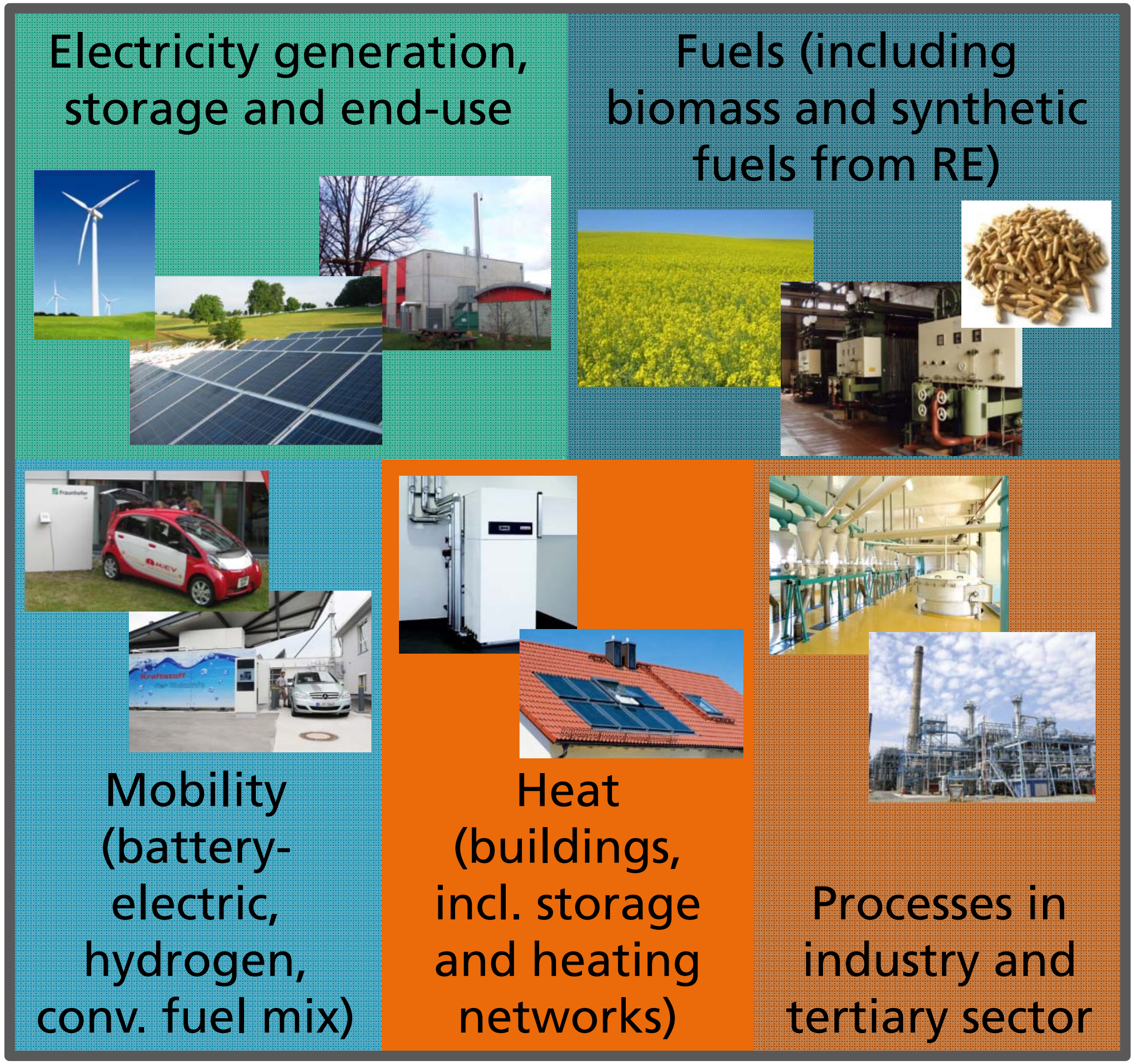
Model Germany's Energy System

REMod-D

Renewable Energy Model – Deutschland

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

Model Germany's Energy System

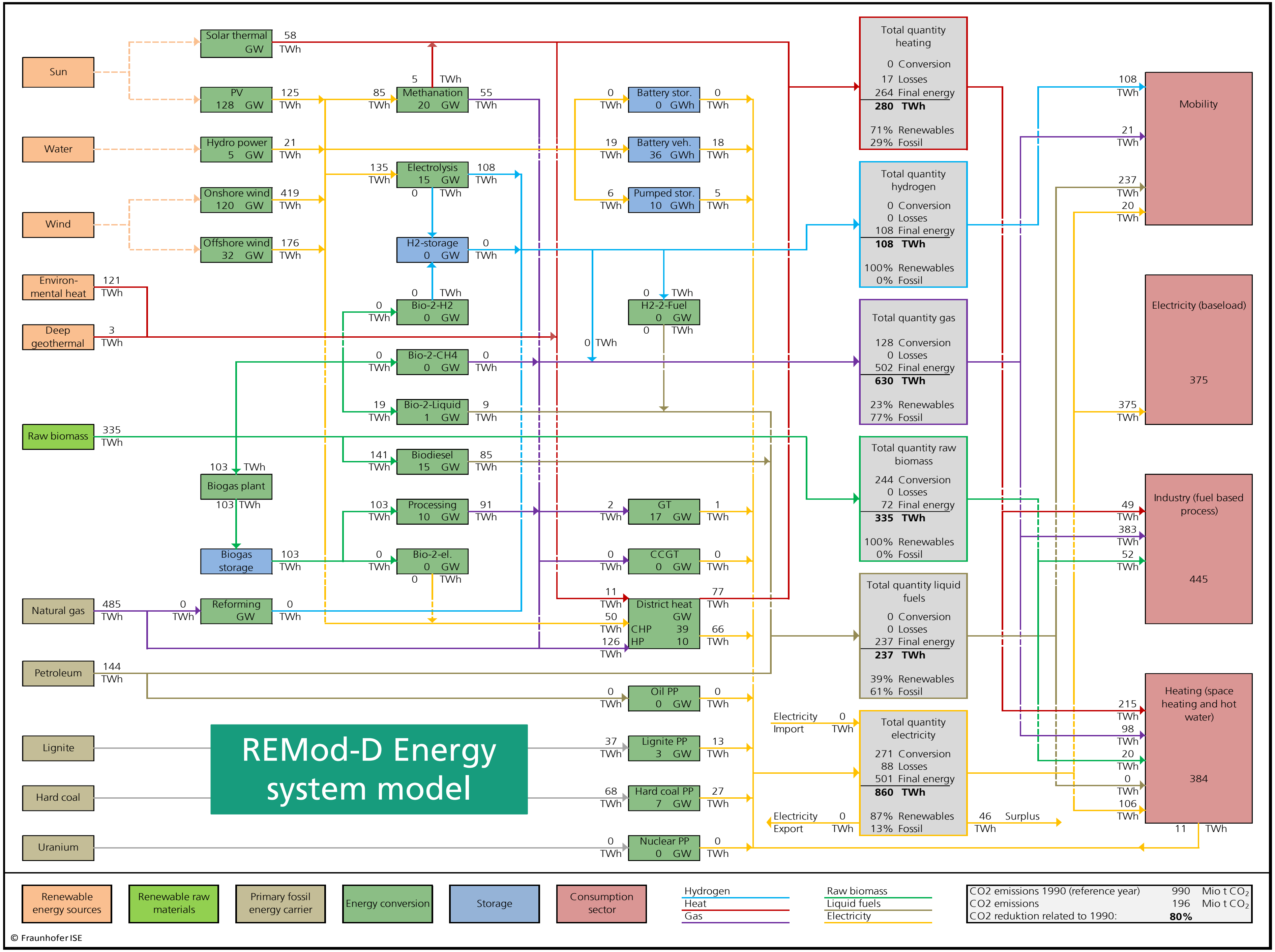


REMod-D

Renewable Energy Model – Deutschland

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

Henning, H-M., Palzer, A.: Was kostet die Energiewende?, Study Fraunhofer ISE, November 2015



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 GW
58 TWh
PV 128 GW
125 TWh
Hydro power 5 GW
21 TWh
Onshore wind 120 GW
419 TWh
Offshore wind 32 GW
176 TWh
Methanation 20 GW
85 TWh
5 TWh
55 TWh
Electrolysis 15 GW
135 TWh
108 TWh
0 TWh
H2-storage 0 GW
0 TWh
Bio-2-H2 0 GW
0 TWh
0 TWh
Bio-2-CH4 0 GW
0 TWh
0 TWh
Bio-2-Liquid 1 GW
19 TWh
9 TWh
Biodiesel 15 GW
141 TWh
85 TWh
103 TWh
Biogas plant
103 TWh
Biogas storage
103 TWh
Processing 10 GW
103 TWh
91 TWh
Bio-2-el. 0 GW
0 TWh
0 TWh
0 TWh
Reforming GW
0 TWh
Battery stor. 0 GWh
0 TWh
0 TWh
Battery veh. 36 GWh
19 TWh
18 TWh
Pumped stor. 10 GWh
6 TWh
5 TWh
H2-2-Fuel 0 GW
0 TWh
0 TWh
0 TWh
GT 17 GW
2 TWh
1 TWh
CCGT 0 GW
0 TWh
0 TWh
District heat GW
CHP 39
HP 10
11 TWh
50 TWh
126 TWh
77 TWh
66 TWh
Oil PP 0 GW
0 TWh
0 TWh
Lignite PP 3 GW
37 TWh
13 TWh
Hard coal PP 7 GW
68 TWh
27 TWh
Nuclear PP 0 GW
0 TWh
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
Electricity Import
0 TWh
Total quantity electricity
271 Conversion
88 Losses
501 Final energy
860 TWh
87% Renewables
13% Fossil
Electricity Export
0 TWh
46 TWh
Surplus
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
11 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

Model Germany’s Energy System

Mimimize total annual cost (operation, maintenance, …)

REMod-D

Renewable Energy Model – Deutschland

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

Electricity generation, storage and end-use

Fuels (including biomass and synthetic fuels from RE)

Mobility (battery-electric, hydrogen, conv. fuel mix)

Heat (buildings, incl. storage and heating networks)

Processes in industry and tertiary sector

See also: https://www.ise.fraunhofer.de/de/veroeffentlichungen/veroeffentlichungen-pdf-dateien/studien-und-konzeptpapiere/studie-energiesystem-deutschland-2050.pdf

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Major Guiding Question for the Model

What is the cost-optimal transformation pathway of the German overall energy system including all sectors?

Essential boundary condition:

- **Political goals of reducing greenhouse gas emissions are fulfilled**
- **Both for the target value and in each single year**

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Methodology

- Hourly simulation of the total energy system from January 1, 2014 until December 31, 2050 (using data from 2011, 2012 and 2013)
- Optimization of the development of the system composition considering all future options
  - Renewables
  - Storage and power-to-gas/fuel/heat technologies
  - Energy retrofit of building sector
- Goal function: minimal overall transformation cost

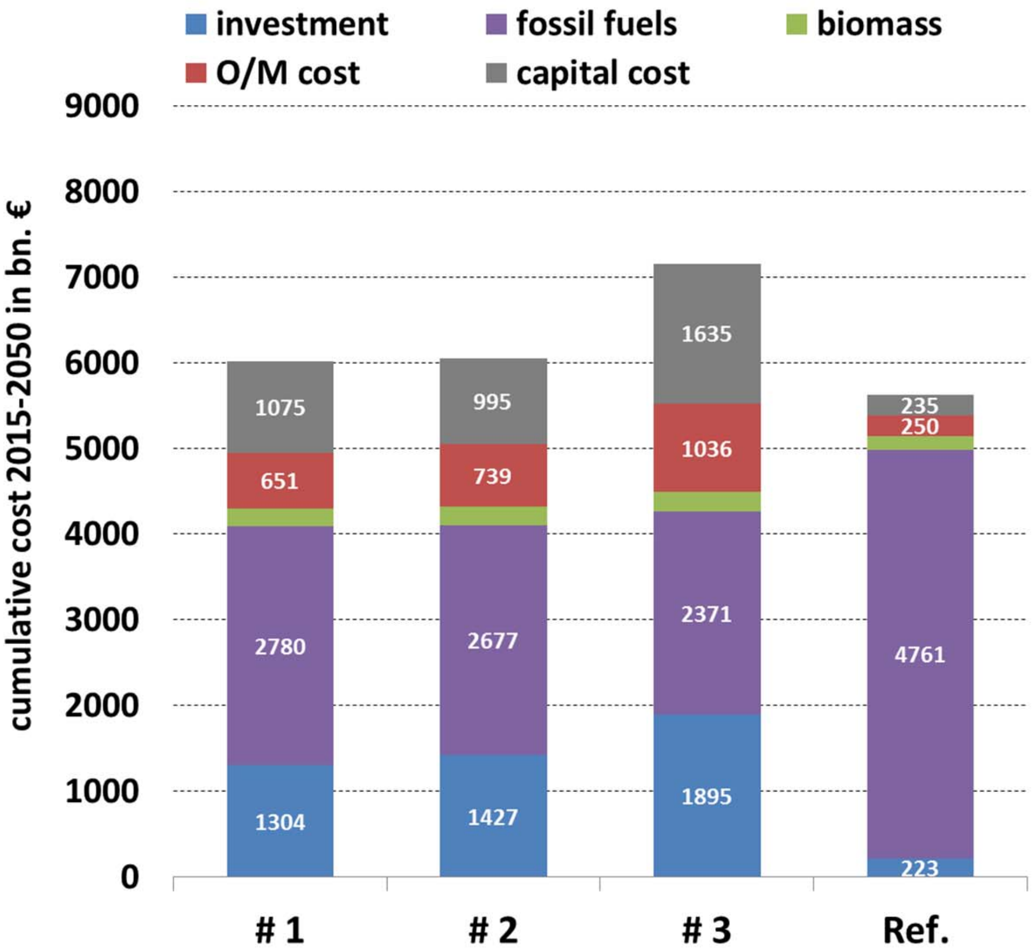
→ Presentation of the full study: November 5th, 2015 in Berlin

Results for Different Scenarios
Comparison of Cumulative Cost

#1 -80 % CO_2 emissions, high rate of building energy retrofit, mix of car concepts, accelerated stop of coal use for electricity production

Results for Different Scenarios
Comparison of Cumulative Cost

- No cost (penalty) for CO_2 emissions
- Constant prices for fossil fuels



#1 -80 % CO_2 emissions, high rate of building energy retrofit, mix of car concepts, accelerated stop of coal use for electricity production

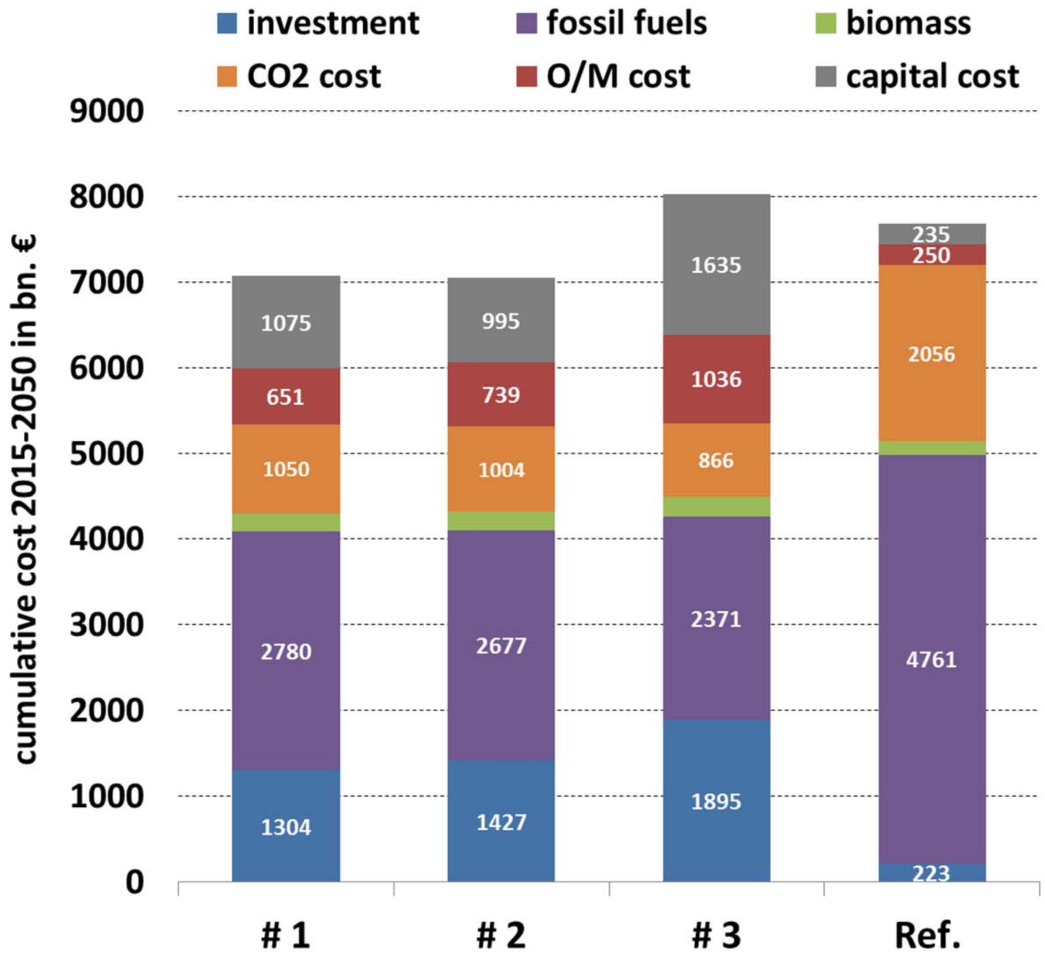
#2 as #1, but -85 % CO_2 emissions

#3 as #3, but -90 % CO_2 emissions

Ref. no change to today's system

Results for Different Scenarios
Comparison of Cumulative Cost

- Increasing cost for CO_2 emissions up to 100 € per ton in 2030; then constant
- Increase of prices for fossil fuels 2 % p.a.



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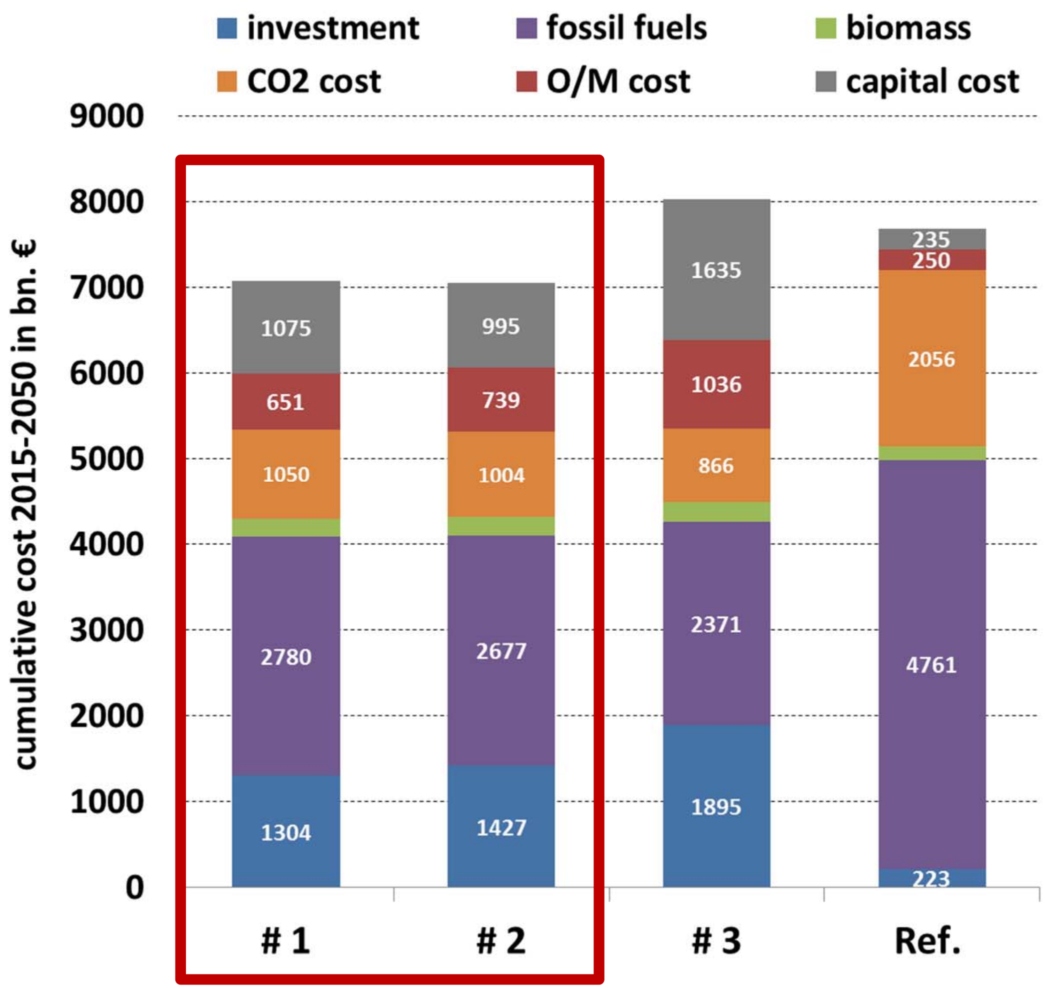

Cumulative cost for 2014-2050 of scenarios #1 and #2 about 600 bn € lower than those of reference

#1 -80 % CO_2 emissions, high rate of building energy retrofit, mix of car concepts, accelerated stop of coal use for electricity production

#2 as #1, but -85 % CO_2 emissions

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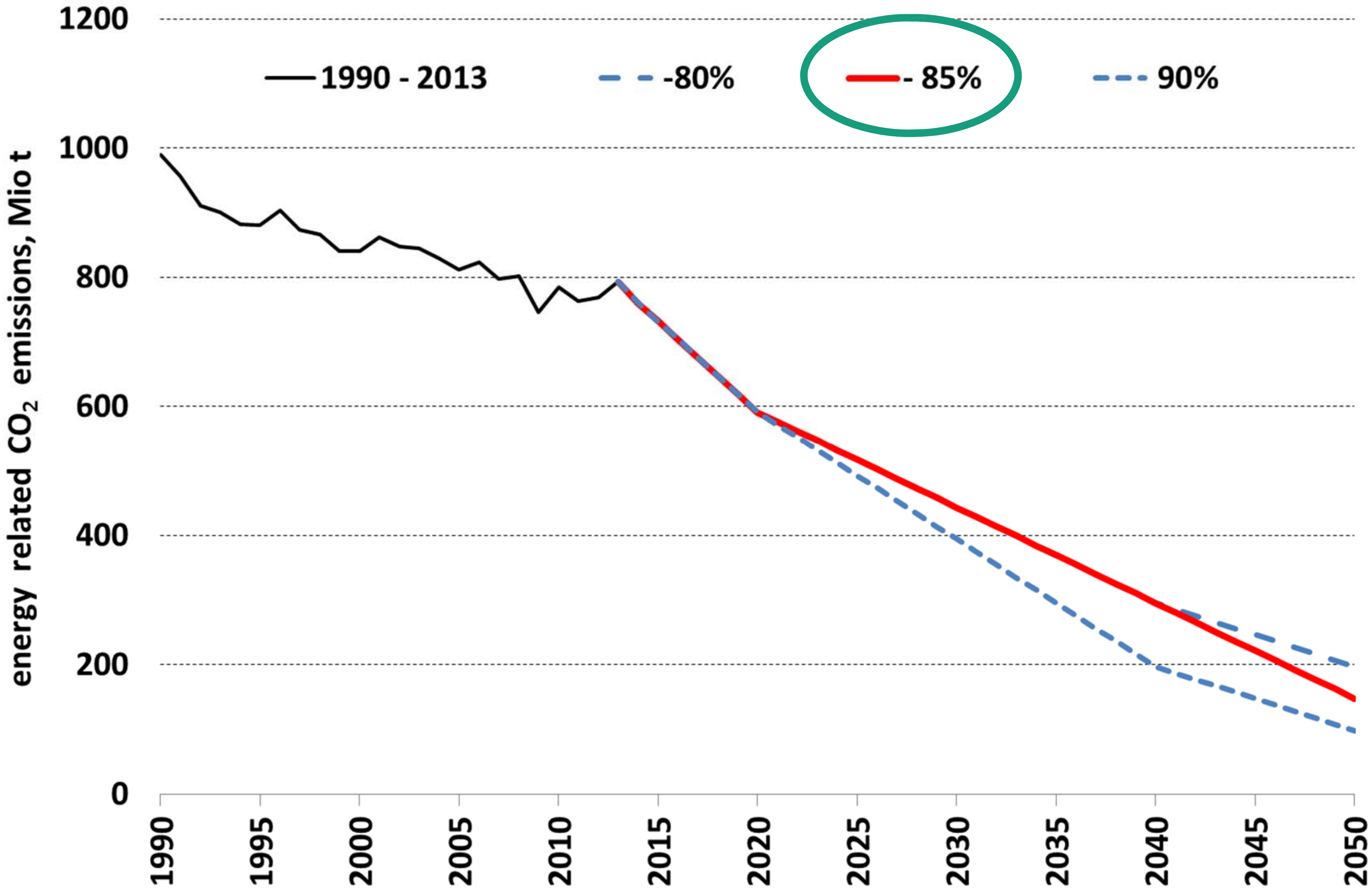
An Important Boundary Condition for the Model: The CO_2 Reduction Pathway



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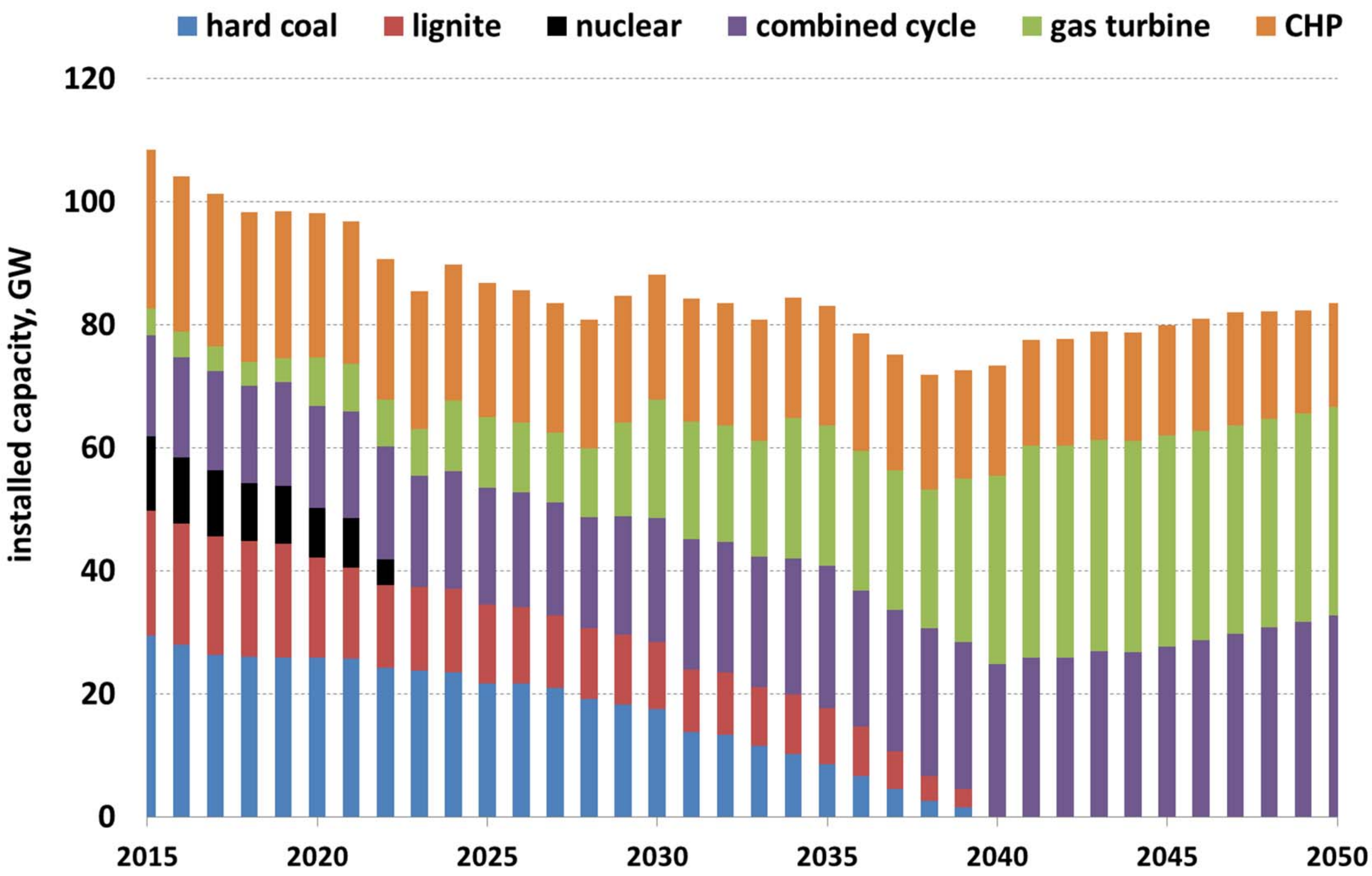
Development of Thermal Power Plants and Large Scale Combined Heat and Power Systems (CHP)



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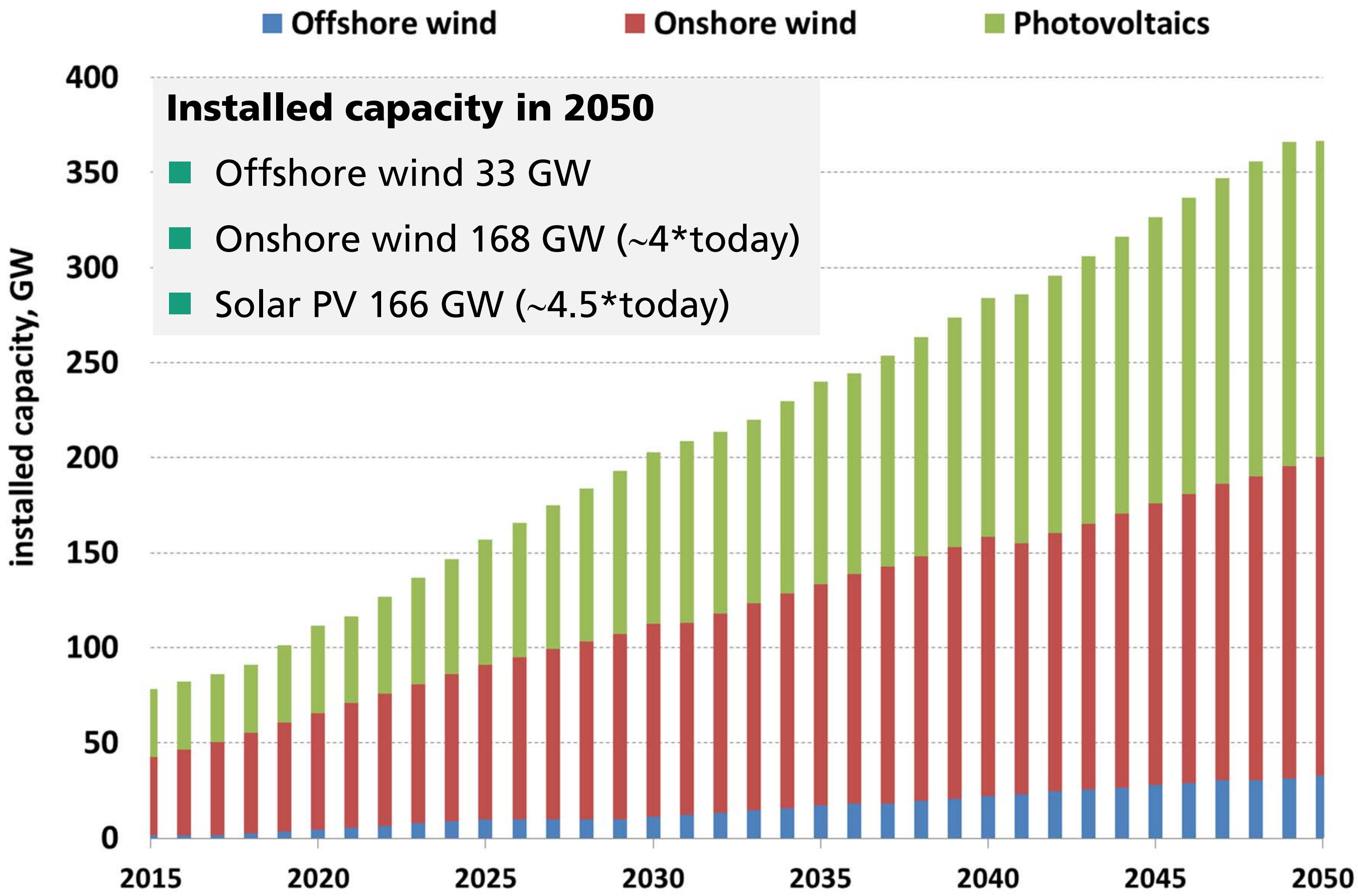
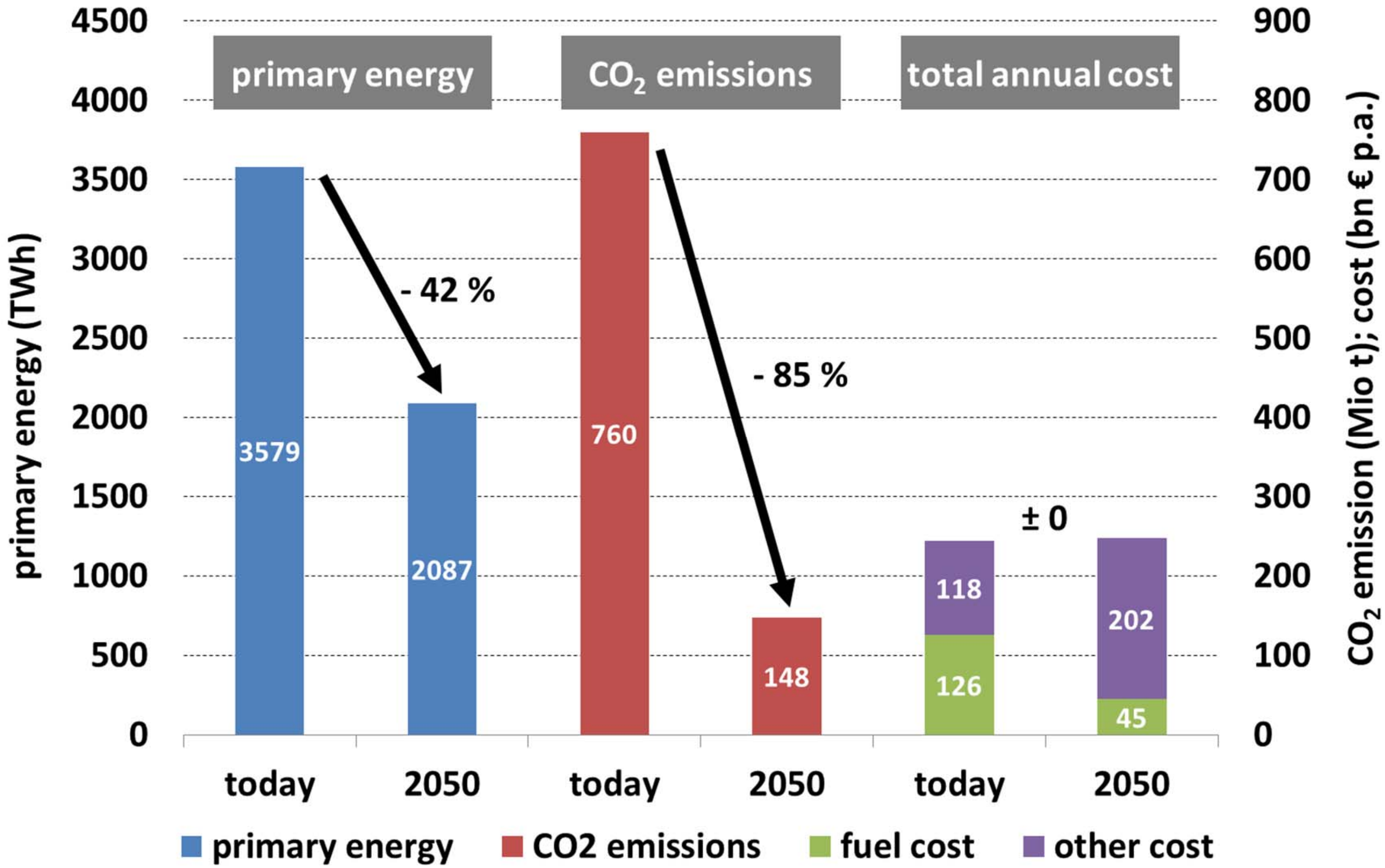
Fluctuating Renewable Energies: Solar, Wind



Overall Results: Today vs. 2050
After Completion of Transformation

- Constant cost for CO_2-emissions: 5 €/ton
- No increase of prices for fossil fuels



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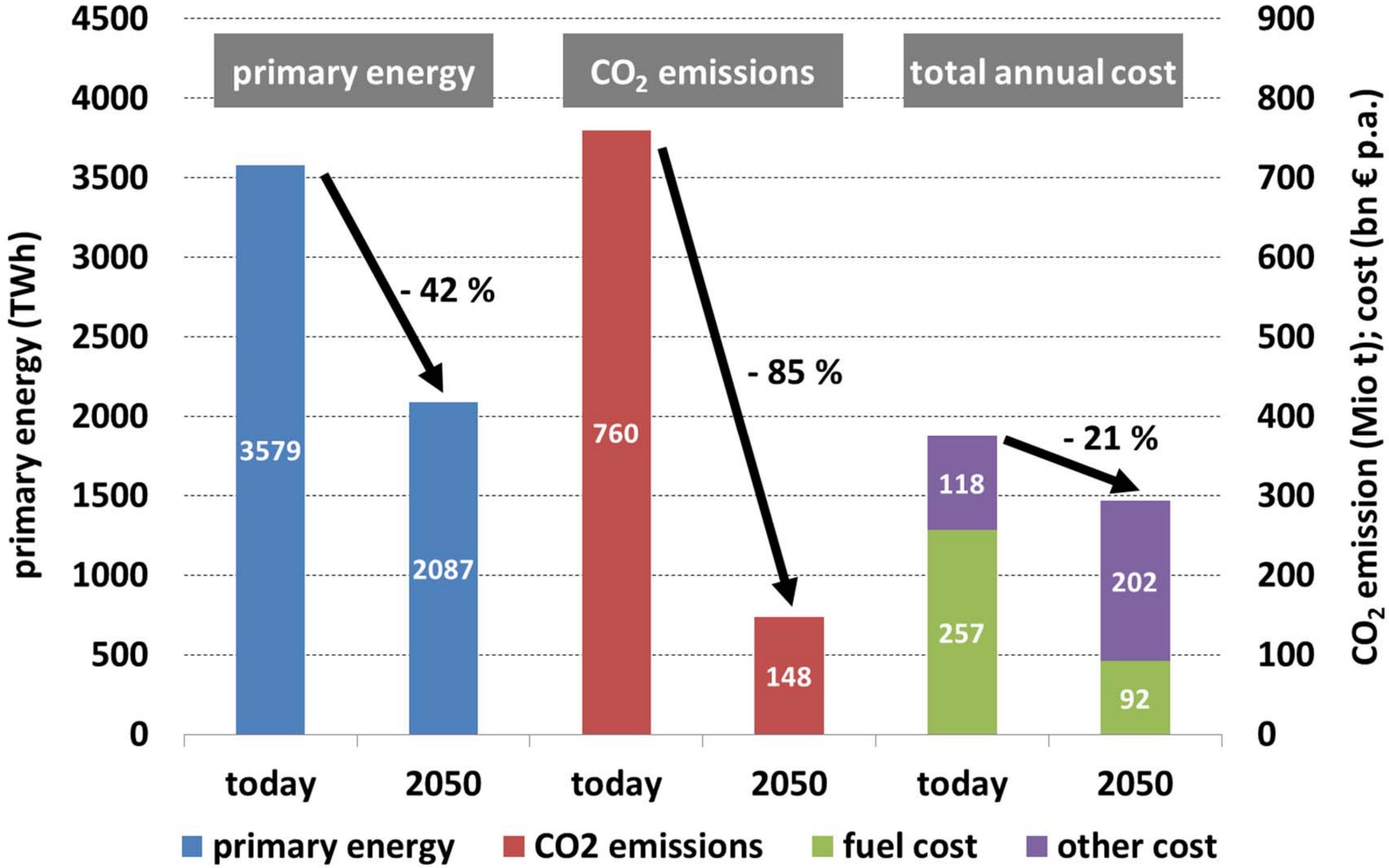
Overall Results: Today vs. 2050
After Completion of Transformation

- Constant cost for CO_2-emissions: 5 €/ton
- 2 % annual price increase for fossil fuels



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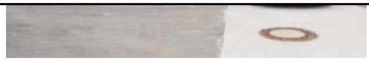
How Will the Energy System Look Like in 2050?

Essential messages out of the model:

The cost of the new Energy System is not higher than the cost for the current system!

The cost for transformation is in the same order as maintaining the current system!



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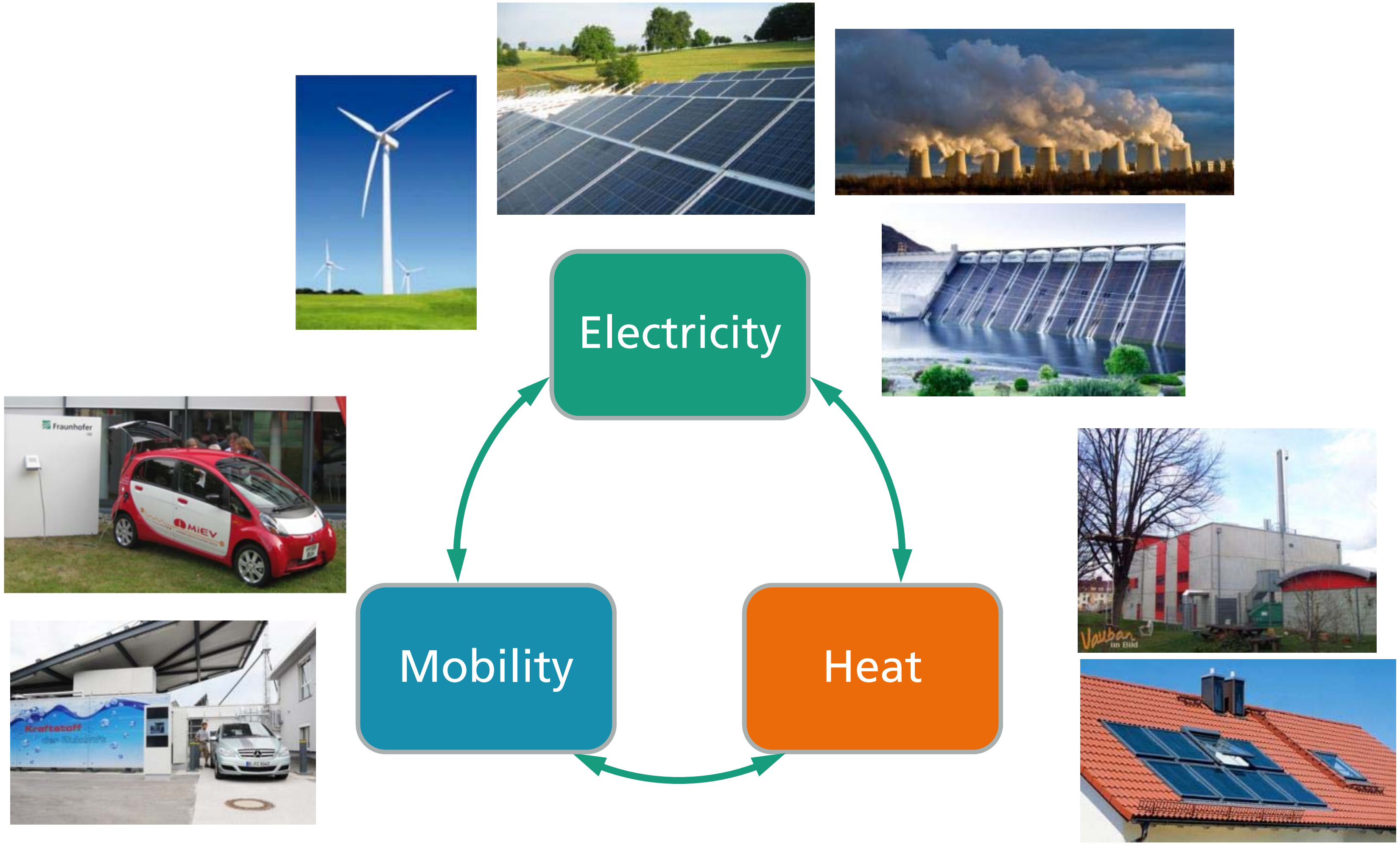
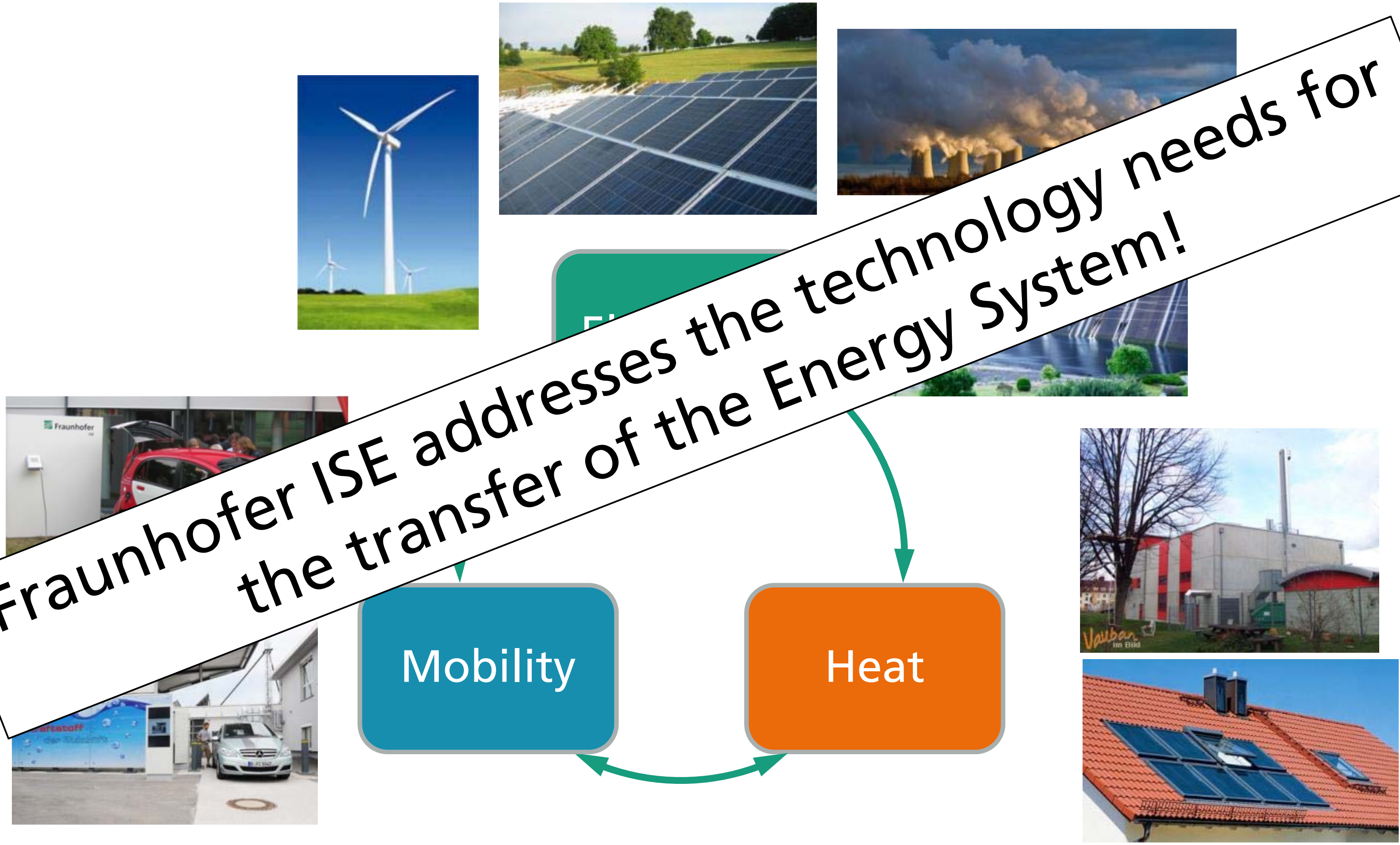


How Will the Energy System Look Like in 2050?



Fraunhofer ISE addresses the technology needs for the transfer of the Energy System!

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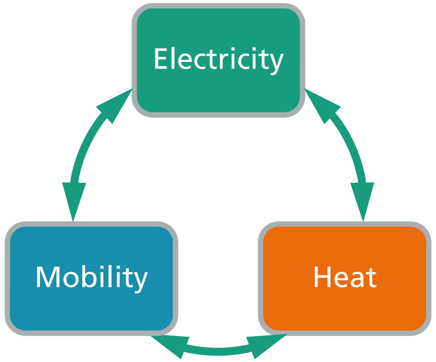
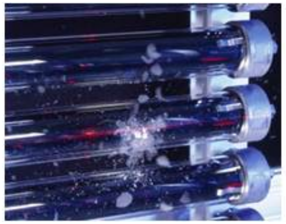
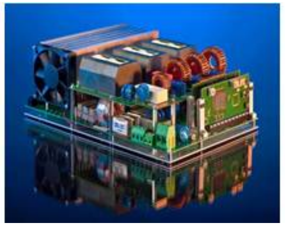
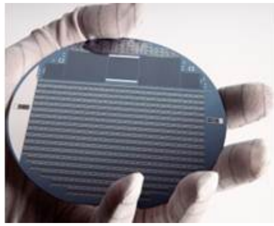
Business Areas






- Photovoltaic Technologies
  Silicon
  III-V and Concentrator
  Dye, Organic and Novel Solar Cells
- Photovoltaic Modules and Power Plants
- Storage Technologies
- Hydrogen and Fuel Cell Technology
- Solar Thermal Technology
- Energy Efficient Buildings
- Energy Efficient Power Electronics
- Zero-Emission Mobility
- System Integration and Grids – Electricity, Heat, Gas
- Energy System Analysis

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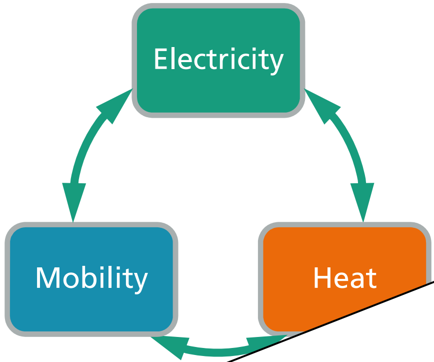
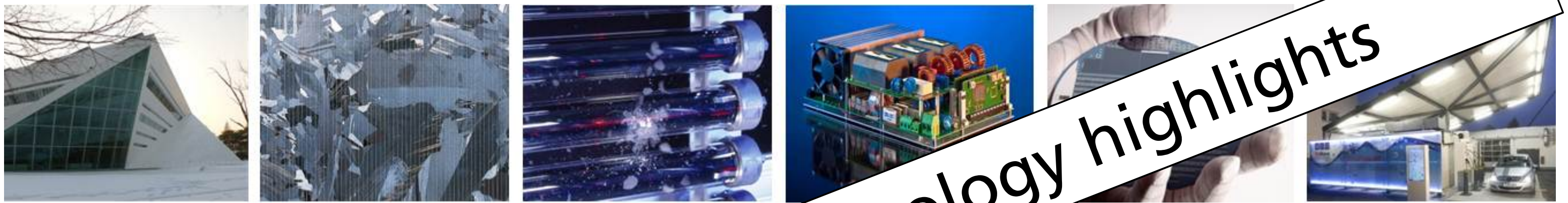
Business Areas



Photos © Fraunhofer ISE



Fraunhofer ISE: PV technology highlights

- Photovoltaic Technologies
  Silicon
  III-V and Concent
  Dye, Organ Solar Cells
- Ph Modules and Power
- Storage Technologies
- Hydrogen and Fuel Cell Technology
- Thermal Technology
- Energy Efficient Buildings
- Energy Efficient Power Electronics
- Zero-Emission Mobility
- System Integration and Grids – Electricity, Heat, Gas
- Energy System Analysis

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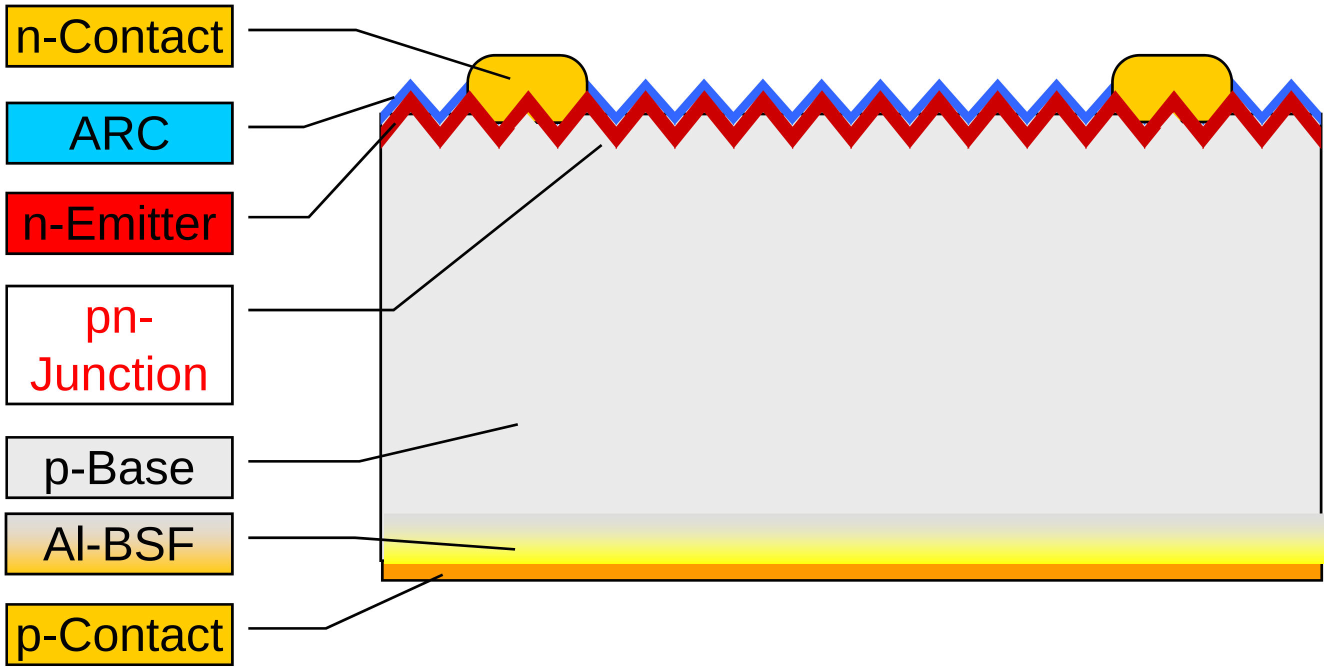
Photovoltaics: Silicon Solar Cell Technology

The State-of-the-Art Industrial Standard
On the Rear Side: Aluminum-BackSurfaceField

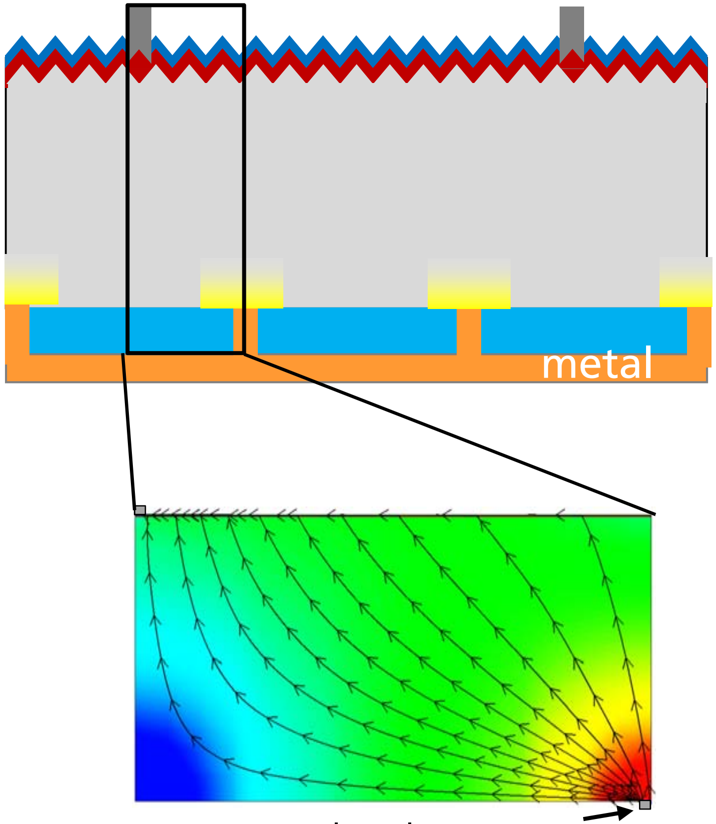


18.0-19.5% Efficiency in industrial production

High-Efficiency Si Solar Cells

PERC* Solar Cell – The New Industrial Standard

*Passivated Emitter and Rear Contact



- Currently roll-out of PERC technologie to overcome the optical and electrical limitations of the silicon solar cell working horse: the full area Al-BSF solar cell

  → Implementation of local contacts to reduce recombination at metal contacts

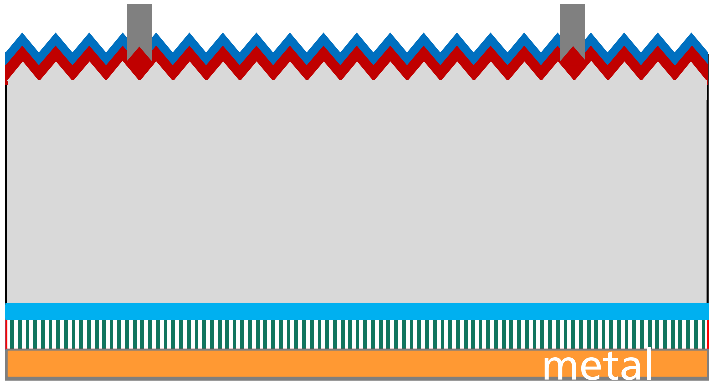
Drawbacks:

- Lateral current flow in the base lead to resistance losses
- Additional patterning step required

20.0-21.0% Efficiency in industrial production

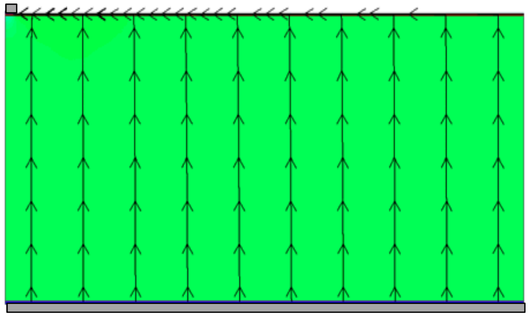
High-Efficiency Si Solar Cells

PERC Solar Cell – And What´s Next ?



Replacing the local contacts with a full area **passivated contact**

- No structuring necessary
- Low recombination
- No lateral current flow



passivated contact

Simple structure with high efficiency potential

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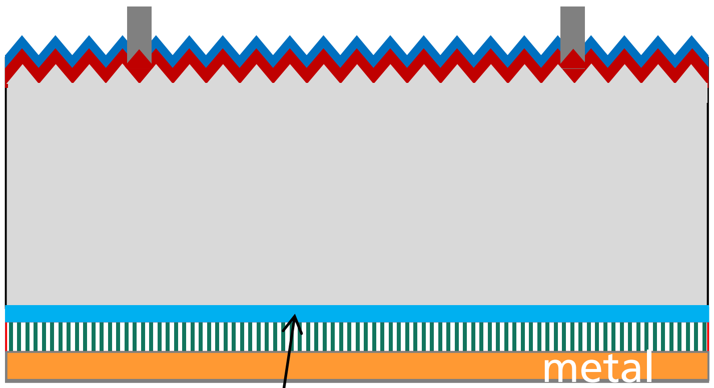
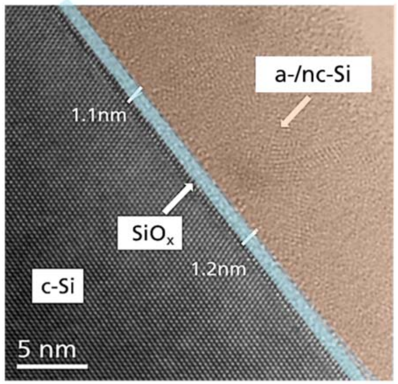
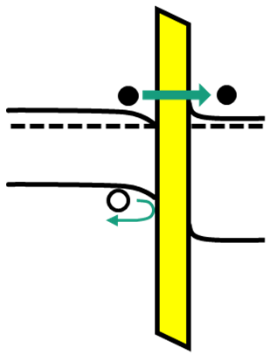
High-Efficiency Si Solar Cells

Passivated Contacts – ISE Developed TOPCon Approach



$J_{0,met} = J_{0,pass}$





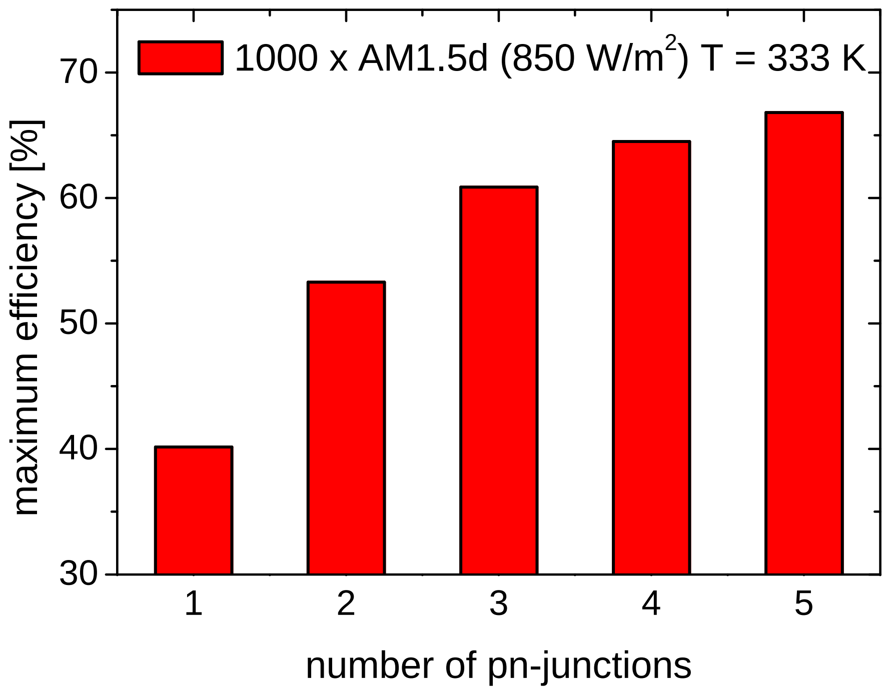
- Implementation of thin tunnel oxide allows for loss carrier transport to the external contacts and suppress the recombination at the contacts

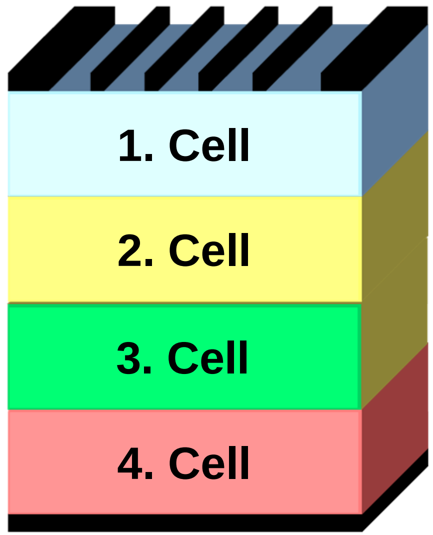
- Fraunhofer ISE achieved new **world record of 25.1%**[1] for both side contacted solar cell using using **TOPCon** technology

V_{oc} [mV]	J_{sc} [mA/cm²]	*FF* [%]	η [%]
718	42.1	83.2	**25.13**

[1] n-type Si 4 cm² (da), Glunz et al., *EUPVSC* (2015)

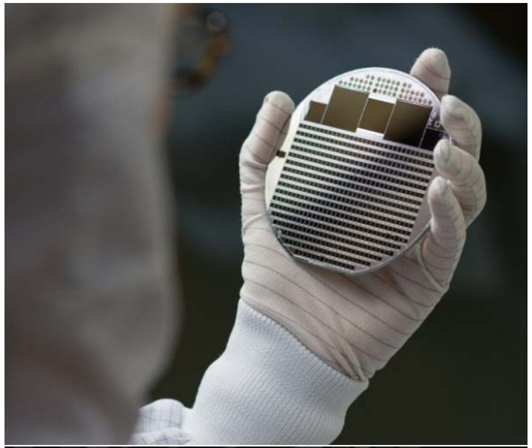
Increase the Solar Cell Efficiency
Multi-junction Solar Cells

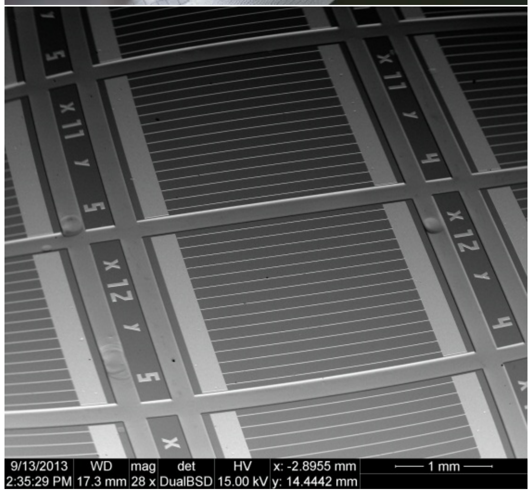


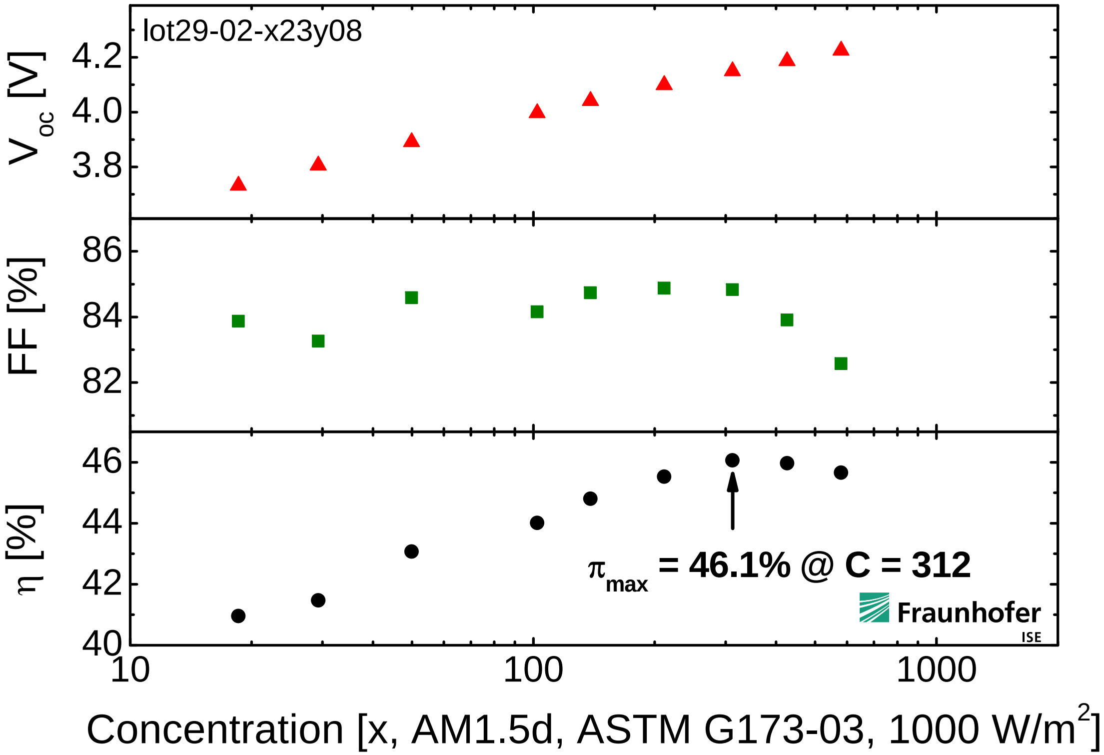


World Record Efficiency at Fraunhofer ISE

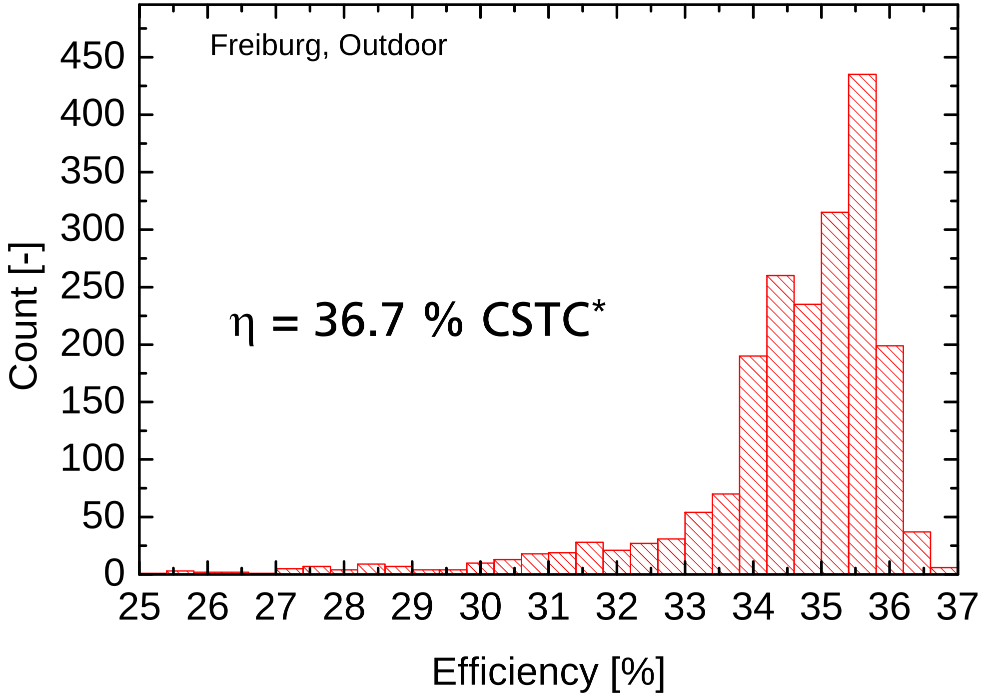
46 % with Wafer-Bonded 4-Junction Solar Cell







Highest Efficiency CPV Modules
FLATCON® Module with Wafer-Bonded 4-Junction Cells



- No temperature correction
- 829.6 cm² aperture area

* Concentrator Standard Testing Conditions, 1000 W/m², 25 °C_{cell}

M. Steiner et al., Progress in Photovoltaics 23(10) (2015)

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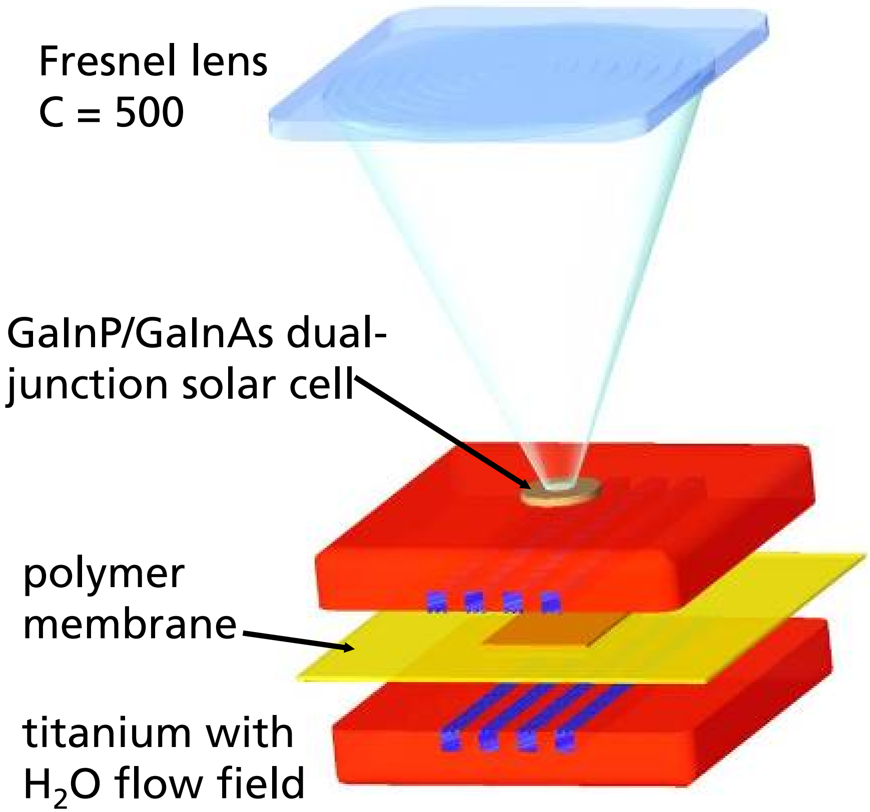
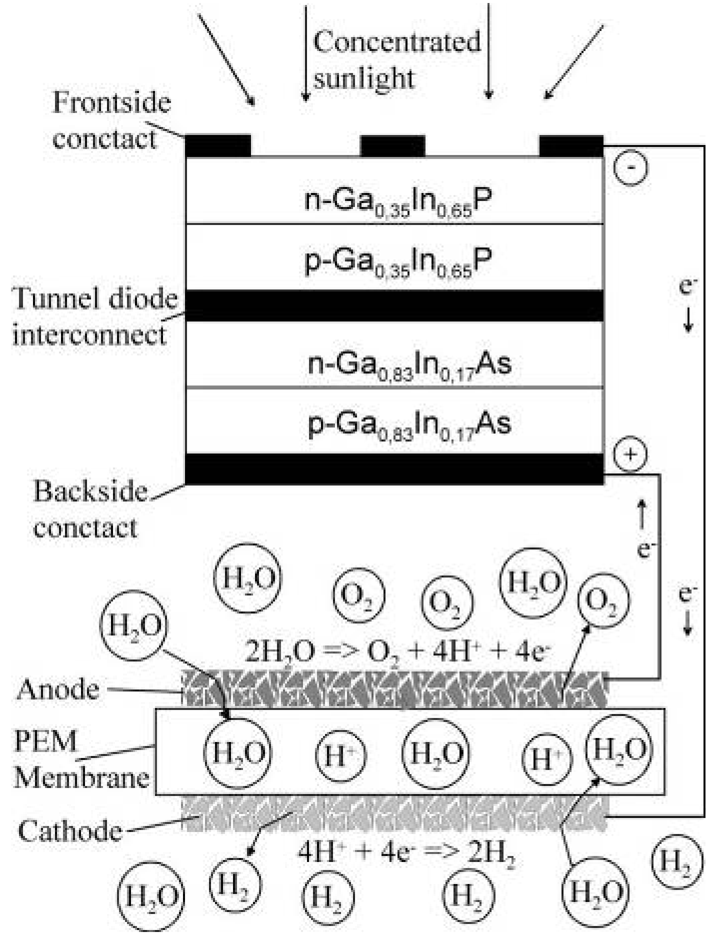
Solar Hydrogen Production





G. Peharz et al., Int. Journal of Hydrogen Energy 32 (2007)

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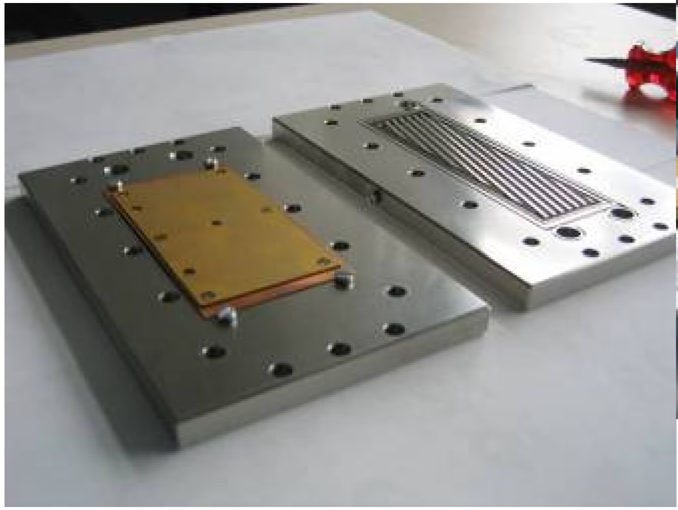
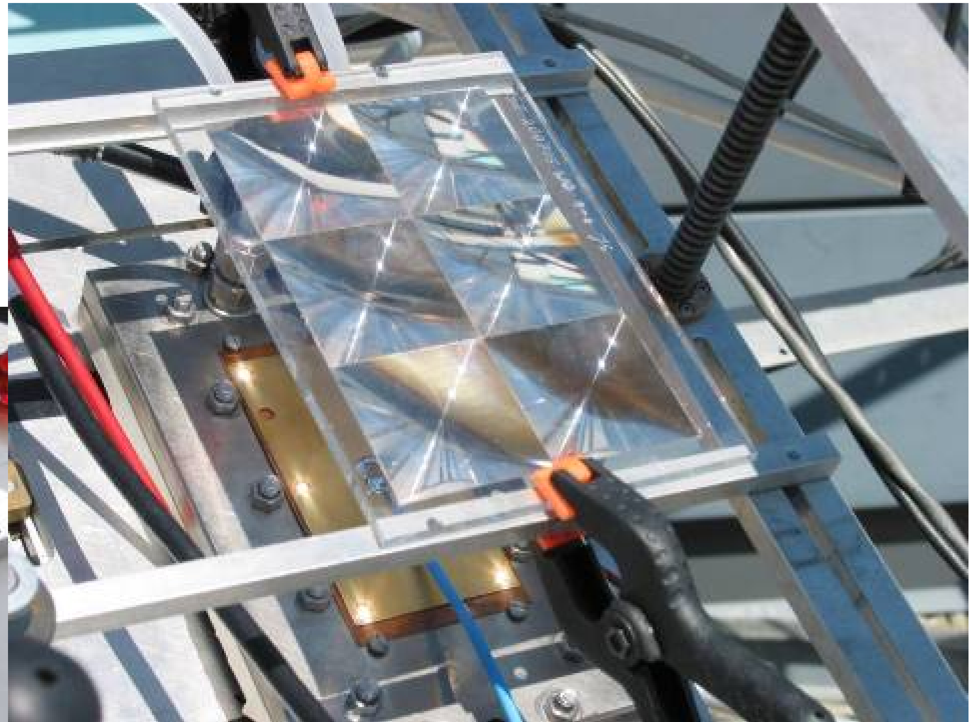
Prototype System with 6 Dual-Junction Solar Cells





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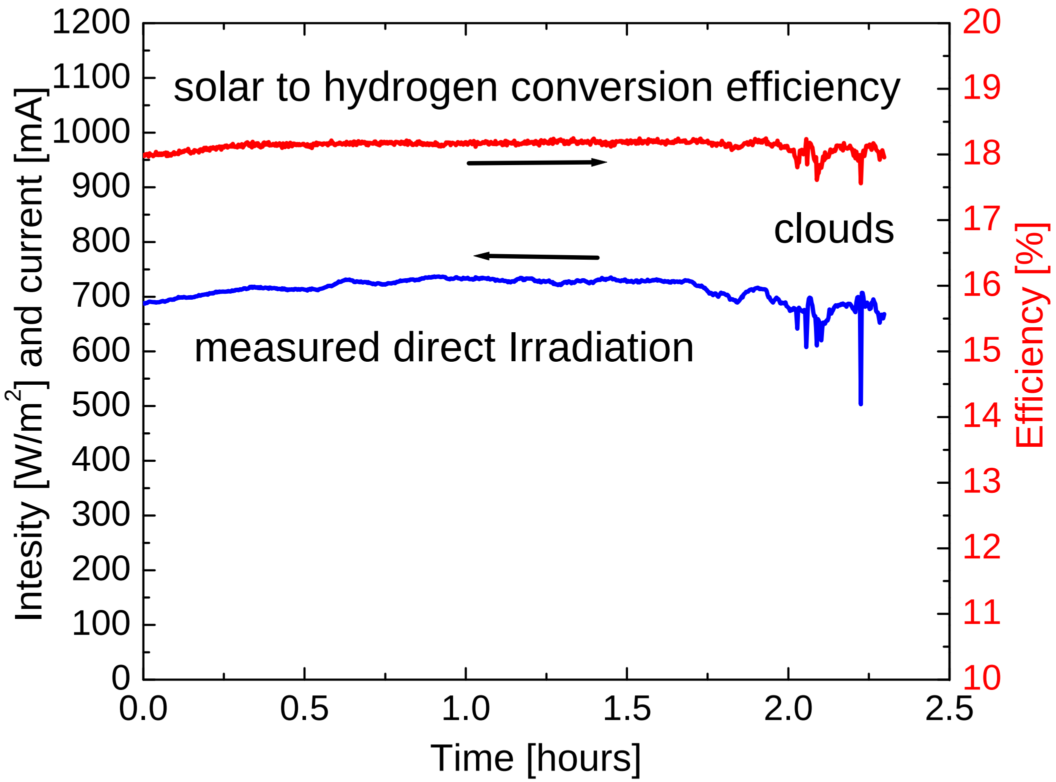
Outdoor Measurements

- Record solar to hydrogen conversion efficiency of 18 %

  → soon 30 % expected



G. Peharz et al., Int. Journal of Hydrogen Energy 32 (2007)

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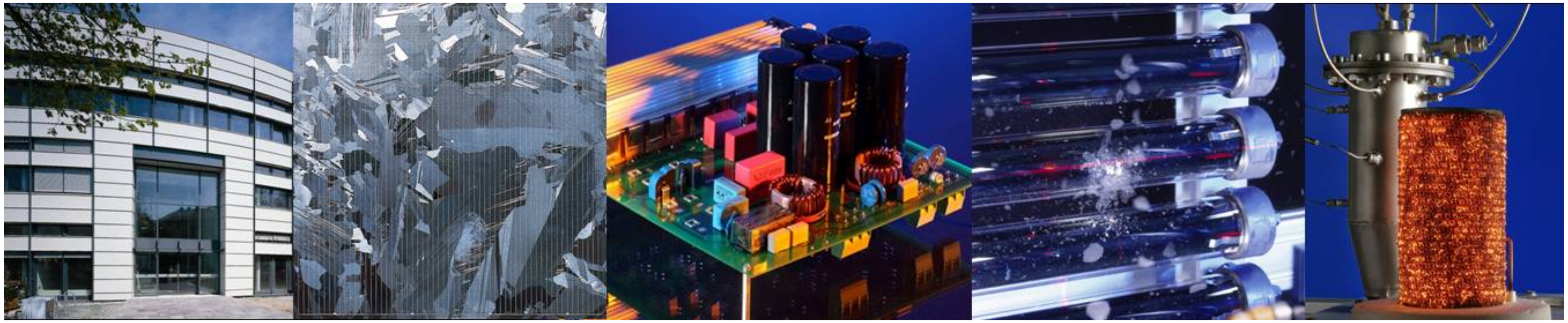
Solar Hydrogen Filling Station at Fraunhofer ISE
From Solar Energy to Sustainable Mobility

- Research platform and publicly accessible filling station
- On-site grid-connected 16 kWp PV system (expansion planned)
- On-site hydrogen production by PEM water electrolysis (0.5 kg/h, 7 kg/d)
- Max. 3 minutes to fill-up car tank

www.h2move.de

Thank you
colleagues at Fraunhofer ISE
and you for your attention



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