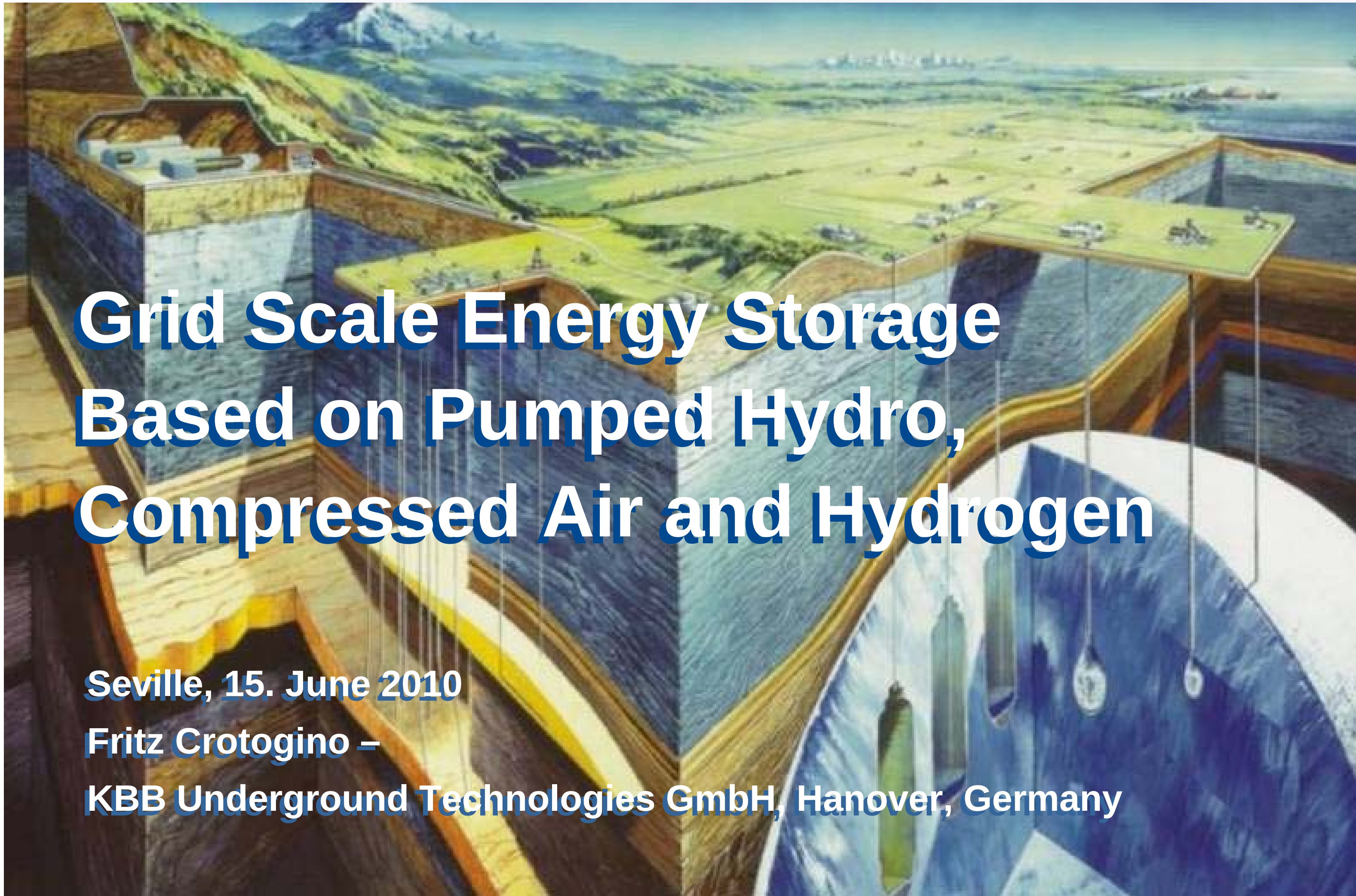

Grid Scale Energy Storage Based on Pumped Hydro, Compressed Air and Hydrogen

Seville, 15. June 2010

Fritz Crotogino –
KBB Underground Technologies GmbH, Hanover, Germany

Content

1. From Natural gas to renewable energy
2. Demand for energy storage (grid scale) – characteristics of wind power
3. Grid scale energy storage options
4. How much storage needed?

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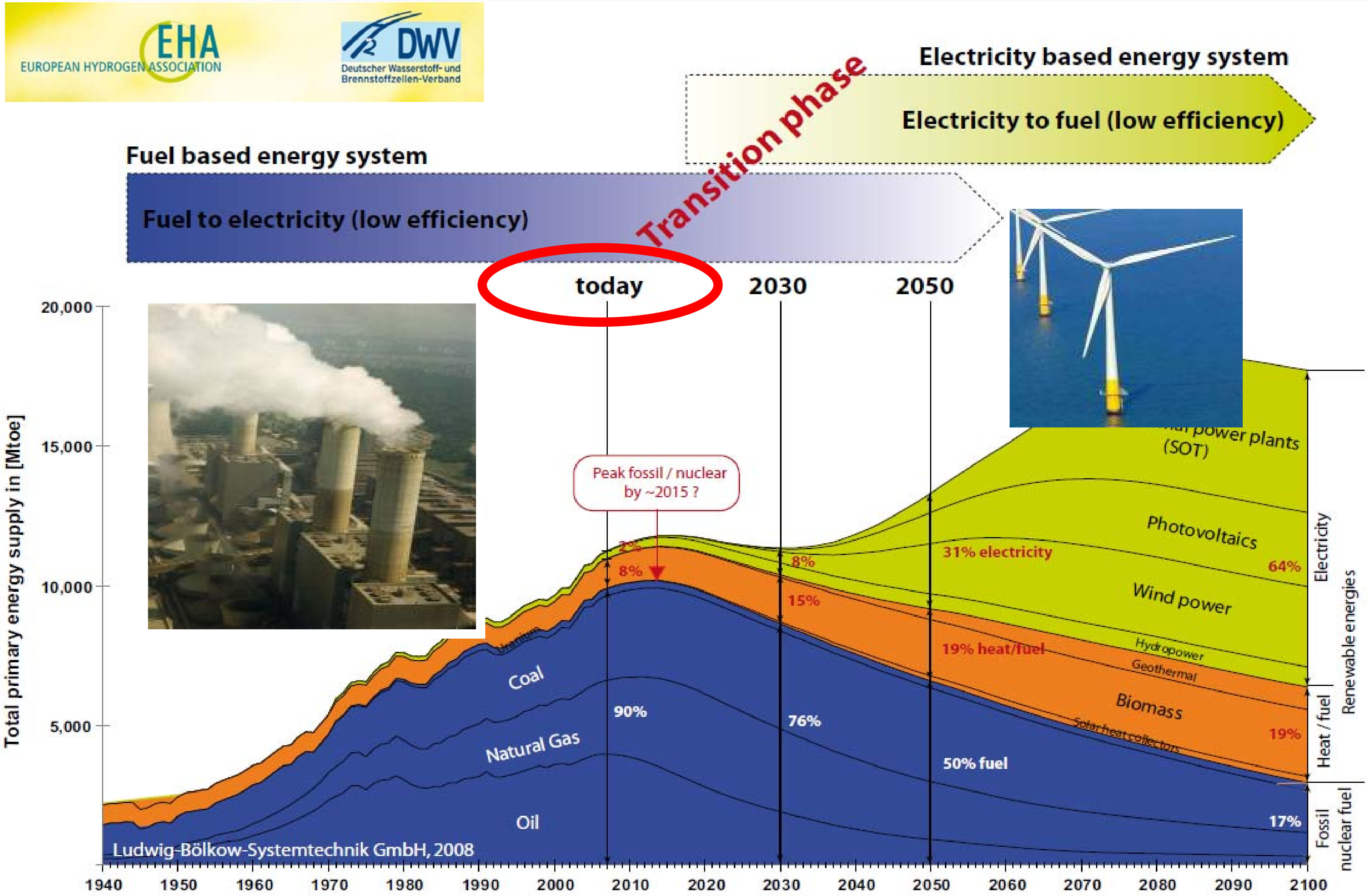
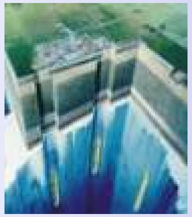
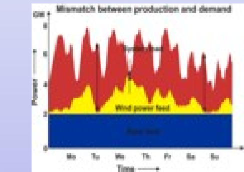
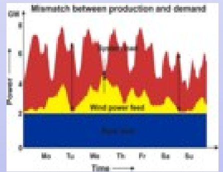
Transition *fuel* to *electrictiy* based energy systems



Energy supply chain - **today**
(Basis: **fossil & nuclear** energy sources)

primary energy carrier

secondary energy carrier electr. power

primary energy source	power vs. time	storage	conversion to power	power vs. time	storage	grid
						
		20% of annual consumption			**0.06% of annual consumption**	

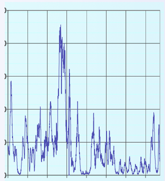
storage of primary energy carrier
before conversion to electric power

Energy supply chain - **tomorrow**
(Basis: **renewable** energy sources)

primary energy source | **secondary energy carrier: electr. power**

primary energy source

power vs. time

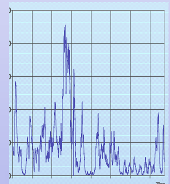


storage

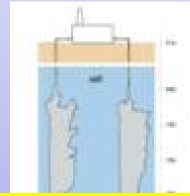
20% of annual consumption

conversion to power

power vs. time

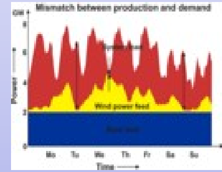


storage



0.06 % of annual consumption

grid



storage of primary energy carrier
after conversion to electric power

1. From Natural gas to renewable energy
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    iii. need for energy storage
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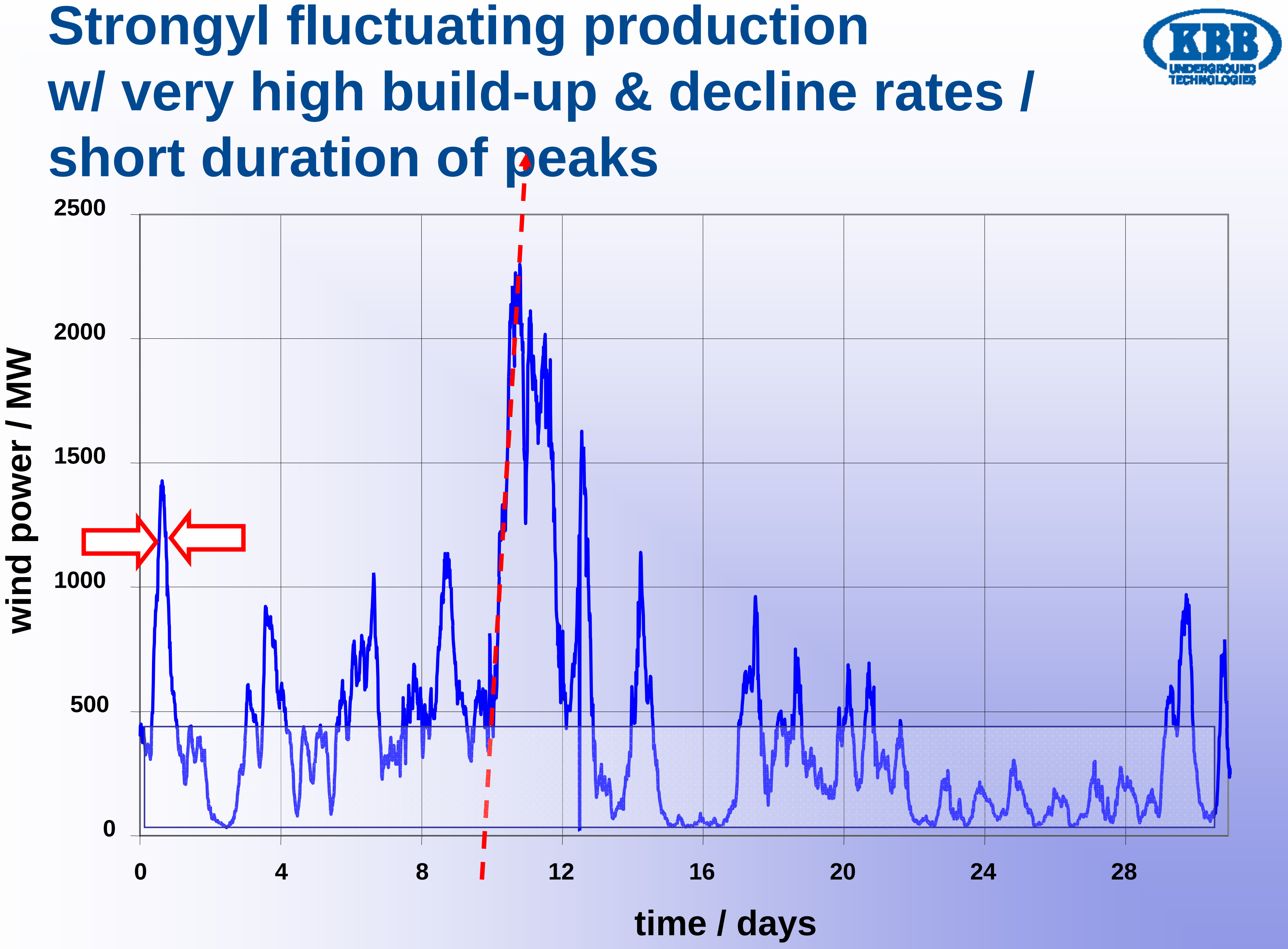
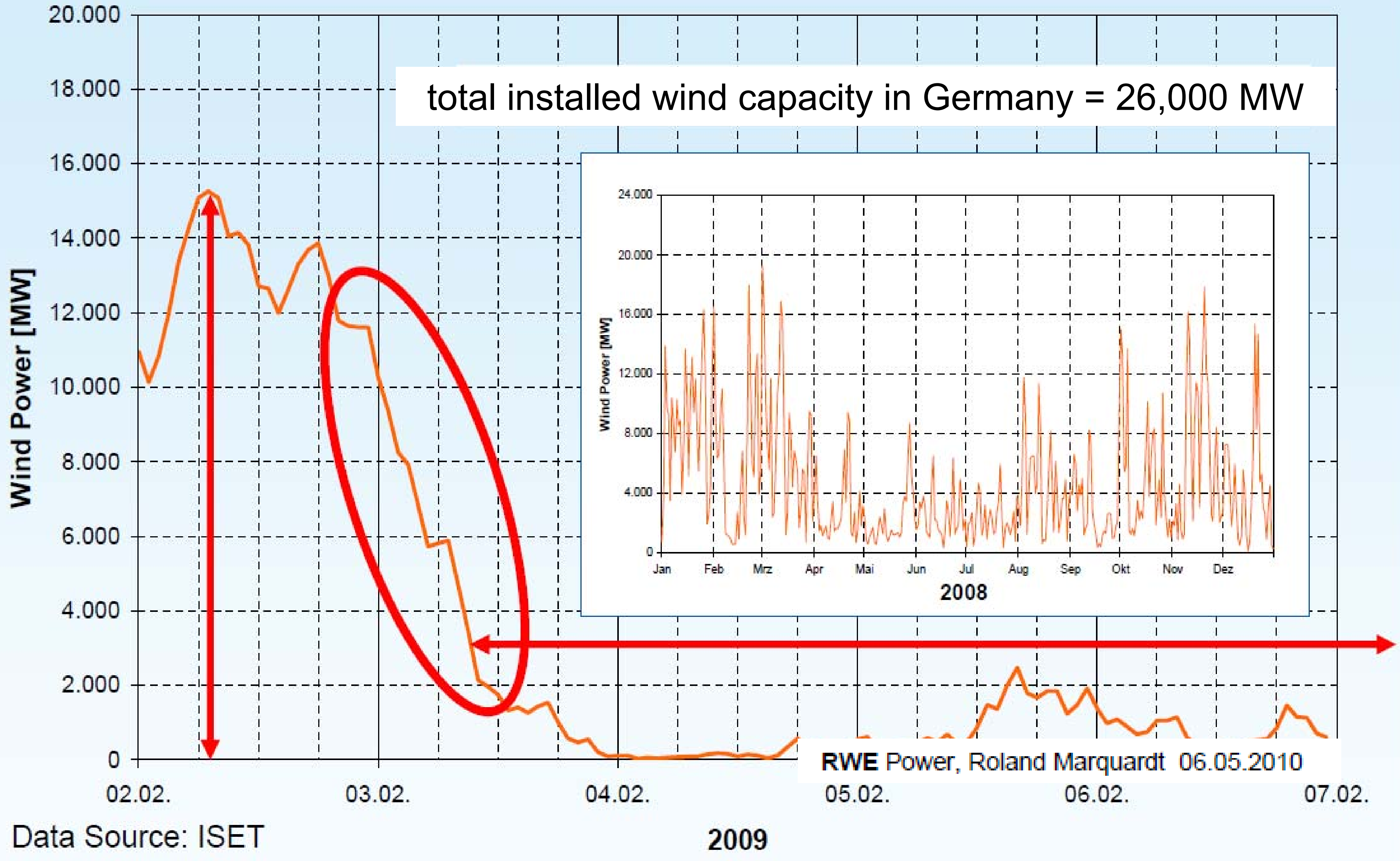
Strongyl fluctuating production w/ very high build-up & decline rates / short duration of peaks

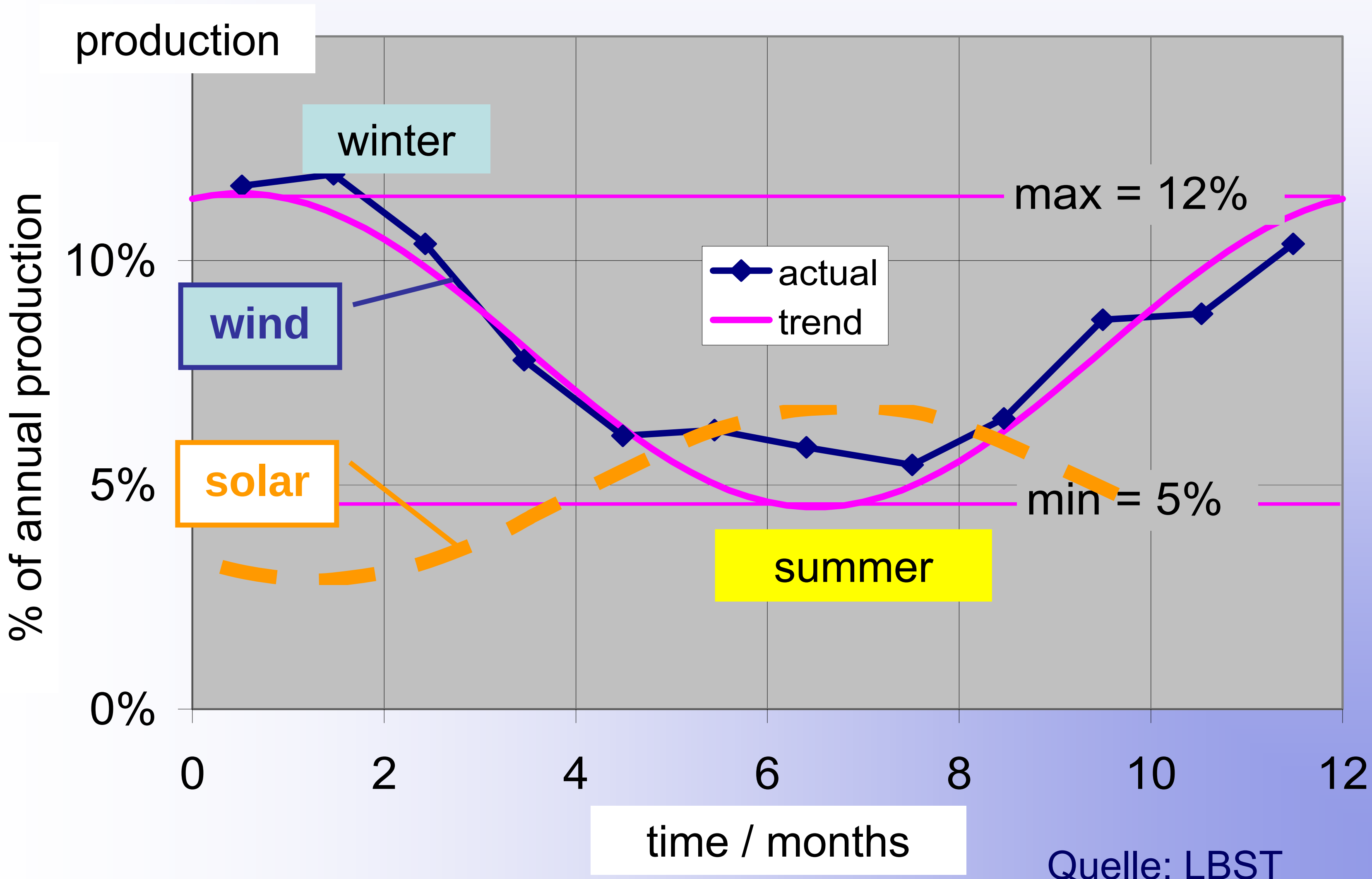


Chance for longer wind flaws (up to weeks)



Data Source: ISET

Seasonal swing of wind & solar power



Quelle: LBST

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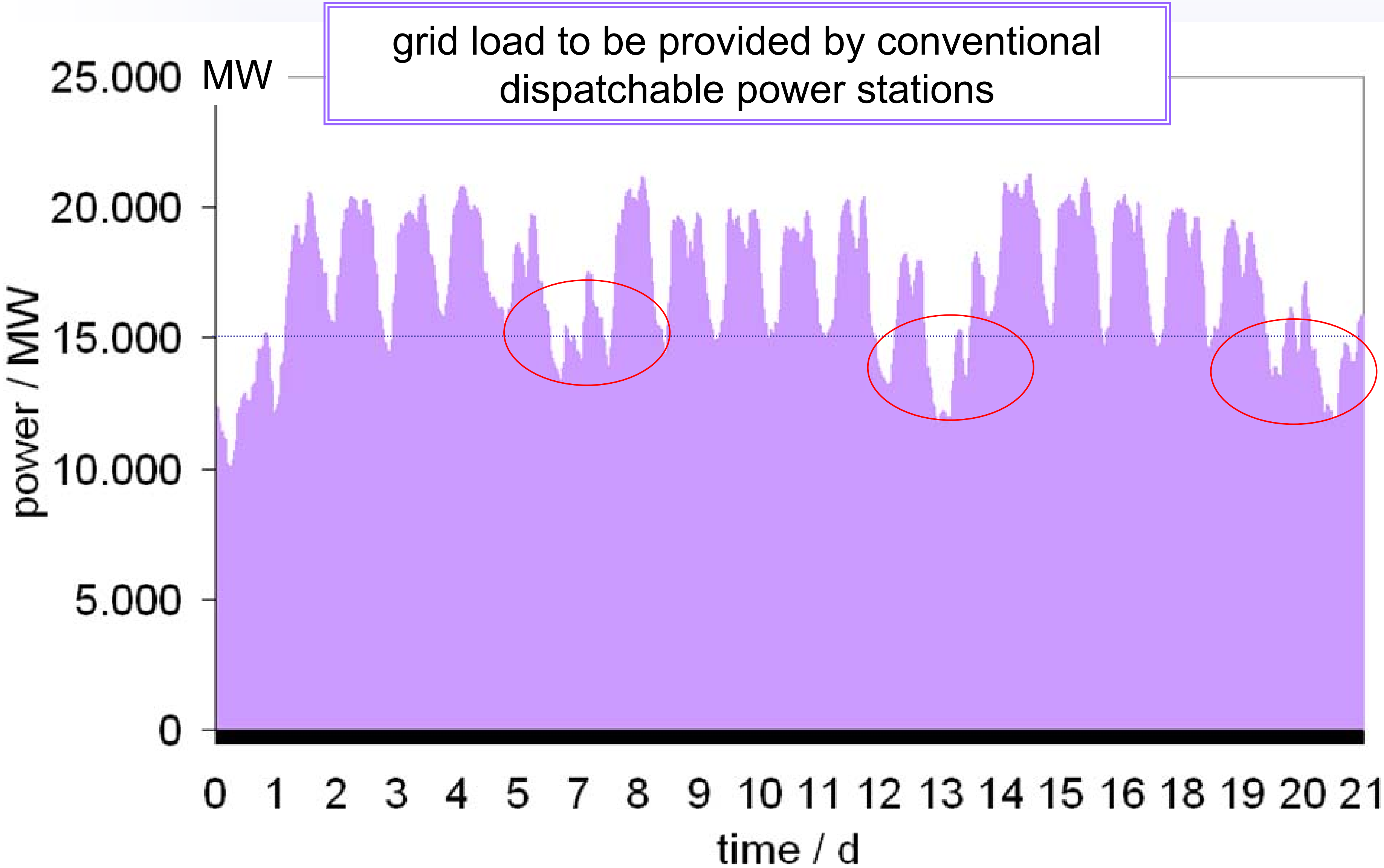
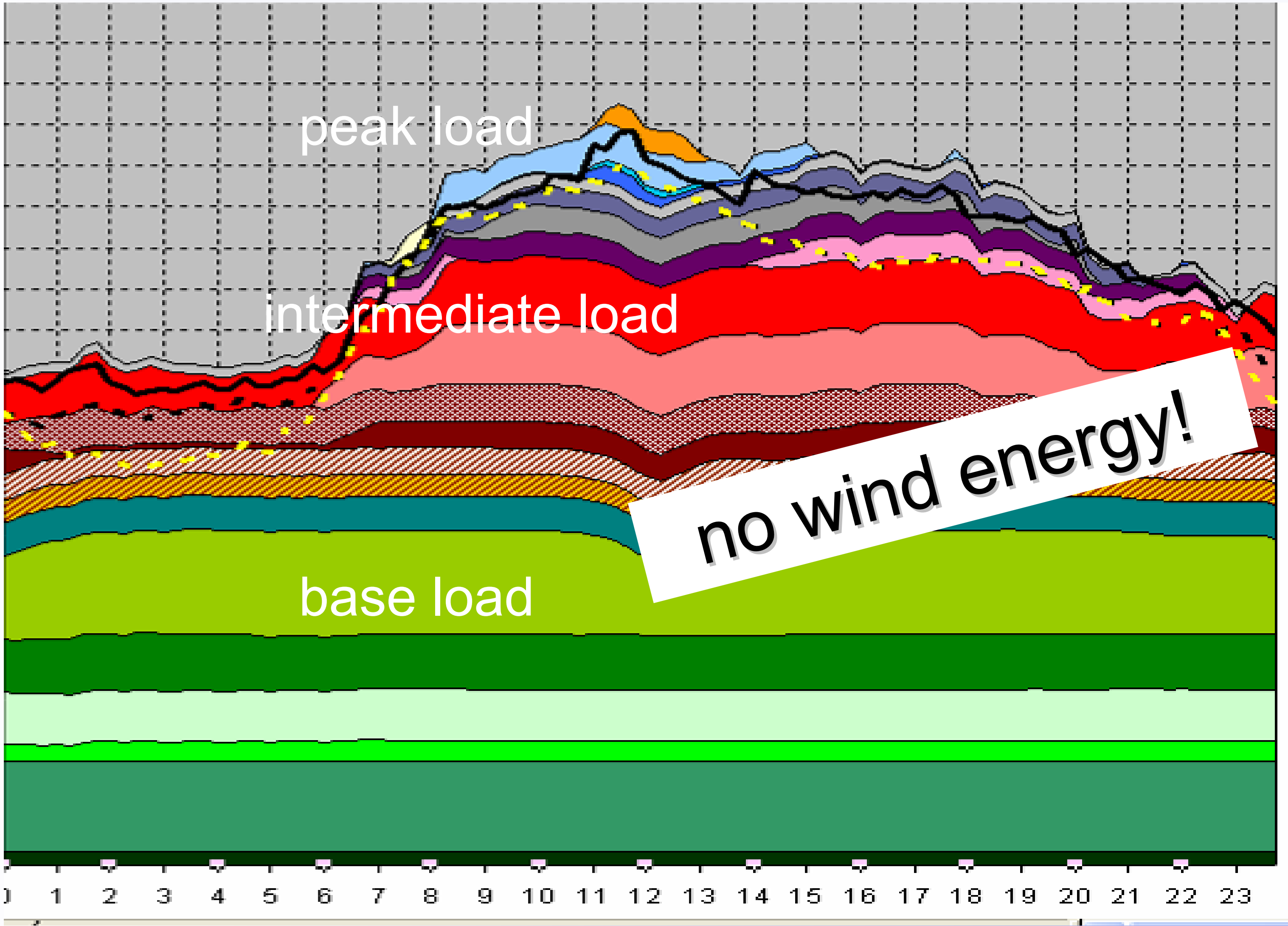
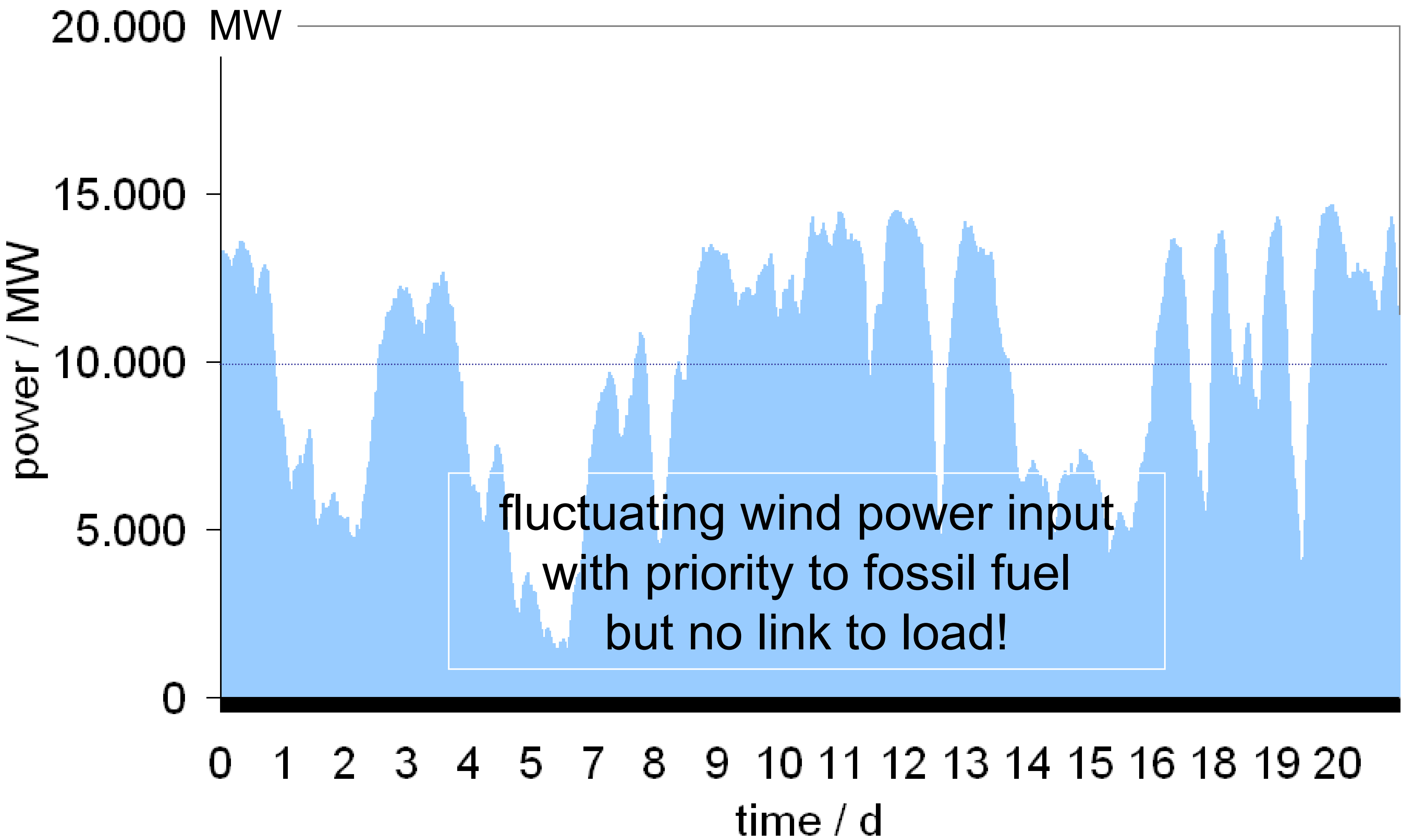
Grid load


grid load to be provided by conventional dispatchable power stations
25.000 MW
20.000
15.000
10.000
5.000
0
power / MW
0 1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 20 21
time / d

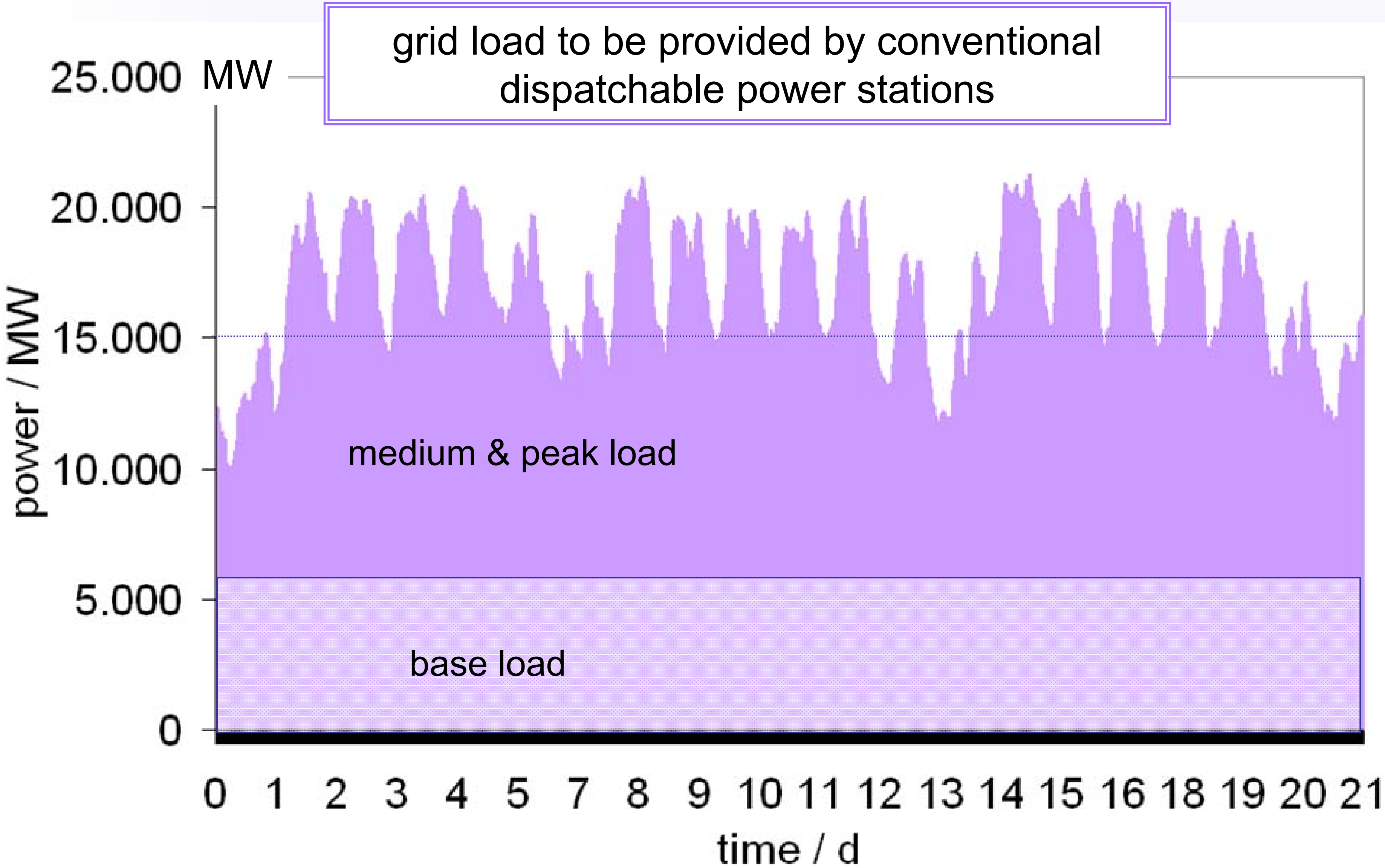
Load = total of up to 20 power stations (no wind power included)



Share of wind production

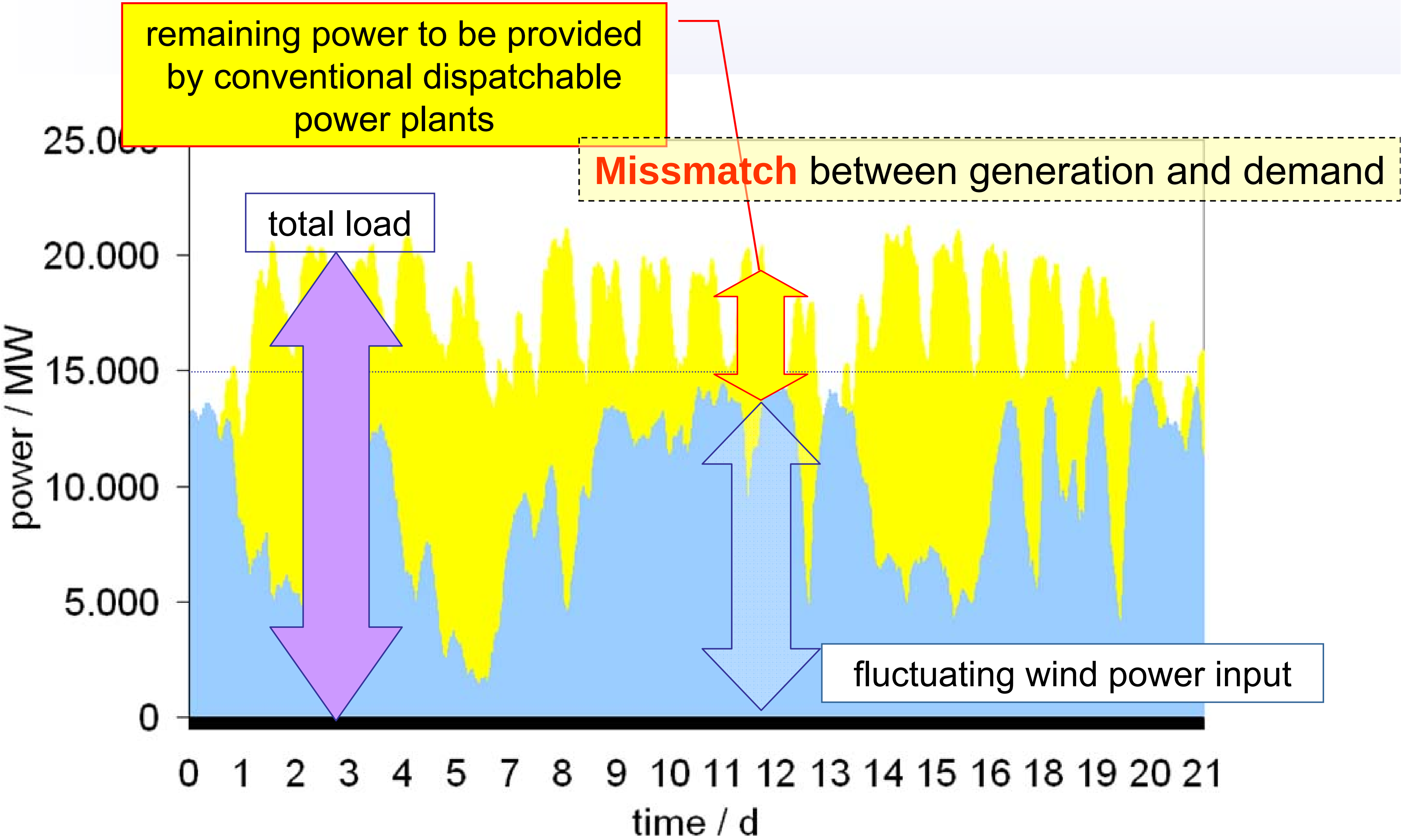


Grid load



grid load to be provided by conventional dispatchable power stations
25.000 MW
20.000
15.000
10.000
5.000
0
power / MW
medium & peak load
base load
0 1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 20 21
time / d

wind production plus fossil / nuclear power plants



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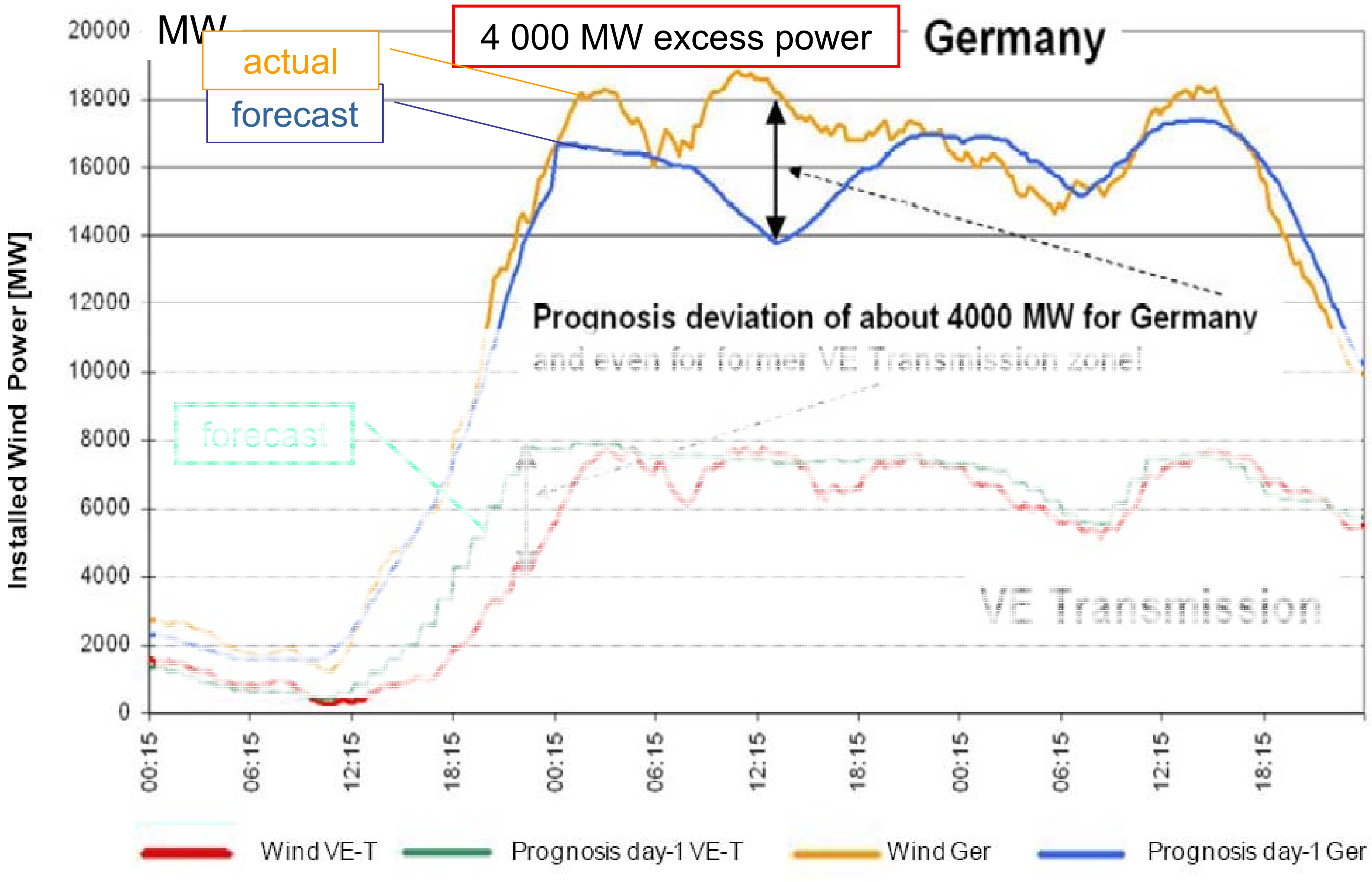
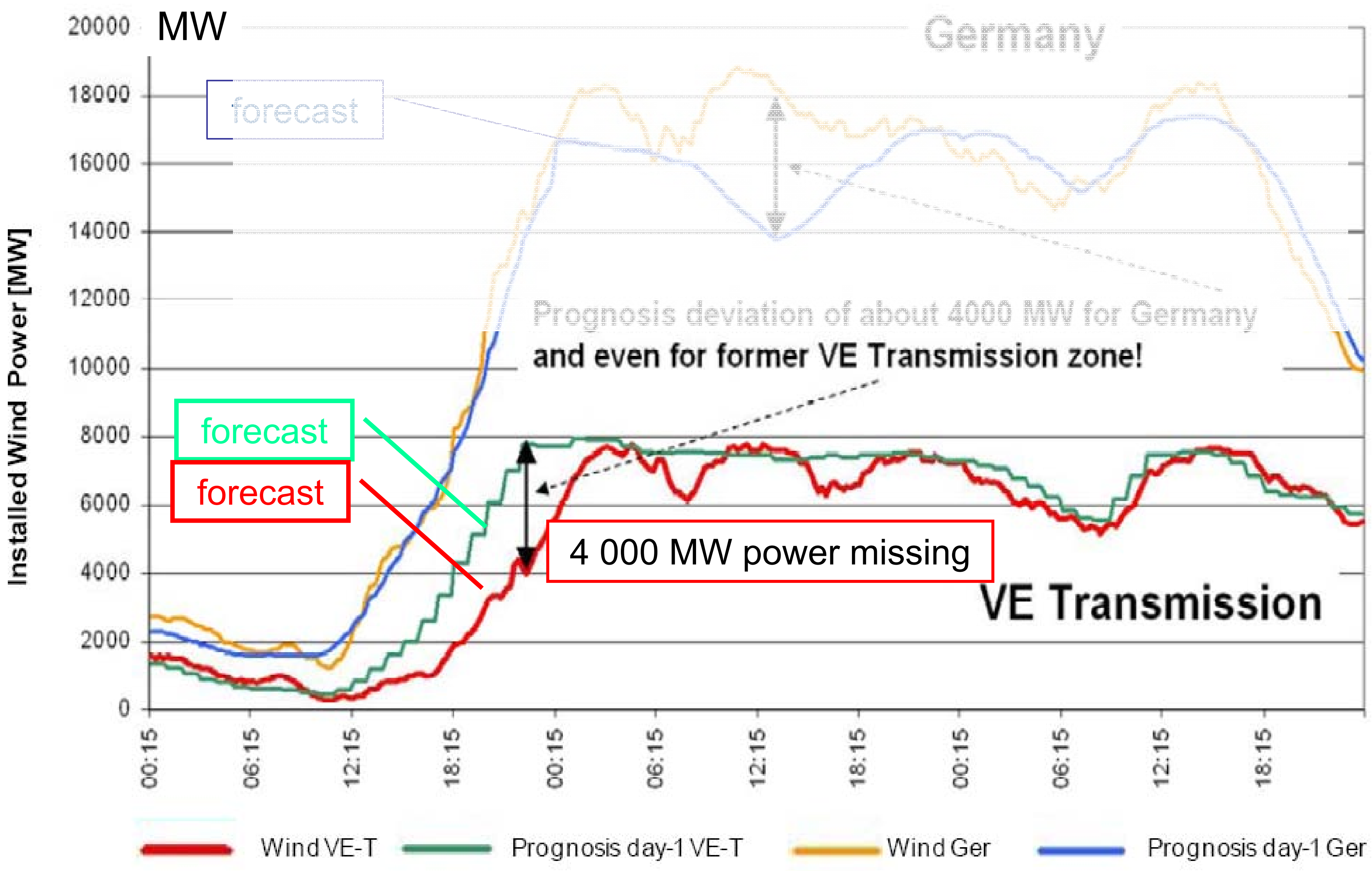
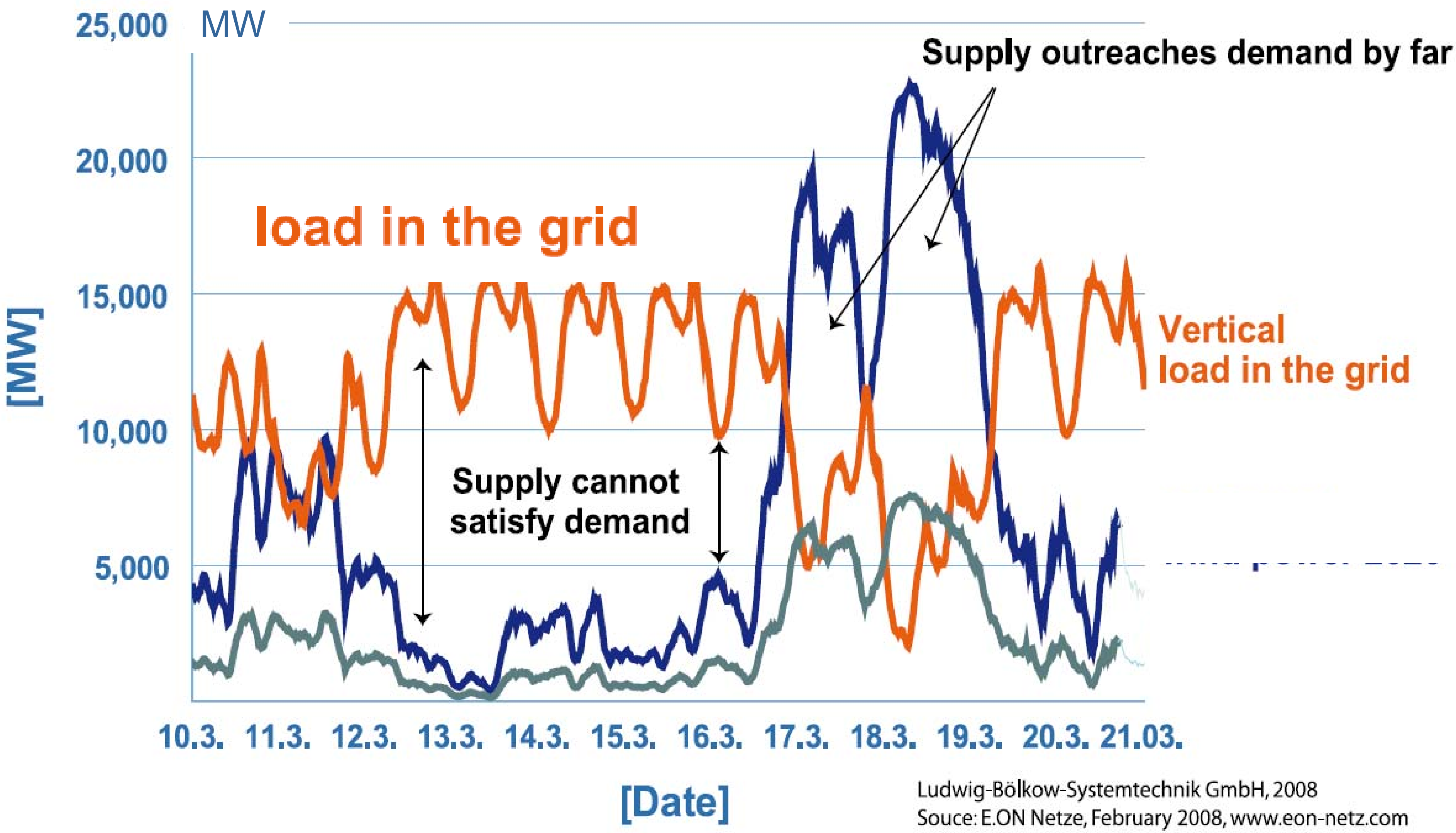
Forecast deviations during storm EMMA



Forecast deviations during storm EMMA

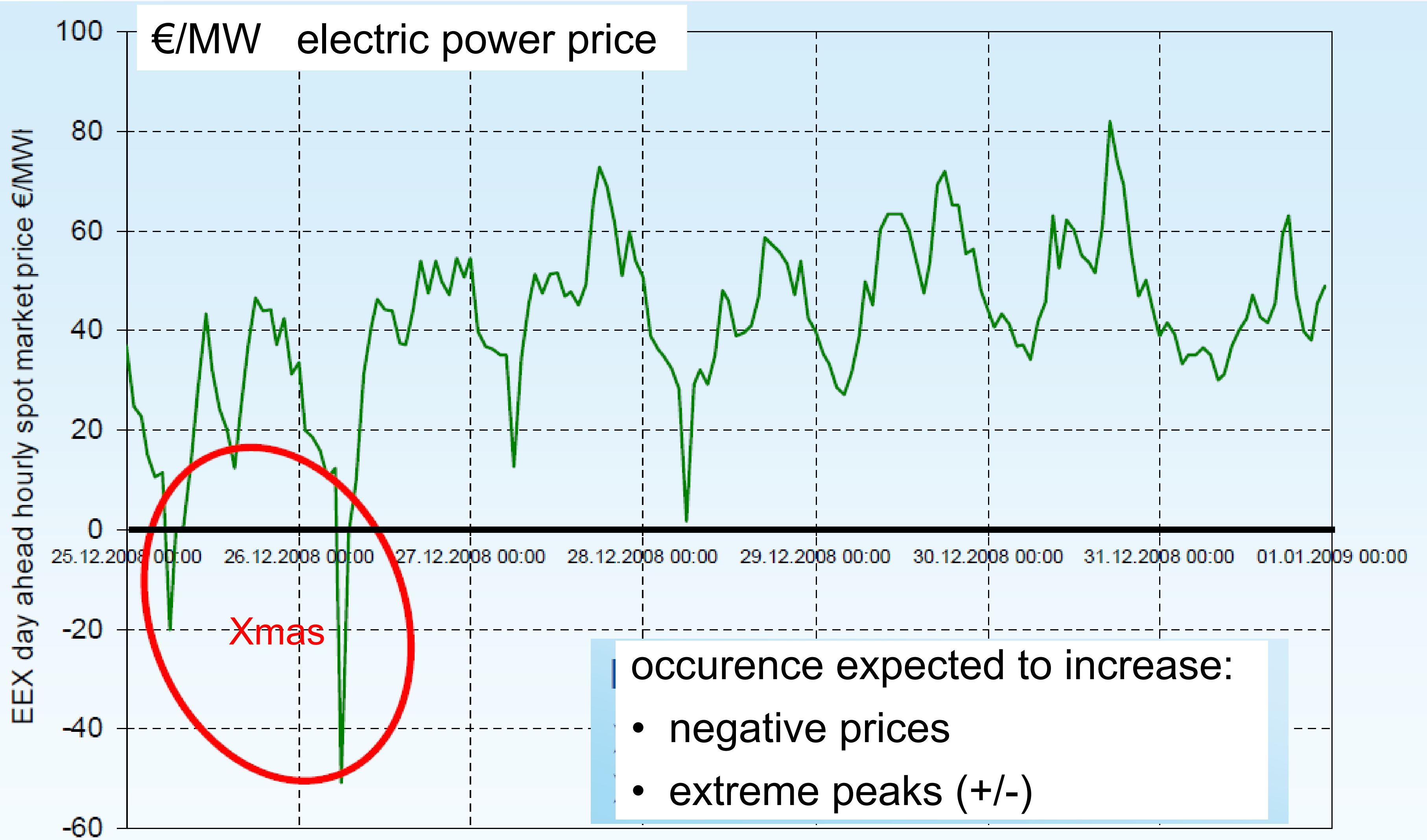


Wind power excess



Ludwig-Bölkow-Systemtechnik GmbH, 2008
Souce: E.ON Netze, February 2008, www.eon-netz.com

Spread of power prices at power exchange



Data Source: EEX

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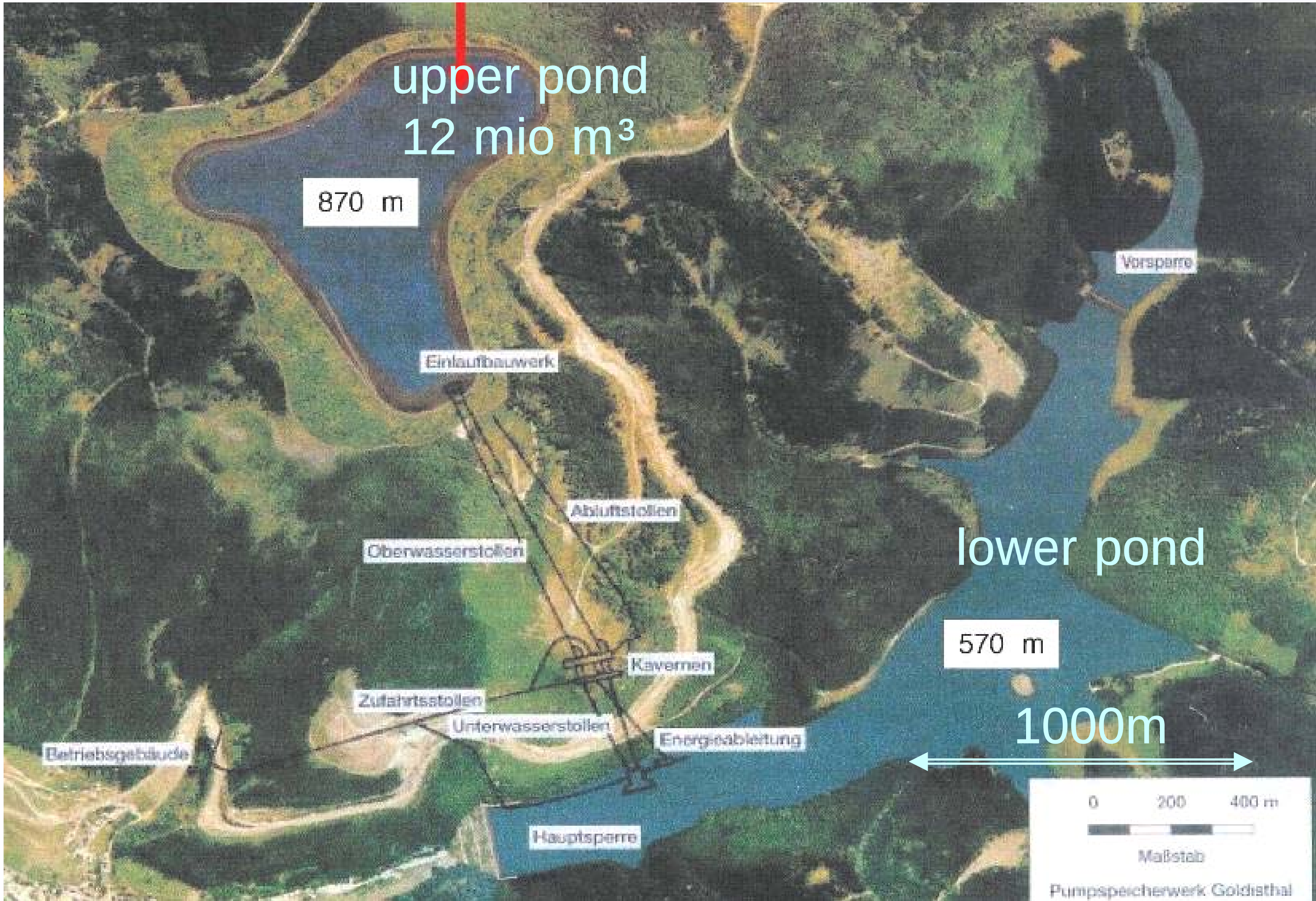
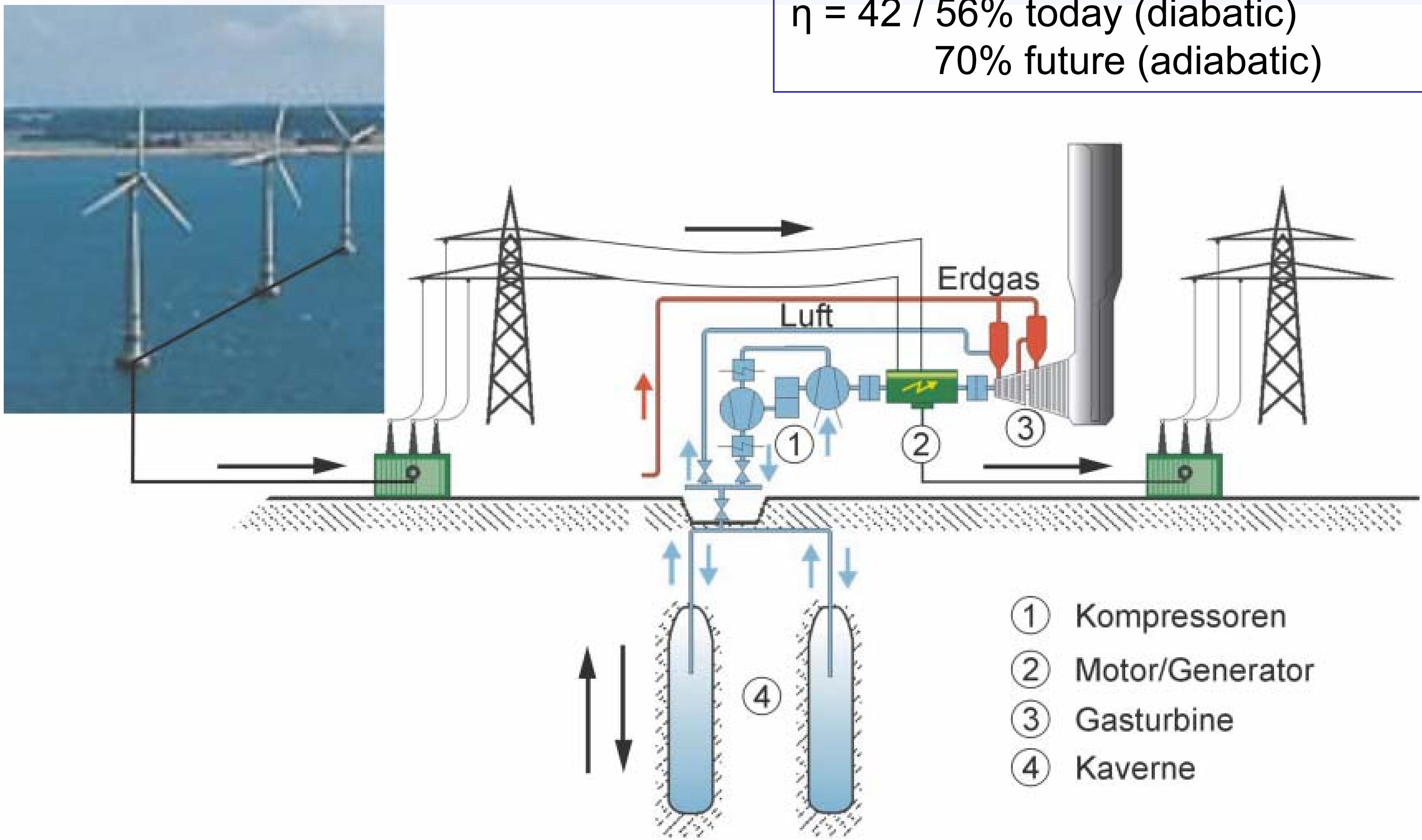
Pumped hydro plant Goldisthal

P = 1.060 MW ♦ W = 8h × 1.060 MW ♦ η> 80%



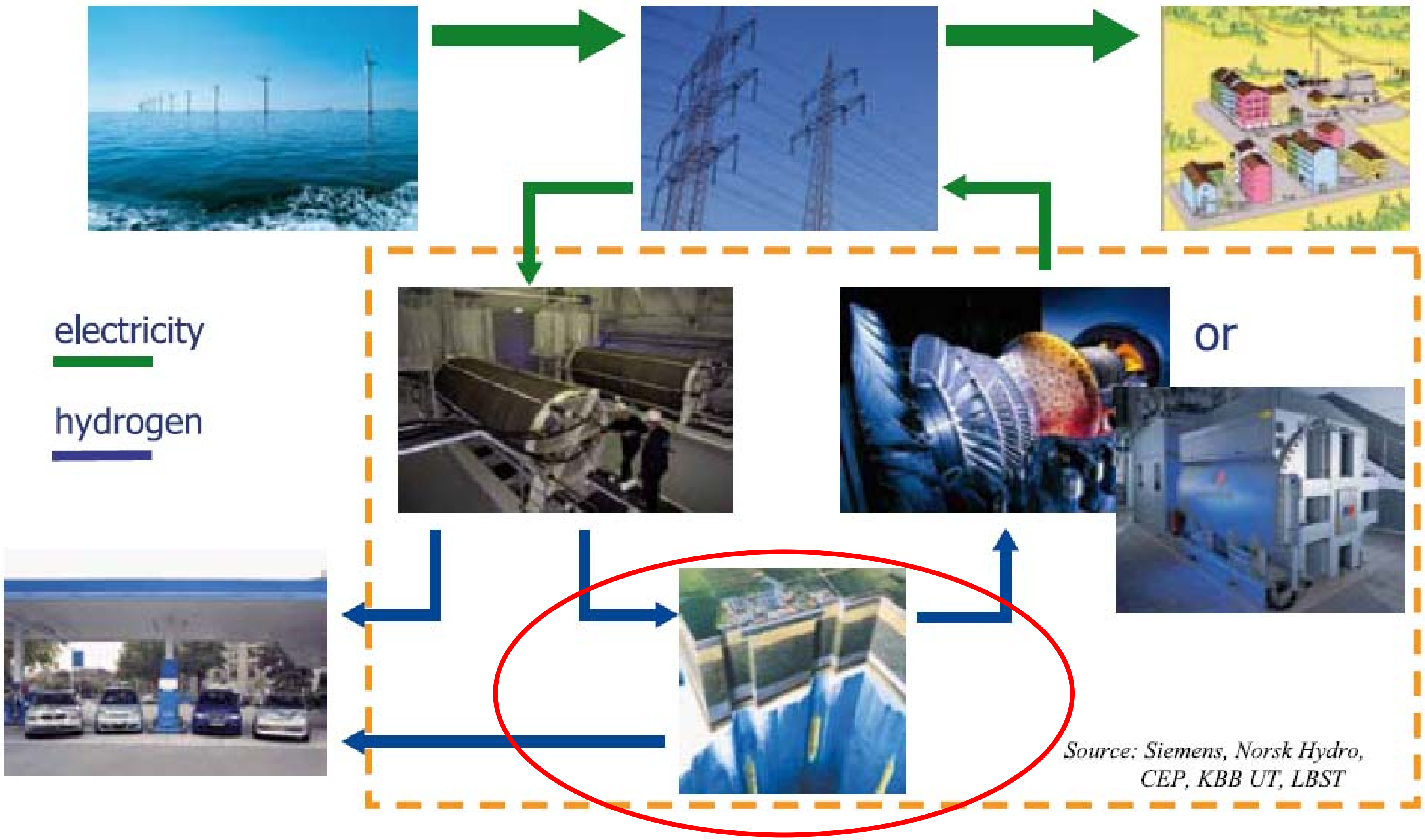
Compressed air energy storage (CAES)

η = 42 / 56% today (diabatic)
70% future (adiabatic)



Hydrogen (electrolysis - **storage** - GT)

$\eta < 40\%$



Stationary batteries

Quelle: Tokyo Electric Power Company

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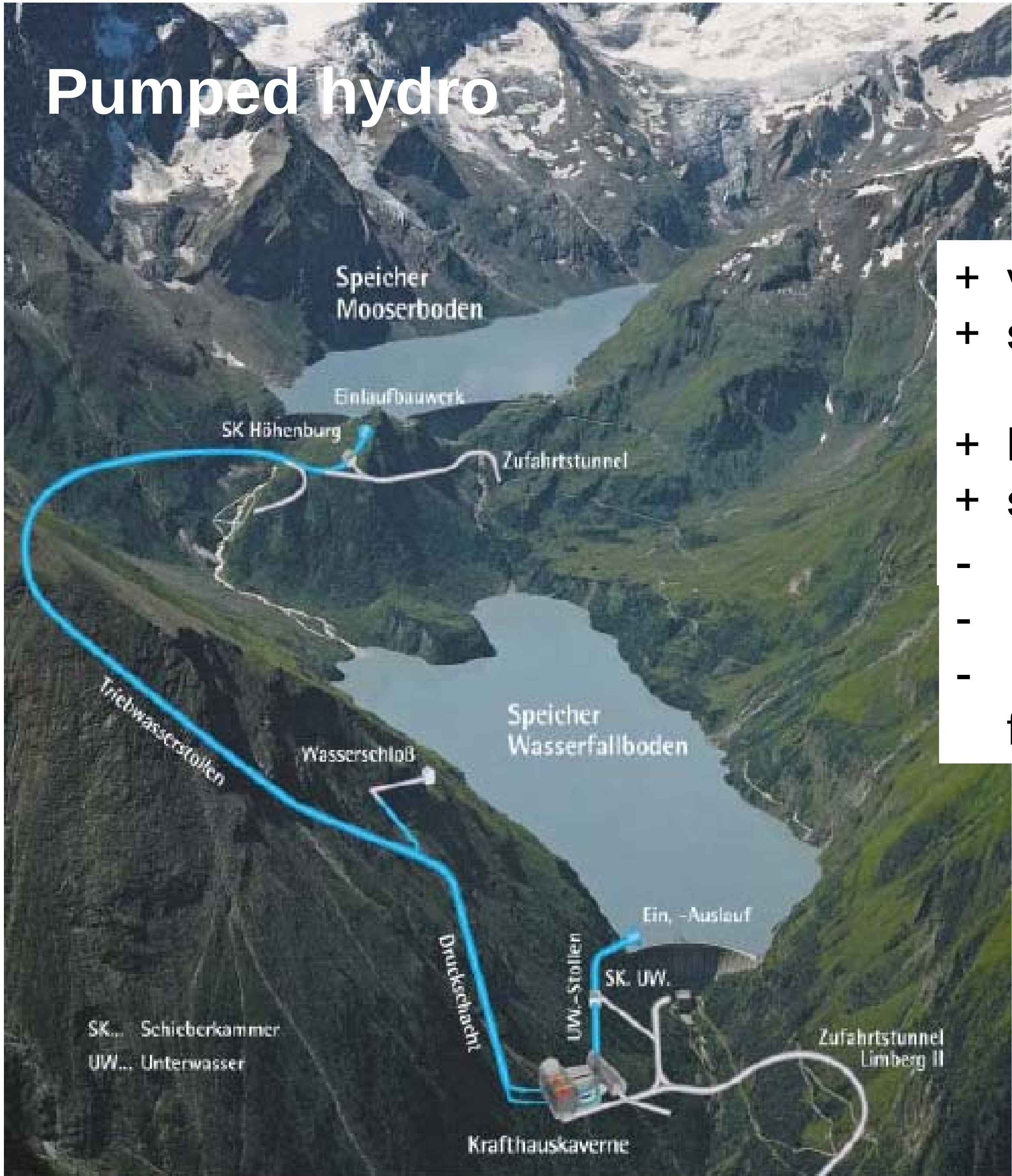
Pumped hydro



+ very flexible
+ short rampup time (< 3 min)
+ high efficiency (<80%)
+ standard practice

- low volum. energy density
- large footprint
- limited potential for new plants

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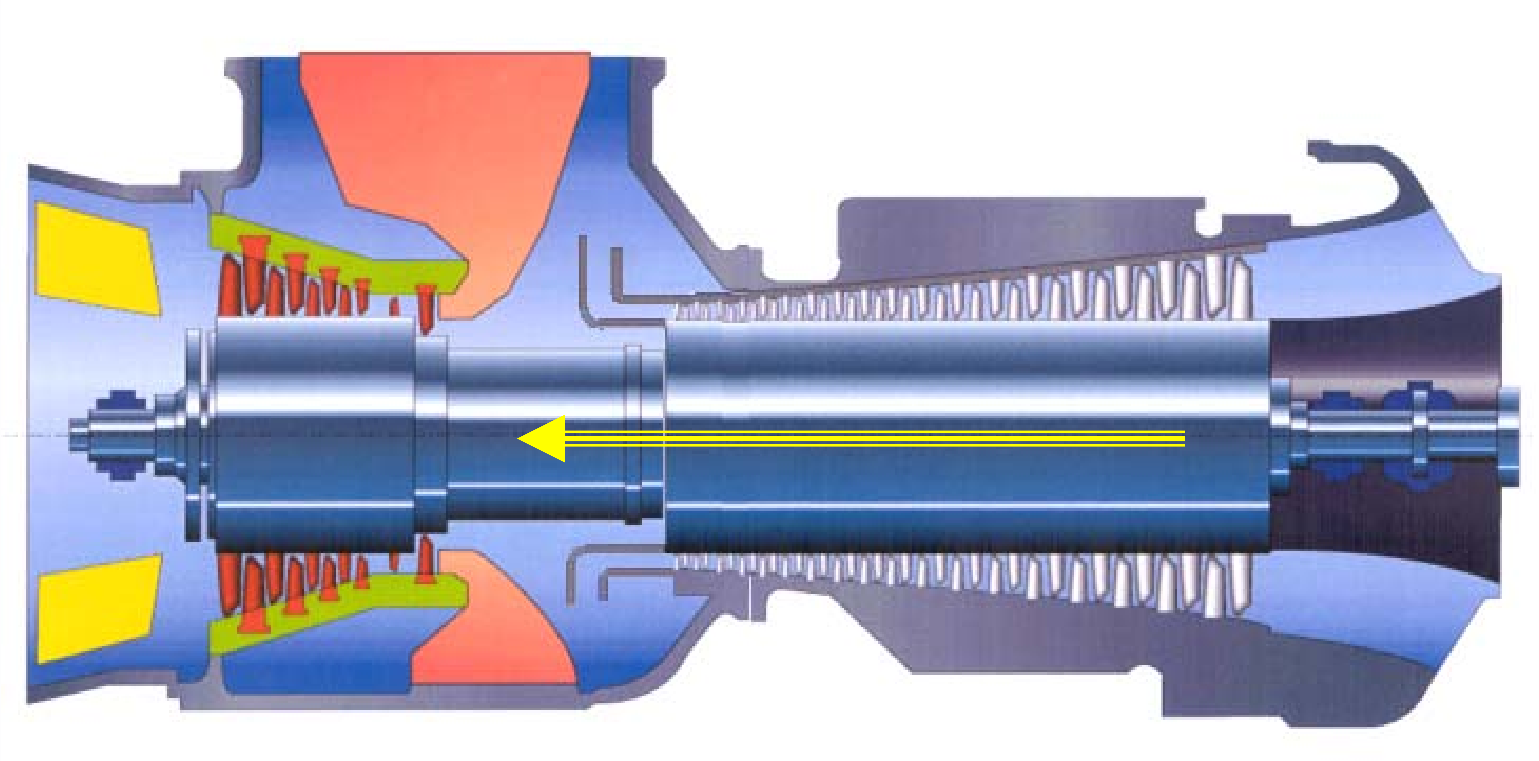
4. Future applications for
   pumped hydro, CAES & GH2

Conventional gas turbine



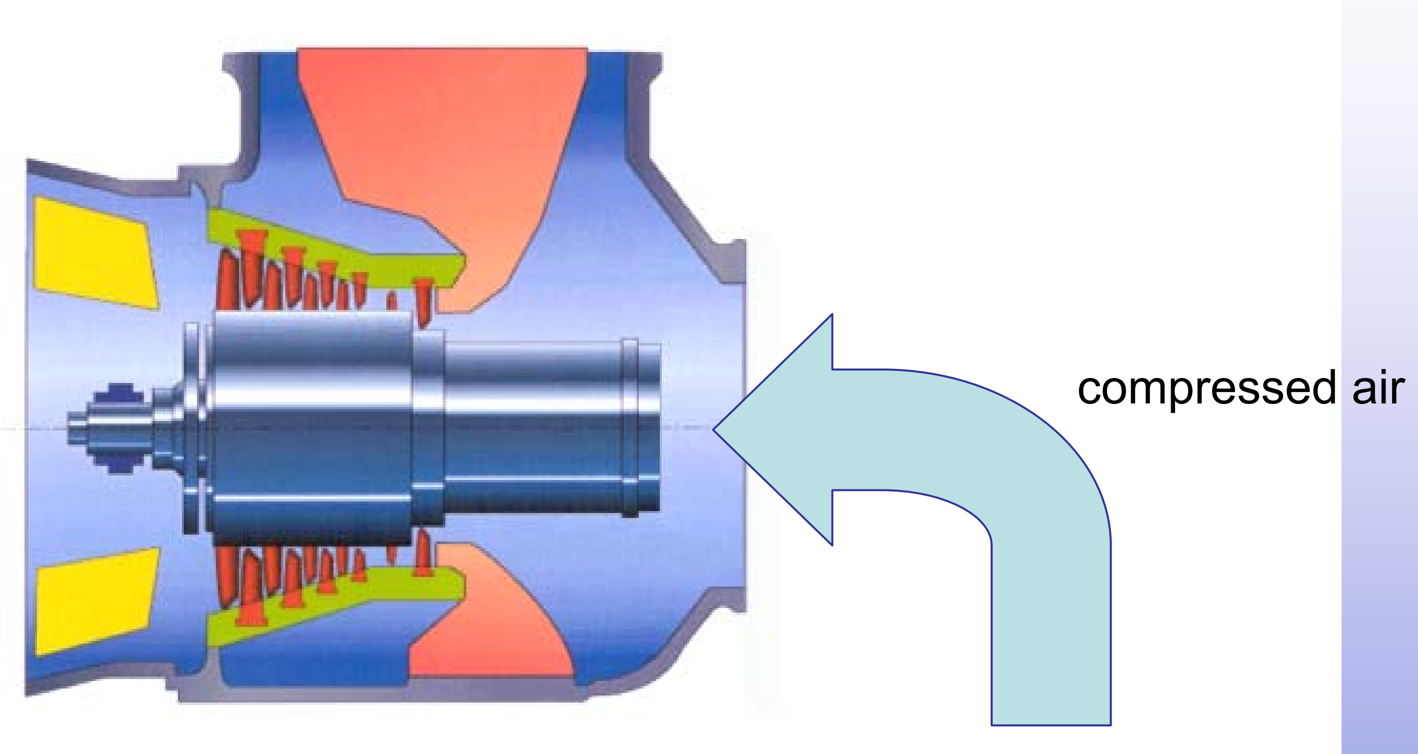
turbine + 300 MW - 200 MW **compressor**

$$\underbrace{\hspace{10cm}}$$

gasturbine

► total: 100 MW

gasturbine without compressor

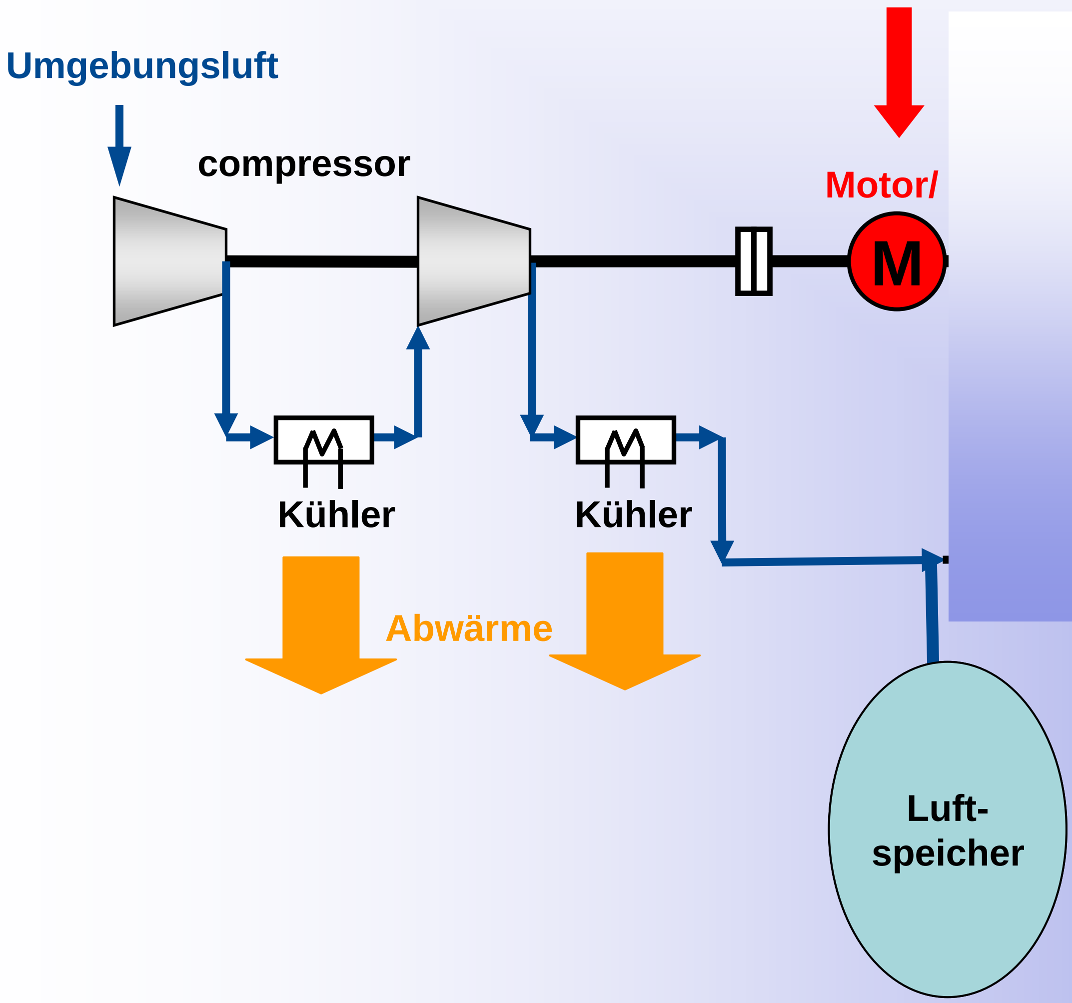


+ 300 MW

► total: 300 MW

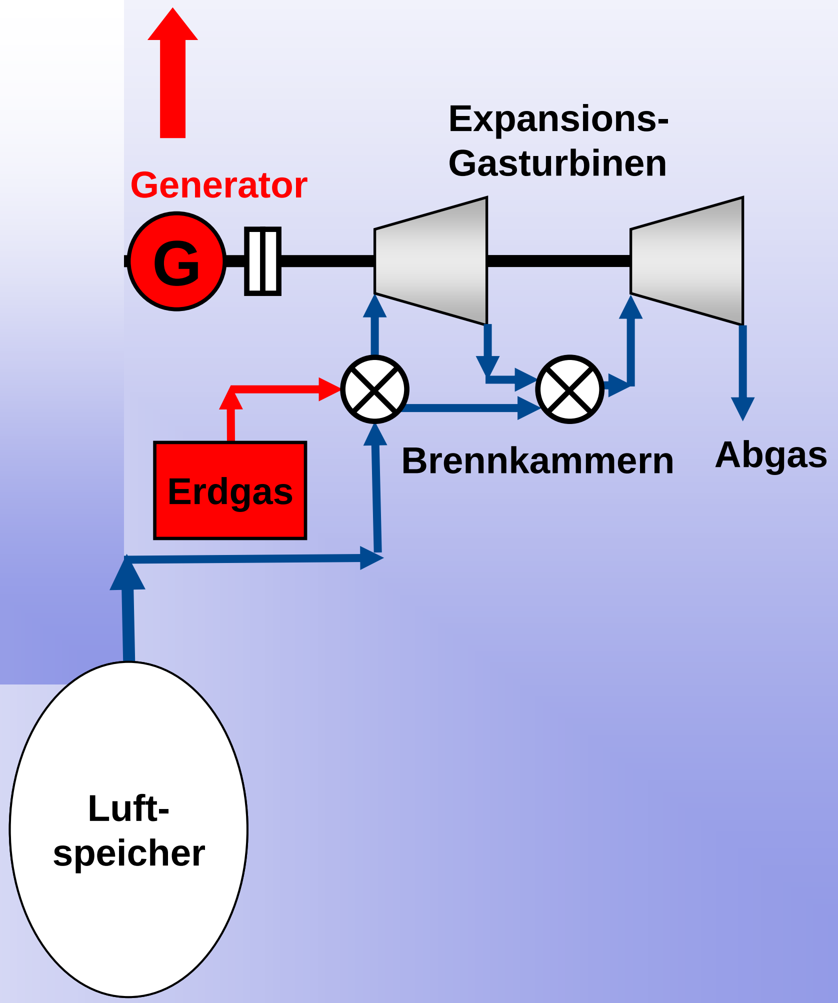
CAES GT-Kraftwerk (Beispiel Huntorf)

Speicherung

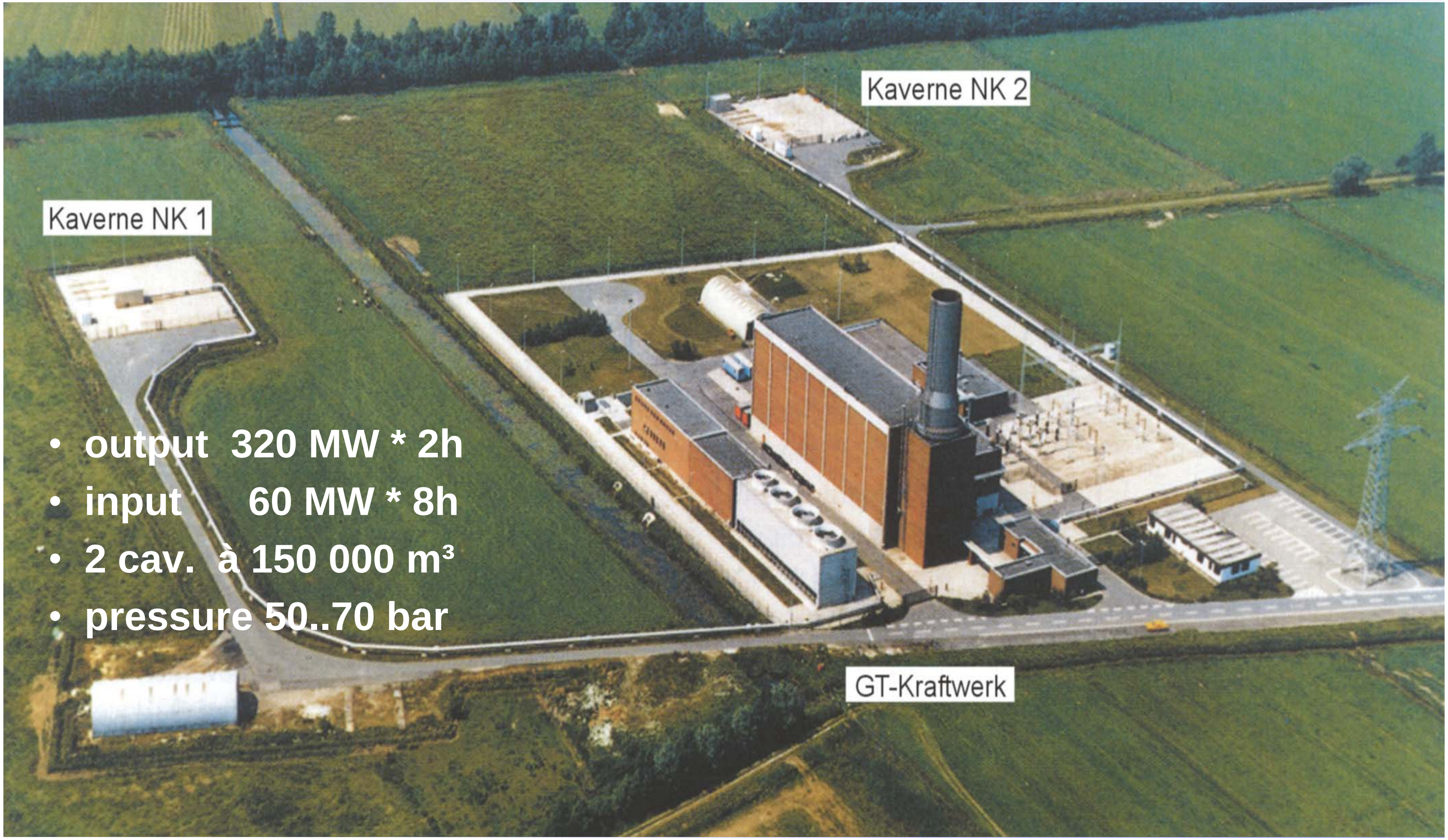


CAES GT-Kraftwerk (Huntorf)

Produktion

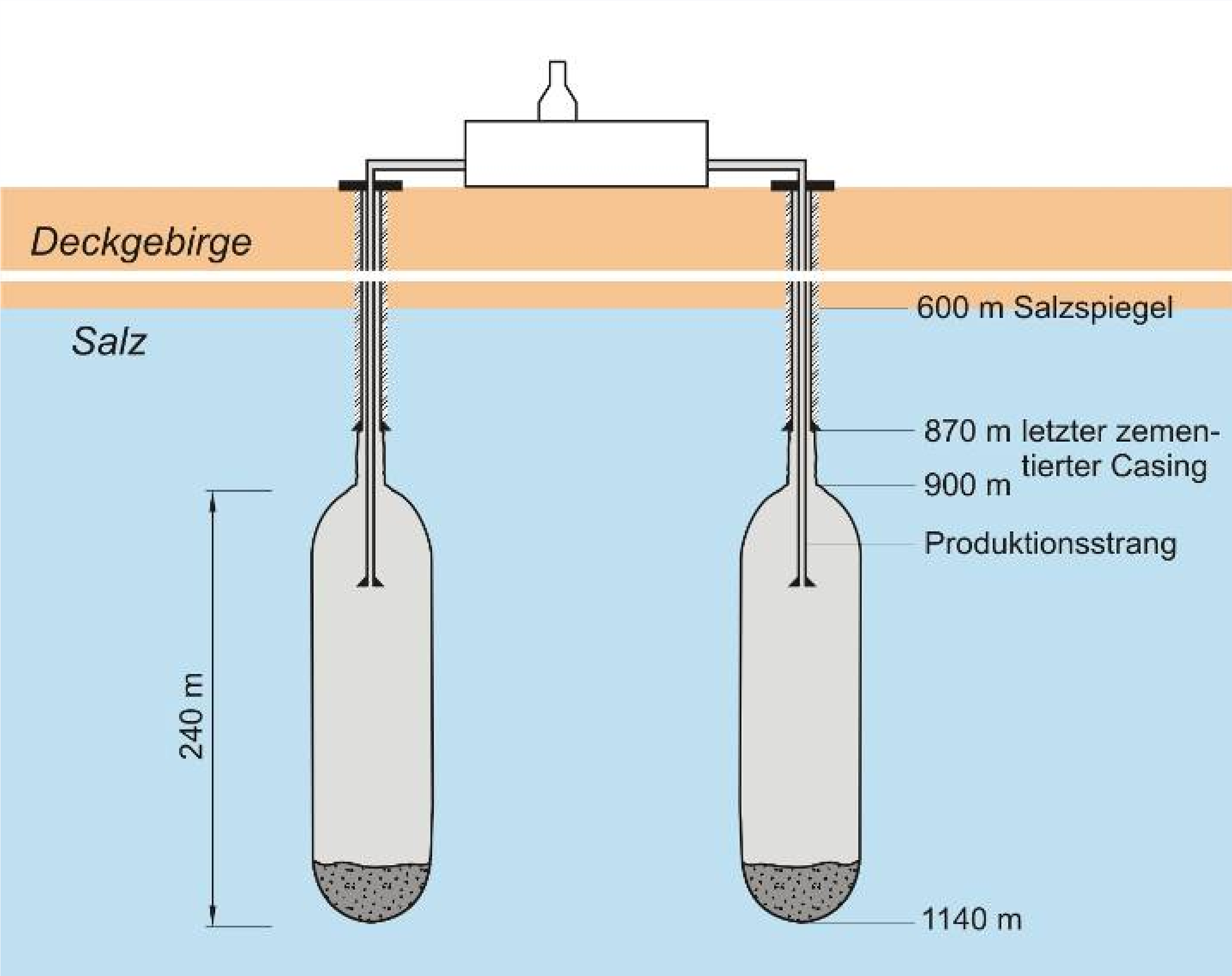


EON 320 MW CAES-power plant Huntorf

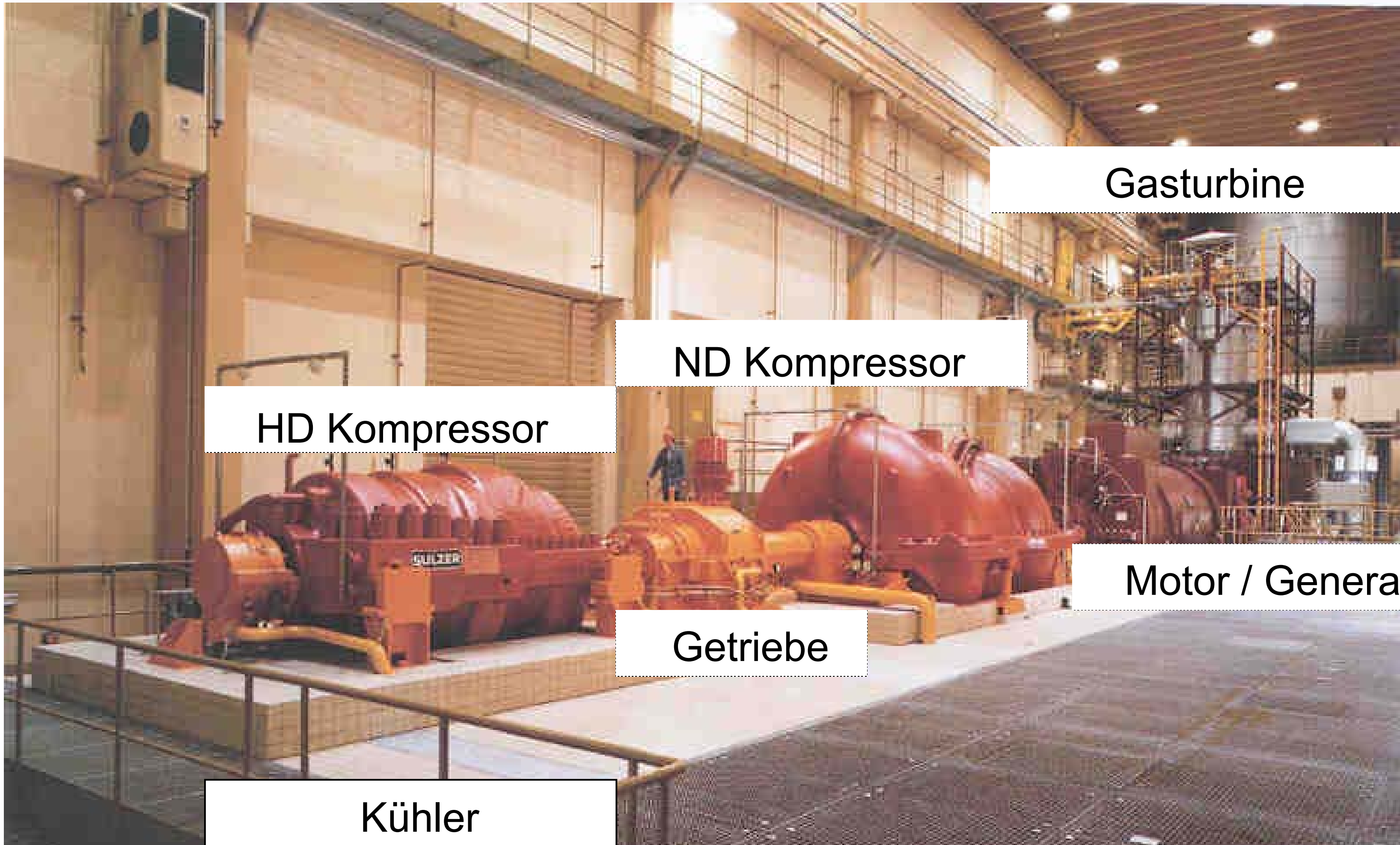


- output 320 MW * 2h
- input   60 MW * 8h
- 2 cav. à 150 000 m³
- pressure 50..70 bar

2 caverns CAES plant at Huntorf



Inner view of Huntorf plant (E.ON KW)



Gasturbine

ND Kompressor

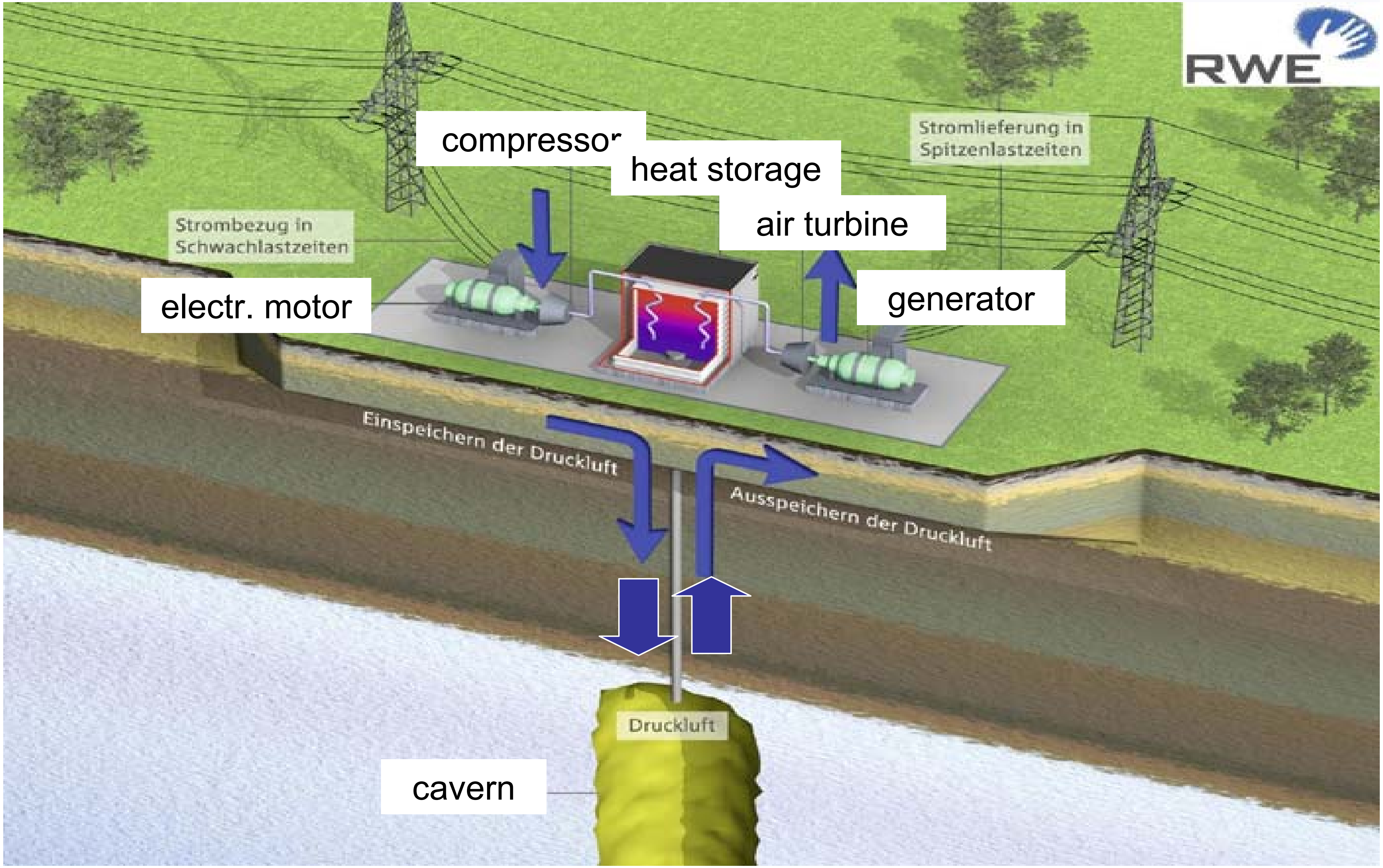
HD Kompressor

Motor / Generator

Getriebe

Kühler
(nicht sichtbar)

Joint GE and RWE Adiabatic CAES project



Pros and cons of CAES power plants

Conventional diabatic CAES GT power plant

+ flexible
+ short ramp up time (< 15 min)
+ standard practice
+ potential for new plants
+ very small footprint

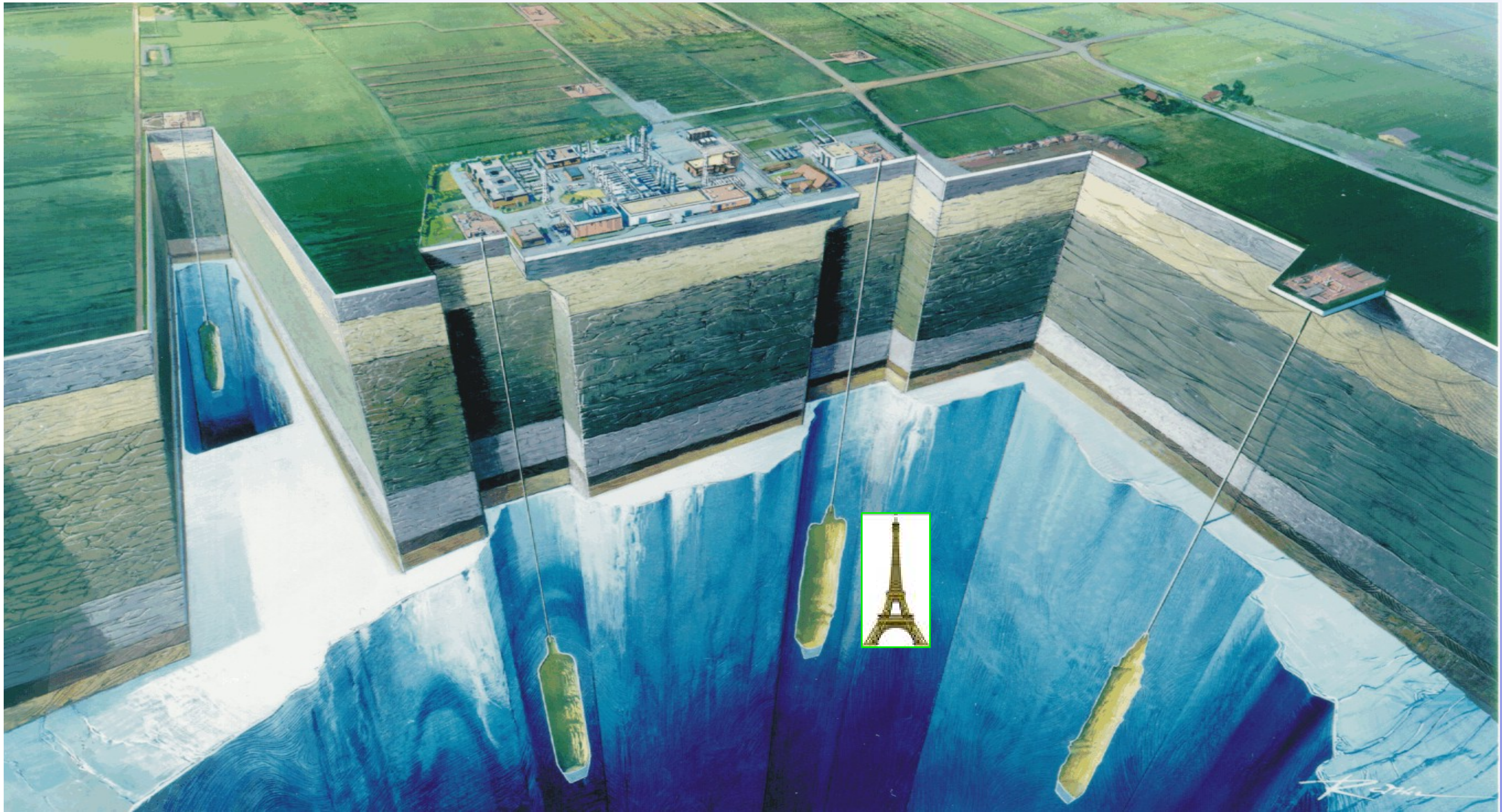
- fair efficiency (42..56%)
- low volumetric energy density
- need for suitable geological formations

Advanced adiabatic CAES power plant

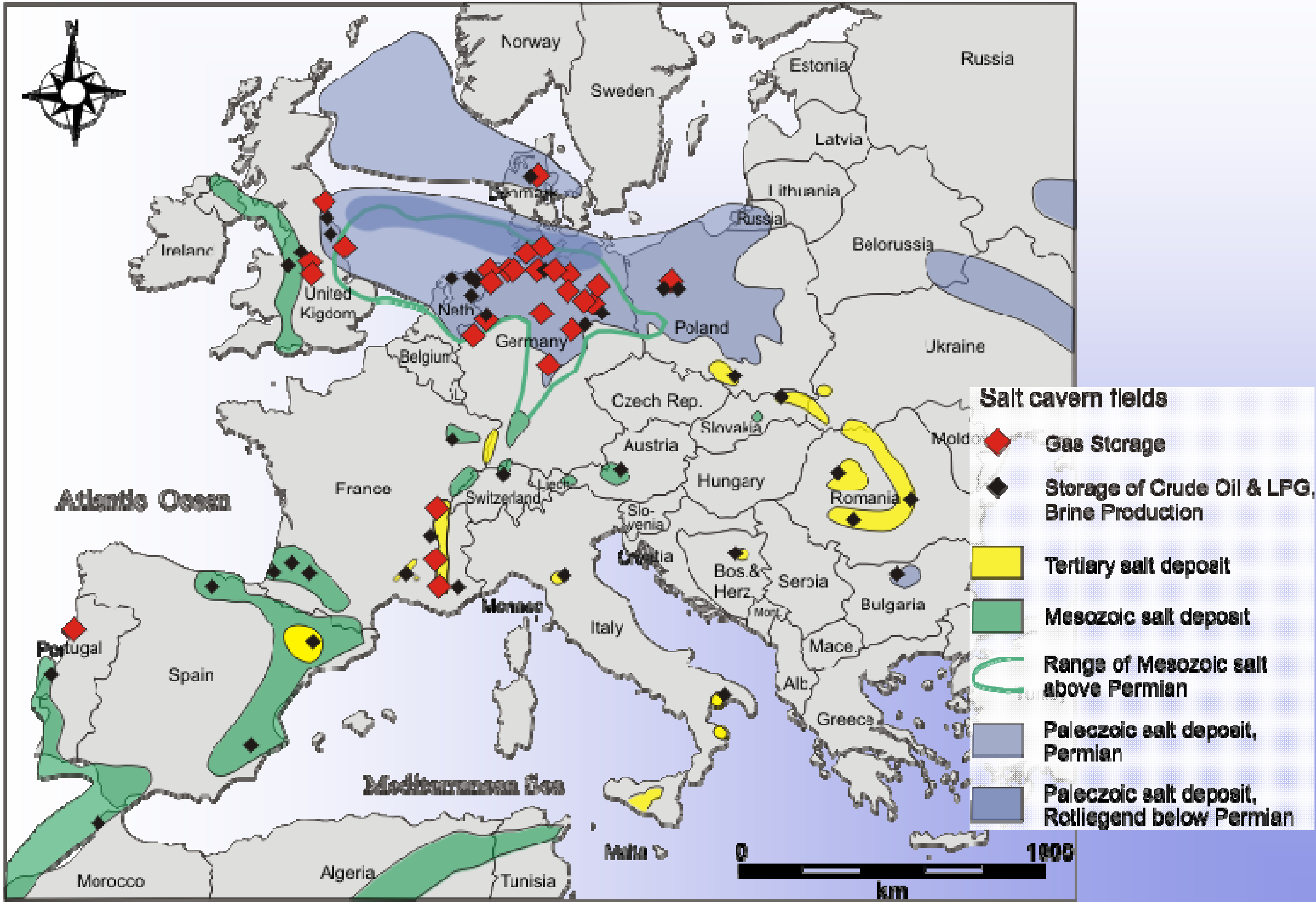
+ high efficiency (<70%)
+ no need for fossil fuel

- challenging R&D task

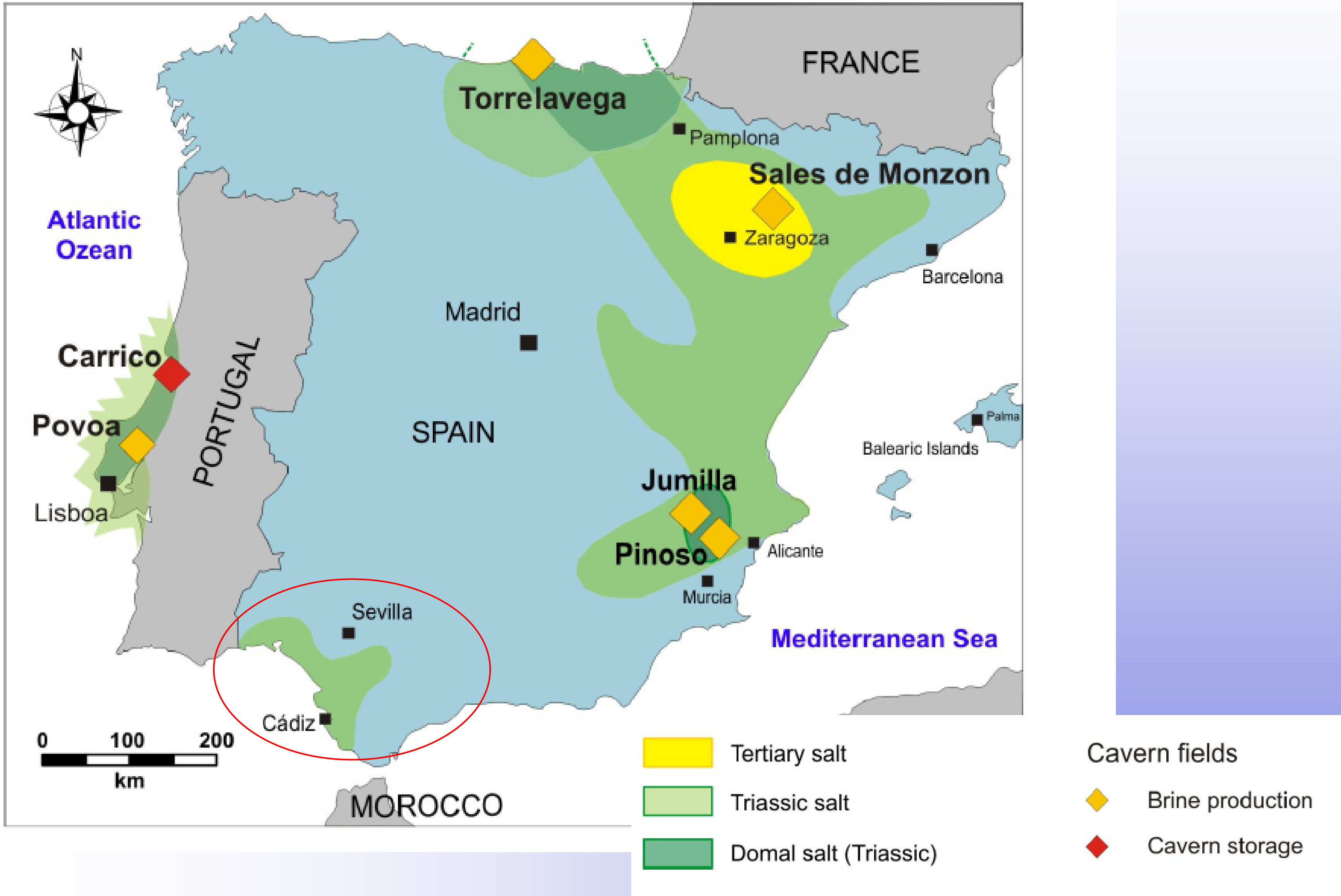
Gas storage in man made salt caverns



Salt deposits and cavern fields in Europe



Salt formations and caverns in Spain



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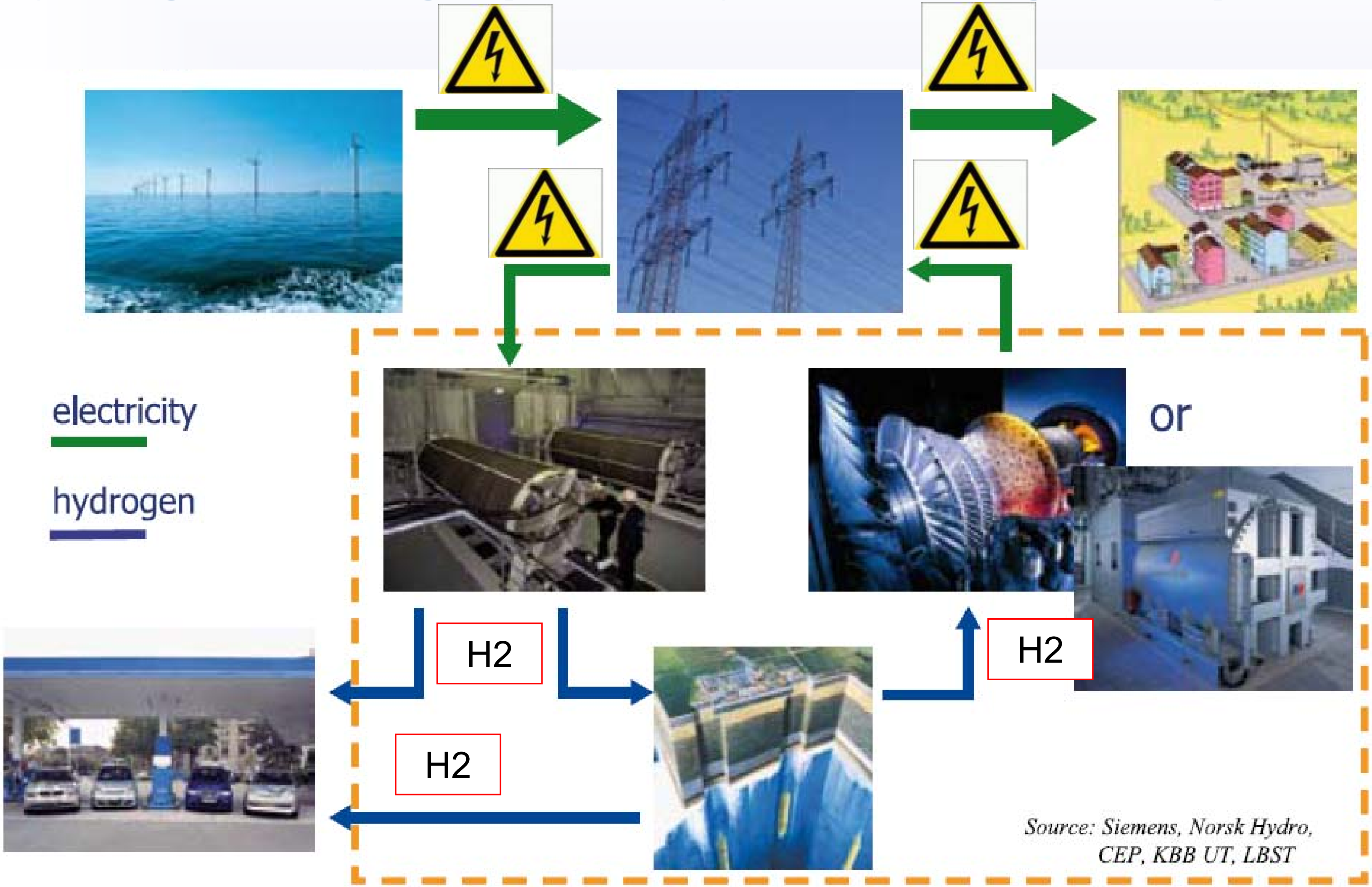
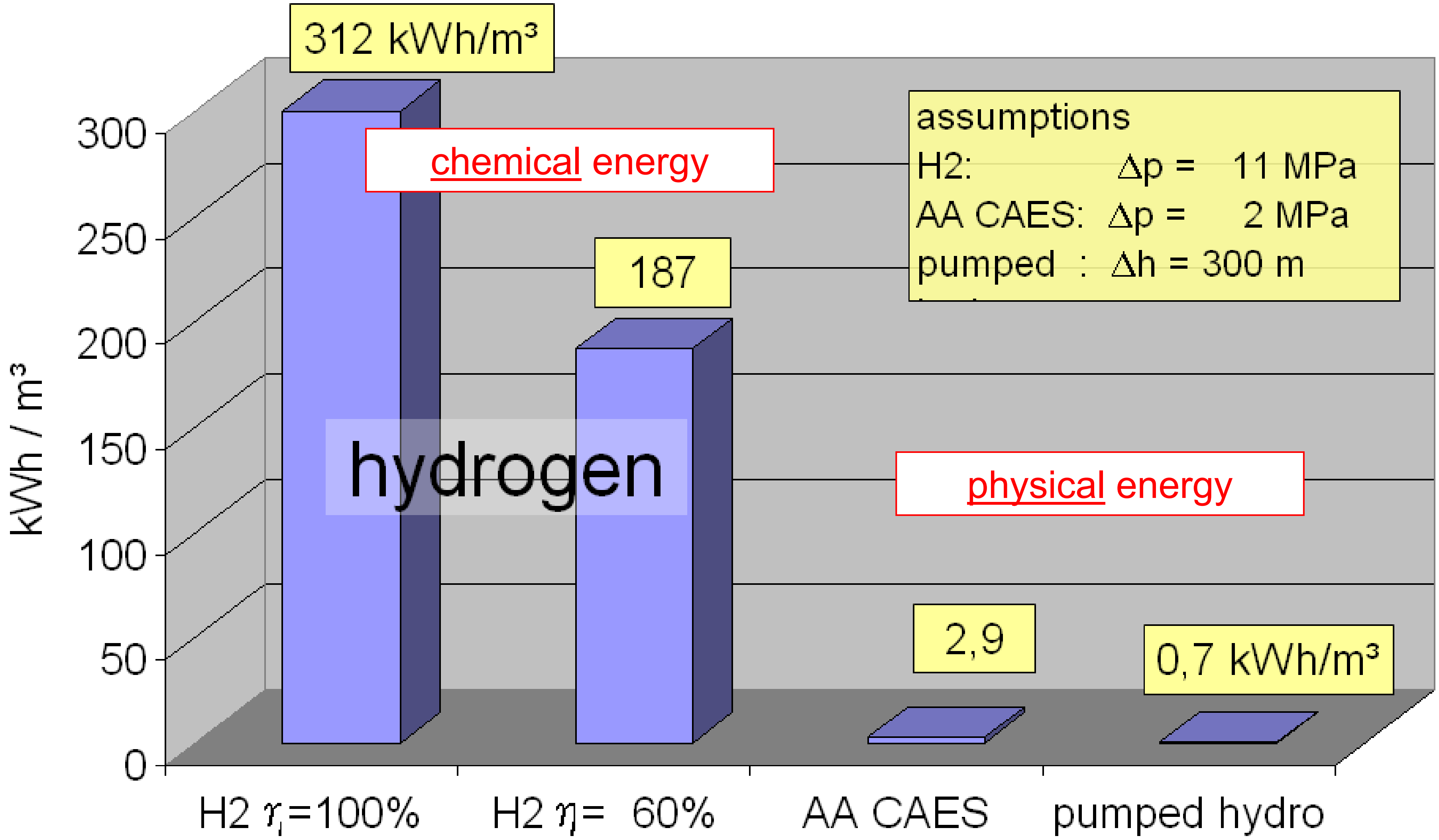
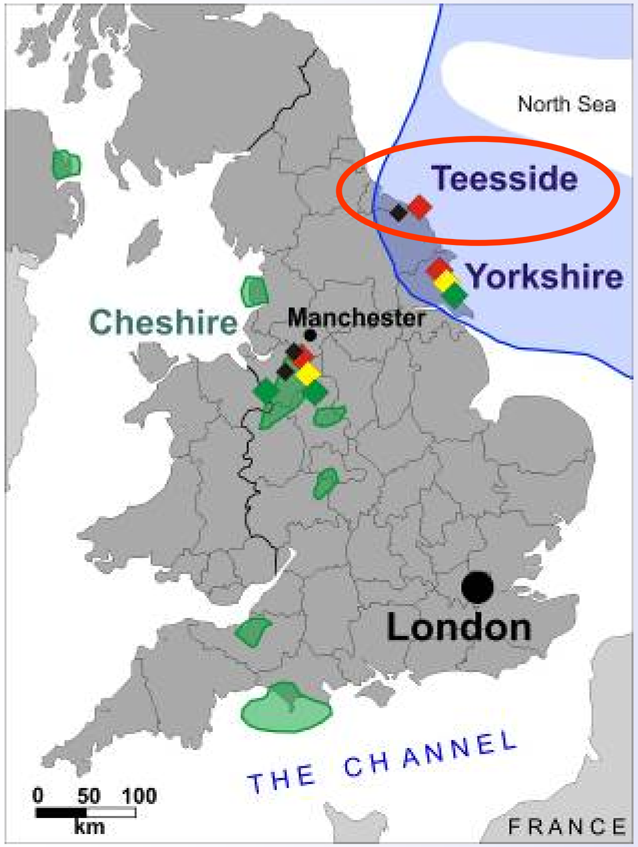
Hydrogen storage (electrolysis - storage - GT)



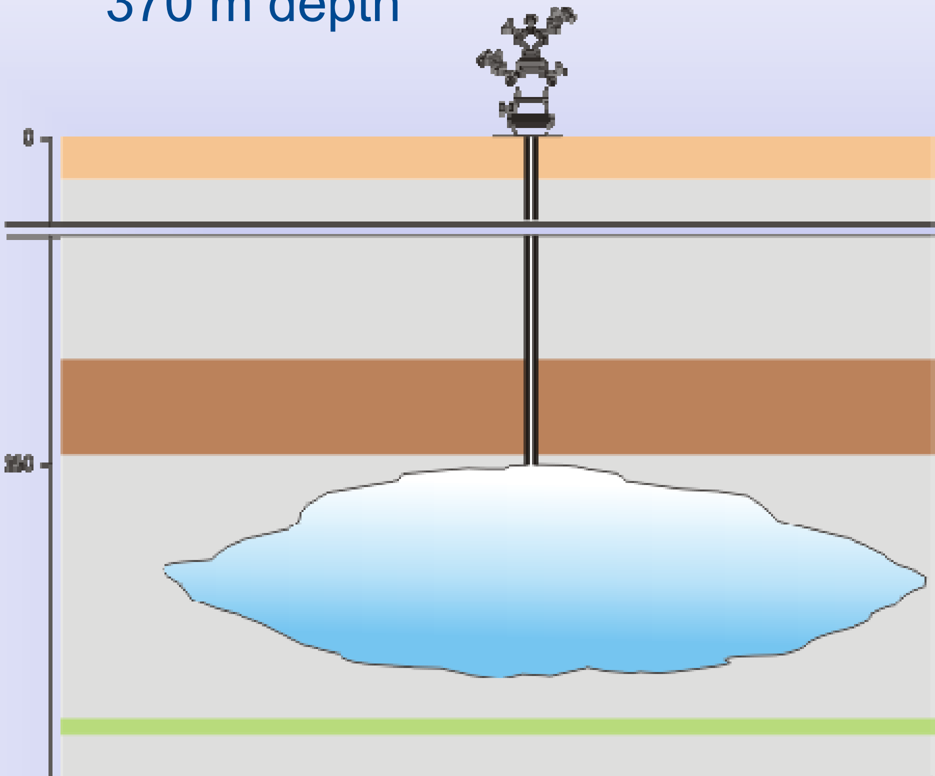
Volumetric energy densities



H2 caverns
Sabic Petrochemicals, Teesside, UK

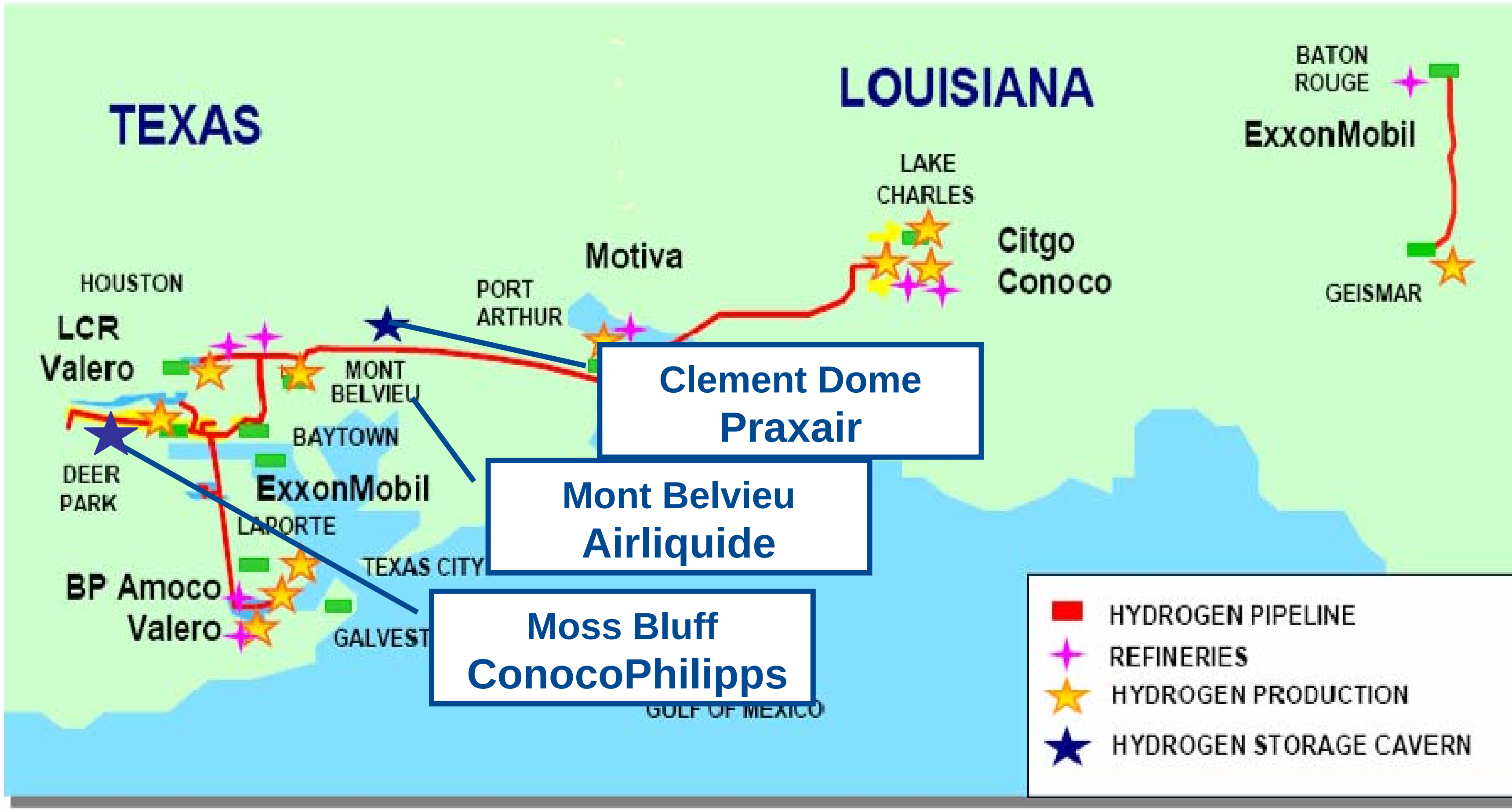


3 caverns
70 000 m³ each
45 bar constant pressure
370 m depth



Cavern pad of Teesside H2 cavern

H2 pipelines und H2 caverns Texas, USA



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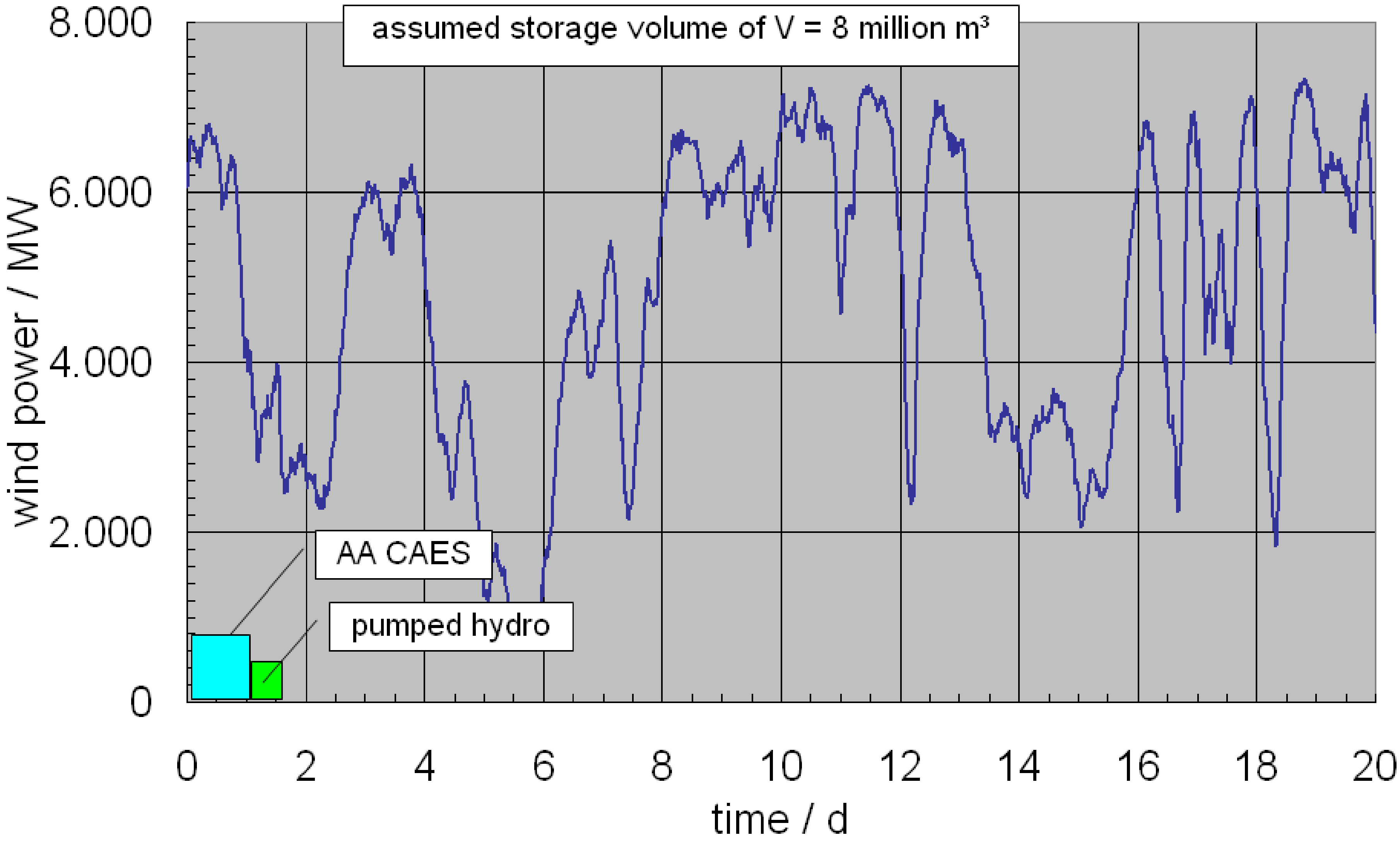
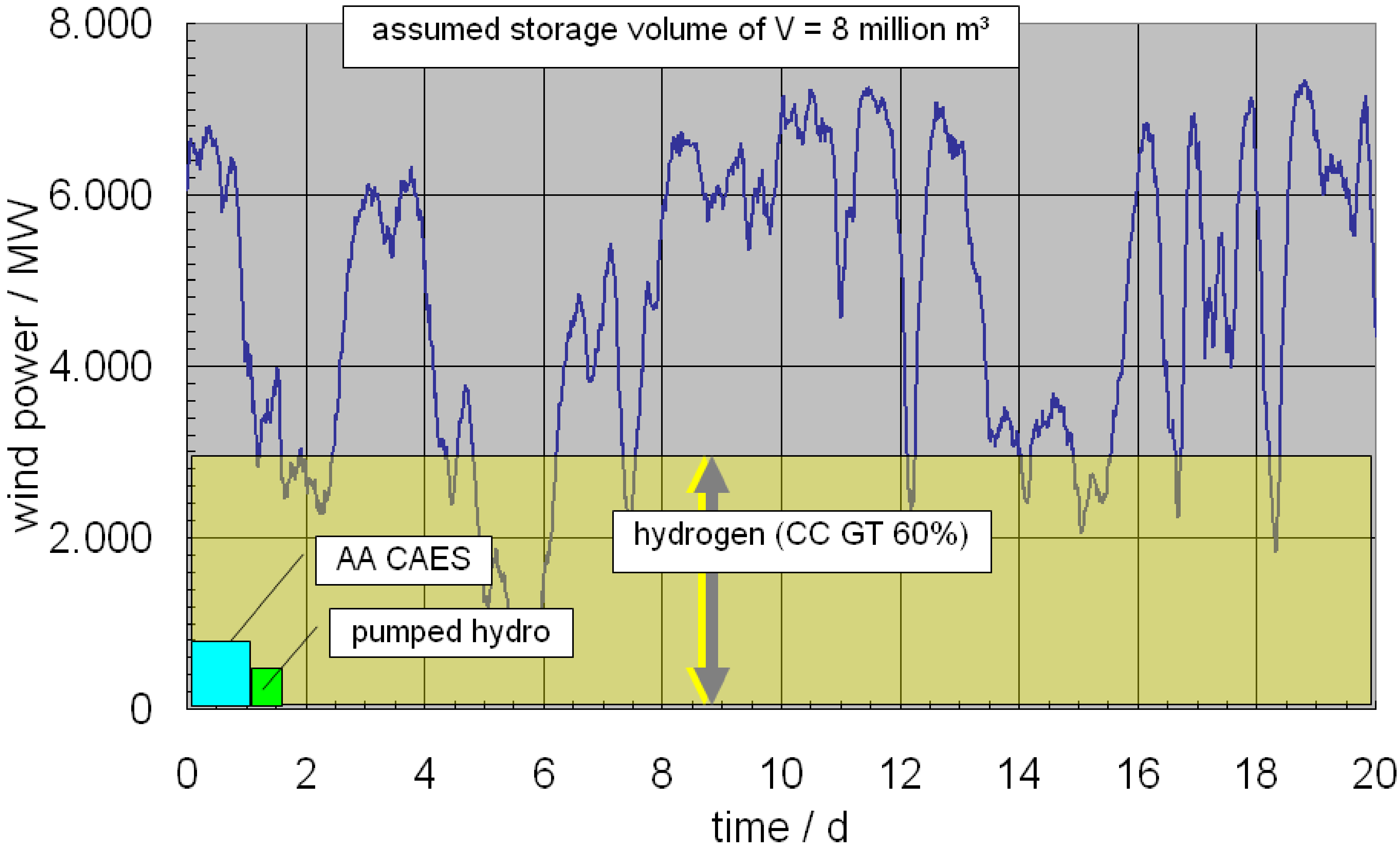
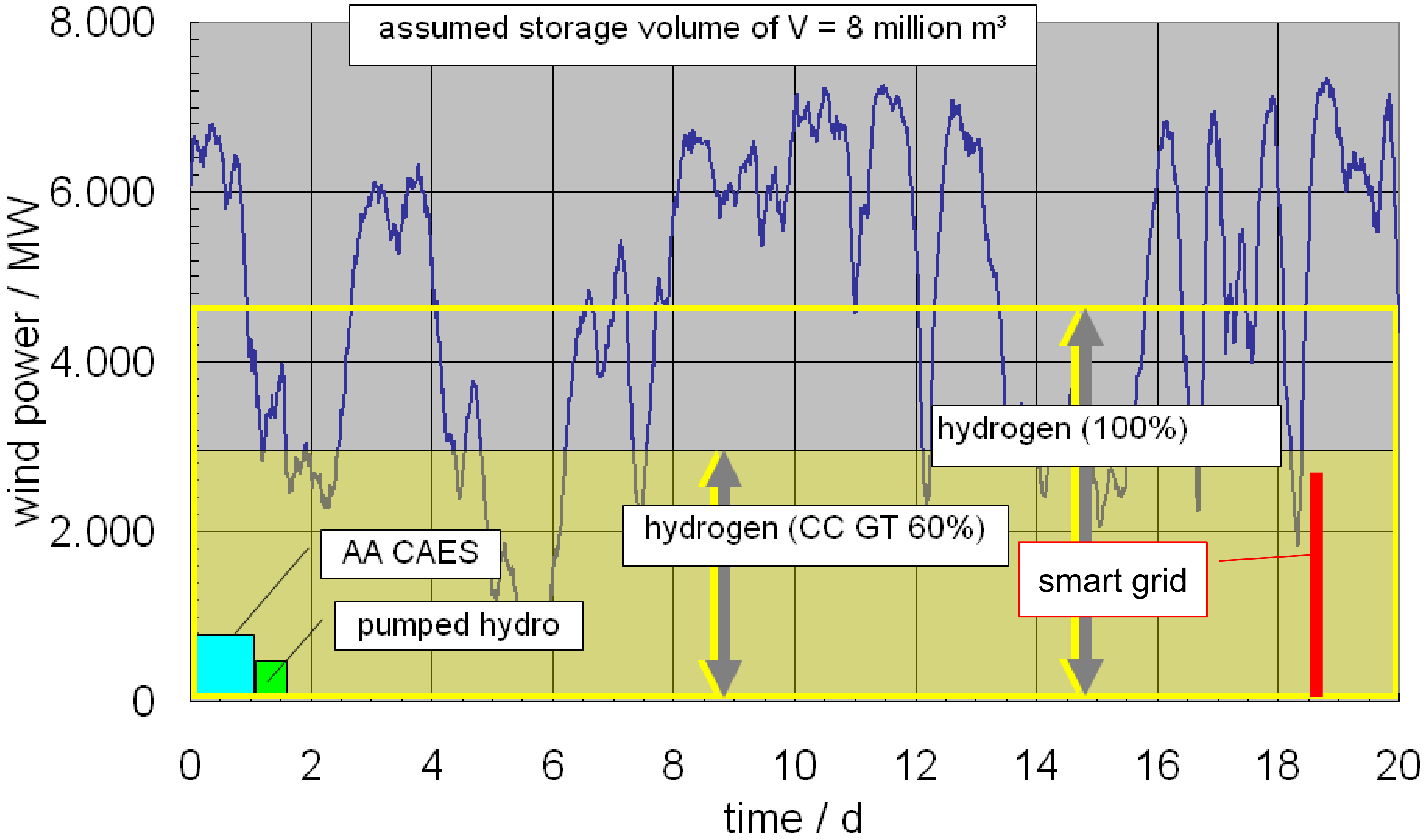
Comparison of storage capacities for 8 mio m³ geometrical volume each



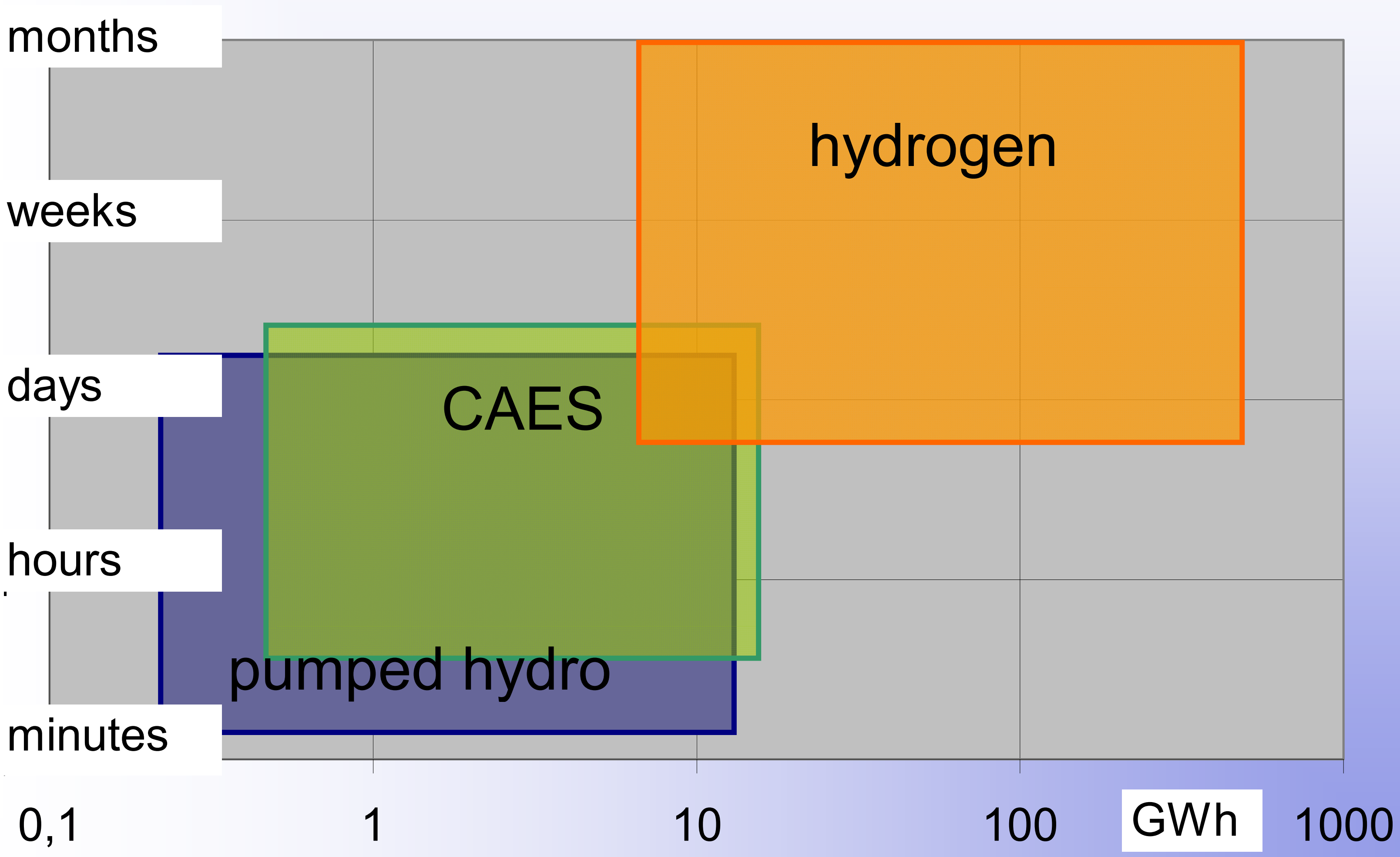
Comparison of storage capacities for 8 mio m³ geometrical volume each



Comparison of storage capacities for 8 mio m³ geometrical volume each



Ranges of application for storage options



Comparison of energy storage options

	pumped hydro	diabatic CAES	adiabatic CAES	hydrogen	
electric power consumption	1.2	0.8 / 0.7*	1.4	2.5	kWh
fuel consumption	0	1.6 / 1.2*	0	0	kWh
electricity output	1	1	1	1	kWh
efficiency	<80%	42 / 56%	70%	<40%	
ramp up time	< 3 min	< 15 min	< 15 min	?	
standard practice	yes	yes	R&D	R&D	

without / with*
heat recuperator

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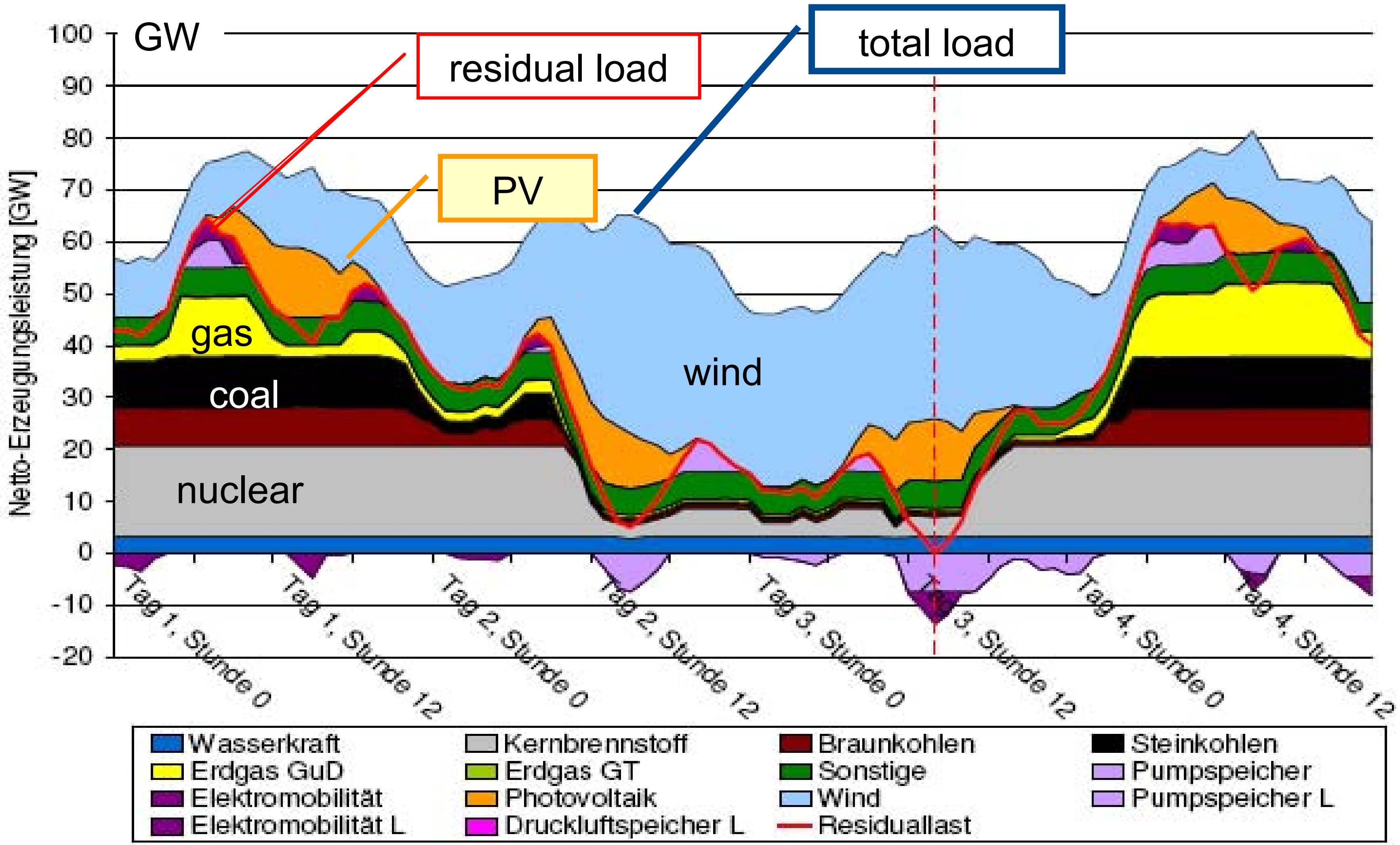
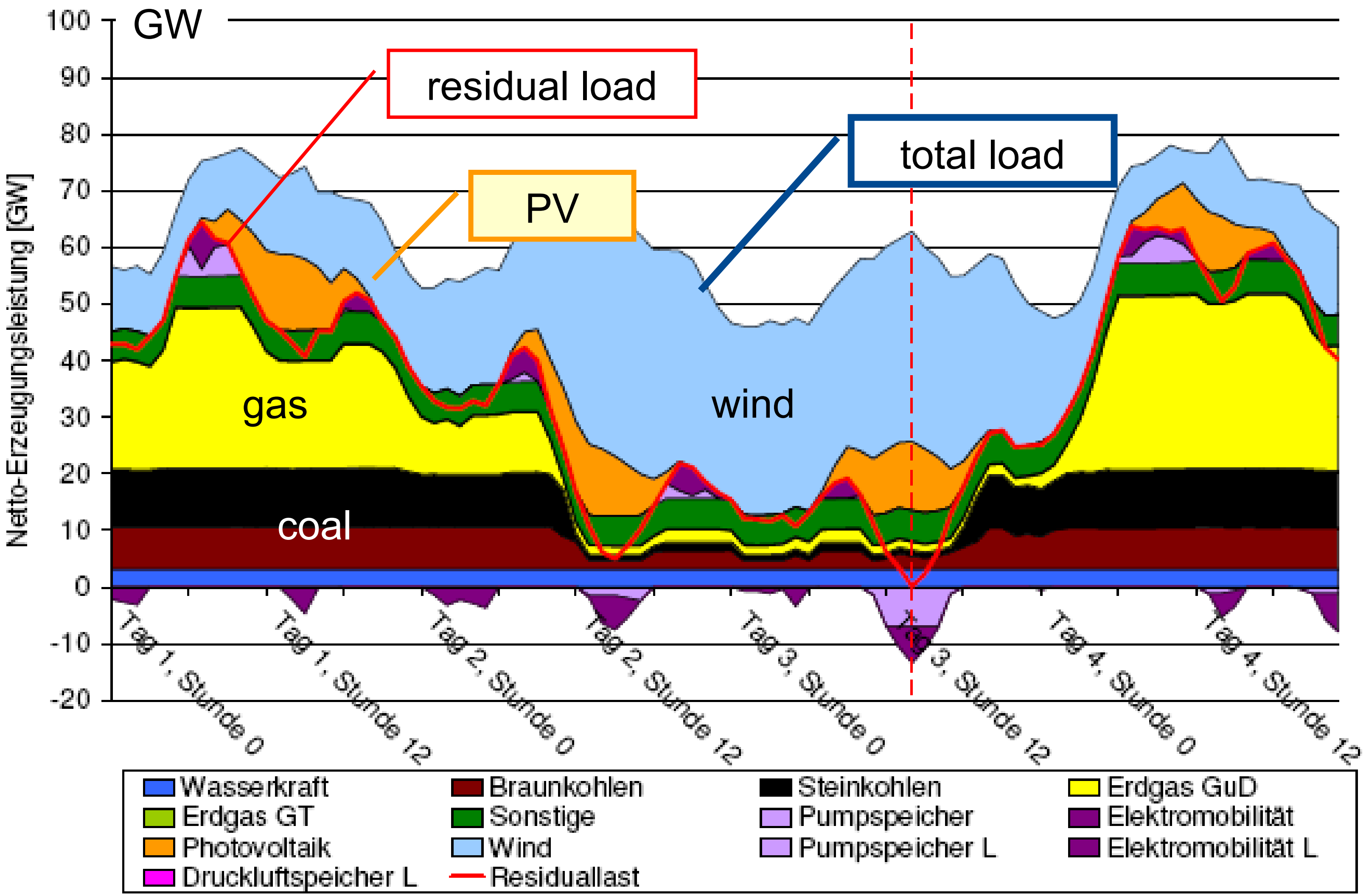
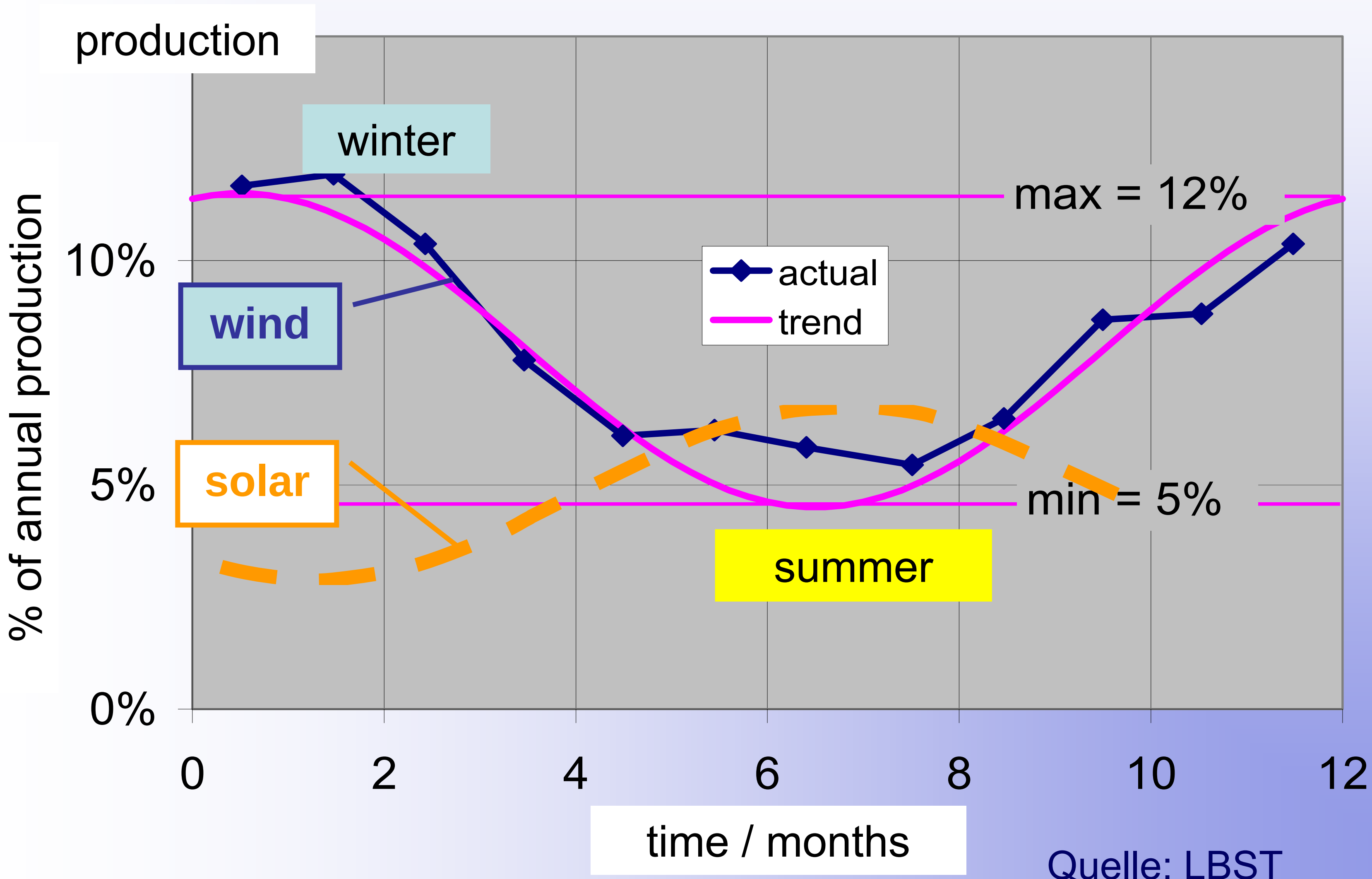
Option: coal, nuclear & natural gas (prognosis for 2030)



Option: coal, ~~nuclear~~ & natural gas (prognosis for 2030)

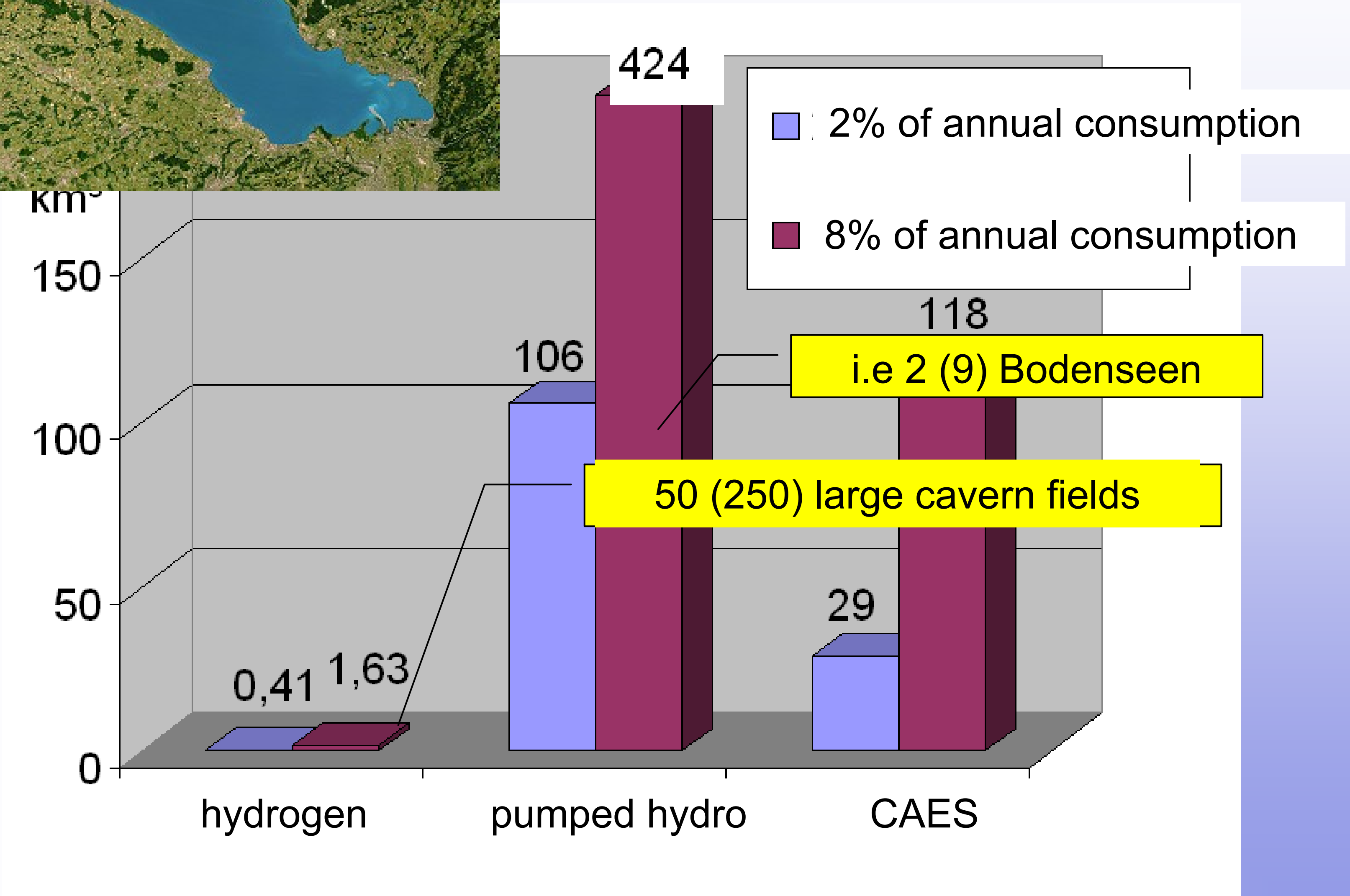


Additional aspect:
Balancing longterm, saisonal deviations



Quelle: LBST

el –
ower in Europe



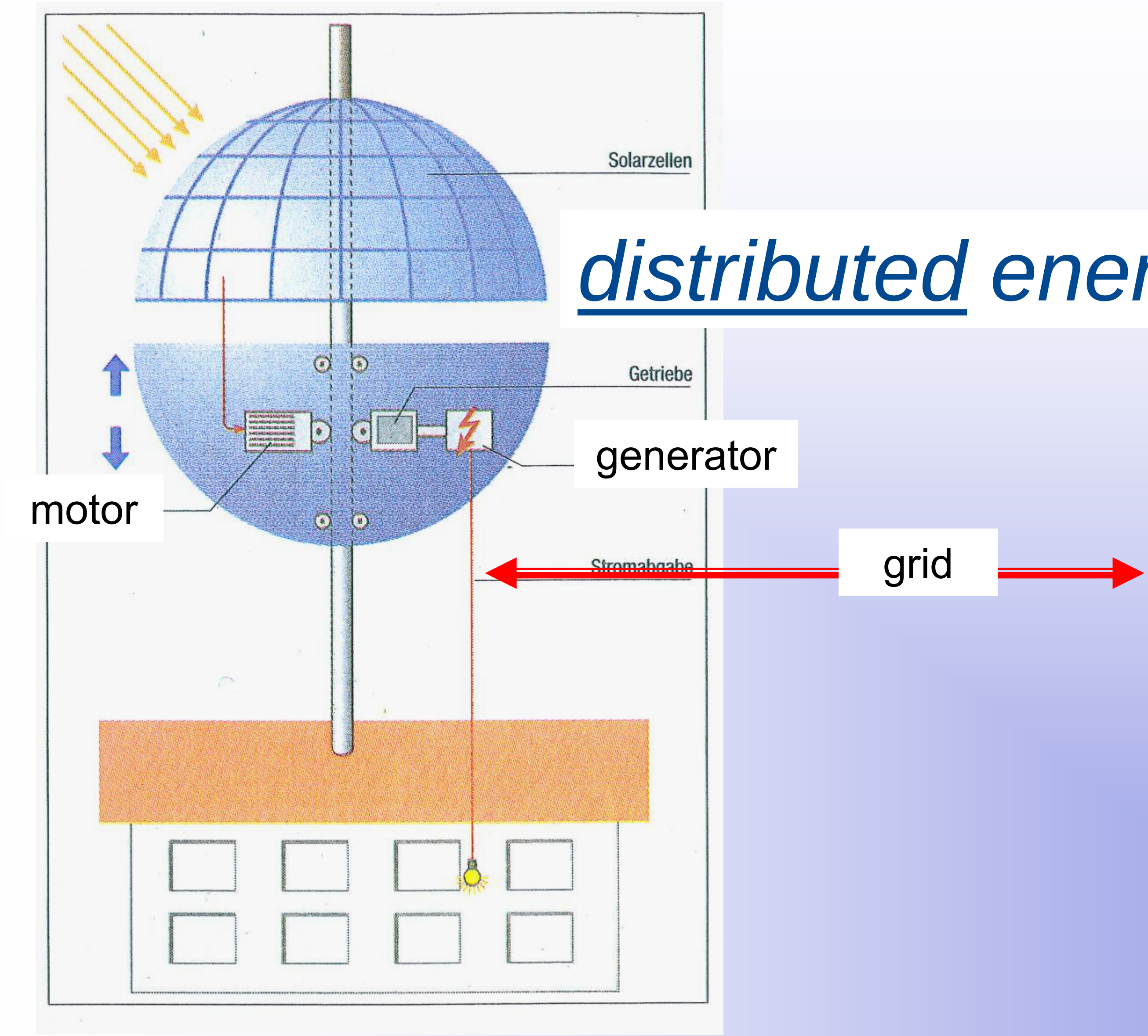
Summary

- > 15 % wind energy share requires grid scale storage
- Pumped hydro & CAES suitable for
  - balancing short term forecast errors
  - power arbitrage
  - limited potential for additional plants
- Adiabatic CAES allows high efficiency, no fuel needed
  - supply of short term balance energy (+ & -)
  - allows power arbitrage
- Hydrogen storage allows longer term balancing
  to overcome longer flaws or periods of excess wind

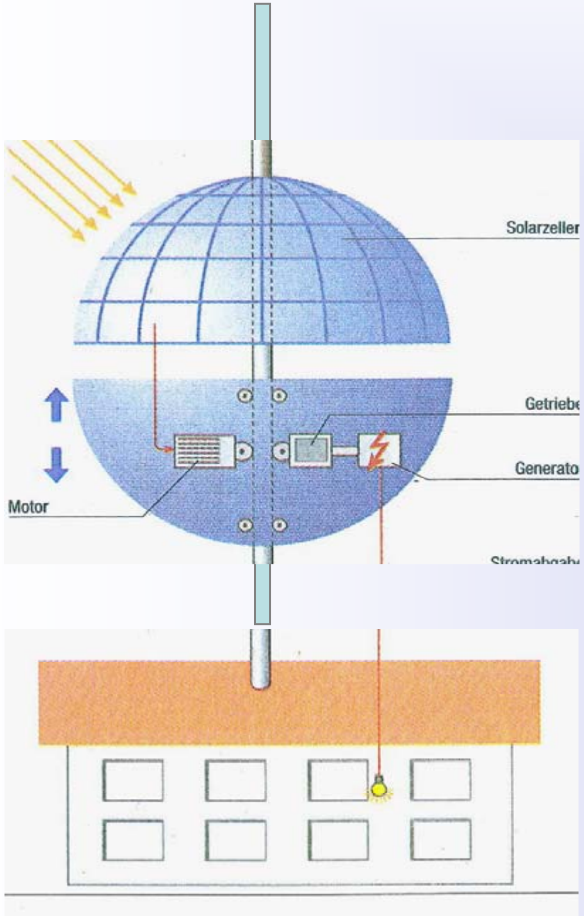
… Attention!

Here is the distributed, small scale storage competition

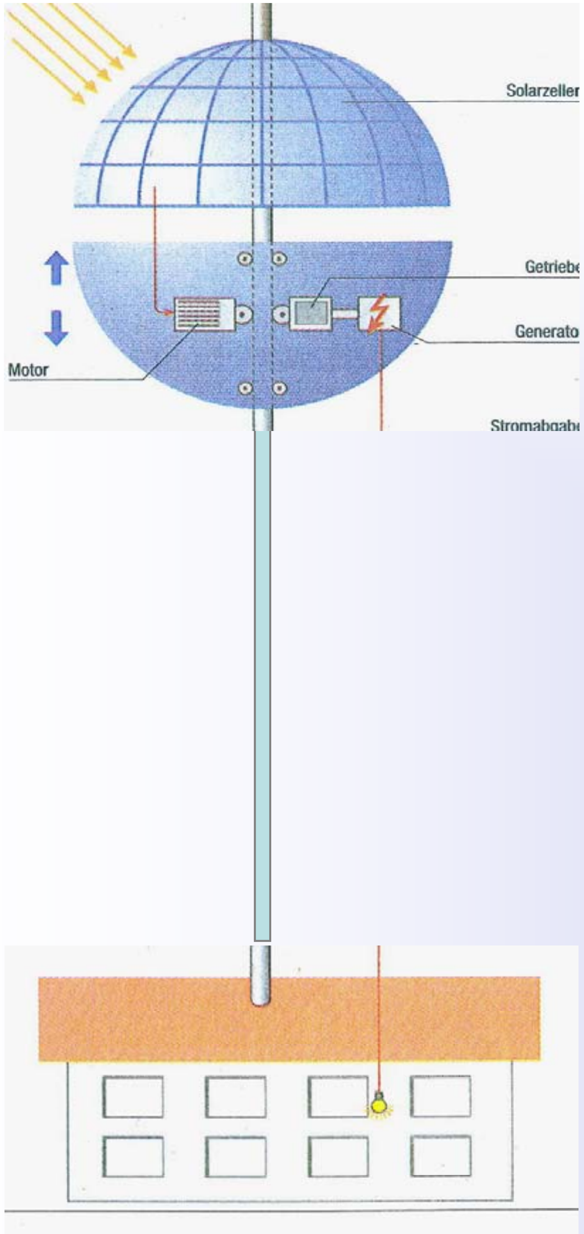
distributed energy storage



in case of excess power in the grid…



energy feed-in



in case of lack of power in the grid…

energy production