TOWARDS AN INTEGRATED ENERGY SYSTEM

System analysis covering all energy sources and sectors


©Fraunhofer ISE/Foto: Guido Kirsch

Prof. Dr. Hans-Martin Henning

Fraunhofer-Institut für Solare Energiesysteme ISE

Max-Planck-Institut für Plasmaphysik, Institutskolloquium

15. November 2019, Garching

www.ise.fraunhofer.de

Fraunhofer ISE

Fraunhofer ISE
Areas of Concentration

Total staff >1200

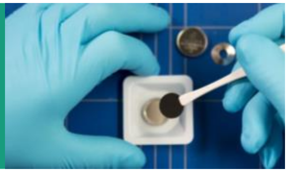
Annual turnover about 90 Mio €

ENERGY TECHNOLOGIES AND SYSTEMS
Prof. Dr. Hans-Martin Henning

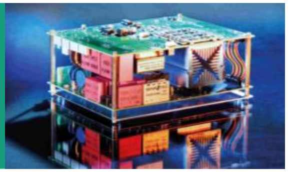
Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes

Hydrogen Technologies and Electrical Energy Storage

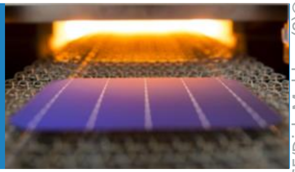


Power Electronics, Grids and Smart Systems

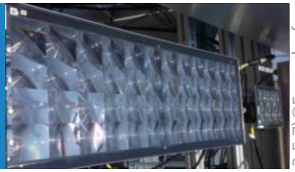


PHOTOVOLTAICS
Dr. Andreas Bett

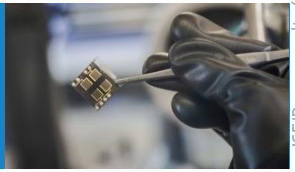
Silicon Photovoltaics



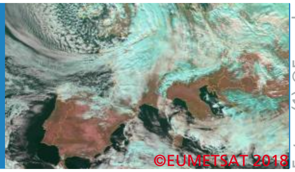
III-V and Concentrator Photovoltaics



Emerging Photovoltaic Technologies



Photovoltaic Modules and Power Plants



Fraunhofer
ISE

Content

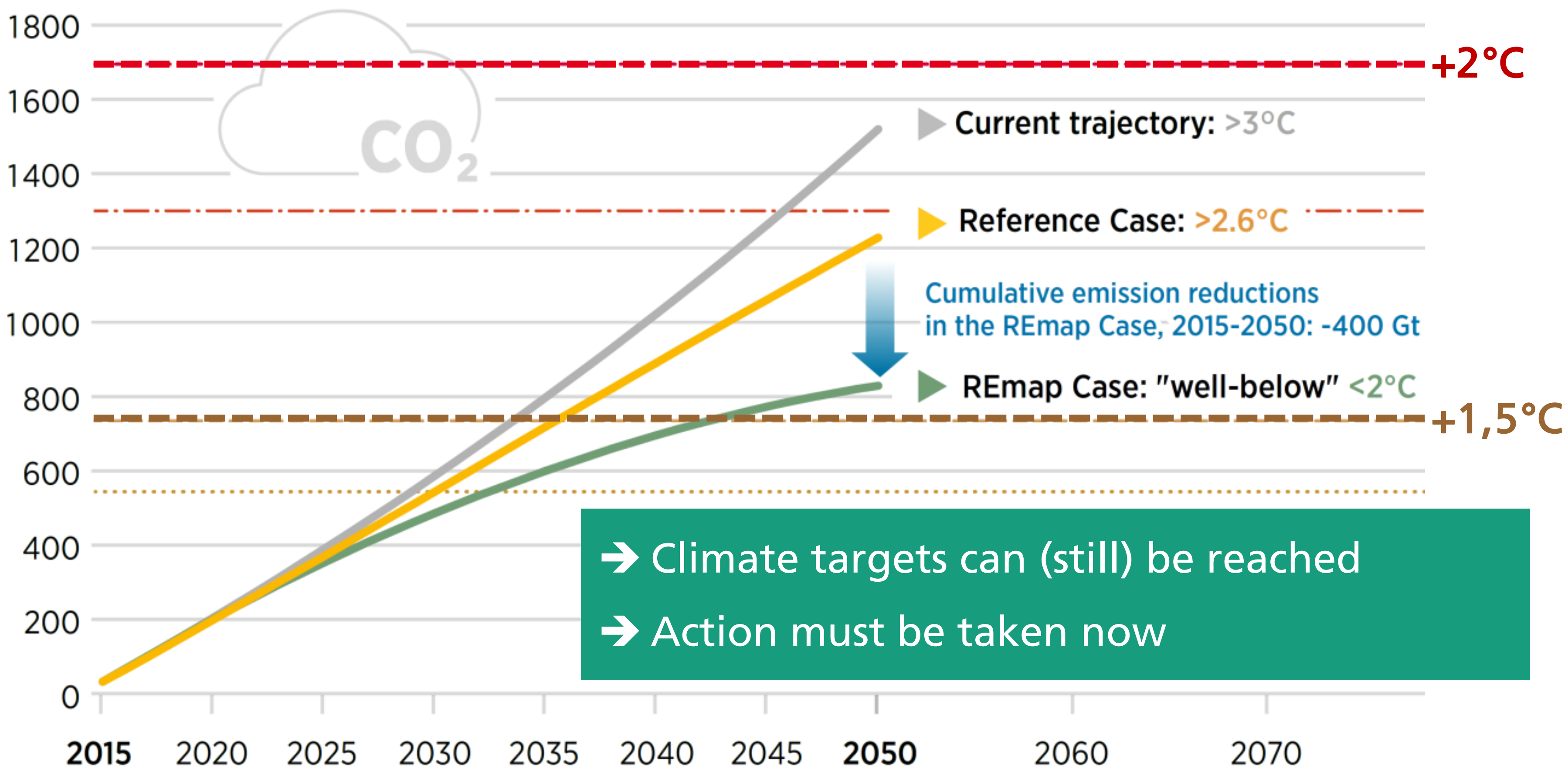
Fraunhofer ISE

Content

Pathway for a well-below 2°C climate target

Energy related CO_2 emissions

Cumulative energy-related CO_2 emissions and emissions gap, 2015-2050 (Gt CO_2)



→ Climate targets can (still) be reached

→ Action must be taken now

Current trajectory: Extrapolation of the recent historical trend line of energy-related CO_2 emissions

Reference Case: considering current and planned policies of countries and includes commitments made in Nationally Determined Contributions

REmap Case: includes the deployment of low-carbon tech-nologies, based largely on renewable energy and energy efficiency

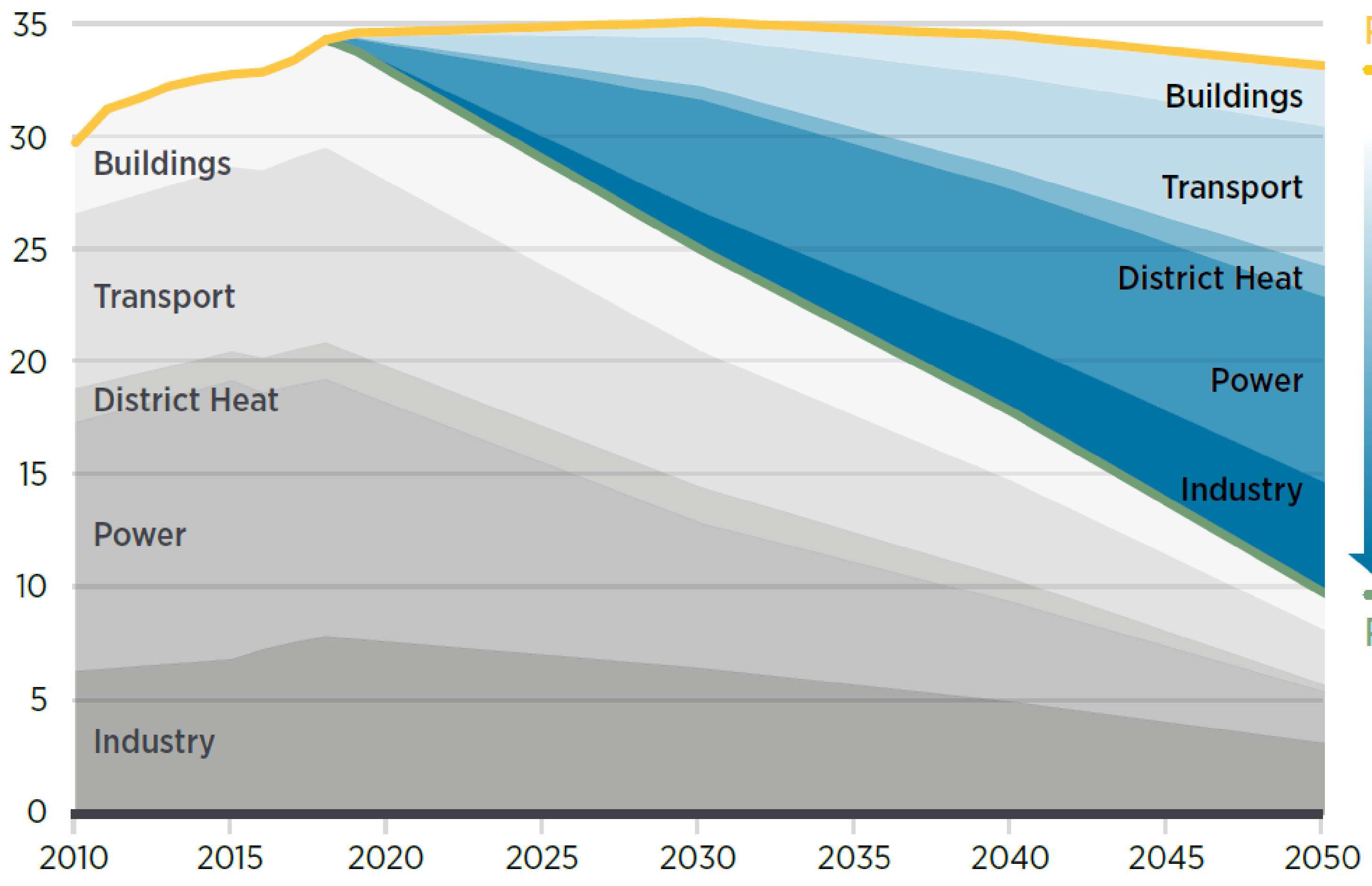
Report: IRENA, Global Energy Transformation – A Roadmap to 2050 (2019 edition), ISBN: 978-92-9260-121-8
https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

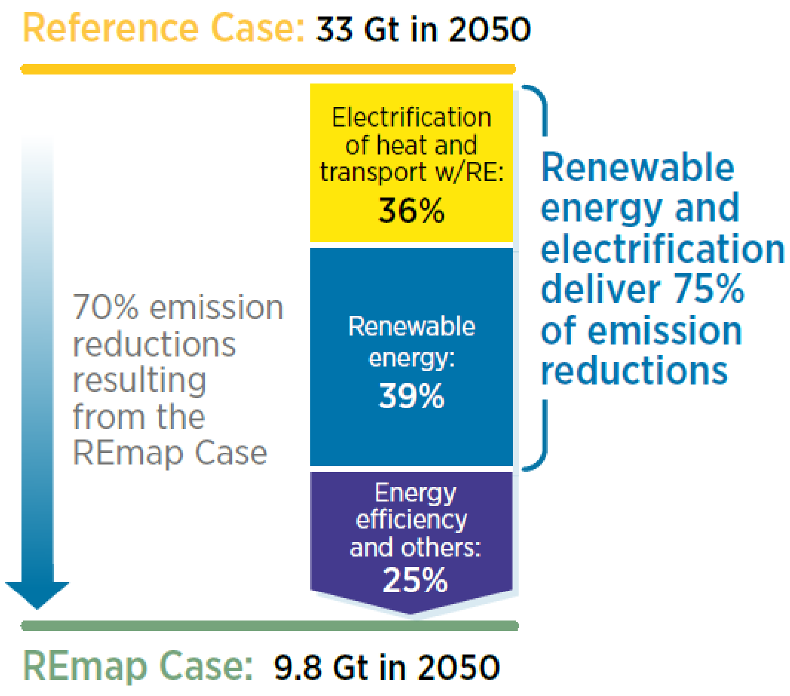
Fraunhofer ISE

Pathway for a well-below 2°C climate target

Renewables and enregy efficiency, boosted by substantial electrification

Annual energy-related CO_2 emissions, 2010-2050 (Gt/yr)





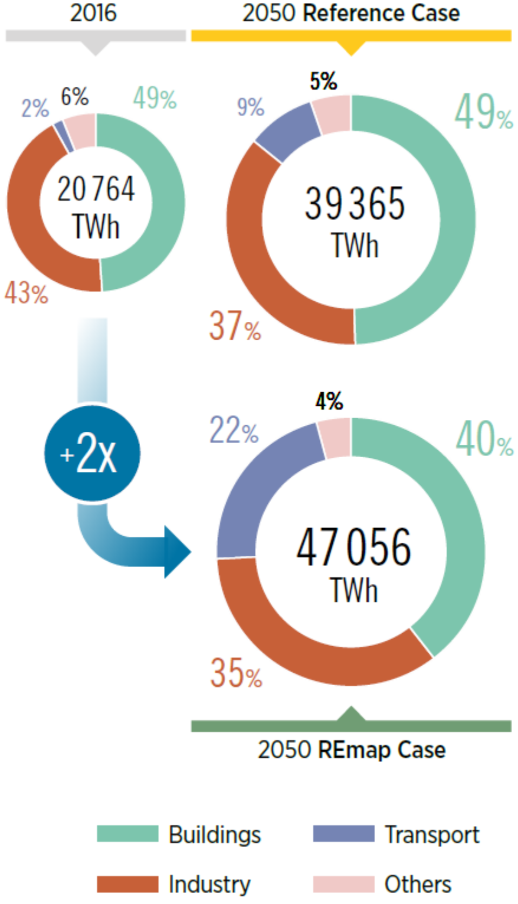
1. Electrification
2. Renewable energies
3. Energy efficiency

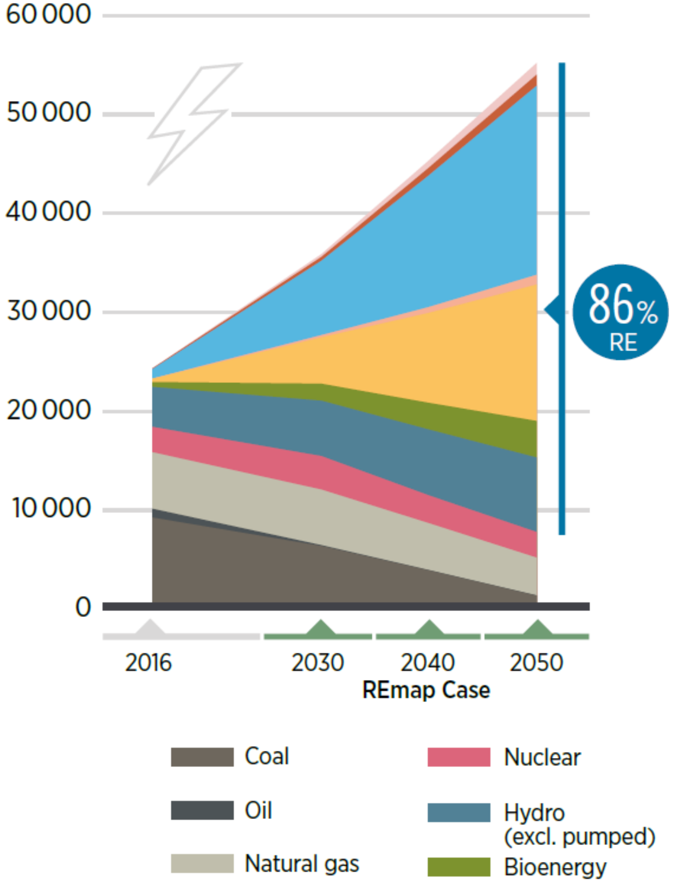
Report: IRENA, Global Energy Transformation – A Roadmap to 2050 (2019 edition), ISBN: 978-92-9260-121-8
https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

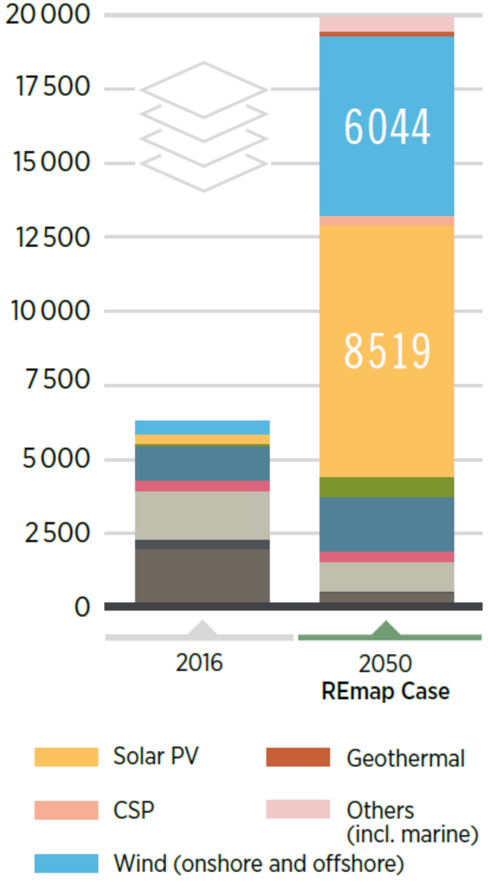
Fraunhofer ISE

Pathway for a well-below 2°C climate target

Wind and solar power dominate growth in renewable-based generation





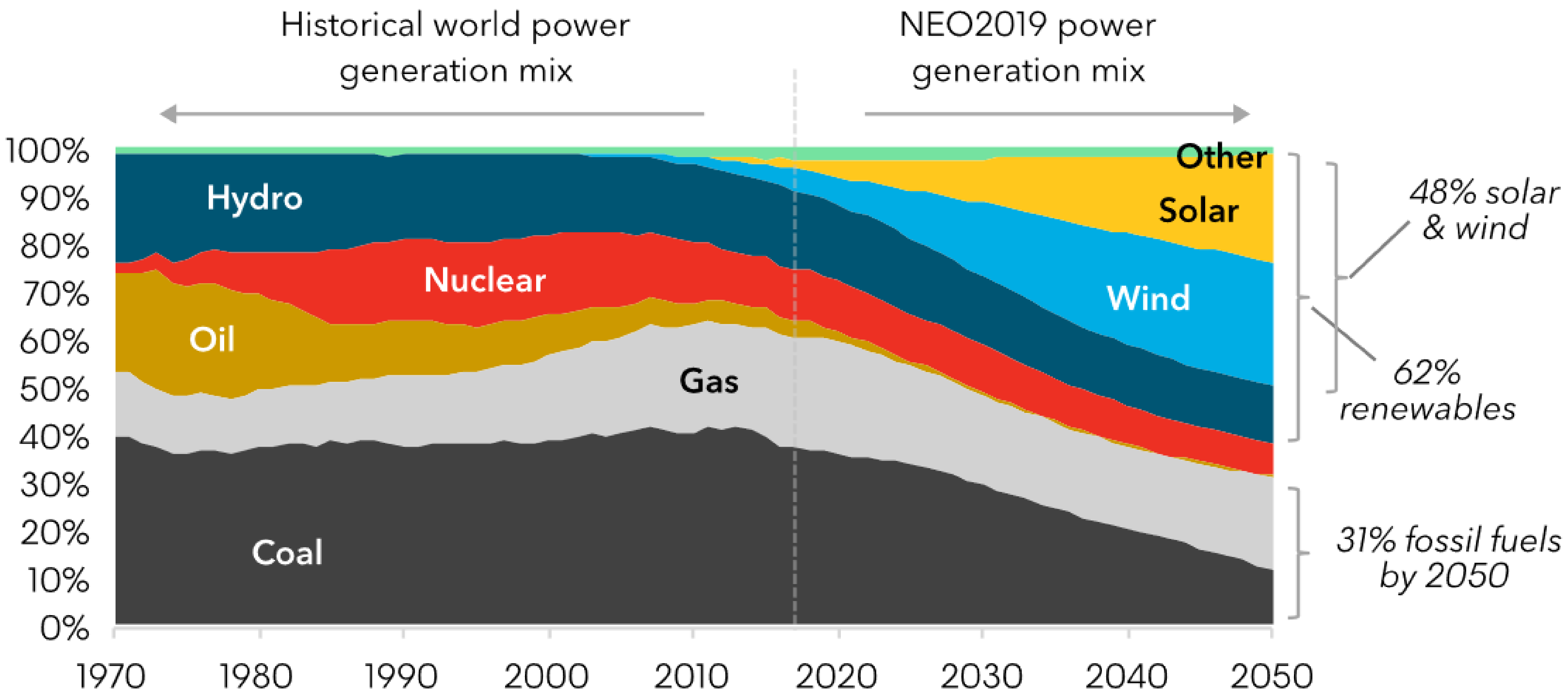


- ➔ Doubling global electricity demand
- ➔ Dominant role of wind energy and photovoltaics

Report: IRENA, Global Energy Transformation – A Roadmap to 2050 (2019 edition), ISBN: 978-92-9260-121-8
https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

Fraunhofer ISE

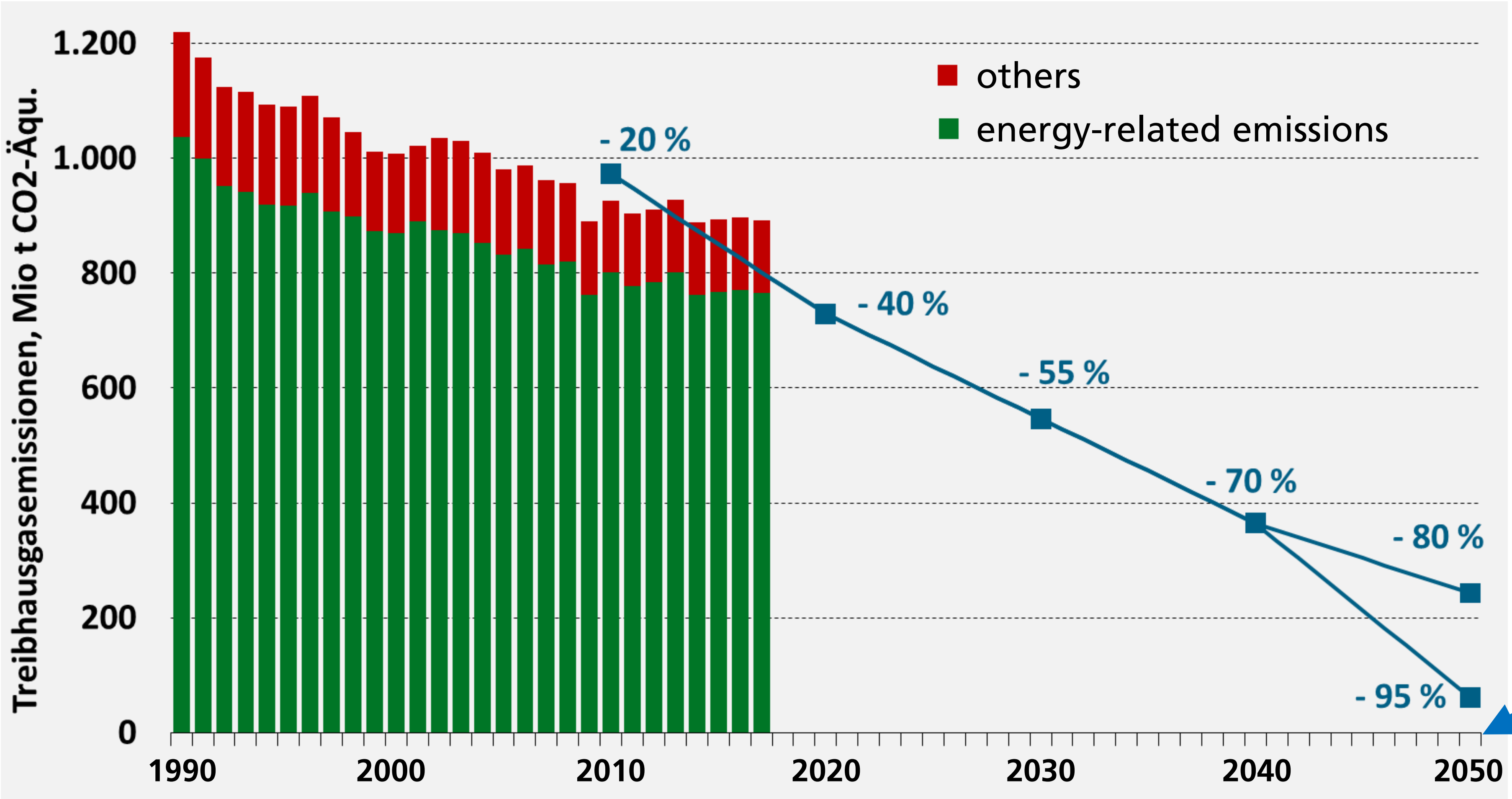
Global power generation mix
Bloomberg New Energy Outlook 2019



Quelle: Bloomberg New Energy Outlook 2019
https://about.bnef.com/new-energy-outlook/

GHG emissions in Germany

History and goals

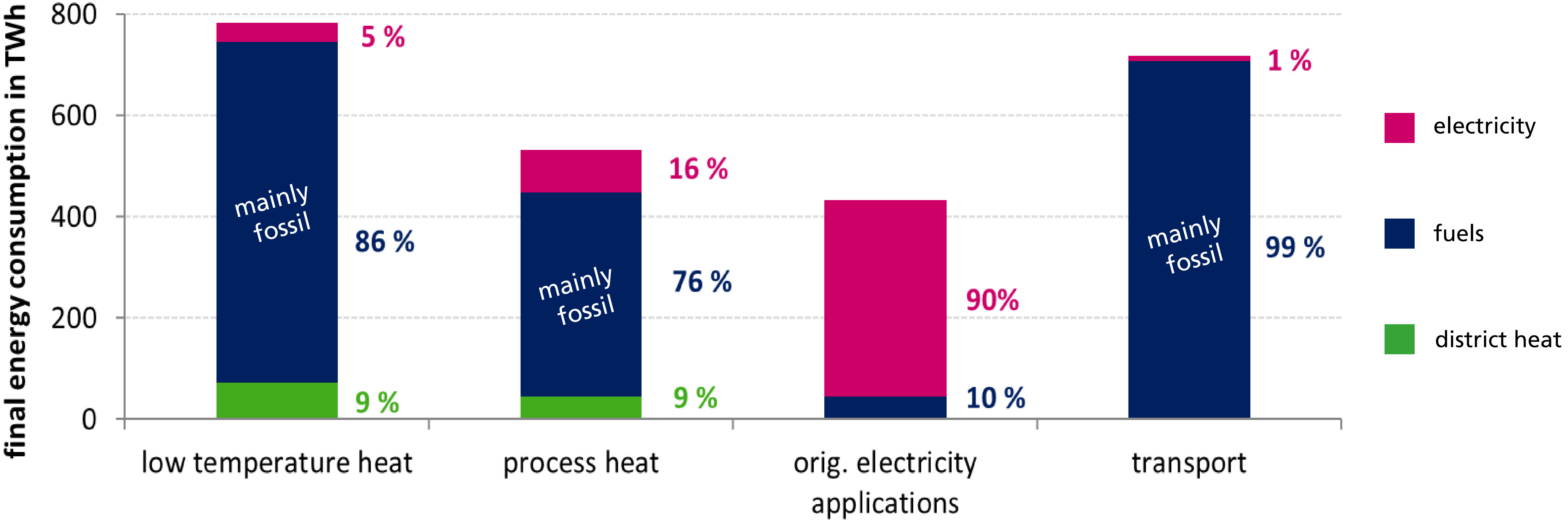


Chancellor Merkel May 2019 and UN Climate Change Summit September 2019: Net Zero GHG emissions in 2050

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

Fraunhofer ISE

German energy consumption today in the four areas of use



Quelle: »Sektorkopplung« – Optionen für die nächste Phase der Energiewende. acatech – Deutsche Akademie der Technikwissenschaften et. al. November 2017. Daten: „Energiedaten, Gesamtausgabe", BMWi, 02/2017.

Fraunhofer ISE

Major questions

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

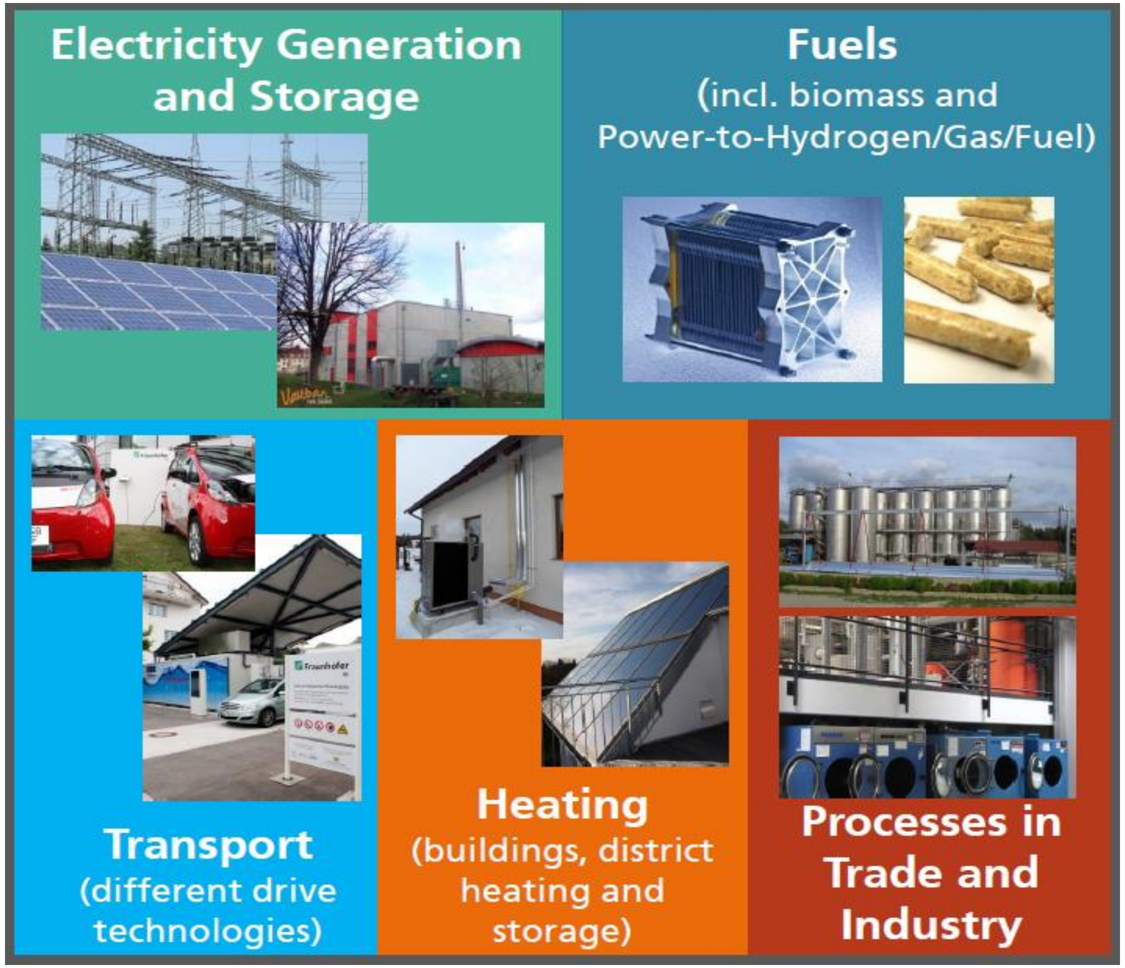
- How can the complex overall system be transformed towards achieving climate targets without compromising on security of supply and at minimal cost?

Content

Fraunhofer
ISE

Renewable Energy Model »REMod«

Mimimize total cost



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

Methodology

Stock

1990	1991	1992	…	2015	2016	2017
Conventional & renewable power (PV, Wind, …)						
Buildings and heating systems						
Mobility (car fleet etc.)						
Processes in industry and tertiary sector						

Roll-out, replacement, retrofit

2018	2019	2020	…	2048	2049	2050
Conventional & renewable power (PV, Wind, …)						
Buildings and heating systems						
Mobility (car fleet etc.)						
Processes in industry and tertiary sector						
Storage (electricity, heat)						
Power-to-X-technologies						

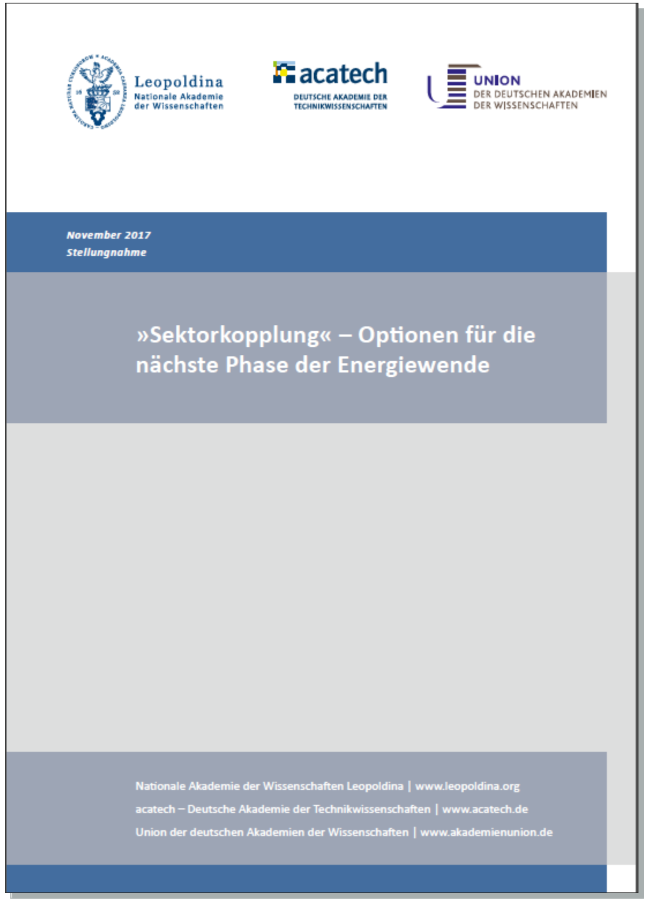
Simulation of the entire systemfrom 2018 to 2050
in hourly time steps

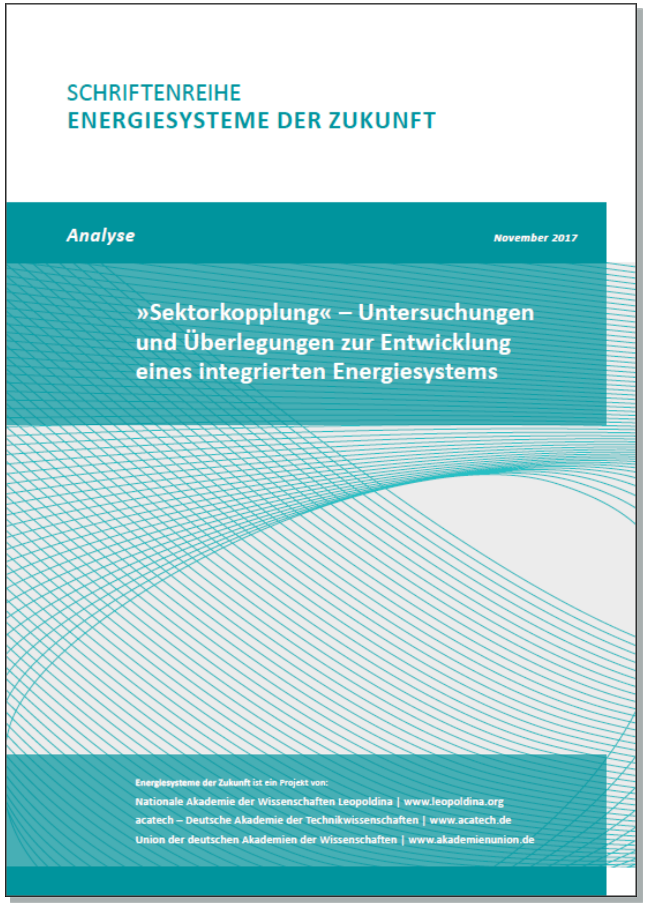
CO_2-limits met (year by year)?

Optimization of roll-out, replacement, retrofit
goal function: minimal cumulative total cost 2016-2050

Fraunhofer
ISE

Study by the German academies of science
Working group sector coupling





AG »Sektorkopplung« im BMBF-geförderten Projekt »Energieysteme der Zukunft (ESYS)«, durchgeführt von den deutschen Wissenschafts-akademien unter Federführung von acatech (Leitung Eberhard Umbach, Hans-Martin Henning)

Veröffentlichungen November 2017

Download : http://energiesysteme-zukunft.de/themen/sektorkopplung/

Study by the German academies of science

Investigated transformation pathways (selection)

Scenario	CO2 target	Major characteristics
No restrictions	Minus 85 % in 2050 (compared to 1990)	❑ No limits for direct electricity use (e.g. heat pumps, transportation)
Hydrogen		❑ Transportation with majority of hydrogen / fuel cell drive trains ❑ High fraction of H_2 in gas network
Power-to-Gas Power-to-Liquid (P2G/P2L)		❑ Transportation with majority of fuel/methane based drive trains ❑ Building heating partly based on methane ❑ Good progress in efficiency in industry
High efficiency		❑ No limits for direct electricity use ❑ Good progess in implementing high efficiency technologies ❑ Good progress in reducing energy demand

acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN

UNION DER DEUTSCHEN AKADEMIEN DER WISSENSCHAFTEN

Leopoldina Nationale Akademie der Wissenschaften

AG »Sektorkopplung« im BMBF-geförderten Projekt »Energieysteme der Zukunft (ESYS)«, durchgeführt von den deutschen Wissenschafts-akademien unter Federführung von acatech (Leitung Eberhard Umbach, Hans-Martin Henning)

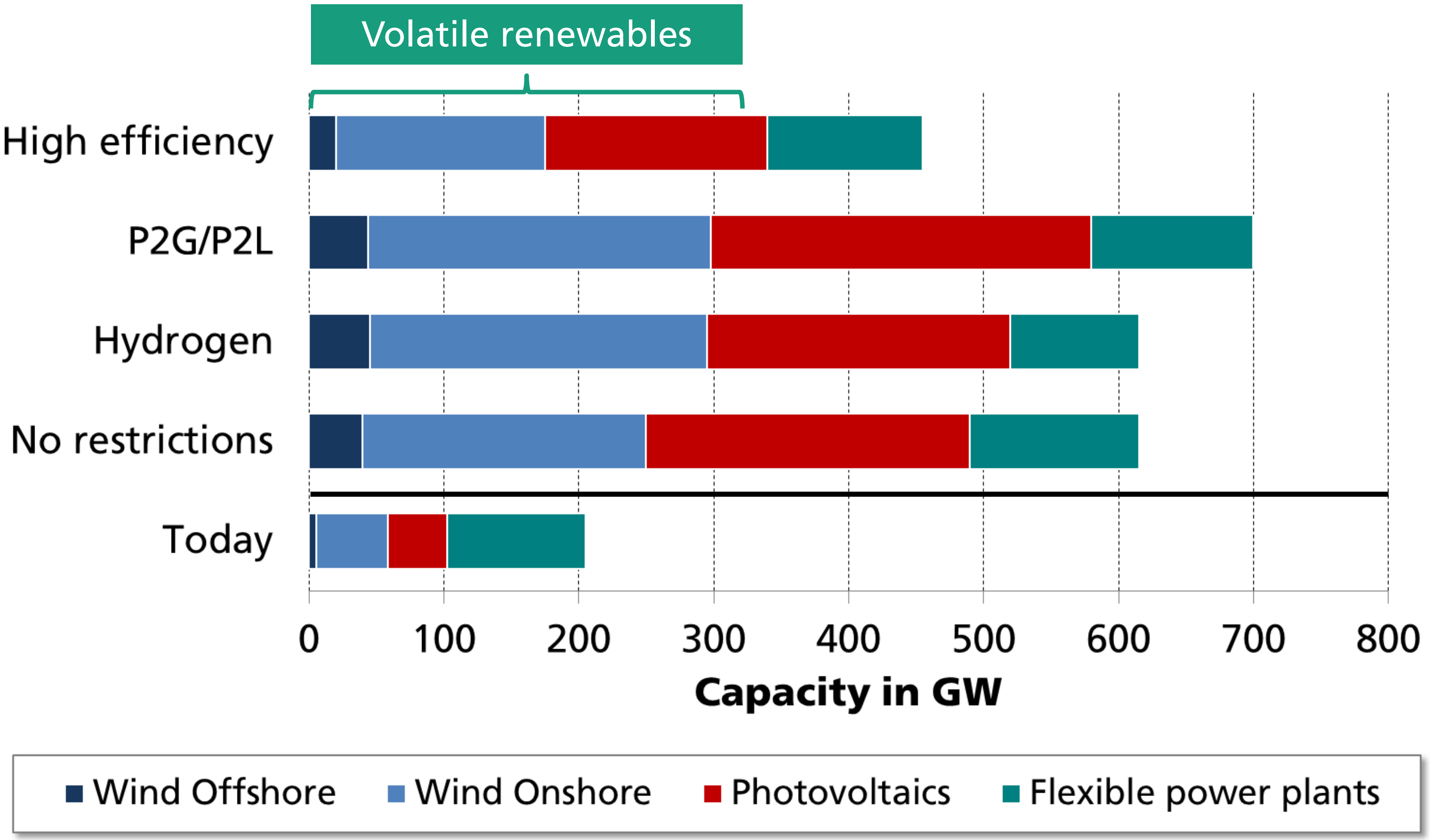
Veröffentlichungen November 2017

Fraunhofer ISE

Content

Electricity generation

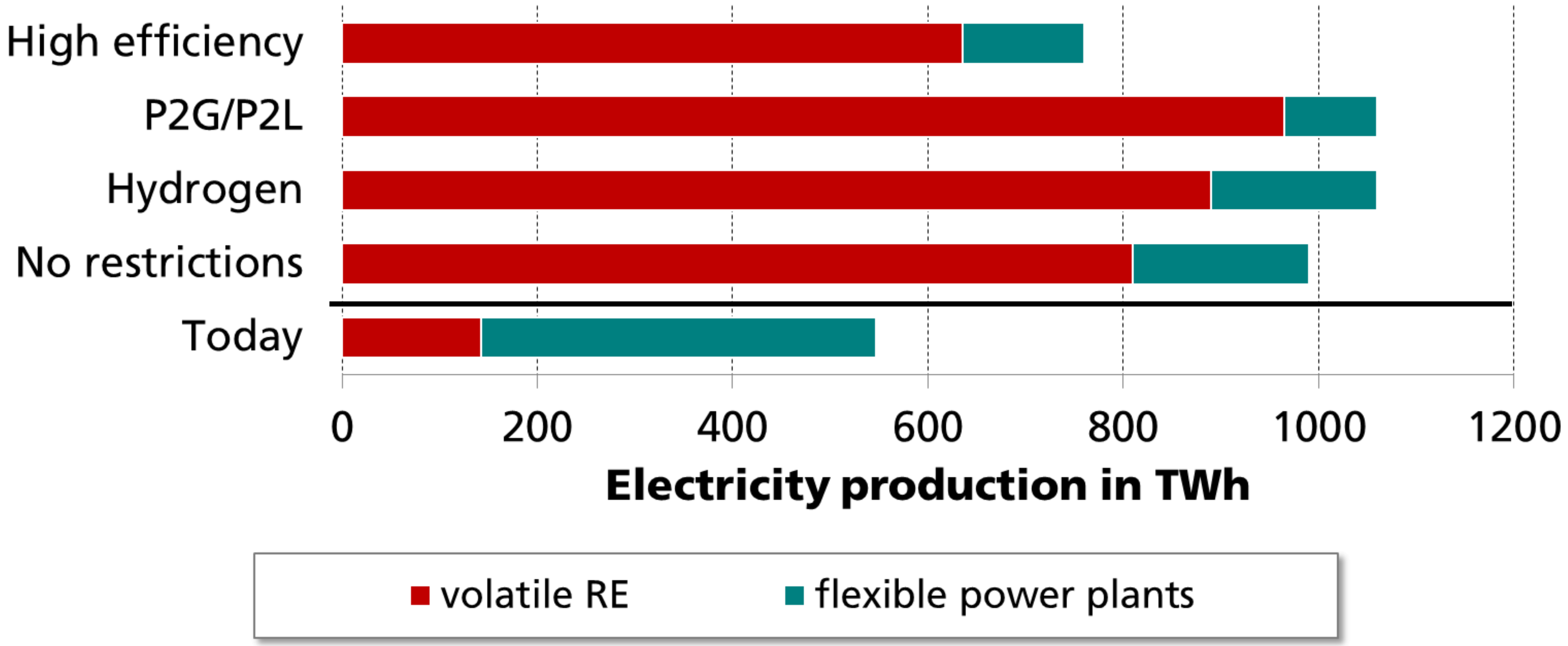
Installed capacity in GW in 2050 and today (CO_2 reduction 85 %)



- Capacity from flexible power plants almost same as today (➔ cold winter, weak wind & solar)
- Volatile renewable energy capacity 340 GW … 580 GW ➔ 3…6 times higher than today
- »High efficiency« scenario leads to significantly lower renewable energy

Electricity production

Annual energy in TWh in 2050 and today (CO_2 reduction 85 %)

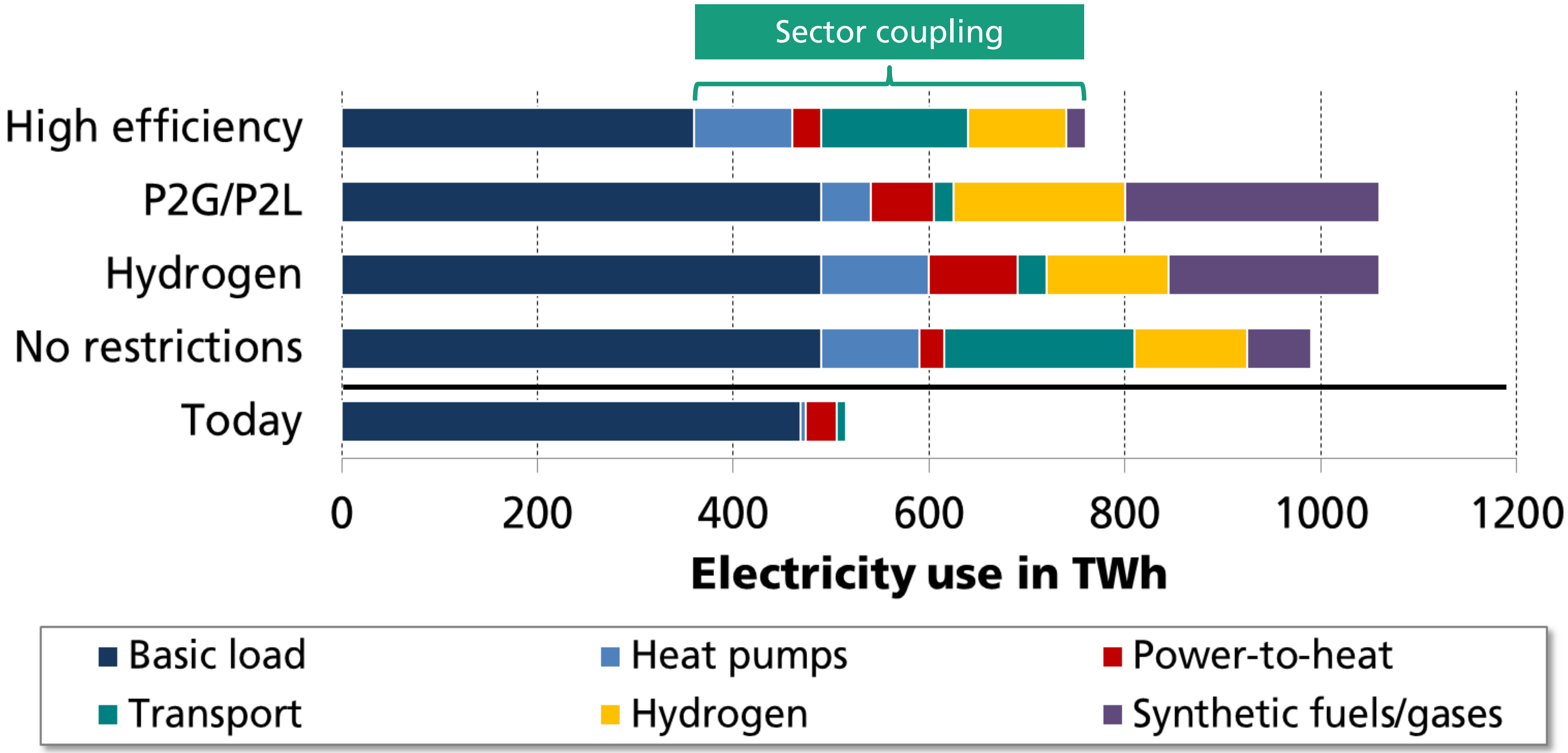


- Electric system dominated by volatile production
  ➔ full **system integration** of volatile renewable production needed
- Far lower production from flexible power plants
  ➔ significantly reduced full load hours
  ➔ capacity market

Fraunhofer ISE

Electricity use

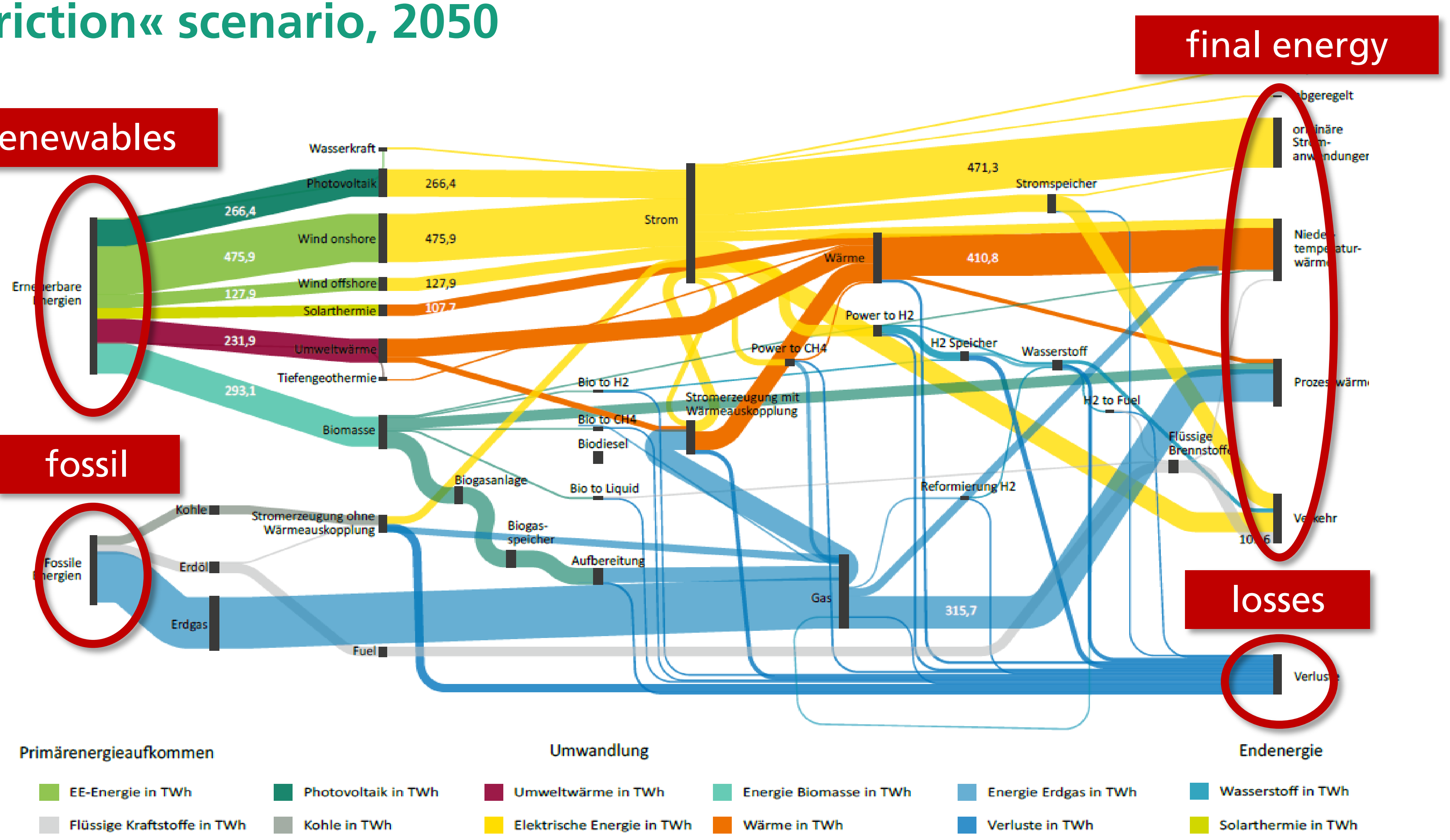
Annual energy in TWh in 2050 and today (CO_2 reduction 85 %)



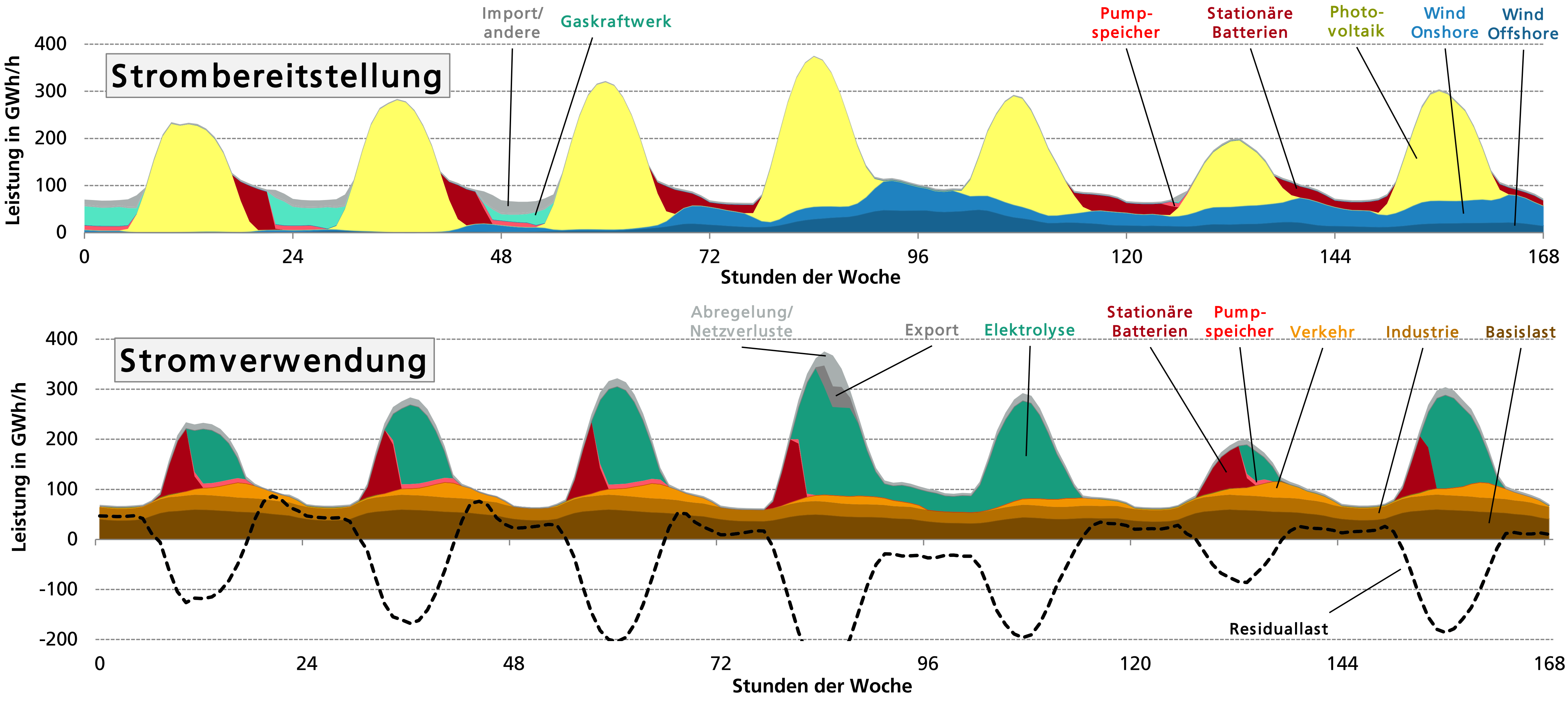
Significant increase of electricity use due to **sector coupling**

- Direct use of electricity in heat and transport sectors (heat pumps, battery / electric drive train vehicles)
- Use of electricity for hydrogen production and power-to-gas and power-to-fuel

Energy flow chart
»No restriction« scenario, 2050

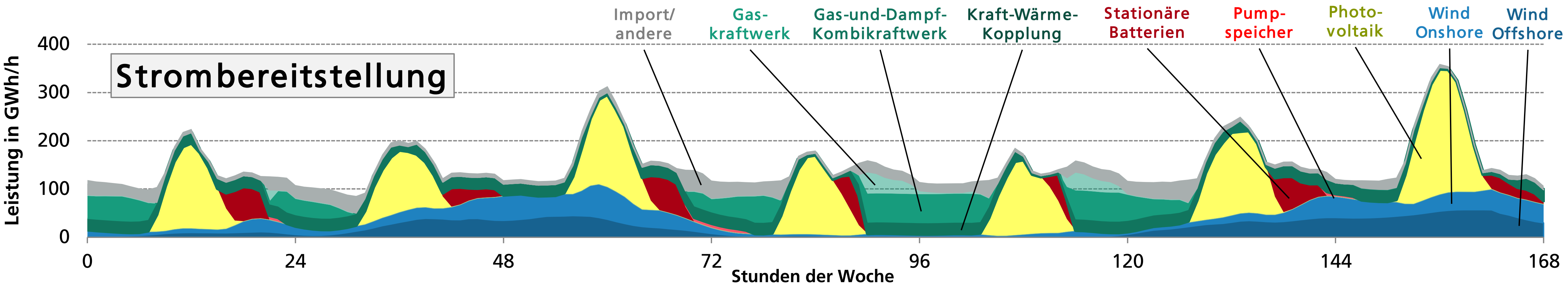


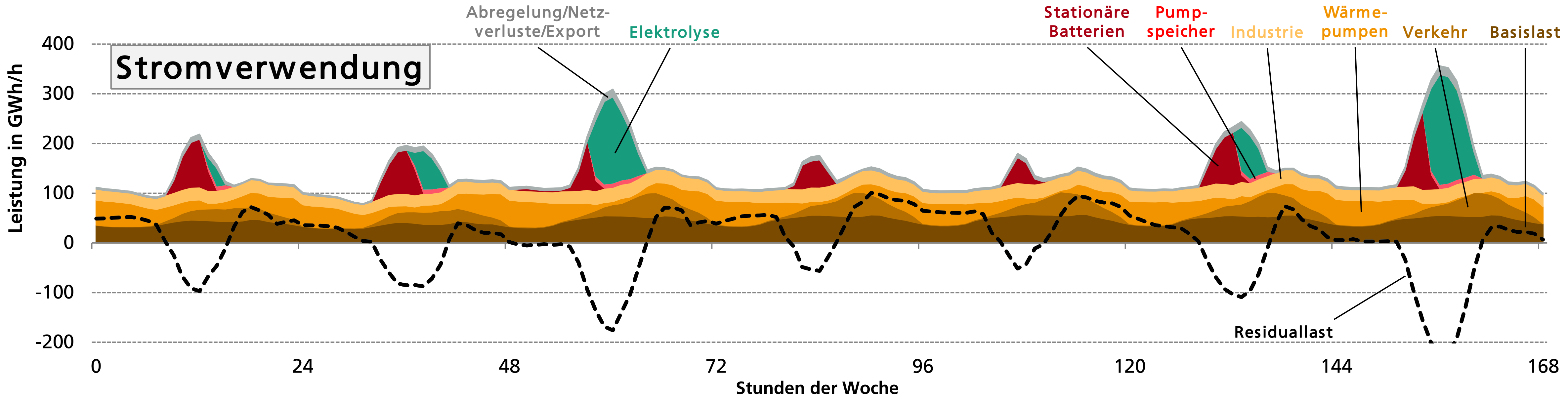
Electricity Production in Germany – Example: Summer week in 2050



Daten: P. Sterchele, „Analysis of Technology Options to Balance Power Generation from Variable Renewable Energies “, Dissertation (2019)

Electricity Production in Germany – Example: Winter week in 2050



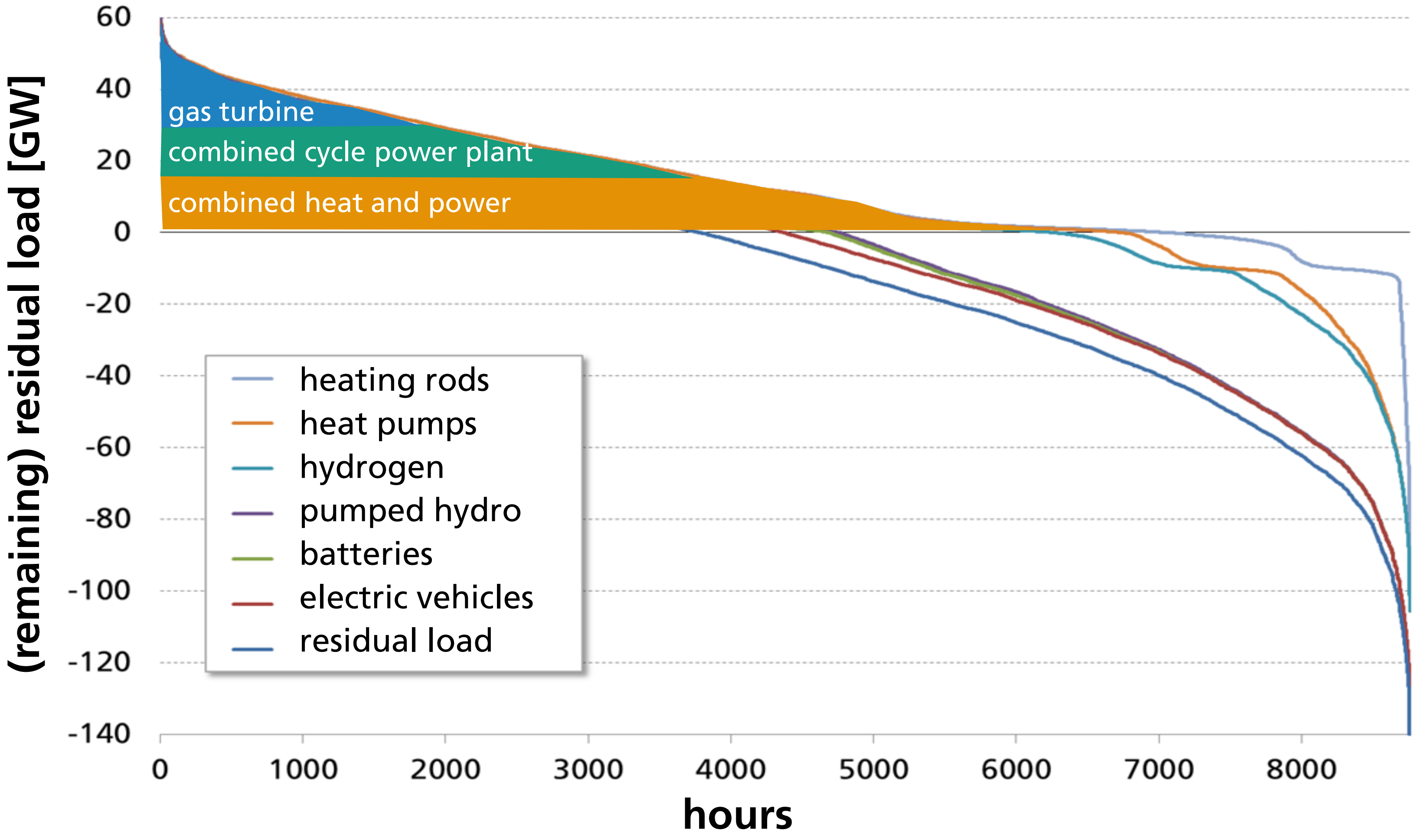


Daten: P. Sterchele, „Analysis of Technology Options to Balance Power Generation from Variable Renewable Energies ", Dissertation (2019)

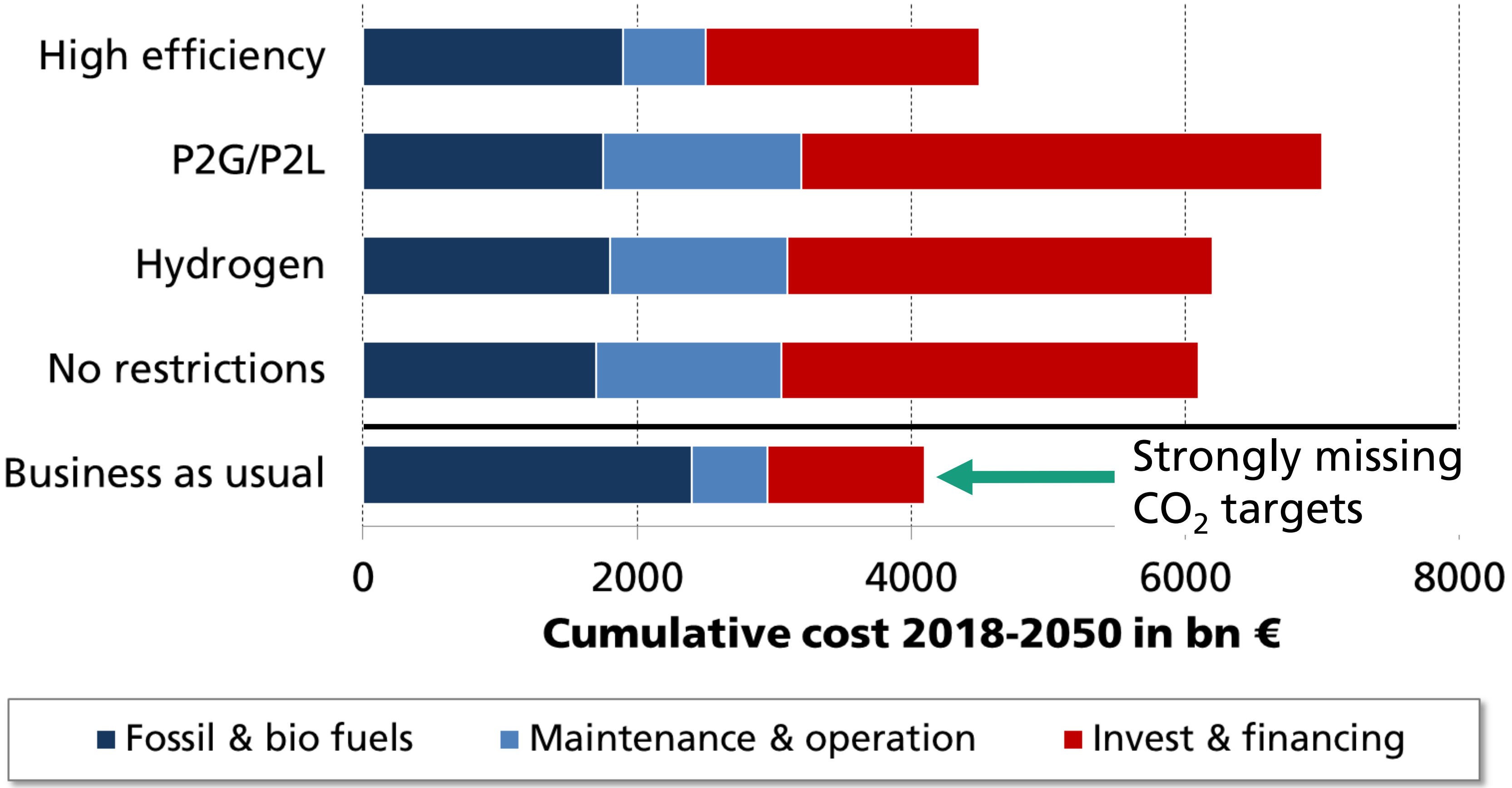
Fraunhofer ISE

Power plants

Sequential coverage of remaining positive residual load



Cumulative systemic total costs until 2050 in Billion €

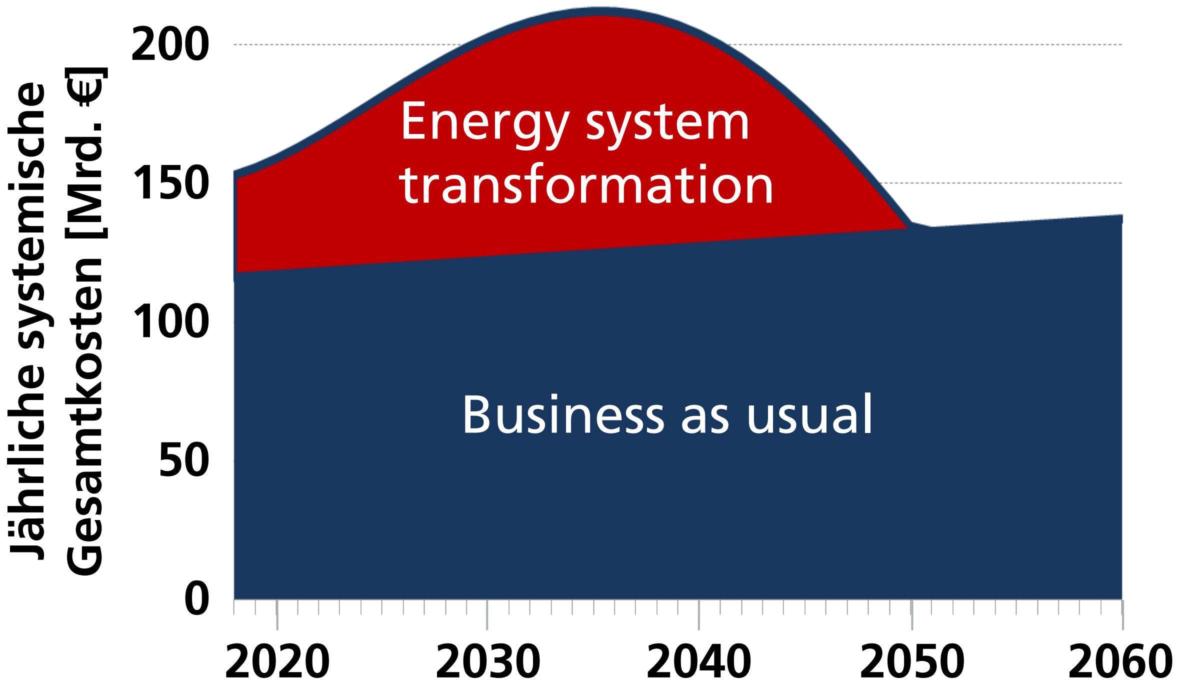


- Cost difference in the range of 500 bn € … >2500 bn €
- Mainly investments ➔ build a new system
- Approx. 0,5…2,5 % of German GDP (2017)
- External cost not included (e.g. health cost for coal)
- No consideration of macro-economic benefits (i.e. value creation, employment)

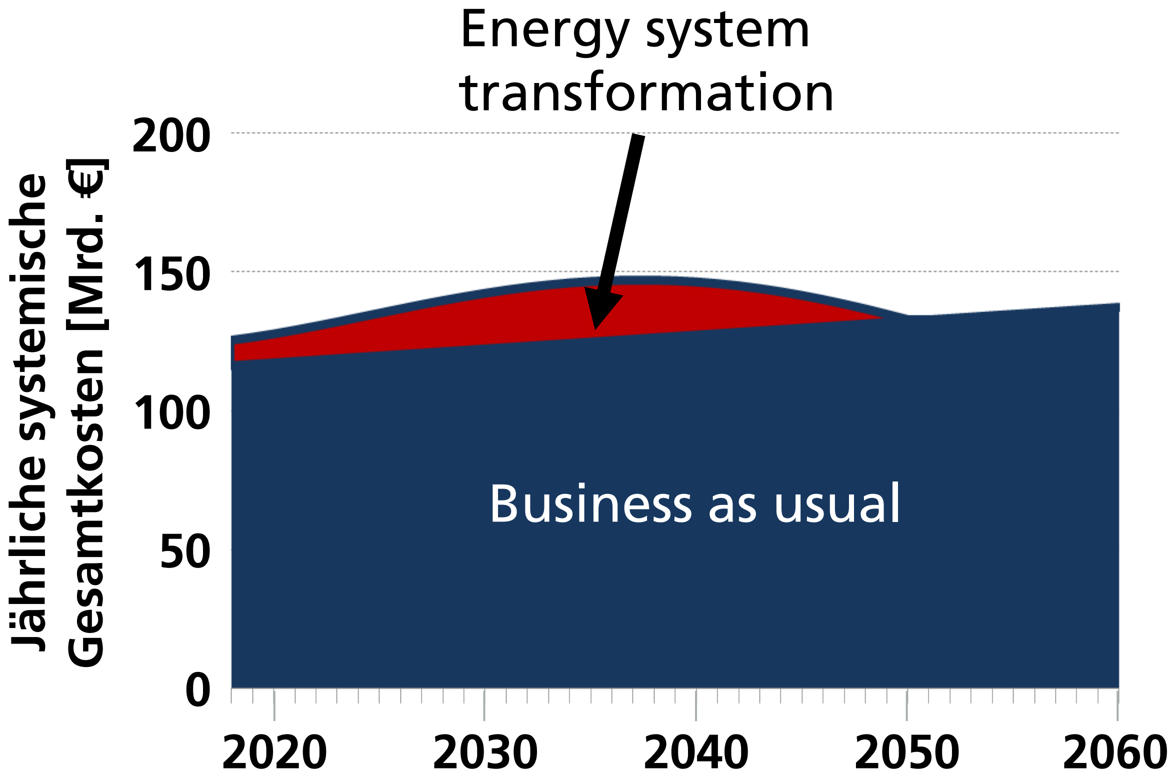
Cost development

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

Scenario »No restriction«



Scenario »High efficiency«



Fraunhofer ISE

Cost analysis
Cost categories and CO_2 pricing

GASTBEITRAG ZUR KLIMAPOLITIK

Die Energiewende erfolgreich steuern

VON KAREN PITTEL, HANS-MARTIN HENNING - AKTUALISIERT AM 12.07.2019 - 06:43

Wer CO2 ausstößt, soll künftig dafür zahlen. Aber welcher Preis ist angemessen? Es geht nicht (nur) darum, Haushalte und Unternehmen stärker zu belasten, sondern ihnen die richtigen Signale zu senden.

Karen Pittel, Hans-Martin Henning

Die Energiewende erfolgreich steuern

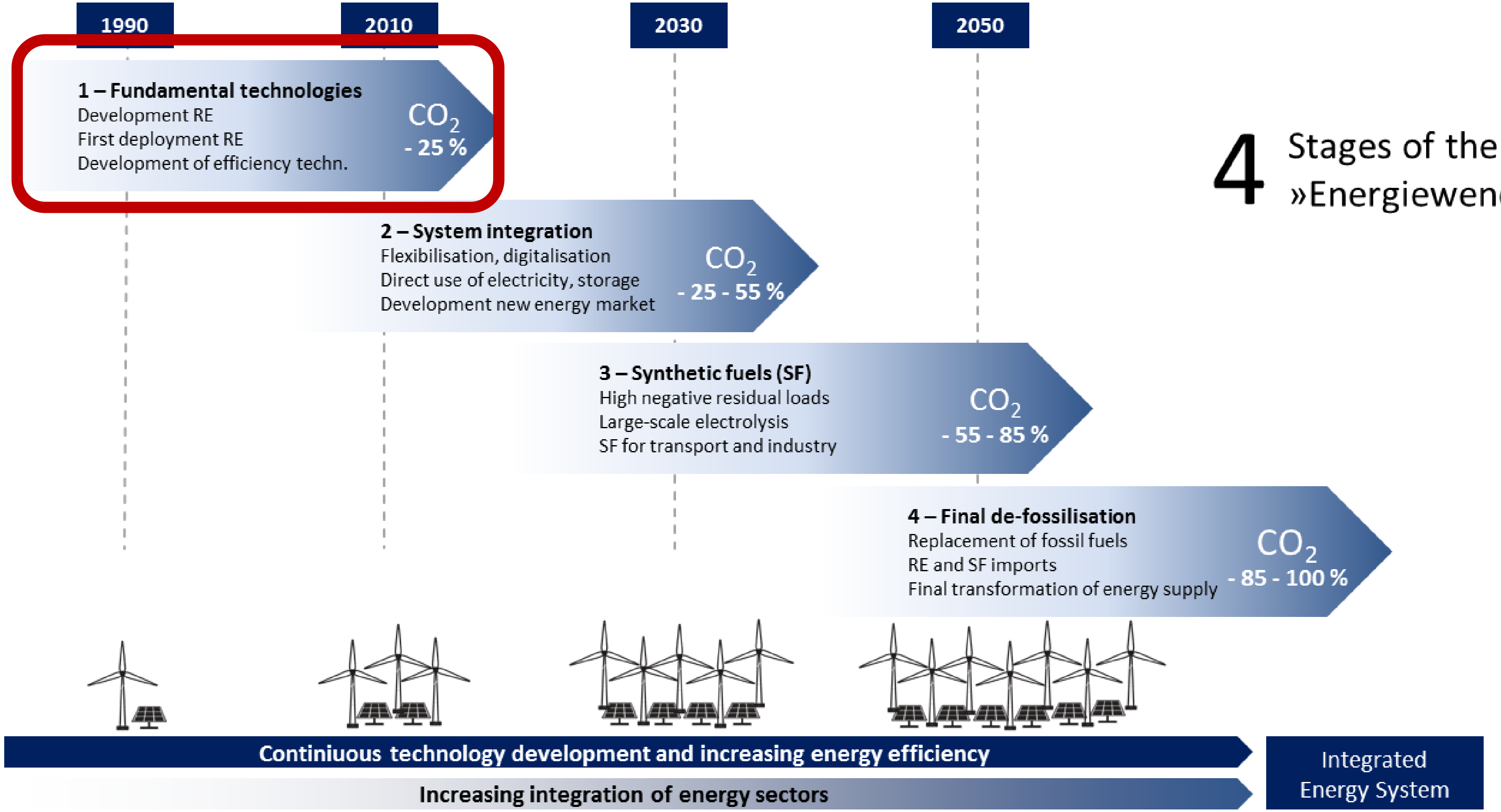
Frankfurter Allgemeine Zeitung
12. Juli 2019

Fraunhofer ISE

Content

»Sektorkopplung« – Optionen für die nächste Phase der Energiewende

Phases of the energy system transformation



4 Stages of the »Energiewende«

acatech
DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN

UNION DER DEUTSCHEN AKADEMIEN DER WISSENSCHAFTEN

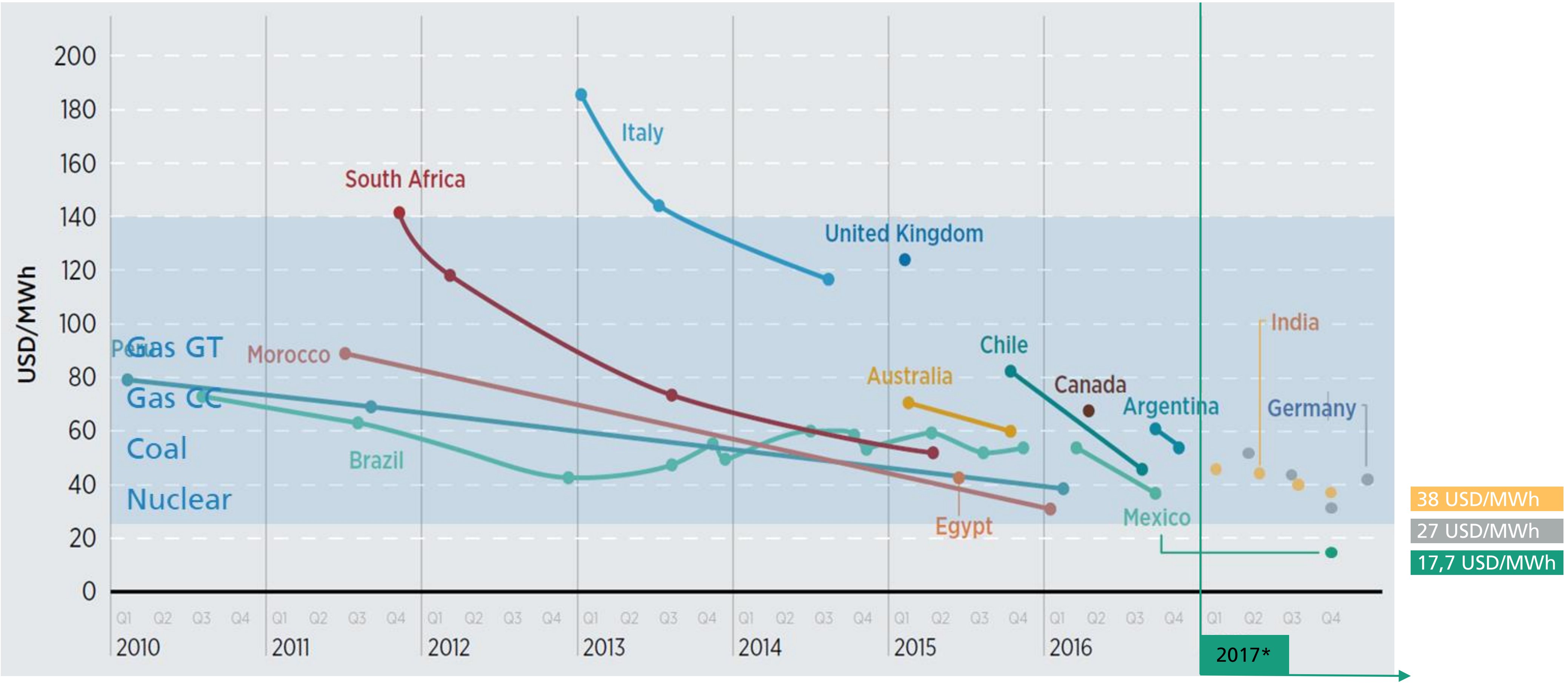
Leopoldina Nationale Akademie der Wissenschaften

Download: http://energiesysteme-zukunft.de/themen/sektorkopplung/

Fraunhofer ISE

Renewable energy technologies

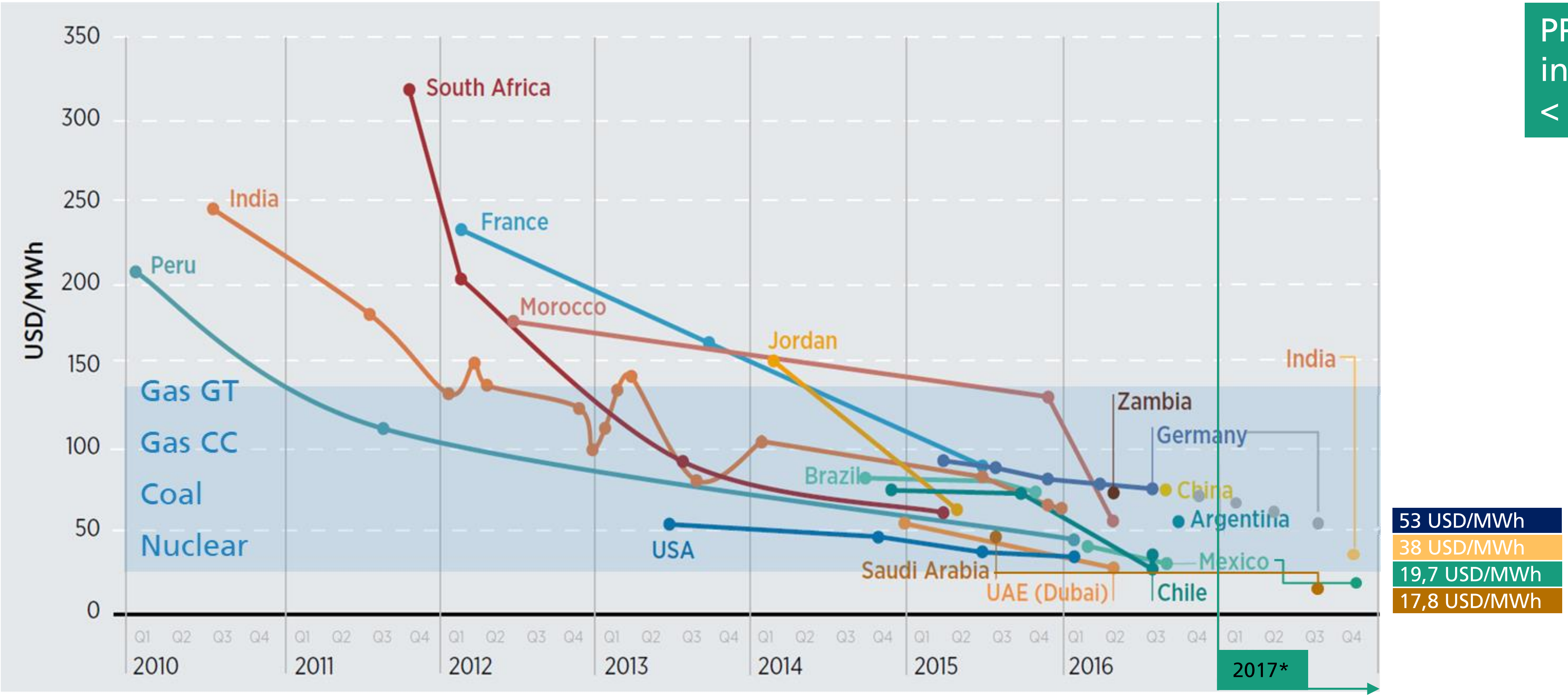
Average prices for wind electricity (January 2010 - December 2017)



Source: Renewable Energy Auctions 2016, IRENA; *Source: Fraunhofer ISE

Renewable energy technologies

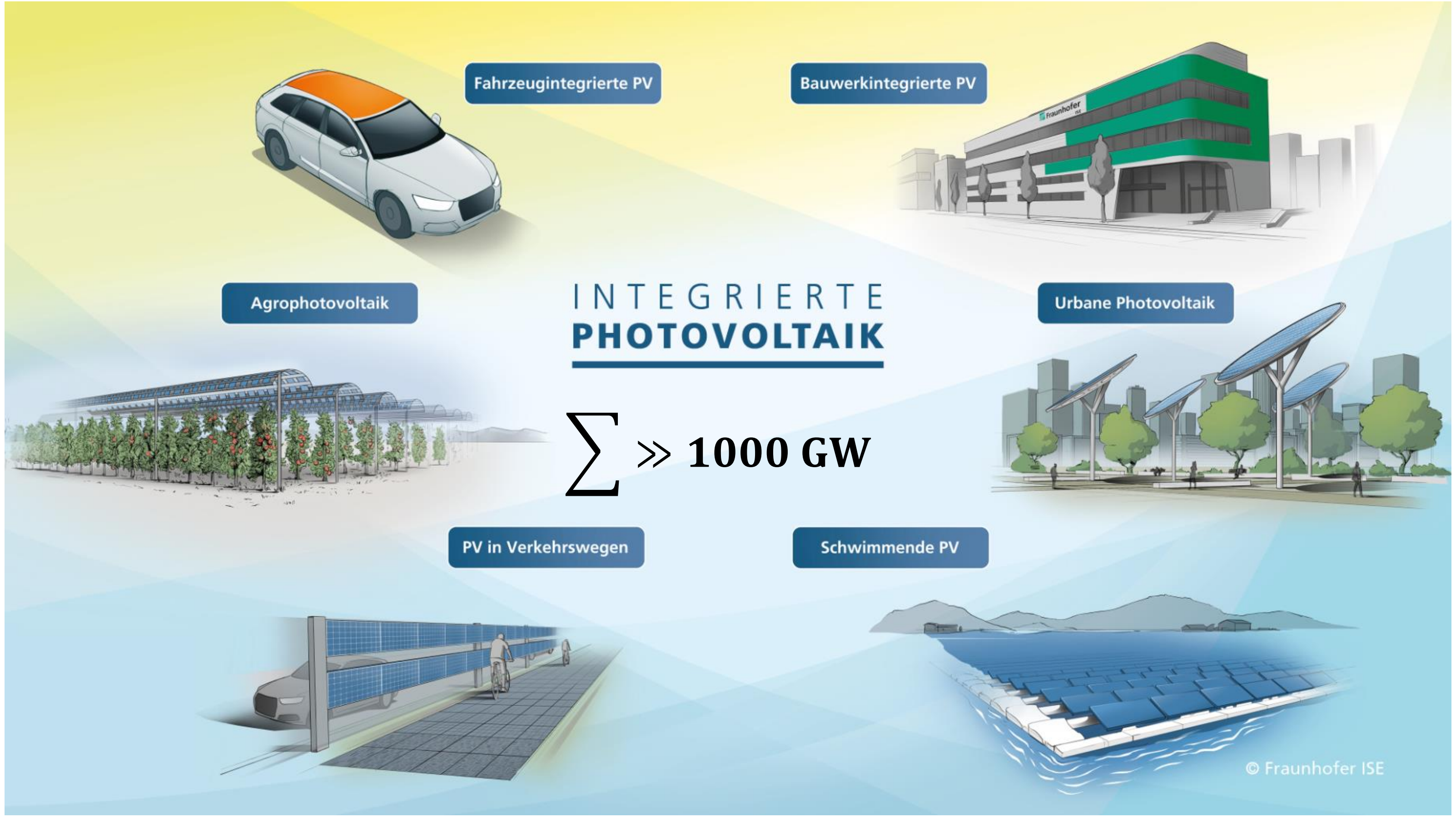
Average prices for photovoltaic electricity (January 2010 - December 2017)



PPAs in Germany in April 2018: < 40 €/MWh

Source: Renewable Energy Auctions 2016, IRENA; *Source: Fraunhofer ISE

Fundamental technologies
Integrated photovoltaics



- no additional area needed
- opens up synergies (substructure, covering material)
- offers multifunctionality (e.g. protection)
- increased range, autonomy
- produces electricity decentrally, close to consumption
- improves the CO_2 balance of the consumer
- improves acceptance for PV expansion
- offers opportunities for German PV production

Fraunhofer ISE

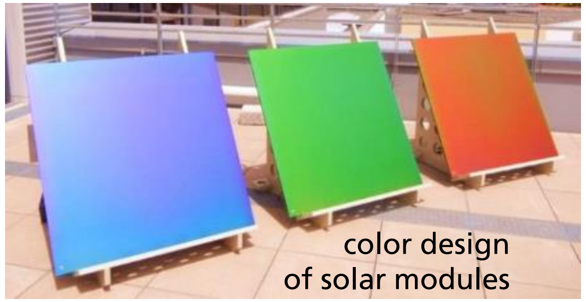
Fundamental technologies
Integrated photovoltaics: Examples


Building integrated PV
(ISE, 2015)


Hofgemeinschaft Heggelbach,
Projekt „APV-RESOLA“, 2017

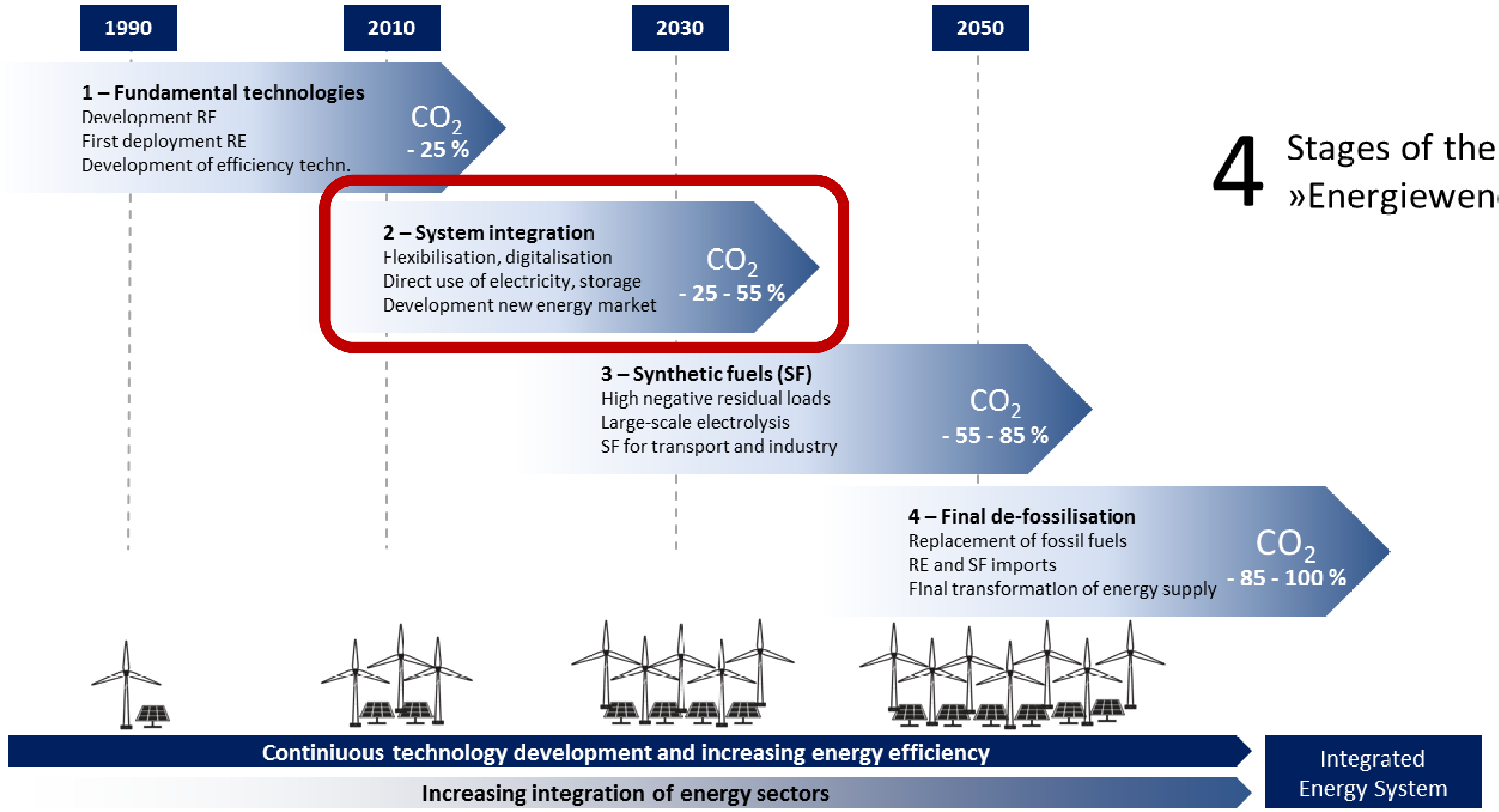

PV car roof presented at IAA 2019


Solar façade


color design
of solar modules

»Sektorkopplung« – Optionen für die nächste Phase der Energiewende

Phases of the energy system transformation



4 Stages of the »Energiewende«

acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN

UNION DER DEUTSCHEN AKADEMIEN DER WISSENSCHAFTEN

Leopoldina Nationale Akademie der Wissenschaften

Download: http://energiesysteme-zukunft.de/themen/sektorkopplung/

System integration
Power electronics

Synchronous machines play an important role today:

- Voltage regulation
- Reactive power supply
- Frequency regulation
- Provision of current reserve
- Network dynamics / Stability
- Network protection

Inverters have to take over many of these ancillary services (in combination with battery storage)

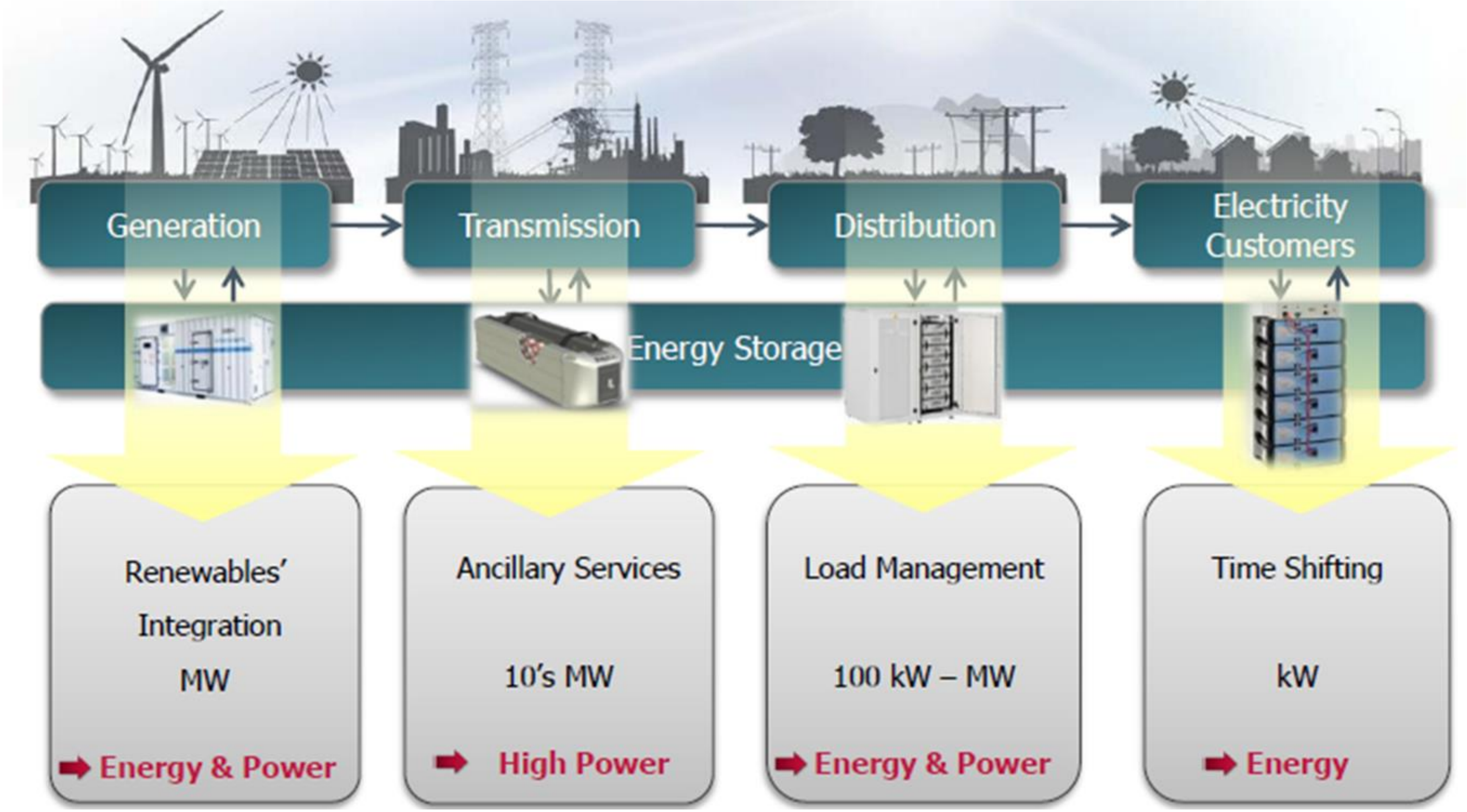
- → Virtual synchronous machines
- → Semi-conductor based grids

Center for Power Electronics and Sustainable Grids

Unique infrastructure for power electronics and dynamic grid regulation up to the multi-megawatt range (110 kV)

System integration

Storage: Application of storage technologies

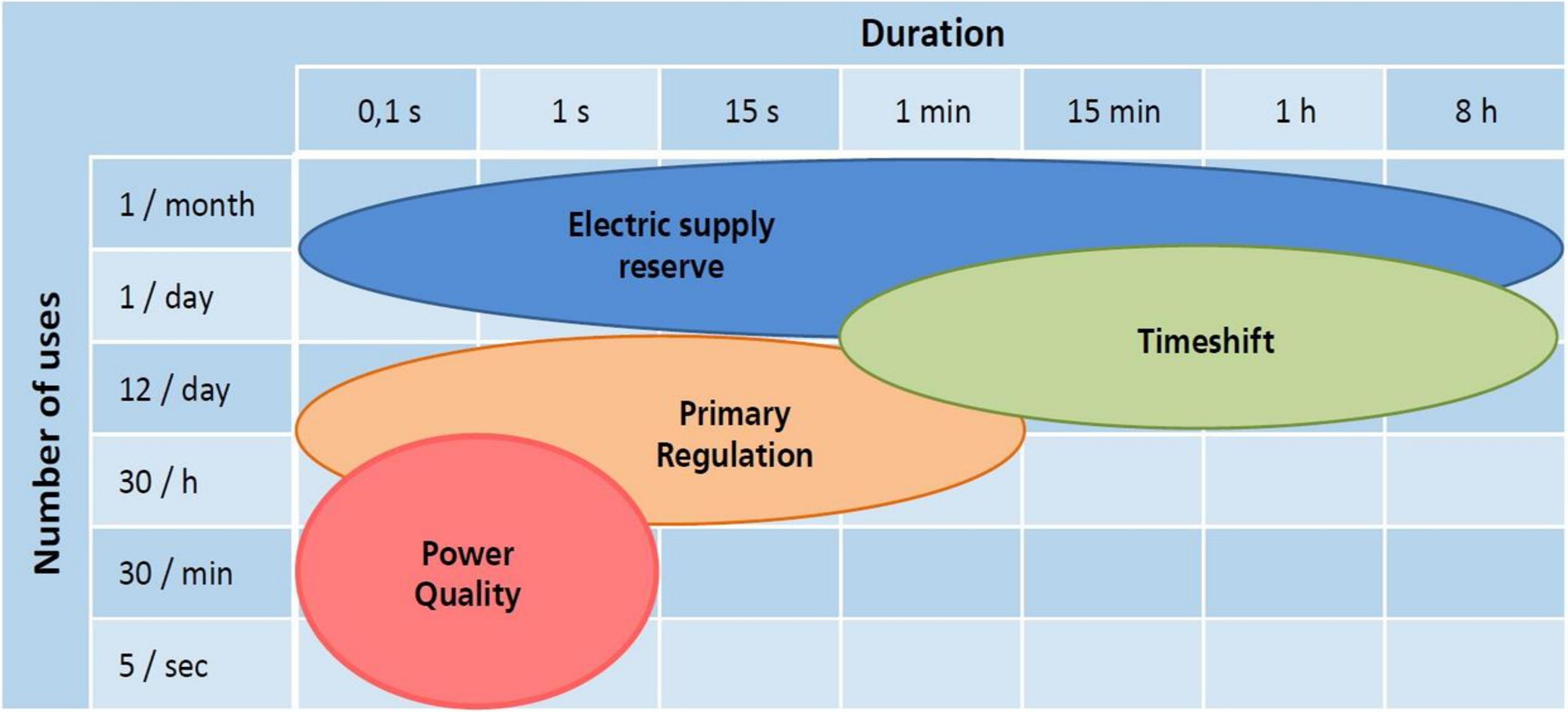


Quelle: Michael Lippert, Li-ion battery storage and renewables, Intersolar Munich, 2014.

Fraunhofer ISE

System integration

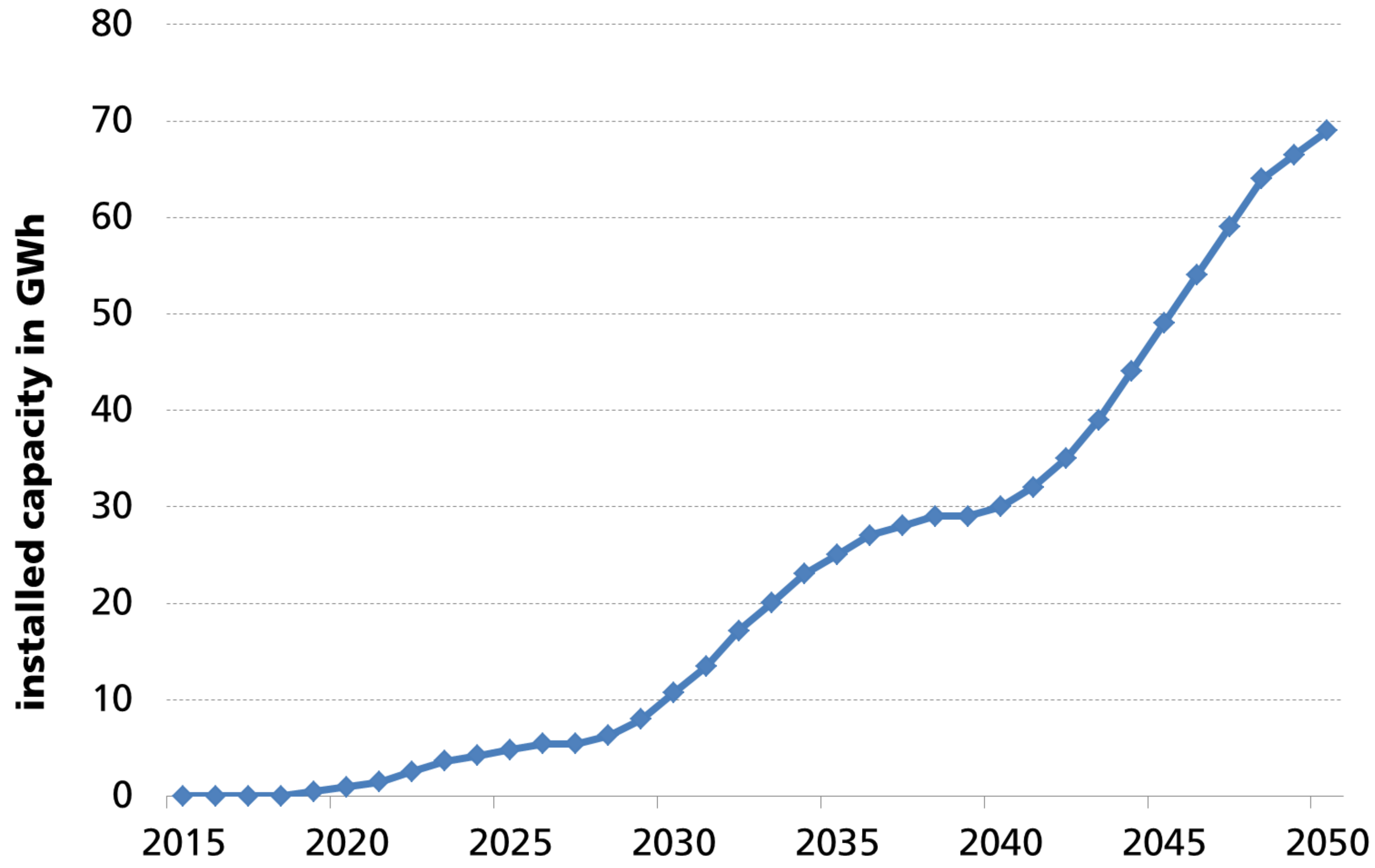
Storage: Role in the energy system in the years 2030 - 2035



Source: IEC white paper electrical energy storage, 2011.

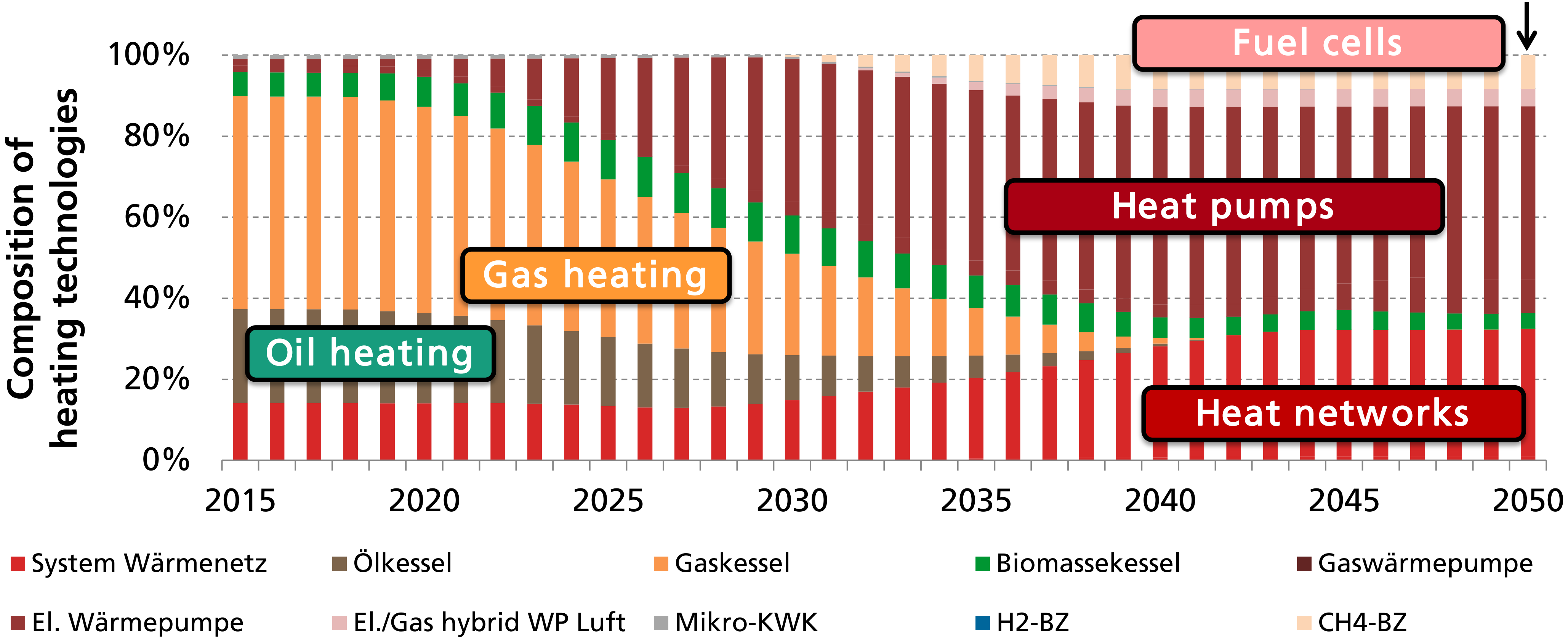
System integration

Storage: Stationary batteries (»No restriction« scenario)



System integration
Heat supply

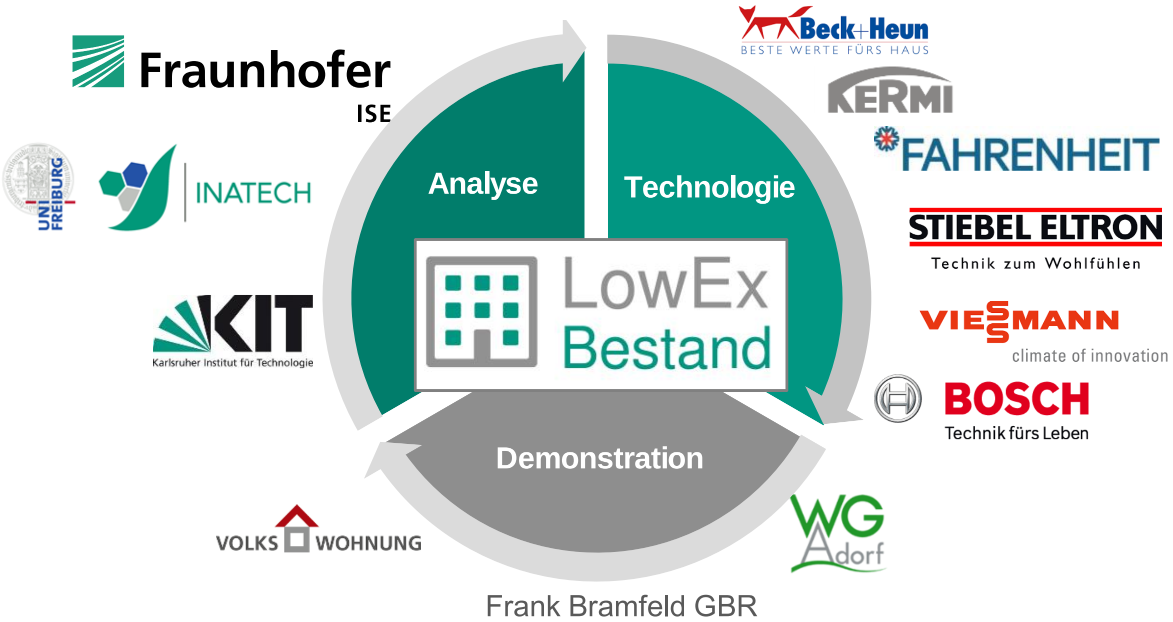
2050: 35 Mio t CO_2 for space heating

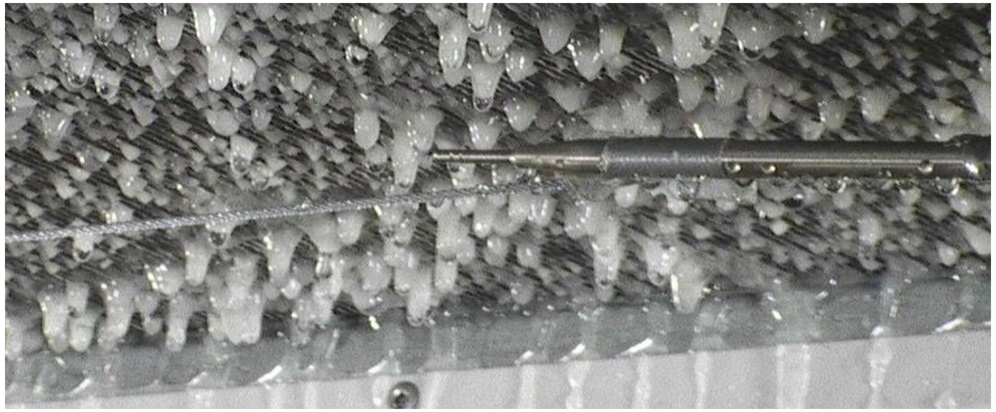


Fraunhofer ISE

System integration

Heat supply – Project LowEx Bestand





- Heat pumps offer energy saving potentials in existing buildings, in particular in combination with building refurbishment

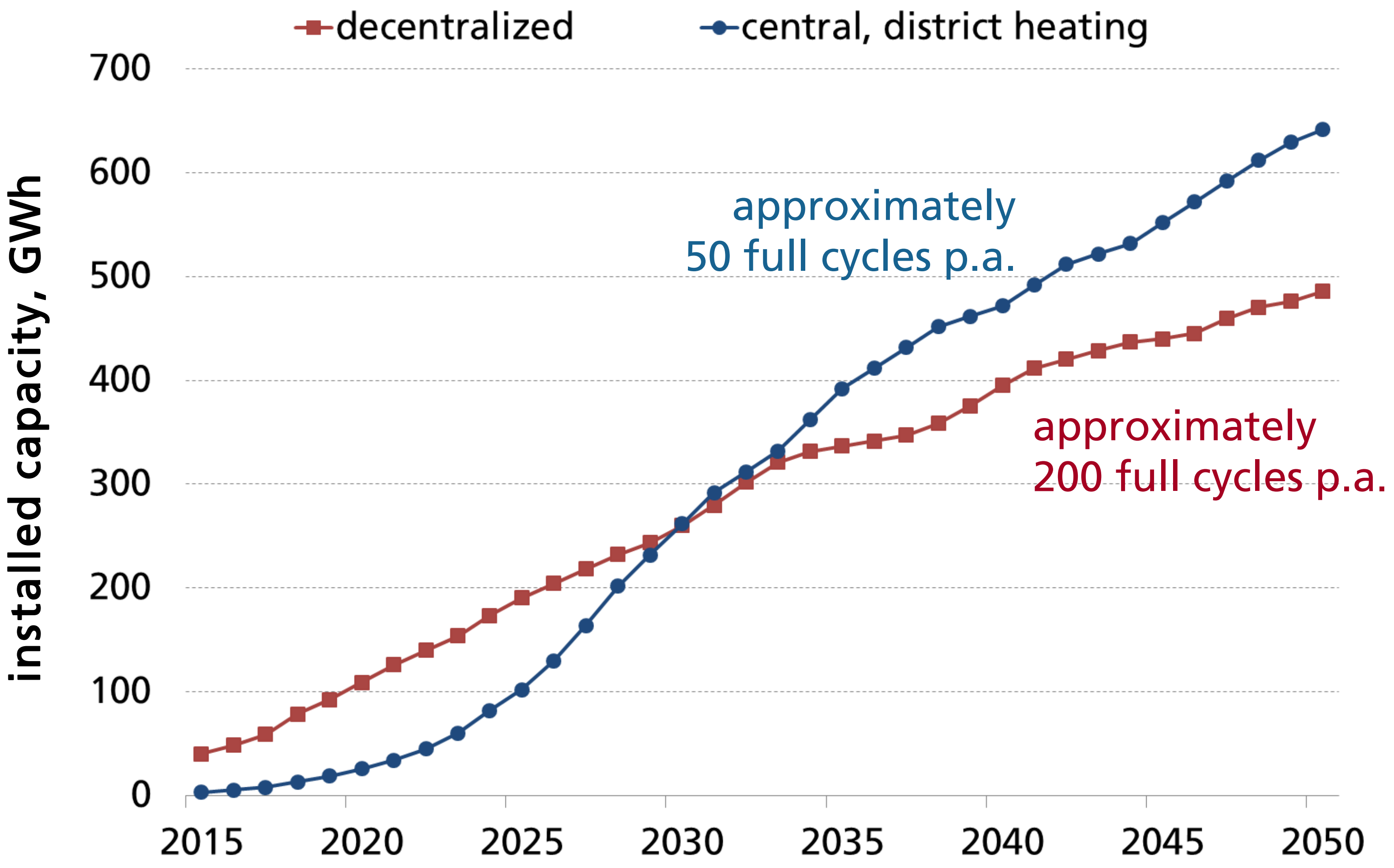
→ Project focus: Decarbonisation of the heat supply of the multiple-family house stock

- Cross-sectional analysis and demonstration of system solutions
- Development of multi-source systems for heat pumps in multi family house portfolio
- Characterization of the icing dynamics

Bundesministerium für Wirtschaft und Energie
Förderung durch das BMWi unter den Förderkennzeichen 03SBE001B (LowEx-Bestand Analyse) und 03ET1540B (Heaven)

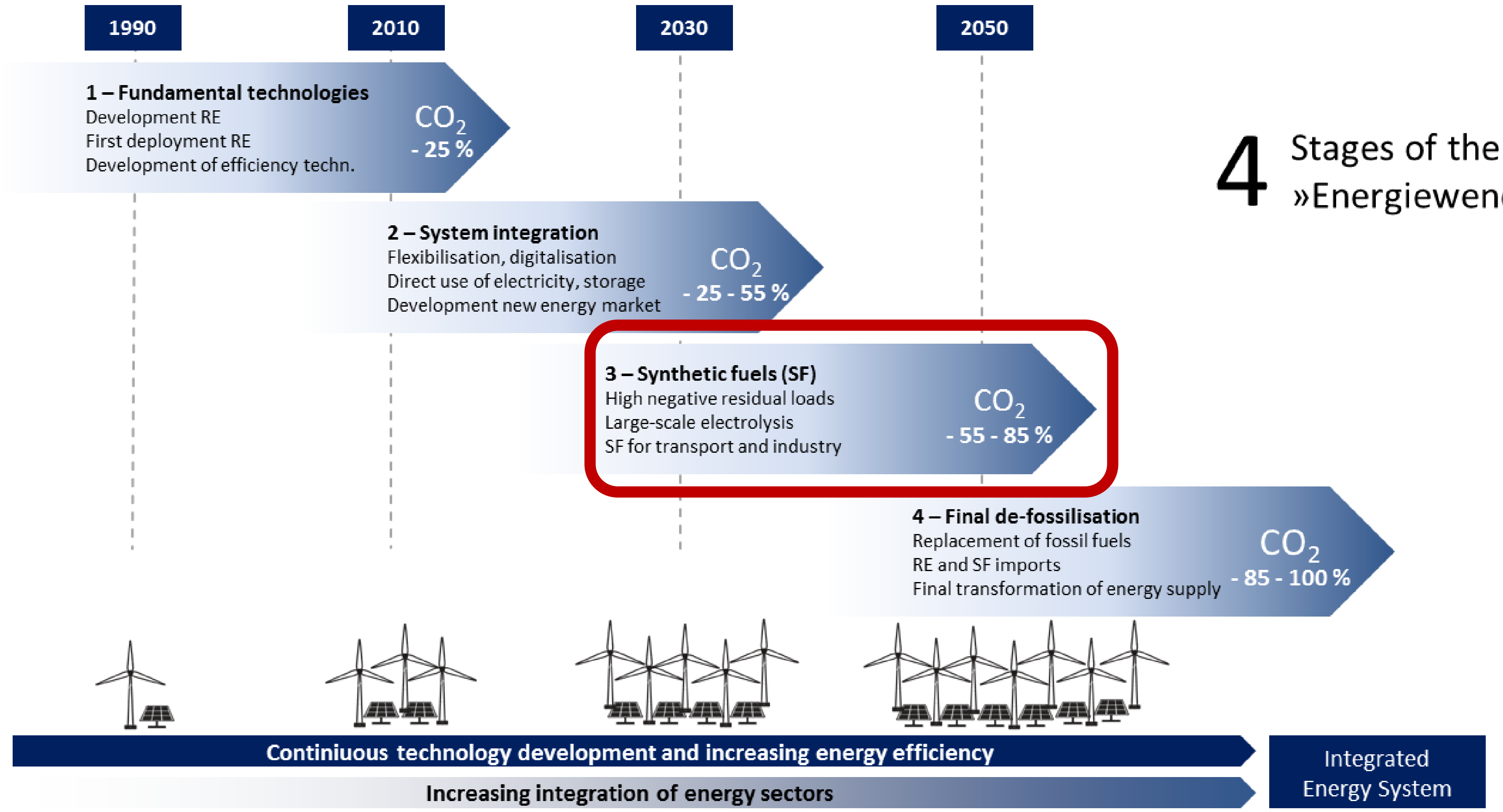
System integration

Heat storage (»No restriction« scenario, CO_2 reduction -85%)



»Sektorkopplung« – Optionen für die nächste Phase der Energiewende

Phases of the energy system transformation



4 Stages of the »Energiewende«

acatech
DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN

UNION DER DEUTSCHEN AKADEMIEN DER WISSENSCHAFTEN

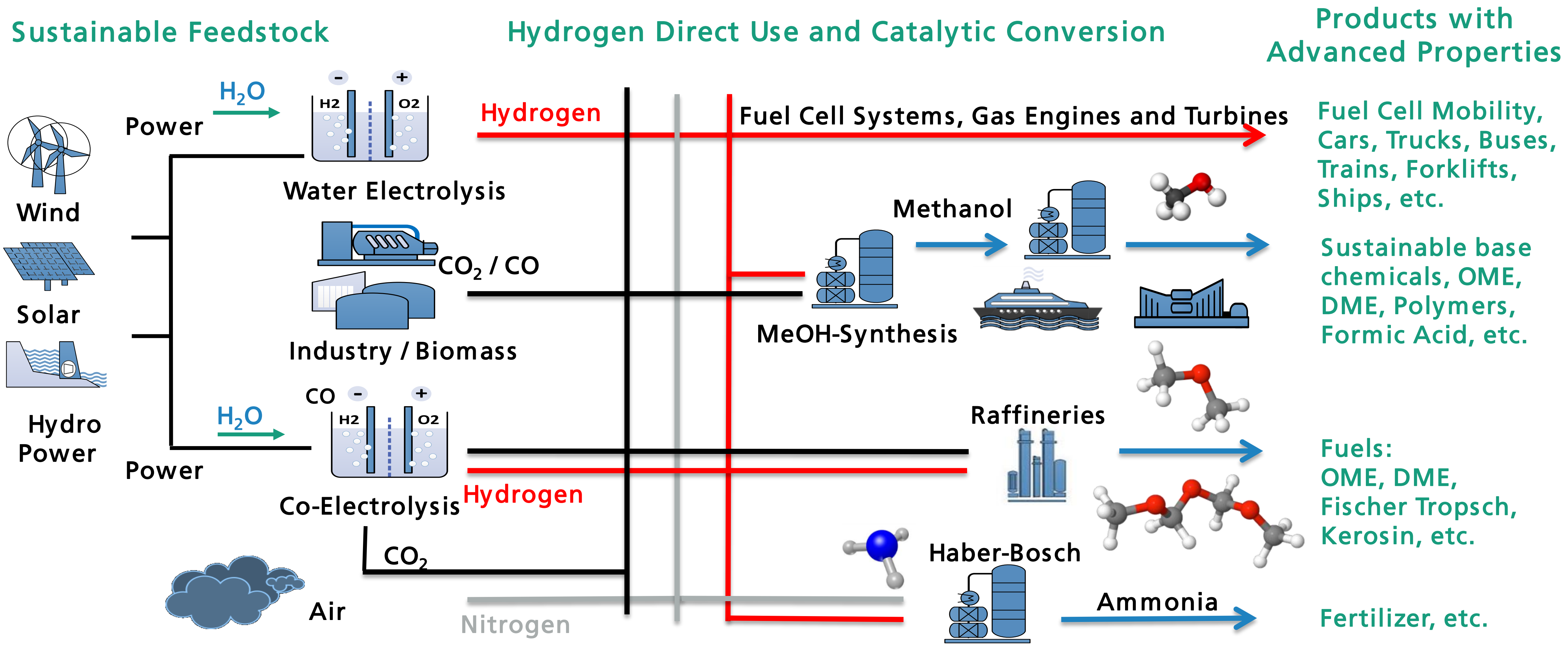
Leopoldina Nationale Akademie der Wissenschaften

Download: http://energiesysteme-zukunft.de/themen/sektorkopplung/

Fraunhofer ISE

Synthetic fuels

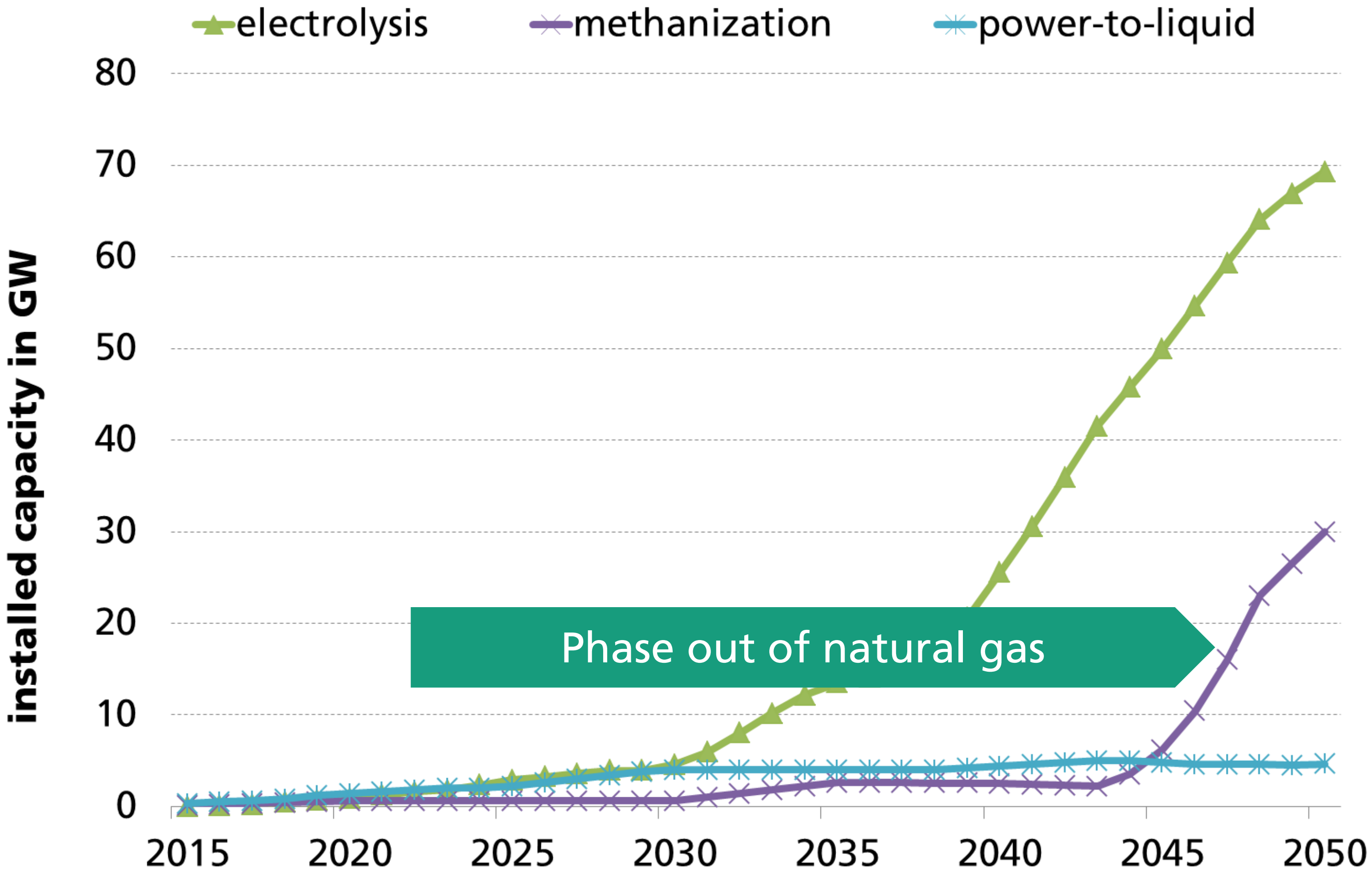
Power-To-X: Hydrogen Value Chain and Applications



Fraunhofer ISE

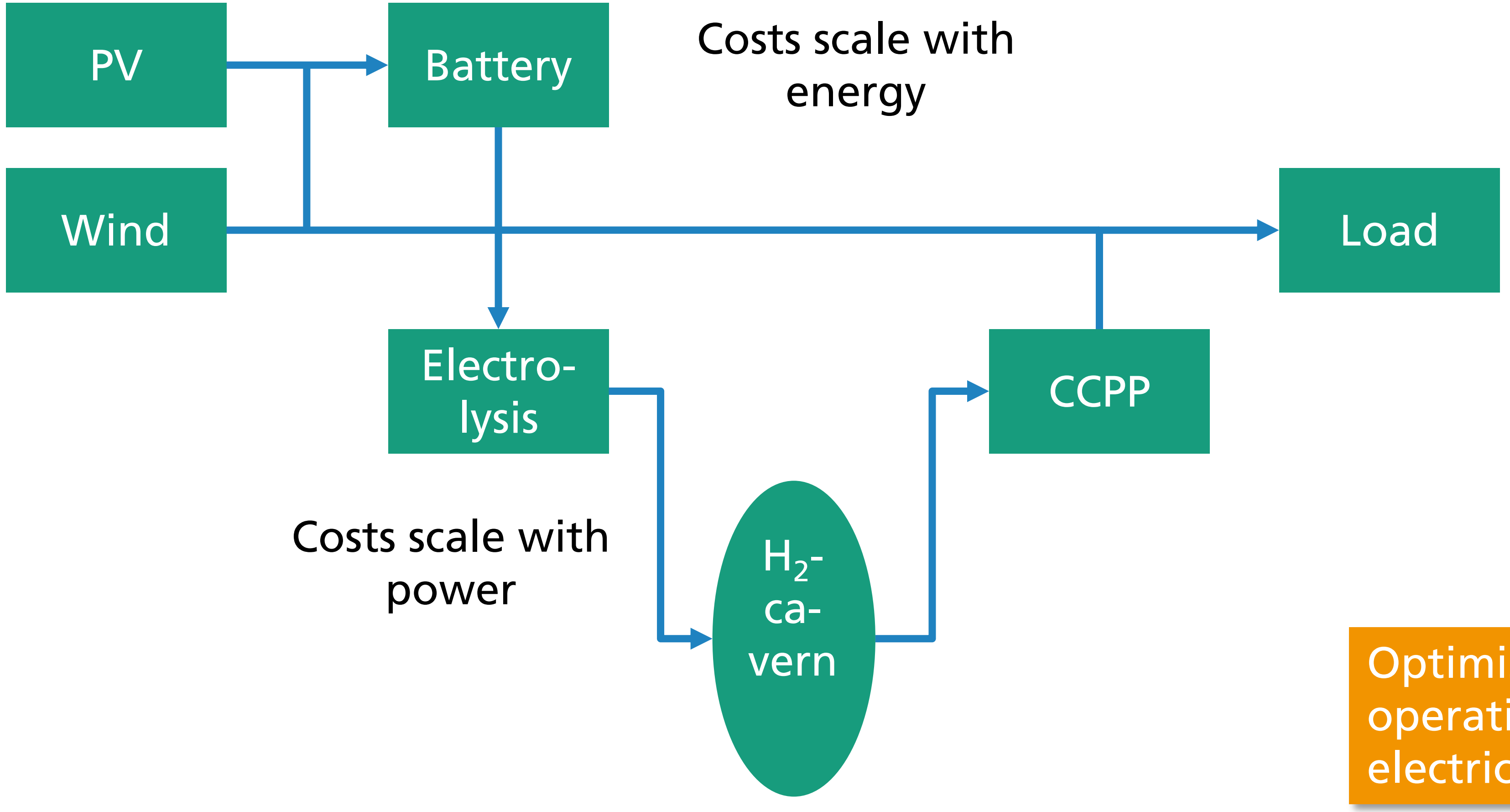
Synthetic fuels

Multi-GW scale electrolysis and P2G/P2L converters (»No restriction« scenario)



Fraunhofer ISE

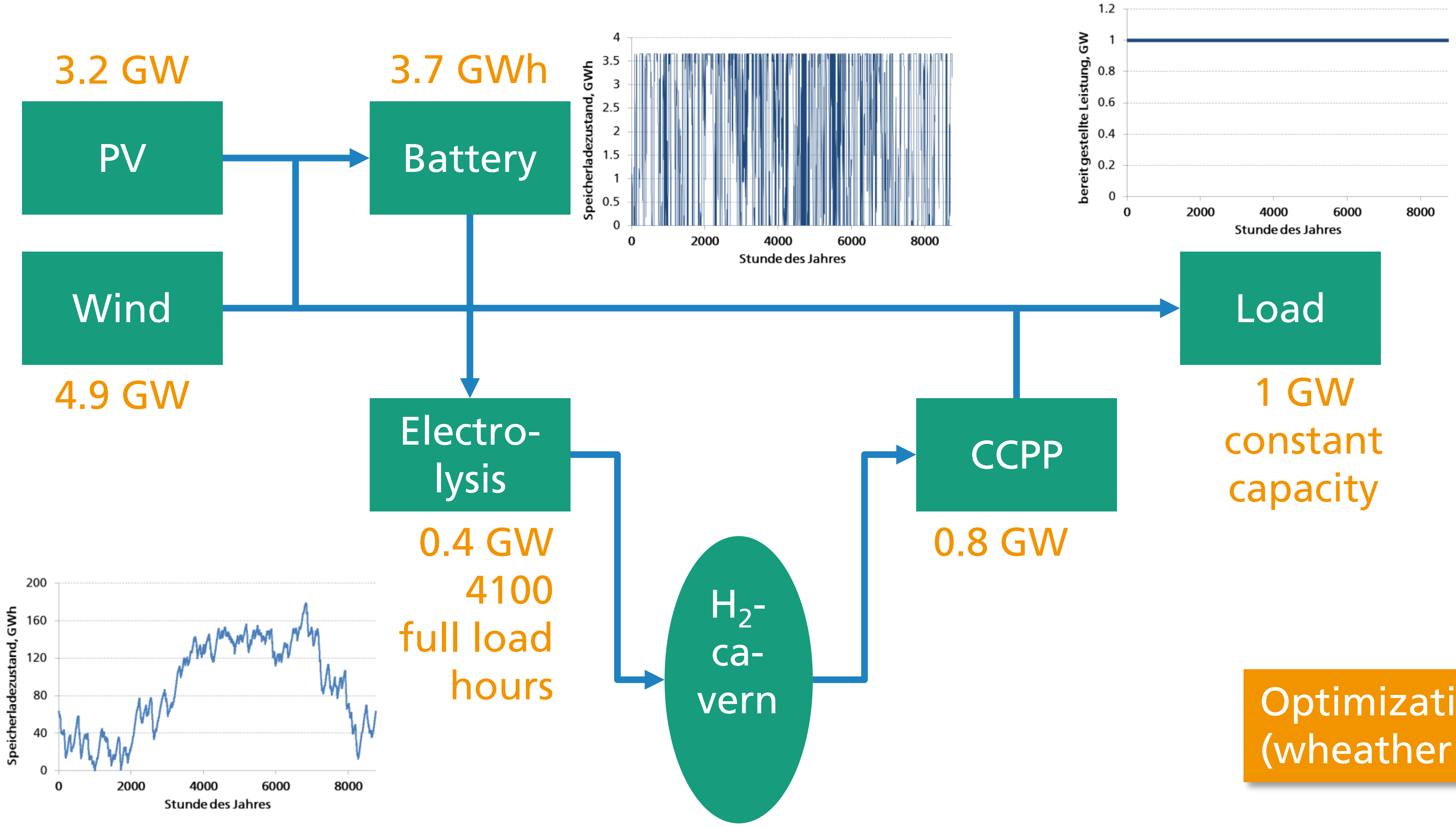
Principle of combination of storage concepts
Example »Guaranteed electricity generation by volatile renewable energies«



Optimization of design and operation to provide guaranteed electricity generation

Principle of combination of storage concepts

Example »Guaranteed electricity generation by volatile renewable energies«

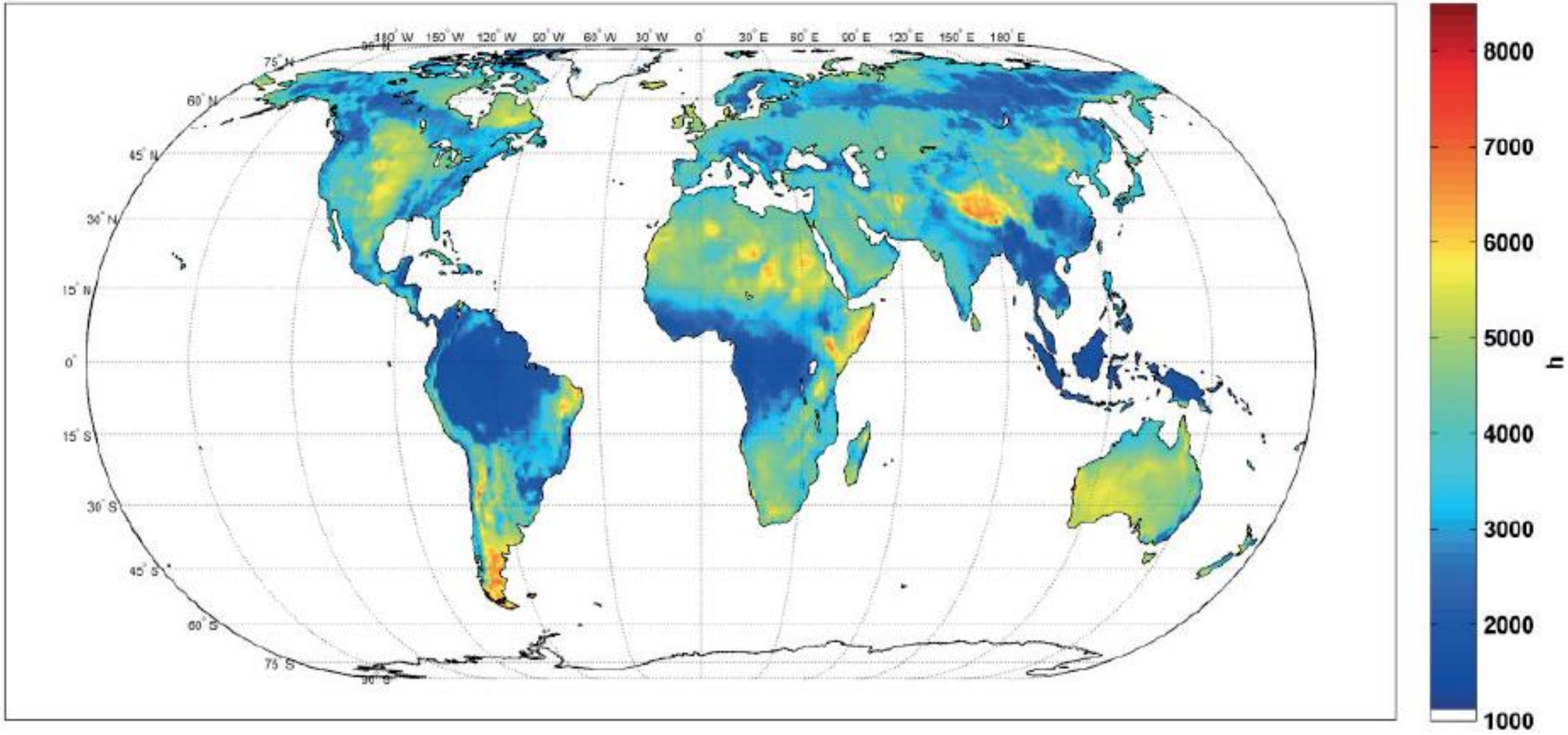


Optimization for northern Germany (wheather data Hannover)

Fraunhofer ISE

Synthetic fuels

Power-To-X: Full Load Hours of PV and Wind Power Plants Combined



Source: IEA (2017) Renewables

Resource efficiency and circular economy
Approaches

- ➔ **Material efficiency:** reduction of the use of raw material or substitution of critical materials
- ➔ **Secondary production of metals via recycling:** re-use of materials to reduce the amount of needed raw material
- ➔ **Design for recycling:** products that are easy to dismantle and that indicate constituent materials on components, allowing for easier material separation

Source: EIT Raw Materials, https://eitrawmaterials.eu/events/spring-school-on-circular-economy/

Content

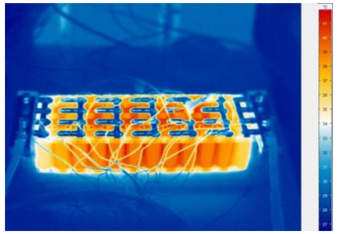
Fraunhofer ISE

Conclusion
1/2

- 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
- Efficiency and reduction of consumption essential (costs, acceptance)
- Importance of electricity rises ➔ increase up to 100 %
- Sector coupling ➔ Use of electricity (direct, indirect) for heating, transport and industry
- System integration of (volatile) renewable energies
  - Flexible power generation: controllable power plants
    ➔ CHP (thermal power plants, fuel cells), CCPP, gas turbines
  - Flexible use of electricity ➔ load management
  - Storage technologies





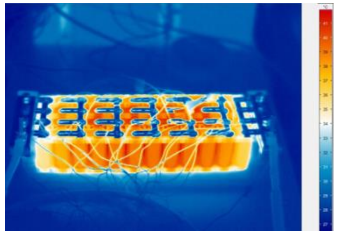



Conclusion
2/2

- Storage technologies in the context of the sector-coupled overall system
  - Batteries for electro-mobility and stationary storage
  - Heat storage for low and high temperature applications
  - Hydrogen as central energy carrier for sector coupling
- High importance of ressource efficiency and circular economy for key materials (from copper and concrete to rare earth materials)
- Important elements for the further development of the market framework
  - Effective pricing of CO_2 emissions - across all sectors and energy sources
  - Incentive mechanisms for flexible energy use and production and system beneficial behaviour

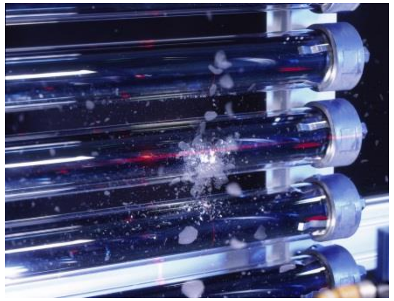
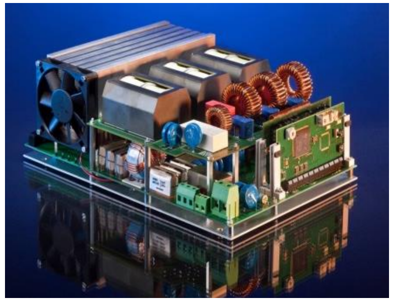
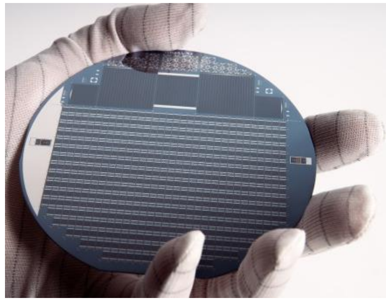




Thank You for Your Attention!




Fotos © Fraunhofer ISE

Fraunhofer-Institut für Solare Energiesysteme ISE

Prof. Dr. Hans-Martin Henning

www.ise.fraunhofer.de

hans-martin.henning@ise.fraunhofer.de

Fraunhofer ISE