Technische Universität Braunschweig

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Institut für Wärme- und Brennstofftechnik

IWBT

Energy-Mix and Power Plant Technology in Europe and Germany

Power Plant Technology Forum ***Hannover Messe 6.4.2011***

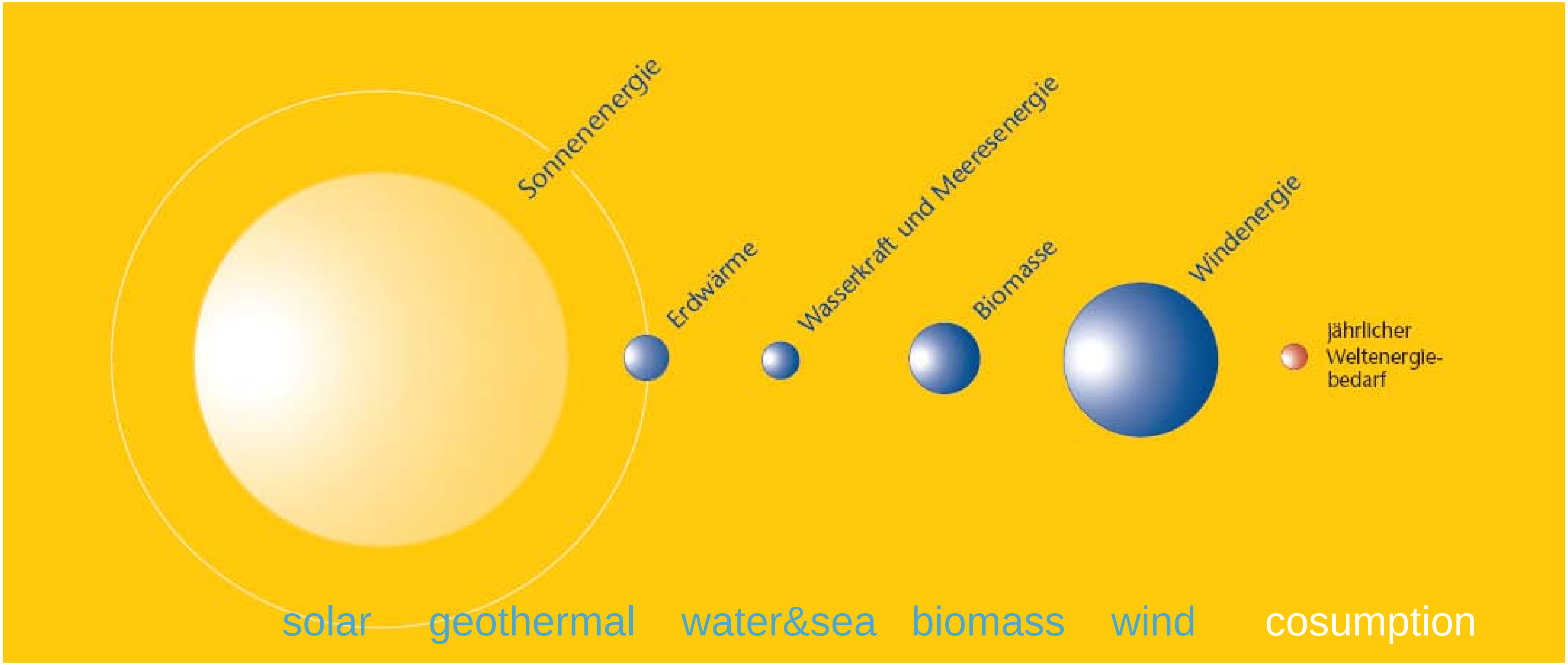
Prof. Dr. techn. Reinhard Leithner

Institut für Wärme- und Brennstofftechnik

Technische Universität Braunschweig

www.wbt.ing.tu-bs.de

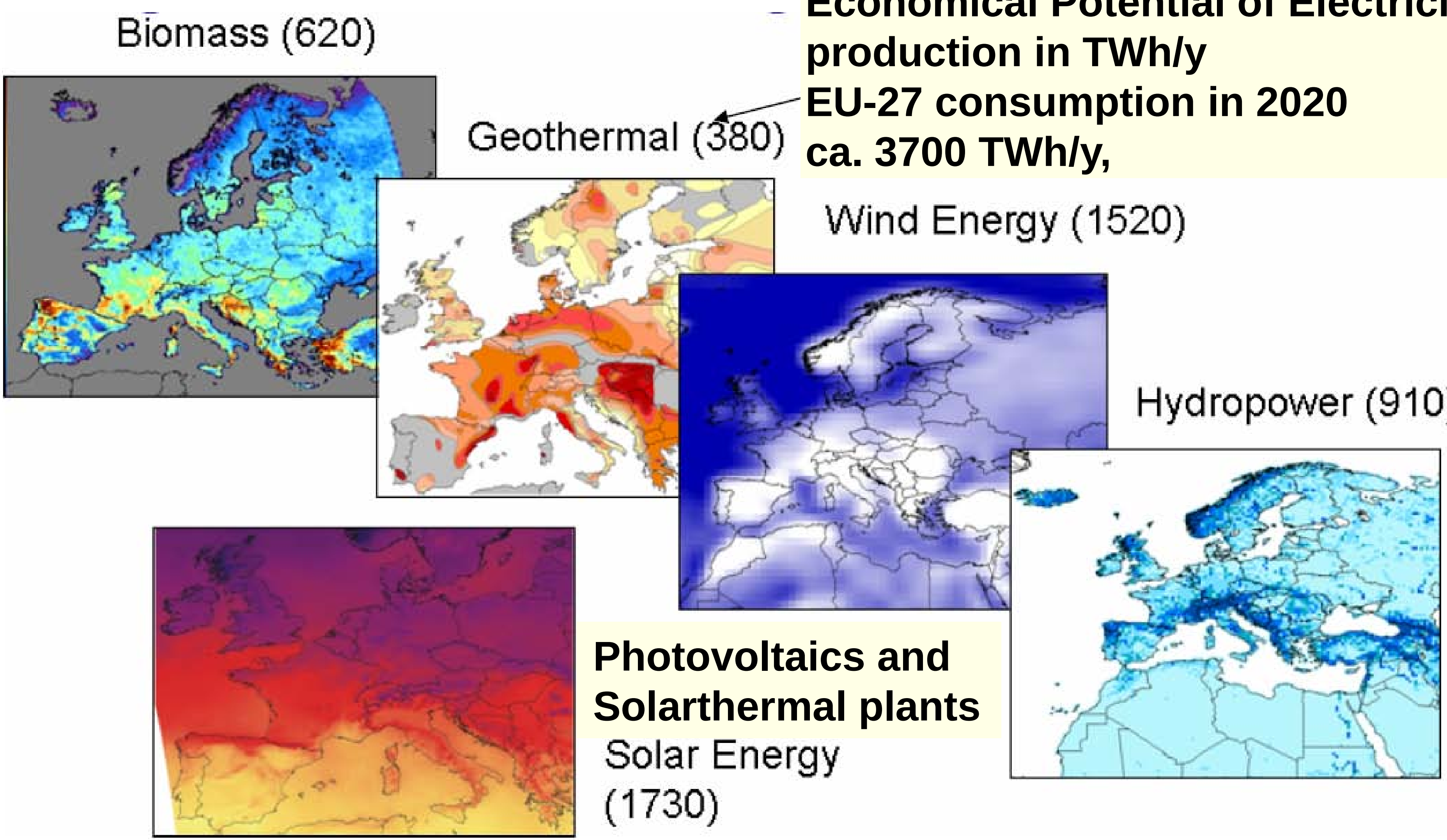
Worldwide Potential of Renewable Energy



Source: Forschungsverbund Sonnenergie, www.fv-sonnenenergie.de

Geographical Distribution of Renewable Energy in Europe

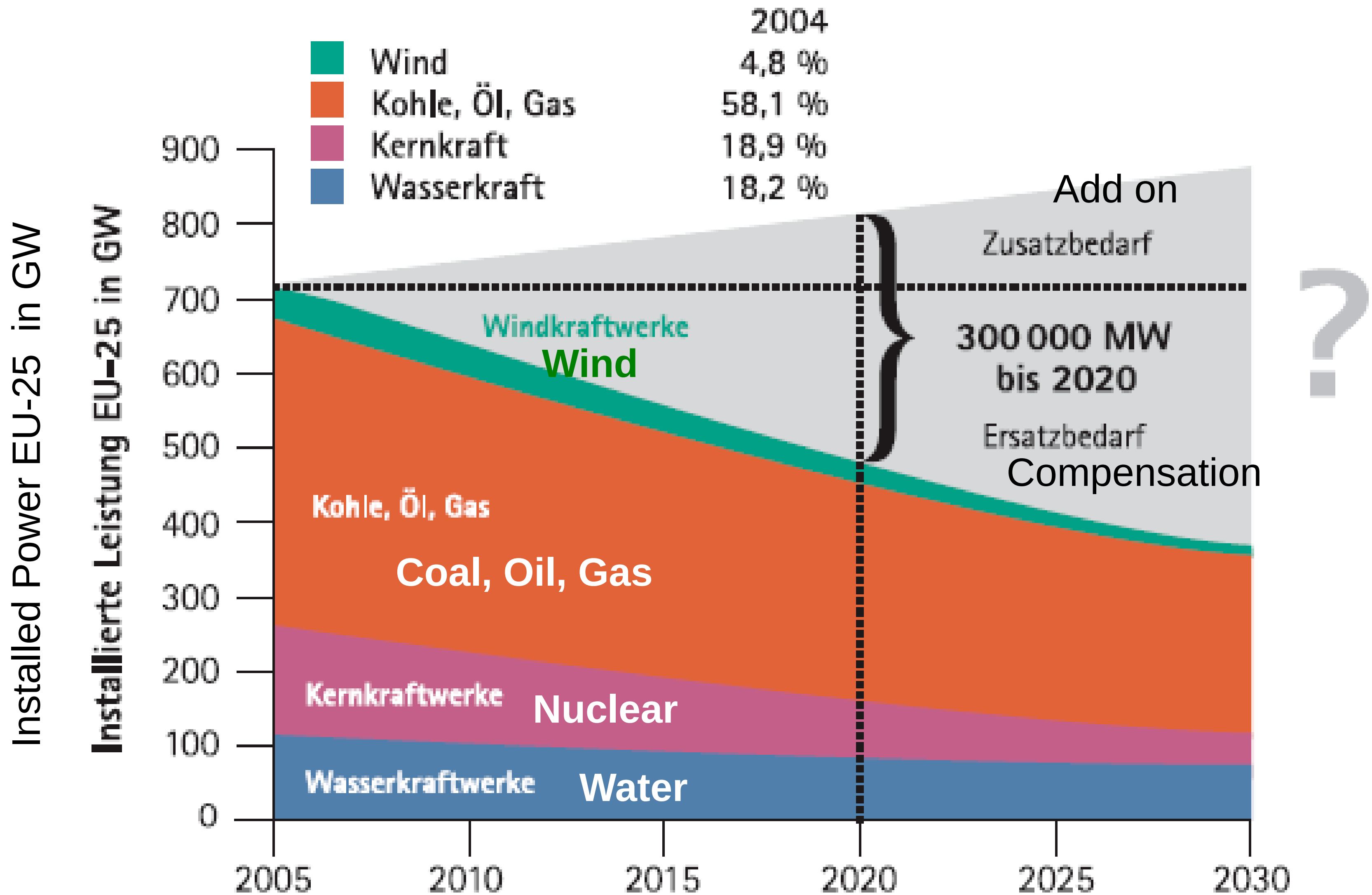
Economical Potential of Electricity-production in TWh/y
EU-27 consumption in 2020 ca. 3700 TWh/y,



Photovoltaics and Solarthermal plants

Source: Zacharias,P.: Netzintegration der erneuerbaren Energien – Steuerung der Energieflüsse, Forschungsverbund Sonnenenergie, Fachtagung 2006

Decline of Installed Capacity EU-25 in GW

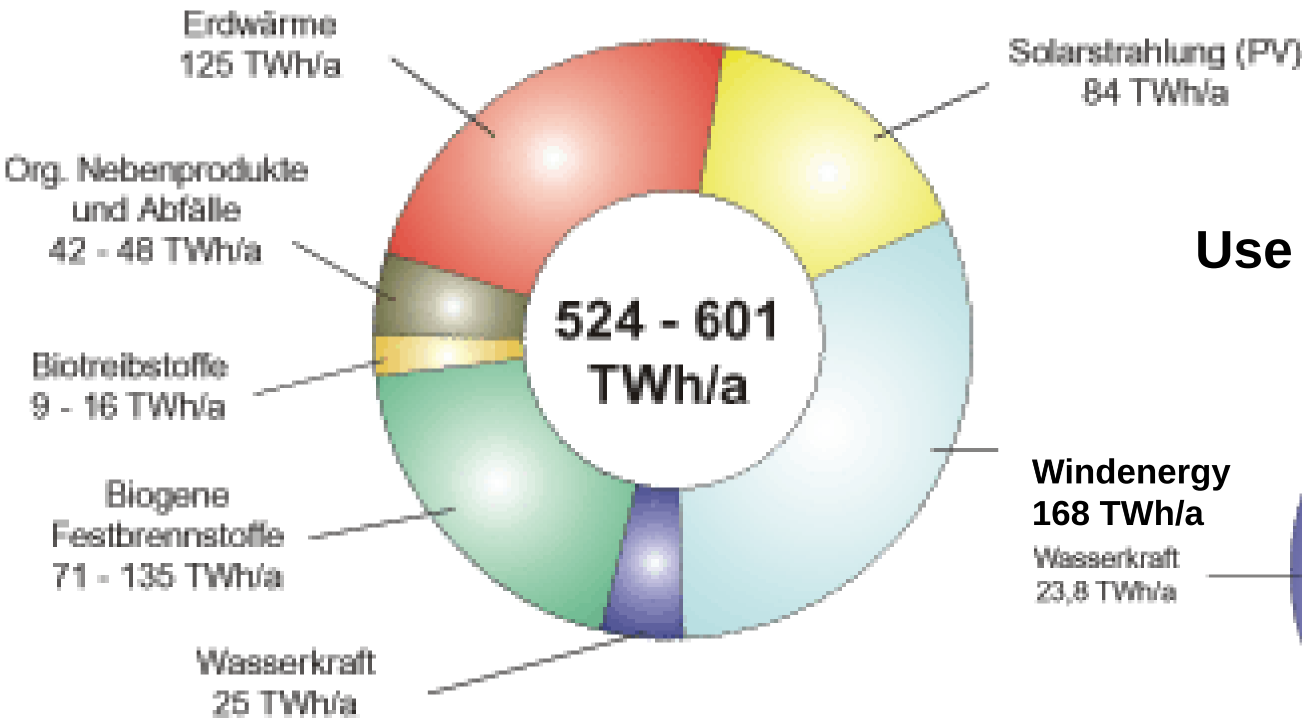


Quelle: VGB Powertech 2006

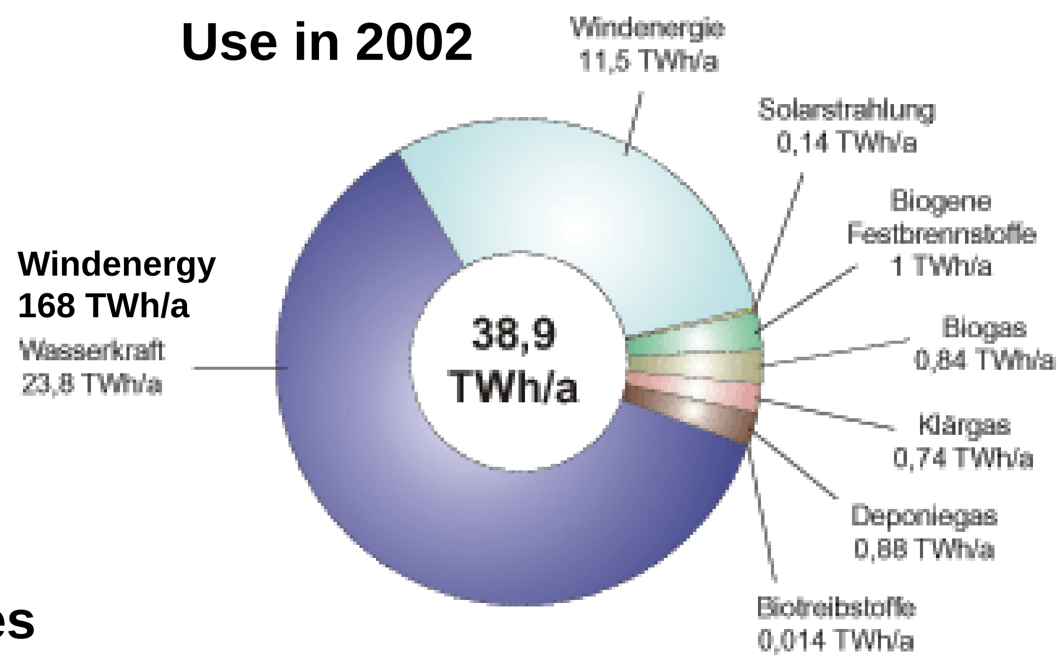
Potentials and Use of renewable Energy in Germany

2006 total german
electricity consumption ca. 640 TWh/a
heat consumption ca. 1400 TWh/a

Potentials



Use in 2002



Aims of German government
till 2020 20% electricity from renewables
till 2050 50% primary energy from renewables

Source: BMU und IE 2002

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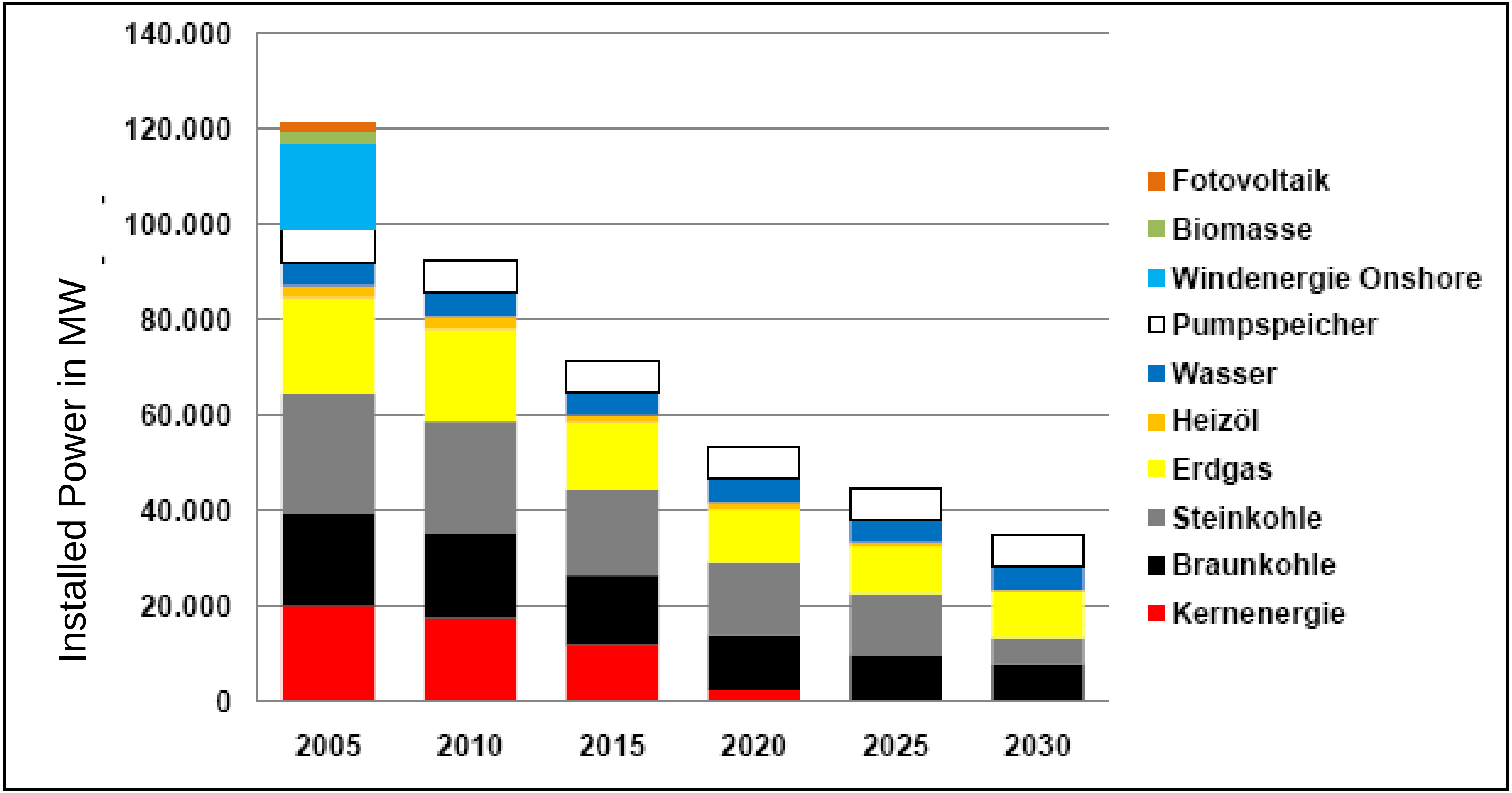
Decline of power plants in Germany – nuclear phase out



S. Kohler „Entwicklung der Kraftwerks-und Netzplanung in Deutschland bis 2020 “, DENA, Konferenz Kraftwerke und Netze für eine nachhaltige Energieversorgung. Berlin, 27.11.2008

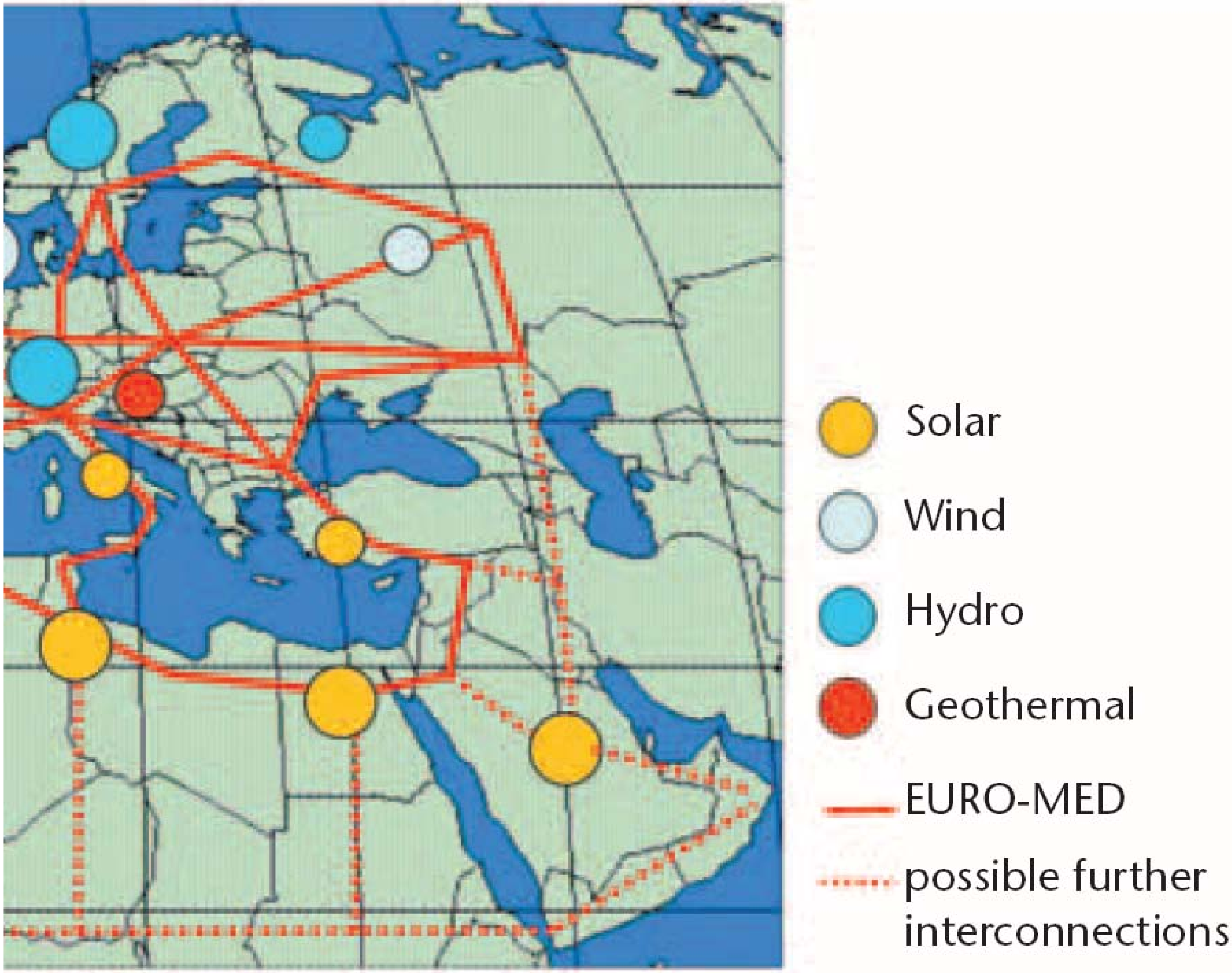
Discrepance between production and consumption

Difference between production and consumption of energy concerning		Solution of problem by		Additional costs because of
Place	→	transport grids	}	investments in plants,
Time	→	storage	}	availability, usage
Energy form (electricity, heating, cooling (temperature level))	→	transformation	}	efficiency
				personnel

Renewable Energy – Balancing Production and Demand

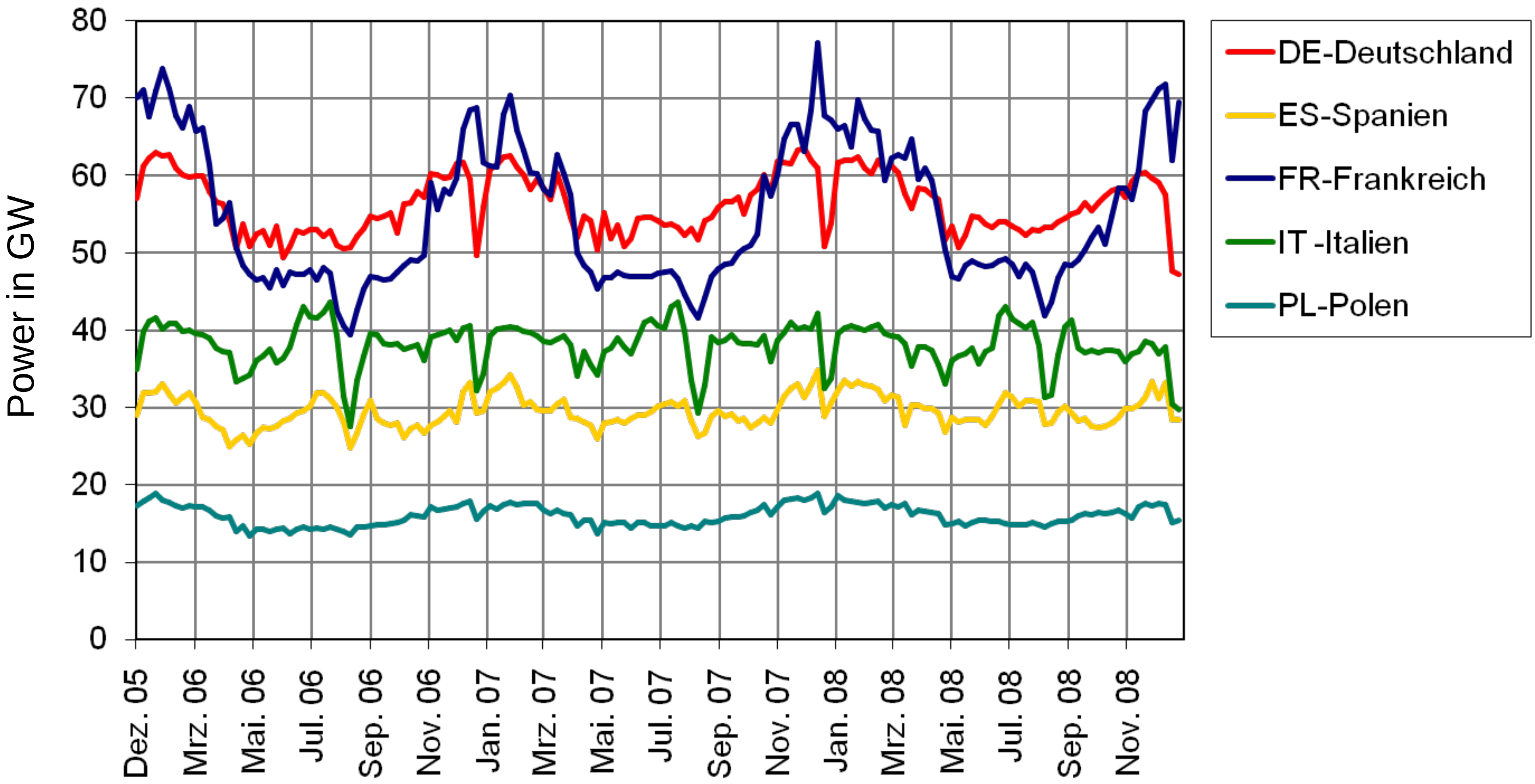
• Biomass, Biooil, Biogas • Geothermal Energy	**Production balancing demand**
• Hydropower • Ocean Energy	**Limited balancing of demand and production**
• Photovoltaic • Solarthermal Energy •Wind Energy	**Production according weather - Balancing by transport and storage**

Vision of an Euro-Mediterranean Power-Network



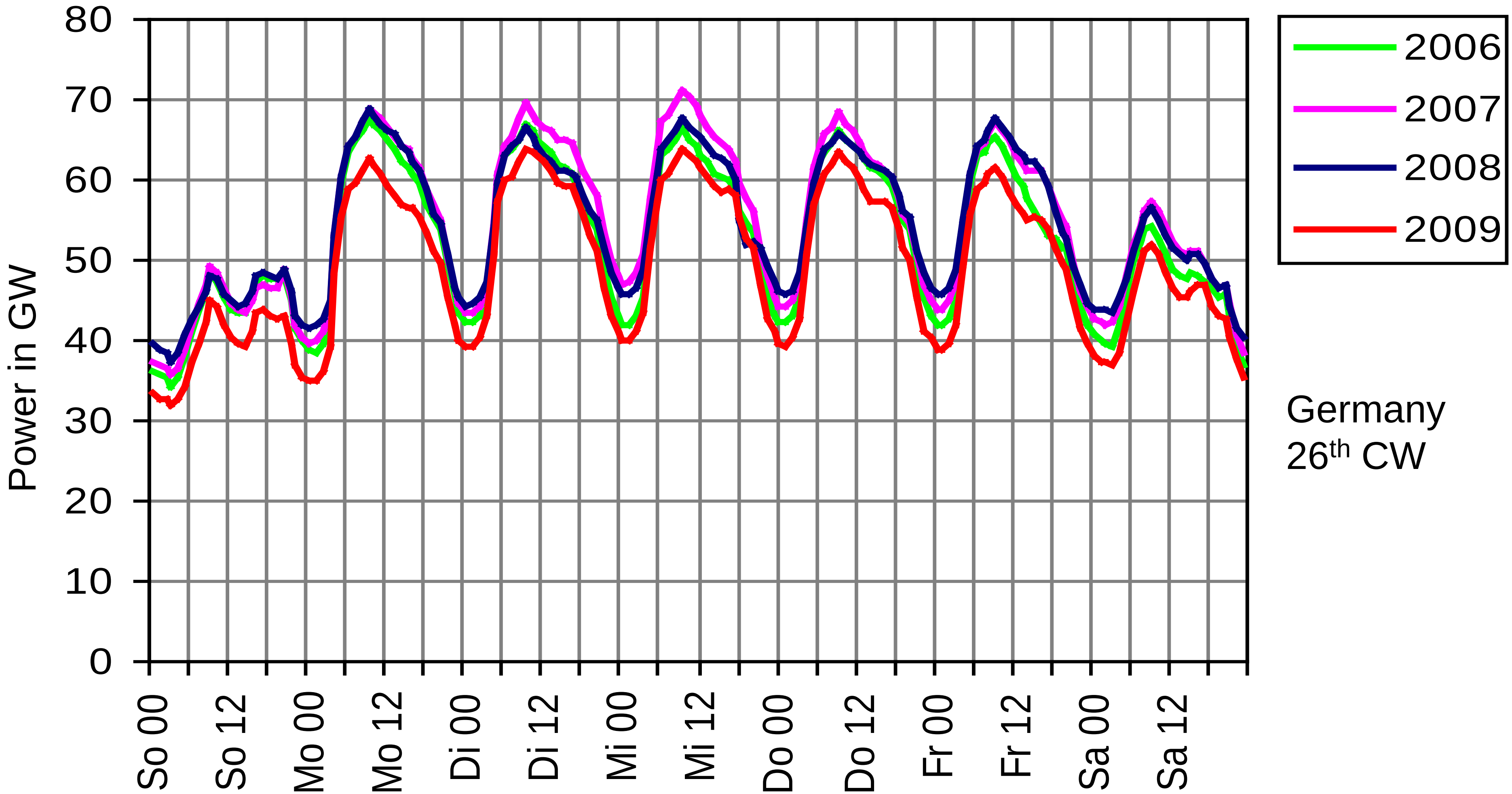
Source: Trieb, F. et.al.: Potenziale, Standortanalysen, Stromtransport, Forschungsverbund Sonnenenergie, Themen 96/97, www.fv-sonnenenergie.de

Long Term 2006-2008 Characteristics of Power Consumption



Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

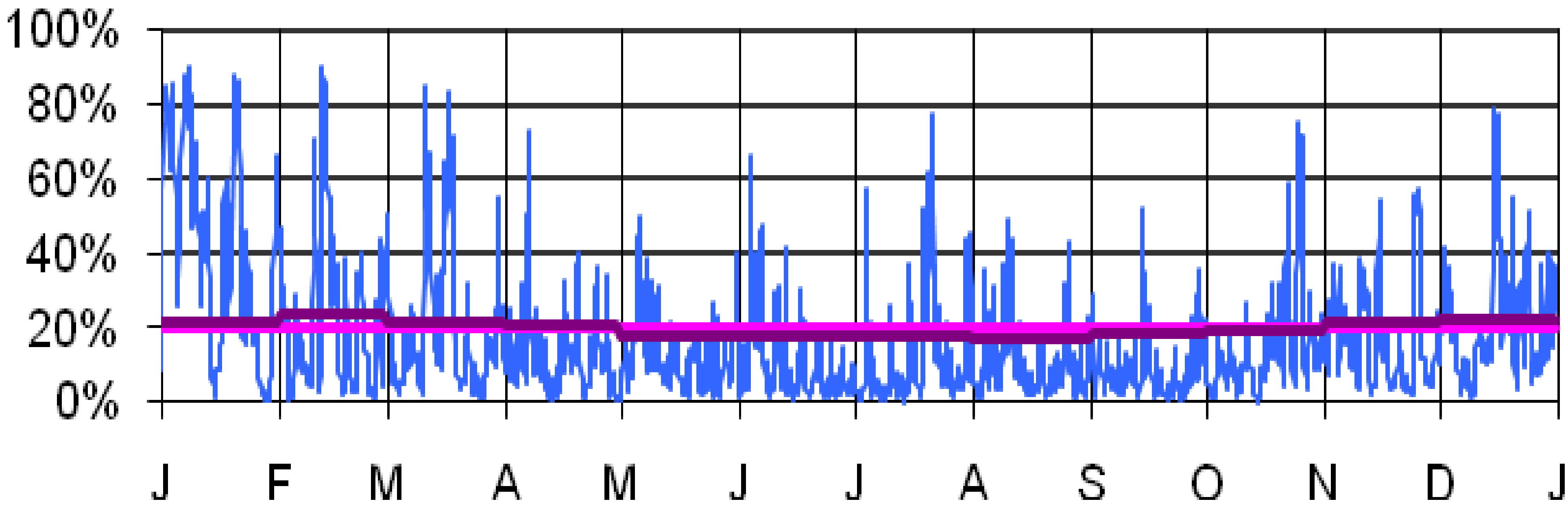
Short Term (one week) Characteristic of Power Consumption



Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

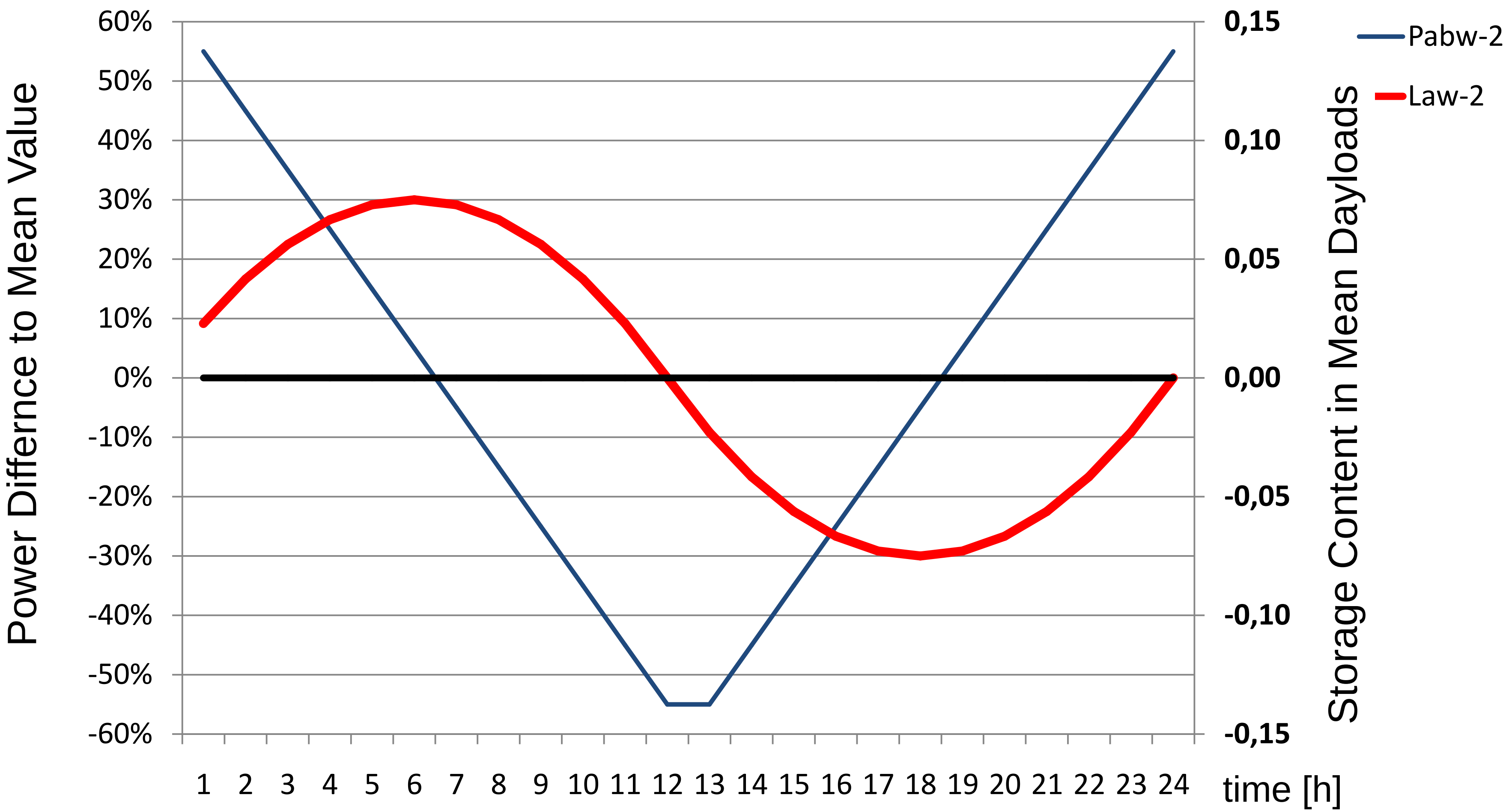
Characteristics of Wind Energy in Germany 2005

Usage ratio ca. 20%



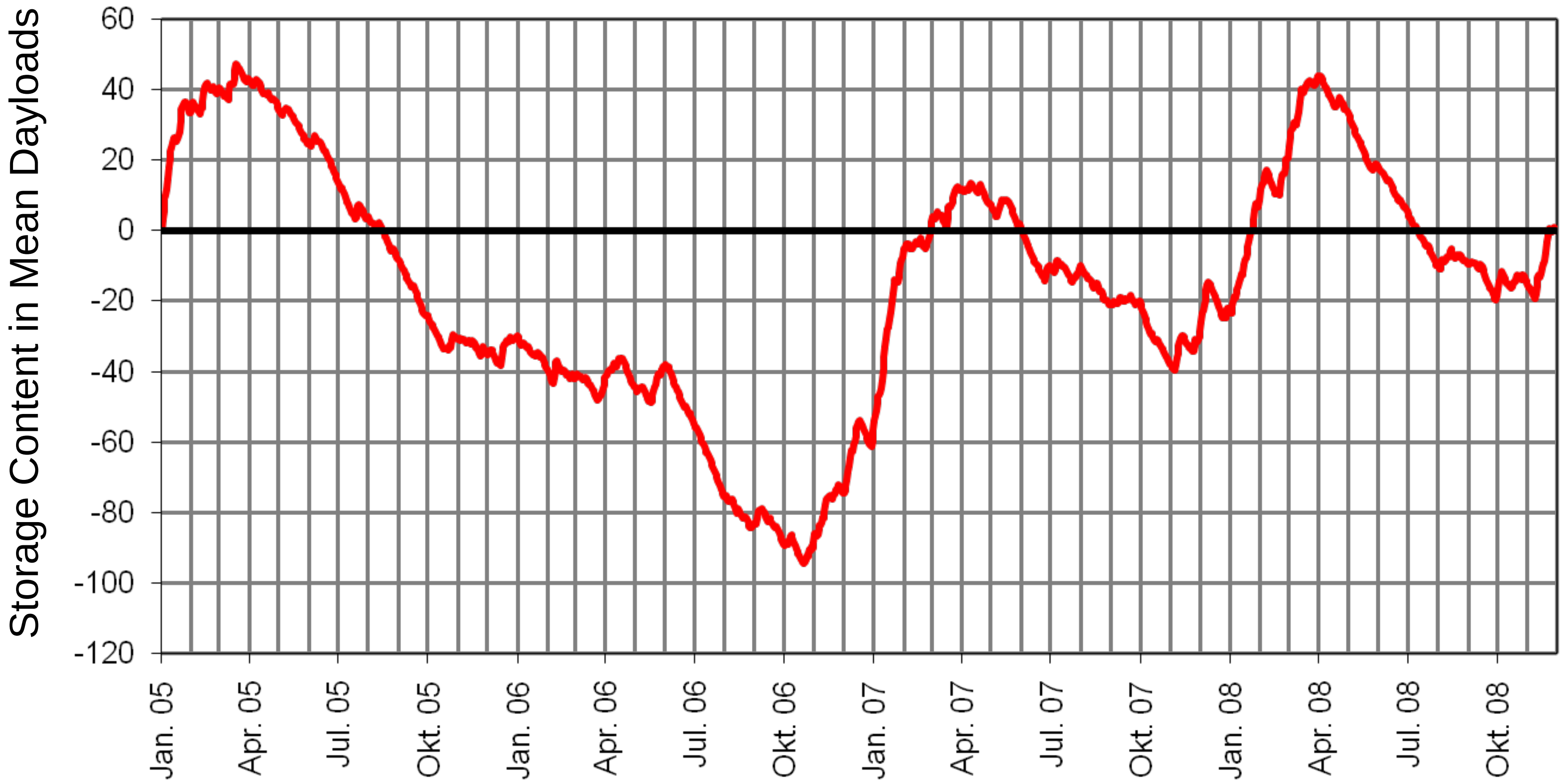
Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Power Characteristic and Storage Content (Integral) Example



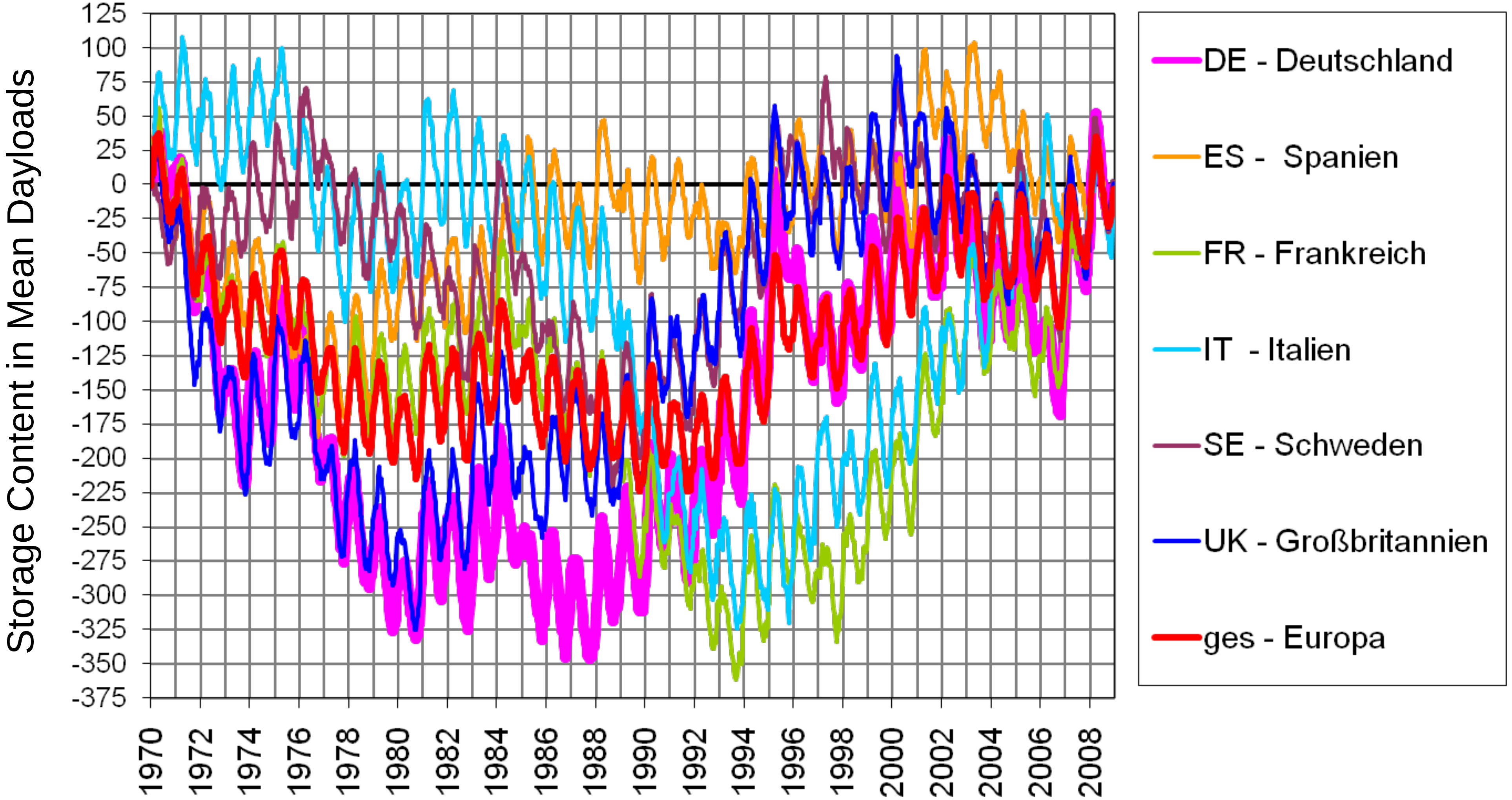
Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Long Term (2005 – 2008) Caracteristic of Wind Power in Germany Integrated – Fictive Storage Content



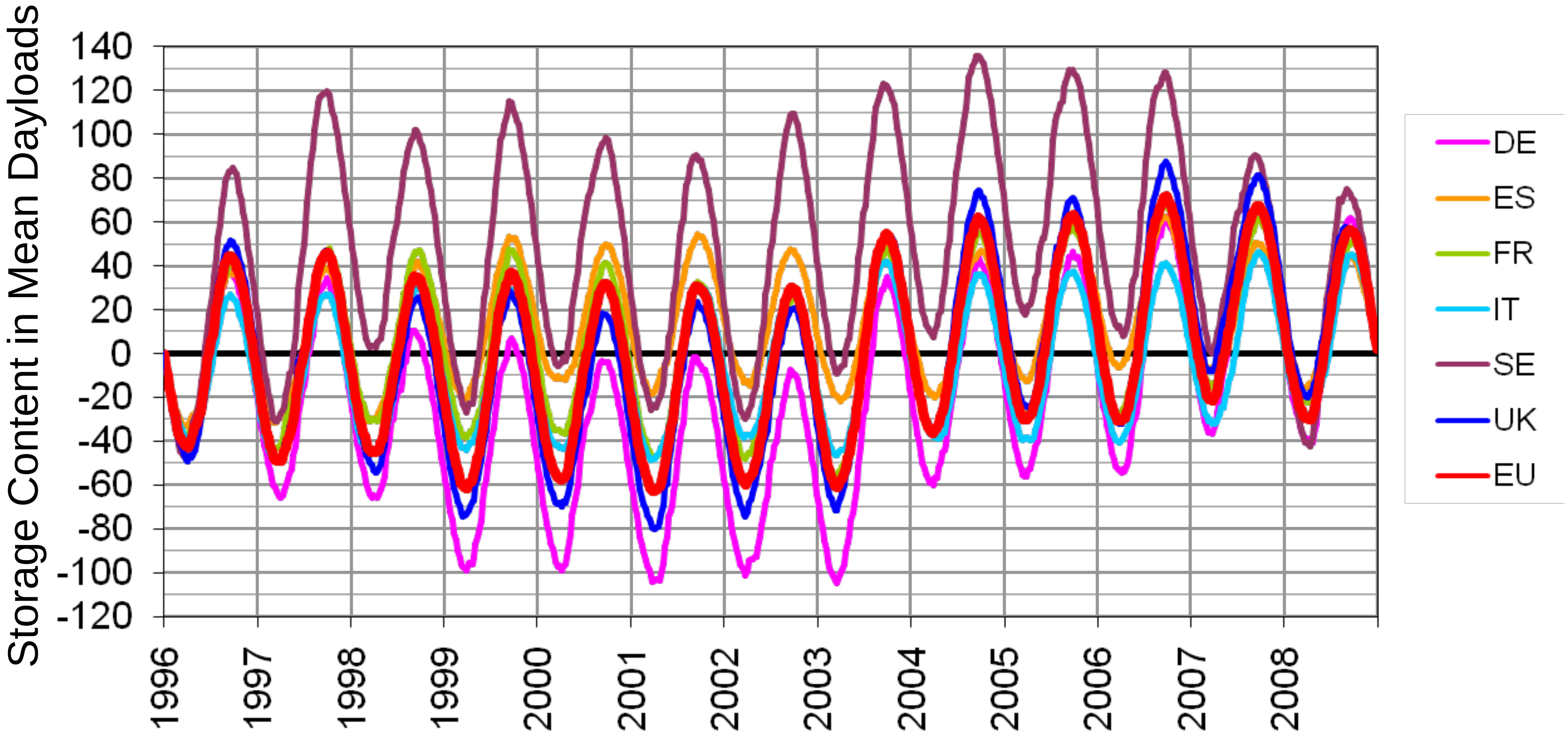
Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Long Term (2005 – 2008) Caracteristics of Wind Power in Europe (Integrated) – Fictive Storage Contents



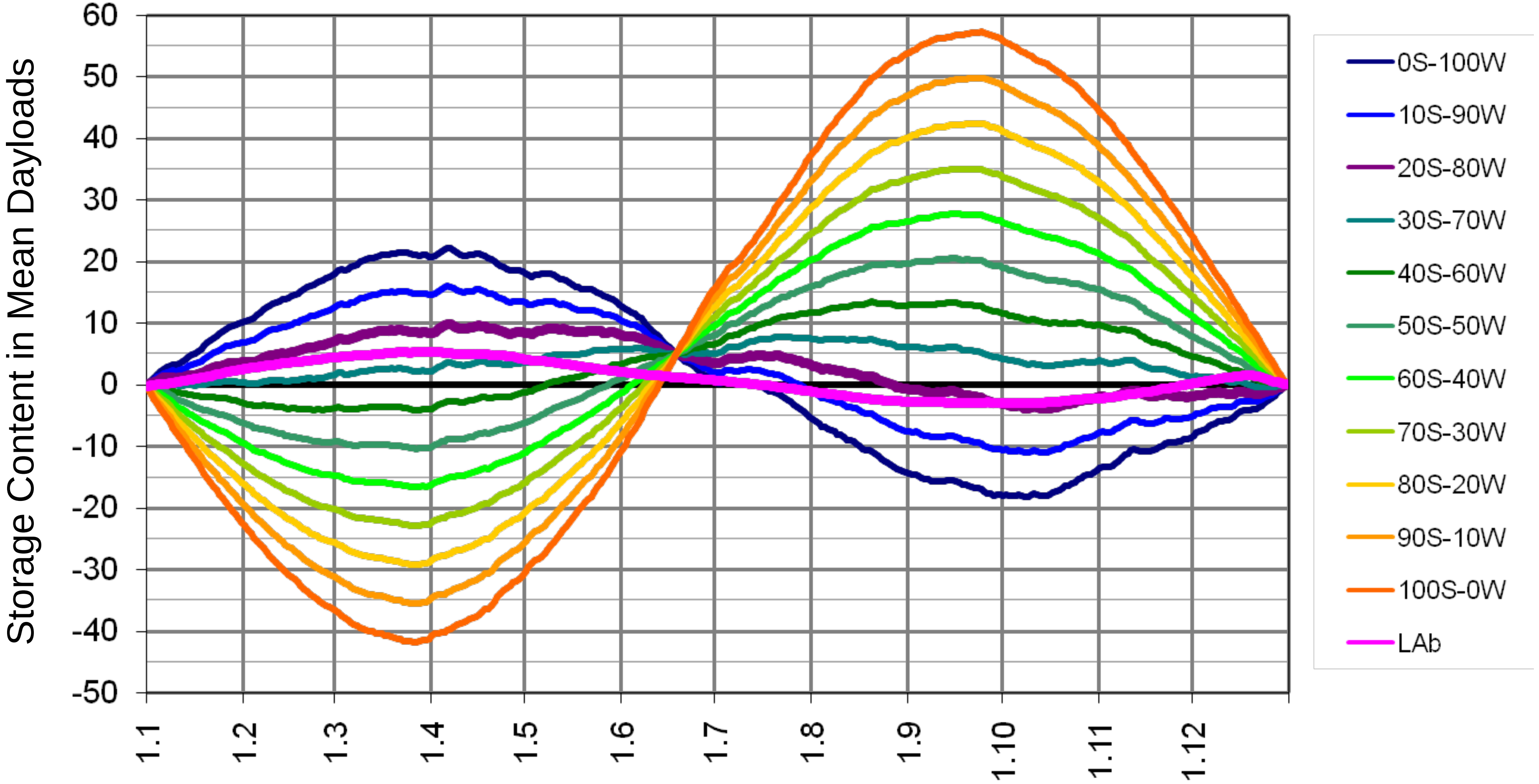
Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Long Term (1996 – 2008) Caracteristics of Solar Power in Europe (Integrated) – Fictive Storage Contents



Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Combination of Wind and Solar Storage Contents

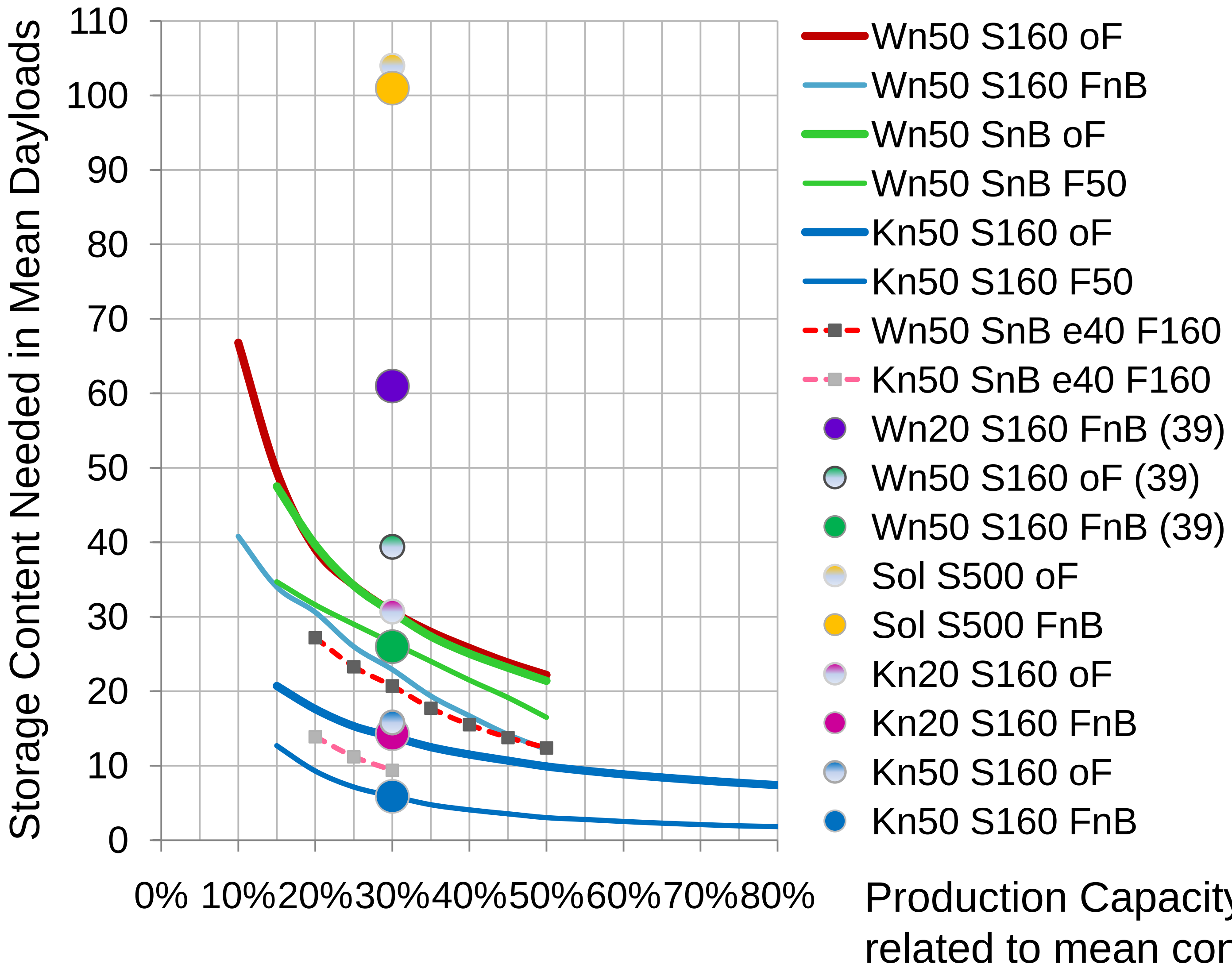


Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Storage Capacity Needed – only wind and solar energy used

Wn50
Usage ratio of wind plants 50%

Storage capacity is reduced when biomass biooil biogas geothermal energy etc. are used as back up



Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

Electricity Storage Possibilities

Physical:

- Electrical: Superconducting Magnetic Ring Storage, Super Caps
- Gravity: Pumped hydro storage power plant, $\eta=0{,}9 \cdot 0{,}9 \approx 70\text{-}80\%$
- Pressure: Compressed Air Energy Storage – CAES with Air Turbine or Combined Cycle or Air driven Motor
- Rotation: Flywheels

Etc.

Electrochemical:

- Batteries
- Metal-Air-Cells
- Redox-Flow Batteries
- Fuel Cell ($\eta=0{,}5\text{-}0{,}6$) after Electrolysis ($\eta=0{,}6\text{-}0{,}7$)

Etc.

Essential Issues:

- Capacity
- Power
- Efficiency
- Cycles
- Costs

} actually only pumped hydro and CAES fulfill requirements

Pump Storage Plant – Goldisthal Thuringia

Volume: 12 Mio m^3
Height: 300 m

8 h full load operation
ca. 8000 MWh
0,5 % of Mean daily Consumption of Germany

Electricity consumption in Germany 2009 ca. 600 Mio MWh

Mean Power in Germany 2009: 68 GW

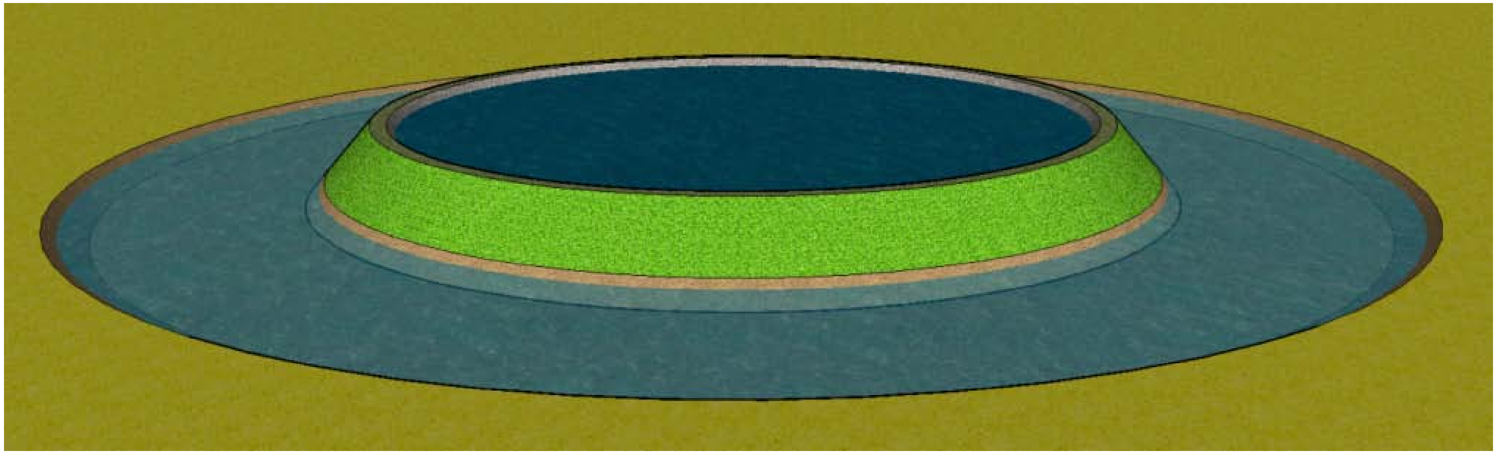
Mean Daily Consumption 1644 GWh

Source:http://www.uni-weimar.de/Bauing/wbbau/studium/zusatz/exkursionen/exberichtWW70.html

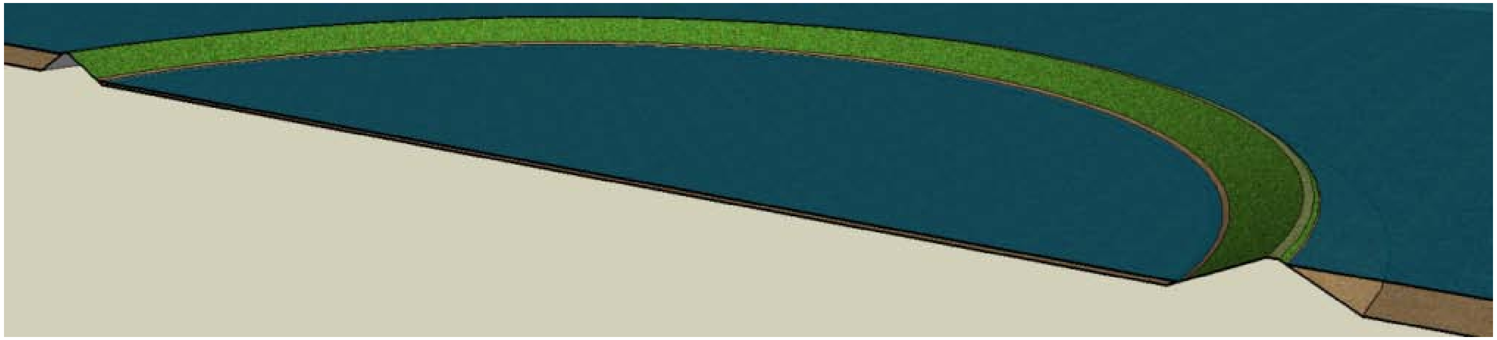
Pumped Hydro Plant Ideas

- Pumped Hydro Plants in Norway
- In the Energy Research Center of Lower Saxony **EFZN** in Goslar research is done on pumped hydro plants in old mines e.g. in the Harz

Ringwall Storage



for „flat land“



for deep sea

Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

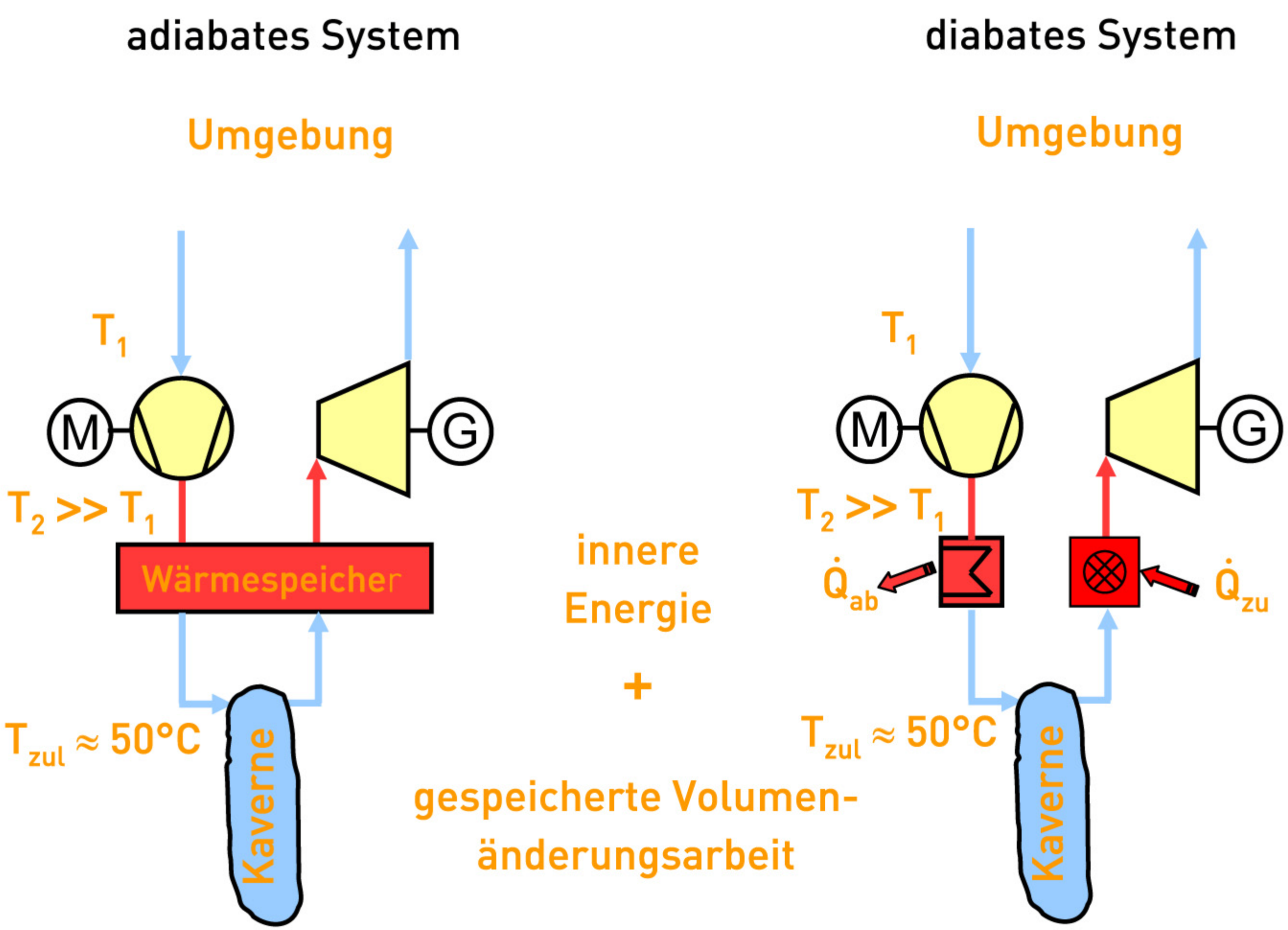
Ringwall Storage Vision

Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5, Bild der Wissenschaft 10/2010

Ringwall Storage comparable to Browncoal Open Cast Mine

Quelle: M.Popp: Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien, Springer 2010, ISBN 978-3-642-01926-5

State of the Art Compressed Air Energy Storage Plants

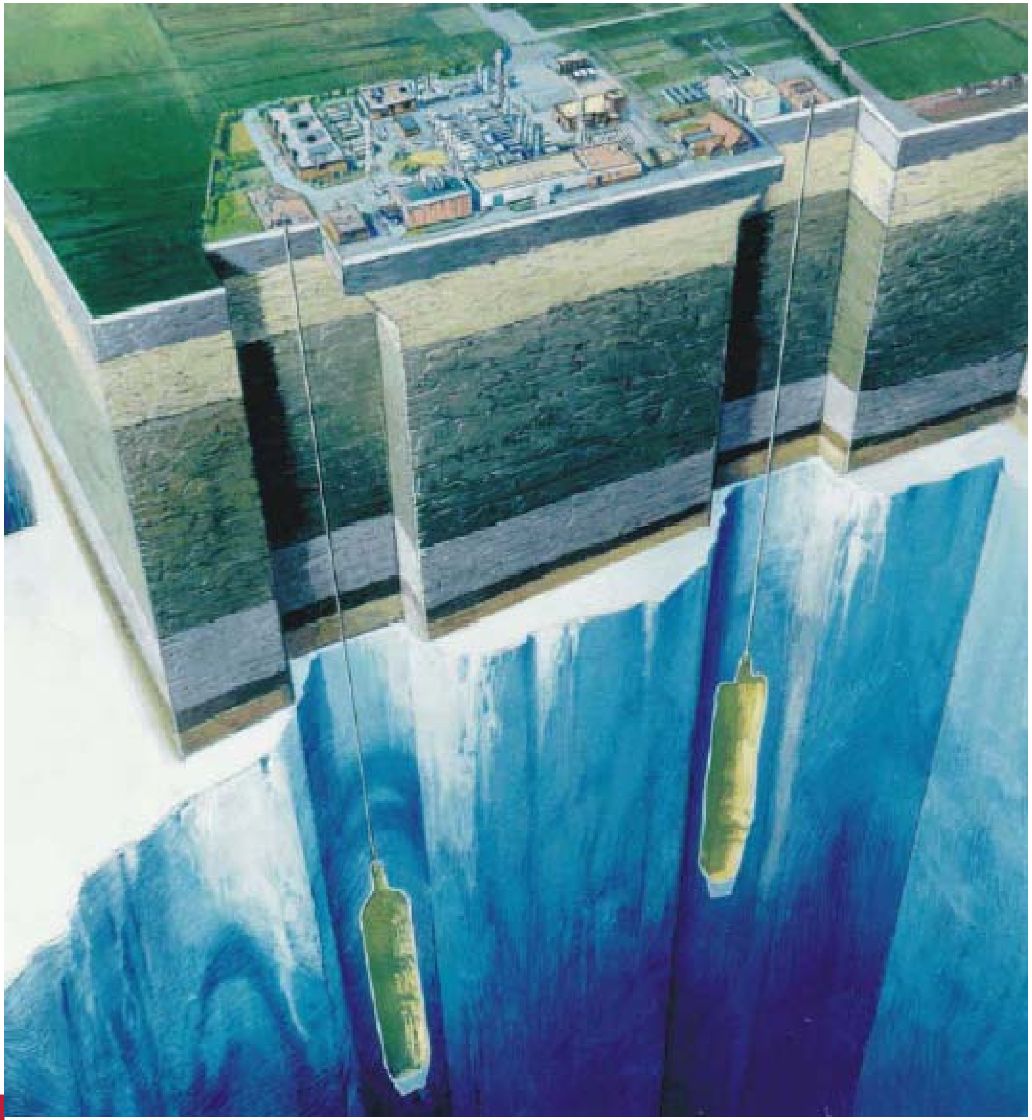


Quelle: [Calaminus2007]

State of the Art CAES plant Huntorf of E.ON AG

Quelle: [Crotogino2006]

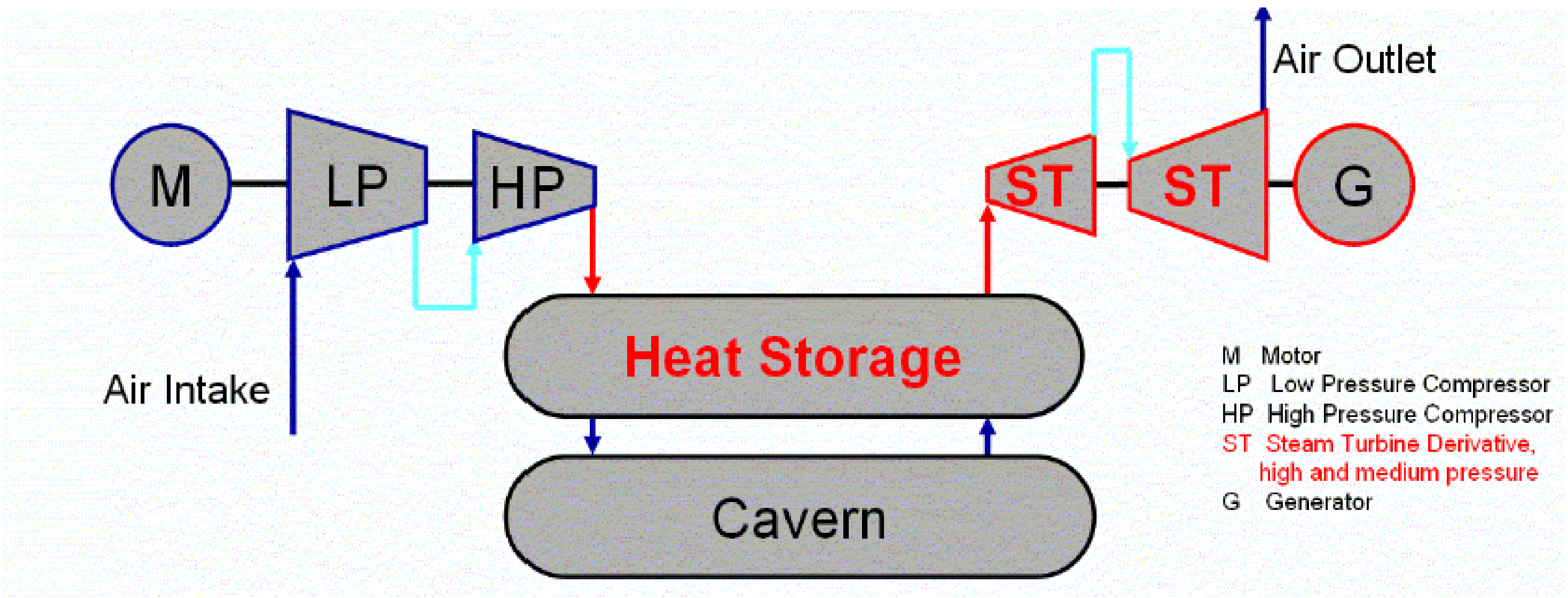
State of the Art CAES plant Huntorf of E.ON AG



Source: [KBB Underground Technologies]

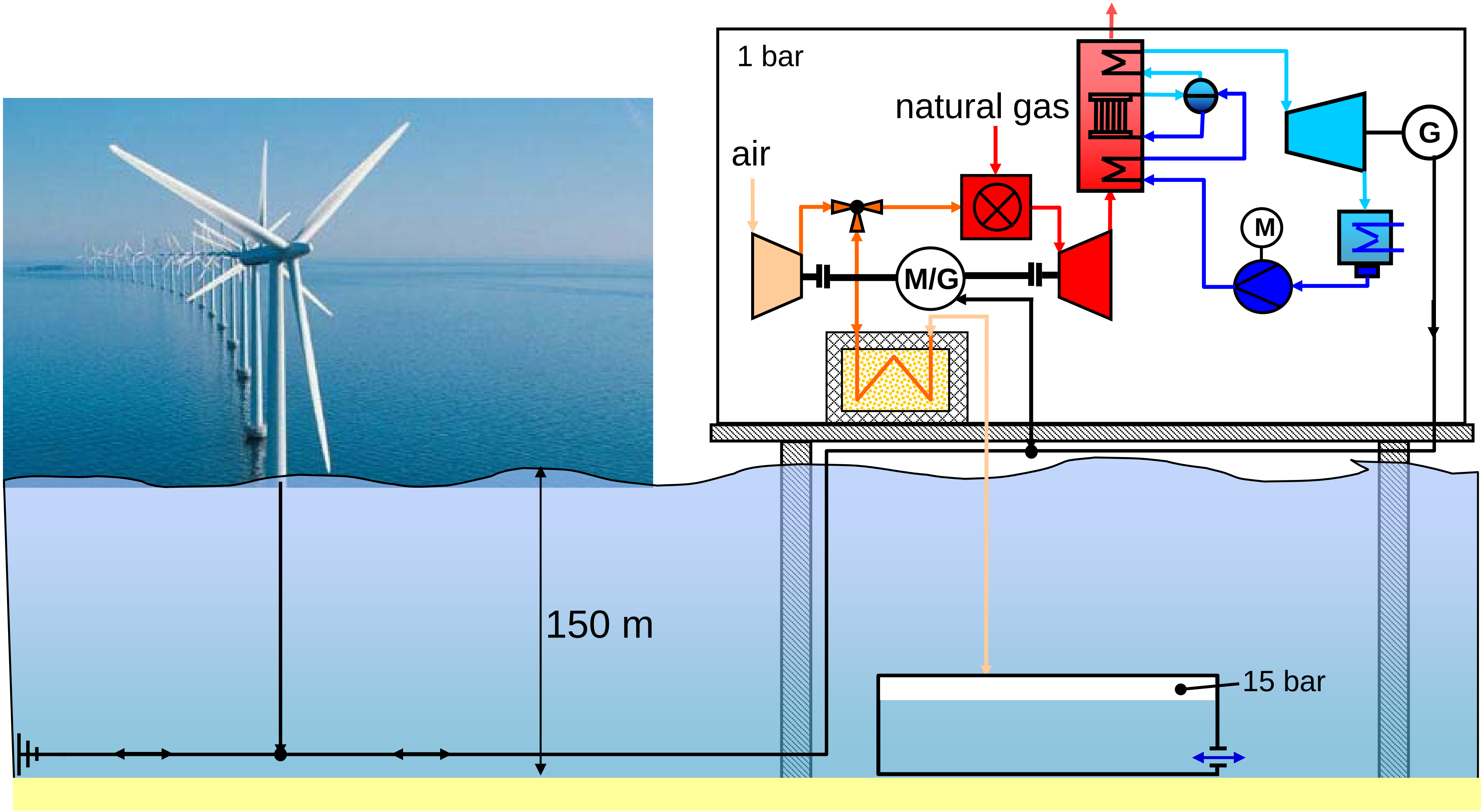
Future Developments: AA-CAES – Advanced Adiabatic - Compressed Air Energy Storage

- Compressed air reservoir with constant volume and variable pressure (cavern)
- Buffering of compressor waste heat
- (with) without additional firing



Source: [KBB Underground Technologies]

Future Developments: Isobaric, Adiabatic Compressed Air Energy Storage Combined Cycle for Offshore Wind-Power Storage



Source: [IWBT]

Comparison with Pumped Storage Power Plant

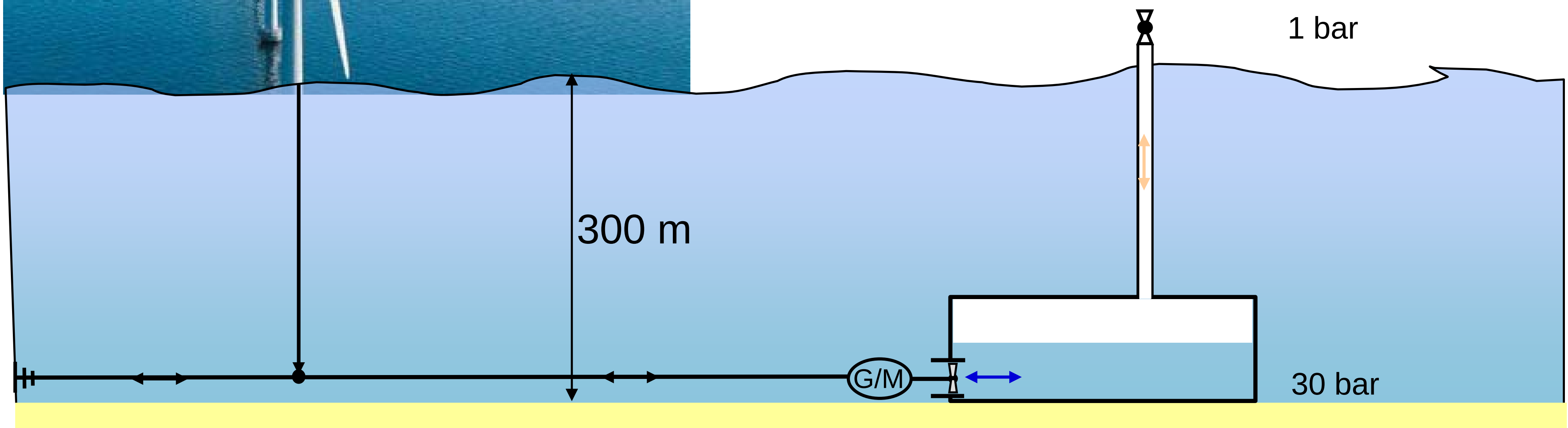
Storable energy (losses neglected):

$$E = V \cdot \rho \cdot g \cdot H$$
$$= 300.000\,m^3 \cdot 1000\,\frac{kg}{m^3} \cdot 10\,\frac{m}{s^2} \cdot 300\,m = 900 \cdot 10^3\,MJ$$

(conversion efficiency of about 90 %)

Ratio of released energy of isobaric, adiabatic compressed air energy storage combined cycle to pumped storage power plant:
(V = 300.000 m³ p = 15 bar)

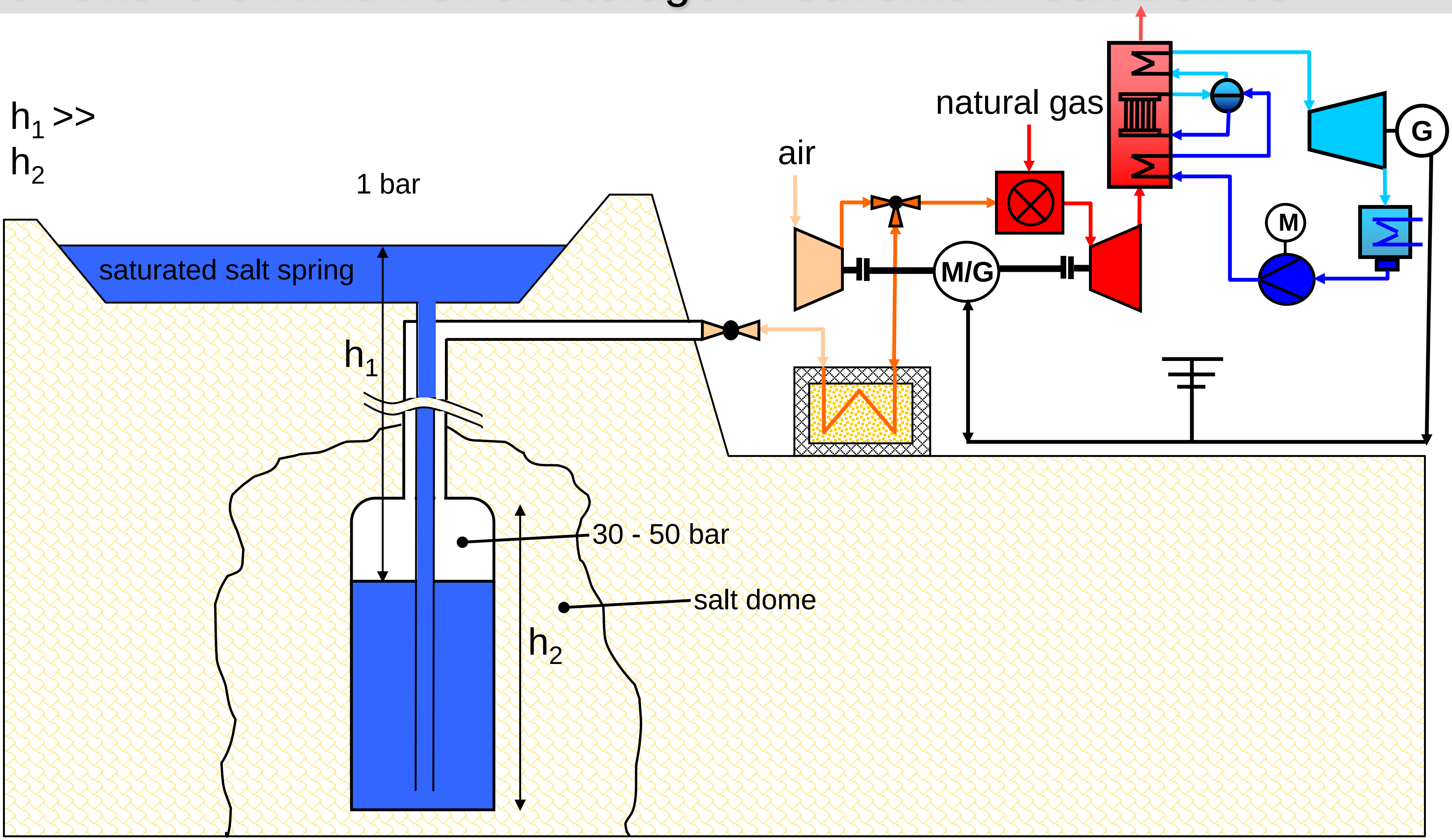
$$\frac{13{,}32 \cdot 10^6\,MJ_{el}}{900 \cdot 10^3\,MJ_{el}} \approx 15$$



Source: [IWBT]

Future Developments: Isobaric, Adiabatic CAES Combined Cycle for Onshore Wind-Power Storage in Caverns in Salt Domes

$h_1 >> h_2$



Source: [IWBT]

Storage Capacity for Germany only provided by ISACOASTCC

Assumptions: Only wind and solar energy is used:

→ <u>Minimum storage capacity ca. 2,5 mean dayloads</u>

Mean electricity consumption in Germany per day: **<u>1644 GWh</u>**

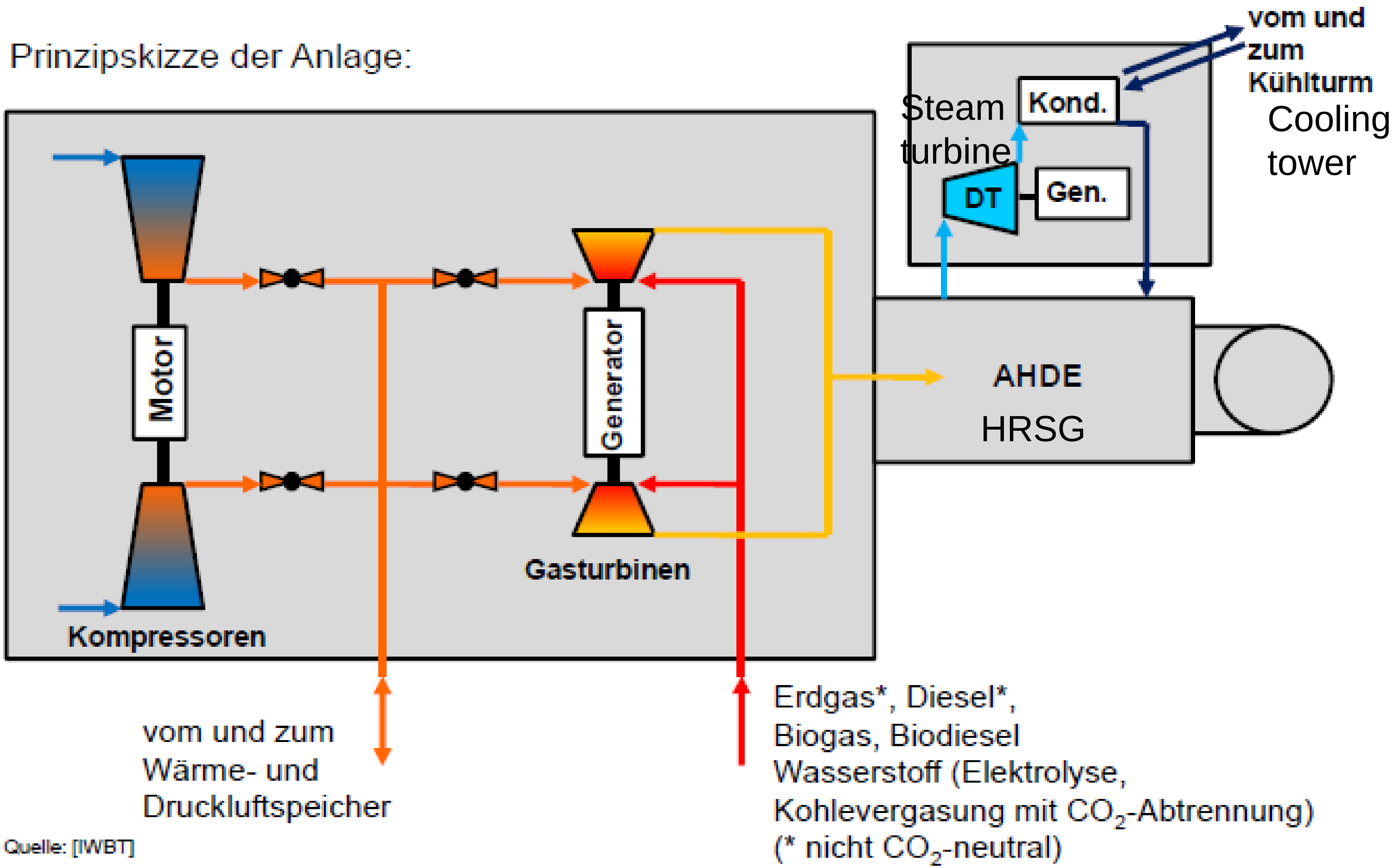
Storage capacity of an ISACOAST-CC plant, based on 2 GT26-gasturbines and designed for **<u>24 h</u>** storage operation: **<u>38,5 GWh</u>**
Power production during discharging ca. **<u>1600 MW</u>**

→ About **<u>107</u>** ISACOAST-CC plants needed

→ **<u>107</u>** ISACOAST-CC plants operated as usual Combined Cycle plants (back up plants) would have a power of ca. **<u>91000 MW</u>** (**<u>850 MW</u>** per plant)

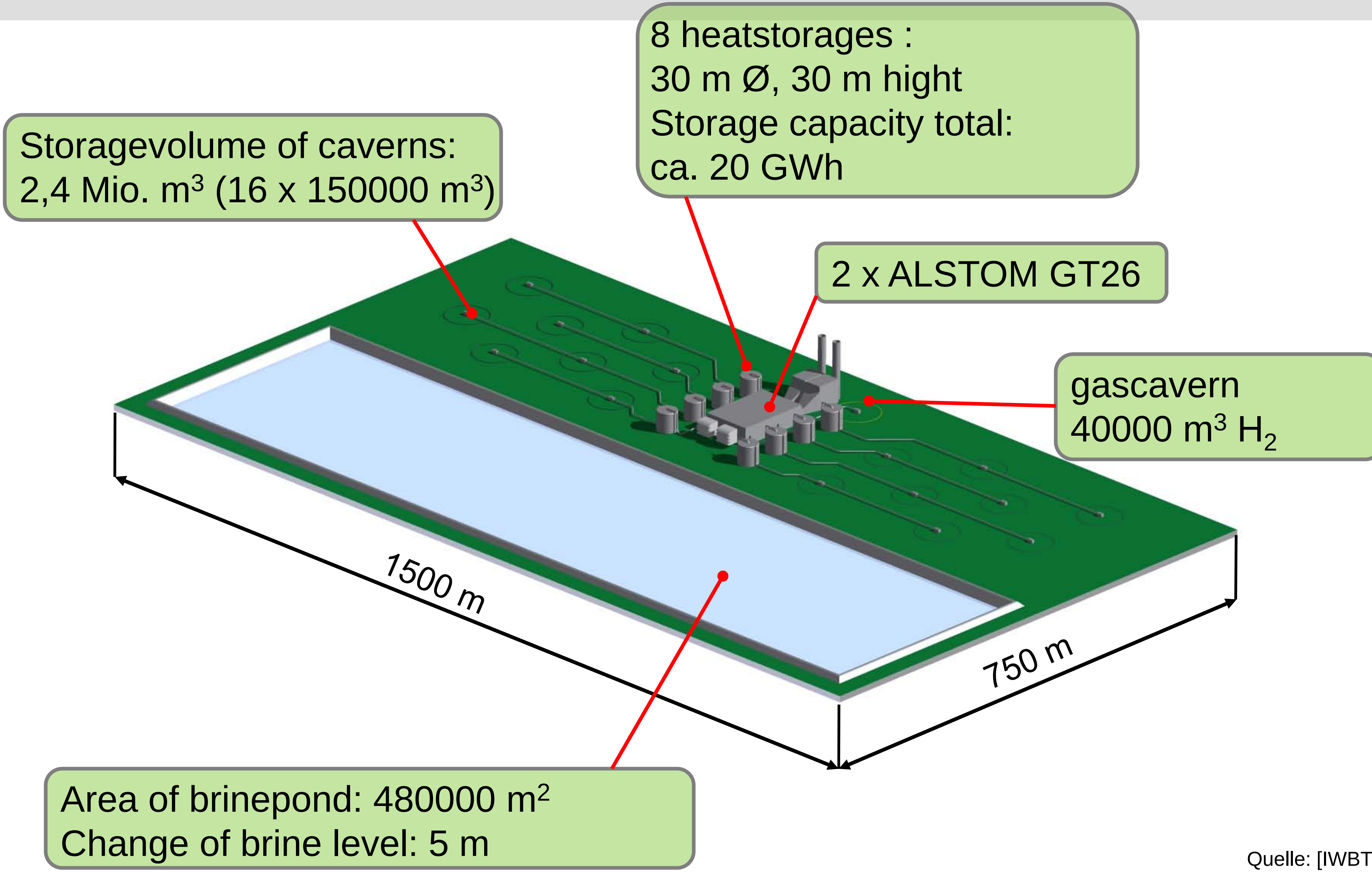
Lay Out of an ISACOAST-CC Plant with 2 GT 26 Gasturbines

Prinzipskizze der Anlage:



Quelle: [IWBT]

24 h ISACOAST-CC Plant with 2 GT 26 Gasturbines



Quelle: [IWBT]

Operation Modes and Possible Fuels

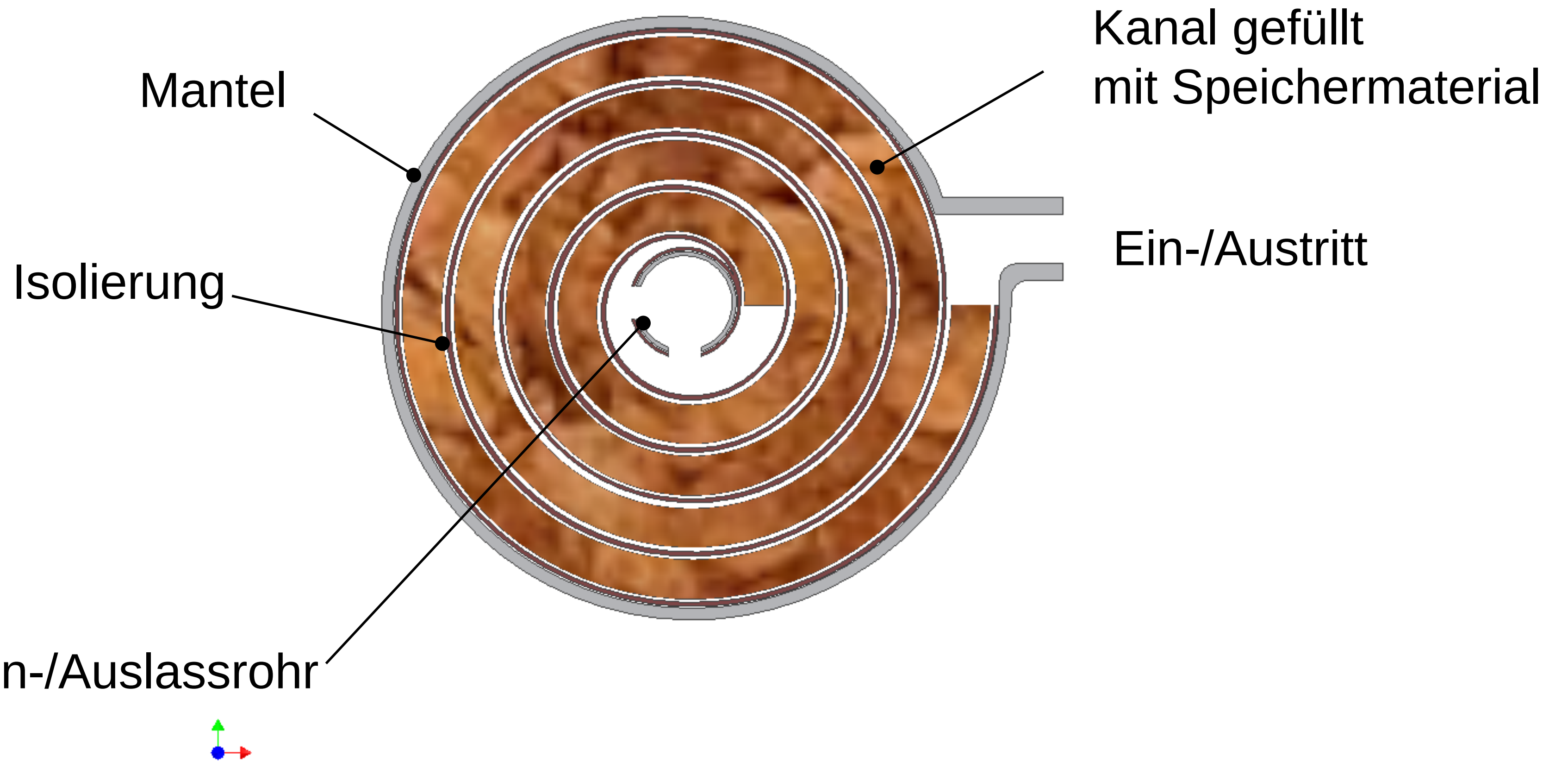
Operation Modes:

- Charging caverne
- Discharging with or
- without (adiabatic) additional fuel
- Usual Combined Cycle Opperation when cavern is empty

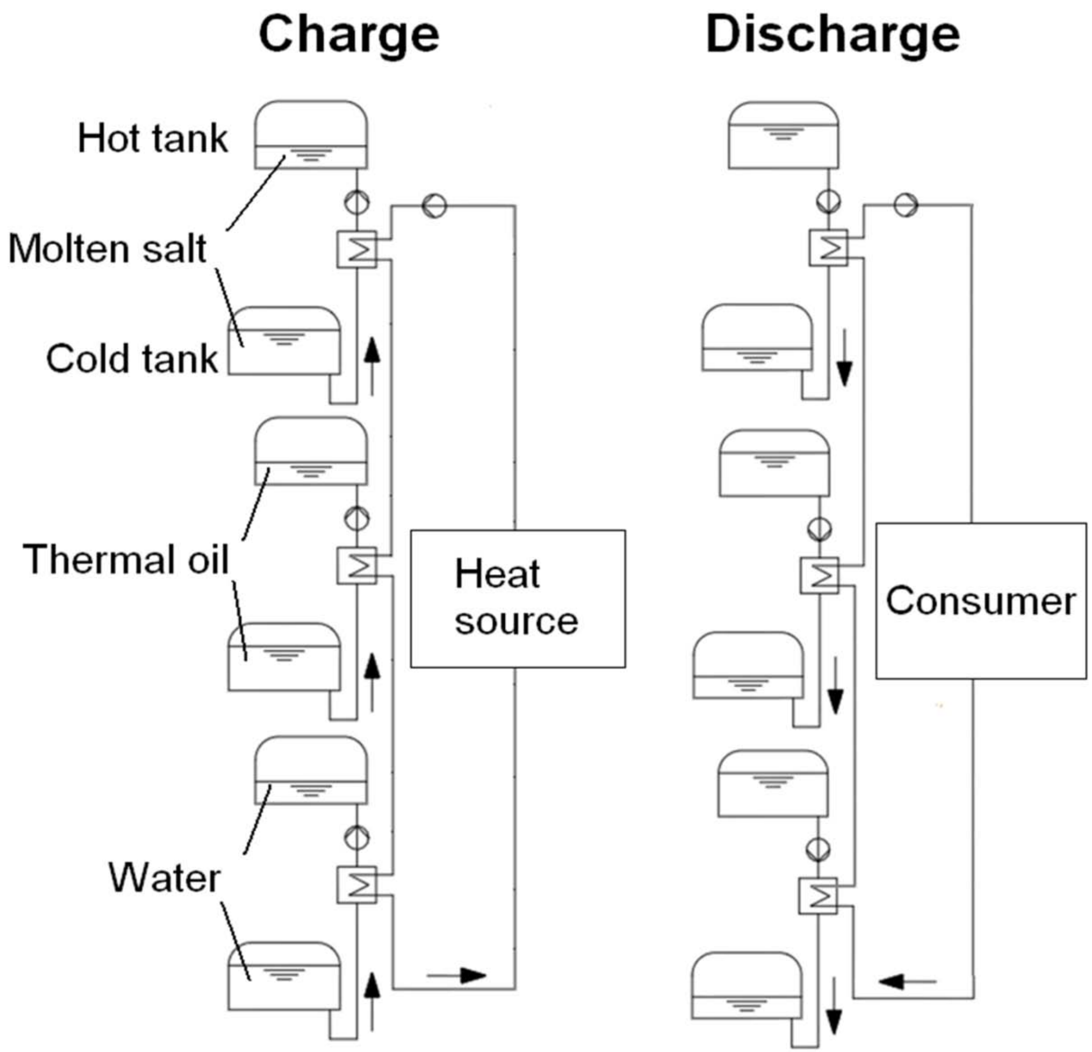
Possible Fuels:

- Methane, Biogas
- Diesel, Biodiesel
- Gasification gas before or after Carbon Capture H2
- Hydrogen from electrolysers

ISACOAST-CC Solid Heat Storage (e.g.tubes in sand)

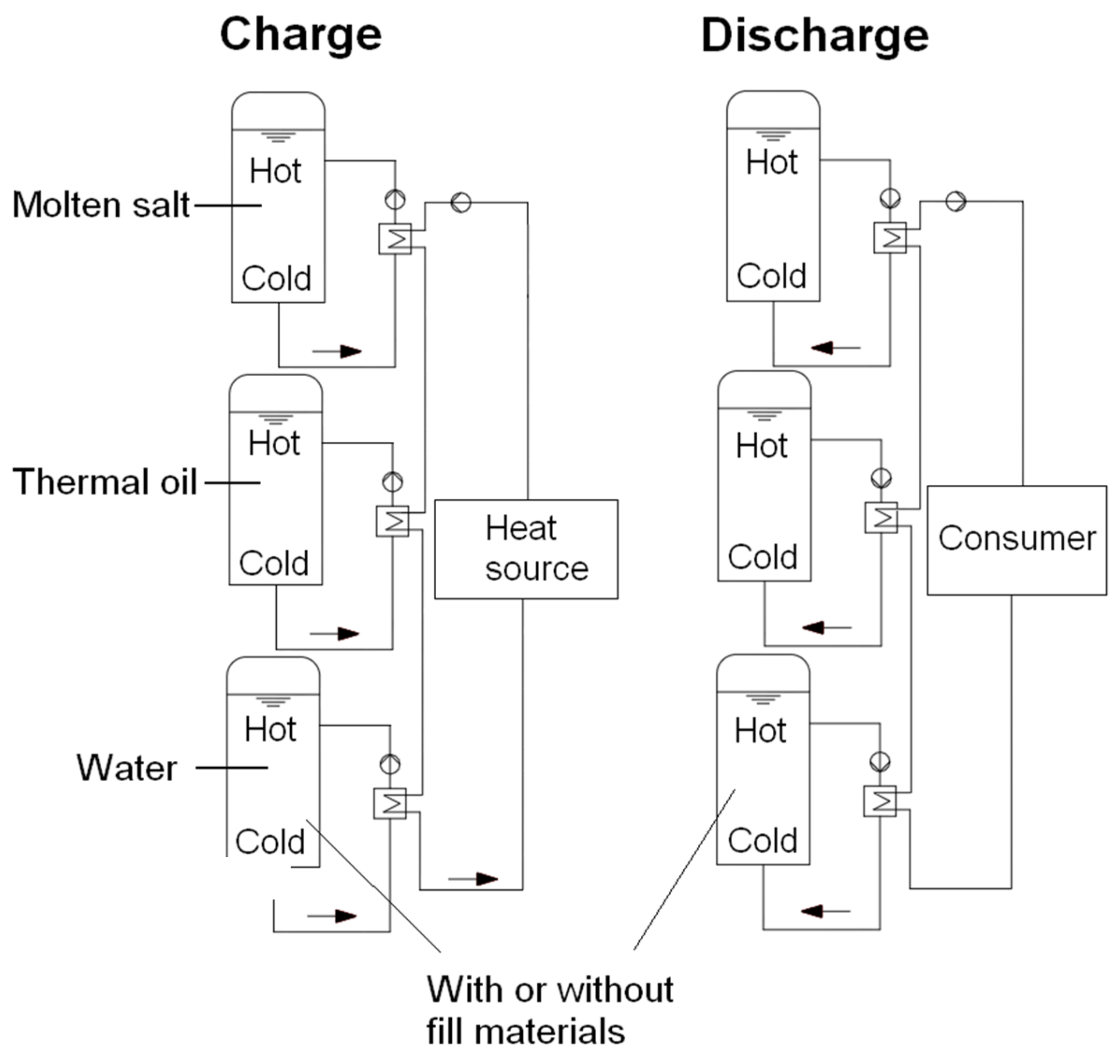


ISACOAST-CC 6-Tank-Heat-Storage



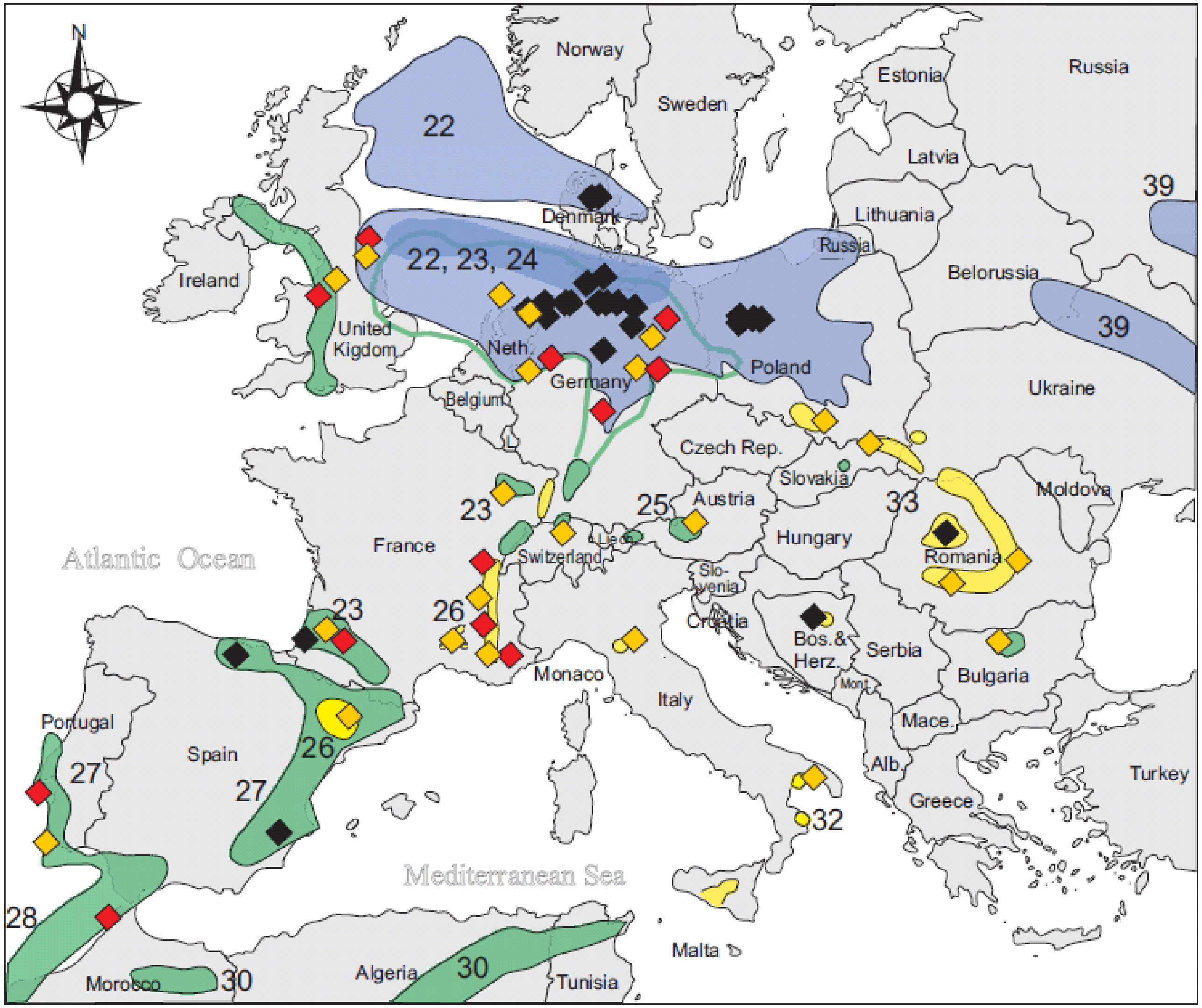
Quelle: [IWBT]

ISACOAST-CC 3-Tank-Thermocline-Heat-Storage



Quelle: [IWBT]

Salt Deposits in Europe



- Tertiary salt deposit
- Mesozoic salt deposit
- Range of Mesozoic salt above Permian
- Paleozoic salt deposit, Permian
- Paleozoic salt deposit, Rotliegend below Permian

Bedded salt cavern fields

- Brine production
- Cavern storage
- Domal salt cavern fields

Quelle: [KBB UT]

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Summary

- Much more storage capacity
- High capacity long distance grid
- Mainly wind and solar power production
- Versatile power plants partly combining production and storage

Acknowledgment

For financial support (e.on international research initiative) and advices:

e·on

For advices:

KBB
UNDERGROUND
TECHNOLOGIES

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[Calaminus2007] B. Calaminus, *Innovatives Druckluftspeicherkraftwerk der EnBW*, Vortrag anlässlich der Energietage Hannover, 31.10.07

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KBB-UT, Kavernen-Bau-und Betriebsgesellschaft Underground Technologies, Hannover
http://www.uni-weimar.de/Bauing/wbbau/studium/zusatz/exkursionen/exberichtWW70.html
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BWK DAS ENERGIE-FACHMAGAZIN

BWK - Das Energie-Fachmagazin - Ausgabe 12-2010
Regenerativstrom im Ringwall speichern

Thank you for your attention!

Any questions?

www.wbt.ing.tu-bs.de