Sustainable Energy Mix for the Future – Example Germany

Prof. Dr. Hans-Martin Henning

Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
and
Karlsruhe Institute of Technology KIT

REvision 2015

Tokyo, March 4, 2015

www.ise.fraunhofer.de

Fraunhofer ISE

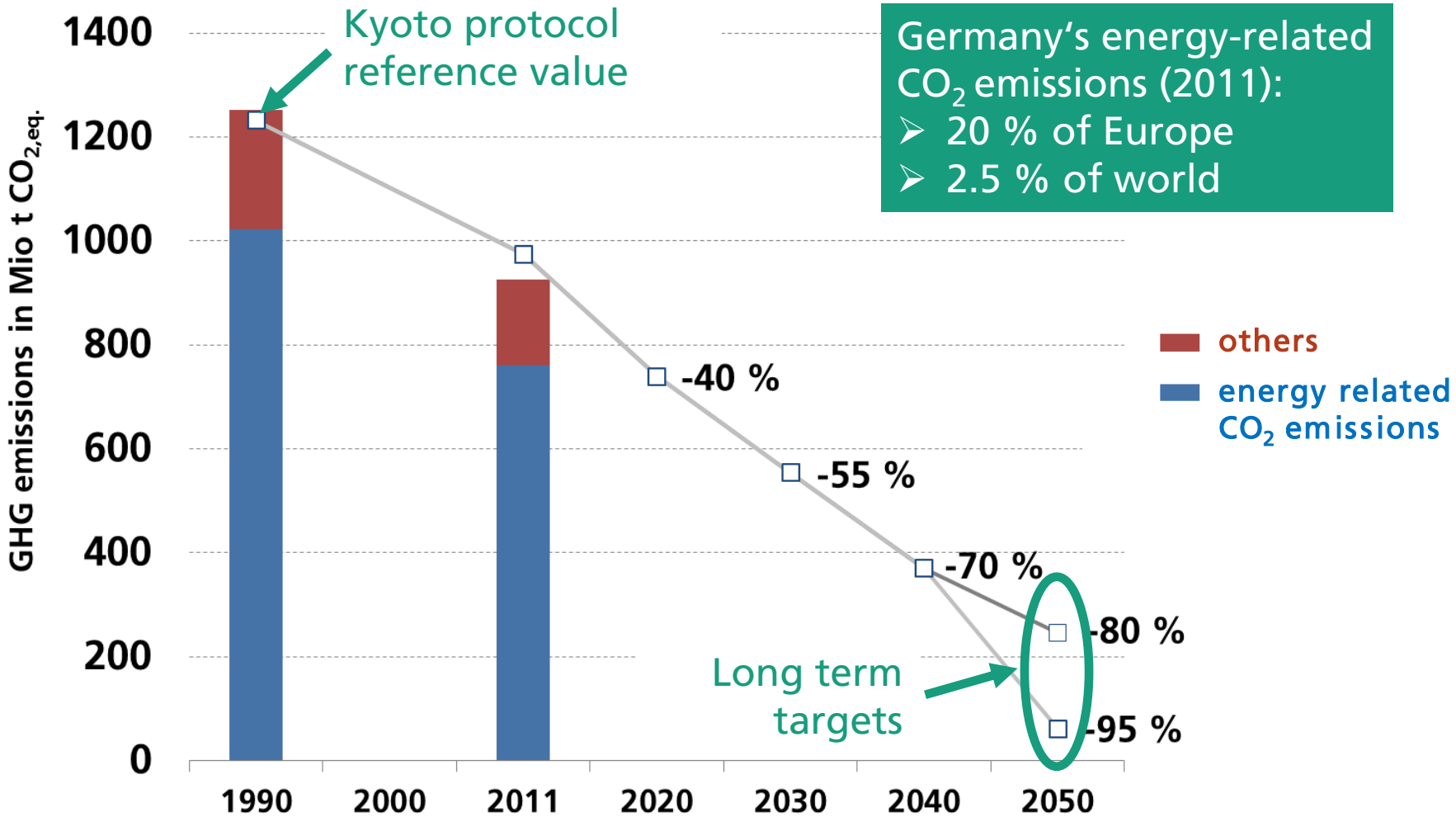
Outline

- Germany's long-term climate policy targets
- Composition of a target system
- Phases of the transformation of the energy system
- Cost analysis
- Conclusions and outlook

Outline

- Germany's long-term climate policy targets
- Composition of a target system
- Phases of the transformation of the energy system
- Cost analysis
- Conclusions and outlook

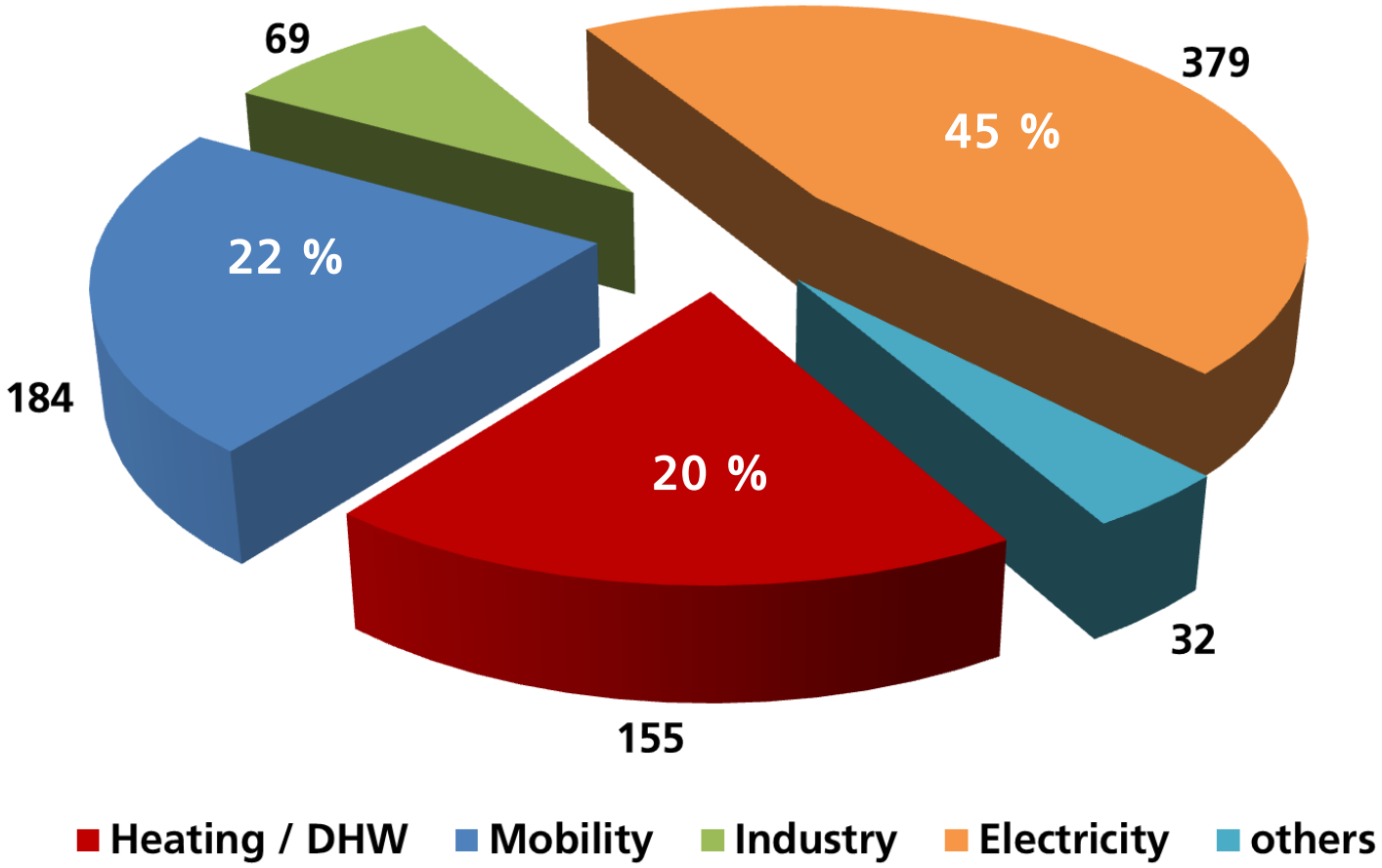
Germany's greenhouse gas emissions – history and targets



Fraunhofer ISE

Germany's energy-related CO_2 emissions (2008)

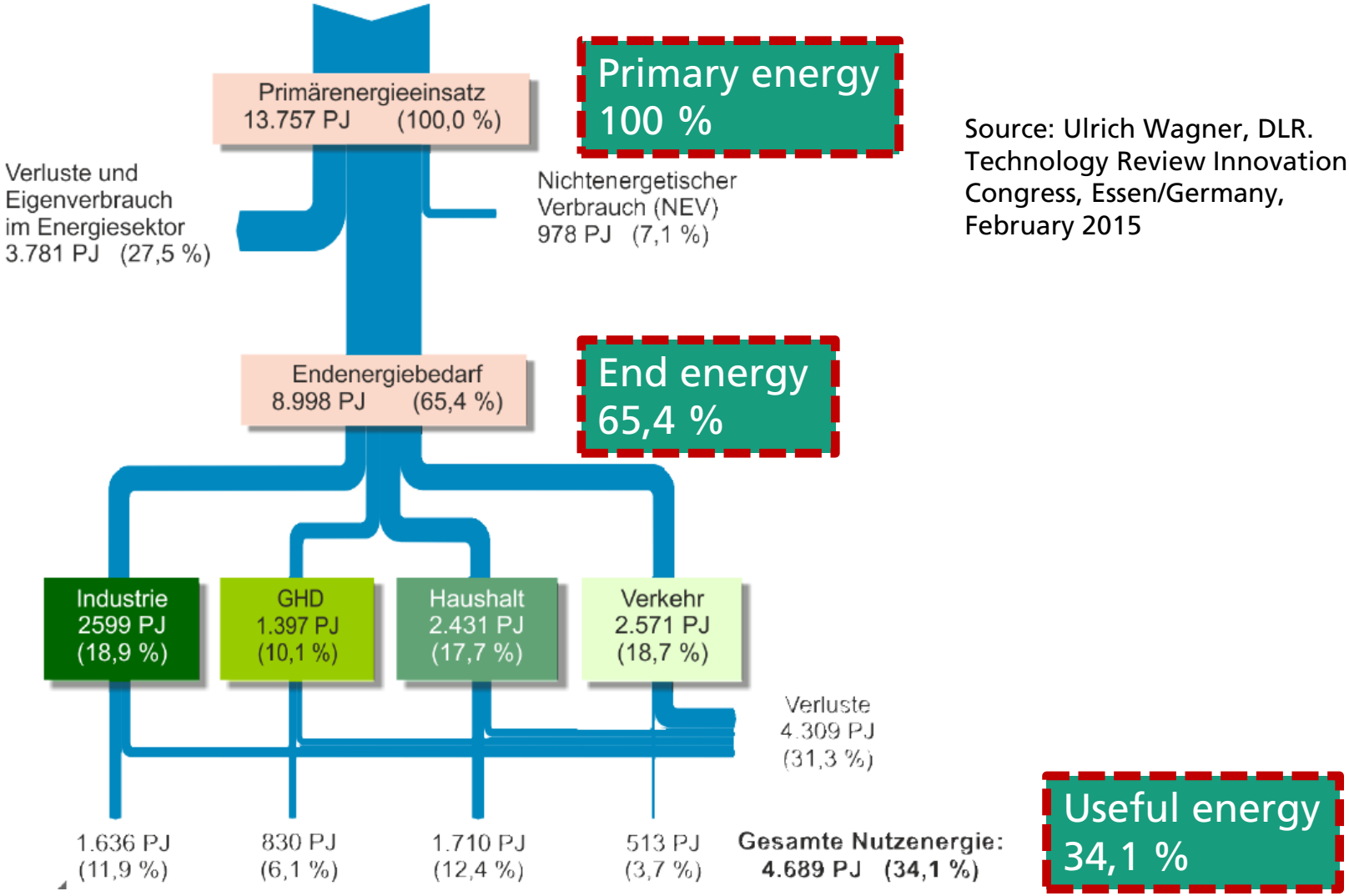
Distribution among sectors (Mio tons)



source: "Politikszenarien für den Klima-schutz VI - Treibhausgas-Emissions-szenarien bis zum Jahr 2030„ Öko-Institut et al. im Auftrag des Umwelt-bundesamtes (UBA), März 2013

Fraunhofer ISE

Energy flow chart of today (Germany, 2012)



Source: Ulrich Wagner, DLR. Technology Review Innovation Congress, Essen/Germany, February 2015

Fraunhofer ISE

Means to achieve long term targets

- Increase **efficiency of conversion** from primary to end energy
- Increase **efficiency** on **end-use** side
- Replace fossil (and nuclear) energy by use of **renewable energies**

Important boundary conditions

- No nuclear energy (fade out in 2022)
- No carbon capture and sequestration/storage

Specific long term goals of the German government (2050)

Overall

- Reduction of greenhouse gas emissions by 80 % to 95 % (compared to 1990)
- Cutting the total primary energy demand by 50 % (compared to 2008)
- Renewable energy fraction of 60 % of gros final energy demand

Electricity

- Reduction of consumption by 25 % (compared to 2008)
- Renewable energy fraction of 80 % in electricity production

Building sector

- Almost carbon neutral building sector
- Reduction of primary energy by 80 %

Outline

- Germany's long-term climate policy targets
- **Composition of a target system**
- Phases of the transformation of the energy system
- Cost analysis
- Conclusions and outlook

Optimization of Germany's future energy system

Mimimize total annual cost (operation, maintenance, …)

REMod-D

Renewable Energy Model – Deutschland

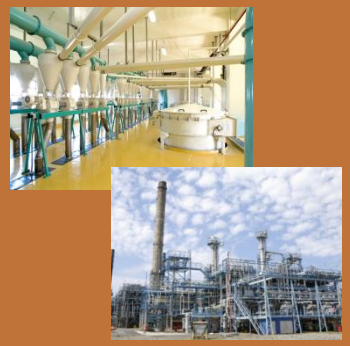
Techno-economic optimization based on comprehensive simulation (hourly time scale)

Electricity generation, storage and end-use

Fuels (including biomass and synthetic fuels from RE)

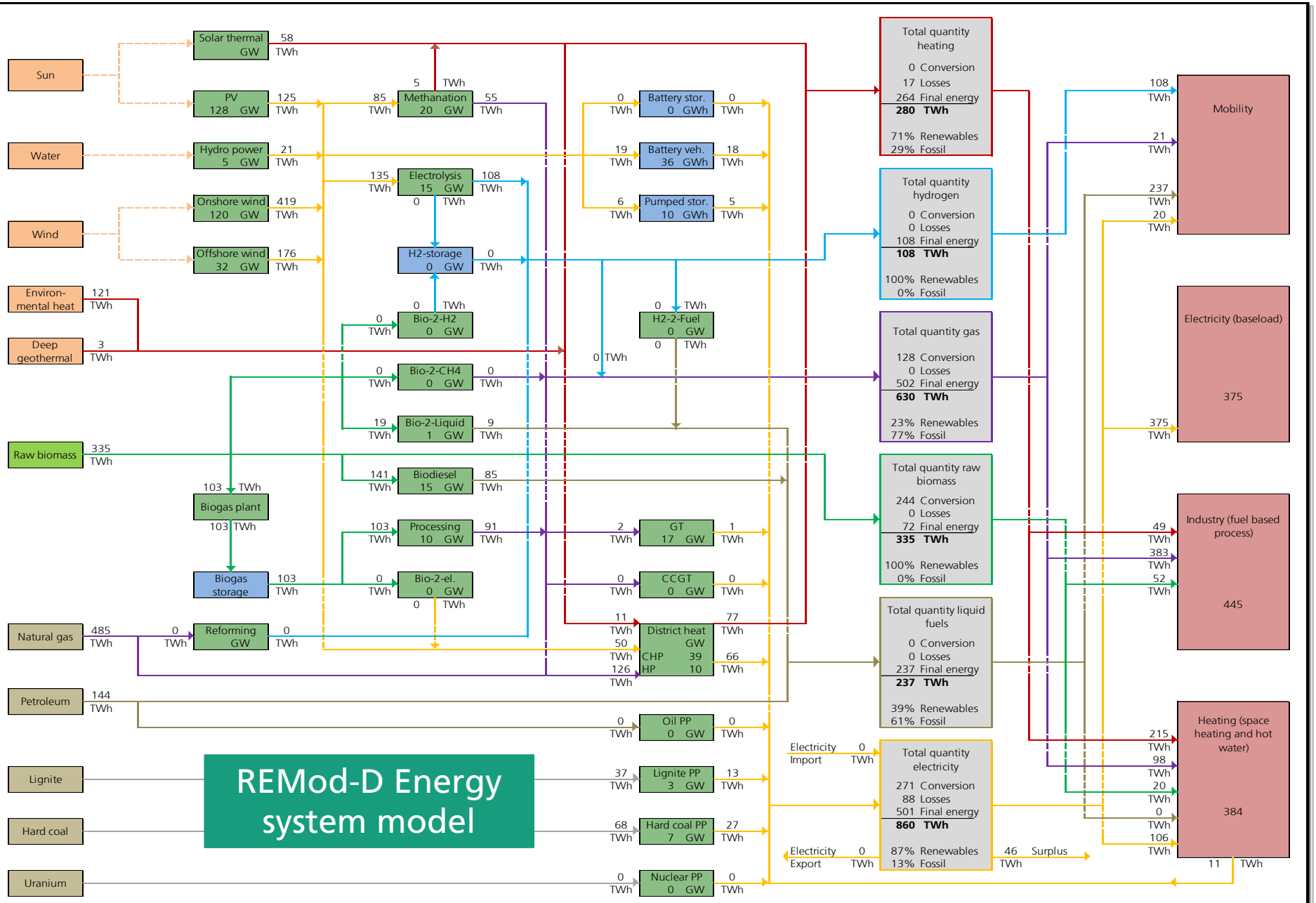
Mobility (battery-electric, hydrogen, conv. fuel mix)

Heat (buildings, incl. storage and heating networks)



Processes in industry and tertiary sector

Fraunhofer ISE



Optimized system – Electricity

Photovoltaics
~ 147 GW_{el}

Onshore Wind
~ 120 GW_{el}

Offshore Wind
~ 32 GW_{el}

Medium and large size CHP
(connected to district heating)
~ 60 GW_{el}

CHP = combined heat & power

Heat

Solar thermal
~ 42 GW_{th}

Solar thermal
~40 GW_{th}

Heat pumps
- ~ 22 GW_{th} (el., ground)
- ~ 19 GW_{th} (el., air)
- ~ 15 GW_{th} (gas)

CHP in heat networks
- ~ 60 GW_{el} installed capacity
- ~ 15 GW_{th} centralized heat pumps

CHP = combined heat & power

Storage

Stationary batteries
Total ~24 GWh (e.g. 8 Mio units with 3 kWh each)

Pumped storage power plants
42 units with a total of 60 GWh

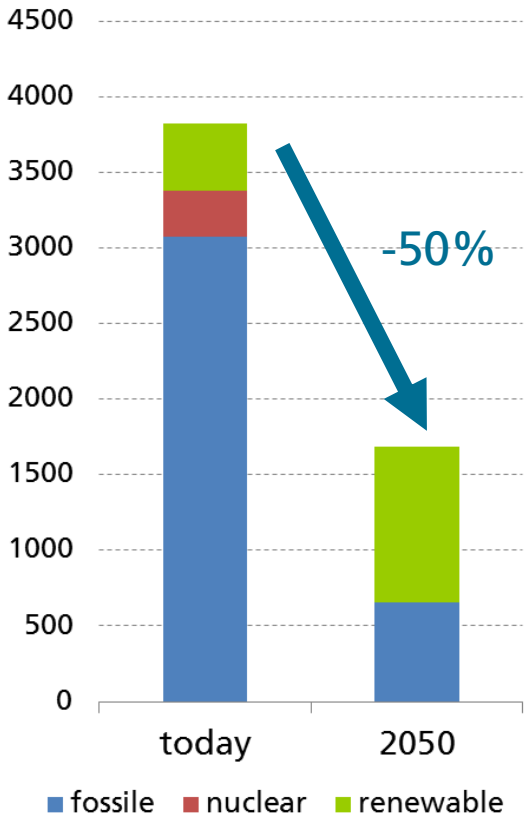
Electrolysers with total capacity of 33 GW_{el} (needed for mobility)

Heat buffers in buildings
Total ~320 GWh (e.g. 7 Mio units with 800 Litres each)

Large scale heat storage in district heating systems
Total ~350 GWh (e.g. 150 units with 50.000 m³ each)

Today's system vs. optimized system in 2050

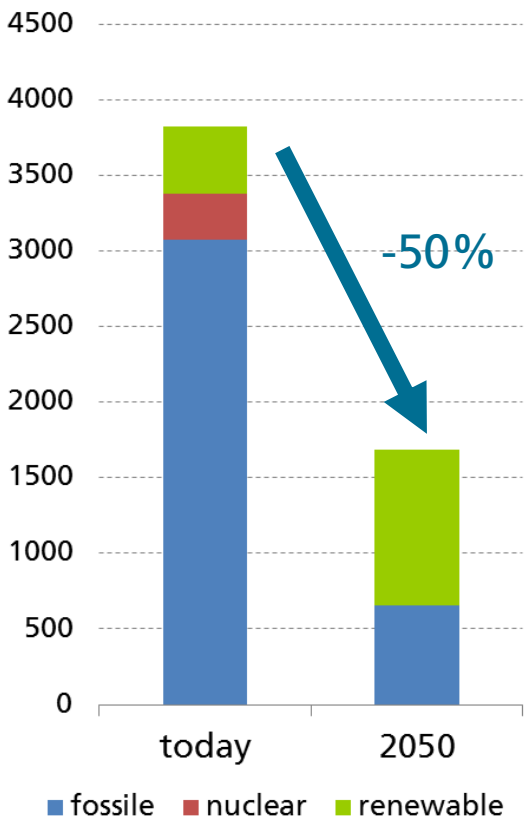
primary energy (TWh)



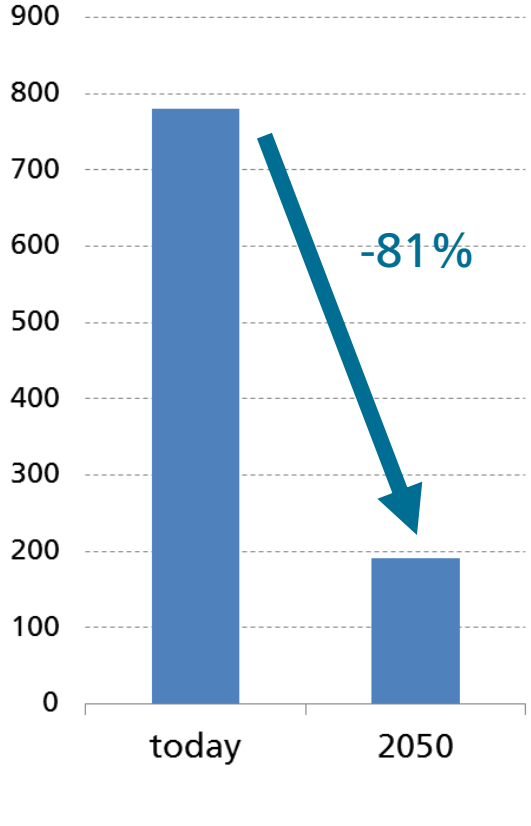
Fraunhofer ISE

Today's system vs. optimized system in 2050

primary energy (TWh)

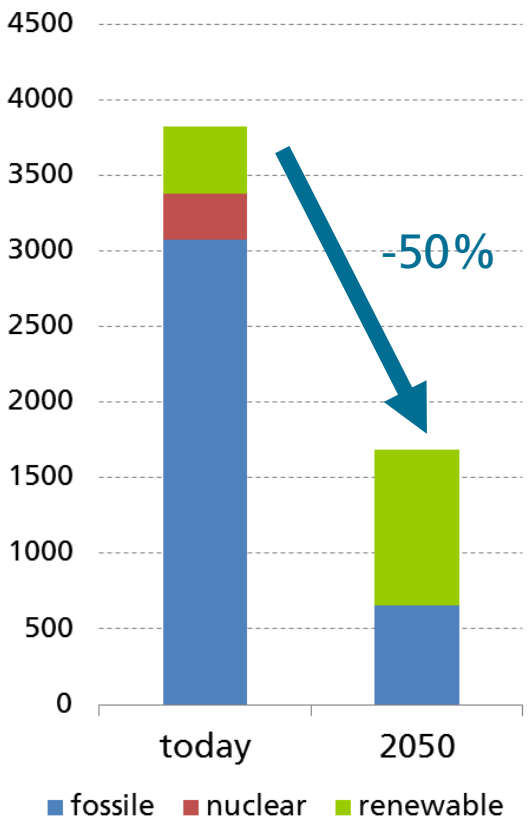


CO_2 emissions (Mt)

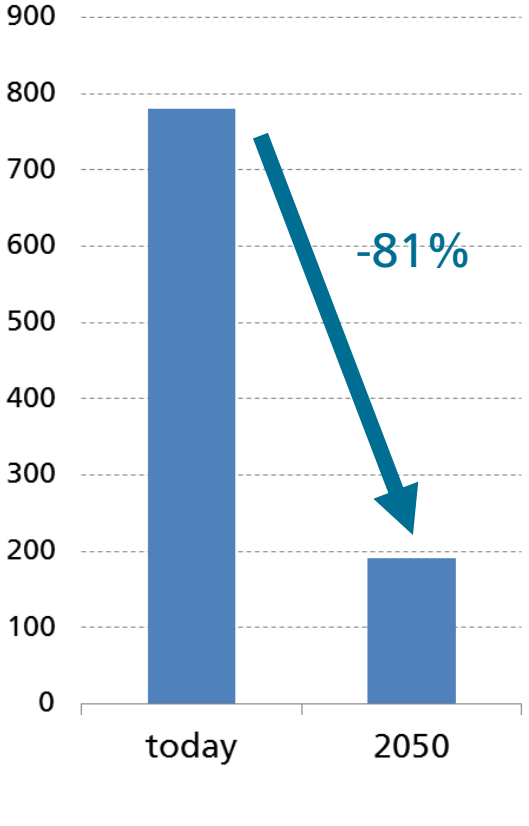


Today's system vs. optimized system in 2050

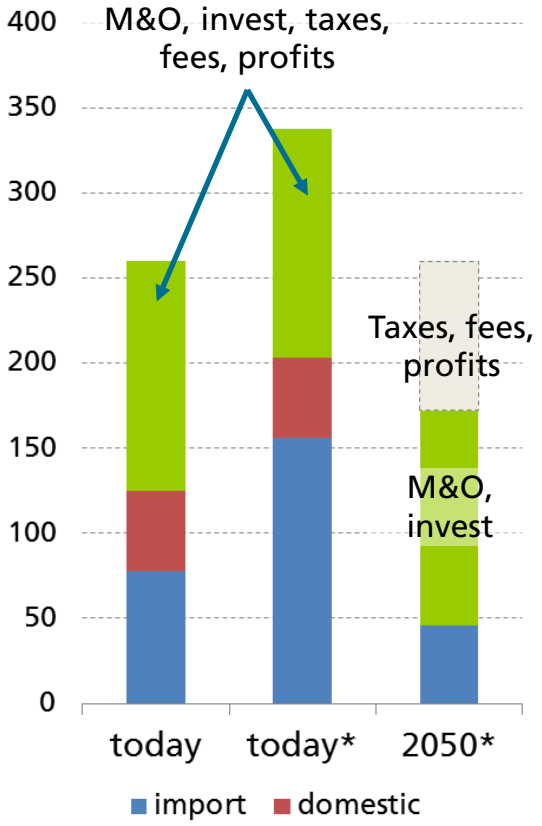
primary energy (TWh)



CO_2 emissions (Mt)



total costs (billion € p.a.)



*Assumed doubling of fossil fuel prices by 2050

Fraunhofer ISE

Outline

- Germany's long-term climate policy targets
- Composition of a target system
- **Phases of the transformation of the energy system**
- Cost analysis
- Conclusions and outlook

Phases of the energy system transformation

Phase 1 „RE development“

CO_2-reduction
~ 0-20%

- Development of basic RE technologies (wind, solar)
- Significant cost reductions
- Market introduction and extension without significant implications for the overall system

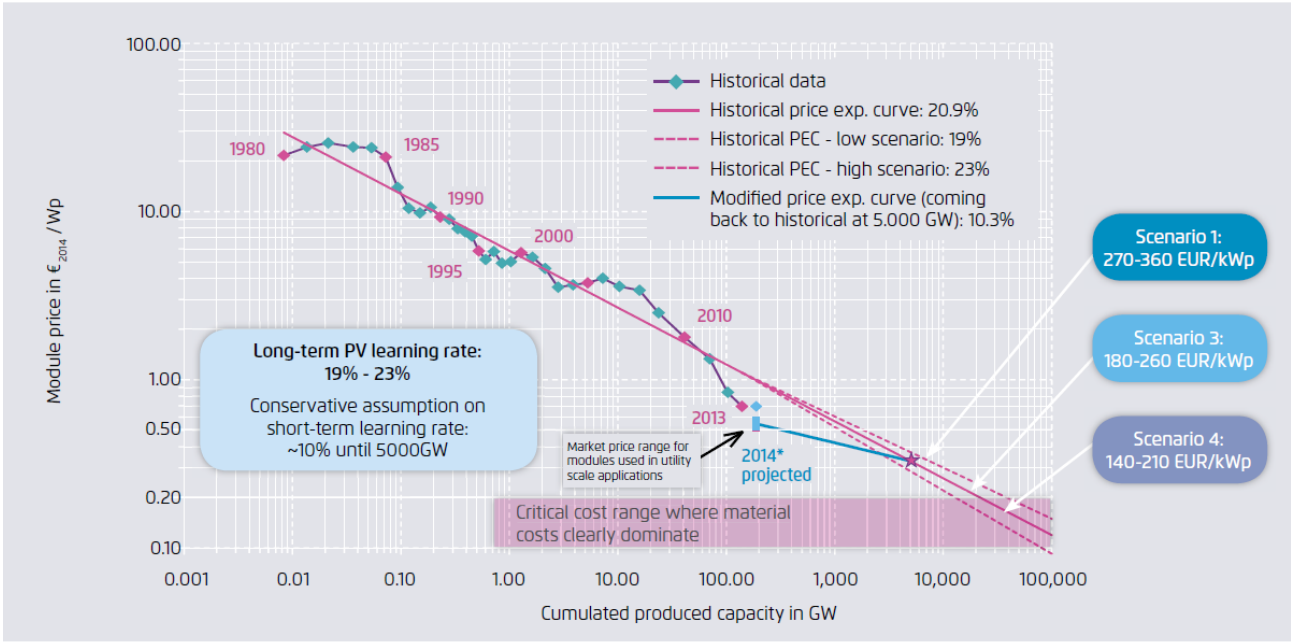
Phases of the energy system transformation

Phase 1 „RE development“

CO_2-reduction
~ 0-20%

- Development of basic RE technologies (wind, solar)
- Significant cost reductions
- Market introduction and extension without significant implications for the overall system

Extrapolation of the price experience curve for PV modules



Own illustration

Fraunhofer ISE

Phases of the energy system transformation

Phase 1 „RE development“	Phase 2 „system integration“
CO_2-reduction ~ 0-20%	CO_2-reduction ~ 20-60%
■ Development of basic RE technologies (wind, solar) ■ Significant cost reductions ■ Market introduction and extension without significant implications for the overall system	■ Activation of flexibilities: residual electricity generation and electricity use ■ Convergence of electricity and heat sector ■ Demand side management ■ Short term storage

Phases of the energy system transformation

Phase 1 „RE development“	Phase 2 „system integration“	Phase 3 „synthetic fuels“
CO_2-reduction ~ 0-20%	CO_2-reduction ~ 20-60%	CO_2-reduction ~ 60-80%
■ Development of basic RE technologies (wind, solar) ■ Significant cost reductions ■ Market introduction and extension without significant implications for the overall system	■ Activation of flexibilities: residual electricity generation and electricity use ■ Convergence of electricity and heat sector ■ Demand side management ■ Short term storage	■ Significant negative residual loads ■ Use of renewable electricity for production of synthetic fuels ■ Increased use of synthetic fuels for mobility sector

Phases of the energy system transformation

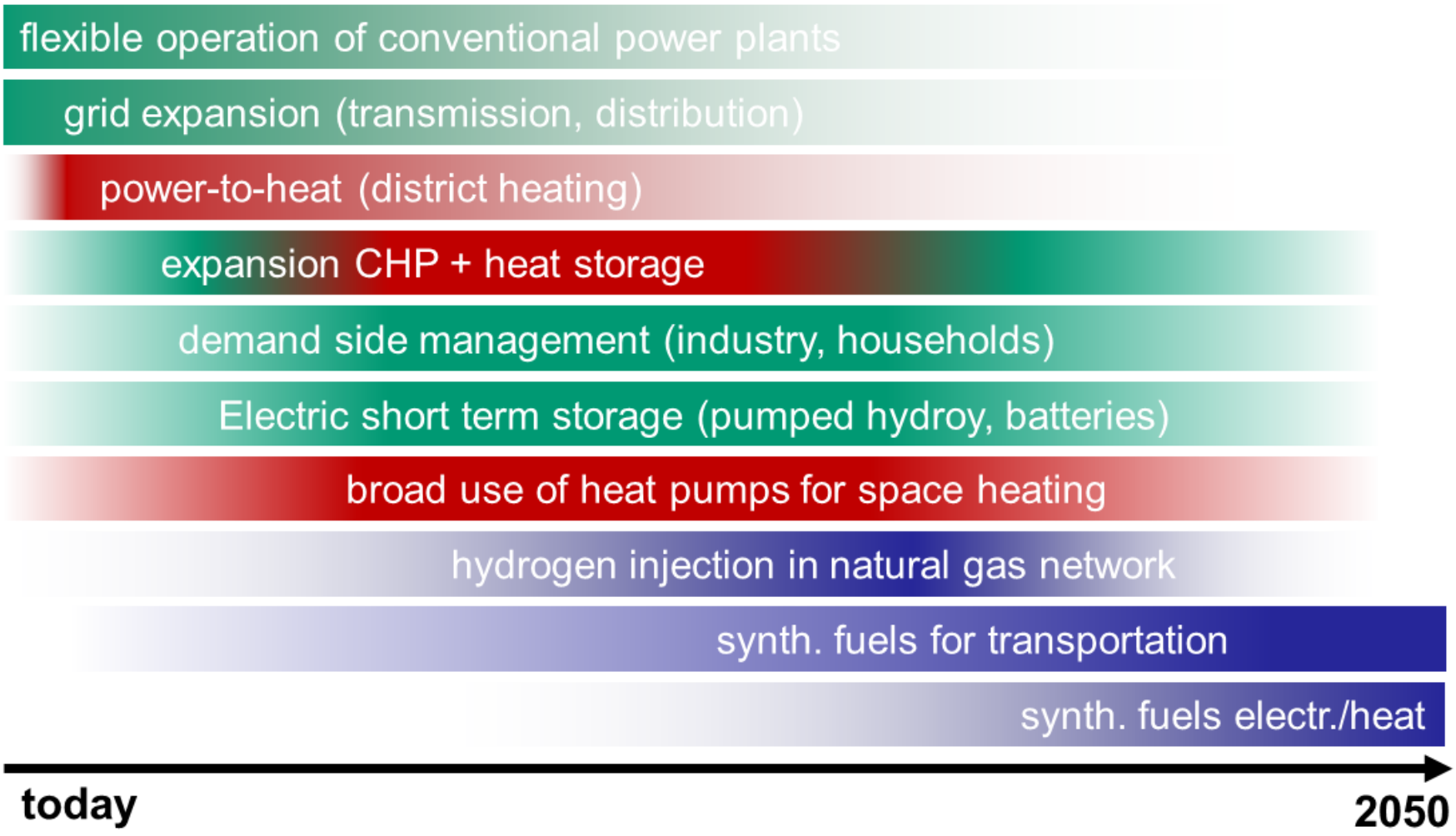
Phase 1 „RE development“	Phase 2 „system integration“	Phase 3 „synthetic fuels“	Phase 4 „RE import“
CO_2-reduction ~ 0-20%	CO_2-reduction ~ 20-60%	CO_2-reduction ~ 60-80%	CO_2-Reduktion ~ 80-100 %
■ Development of basic RE technologies (wind, solar) ■ Significant cost reductions ■ Market introduction and extension without significant implications for the overall system	■ Activation of flexibilities: residual electricity generation and electricity use ■ Convergence of electricity and heat sector ■ Demand side management ■ Short term storage	■ Significant negative residual loads ■ Use of renewable electricity for production of synthetic fuels ■ Increased use of synthetic fuels for mobility sector	■ Final displacement of fossil fuels in all end-use sectors ■ Import of renewable fuels, e.g. from regions in the sun belt (e.g. north africa)

Phases of the energy system transformation

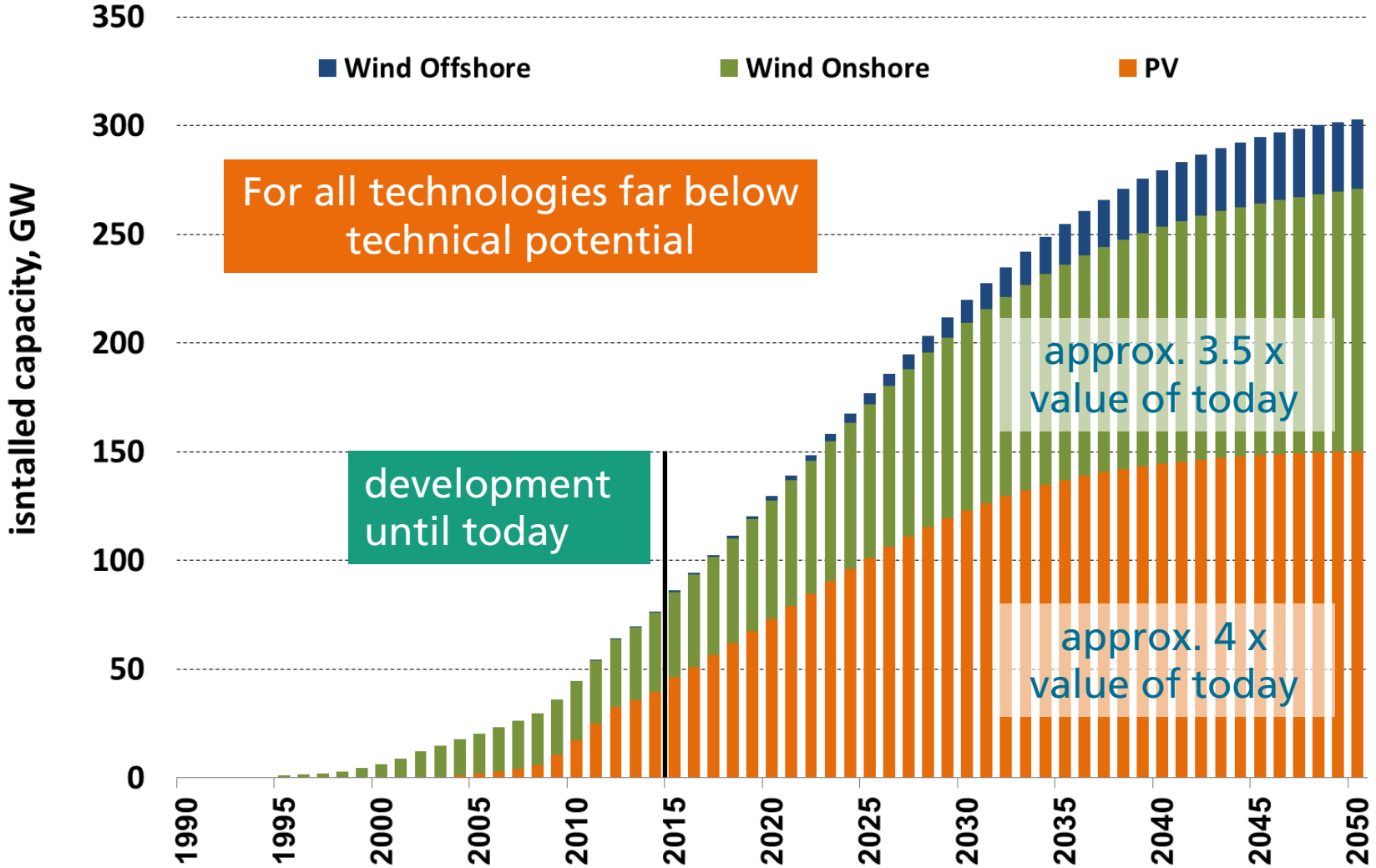
Phase 1 „RE development“	Phase 2 „system integration“	Phase 3 „synthetic fuels“	Phase 4 „RE import“
CO_2-reduction ~ 0-20%	CO_2-reduction ~ 20-60%	CO_2-reduction ~ 60-80%	CO_2-Reduktion ~ 80-100 %
■ Development of basic RE technologies (wind, solar) ■ Significant cost reductions ■ Market introduction and extension without significant implications for the overall system	■ Activation of flexibilities: residual electricity generation and electricity use ■ Convergence of electricity and heat sector ■ Demand side management ■ Short term storage	■ Significant negative residual loads ■ Use of renewable electricity for production of synthetic fuels ■ Increased use of synthetic fuels for mobility sector	■ Final displacement of fossil fuels in all end-use sectors ■ Import of renewable fuels, e.g. from regions in the sun belt (e.g. north africa)

- Continuous increase of efficiency in end-use sectors
  - Energetic refurbishment (building stock)
  - Reduction of electricity use in classical end-use applications (e.g. artificial lighting, pumps and drives, …)
- Continuous extension of renewable energy converters (solar, wind, geothermal)

Transition steps



Projection of RE development



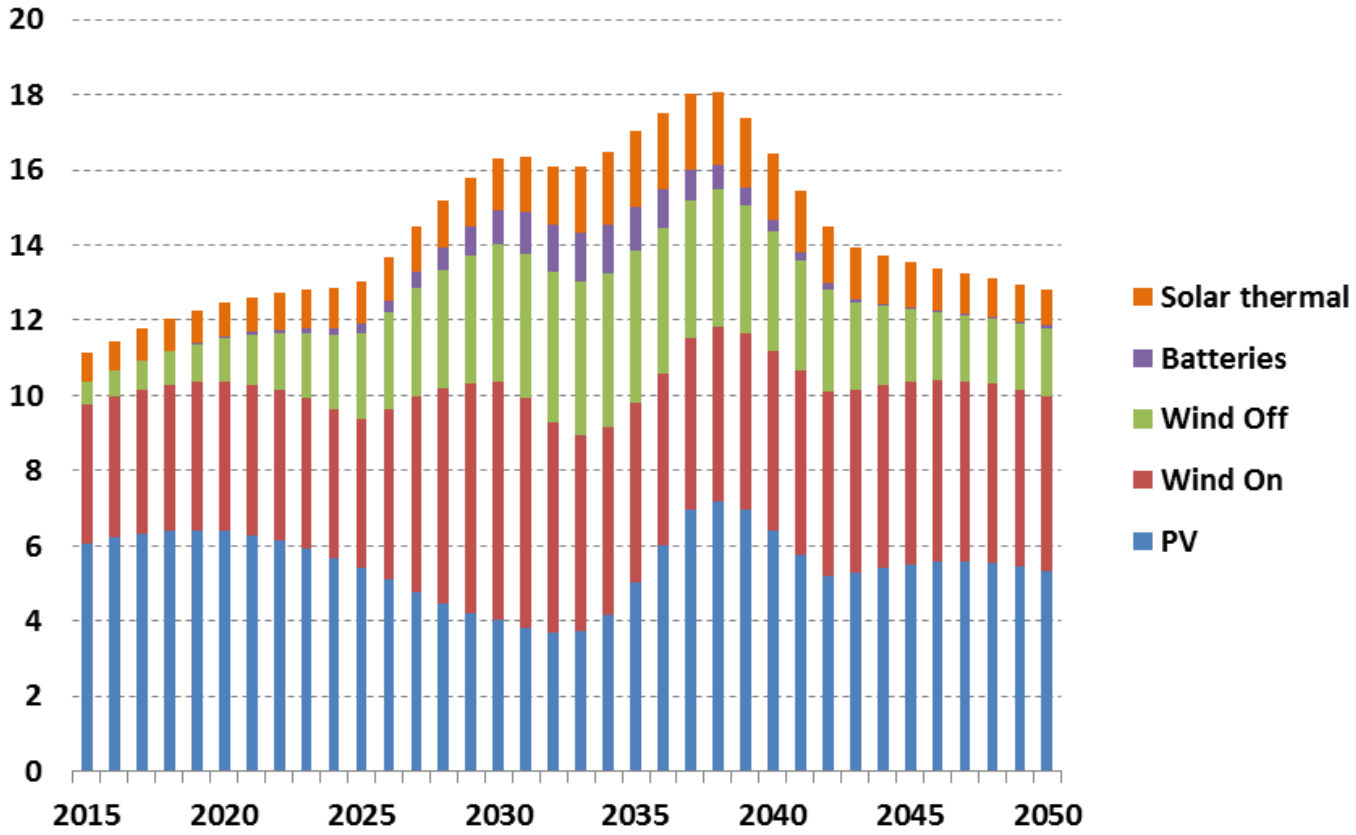
Fraunhofer ISE

Outline

- Germany's long-term climate policy targets
- Composition of a target system
- Phases of the transformation of the energy system
- **Cost analysis**
- Conclusions and outlook

Investments for RE (wind, solar) and stationary batteries

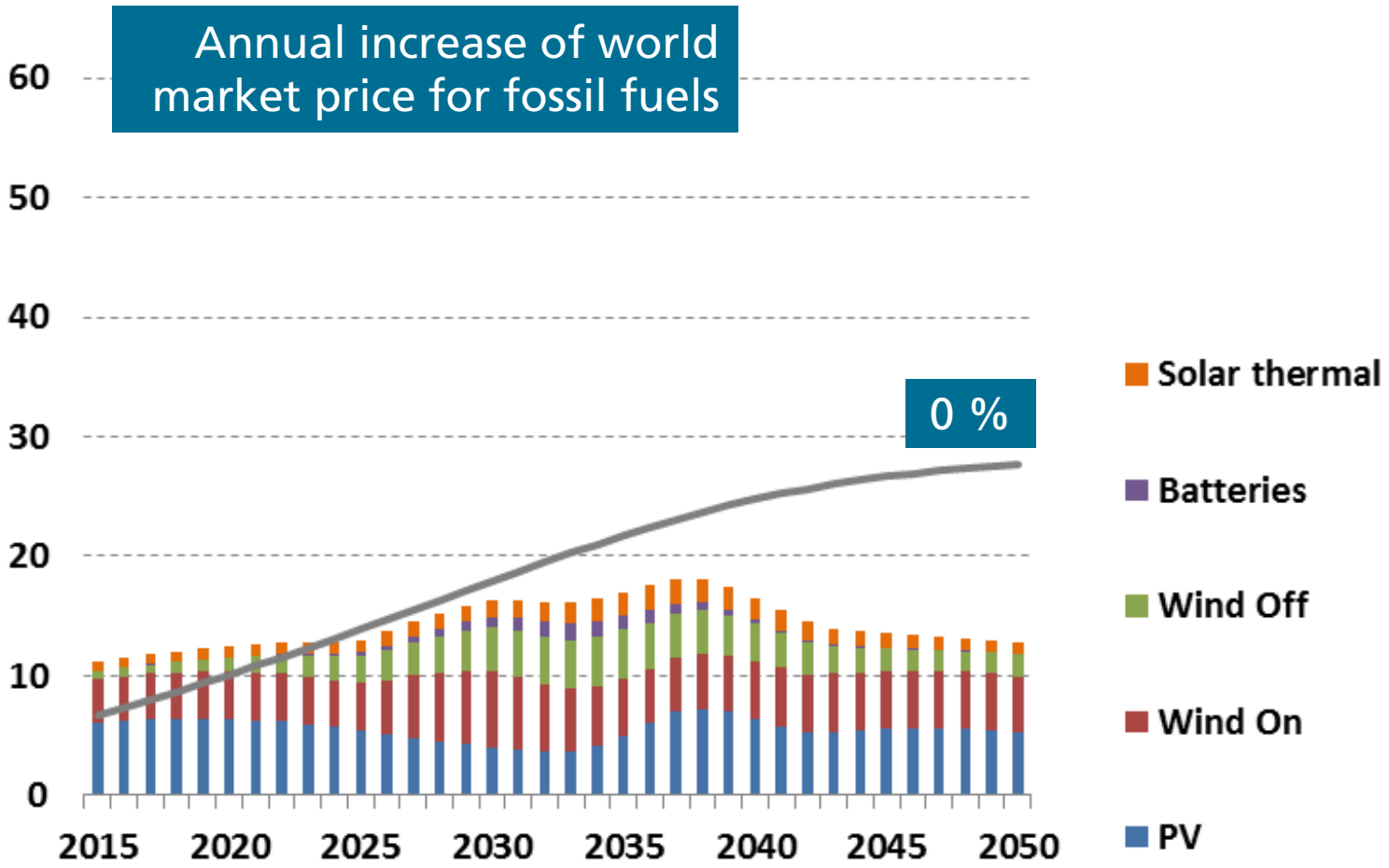
bn € p.a. (incl. repowering)



Total investments (w/o capital cost, incl. re-powering) from 2015 to 2050: 515 bln $€_{2014}$

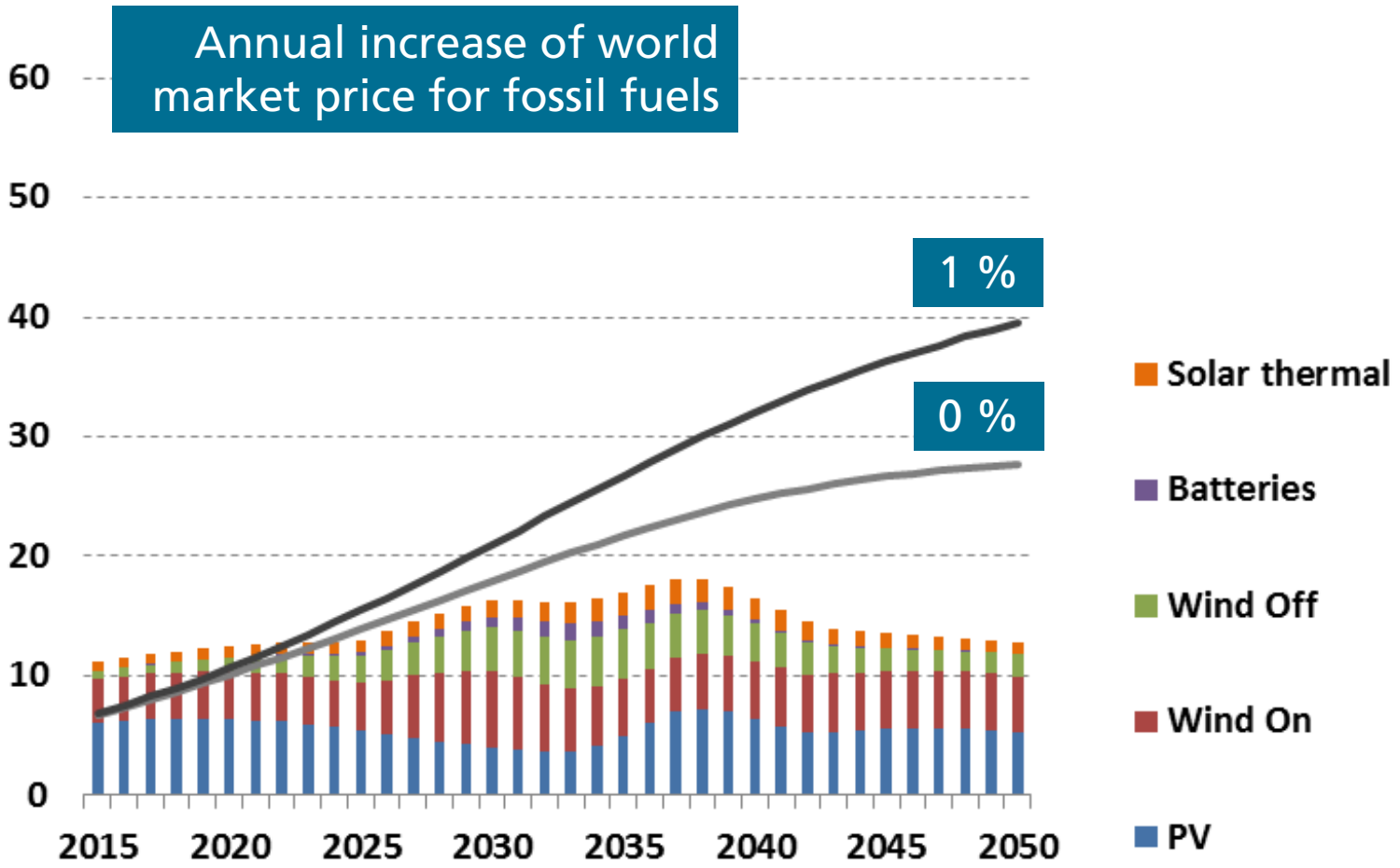
Fraunhofer ISE

Investments vs. saved fuel cost in bn € p.a.



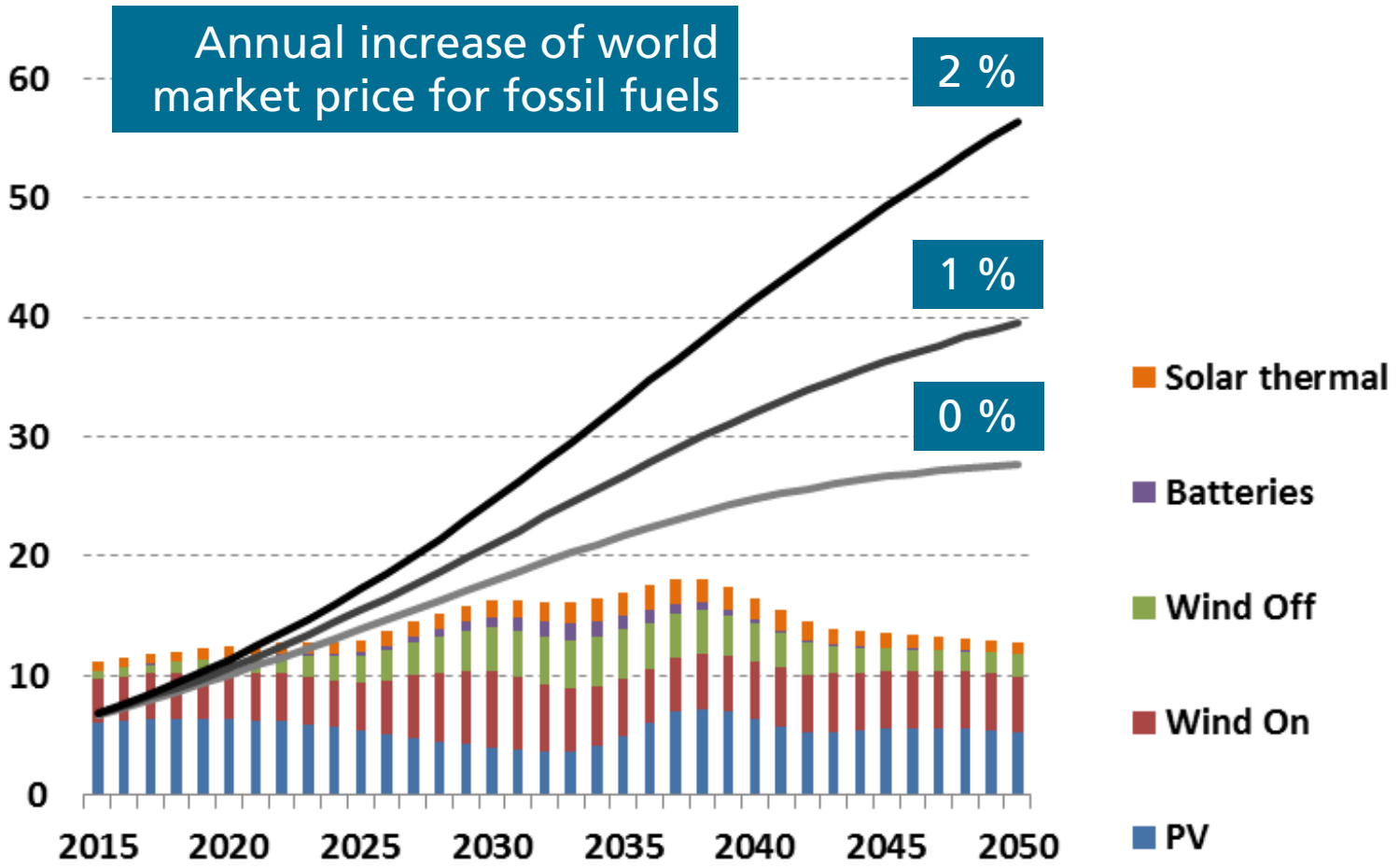
Fraunhofer ISE

Investments vs. saved fuel cost in bn € p.a.

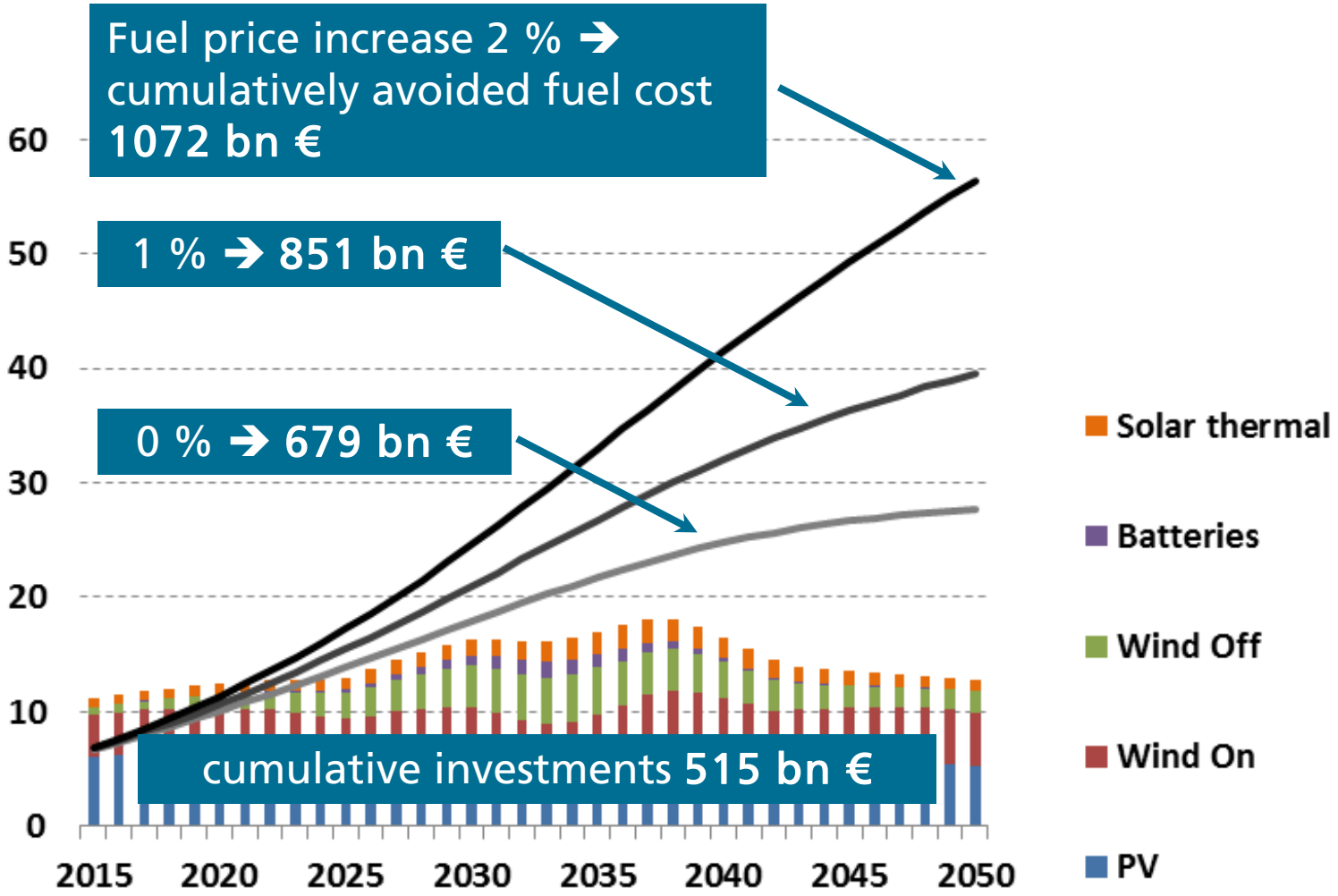


Fraunhofer ISE

Investments vs. saved fuel cost in bn € p.a.

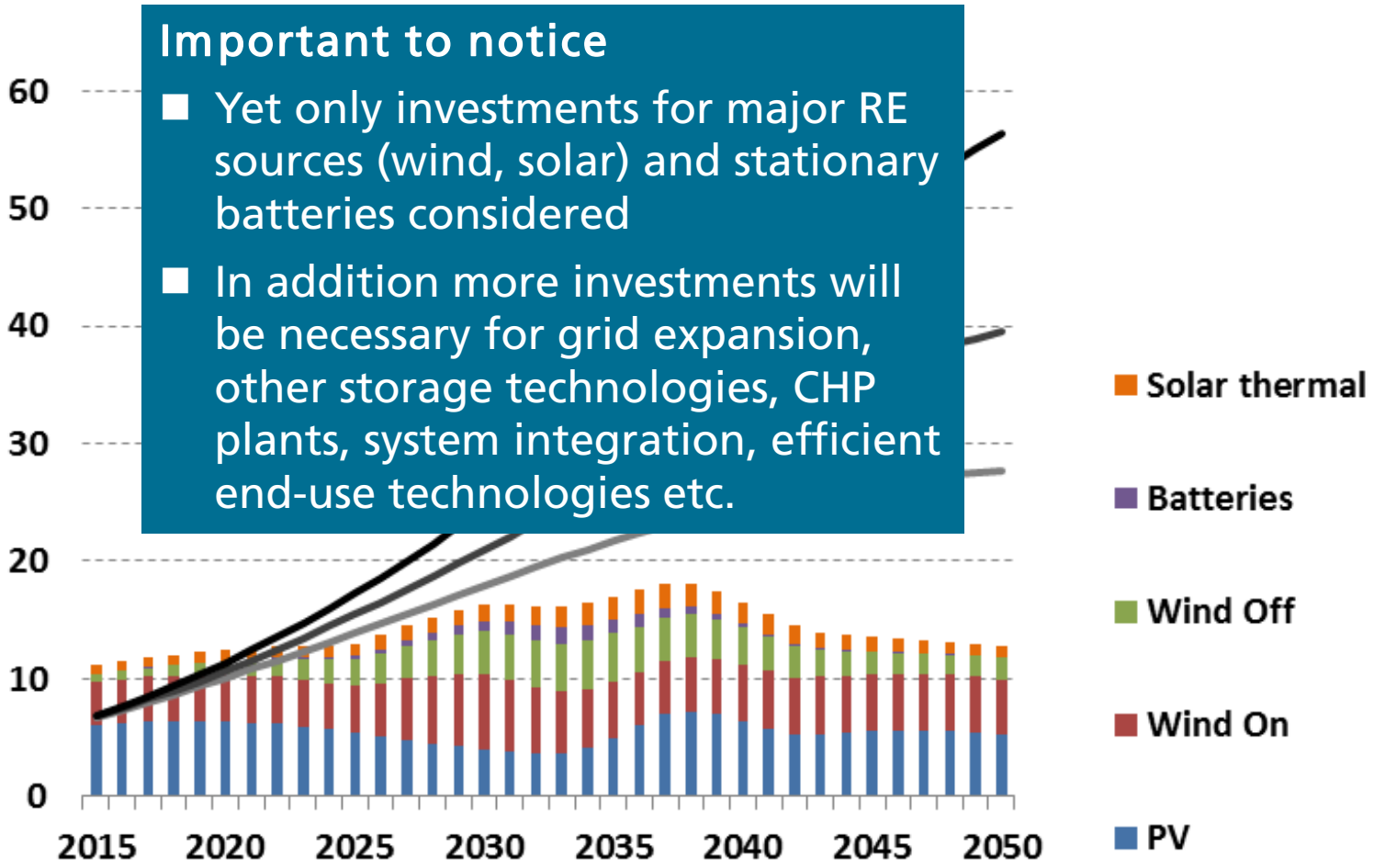


Investments vs. saved fuel cost in bn € p.a.



Fraunhofer ISE

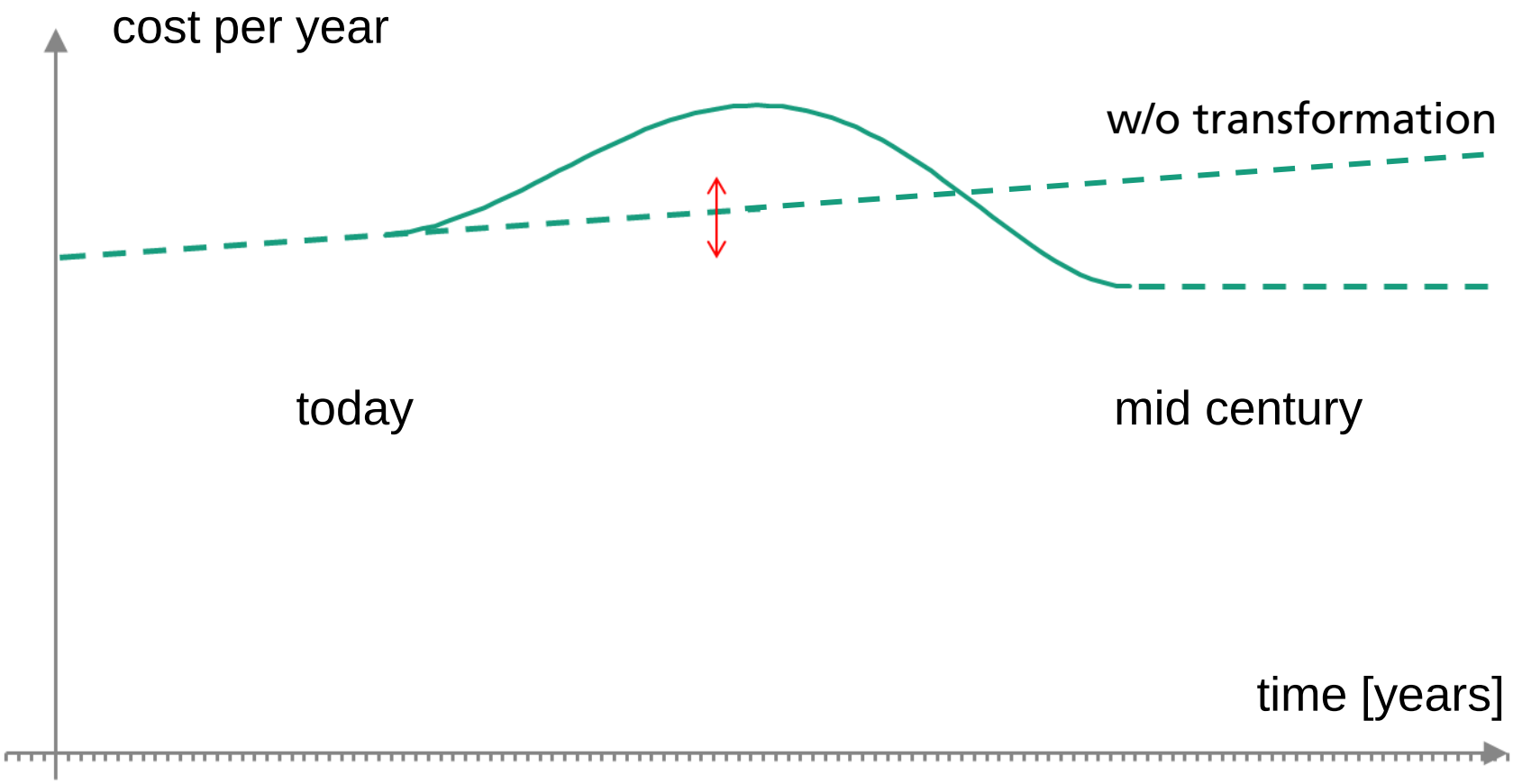
Investments vs. saved fuel cost in bn € p.a.



Fraunhofer ISE

Transformation of the energy system

Qualitative trend of total annual cost



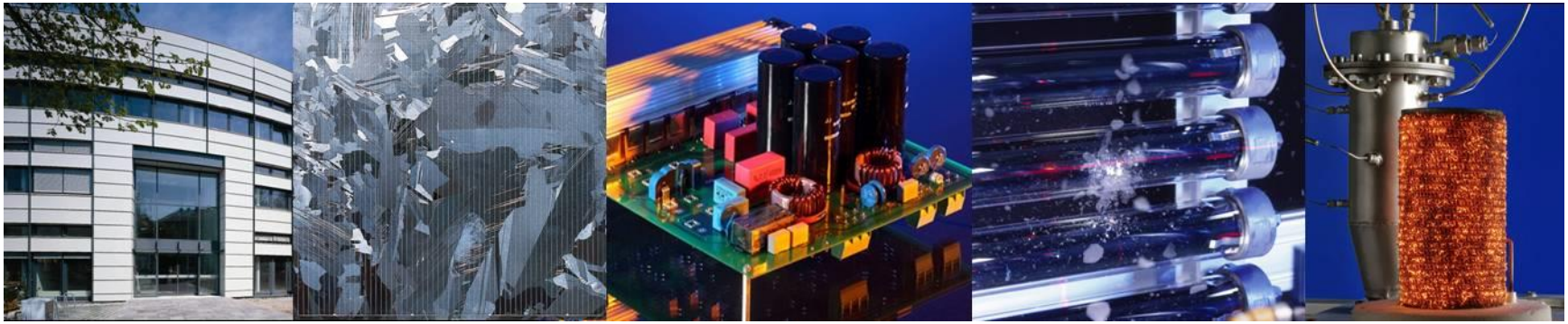
Outline

- Germany's long-term climate policy targets
- Composition of a target system
- Phases of the transformation of the energy system
- Cost analysis
- Conclusions and outlook

Conclusions and outlook

- Reduction of energy-related CO_2 emissions by 80 % and above possible
- Lower cost on long term (once major transformation completed)
- Significantly reduced dependence on imports of energy resources
- Flucutuaing renewable energies (wind, solar PV) become backbone of electricity generation and dominate the overall system
- Flexibilization of residual electricity production and electricity use in all end-use sectors (mobility, heating)
- Intersectorial integration important: electricity, heat, transportation, industry processes
- Significant local value and employment creation
- Results can be transferred to other industrialized regions or countries
- Ongoing further model development: optimization of transformation pathway (minimizing overall transformation cost)

Thank you for your attention…



Fraunhofer Institute for Solar Energy Systems ISE

Hans-Martin Henning

www.ise.fraunhofer.de
hans-martin.henning@ise.fraunhofer.de

Fraunhofer ISE