

DESIGN OF FUTURE ENERGY SYSTEMS TOWARDS 100 % RENEWABLES



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Outline

GHG emissions and targets in Germany and Europe

Optimization of transformation pathways – methodology

Results

Phases of energy system transformation

Conclusions

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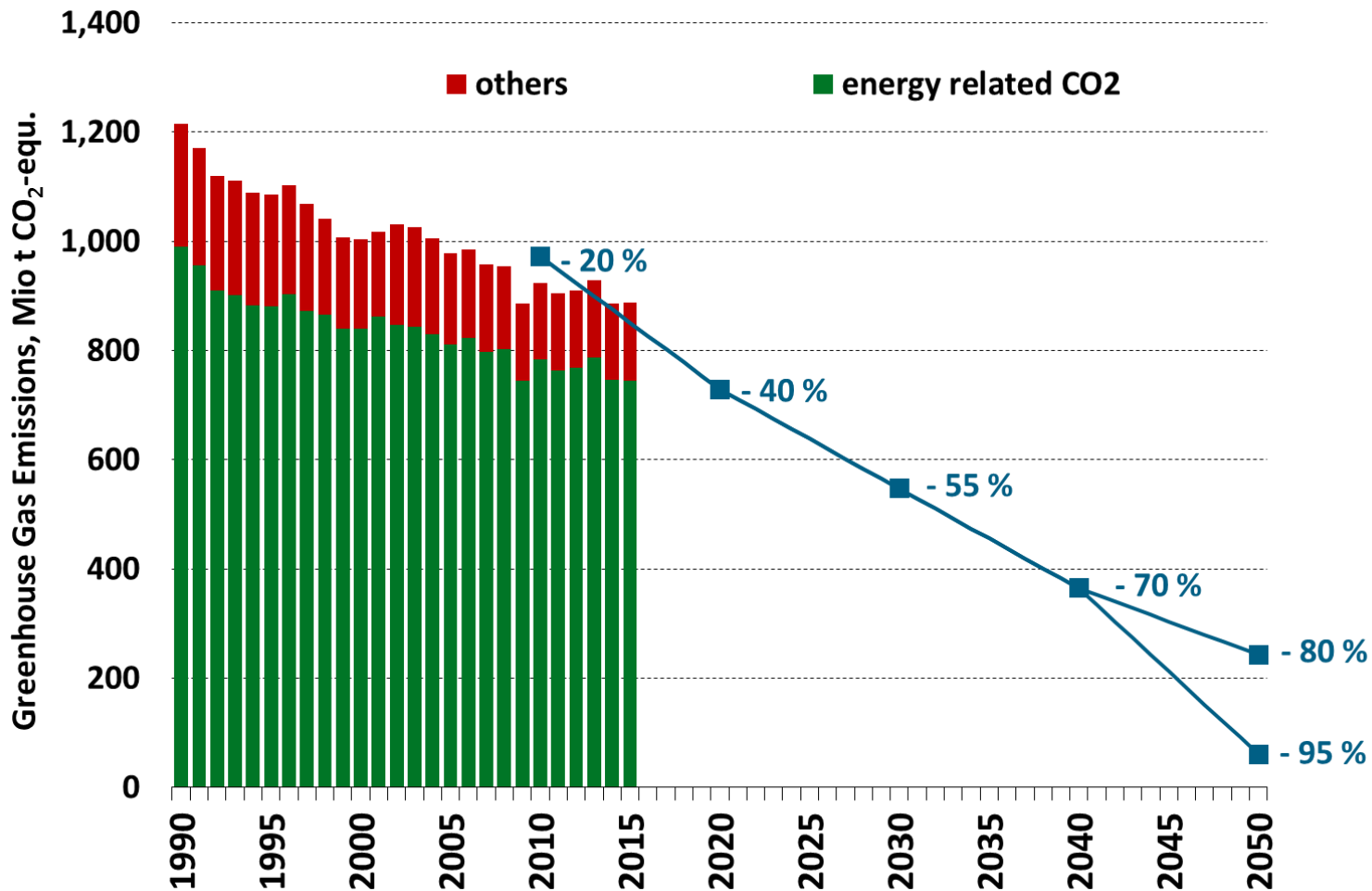
Deep transformation of our energy systems

- Climate and sustainability targets are key topics on the global political agenda
 - Energy supply causes major parts of anthropogenic climate change
 - Clear target → energy systems with drastically reduced CO₂ emissions
 - But: the pathway is highly complex
- Powerful tools & models needed for comprehensive optimization of energy system transformation pathways



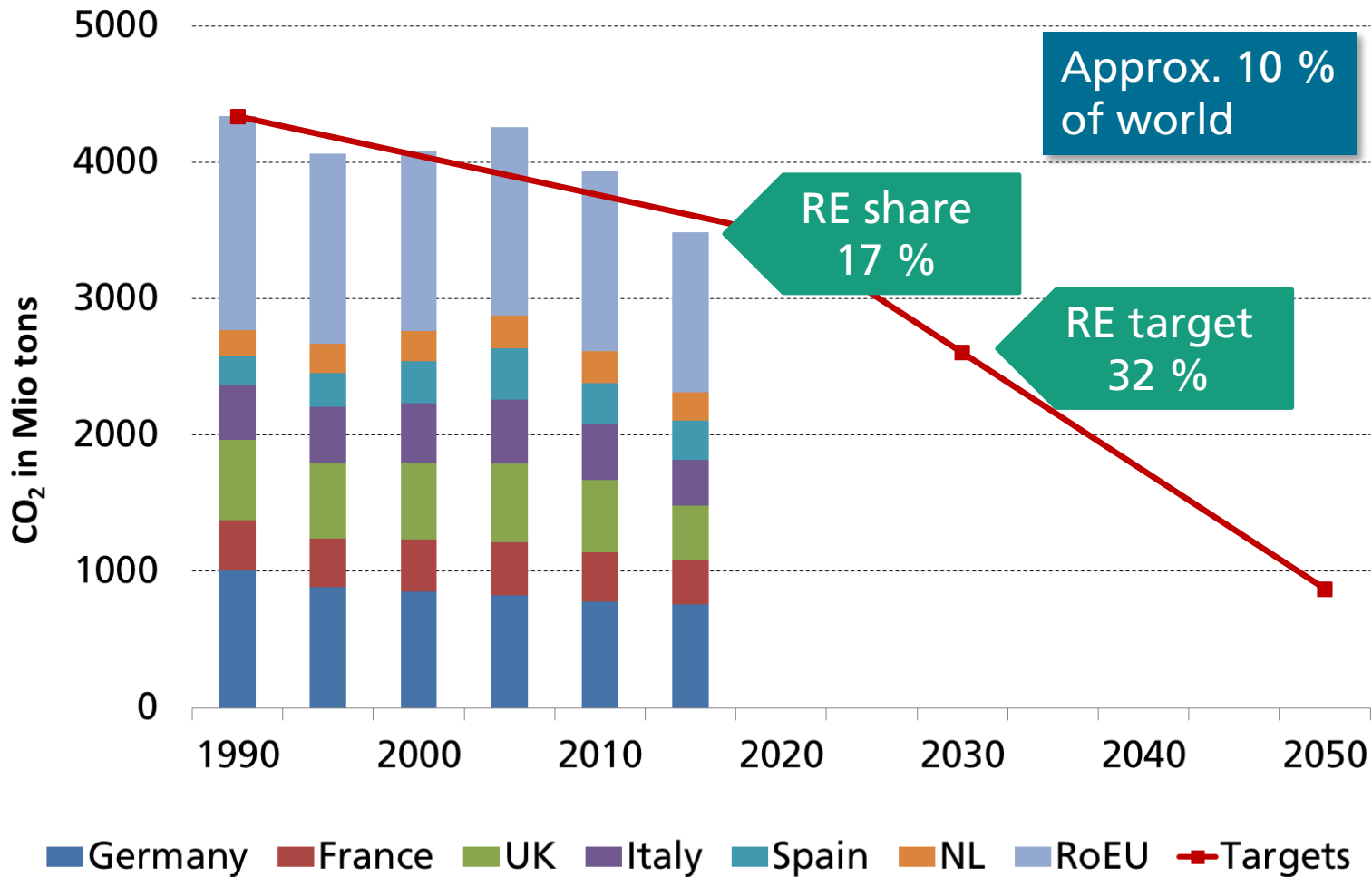
German GHG emissions

Historical values 1990-2015 and target values until 2050



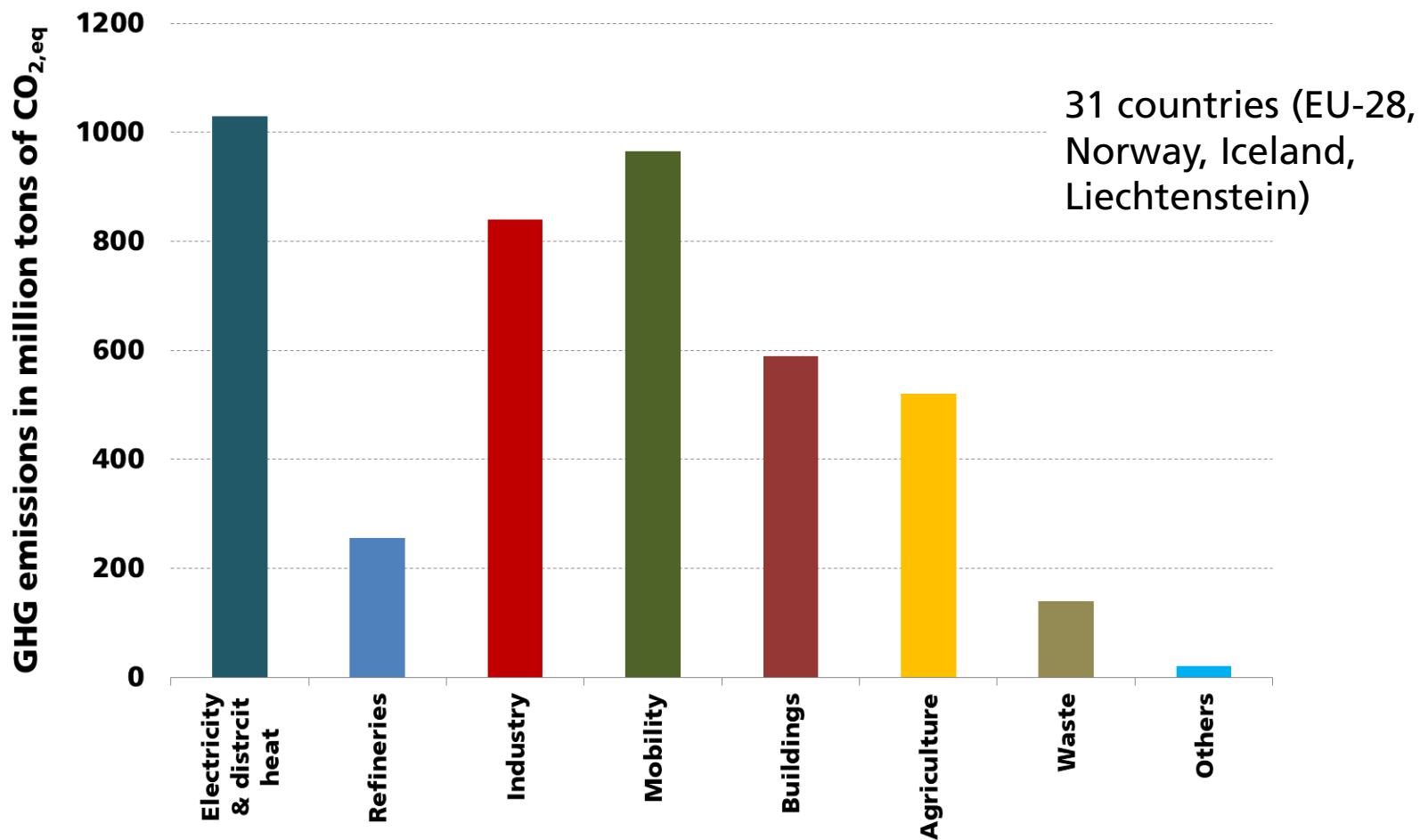
European Union CO₂ emissions

Historical values 1990-2016 and target values until 2050



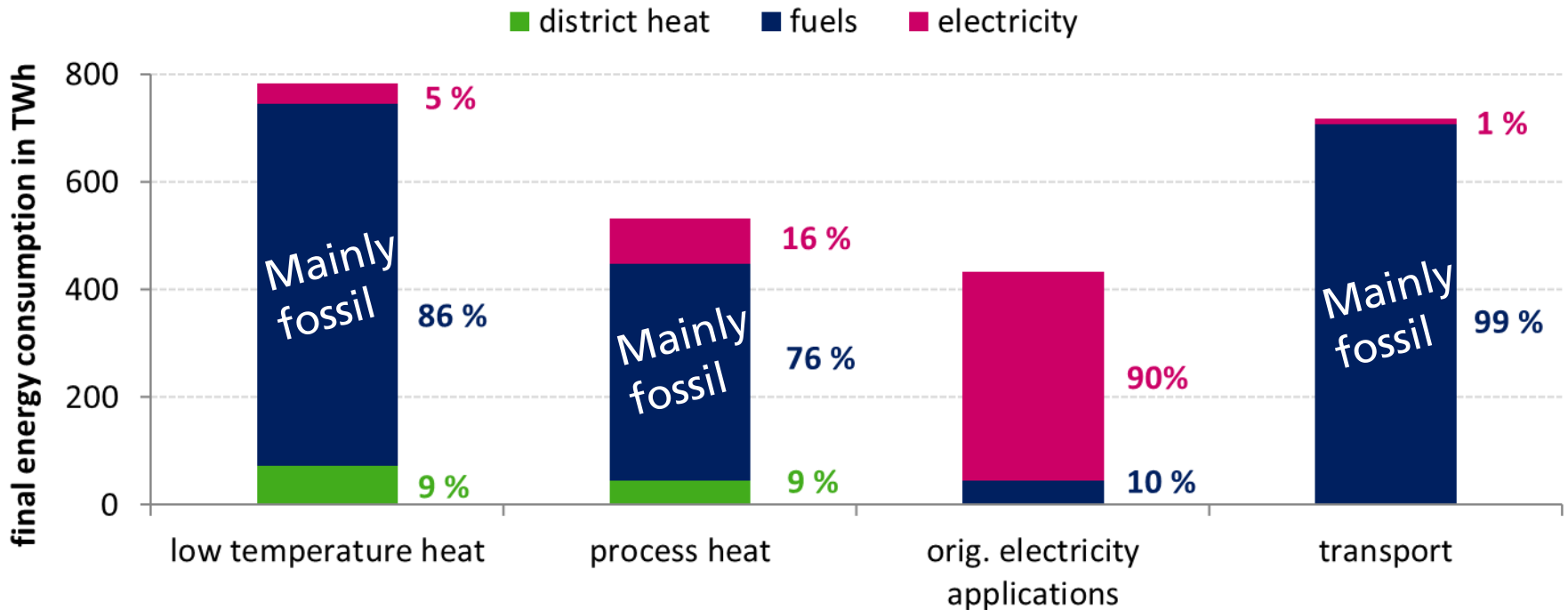
Greenhouse gas emissions in Europe (2016)

Sectorial distribution



German energy demand of today

Composition of final energy



Source of data: „Energiedaten, Gesamtausgabe“, BMWi, 02/2017

Major questions

- How can **heat (buildings, industry processes)** and **transportation** sectors become less dependent from fossil energy sources?

- How can the **complex overall system** be transformed towards achieving **climate targets** without compromising on **security of supply** and at **minimal cost**?

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Renewable Energy Model »REMod«

Mimimize
total cost



Electricity Generation and Storage



Fuels (incl. biomass and Power-to-Hydrogen/Gas/Fuel)



REMod

Strictly model-based
techno-economic
optimization of
transformation
pathways based on
comprehensive
simulation of
energy systems
(hourly time scale)



Transport (different drive technologies)

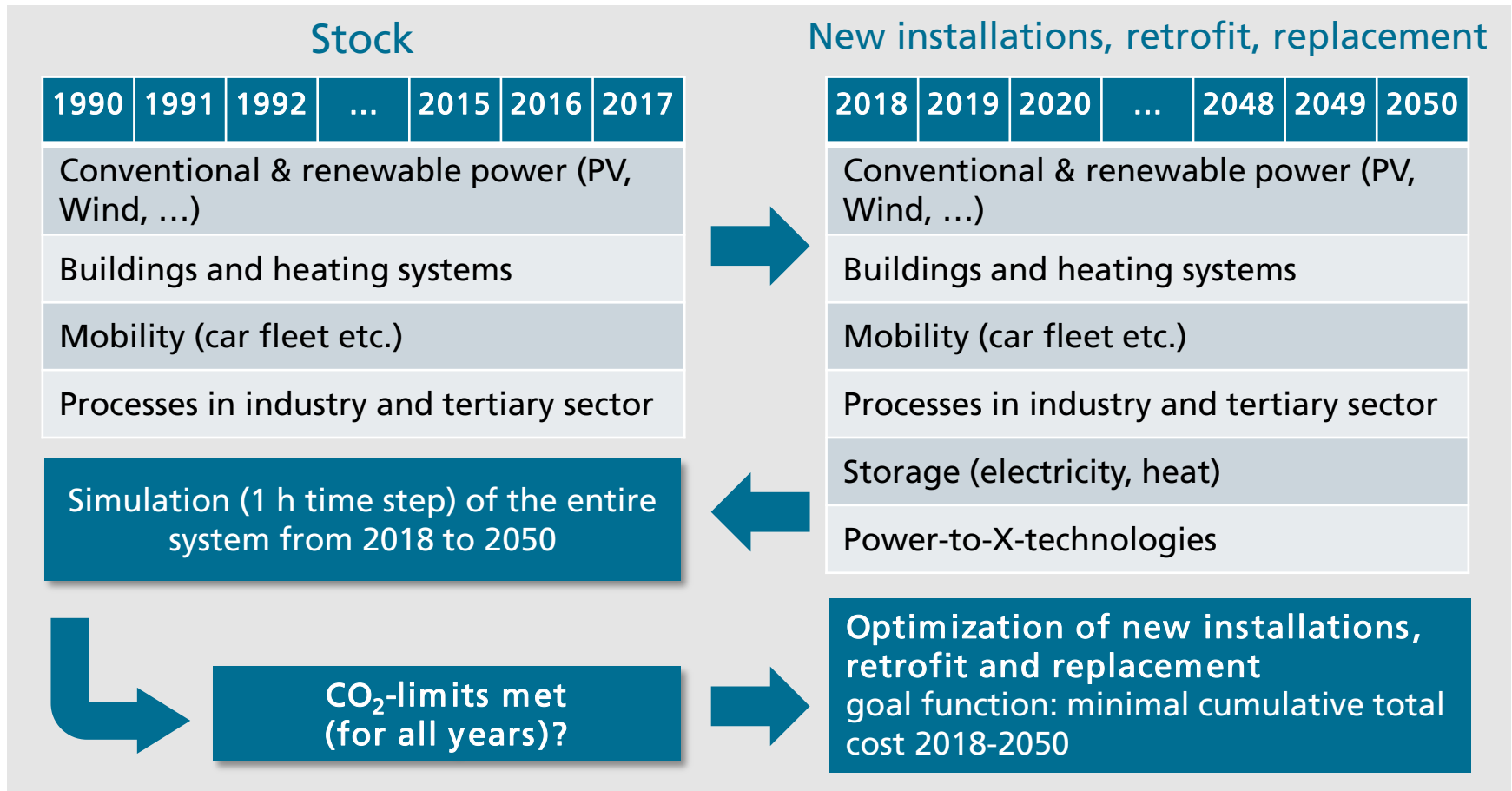


Heating (buildings, district heating and storage)



Processes in Trade and Industry

Methodology



Study by the German academies of science

Investigated transformation pathways

Scenario	CO ₂ goal	Major characteristics
No restrictions		<ul style="list-style-type: none"> ❑ No limits for direct electricity use (e.g. heat pumps, transportation)
Hydrogen	Minus 85 % in 2050 (compared to 1990)	<ul style="list-style-type: none"> ❑ Transportation with majority of hydrogen / fuel cell drive trains ❑ High fraction of H₂ in gas network
Power-to-Gas Power-to-Liquid (P2G/P2L)		<ul style="list-style-type: none"> ❑ Transportation with majority of fuel/methane based drive trains ❑ Building heating partly based on methane ❑ Good progress in efficiency in industry
High efficiency		<ul style="list-style-type: none"> ❑ No limits for direct electricity use ❑ Good progress in implementing high efficiency technologies ❑ Good progress in reducing energy demand

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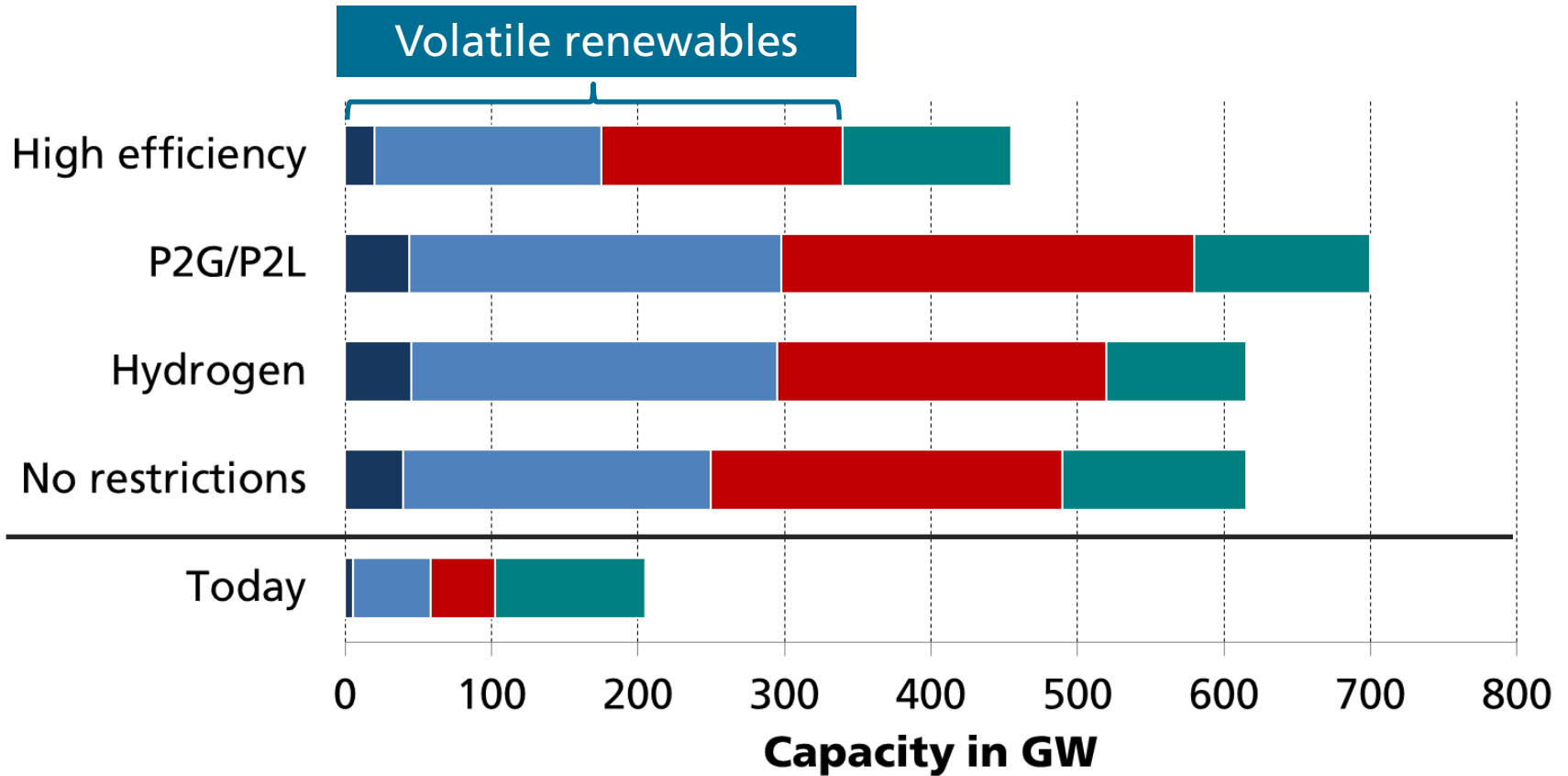
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Electricity generation

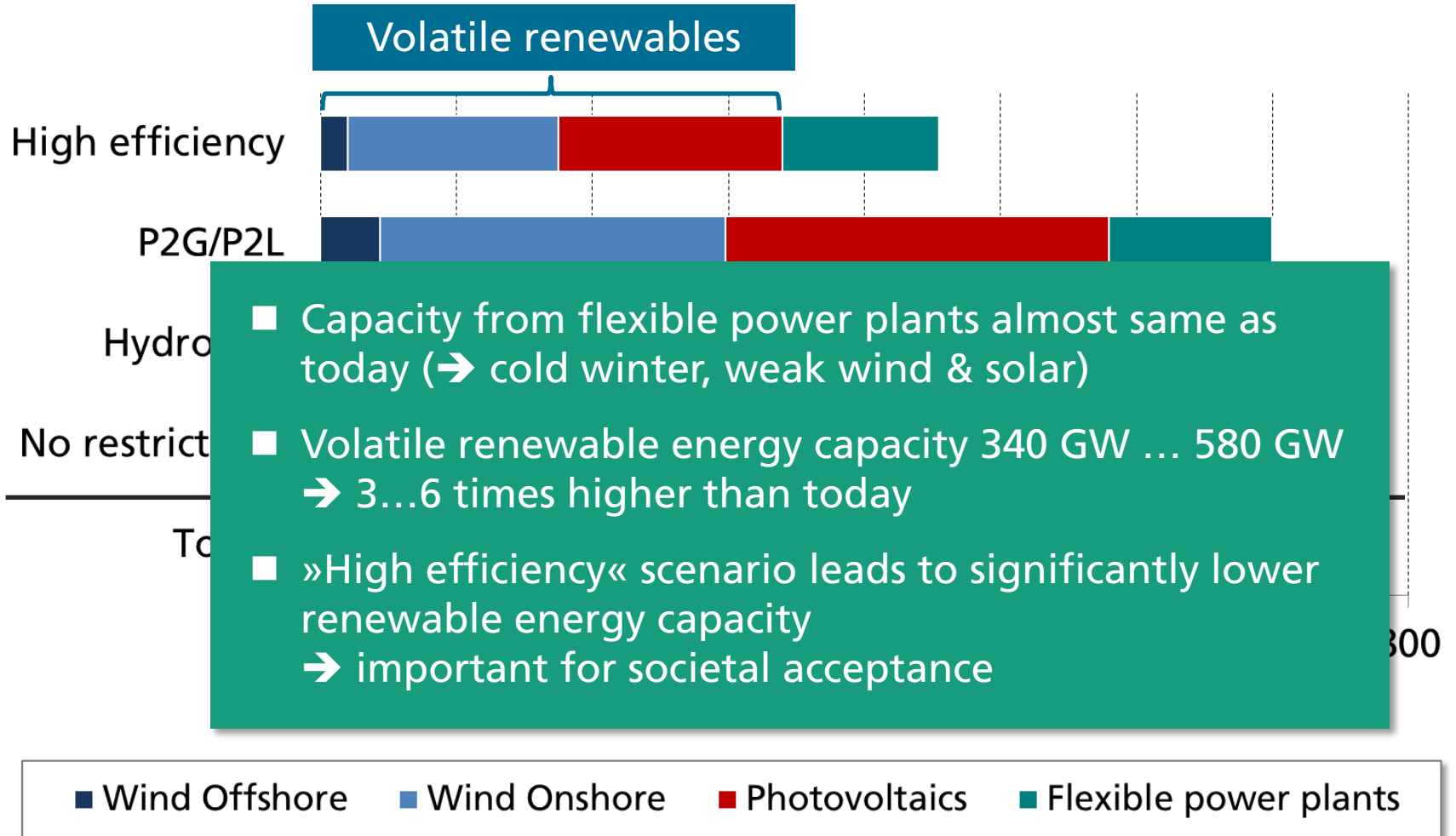
Installed capacity in GW in 2050 and today



■ Wind Offshore ■ Wind Onshore ■ Photovoltaics ■ Flexible power plants

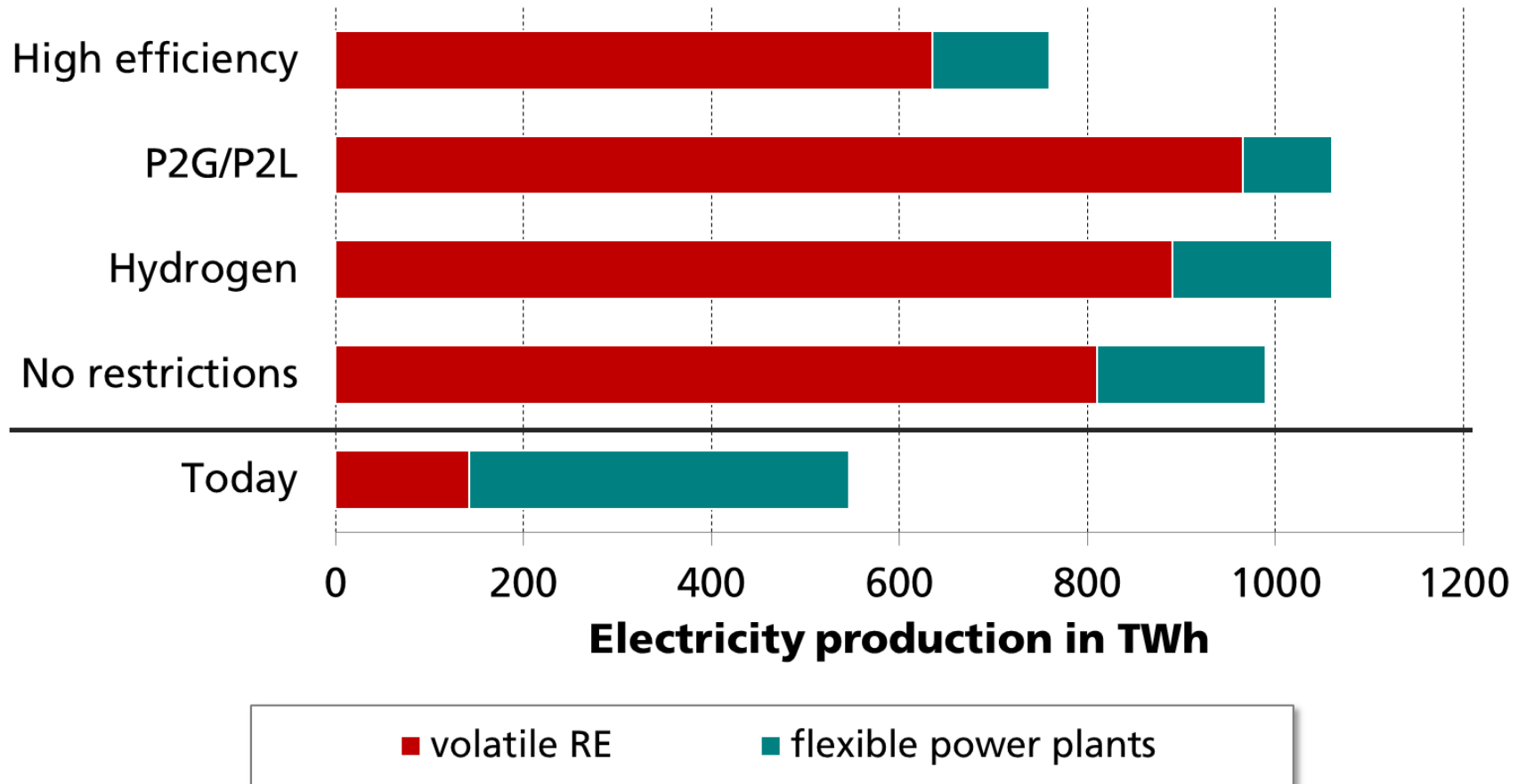
Electricity generation

Installed capacity in GW in 2050 and today



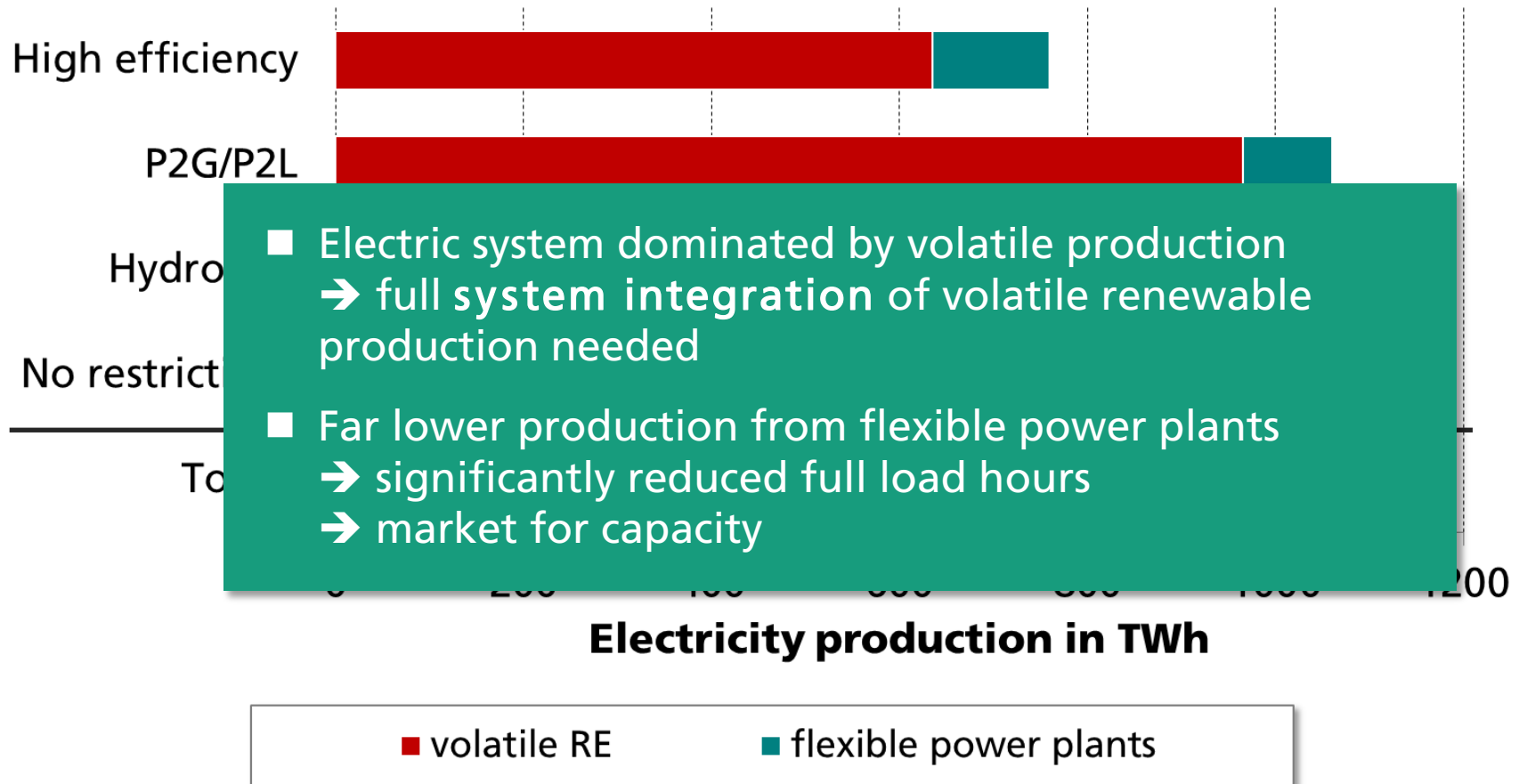
Electricity generation

Annual energy in TWh in 2050 and today



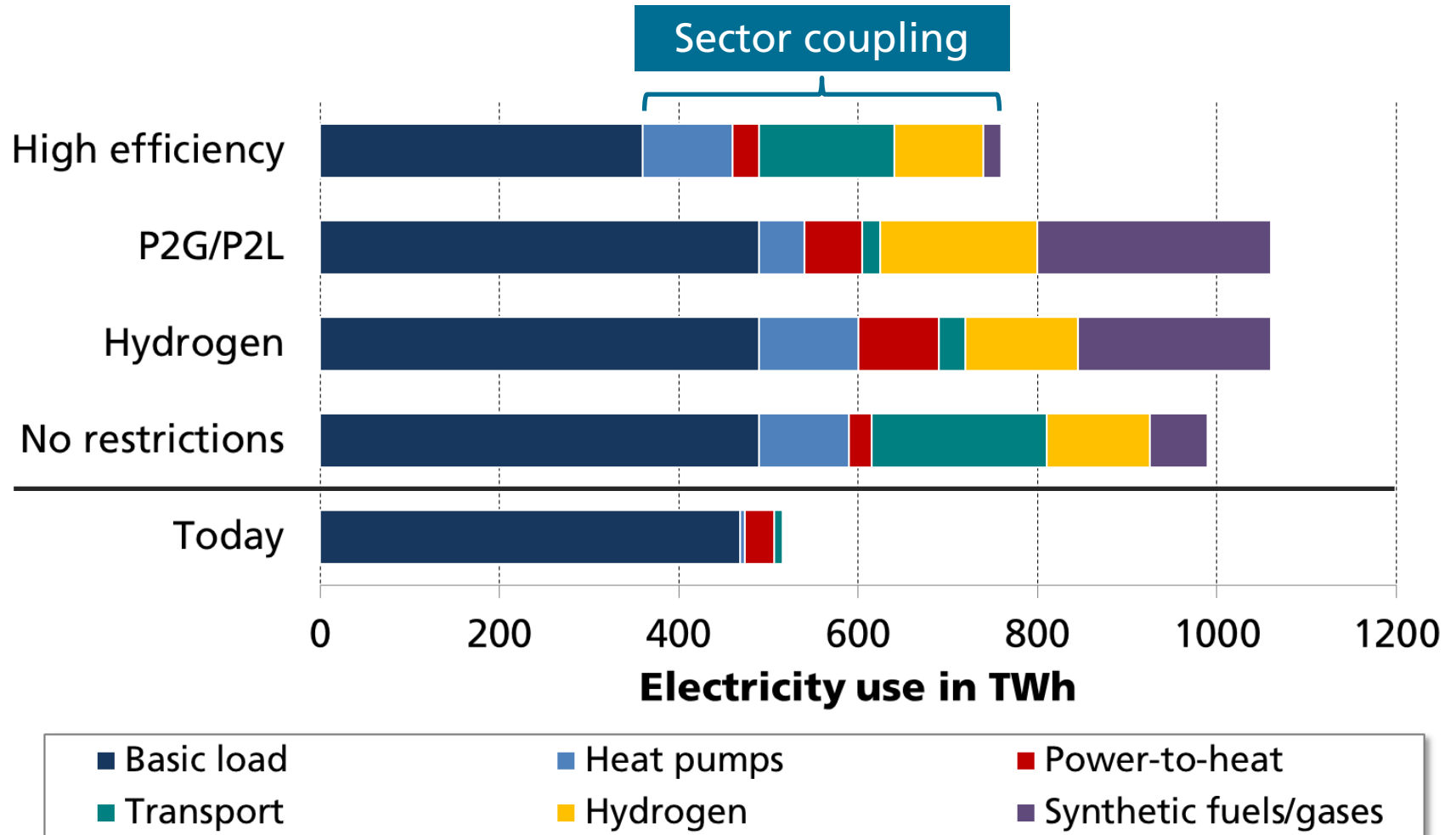
Electricity generation

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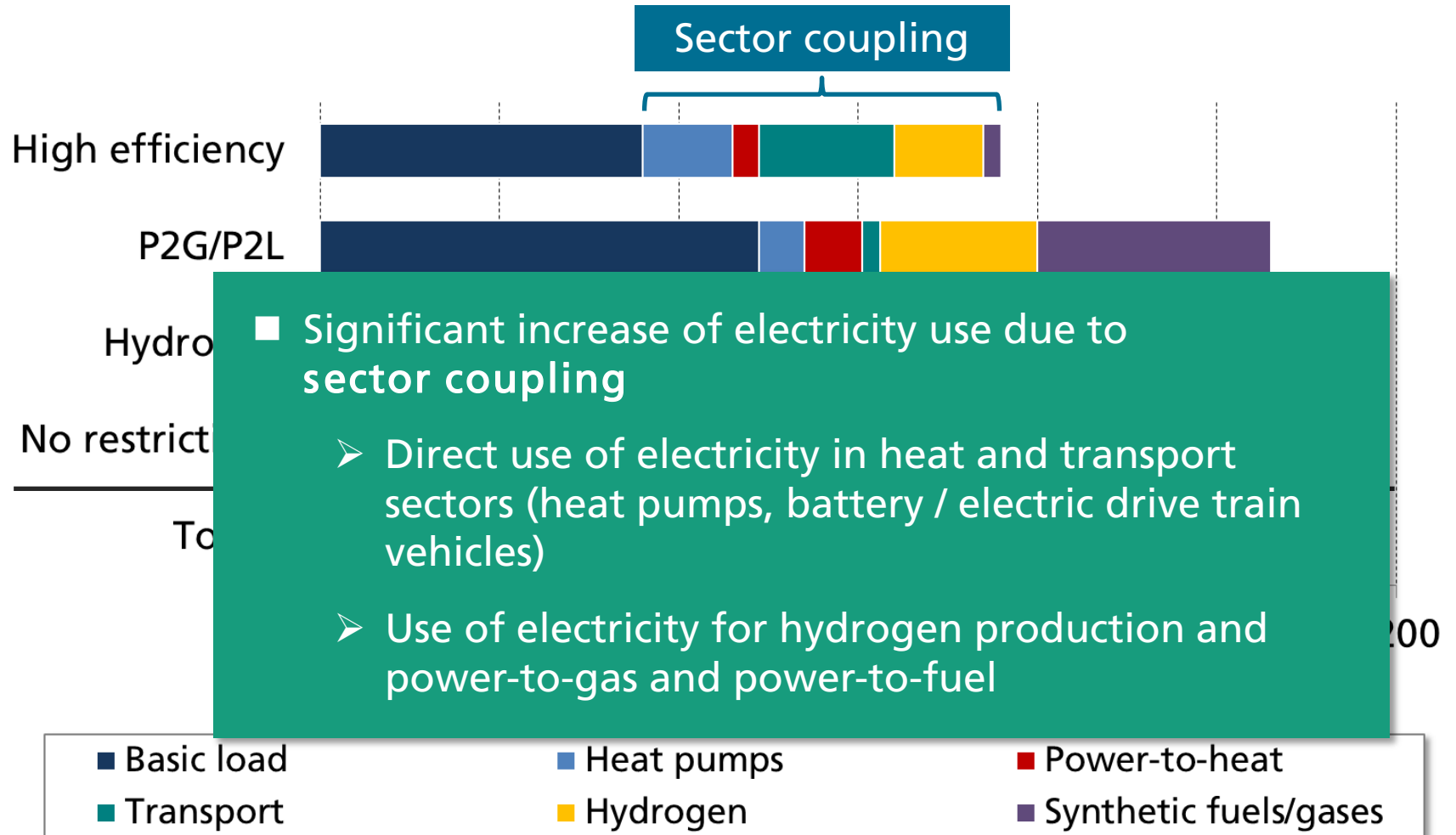
Electricity use

Annual energy in TWh in 2050 and today



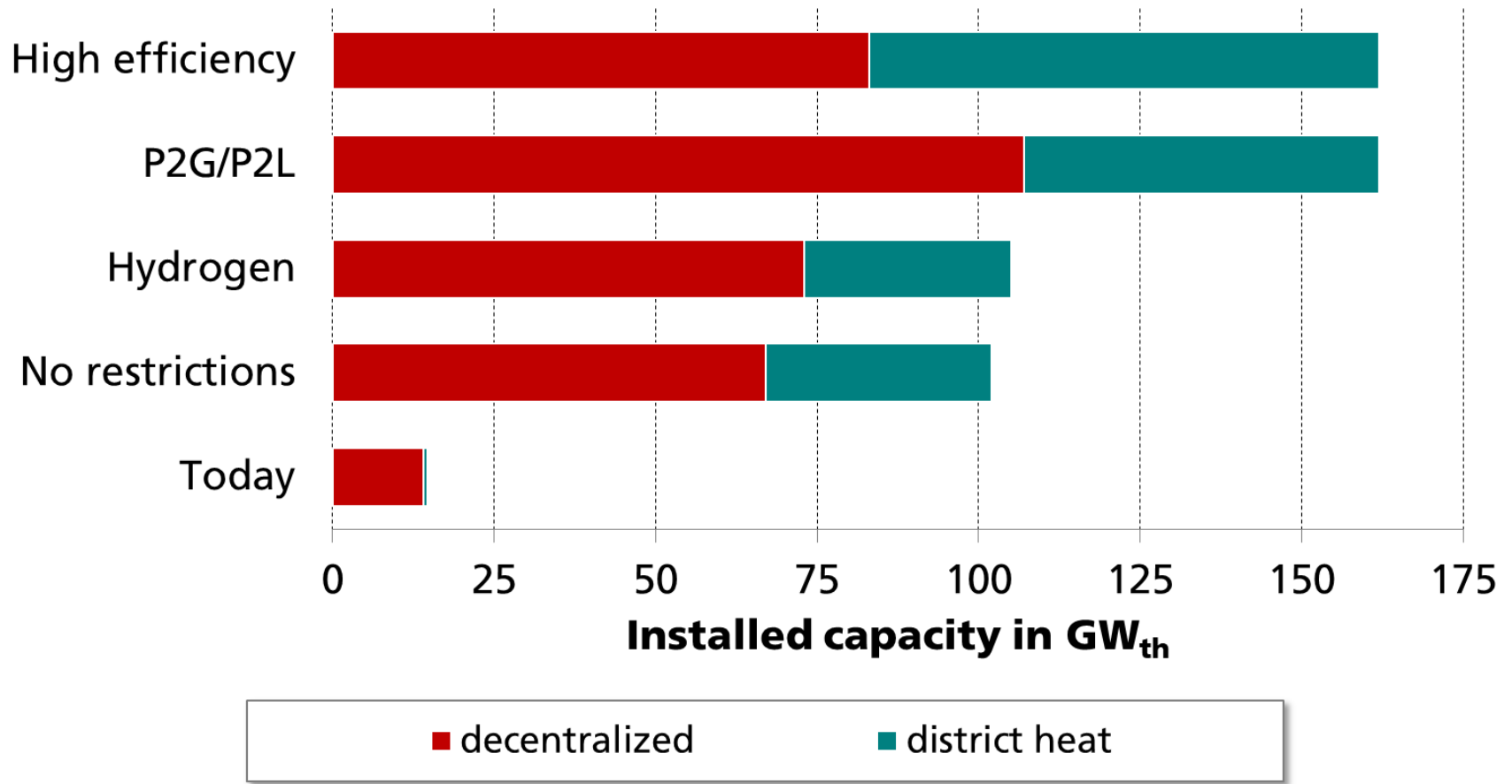
Electricity use

Annual energy in TWh in 2050 and today



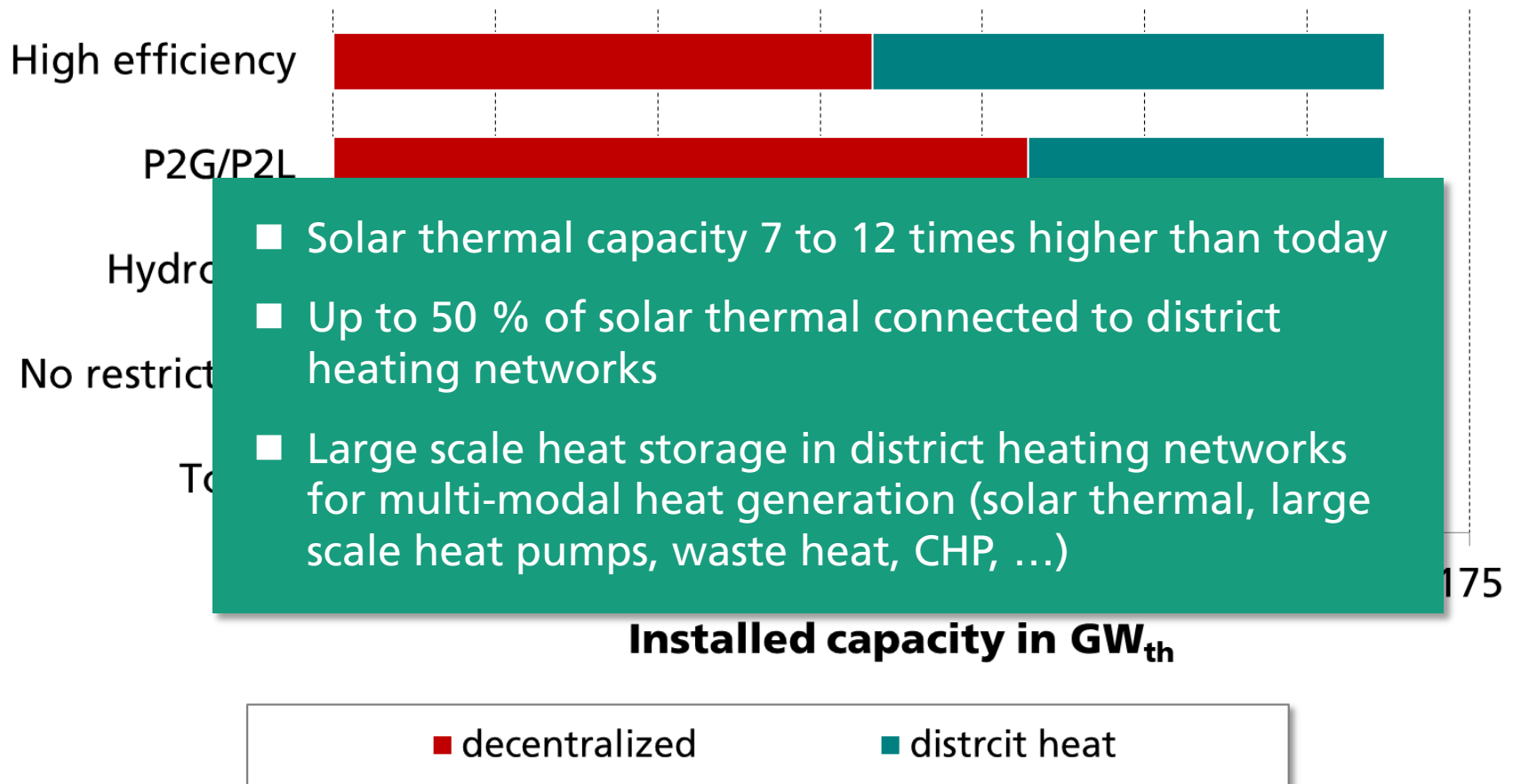
Solar thermal for building sector

Installed capacity in GW in 2050 and today



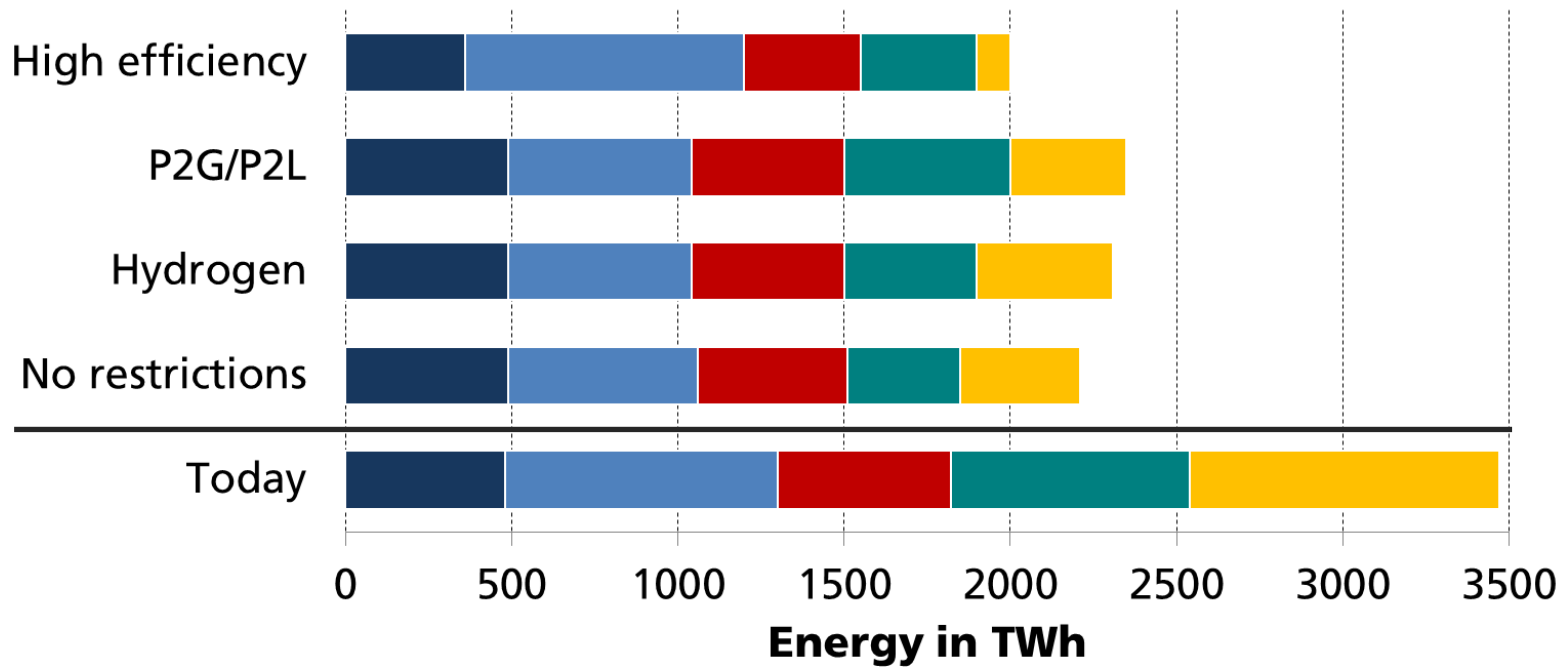
Solar thermal for building sector

Installed capacity in GW in 2050 and today



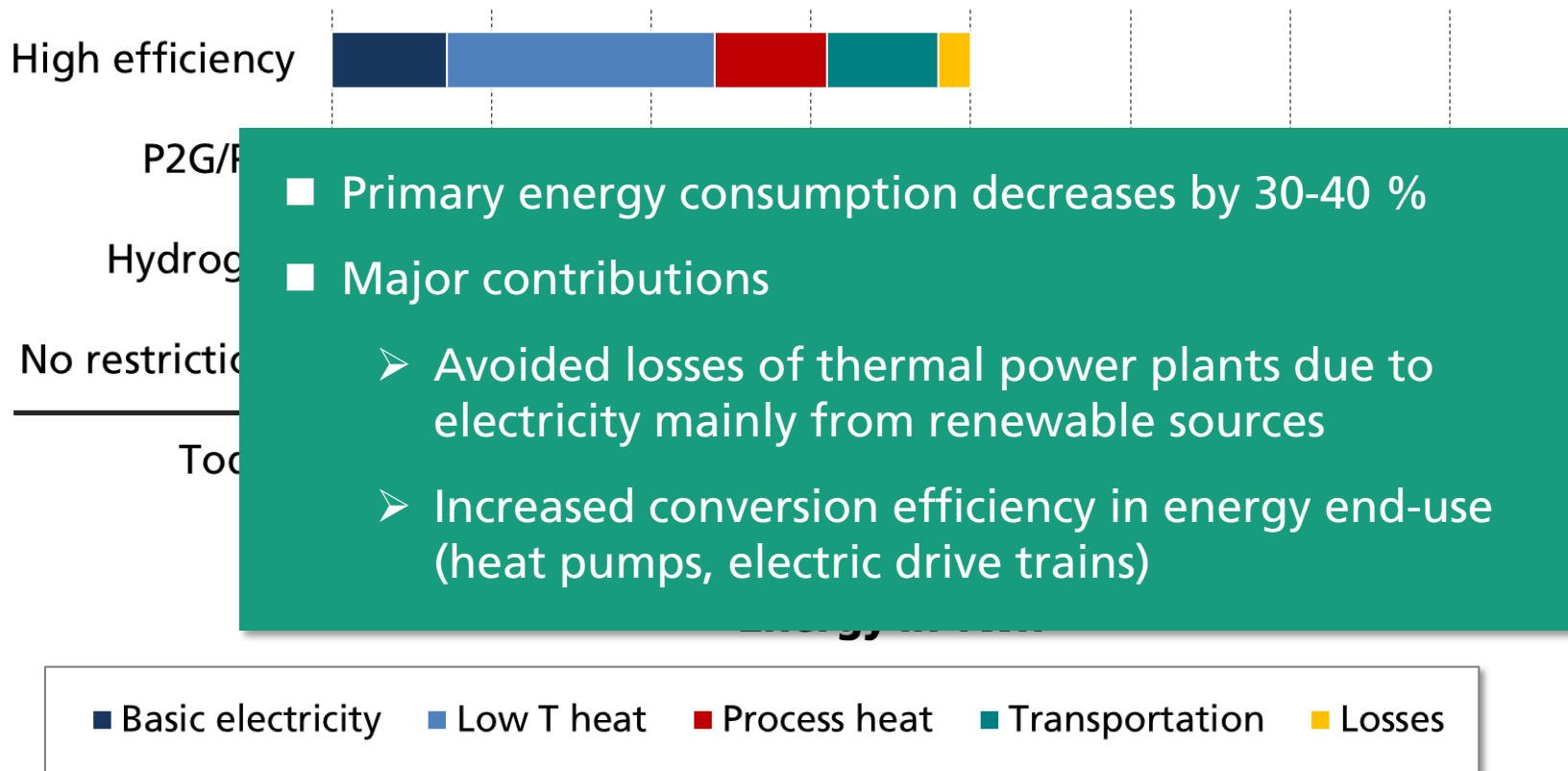
Primary energy

Annual primary energy in TWh in 2050 and today for main uses



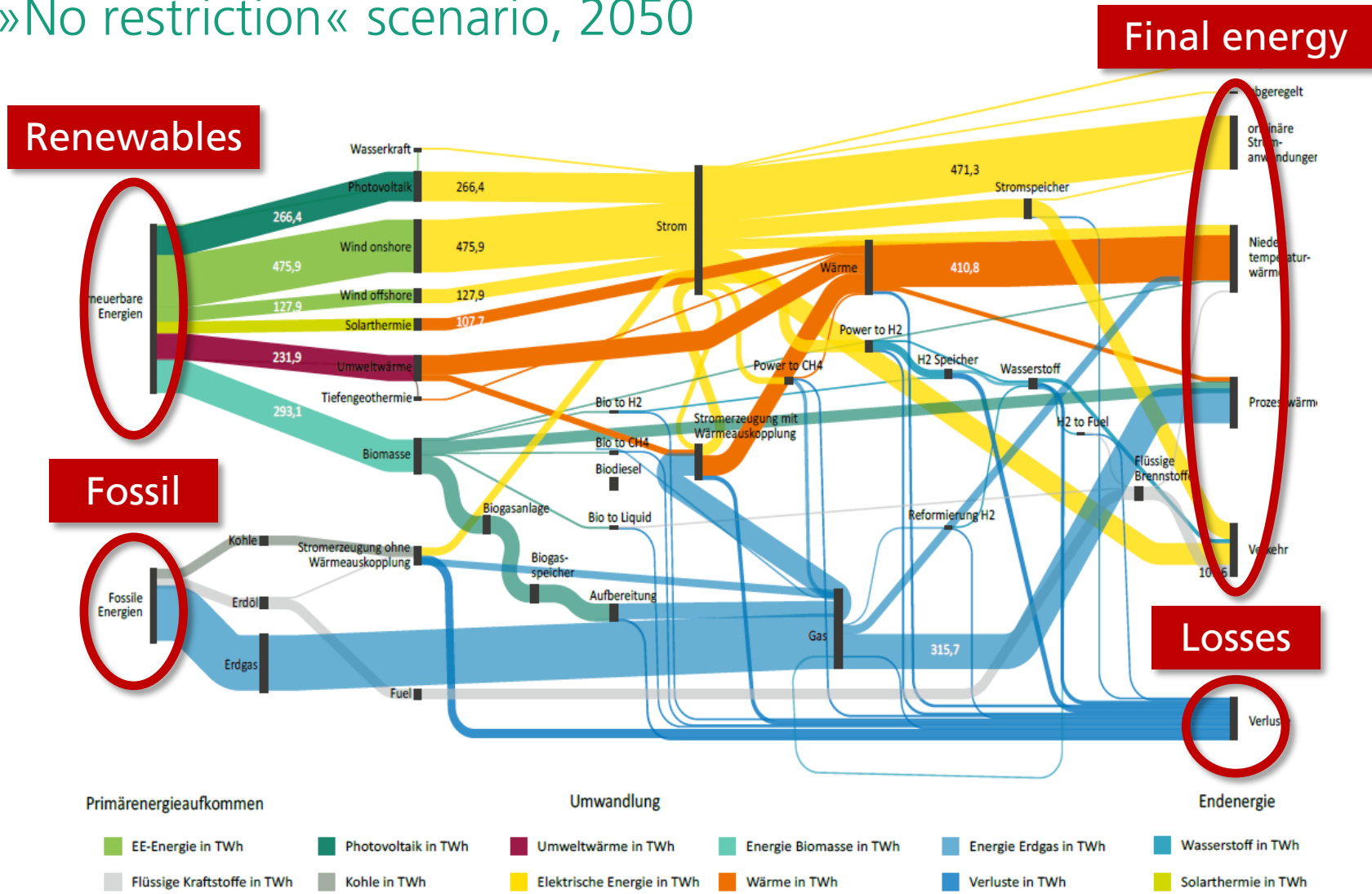
Primary energy

Annual primary energy in TWh in 2050 and today for main uses



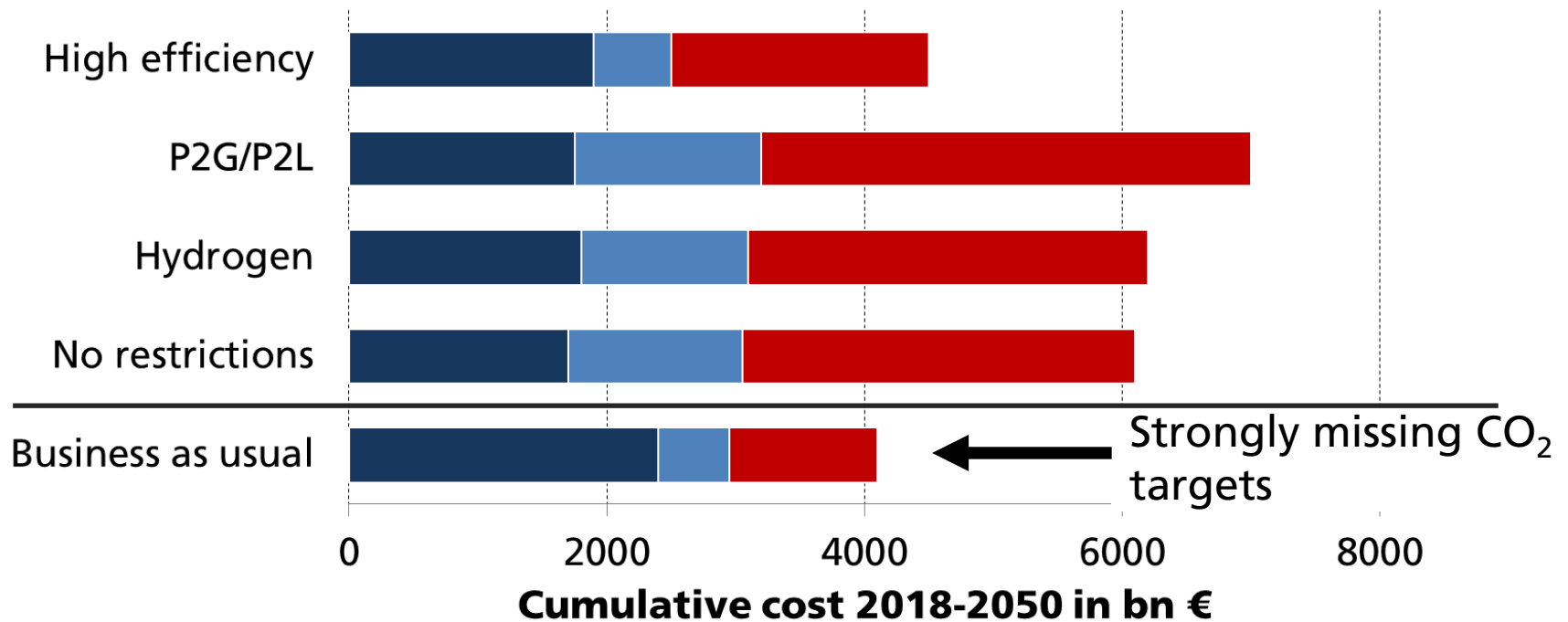
Energy flow chart

»No restriction« scenario, 2050



Cost

Cumulative total energy system cost until 2050 in billion €



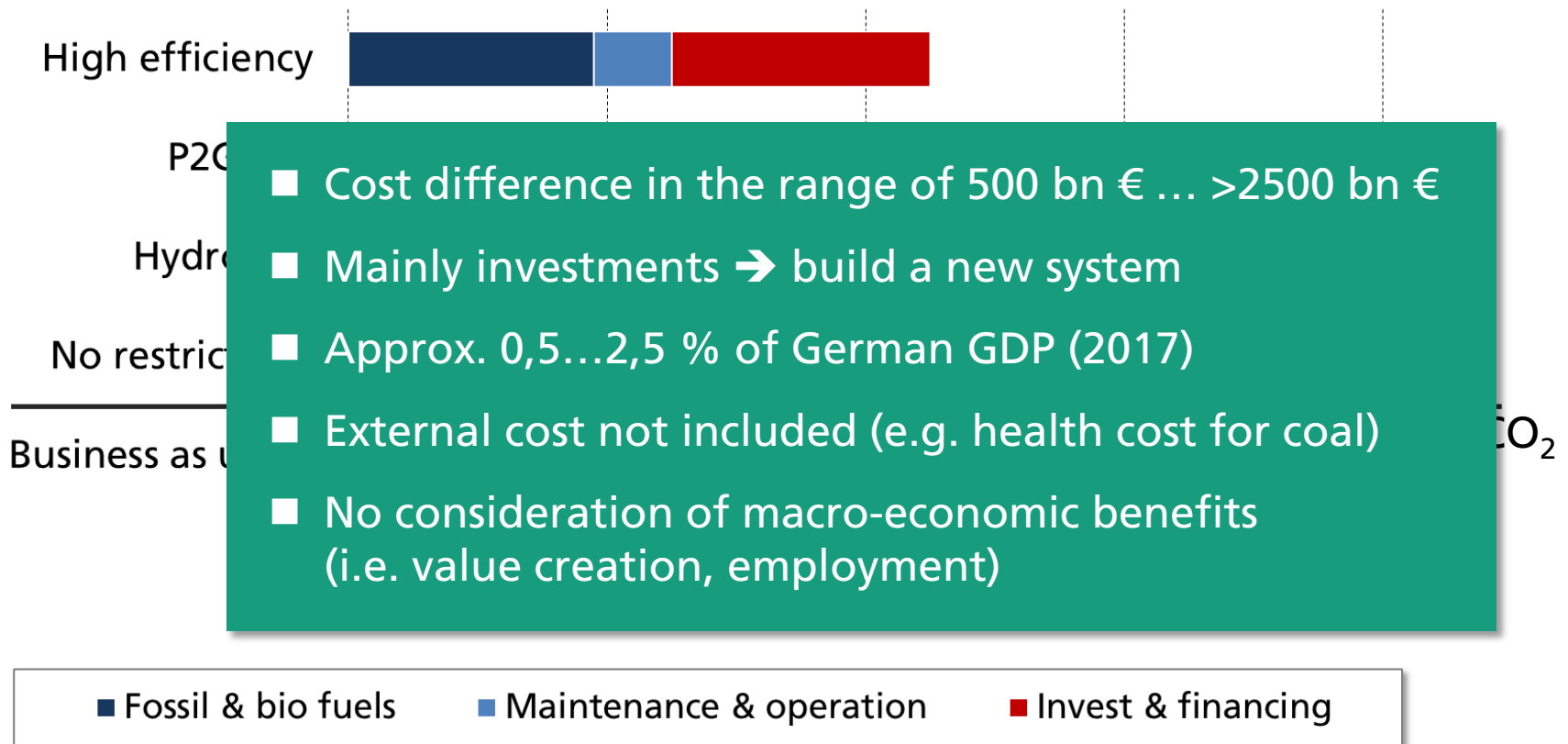
■ Fossil & bio fuels

■ Maintenance & operation

■ Invest & financing

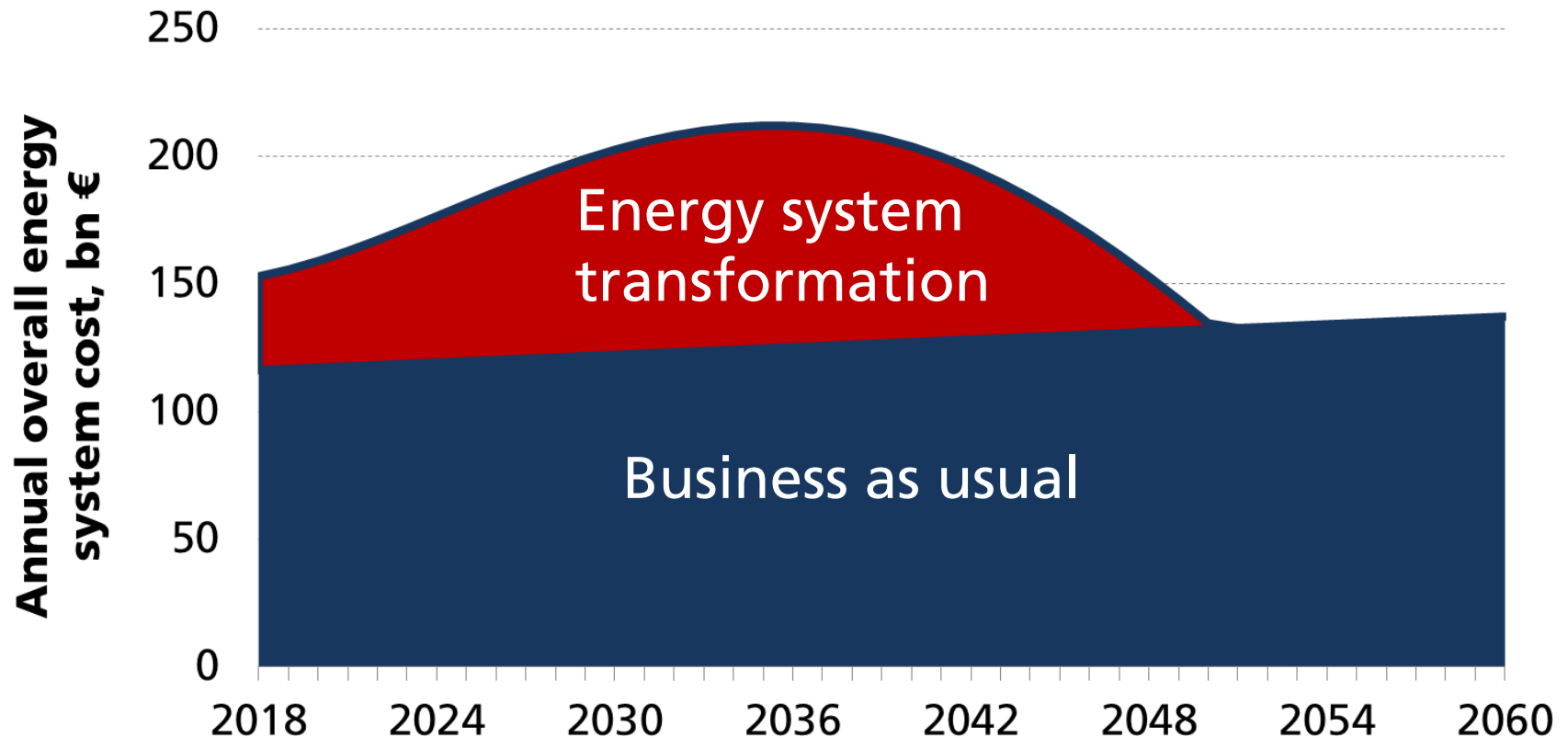
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Cumulative total energy system cost until 2050 in billion €



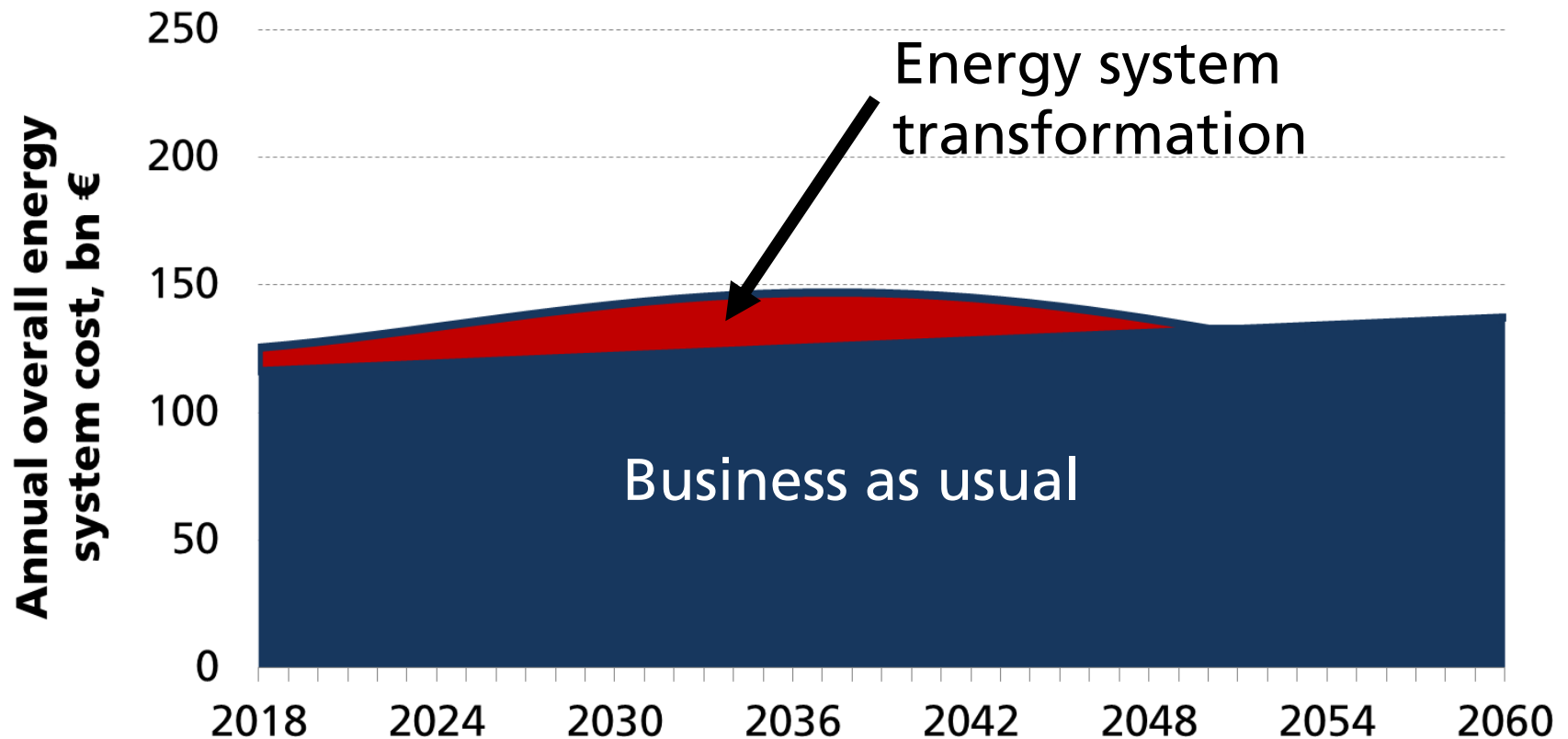
Cost development for »No restriction« scenario

Overall macro-economic energy system cost in bn € per year



Cost development for »High efficiency« scenario

Overall macro-economic energy system cost in bn € per year



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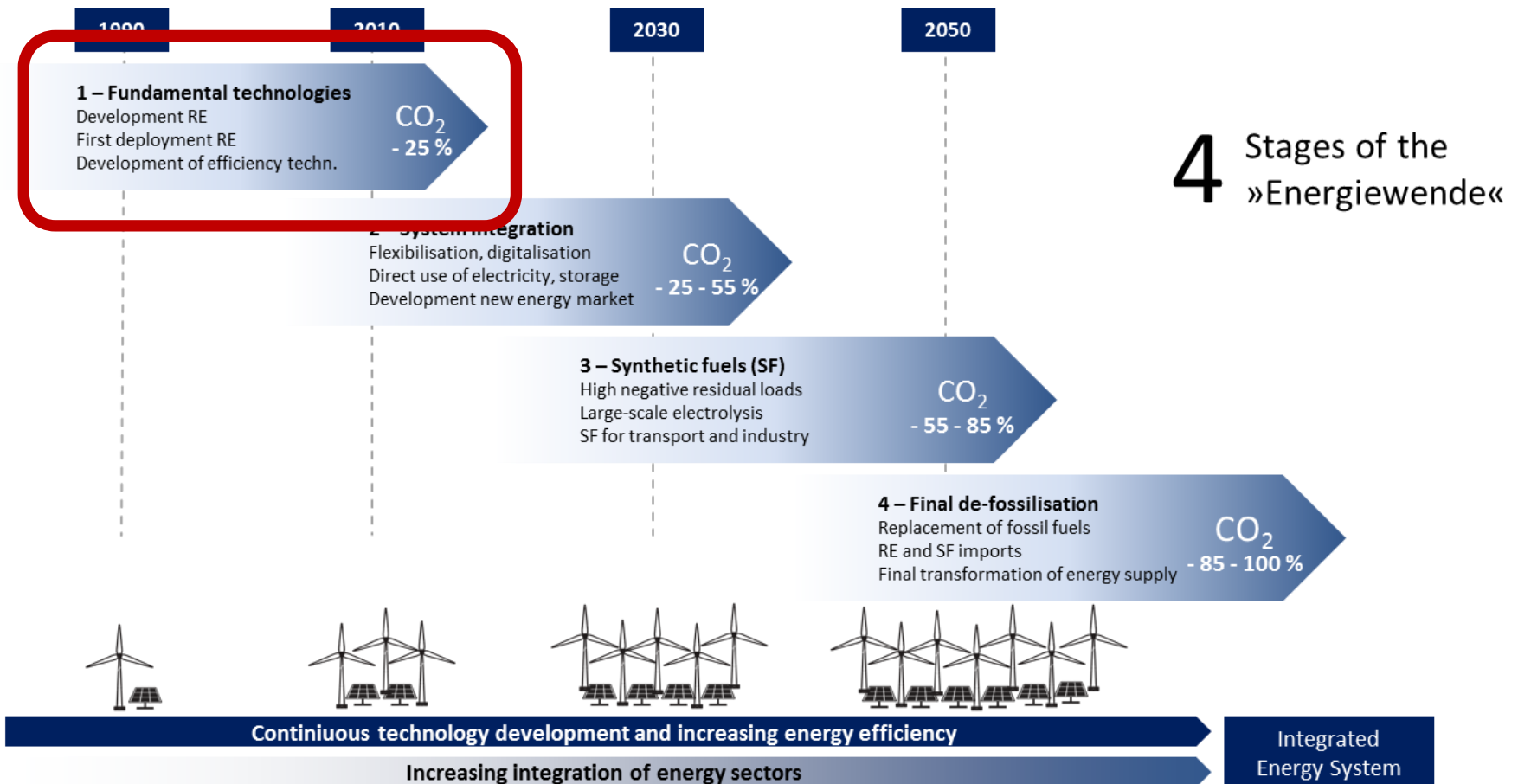
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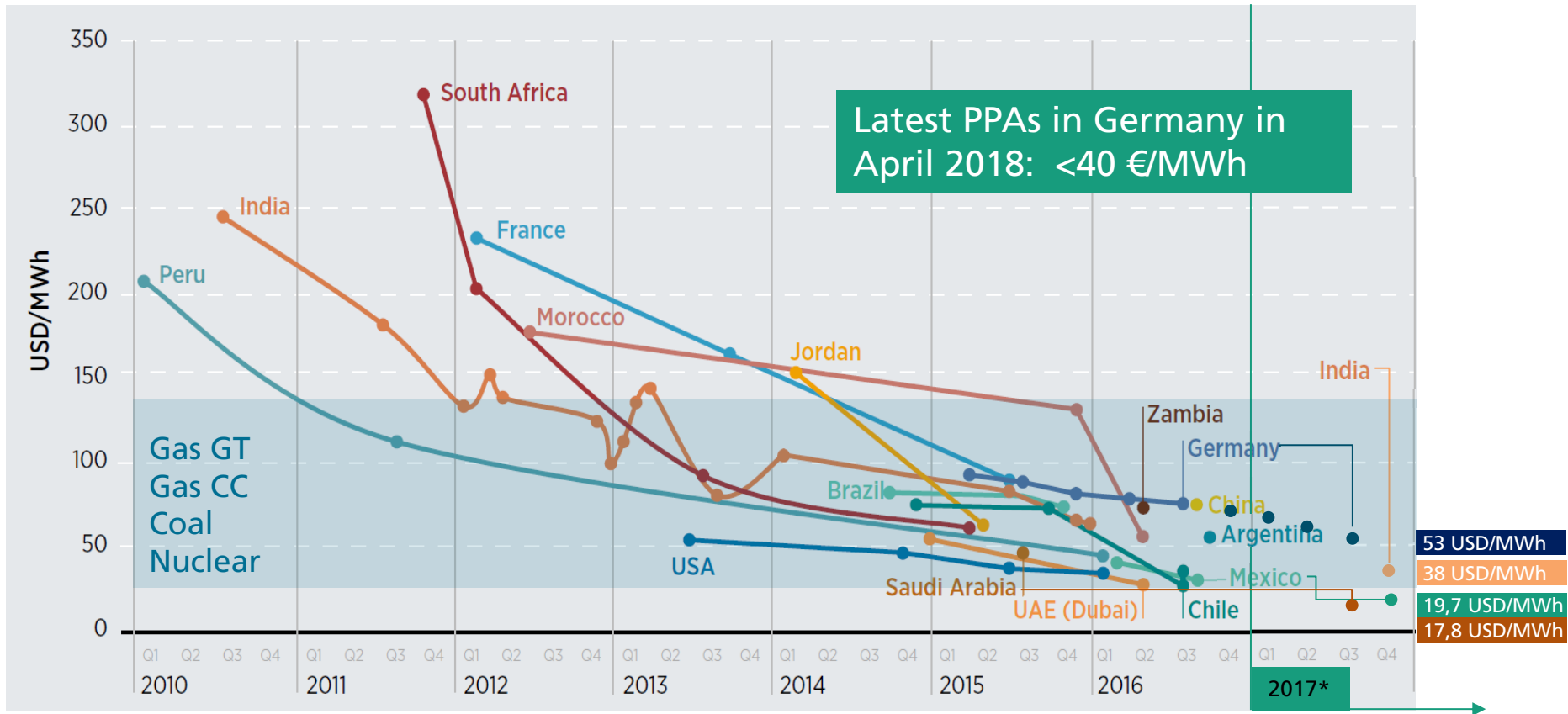
Phases of the energy system transformation



4 Stages of the »Energiewende«

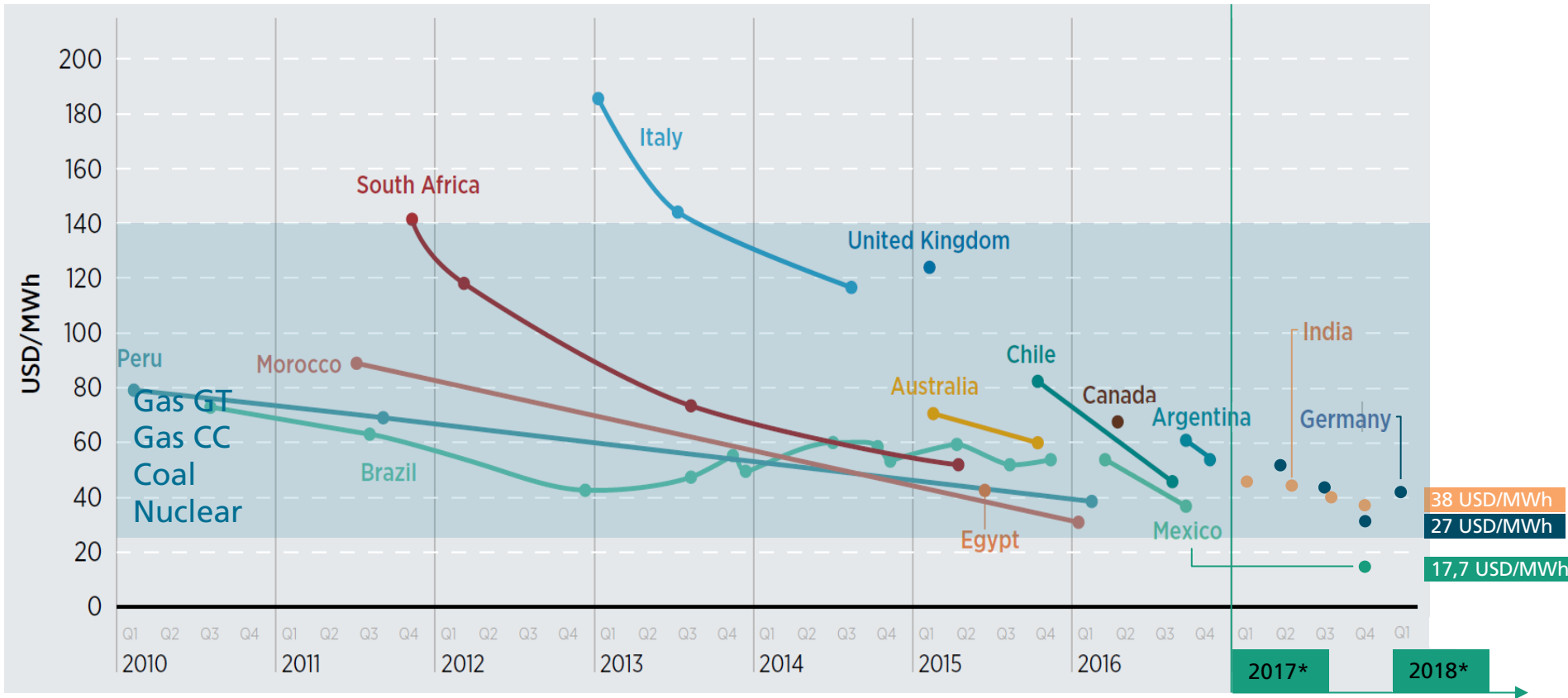
Average prices for PV electricity in PPAs

January 2010 - December 2017

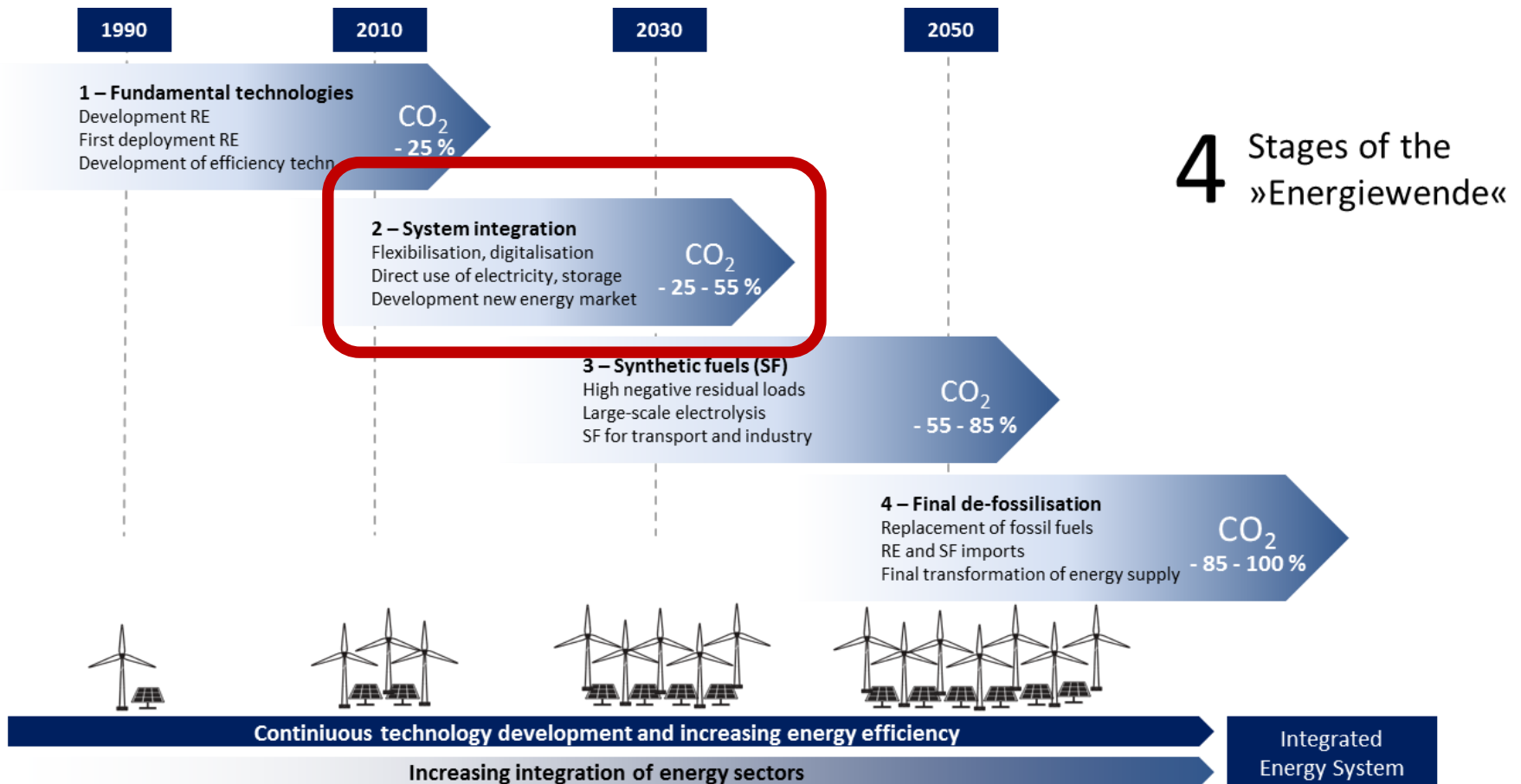


Average prices for Onshore-Wind electricity in PPAs

January 2010 - December 2017



Phases of the energy system transformation



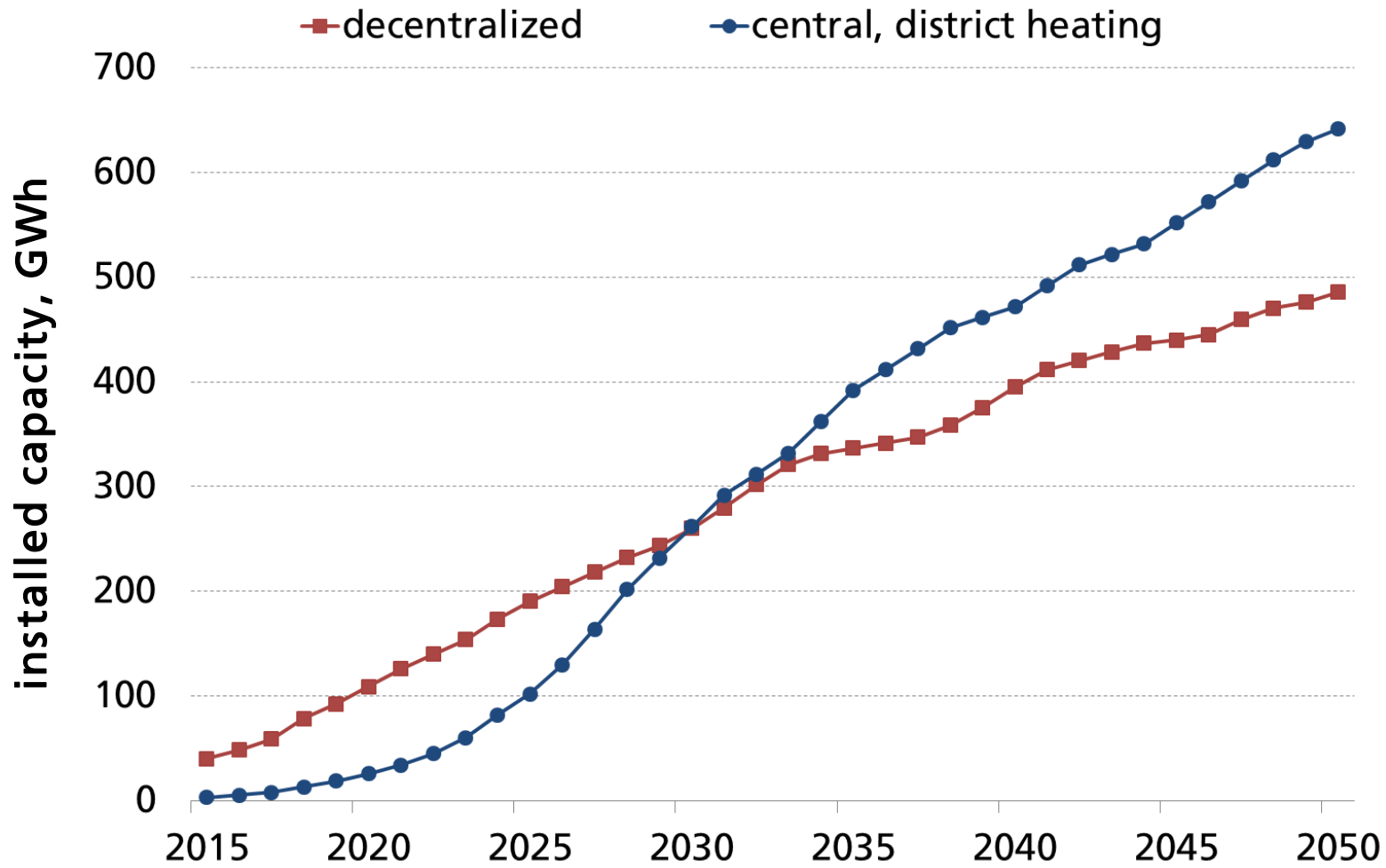
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Source: »Sektorkopplung« - Optionen für die nächste Phase der Energiewende. Published by acatech, November 2017

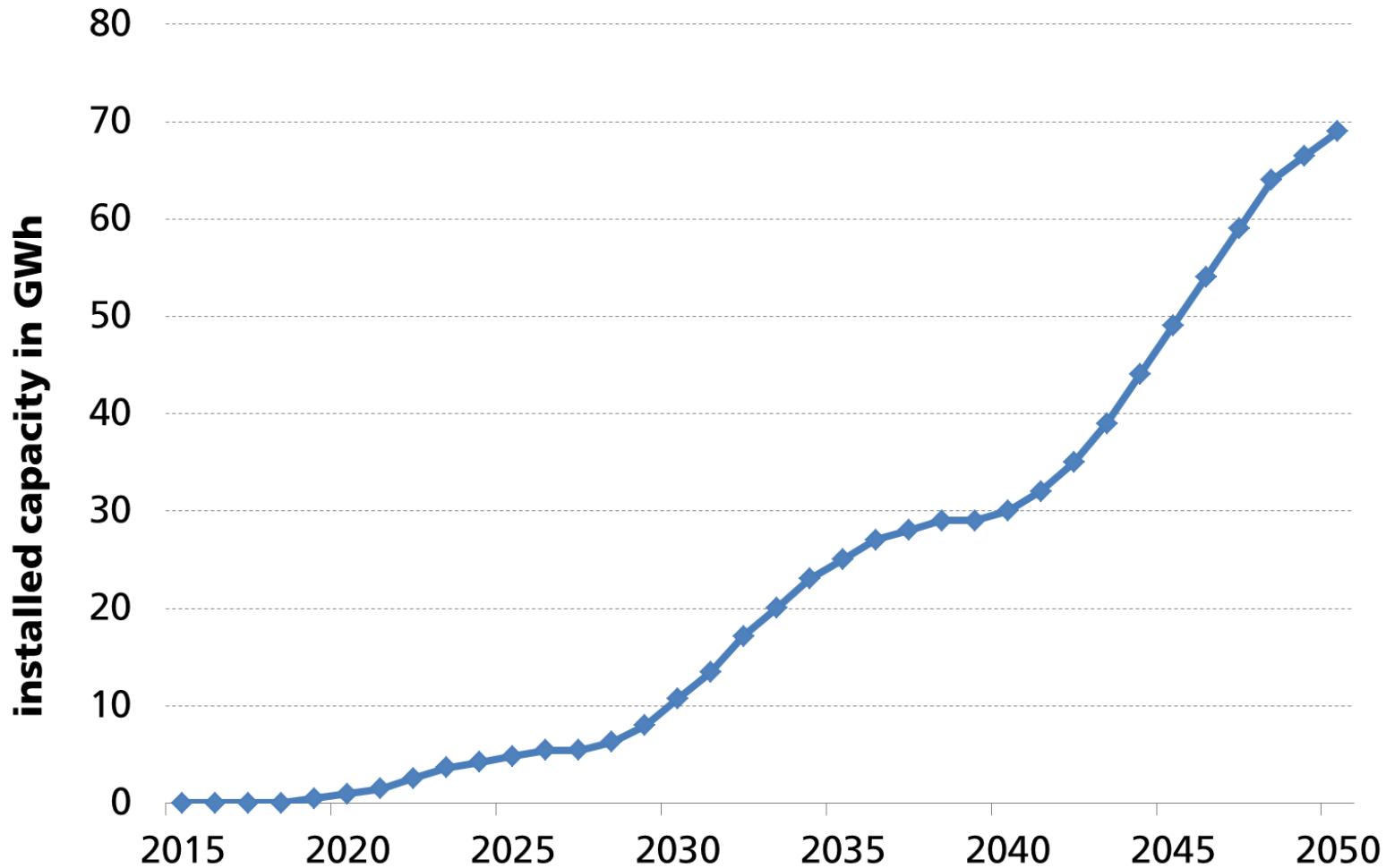
Heat storage

»No restriction« scenario



Stationary battery storage

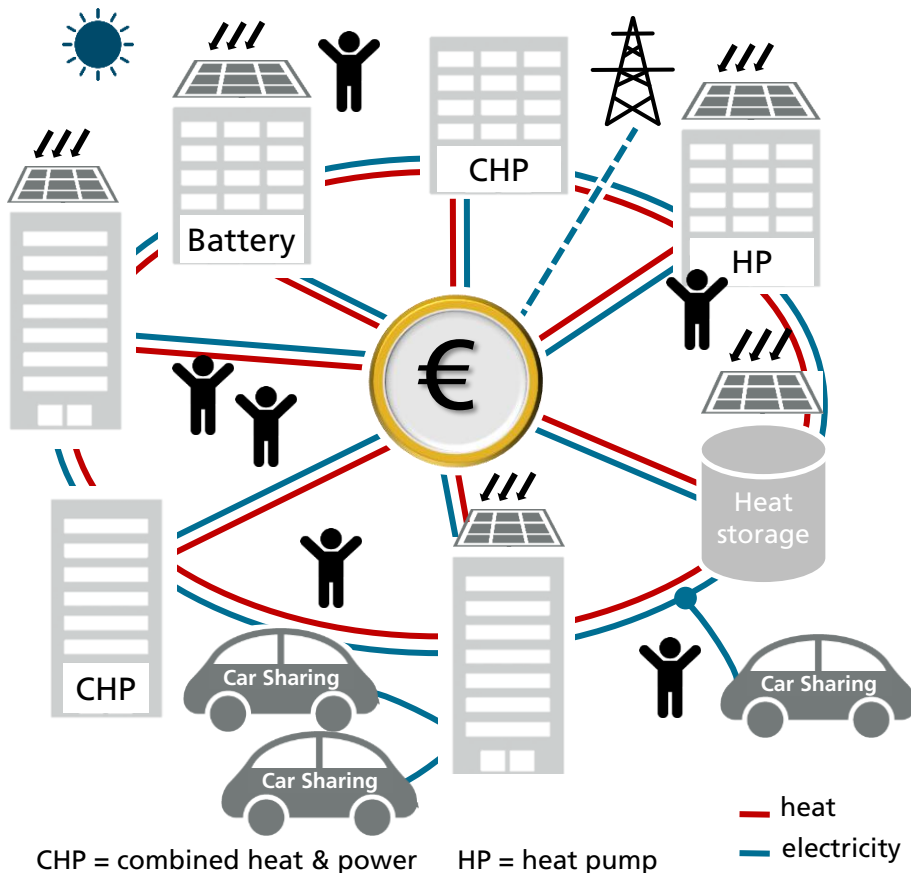
»No restriction« scenario



New markets and new market design

New market actors and digital services

Description



Elements

Digital market place

- Fully automated execution and accounting of EMS transactions

Self-learning EMS

- Smart contracts
- Conformity to energy market design
- Fully integrated load management

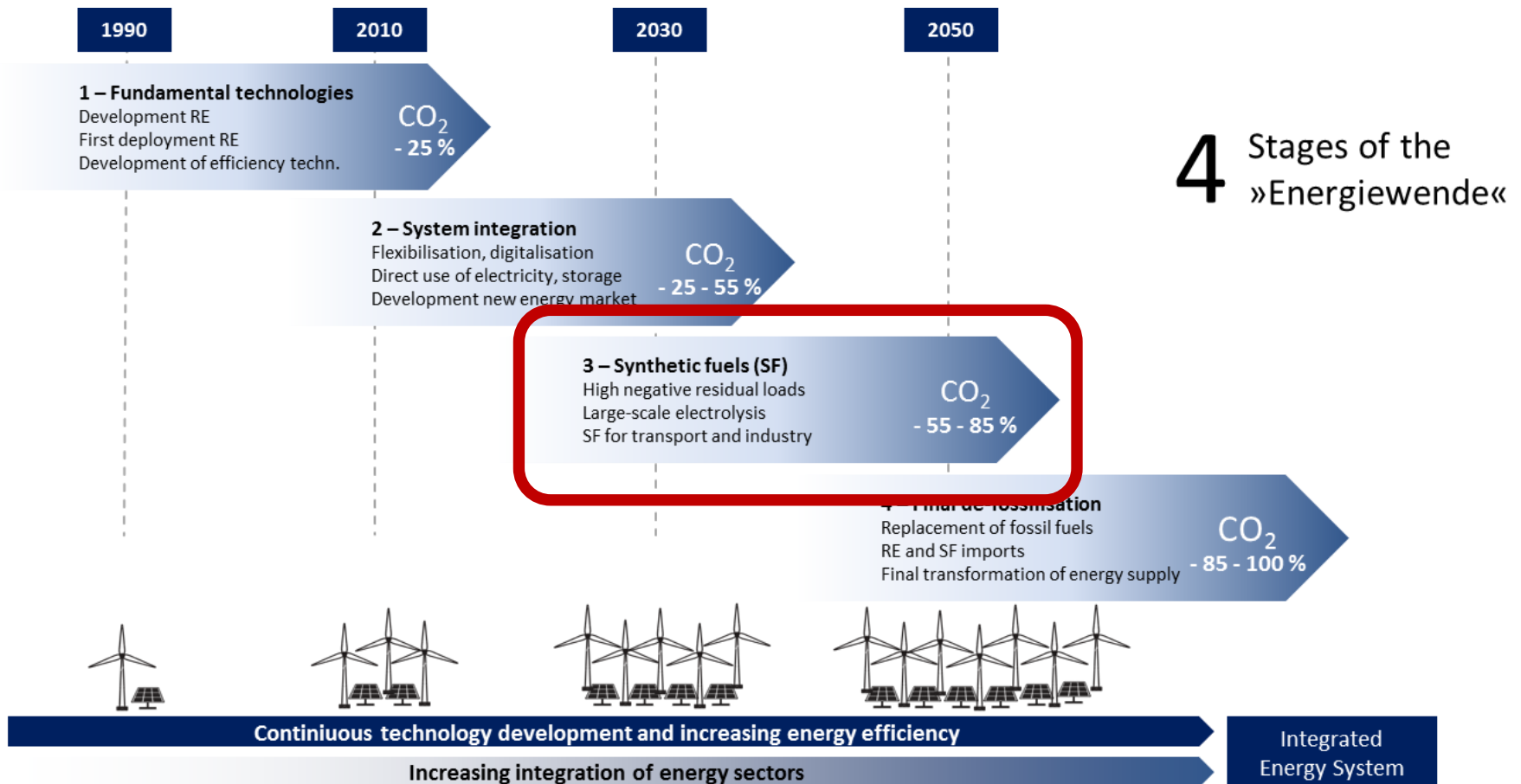
Cyber-Security

- Artificial intelligence for prognosis and control

Planning tools

- Resiliency of decentralized energy and IT structure
- Powerful tools for design and planning

Phases of the energy system transformation



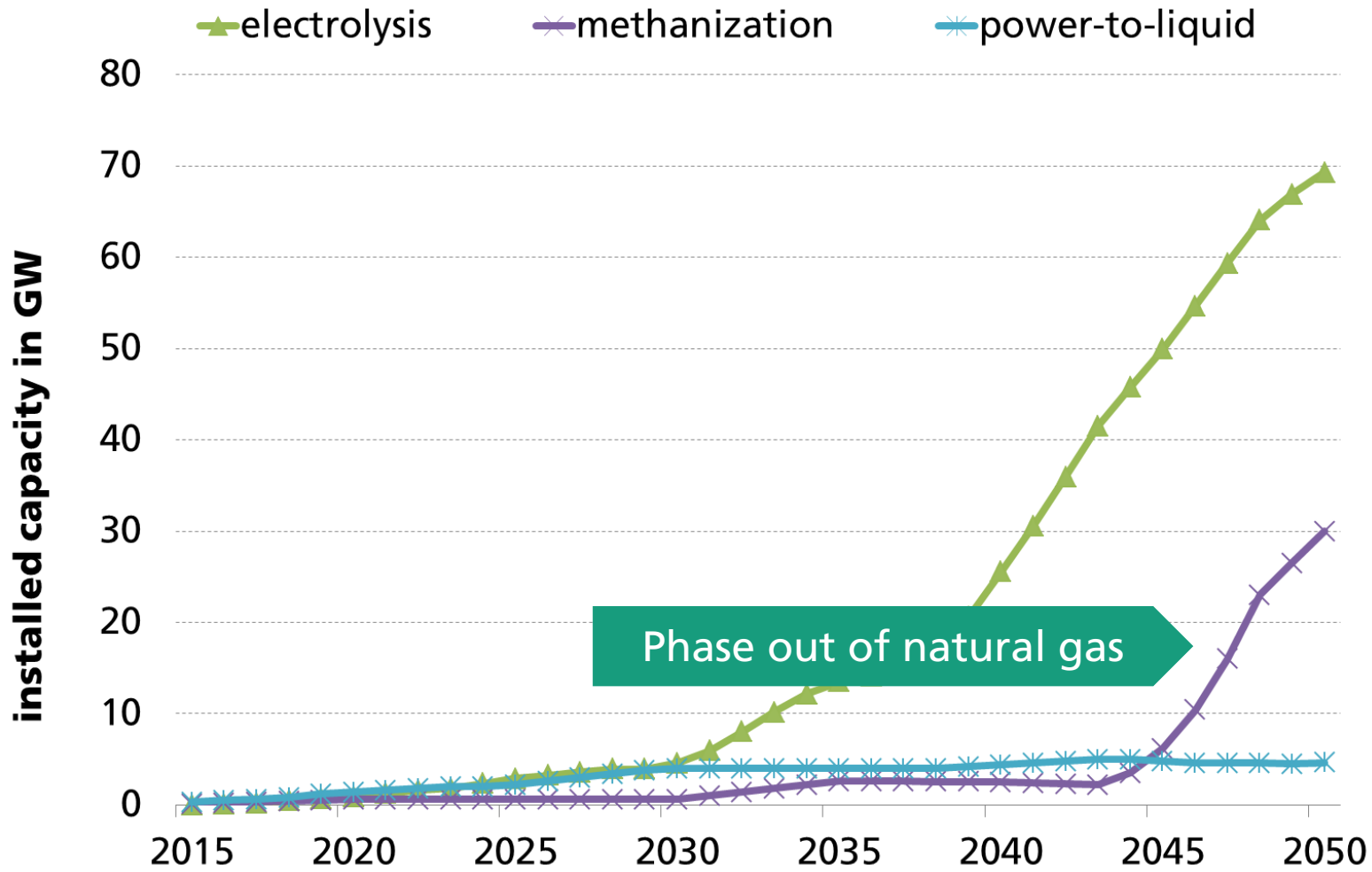
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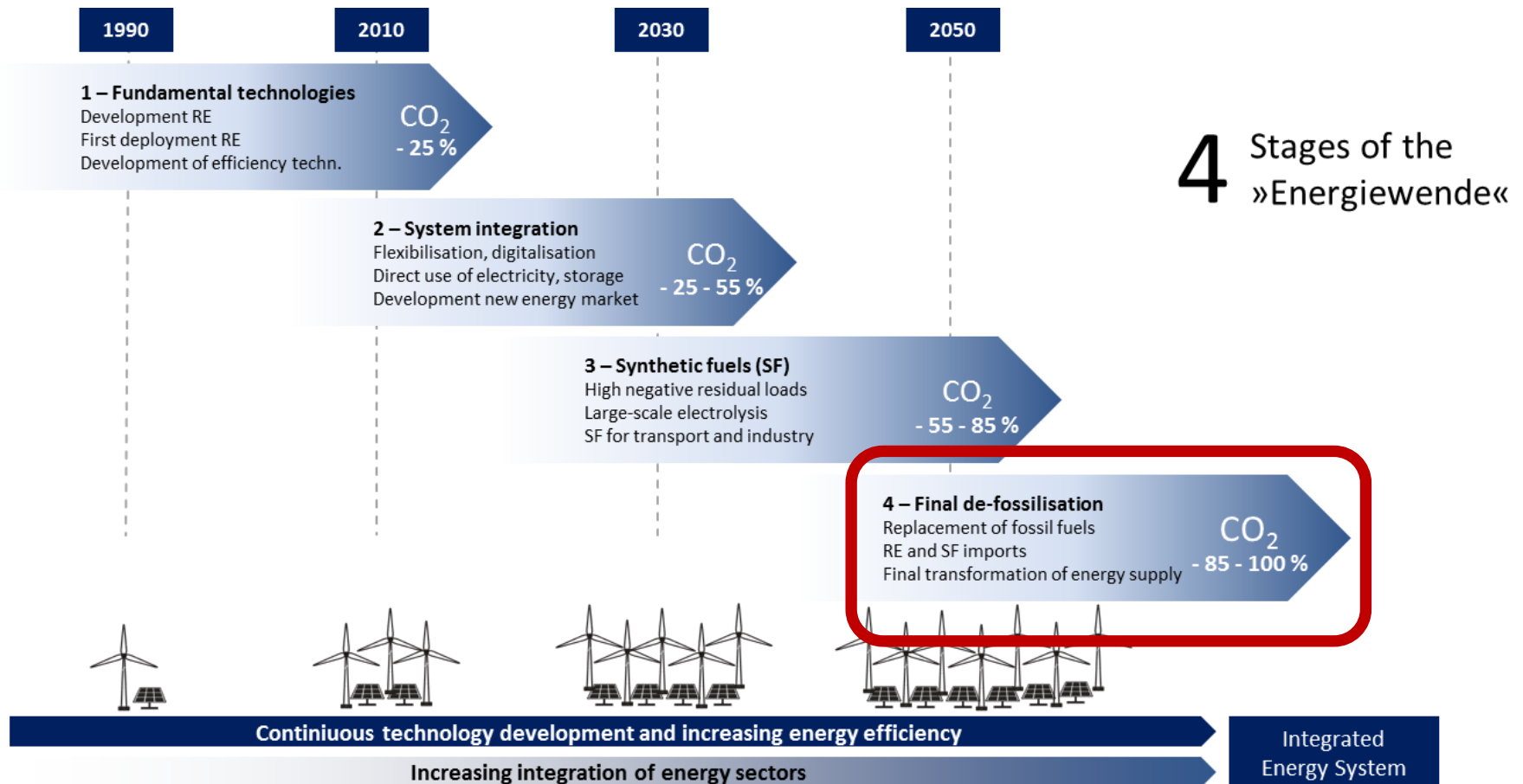
Source: »Sektorkopplung« - Optionen für die nächste Phase der Energiewende. Published by acatech, November 2017

Multi-GW scale electrolysis and P2G/P2L converters

»No restriction« scenario



Phases of the energy system transformation



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- Transformation of energy systems in line with GHG emission reduction targets seems in principle technically feasible
- Renewable energies (in particular solar and wind) become dominant
- Major measures of transformation
 1. Efficiency and reduction of consumption (far lower cost and lower needed capacity of wind and solar → societal acceptance)
 2. Direct use of renewable sources within sectors: e.g. solar thermal for buildings and in industry
 3. Sector coupling: direct use of electricity in various sectors (e.g. heat pumps, e-mobility)
 4. Sector coupling: indirect use of electricity → large scale conversion of renewable electricity into synthetic energy carriers (hydrogen, liquids, chemicals, methane)

Conclusions

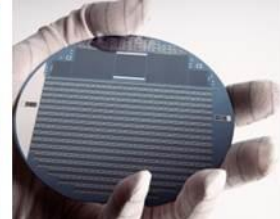
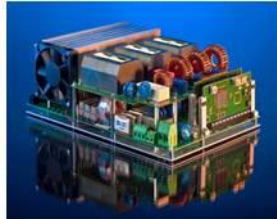
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- Elements of **framework conditions** triggering the transformation
 - Effective **pricing mechanism** for **greenhouse gas emissions** covering all energy sectors (e.g. ETS covering all sectors with minimum CO₂ price)
 - Provide **reliable and trustable conditions** for investments in energy efficiency and renewable energies
 - **Support policies for key technologies** (e.g. renewables, hydrogen) of the future energy system (such as e.g. IPCEI mechanism discussed for battery technology)
 - **Variable electricity tariff** systems to stimulate load management and storage application
- **New system cost competitive** once major investments have been made and the main steps for transforming the energy system have been taken

IPCEI = Important Project of Common European Interest

Many thanks for your attention...

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