The Role of Hydrogen in a Renewable Energy Economy

Christopher Hebling, PhD

First International Workshop

Durability and Degradation Issues in PEM Electrolysis Cells and ist Components

March 12 and 13, 2013, Freiburg

Fraunhofer Institut for Solar Energy Systems ISE
Freiburg, Germany

christopher.hebling@ise.fraunhofer.de

Fraunhofer ISE

The Fraunhofer-Gesellschaft: Locations in Germany

- 22,000 employees
- 66 institutes & research units
- Budget 2 billion €
- > 70% with contract research
- growing international activities

Fraunhofer ISE

Fraunhofer-Institute for Solar Energy Systems ISE

Largest Solar Energy Research Institute in Europe

About 1300 members of staff (incl. students)

10% basic financing
90% contract research
50% industry, 40% public
76.5 M€ budget (2012)
> 10% p.a. growth rate

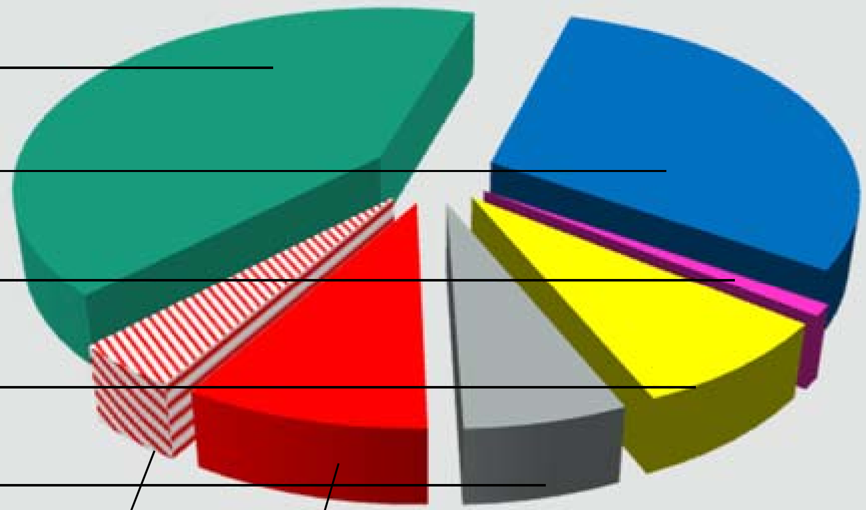
Areas of business:

- Energy-Efficient Buildings
- Photovoltaics *(Si, CPV, OPV)*
- Solar Thermal *(ST, CST)*
- Energy Storage Systems
- Hydrogen Technology
- Emission-free Mobility

Revenue Structure, Operation 2012

Operation	€66.3 million
Investment**:	€10.2 million
Total:	€76.5 million

Industry	42 %
Fed. Gov. Projects	30 %
Regional Gov. Projects	1 %
European Union	8 %
Others	6 %
Special Programs, FhG	4 %
Basic Funding*	9 %

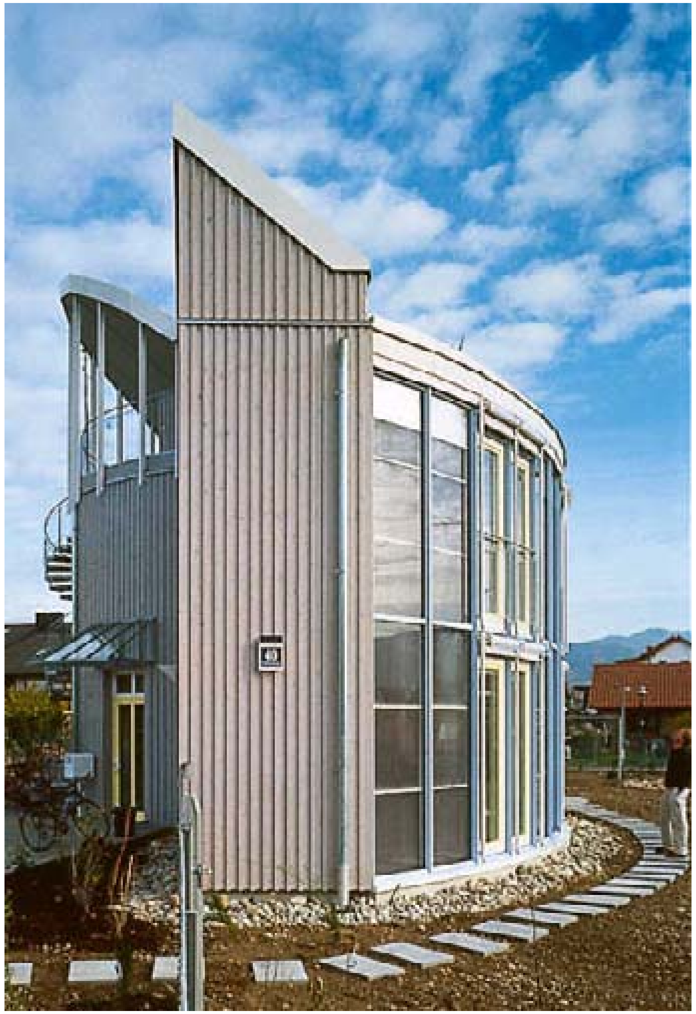


* 90% federal and 10% state funds
** without building investment and economic program

Updated: January 2013

The Self-sufficient Solar House in Freiburg

1992

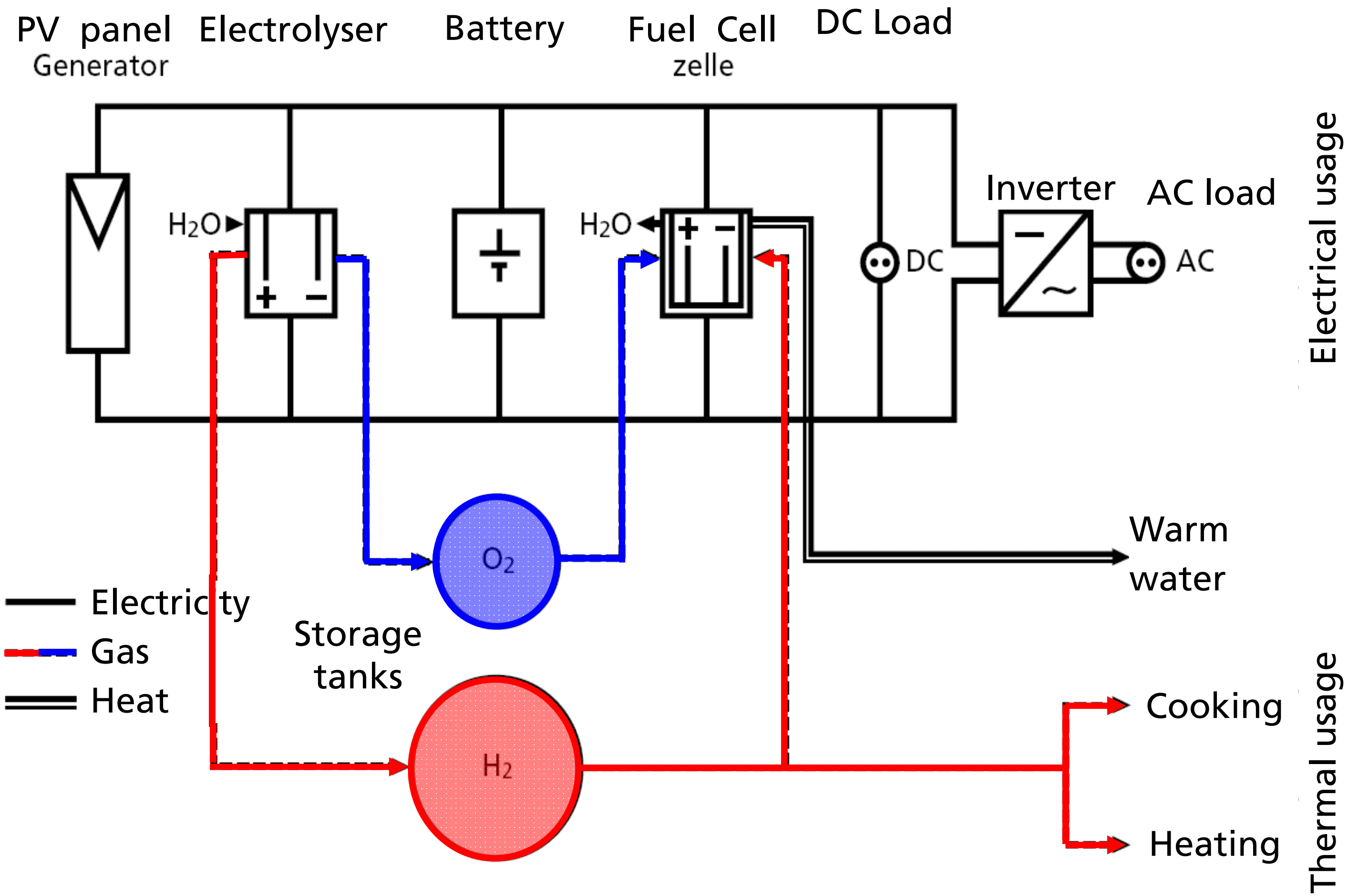


- … begin of R&D activities in PEM electrolysis at Fraunhofer ISE
- First developments in the Eighties
- Field test: 1992-1995
- Complete hydrogen storage system consisting of:
  - PEM electrolyser
  - (30 bar / 2 kW_{el})
  - H_2 and O_2 pressure tanks
  - PEM fuel cell

The Self-sufficient Solar House in Freiburg …

Regenerative fuel cell:

- PEM electrolysis unit (30 bar / 2 kW_{el})
- H_2/O_2 storage tanks
- PEM fuel cell
- No mech. compressor!



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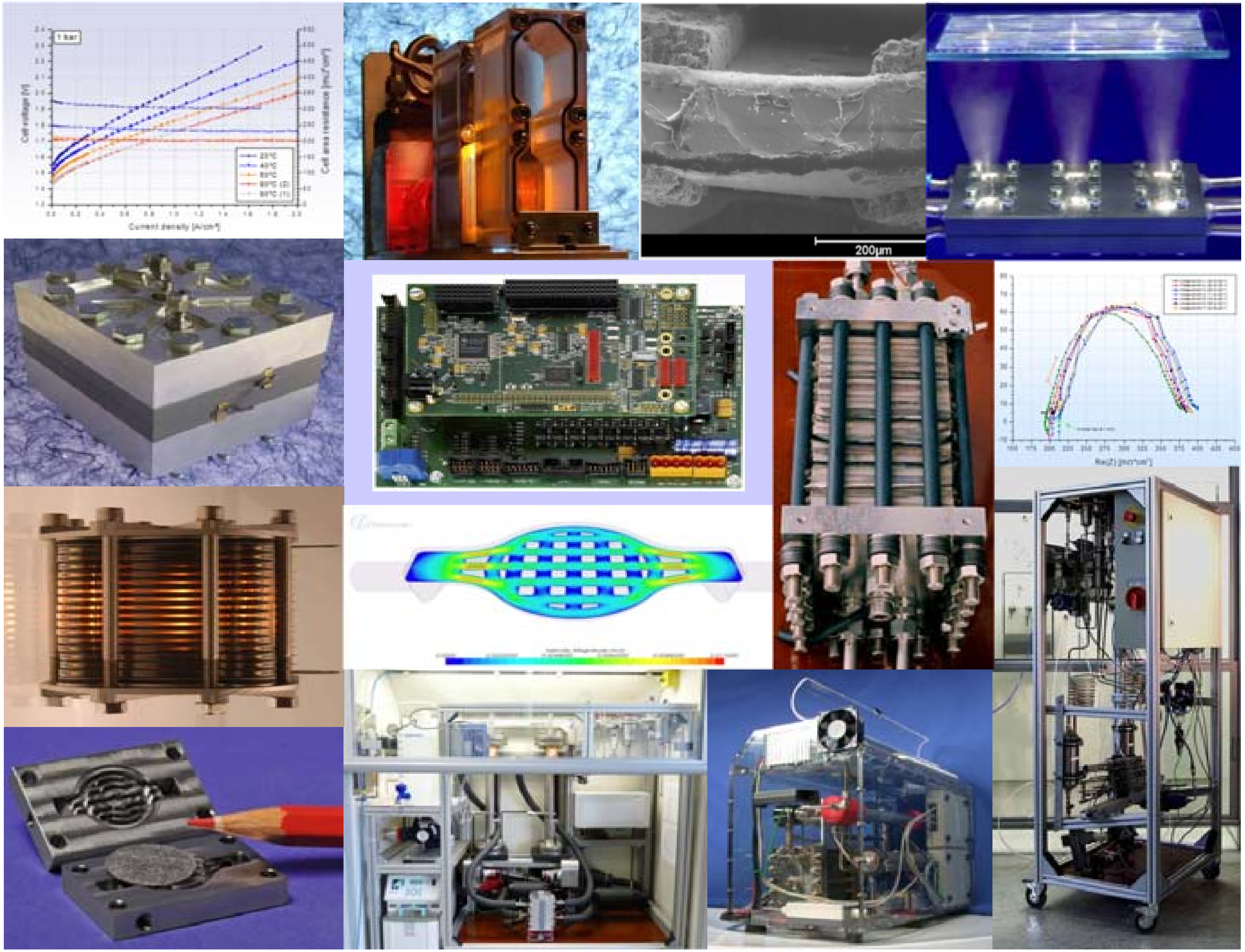
Experience in PEM Electrolysis

- Material characterisation
- Cell and stack design by CFD simulation
- Electrochemical modelling
- Balance of plant
- Control strategies
- Power electronics
- Integration with RES
- System evaluation



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Hydrogen Filling Station at Fraunhofer ISE

WASSERSTOFF-ENERGIEKETTE
FREIBURG

- Main components of the filing station:
  - (Pressure) electrolyser (30 bar / 6 Nm³/h)
  - Mechanical compressor
  - Storage tanks
  - Dispenser units (200/350/700bar)
  - Filling according to SAE J2600
- Integrated container solution
- Publicly accessible filling station
- Located at premises of Fraunhofer ISE
- Coupled with renewable energies:
  - Photovoltaic modules (roof)
  - Certified green electricity

badenova Freiburg IM BREISGAU Fraunhofer ISE

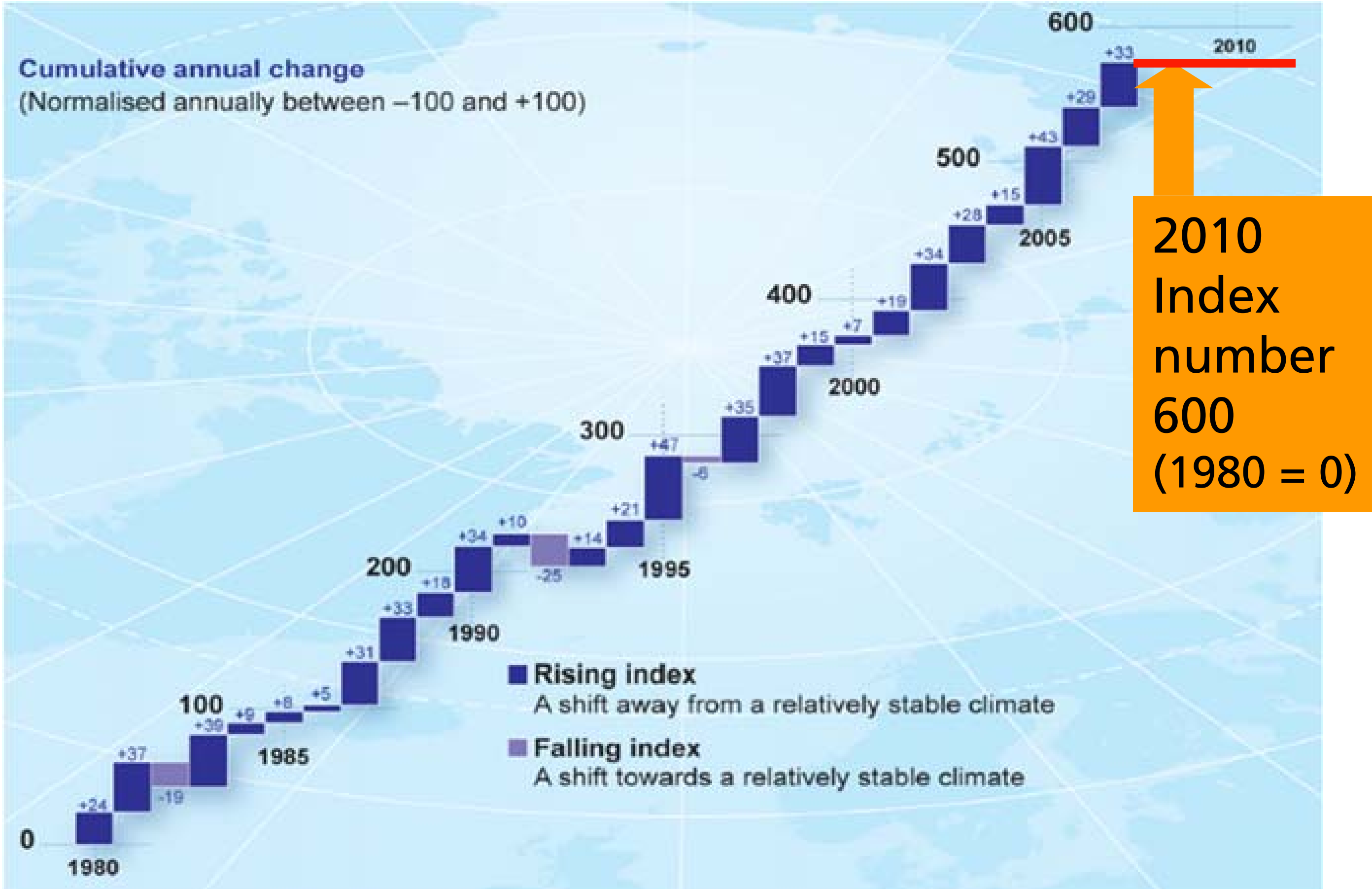
New Test Center for Electrolysis and Redox Flow Batteries

- New facilities for Fraunhofer ISE in Freiburg
  - Heat transformation
  - Battery test lab (MW scale)
  - Redox flow test lab (100 kW)
  - Electrolysis test lab (1 MW)
- 750 m² laboratory for EL and RFB
- Cell and stack development
  - Material characterisation/analysis
  - Different test benches (up to 50 bar, 4,000 A)
  - Stack testing (long-term, AST)
- In the future: H2 feed into pipelines

Climate Change Index – Cumulated Annual Change
International Geosphere Biosphere Program IGBP

The Index combines various parameters (normalized annually between -100 and +100):

- CO_2-concentration in the atmosphere (280 to >400 ppm)
- Mean temperatur on the earth (Increase >0.8^{0}C)
- Height of Sealevel (increase of 10 inch since 1880)
- Ice coverage summer min. in the arctic (ice coverage -50% since 1970)



Source: International Geosphere-Biosphere Programme (IGBP)

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Why Hydrogen Energy

Photovoltaic

Biomass

Onshore wind

Solar thermal - decentralized

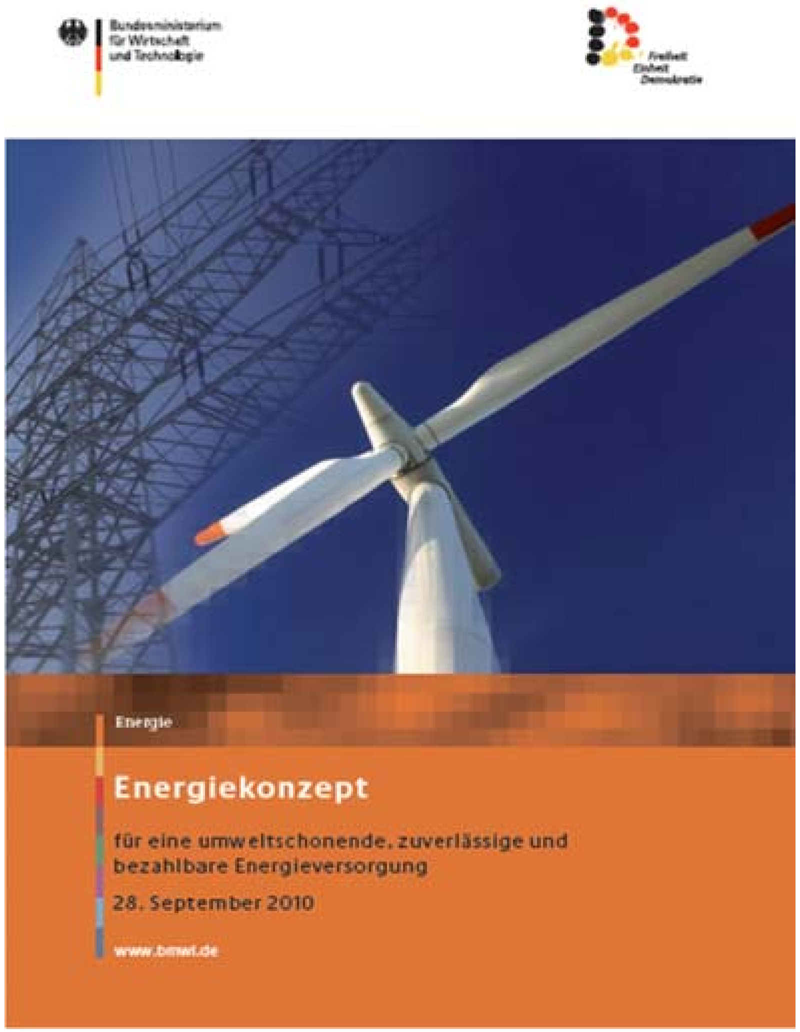
Offshore wind

Solar thermal - centralized

Hydropower

The Energy Concept of the German Government

- Guideline for the transition of the energy systems, in order to reach the 2050 targets
- A transition towards the era of renewable energy is feasable both technically and in terms of investments
- Target: Decarbonization of both the energy system and the mobility sector



German Government: Targets for the Energy Supply Until 2050

Targetes for the year	2020	2050
Reduction green house gases	- 40%	- 80-95%
Reduction primary energy consumption	- 20%	- 50%
Reduction electricity consumption	- 10 %	- 25 %
Proportion renewables on energy cons.	18 %	60%
Proportion renewables on electricity cons.	35%	80%

=> Fundamental and fast change of energy system is necessary

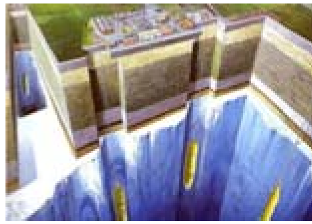
Source: Energiekonzept 2050, Bundesregierung, Sept 2010

Cornerstones for a transition of the energy systems

- Refurbishing of the building stock
  Doubling the refurbishing rate

- Massive increase of all renewable energies
  Photovoltaics, Solar thermal, wind, hydro, geo thermal, biomass

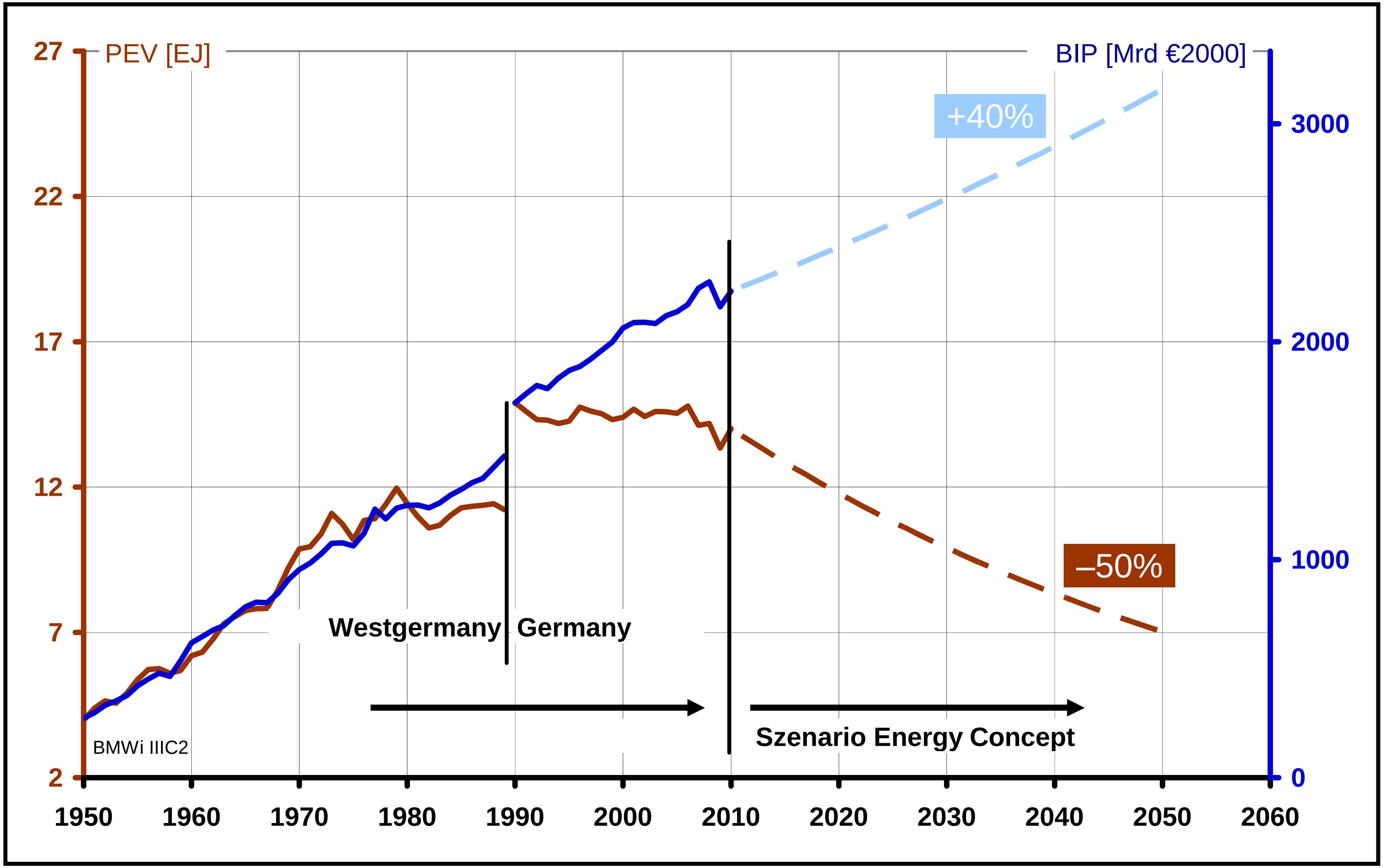
- Fast development of the electric grid
  Transmission and distribution grid



- Development of large scale energy storage systems
  Electricity, hydrogen, methane, biogas, solar thermal storage systems

- Mobility integral part of energy system
  Electric mobility by means of batteries and hydrogen/fuel cells

Gross Domestic Product GDP and Energy Consumption in Germany



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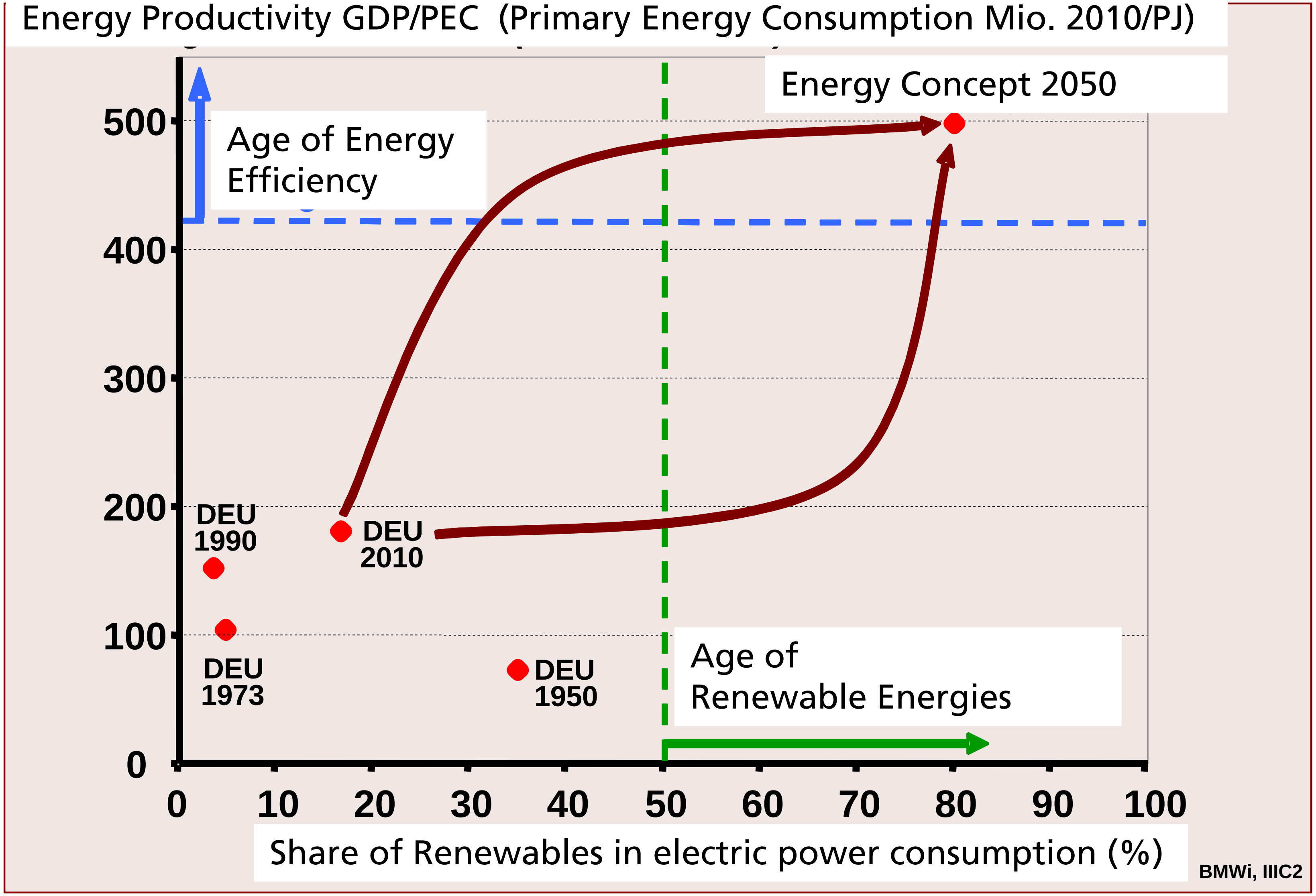
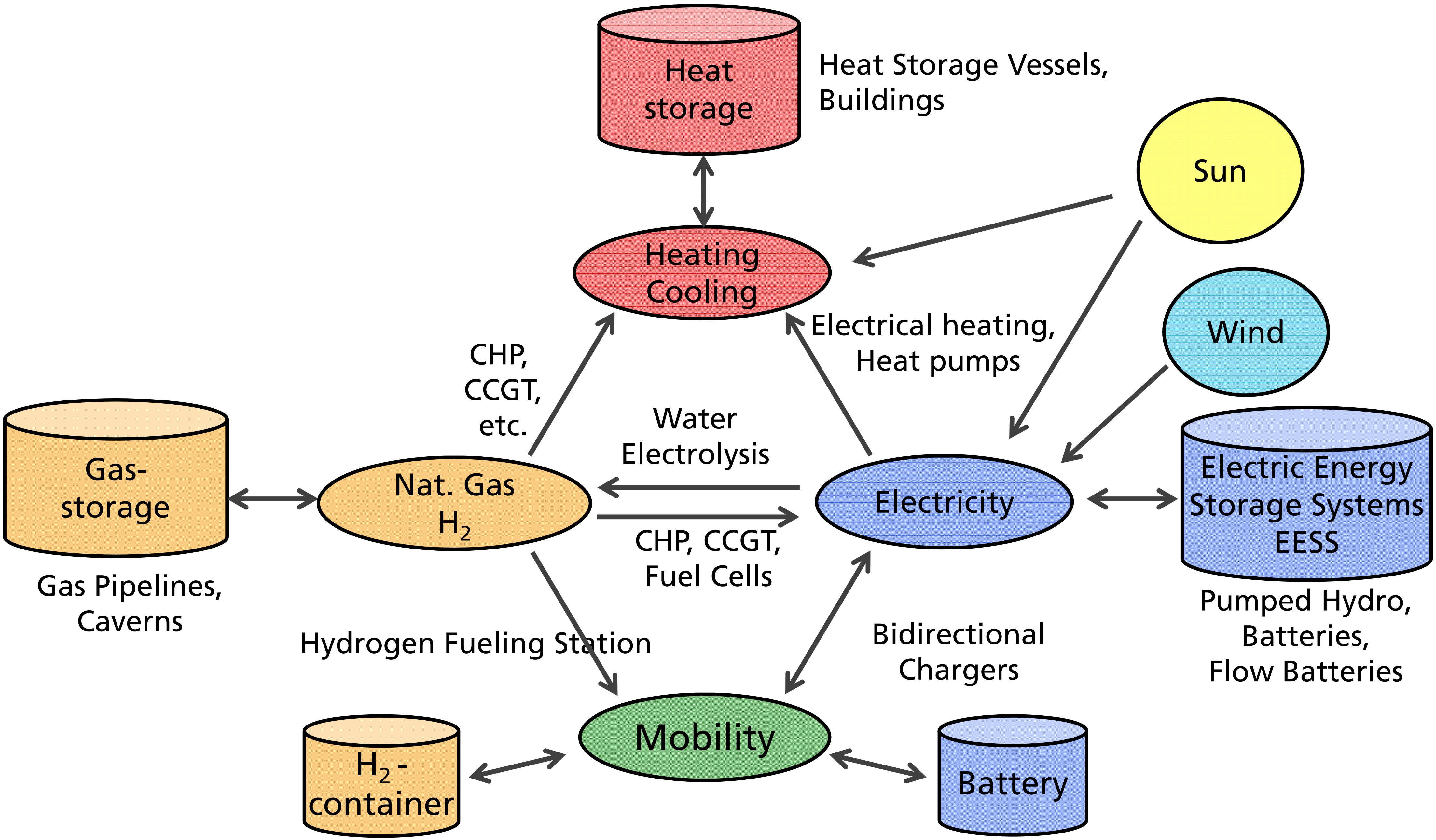
Development of Energy Efficiency and Renewable Energies in Germany

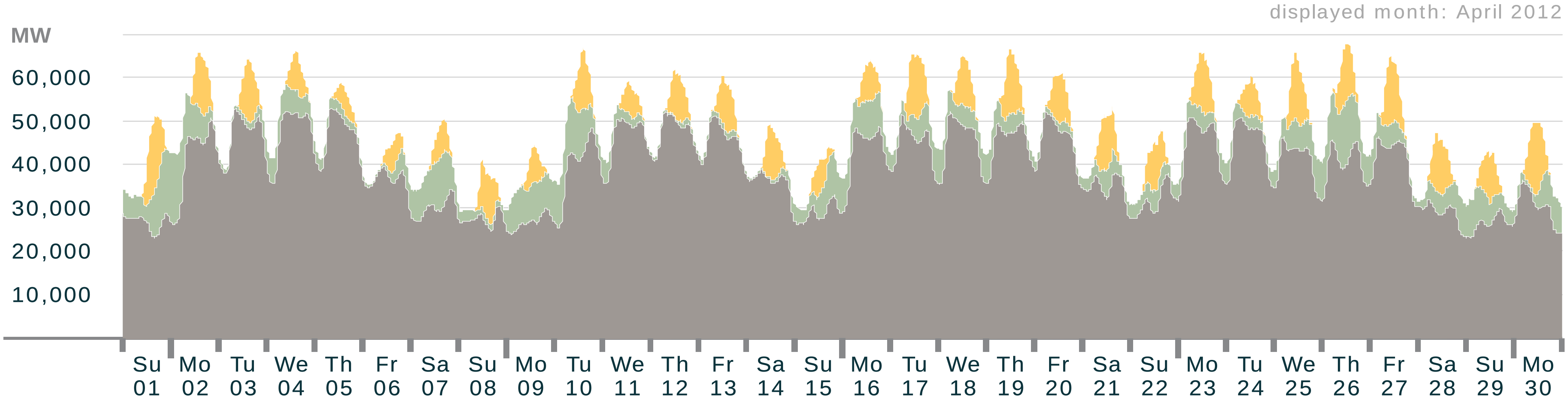


Transition to a Solar Energy Economy



Electricity Production in Germany: April 2012

Actual production



	max. power	date max. power	monthly energy
Solar	16.8 GW	30.04., 12:45 (+2:00)	2.6 TWh
Wind	16.5 GW	01.04., 23:30 (+2:00)	3.4 TWh
Konventionell > 100 MW	53.2 GW	05.04., 08:00 (+2:00)	28.0 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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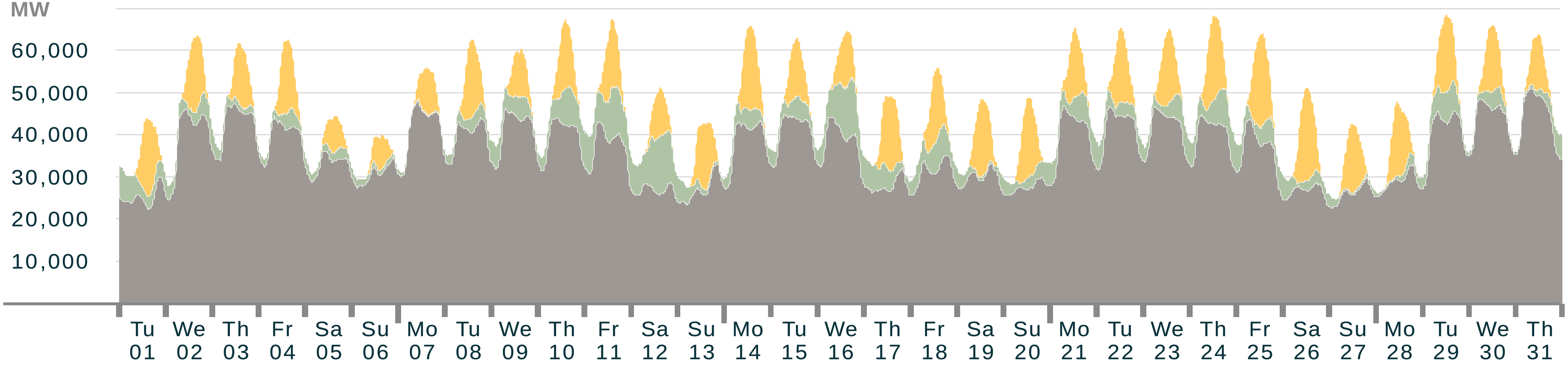
Electricity Production in Germany: May 2012

Actual production

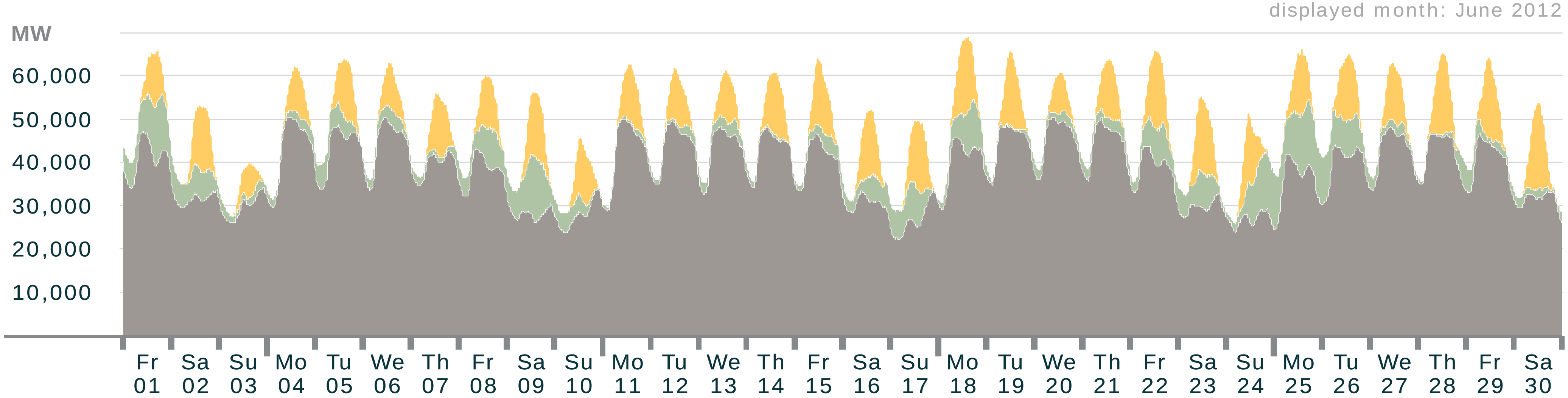


	max. power	date max. power	monthly energy
Solar	22.4 GW	25.05., 12:45 (+2:00)	4.1 TWh
Wind	14.1 GW	12.05., 17:00 (+2:00)	2.9 TWh
Conventional > 100 MW	51.2 GW	31.05., 11:00 (+2:00)	26.6 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

Electricity Production in Germany: June 2012

Actual production



	max. power	date max. power	monthly energy
Solar	19.7 GW	30.06., 13:00 (+2:00)	3.7 TWh
Wind	15.3 GW	25.06., 18:45 (+2:00)	2.9 TWh
Conventional > 100 MW	50.5 GW	04.06., 11:00 (+2:00)	27.4 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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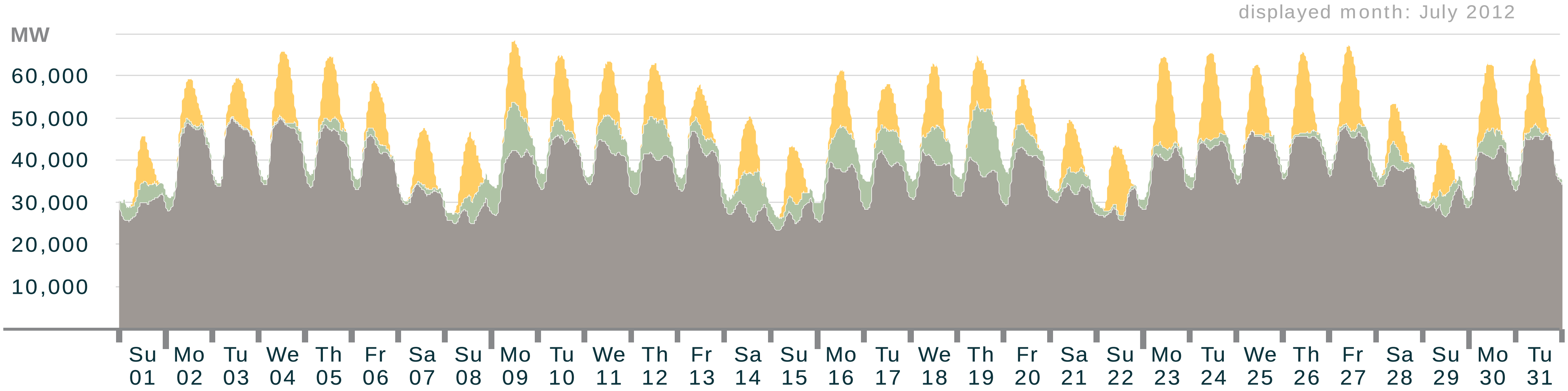
Electricity Production in Germany: July 2012

Actual production



	max. power	date max. power	monthly energy
Solar	21.8 GW	23.07., 13:15 (+2:00)	3.7 TWh
Wind	16.2 GW	19.07., 16:30 (+2:00)	2.6 TWh
Conventional > 100 MW	50.3 GW	03.07., 10:00 (+2:00)	27.7 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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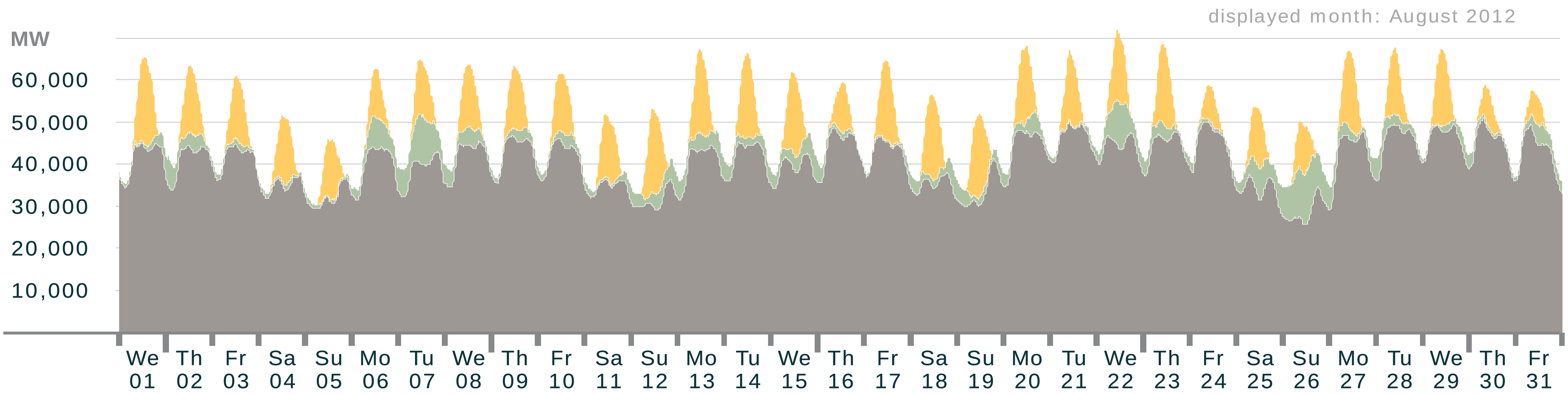
Electricity Production in Germany: August 2012

Actual production

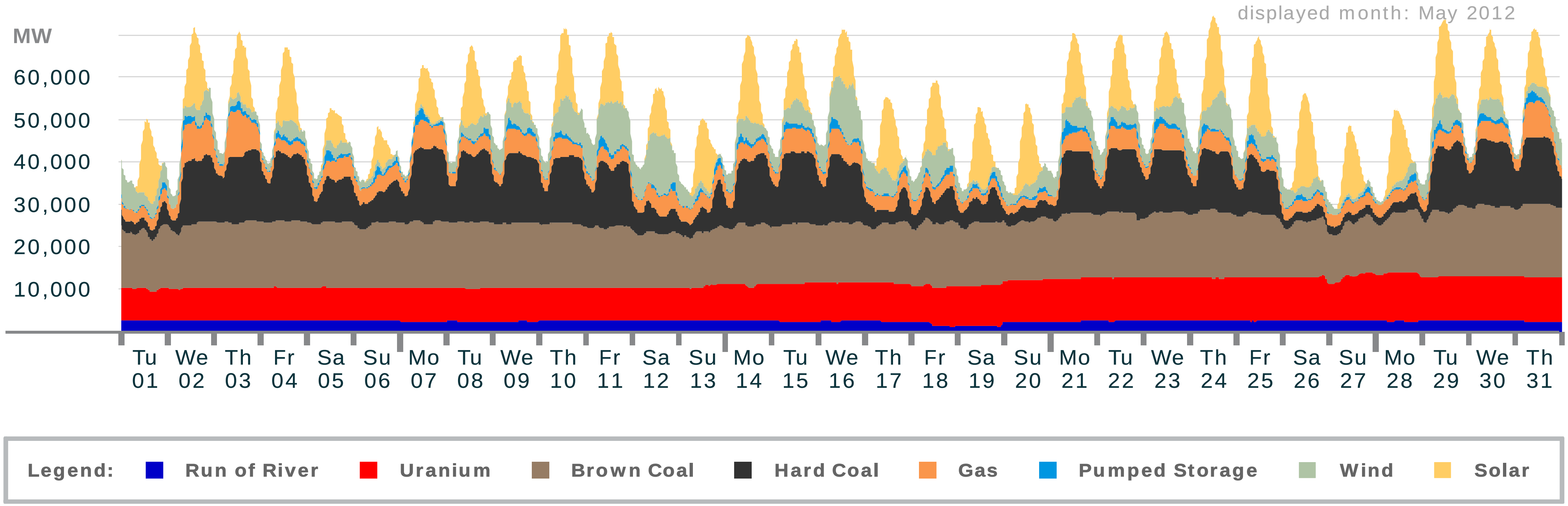


	max. power	date max. power	monthly energy
Solar	20.6 GW	01.08., 13:15 (+2:00)	3.9 TWh
Wind	12.8 GW	26.08., 14:45 (+2:00)	2.2 TWh
Conventional > 100 MW	51.1 GW	30.08., 10:00 (+2:00)	30.0 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

Detailed Electricity Production: Mai 2012

Actual production



	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
max. power (GW)	1.5	6.9	11.2	1.5	1.9	0	0.26	0
monthly energy (TWh)	3.0	11.4	17.6	17.8	11.1	4.0	14.1	22.4
	1.6	6,7	10.3	7.7	3.0	0.54	2.9	4.1

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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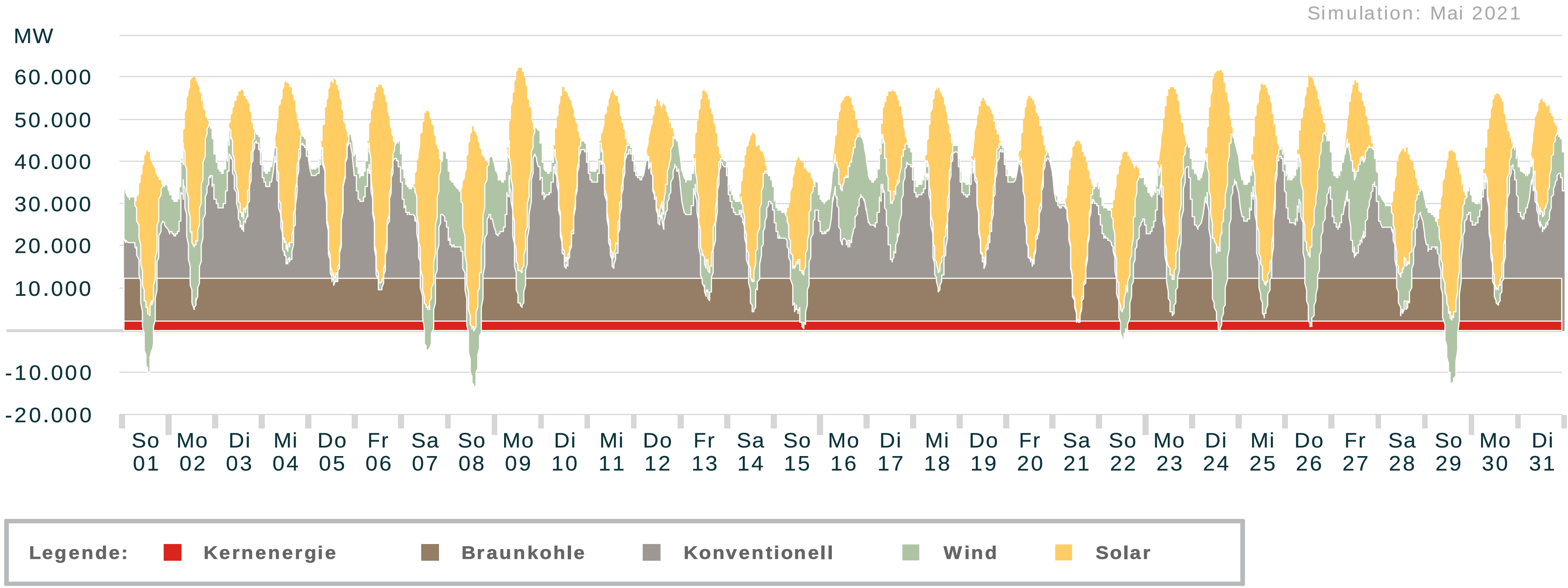
Simulation: Mai 2021
70 GW Solar, 48 GW Wind installed

Simulation



- For Mai 2021 (projection): Solar: max. 48,6 GW; 9,6 TWh, Wind: max. 24,8 GW; 5,2 TWh
- Conventionel: min. -14,1 GW; max. 44,5 GW; 17,9 TWh

Grafik: B. Burger, Fraunhofer ISE; Daten: Leipziger Strombörse EEX

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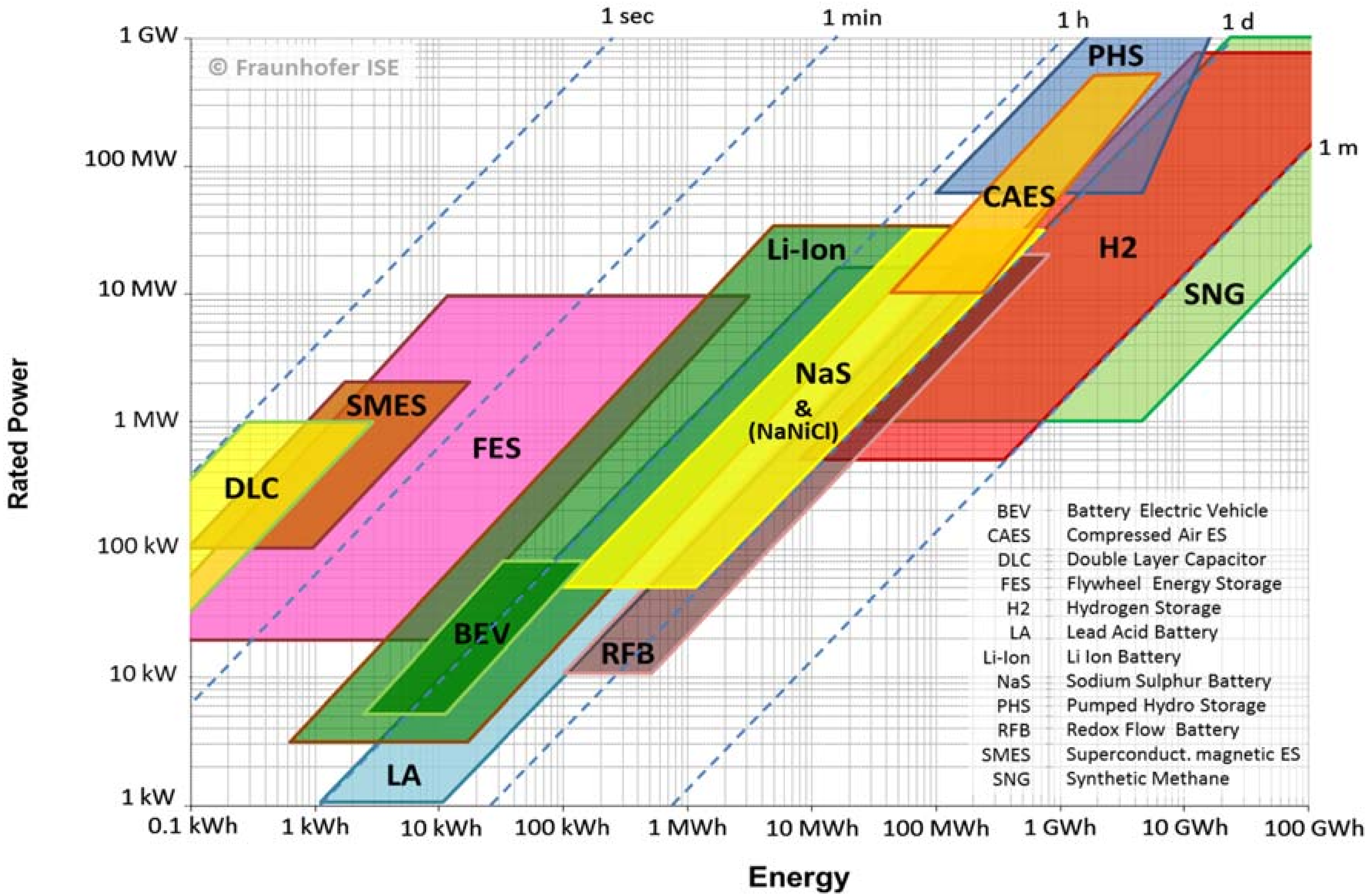
Hydrogen Energy Storage

Storage principles: Electrochemical, Chemical, Mechanical,Electromagnetic



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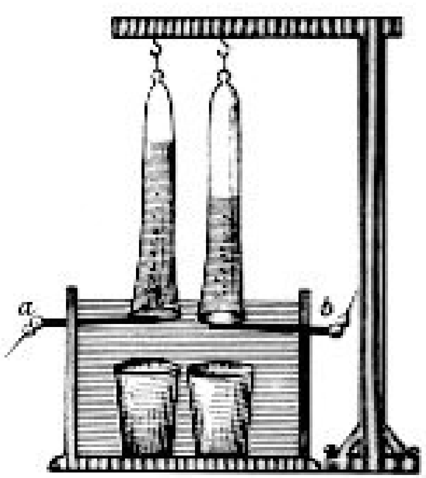
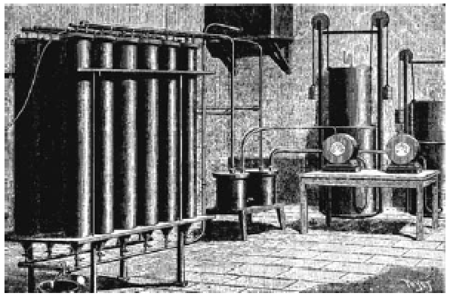
Electrolysis: Electrolytical Water Splitting

For more than 200 years



Test set-up of Ritter



Alkaline electrolyser around 1900

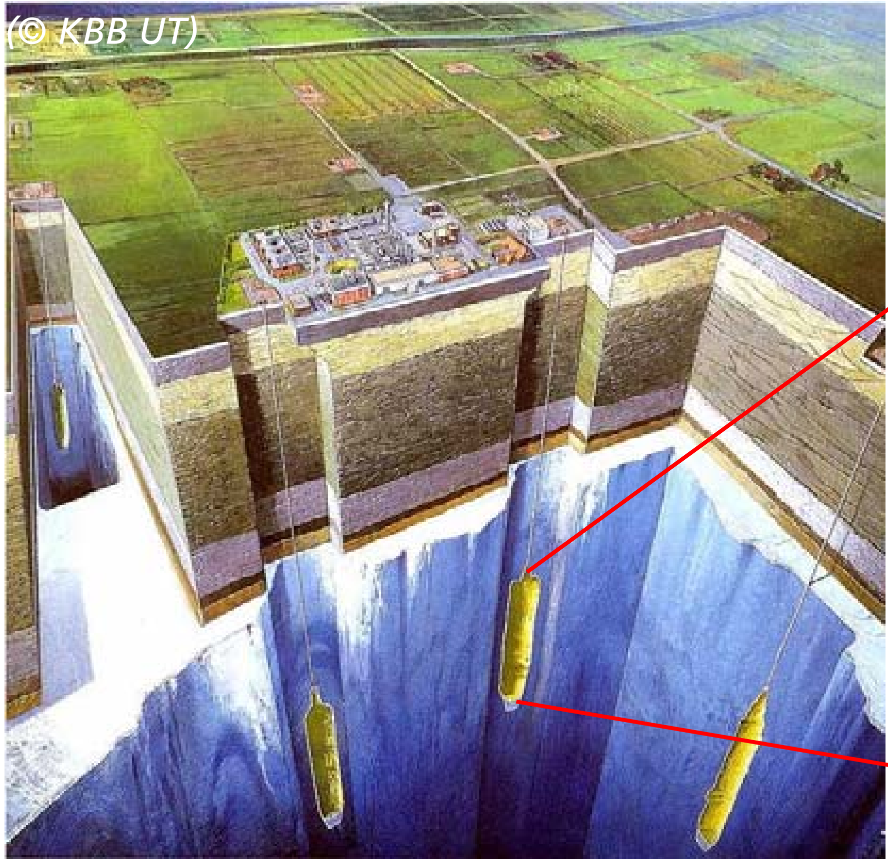
$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

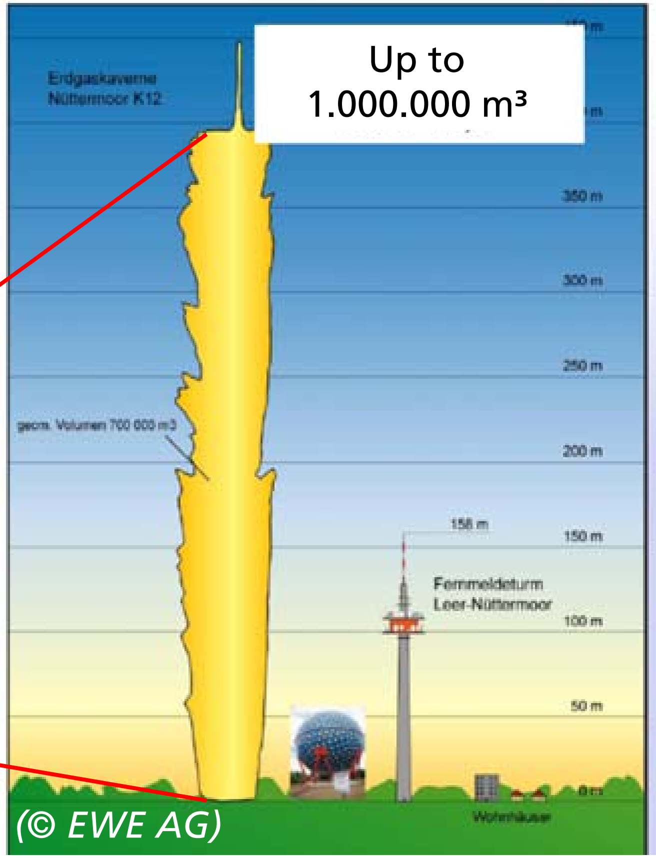
- Invention of voltaic pile (1799) enabled investigations of electrolytic approaches
- Main principle demonstrated around 1800 by J. W. Ritter, William Nicholson and Anthony Carlise

Johann Wilhelm Ritter (1776-1810)

Hydrogen Energy Storage : Underground Storage in Salt Caverns

- In the past: Storage of town gas in Germany
- Today: Natural gas reserve in Germany
- Hydrogen salt cavernes in UK and US





Echometric cavern survey

Hydrogen Storage in Salt Caverns

Town gas in Germany 1850 - 1950
(H_2-proportion > 50%) in salt caverns and pipelines

Hydrogen caverns in operation:

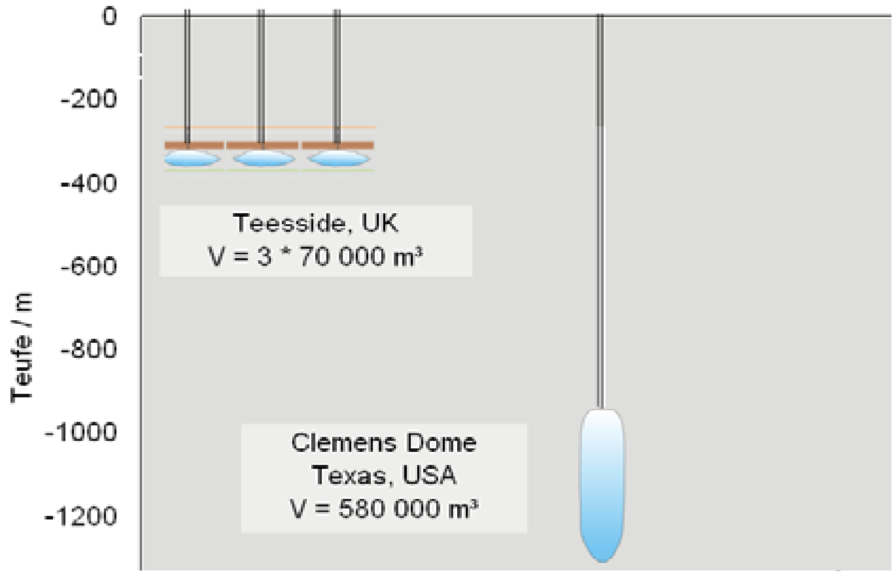
Teeside, UK, Operator: Sabic Petrochemicals,
3 x 70.000m3, 4.5MPa (konst.), 25 GWh,
30 years in operation

Clemens, Dome, Lake Jackson, Texas, USA,
Operator: ConocoPhillips, 580.000 m3,
7,0 – 13,5 MPa, 92 GWh, since 1986

Moss Bluff Salzdom, Liberty County, Texas,
Operator: Praxair, 566.000 m3 storage
volume, 7,6 – 13,4 MPa, 80 GWh,
since 2007

(Source: KBB UT)

Outlet valve of a hydrogen caverne



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Local Hydrogen Storage

1.5 GWh Storage Capacity (filled with hydrogen, 1.6 ha)

Source: Rosetti Marino - Italy

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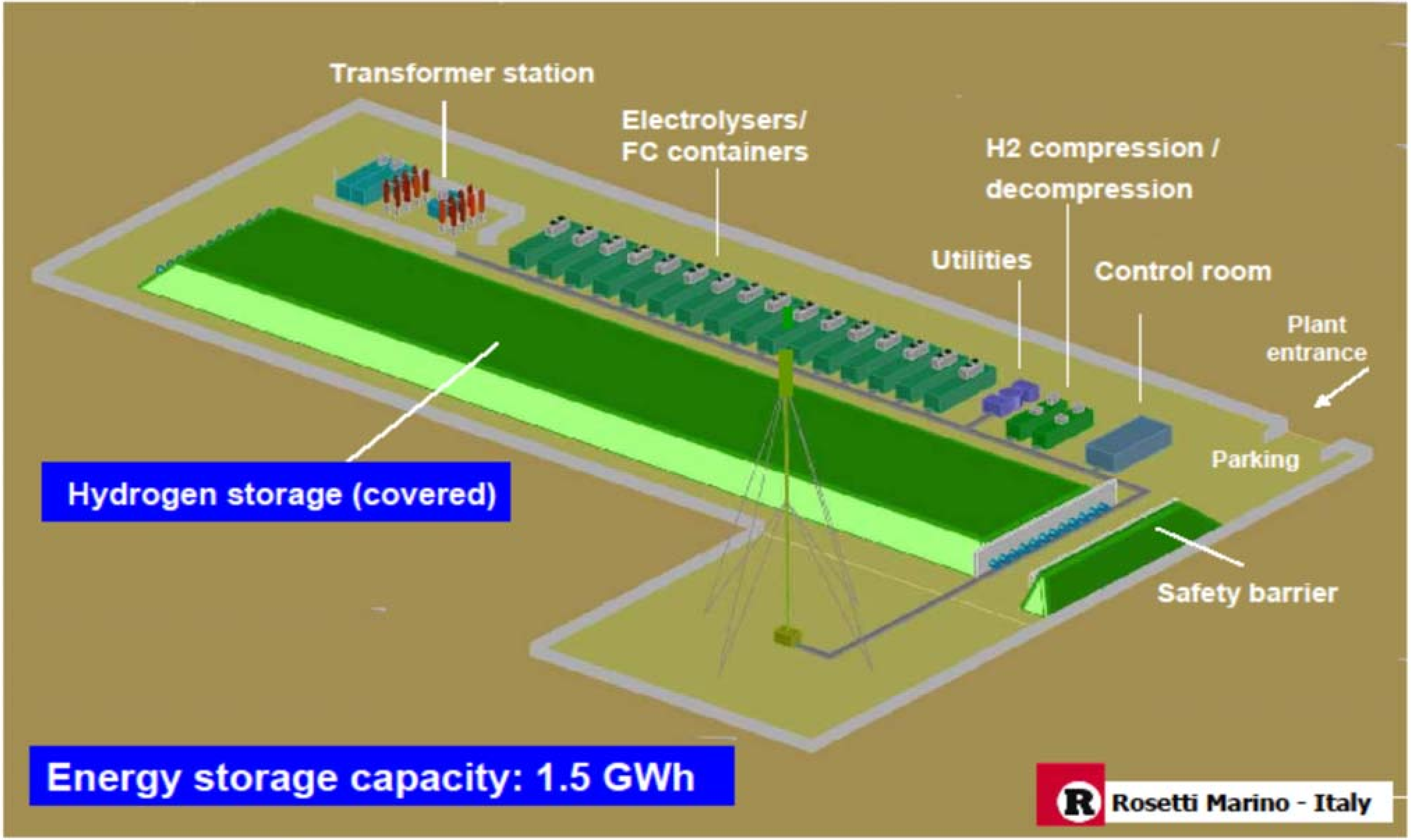
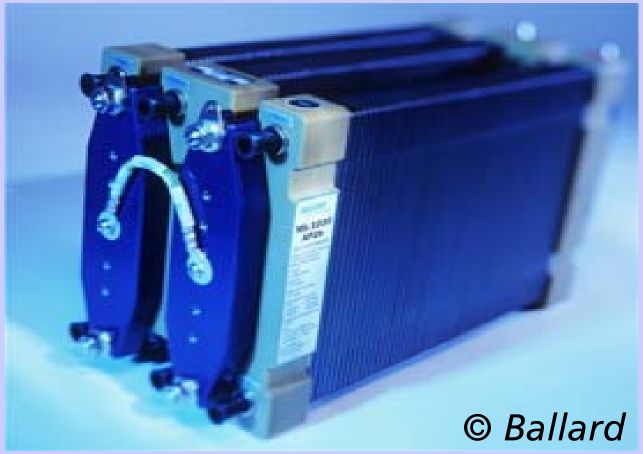
Renewable Energy Peakshaving Facility with Hydrogen Storage



Hydrogen Energy: Power generation

Fuel Cells

- High efficiency
- Mobile (fuel cell car)
- (Portable / stationary)
- 1 W - 100 kW



© Ballard

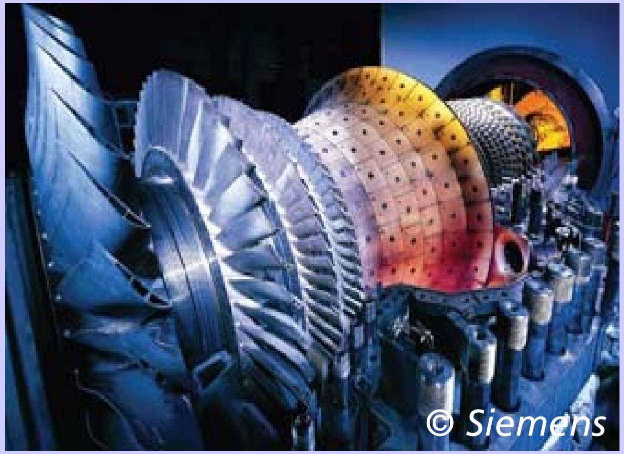
Gas Engines

- Internal combustion
- Robust and reliable
- Stationary
- 10 kW - 5 MW

© GE Jenbacher Gasmotoren

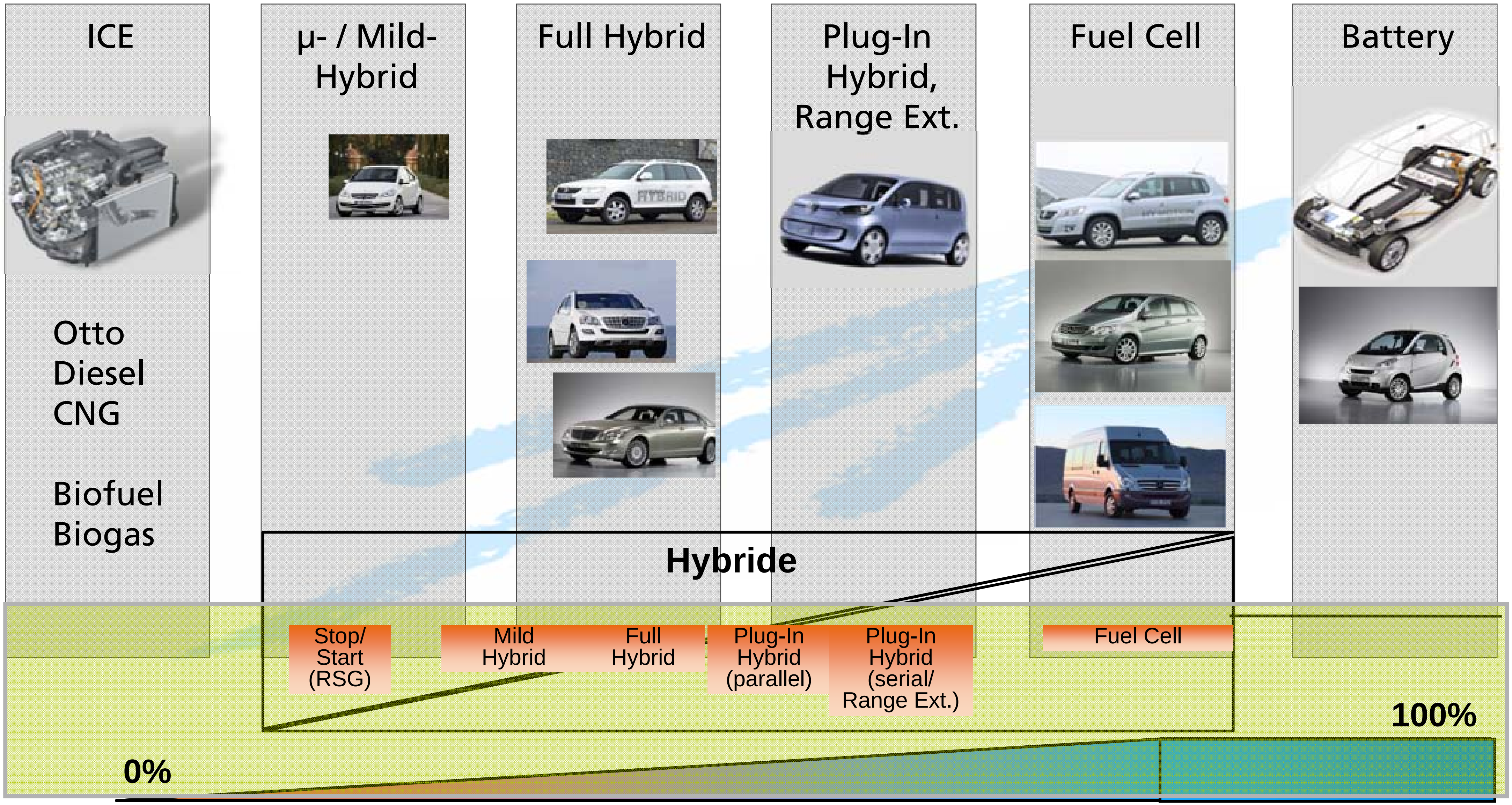
Gas Turbines

- Power plant technology
- Moderate efficiency
- Stationary
- 1 MW - 300 MW



© Siemens

Hydrogen usage: Mobility



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Conclusions

- The transformation to a sustainable energy system for the world requires a fast transition towards the use of 100% renewable energy
- Photovoltaic electricity costs are today already less than 10ct/kWh in sun-rich areas, and costs will come further down. The market will create exciting business opportunities worldwide.
- Increased energy storage capabilities and long-range grid interconnections integrate large amounts of fluctuating electricity sources into the energy system
- Hydrogen will play an important role as an universal energy carrier for storing energy, as a fuel in the transportation sector and a chemical component
- The reward for this transformation will be long-term sustainability of the world's energy needs at lower, stable and thus predictable energy costs.

Thank you

Fraunhofer Institute for Solar Energy Systems ISE

Christopher Hebling,
Director Division Energy Technology

www.ise.fraunhofer.de
christopher.hebling@ise.fraunhofer.de

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