Regenerative Energy Conversion in Germany

Andreas Binder
Elektrische Energiewandlung

TU Darmstadt

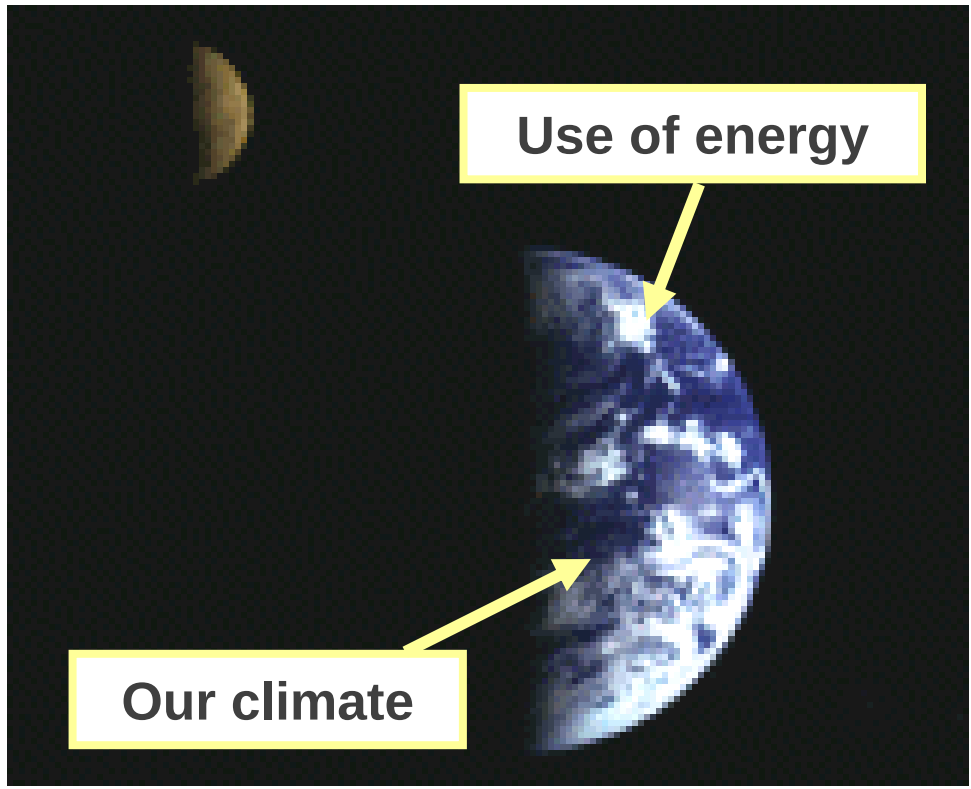
abinder@ew.tu-darmstadt.de

Overview

- Motivation
- Electrical energy situation in *Germany*
- Regenerative energy conversion
- Integration of large wind power plants
- Summary

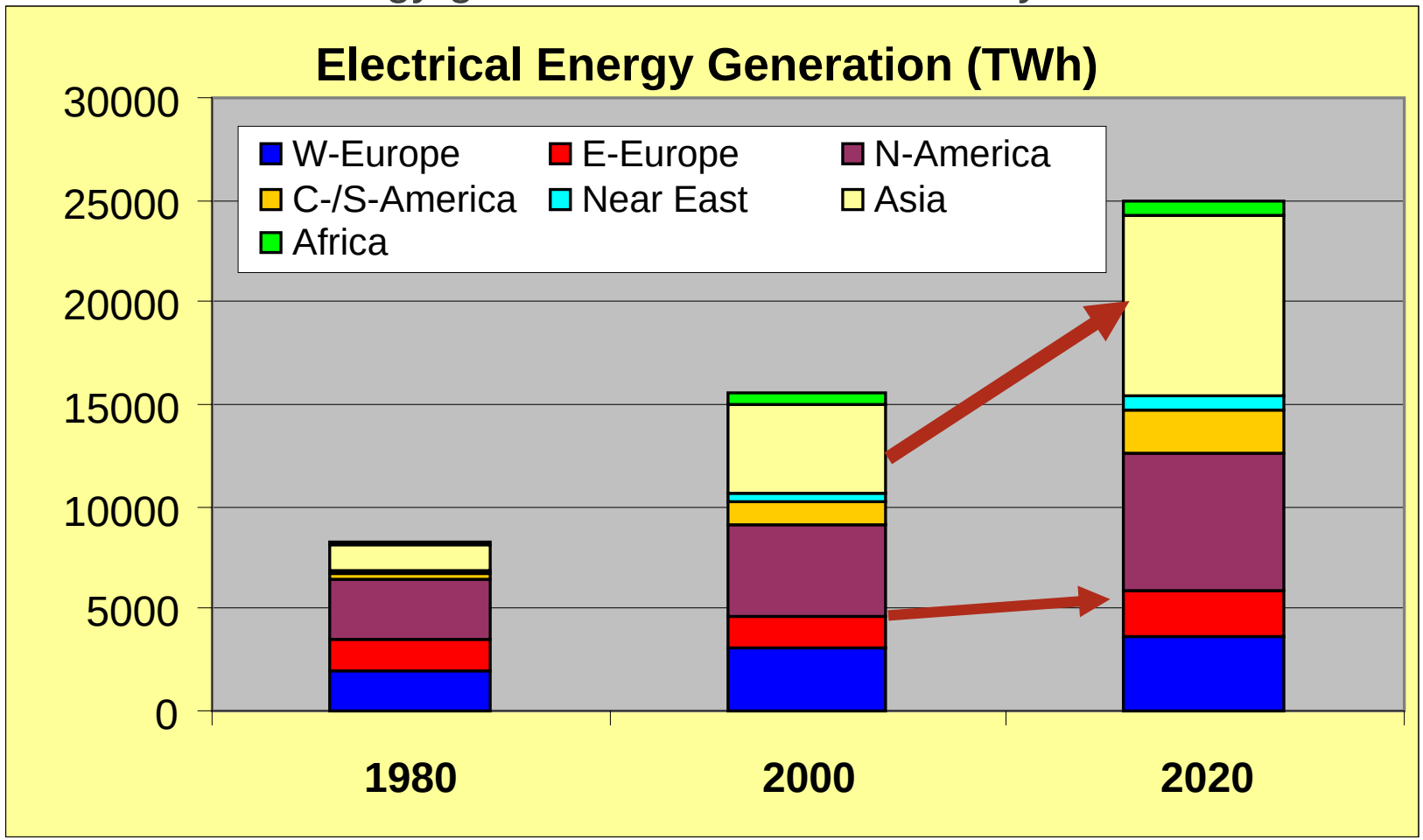
Protect our earth – it is our home

- Impact of the use of energy on climatic change:
- Here the impact of electric energy conversion is considered.
- A reduction of carbon dioxide production is necessary.
- *Germany* can contribute.
- The influence of regenerative energy conversion is discussed.



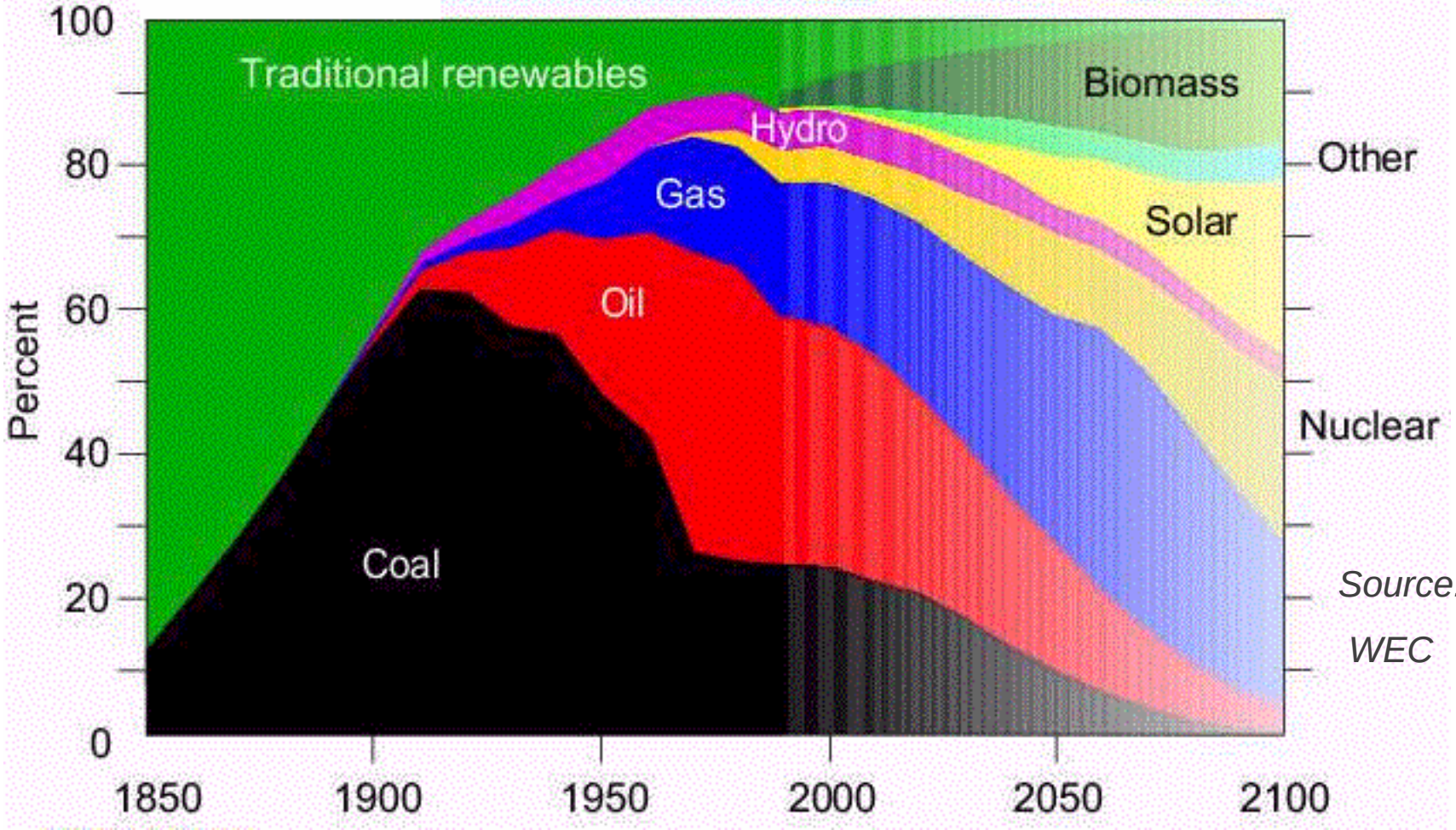
Increase of electrical energy in the world

Asia and **America** will determine mainly the world energy growth in the next 20 … 30 years !



Long term vision of primary energy

World wide trend: Increase of regenerative energy contribution to power supply, especially solar, bio mass, but also wind and hydro.



Source: WEC

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Situation in Germany 2007

- Electric energy conversion in *Germany*:
- Per year need for electric energy of ca. 510 TWh, with a 1 … 2% annual increase.
- For these 510 TWh (100%) we need 175 % of primary energy (coal, nuclear power, natural gas) in order to compensate the losses in the power plants and transmission.
- About 75% of primary energy is imported.
- The primary energy for electrical energy conversion is 38 % of total primary energy in Germany (which is 14 440 PJ).
- Electric energy conversion in power plants causes ca. 30 % of the total German CO_2-emission.

Electrical energy conversion – Energy mix (*Germany 2006*)

Wind 5%

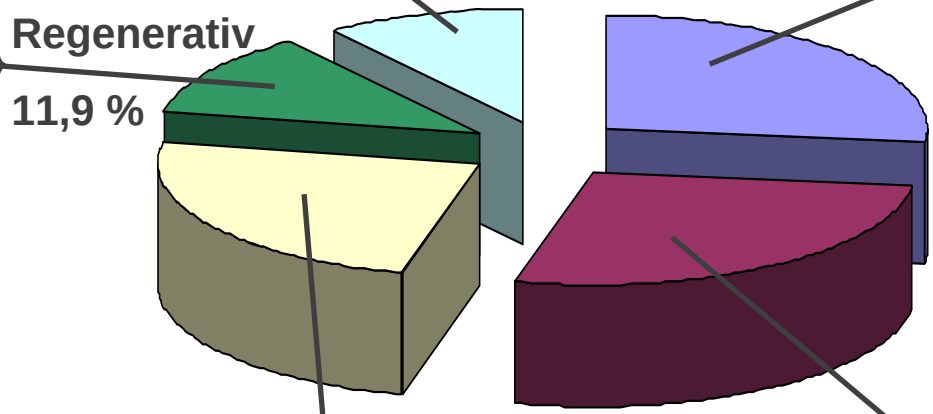
Hydro 3,5%

Bio mass 3,1%

PV 0,3%

Natural gas 10%

Black coal 27%

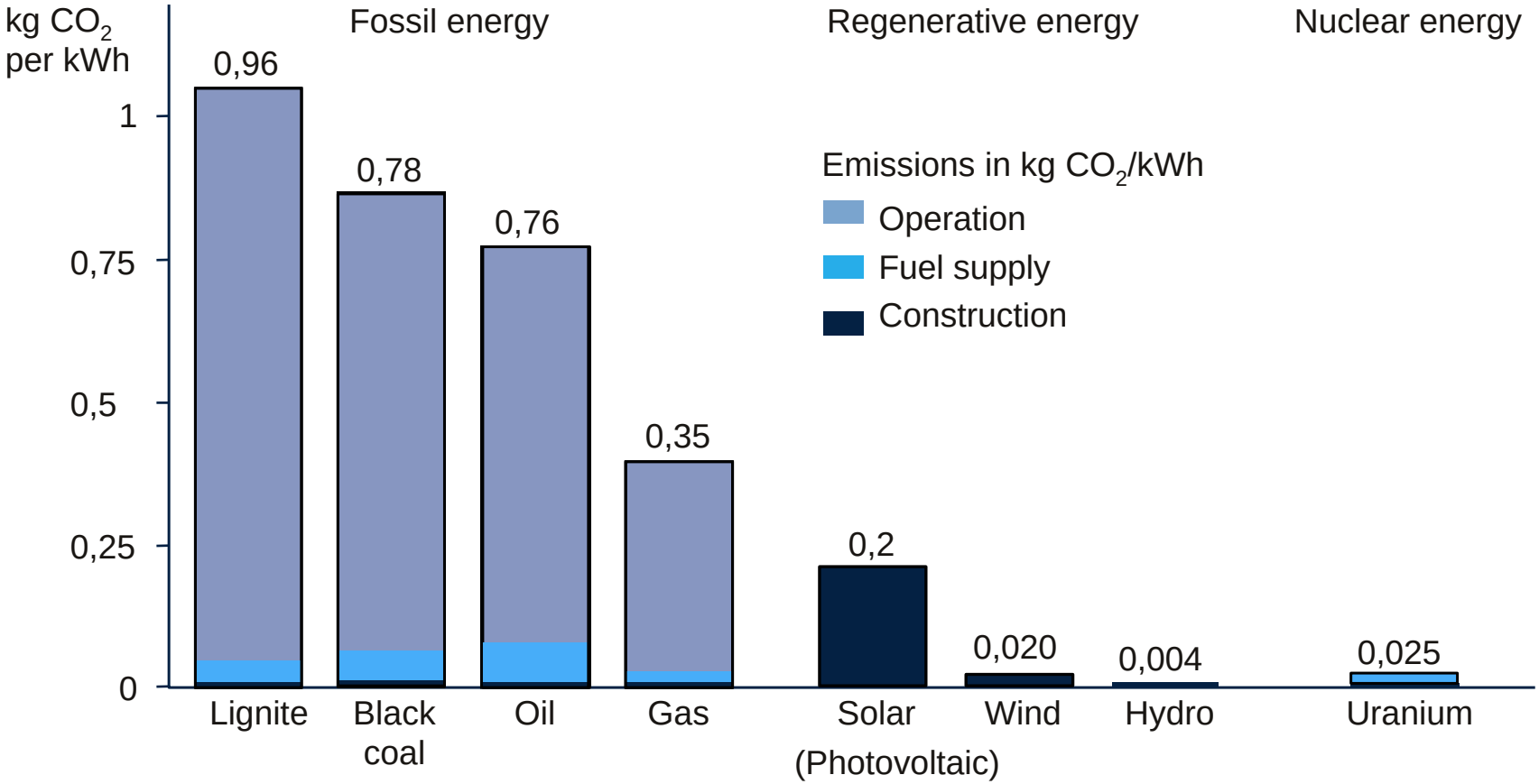


Nuclear 24,1%

Brown coal 27%

CO_2-Emissions due to electrical power generation

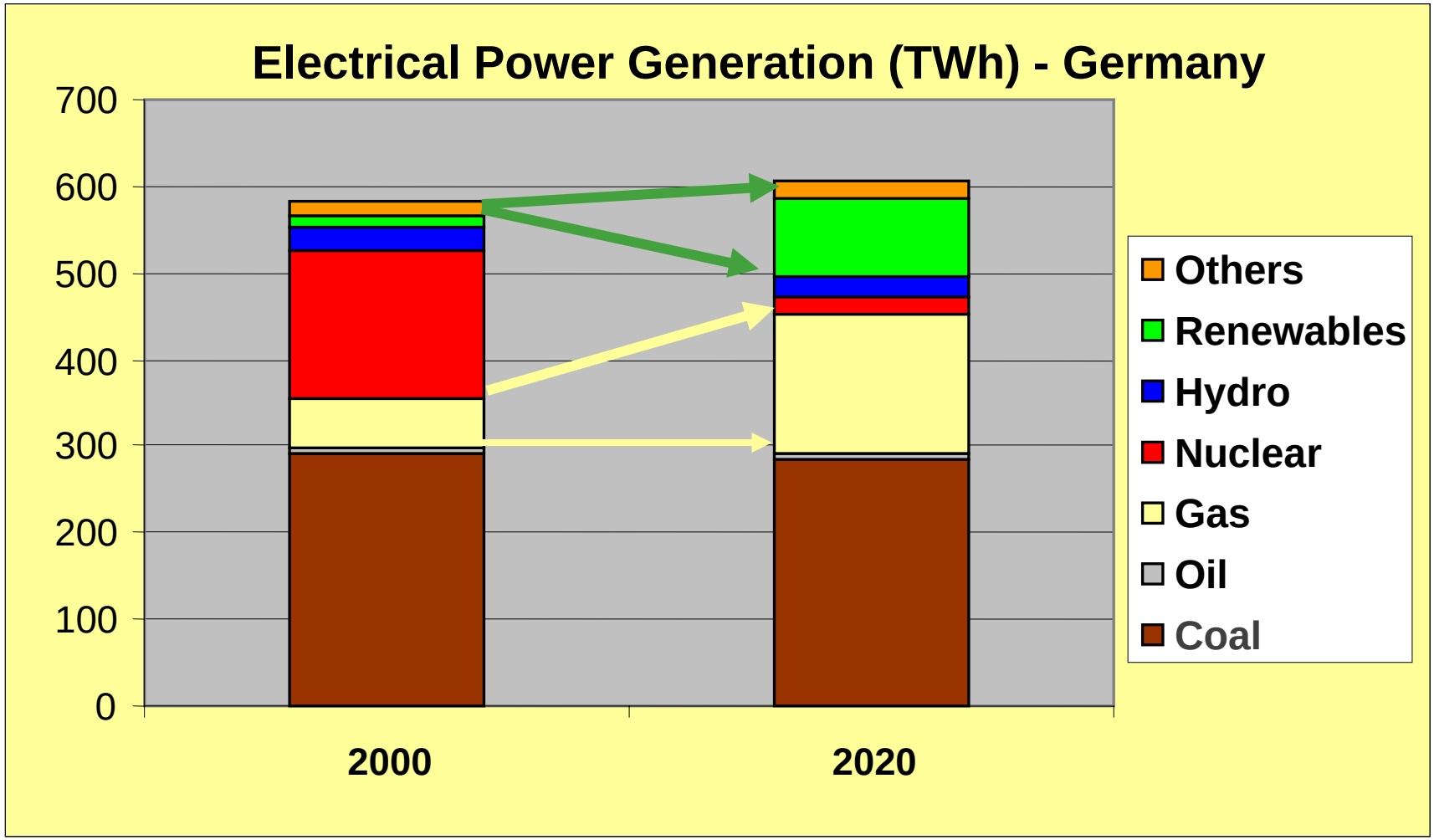
CO_2 –Emissions in different types of power plants



Source: Siemens

Electrical power generation (D) -Trend

Electrical power generation from natural gas and renewables (wind, bio mass) will increase. Nuclear power will be stopped (political will).



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Alternative energy conversion for reduction of CO_2

- **Wind energy „off-shore“: Efficiency ca. 45%, ca. 2500 full load hours**
- **Hydro power: Efficiency ca. 80%, ca. 6500 full load hours**
  - **Upgrading, refurbishment**
  - **Additional pump storage plants in neighbor countries**
- **Bio mass: Efficiency 30%, Organic fuel burning is neutral in CO_2**
- **Photo voltaic: Efficiency 10%, ca. 800 full load hours**
- **Geothermal energy: Aim: 3 … 5 km deep bore holes**
- **Still mainly research:**
- **Fuel cell power plants: Gas turbine combined with fuel cell**
  - **Aimed efficiency: 70% (Prototype ca. 300 kW)**
  - **Solid oxide fuel cell (SOFC) uses hydrogen from reformed natural gas, waste gas is afterwards burnt in gas turbine**
- **Fusion energy: Heavy water protons (Deuterium) are fusioned to Helium, thus producing fast neutrons (= kinetic energy)**
  - **Test facility 500 MW ITER under construction in *Cadarache/France***
  - **10 Billion Euros budget: Germany contributes!**

Regenerative electrical power generation (*Germany* 2006)

Wind	**30.5 TWh**	**5.0%**	
Hydro	21.6 TWh	3.5%	without pump storage
Bio mass	19.1 TWh	3.1%	incl. waste gases
Solar power	2.0 TWh	0.3%	
	73.2 TWh	**11.9%**	

Brutto-Consumption of electrical power 2006: 615.8 TWh
100%

= Consumption + Power station supply + pump storage operation
92% 6.5% 1.5%

Electrical power generation 2006: 635.8 TWh

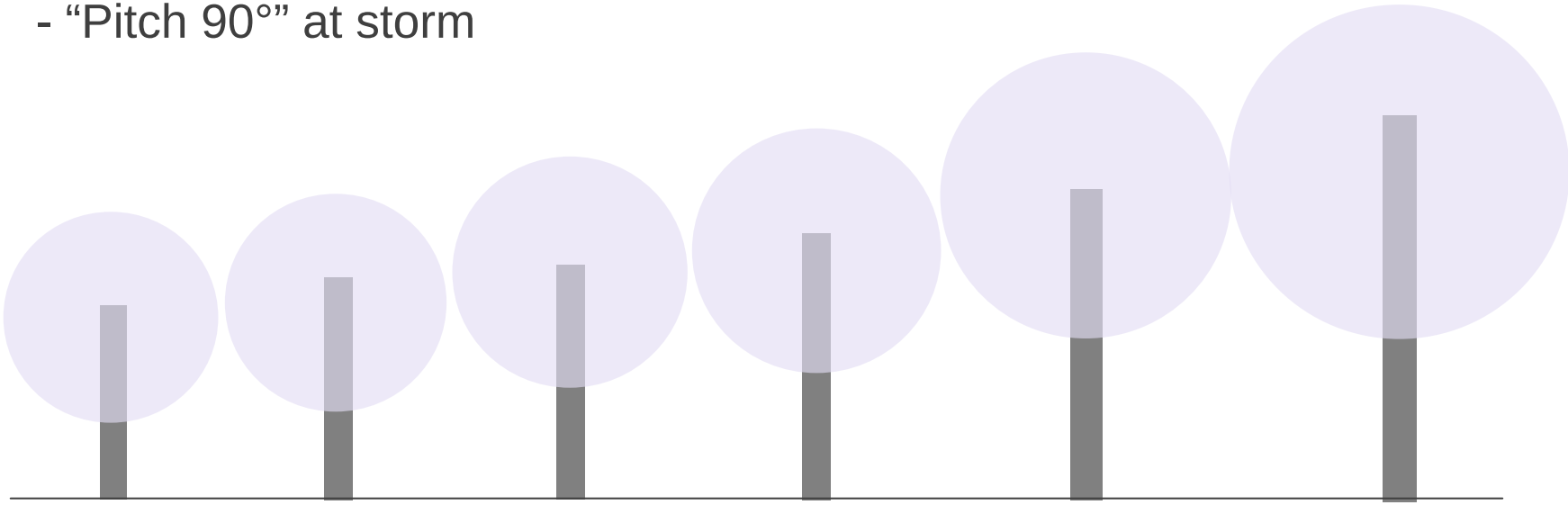
= Utilities + Private + Industry
539.5 45.1 51.2 TWh

Wind power in Germany

30.5 TWh **5.0%**

Wind turbines - ratings

- Rotor blades are pitched to adjust wind power
- Variable speed operation to extract maximum wind power at variable wind velocity
- “Pitch 90°” at storm



Rated power *P*

Rotor diameter *D*

Modern wind turbine data

- Three-blade rotors, pitching for optimum power operation at variable wind speed, full load operation 1500 … 2500 h/y, 40 … 45 % efficiency
- **5 MW rating is developed as standard size for the next years !**

P / MW	D_R / m	n_R / min^{-1}	Generator	v_{Rmax}/km/h	v, v_N /m/s	Gear i
1.5	77	9...17	DS-ASM	247	3...20, 11.1	104
2.0	80	9...19	DS-ASM	287	4...25, 15	ca. 100
2.7	84	6.5...18	DS-ASM	285	4...25, 14	70.65
3.0	90	10...20	PM-Syn	339	3 … 20	Gearless
3.6	104	8.5...15.3	DS-ASM	300	3.5...25, 14	ca. 100
4.5	104	ca. 7 … 13	Syn-G SL	ca. 300	3 … 25	Gearless
5.0	125	7...13	DS-ASM	306	4...30, 12	98.3

DS-ASM: Doubly fed induction generator: Rotor fed via slip ring set from inverter (inverter rating 30%)

PM-Syn / Syn-G SL: Synchronous generators: Permanent magnet & electrical excitation, gearless or low transfer ratio < 10, 100% inverter rating

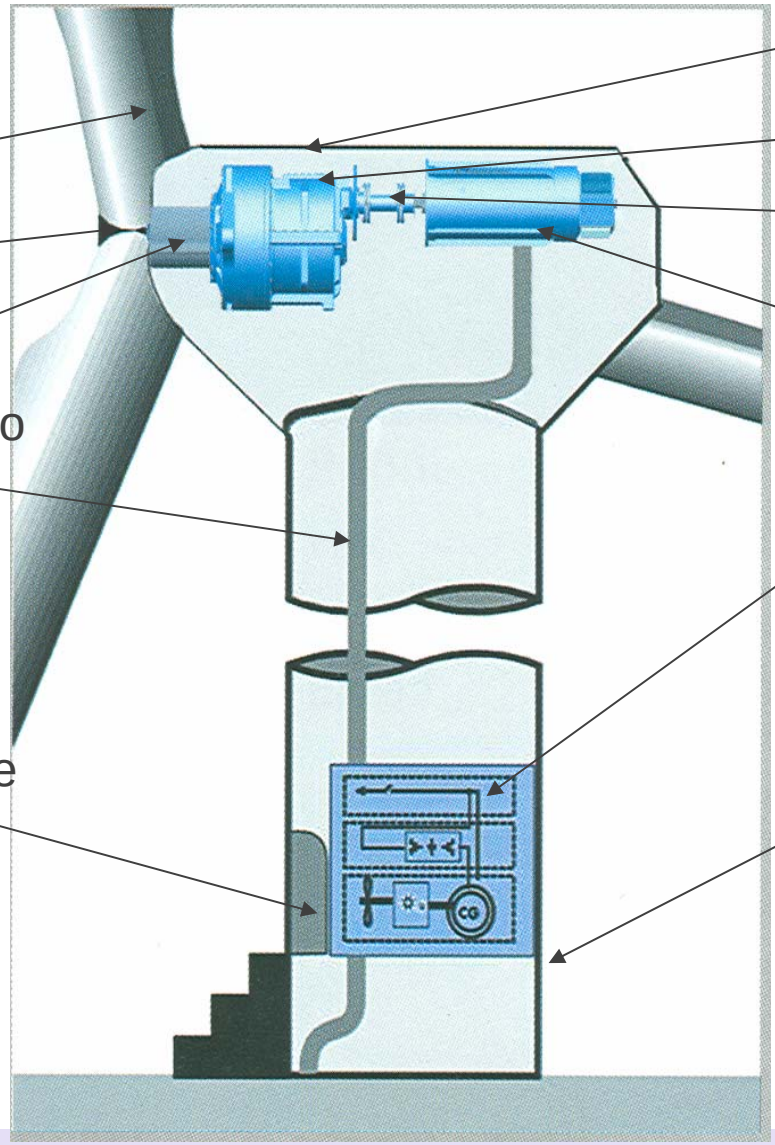
Geared wind turbines - Example: 5 MW

Wind rotor: 110 t

- Rotor blade
- Rotor spider
- Turbine shaft

Generator-Cable to the grid, three-phase 690 V

Transformer for increase of voltage 690V/20 kV



Nacelle: 240 t

Three-stage gear 1:100

Generator shaft + Coupling

Doubly-fed induction generator, needs slip rings

Rotor feeding inverter, 1/3 of generator rating

Mast

Source: Winergy, Germany

Hydro power in Germany

21.6 TWh 3.5%

Large Hydro Power

- Equivalent full load hours typically 6000 … 7000 h/y, efficiency **~ 80%**

- In *Germany*: Limited potential for new plants

- *Focus on:* - Refurbishment – Increase of efficiency
  - Increase of power rating in existing pump storage plants in neighboring countries

Needed a) to equalize wind power, b) grid stabilization in a liberal market

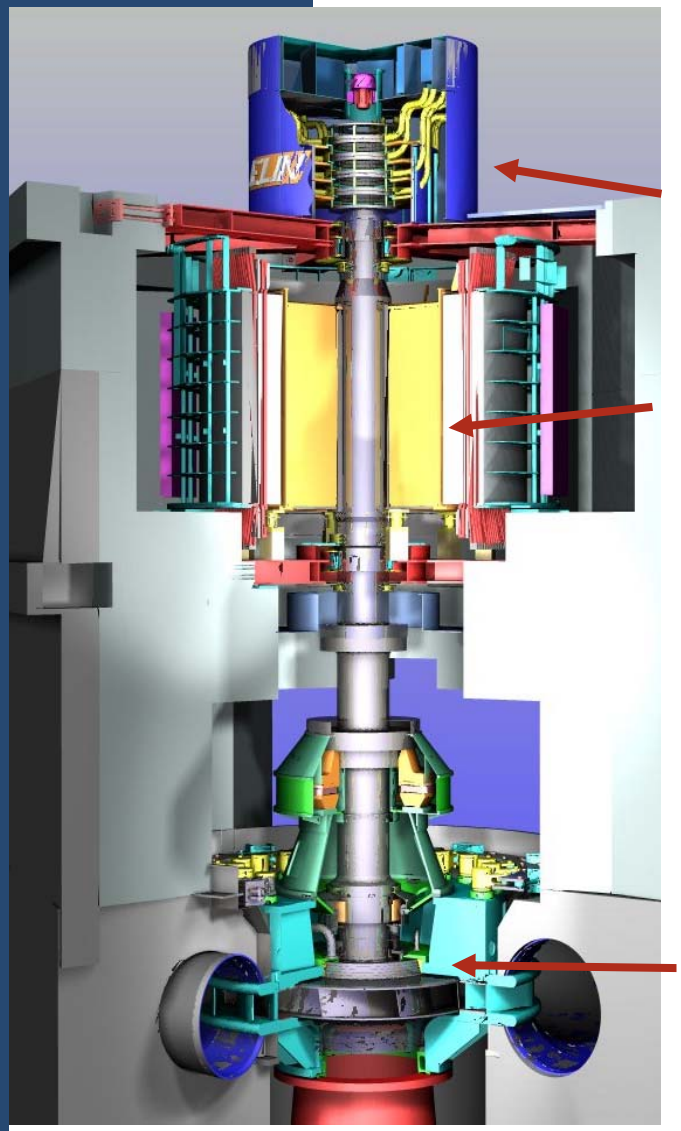
Examples:

- *Kopswerk (Austria):* + 500 MW (= + 100%), co-financed by EnBW
- *Vianden/Luxembourg* (additional 10th generator)

Pump storage
Geesthacht
near *Hamburg*

Francis-Turbines

Pump storage power plant *Goldisthal/Thuringia (D)*



Slip-rings for inverter feeding

Doubly-fed induction generator

pump-turbine

Innovation: Speed variable pump storage operation:

Two of 4 turbines operate at variable speed with data:
2 x 340 MVA, 300 ... 346/min, 18 poles, 50 Hz

Asynchronous doubly-fed generators, rotor fed via cyclo-converter

- Improved efficiency

- Enhanced operation

Source: VA Tech Hydro

Bio mass in Germany

19.1 TWh **3.1%**

Bio mass power plants

- **Bio mass:** Burning of organic material
  - wood, - gas from garbage deposits

Produced CO_2 equals consumed CO_2 during growth of the plants

- **CO_2-neutral**

- **Problems:** Deposits and corrosion in the burning chamber

Examples:

Landesbergen (D) (2003): 20 MW el. power, 31% efficiency, wood

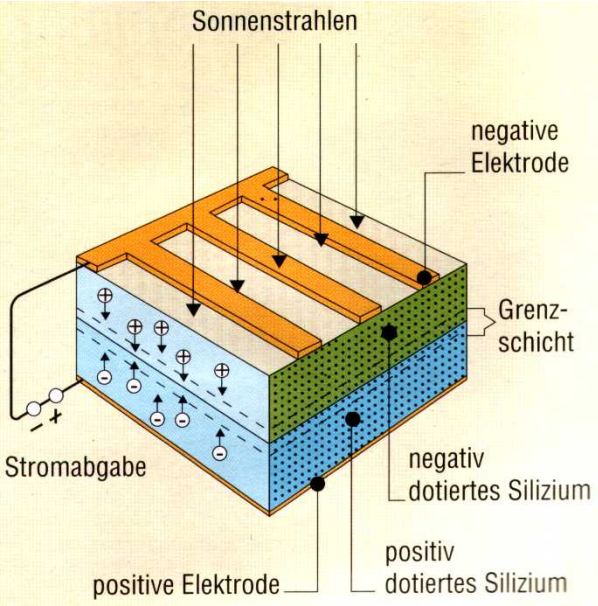
Düsseldorf (D): (08/2007): 25 GWh/a el. Power, 78 GWh/a heating

- **Research:** Wood gasification, burnt in combined cycle power plants:
  expected efficiency: 40%
  mixed with natural gas: 60%

Solar power in Germany (Photo voltaic)

2.0 TWh **0.3%**

Solar power - Photovoltaic



Basic principle of photo diode as electric DC voltage source

Vision of future large array photo-voltaic power plant in southern regions

Germany: 2006:

- 750 MW new installed photovoltaic power (private & utilities)
- Totally installed power: 2.6 GW; delivered energy to the grid: 2 TWh

- Island-use (e.g. traffic systems): totally 32 MW installed power !

Photovoltaic power plants (D)

Germany: 2006:

Over 30% thin layer solar cells in use in new solar parks!

Examples:

- *Solar park Gut Erlasee: (Arnstein/Bavaria):* 12 MW peak power
- *Solar park Pocking (Bavaria):* 10 MW peak
- *Solar park Leipziger Land (Saxonia):* 5 MW peak
- *BGZ Solarpark Passauer Land (Bavaria):* 3.3 MW
- *Bürgersolarpark Fünfstetten:* 1.7 MW peak
- Under construction: till 2009
  Solar park Waldpolenz (Leipzig): 40 MW pk
  550000 solar modules
  covered area: 220 hektar
  40 Million kWh/a
  20000 tons CO_2 saved per year

Photovoltaic power generation (D)

***Solar park Leipziger Land (Saxonia):* 5 MW peak**

Source: GEOSOL

Germany:

Since 2006: Largest installed photovoltaic peak power in the world (2.6 GW) – Second: *Japan*

- Installed photovoltaic power per capita: 150% of *Japan*

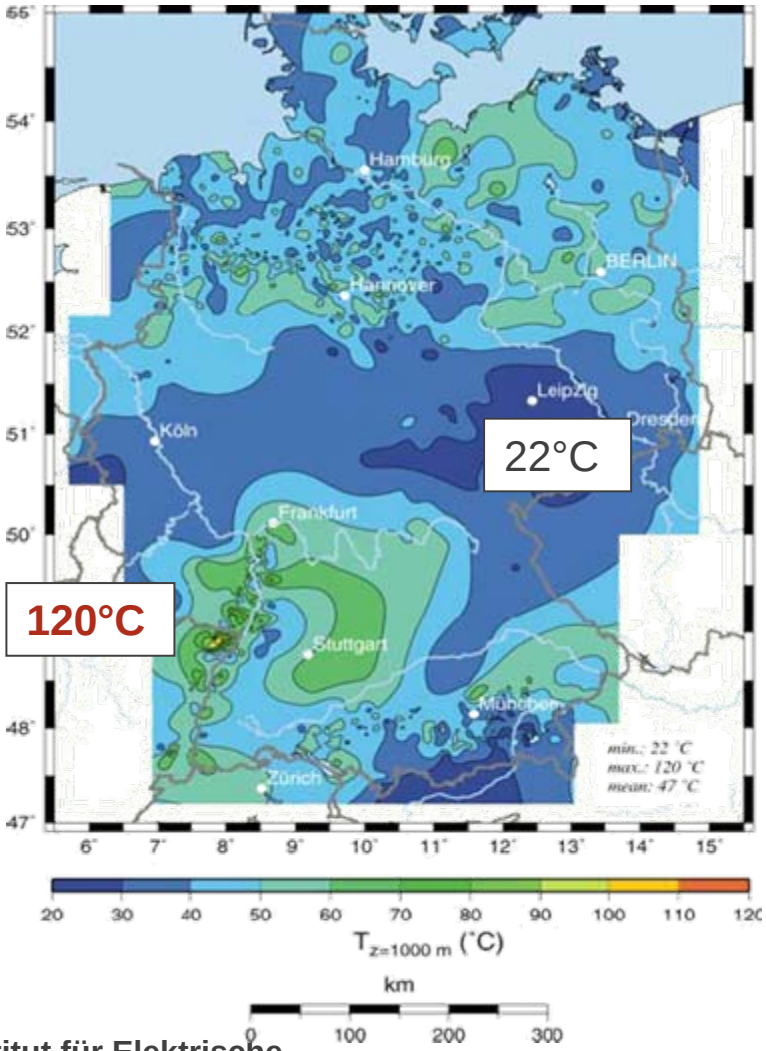
Geothermal power in Germany

First projects

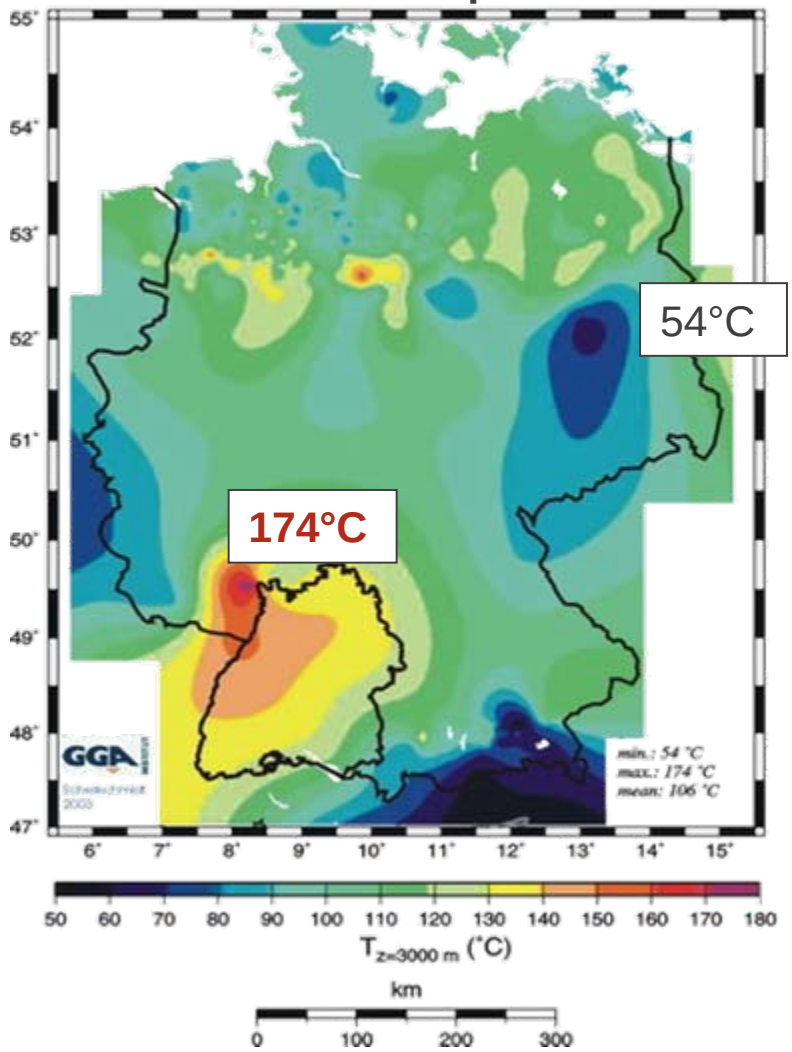
Geothermal potential in *Germany*

Per 100 m depth plus 3°C rock temperature

1000 m depth



3000 m depth



Electrical energy conversion with geothermal power plants

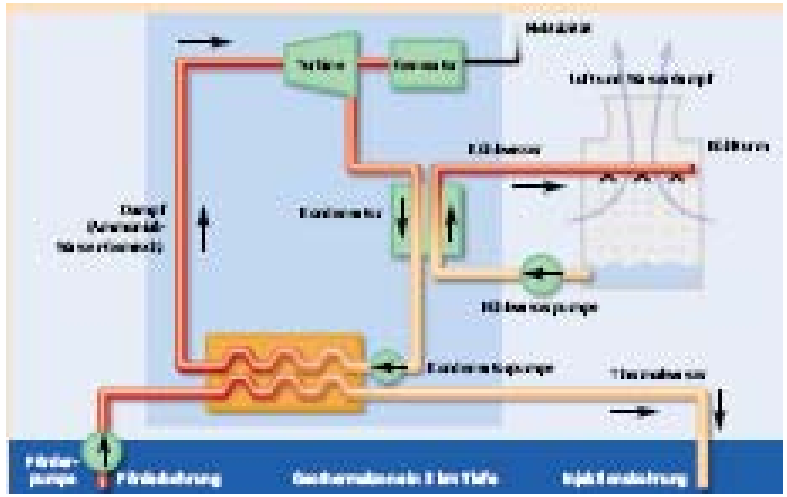
- 3 km deep bore hole: ca. 120°C hot water – evaporates at the surface: but steam pressure too low for turbine operation

- *Kalina*-cycle: Heat exchanger: Water-Ammoniac-mixture (low boiling point: ammoniac: -33°C): high steam pressure sufficient for turbine

- Closed cycle between heat exchanger and cooling tower

- Project *Munich-Unterhaching (2007)*: 3300 m, 122°C, 150 l/s, 3,3 MW electrical power

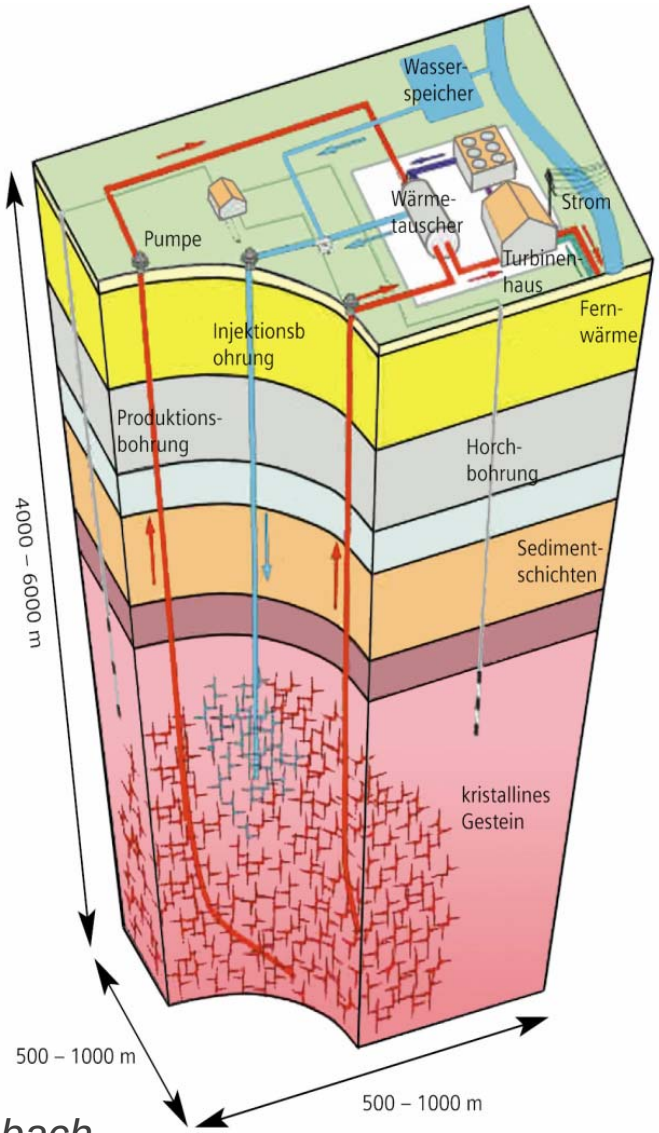
- In addition:
  Cogeneration of heat
  - central heating for 10 000 persons, 25 l/s
  - 12000 tons CO_2 are avoided per year



Source: Siemens

STILL IN RESEARCH: Hot Dry Rock - Cycle

- When no hydrothermal rock bed is found: Hot Dry Rock-Cycle: Injection of surface water to produce steam
- Between injection hole and extraction hole an artificial hydro circulation is installed
- Via hydraulic stimulation (= high pressure water injection) cavities are produced in the rock bed. Here the water can circulate.
- 4 … 6 km deep holes are needed.
  Test drillings have been done (e.g. near *Speyer* in the *Rhine* valley)
  Deep drilling is expensive !



Source: TU Darmstadt, Prof. Katzenbach

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German high voltage grid

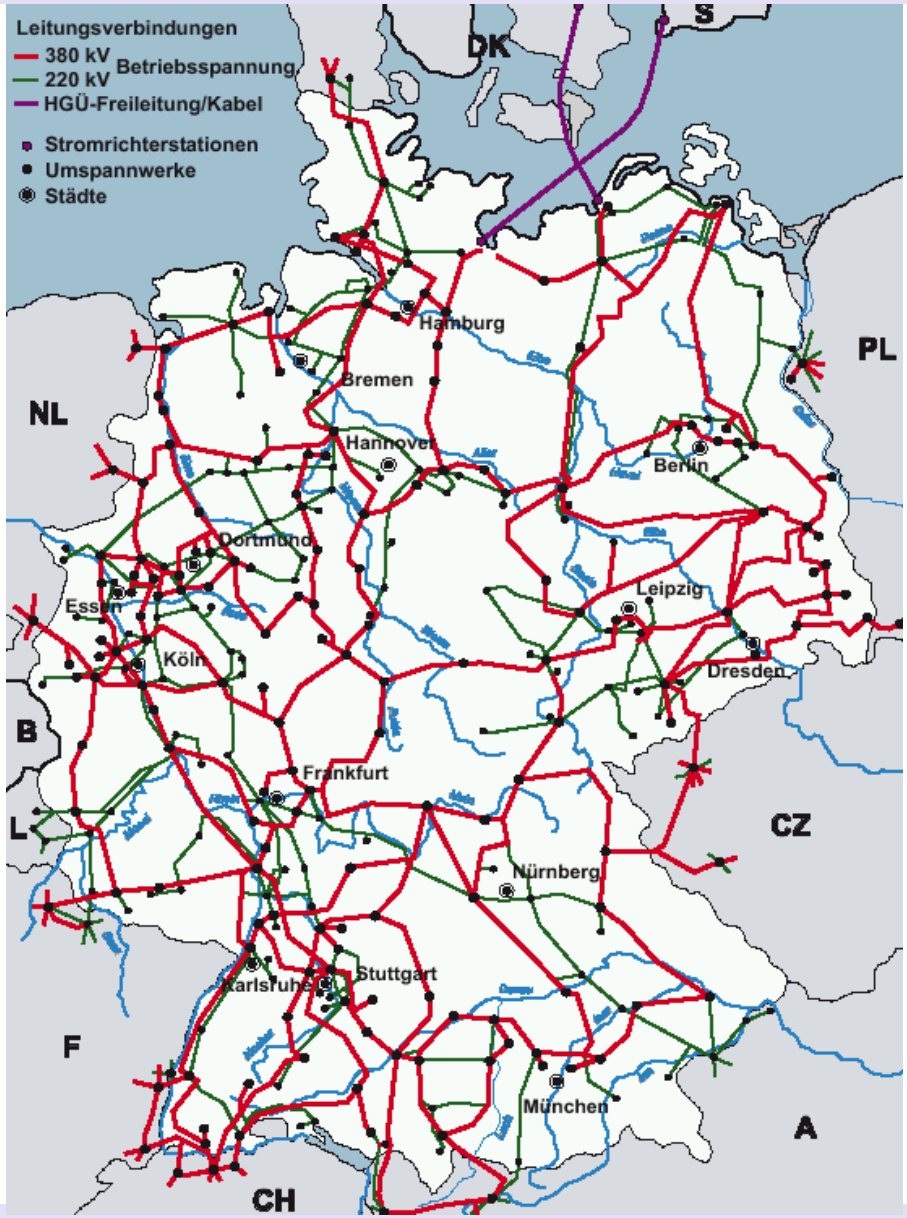
3-phase, AC:

380 kV

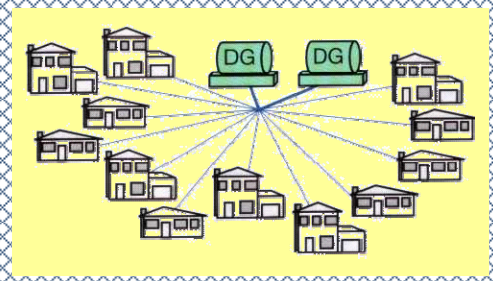
220 kV

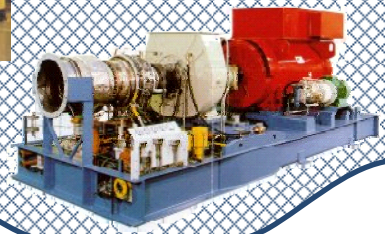
Single phase, HV DC

Connection sub-sea to the *Baltic*



Regenerative and small power energy sources – decentralized grid





Integration of

-Wind farms

-Fuel cell plants

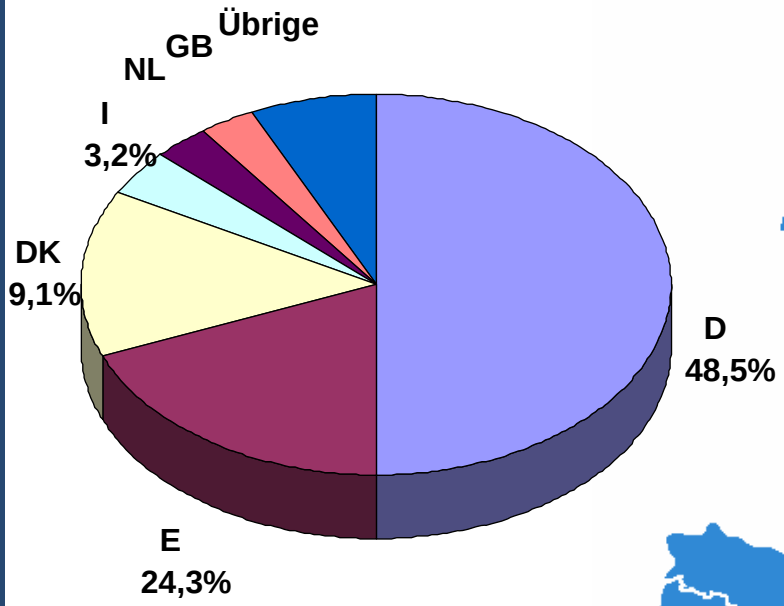
- Photo-voltaic

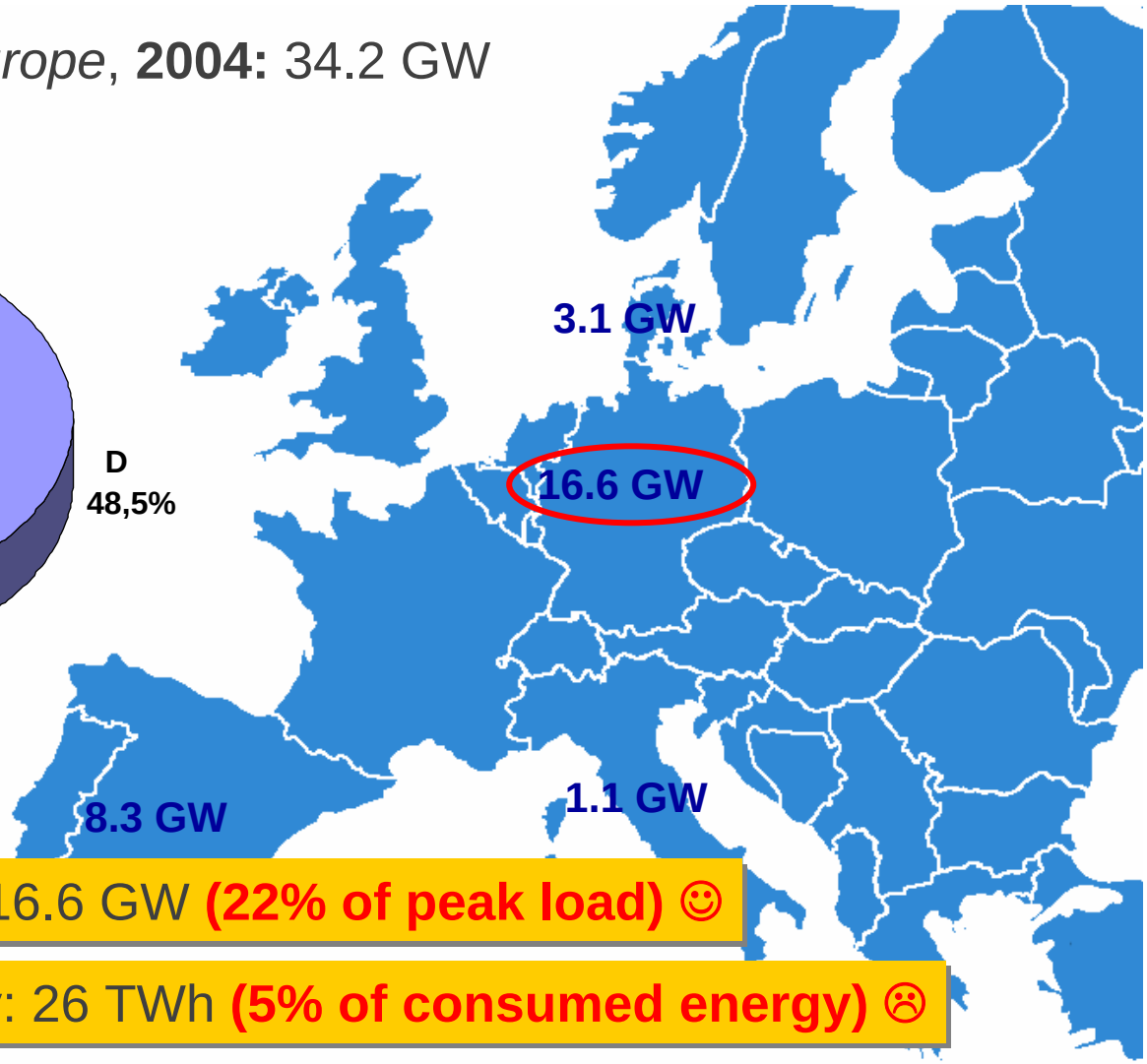
- Small bio mass

Partially dual directed energy flow !

Integration of big wind power flow

Installed wind power, *Europe*, **2004:** 34.2 GW



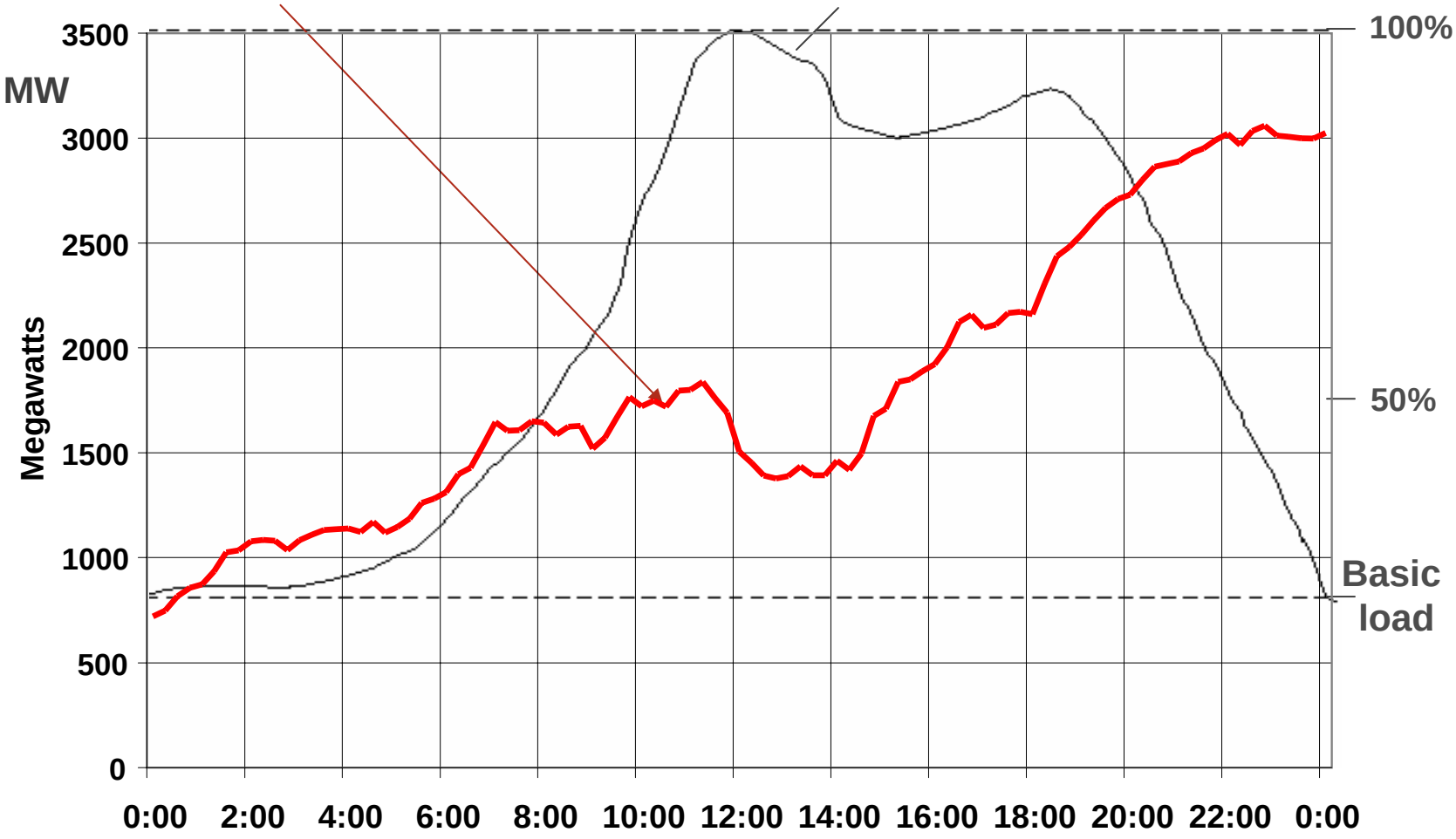


In Germany:

- installed wind power: 16.6 GW **(22% of peak load)** ☺
- produced wind energy: 26 TWh **(5% of consumed energy)** ☹

Wind power: Daily availability

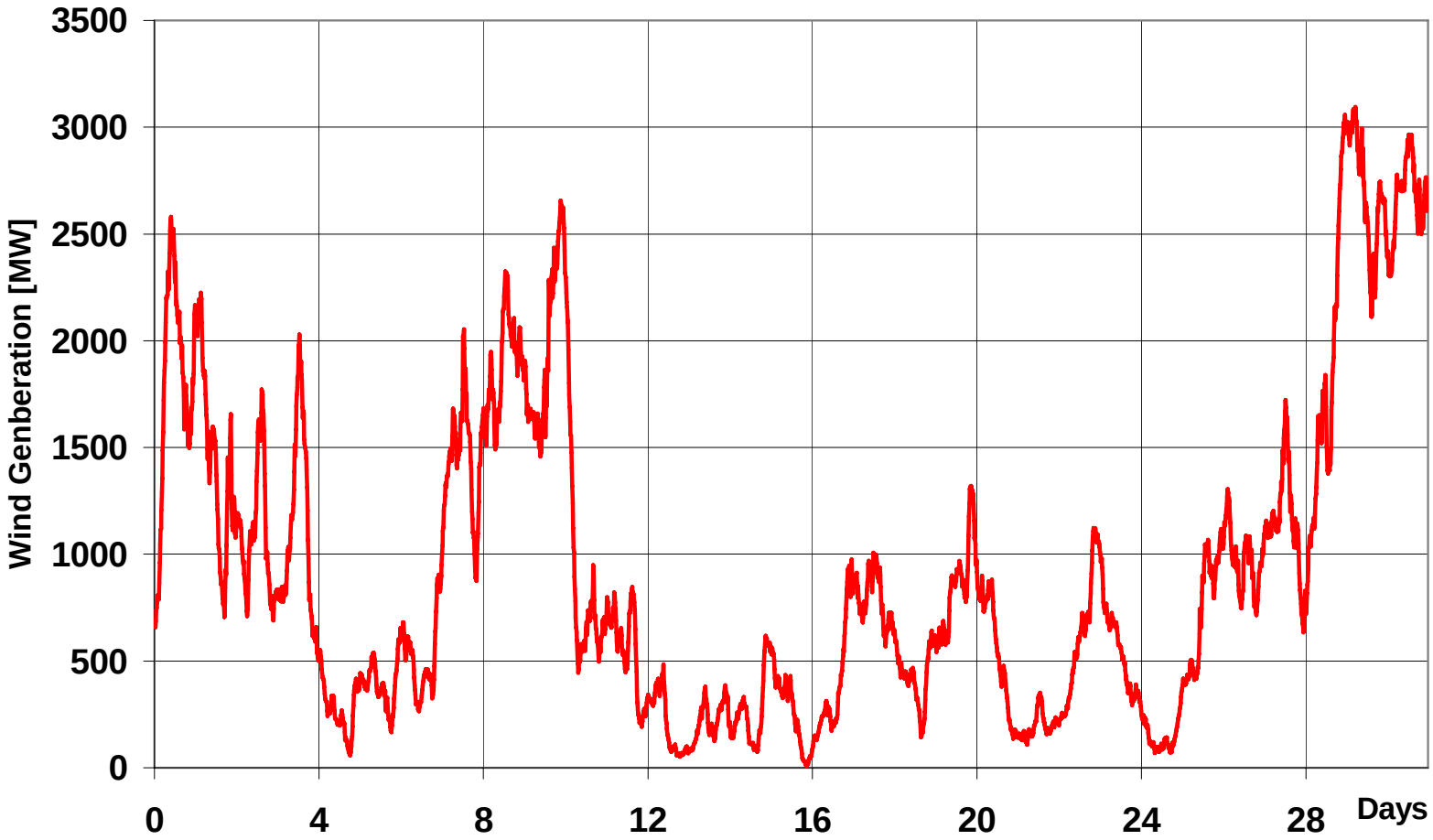
Energy of 5400 wind turbines at 28.10.2001 Load curve of the grid



Source: ISET

Wind power: Monthly availability

Energy of 5400 wind turbines during October 2001

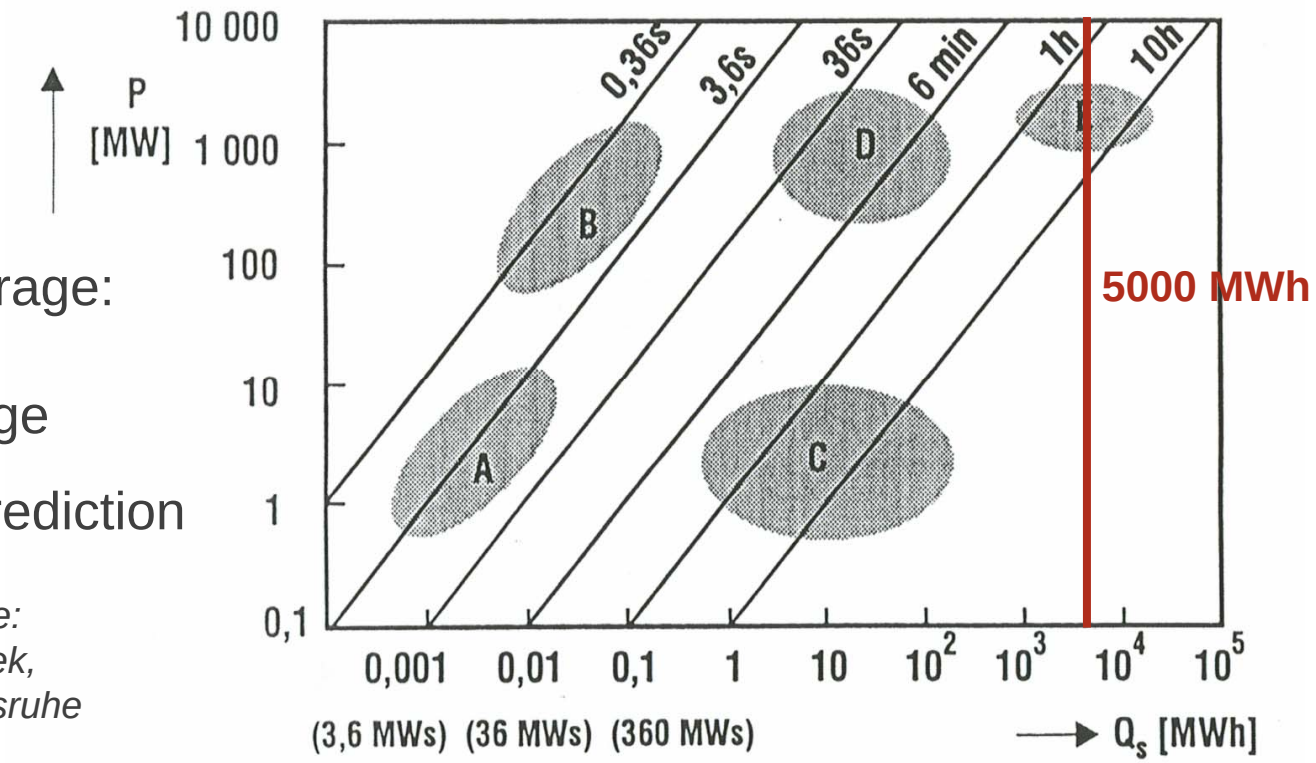


Wind power availability – Additional storage necessary

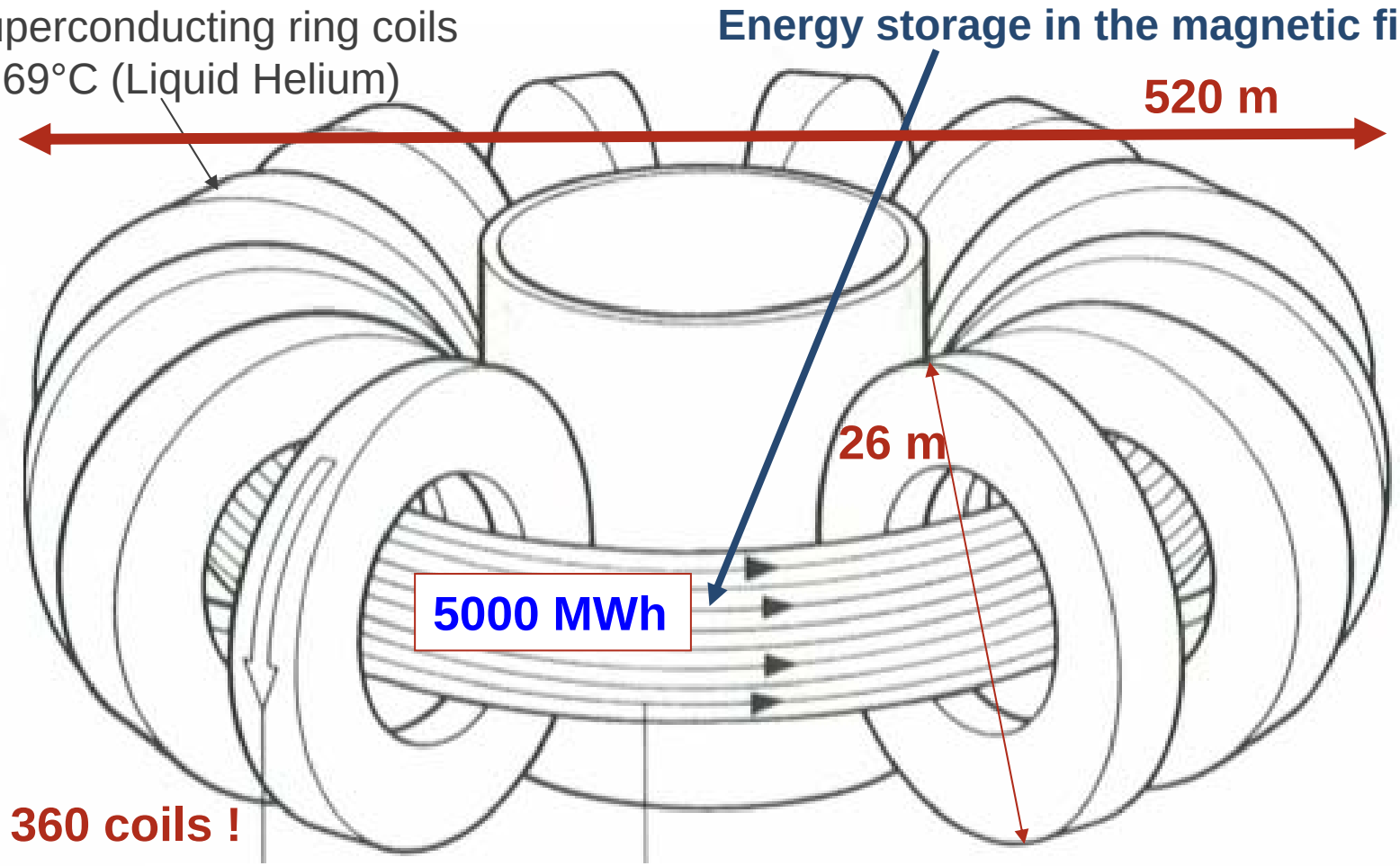
- Additional storage:
pump storage
magnetic storage

- Better wind prediction

Source:
Komarek,
FSZ Karlsruhe



Future: Large magnetic storage device ?

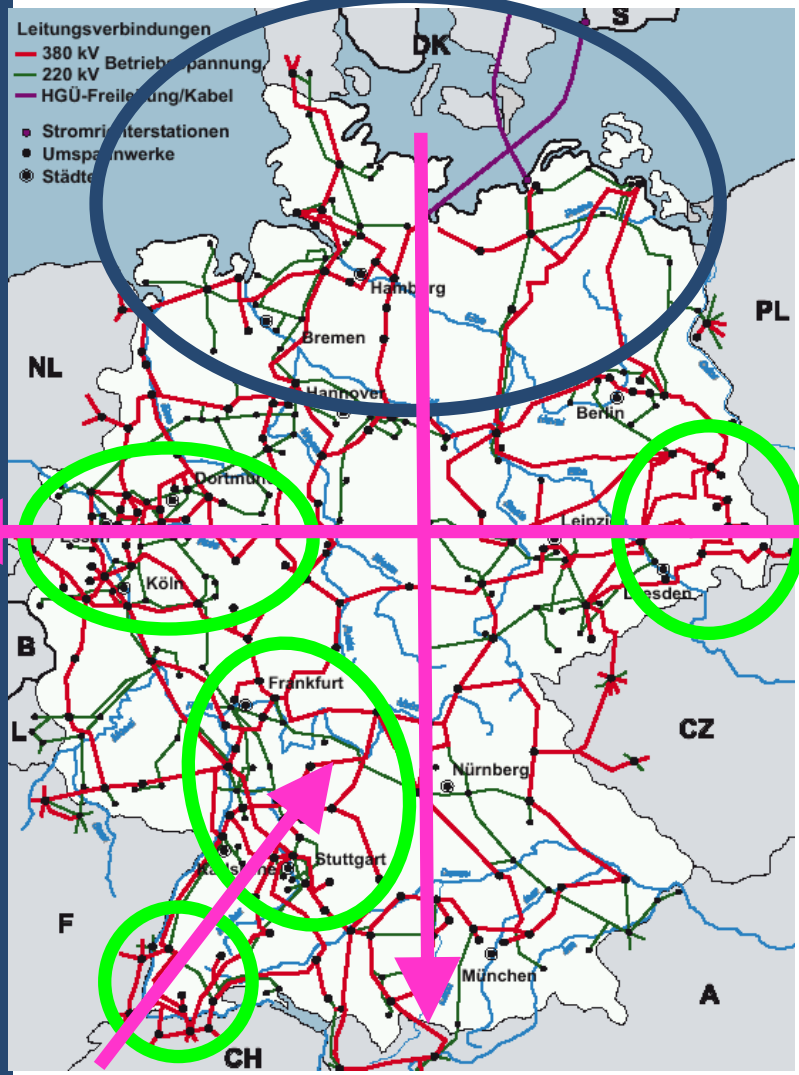


Coil current
150 kA

Magnetic flux density
9 T

Source: Max Planck Gesellschaft

Wind energy
Flow across the country



Northern Germany: many wind farms, but low consumer density

Consumer centers, where the power is needed

Main power flow directions

- Liberalized market and
- Increased size of wind farms

The high voltage grid needs

a) to be enlarged
b) thermal monitoring
c) FACTS to avoid reactive power.

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- *Germany* is world leader in installed wind power and photo voltaic
- Regenerative energy shall increase from 11% to about 25% in electric energy production in Germany
- Electrical power generation: NOT revolution, BUT Evolution
- Find the right Energy-Mix with a co-existence of conventional and – with increasing part – of regenerative energy sources
- Increased need of new storage devices and new power transmission lines

Thank you for your attention !

abinder@ew.tu-darmstadt.de