Geothermal power in the reality of the electricity market

Session VII: Plant operation, energy supply and grid integration

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Topic of the presentation: energy supply, electricity grid & plant operation
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Brief portrait
EnBW Energie Baden-Württemberg AG

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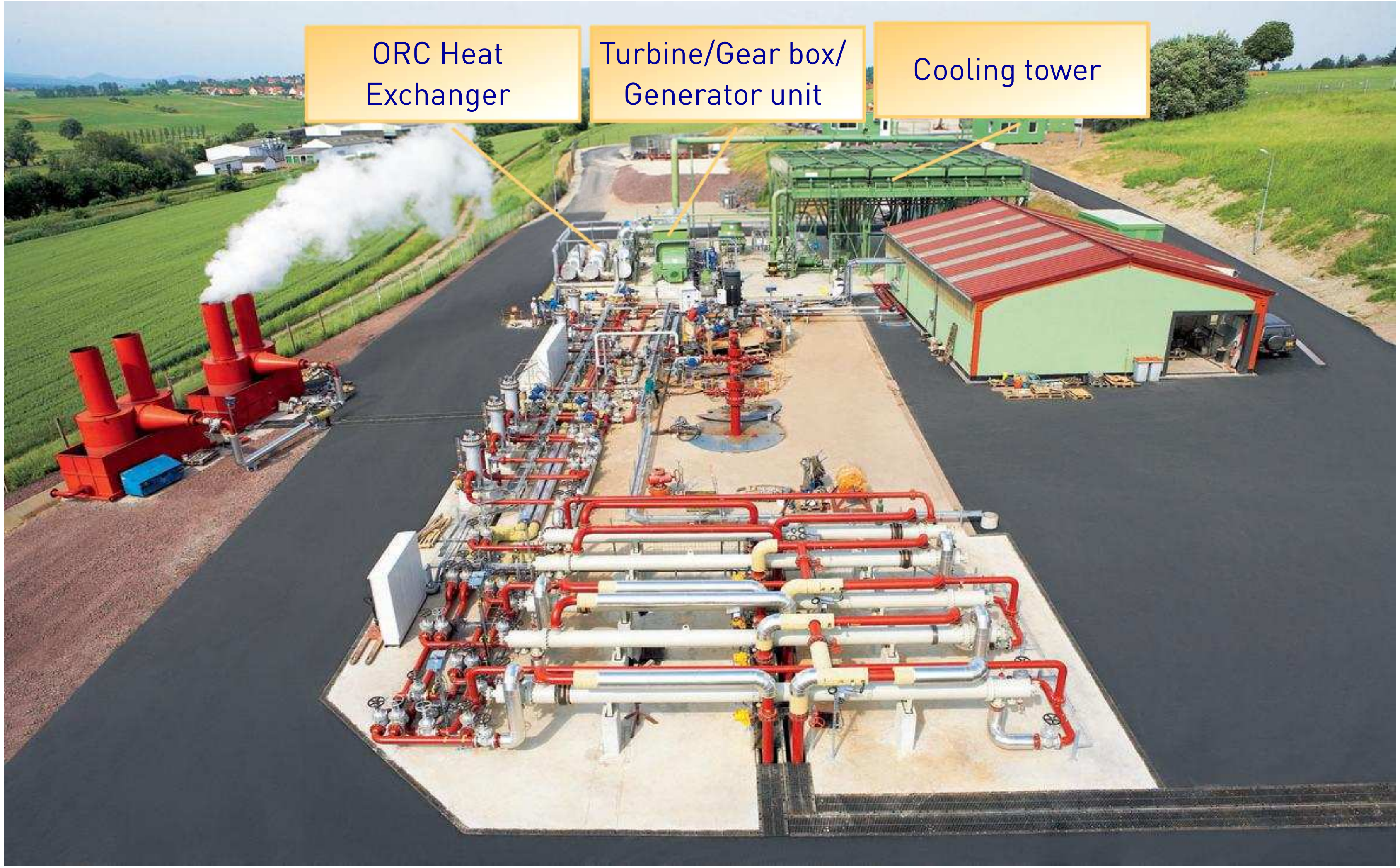
- One of the largest energy companies in Germany and Europe
- Business segments:
  electricity generation and trading, electricity grid and sales,
  gas, energy and environmental services
- Annual revenue 2011: in excess of € 18 billion
- Customers: some 5,5 million
- employees: some 20,000
- Installed capacity: 13 042 MW thereof 2538 renewable
- 2 geothermal power plants

Geothermal power plant in Soultz-sous-Forêts, France
Upper Rhine Valley



Source G.E.I.E, 2010

Geothermal power plant – Soultz-sous-Forêts

French-German consortium (federal agencies, research agencies; industry)

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Thermal capacity

25-35 l/s
Flow rate

175 °C
Flow temperature

70 °C
Return flow temperature

~ 14 MW
Thermal capacity

Power plant

ORC power plant

~ 19 bar
Pressure

Isobutan
Working fluid

Air cooling tower

~ 2,1 MW
Gross electrical output

boreholes

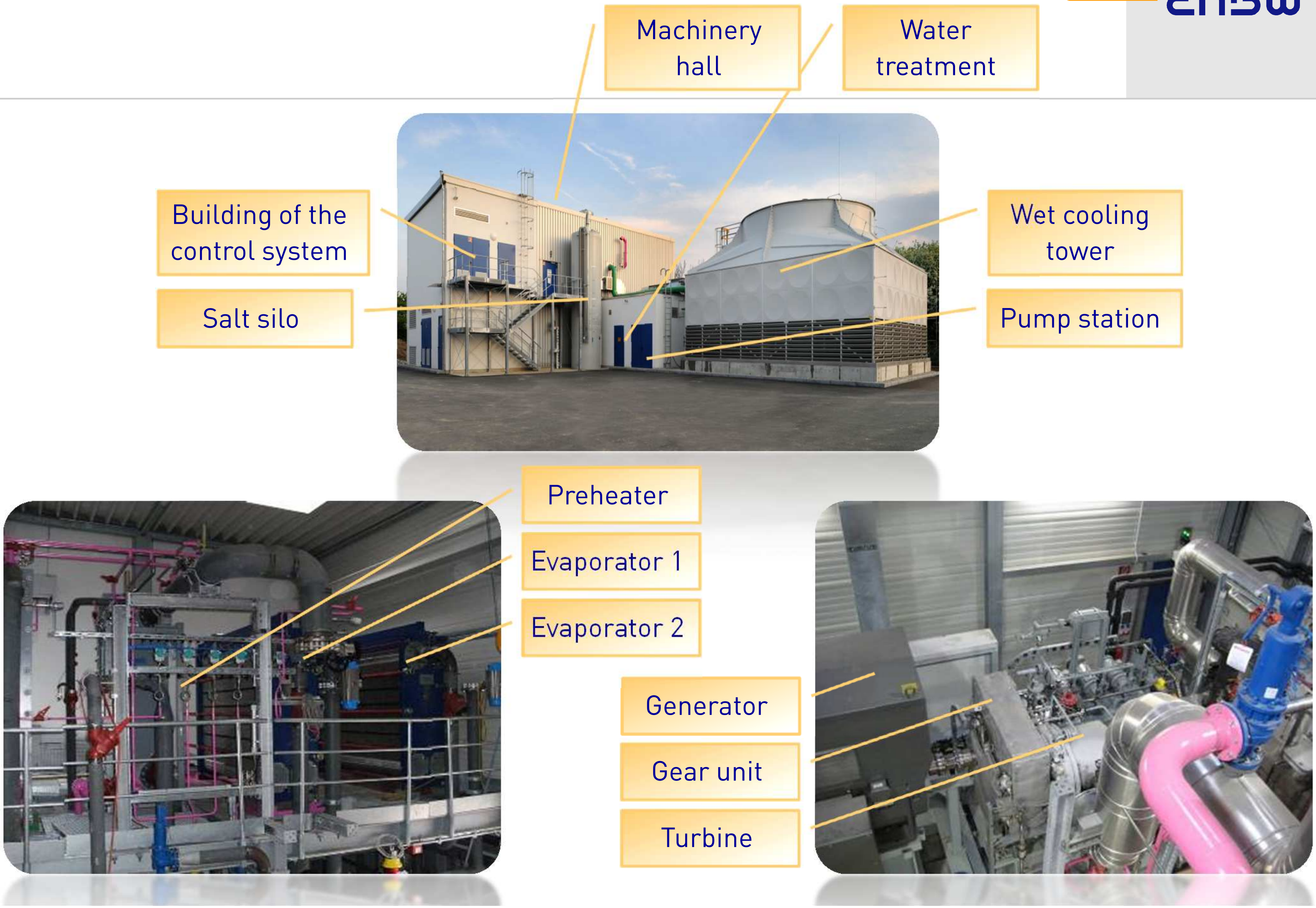
EGS-power plant

4
Number of boreholes

3600 m / 5100 m / 5100 m / 5260 m
Depth of GPK1/GPK2/GPK3/GPK4

Electric submersible pump/ lineshaft pump

Kalina pilot plant in Bruchsal



Geothermal power plant – Bruchsal
consortium between ewb & EnBW

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Thermal water

24 l/s
Flow rate

120 °C
Flow temperature

60 °C
Return flow temperature

~ 5.5 MW
Thermal capacity

Power plant

Kalina power plant

~ 22 bar
pressure

Water-ammonia
Working fluid

Wet cooling tower

~ 0.55 MW
Gross electrical output

boreholes

Hydrothermal

2
Number of boreholes

- 1874 m/ - 2542 m
Depth of GBI/GBII

Electric Submersible pump

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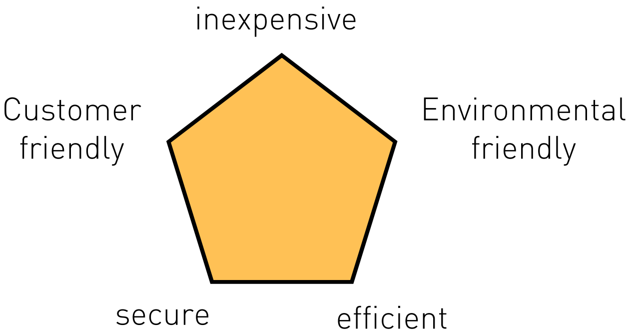
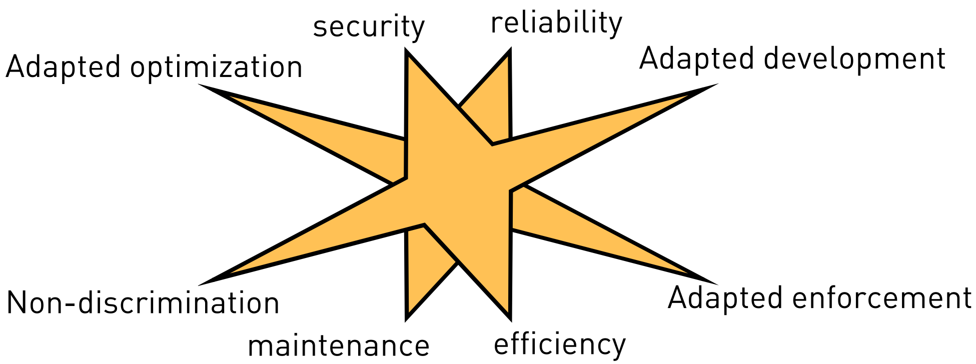
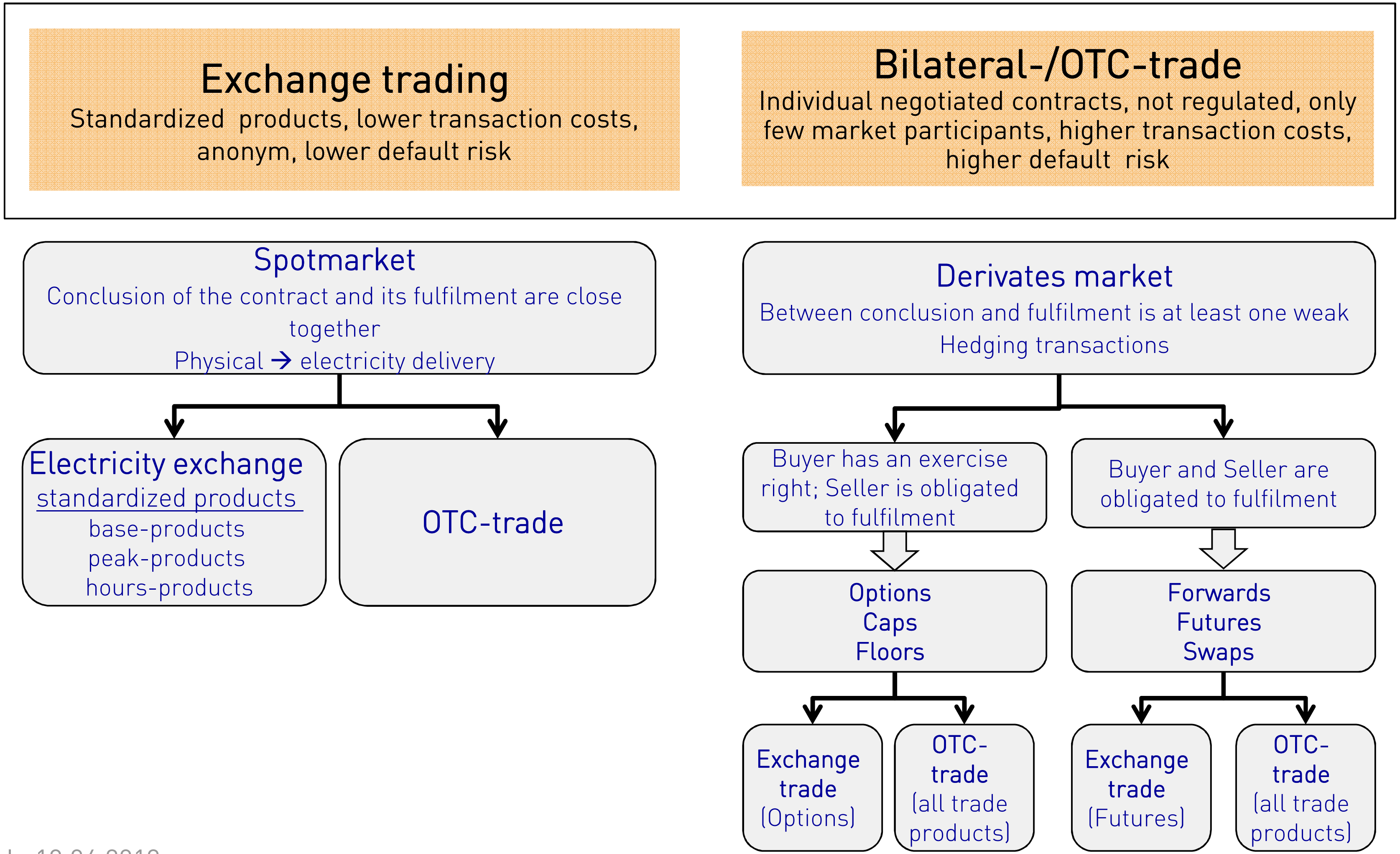
Regulation in the European electricity business





- 96/92/EC – Liberalization of electricity and gas markets
  - Free Choice of electricity supplier
  - Unbundling of production; transport; distribution; sales/trade
  - Discrimination free grid access
  - Network fees are regulated

Electricity trade in the liberalised market



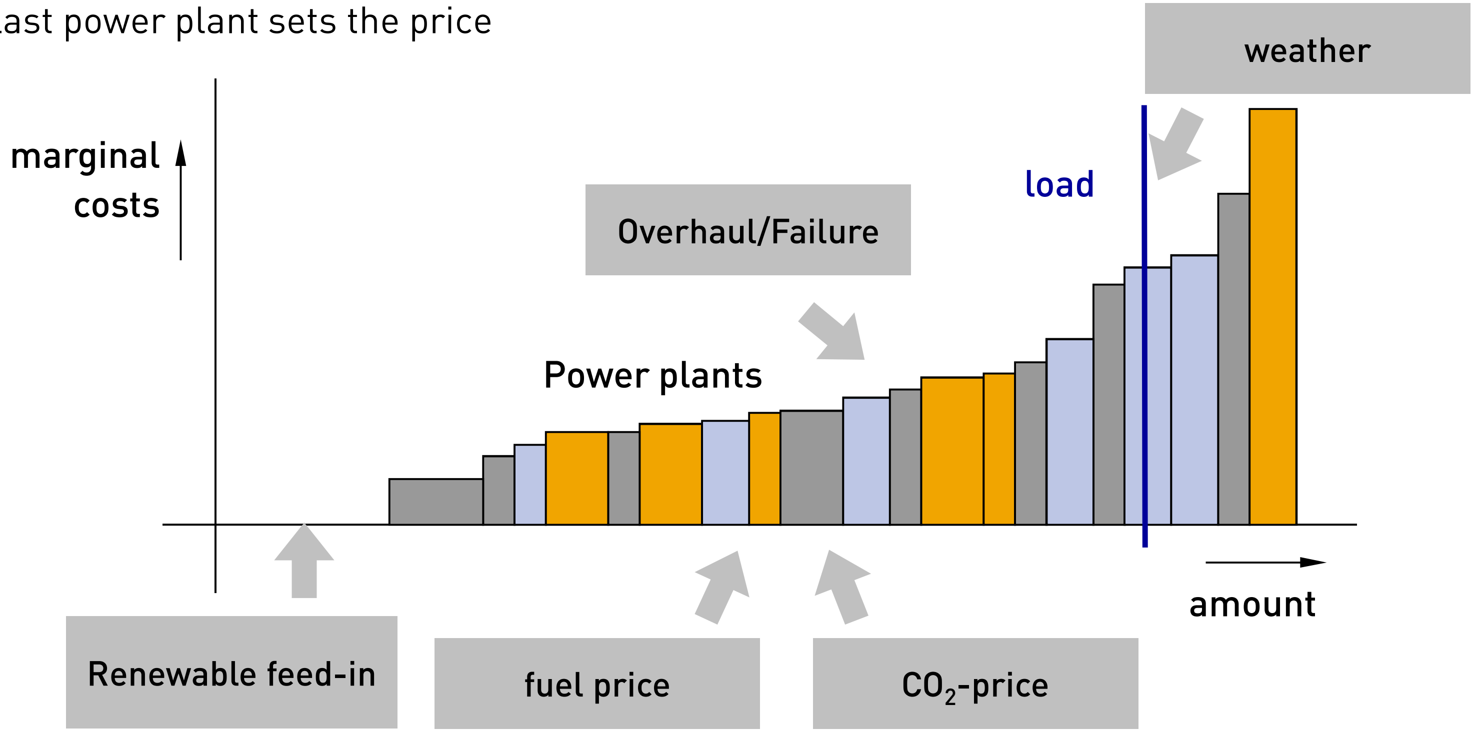
Source: Konstantin, 2007, S. 42

Electricity trade in the liberalised market

Development of the electricity price - theoretical

- Electricity prices develop through the equilibrium of
  - Offered power plant capacity (Merit-Order)
  - Load demand
- Amount offered, price and demand are influenced by different circumstances.
- Typically there are hourly price equilibriums identified

  → This means 8760 different markets with different influencing factors
- The last power plant sets the price

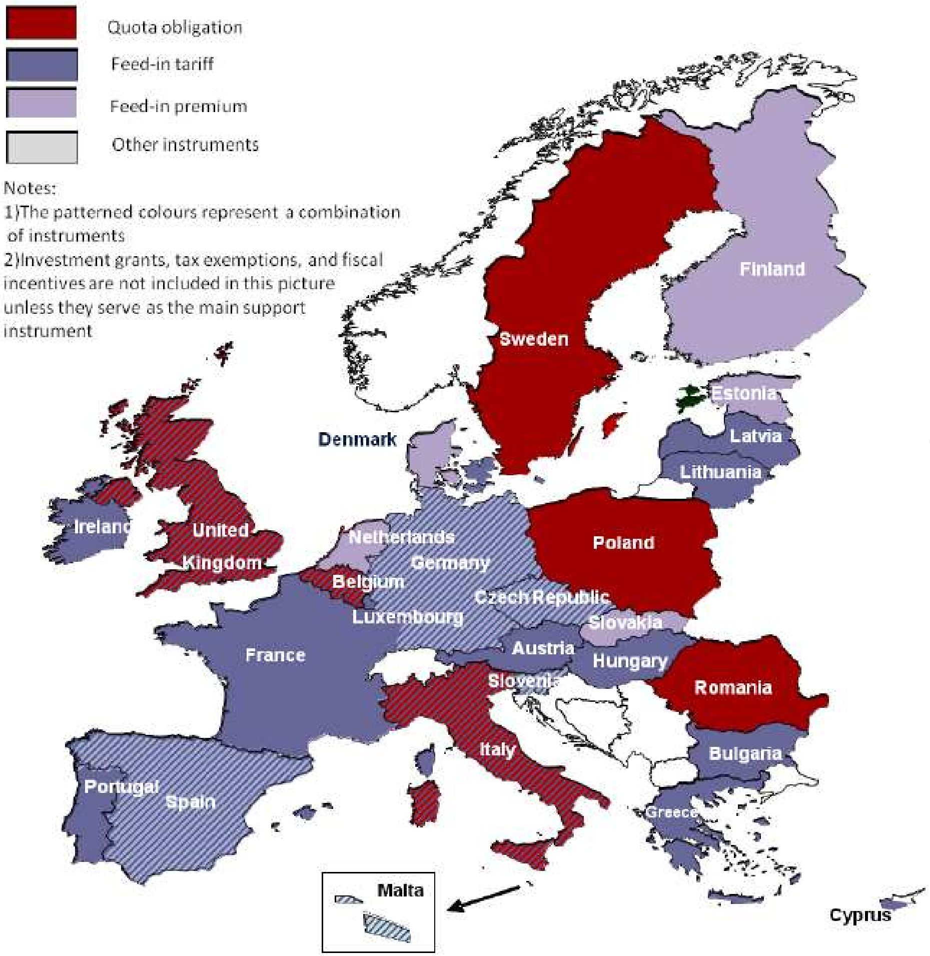


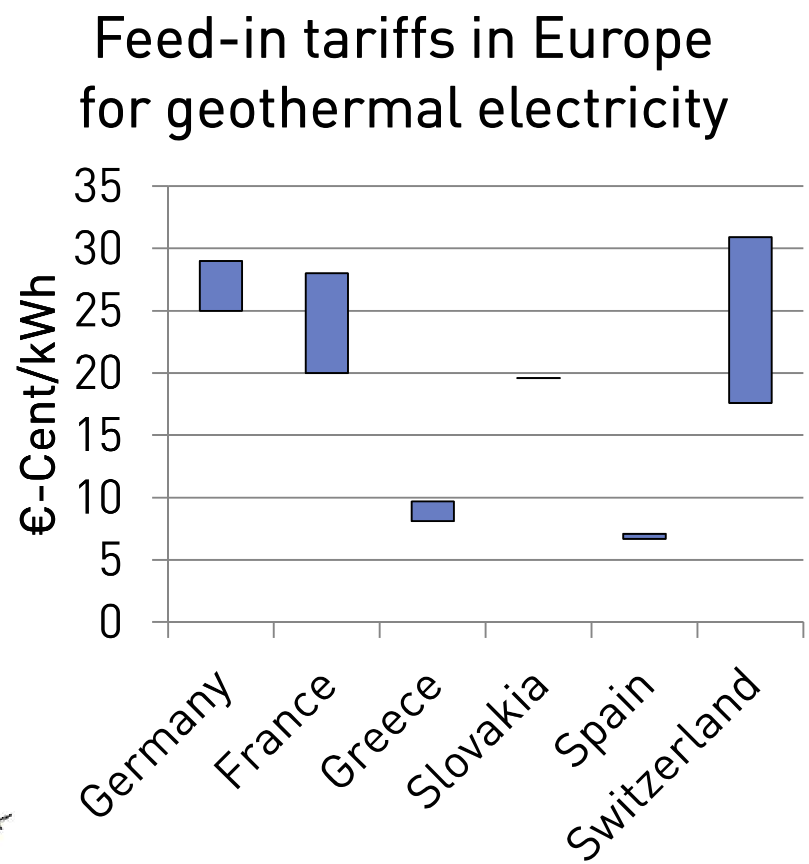
Support Systems for renewable energy in Europe Directive 2009/28/EC

- Goals
  - Reduction of CO_2 – emissions
  - Reduction of the dependence on fossil energies
  - Fulfilment of the individual goals from directive 2009/28/EC
- Directive 2009/28/EC guaranties a priority feed-in for Renewables

Feed-in tariffs	• Legal determined feed-in tariff • Customers are charged for the extra costs
Quota systems	• Legally determined quota for RES in the elec. production • Projects are financed through energy price and certificate price
Tender models	• Tendering for a fixed amount for renewable capacity • Cheapest project is done
Tax reduction	• Tax reduction for renewable energy • Widely used

Support Systems for renewable energy in Europe





Source: Ragwitz et.a l.; 2012; Recent developments of feed-in systems in the EU

Source: Gipe; 2011; Geothermal Feed-in Tarifs Worldwide

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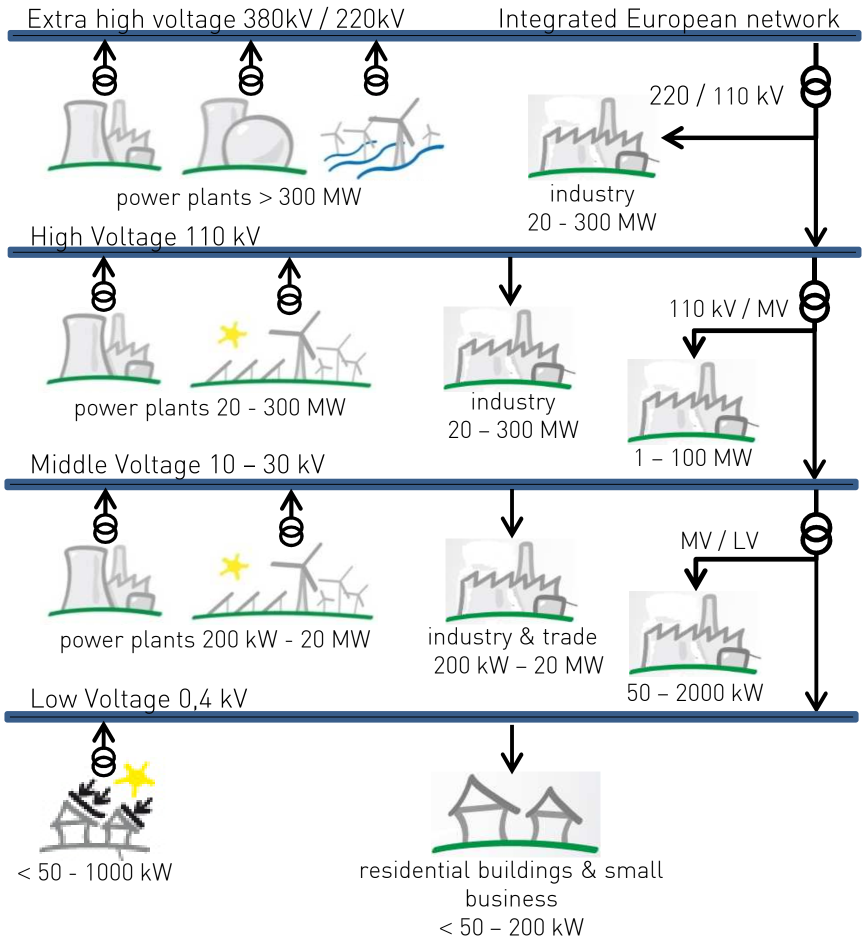
1. Energy supply
   a. Regulation
   b. Energy trade
   c. Support Systems for RES in Europe
2. Electricity grid
   a. General structure of the electricity grid
   b. Power flows in Europe
   c. Integration of renewable energies
   d. Control of the European electricity grid
3. Plant operation
   a. Demand for geothermal power
   b. Lessons learned

The electricity network



Fundamentals of electricity distribution:

$$P = U * I * \sqrt{3} * \cos\varphi$$
$$P_V = n * R' * d * I^2$$

- Different losses occur through electricity transport
  - Losses of the alternating current (AC)
  - Losses of the overhead lines
  - Losses of the wire
- Losses of the wire
  - Ohmic resistance
  - Limited heat resistance

Load distribution in the network

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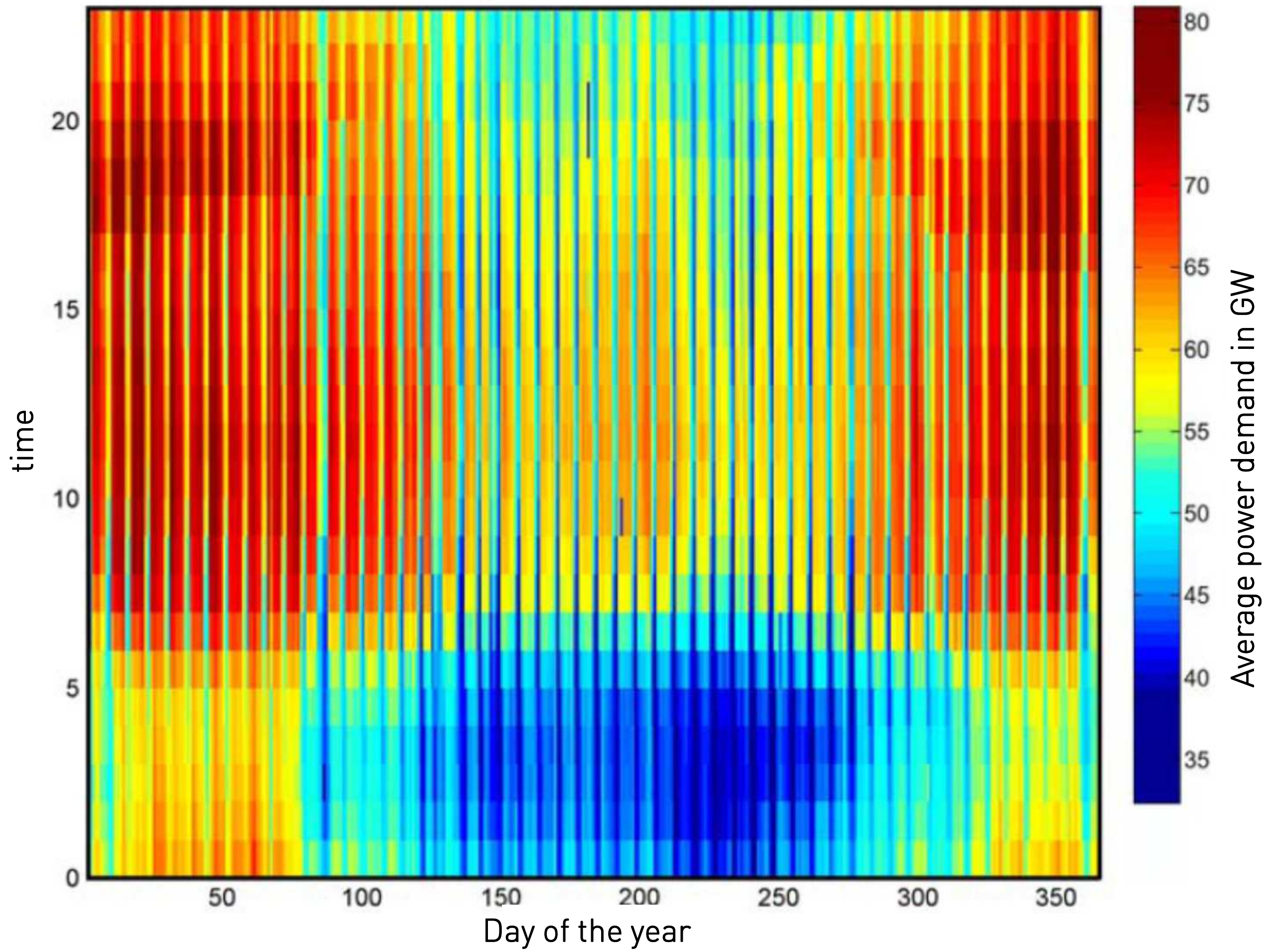
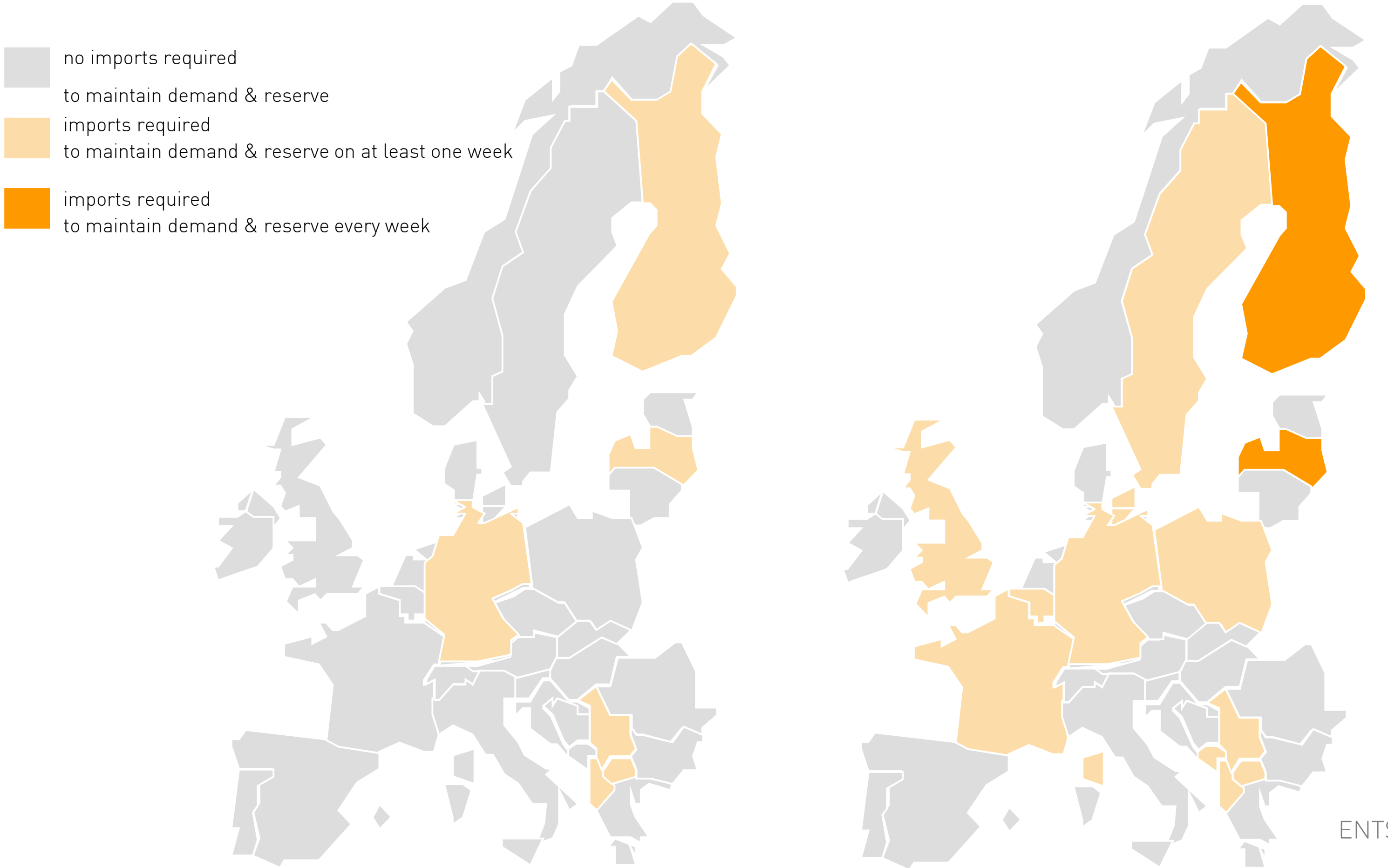
›Quelle: M.Beer, CO2-Vermeidung in DE, Teil II „Umwandlung & Ind., S.17, FfE München, 2009,



Load and demand in Europe

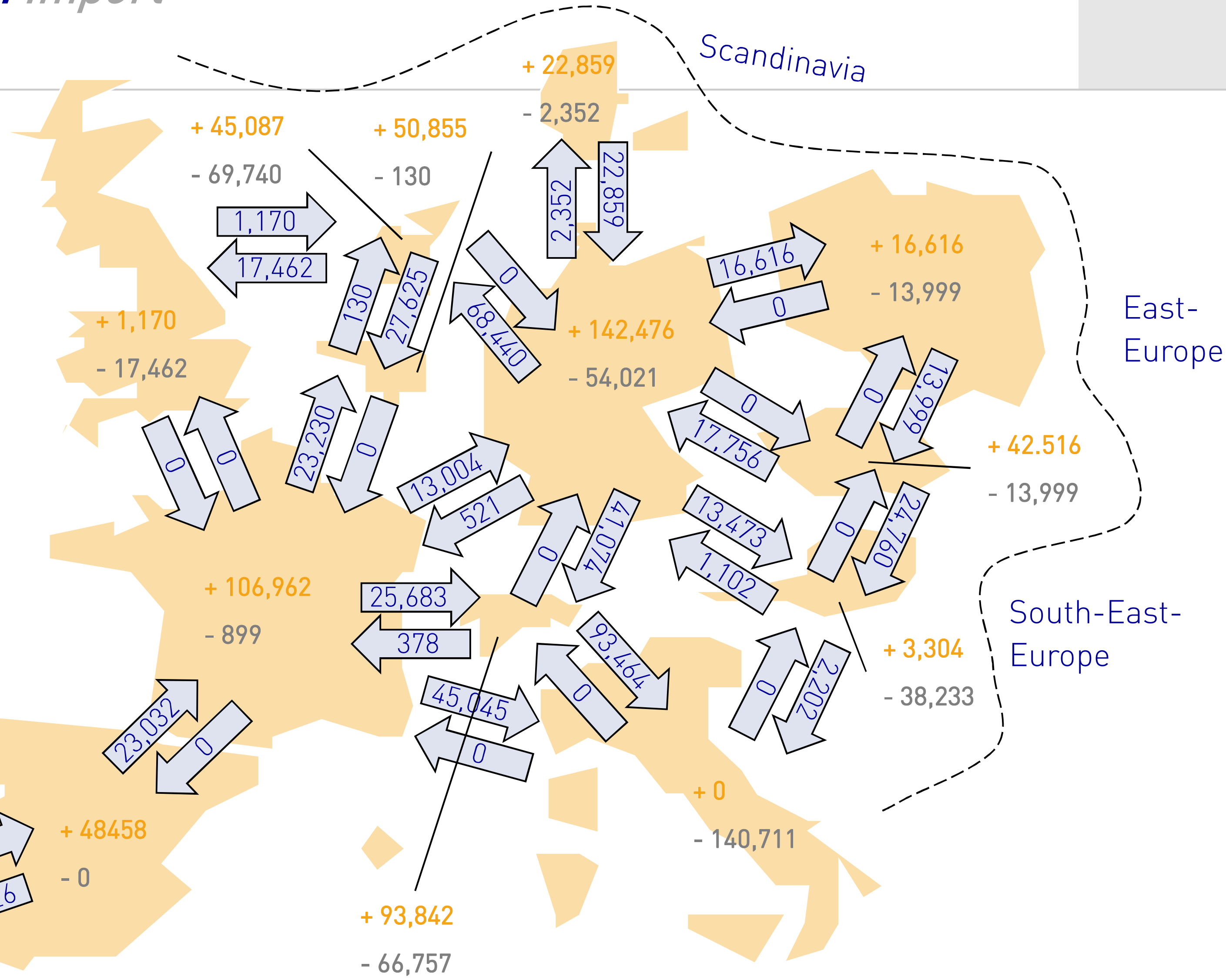
Country analyses under normal & severe conditions



ENTSO-E 2011

Physical power flows in Central - Europe 17.10.2012;

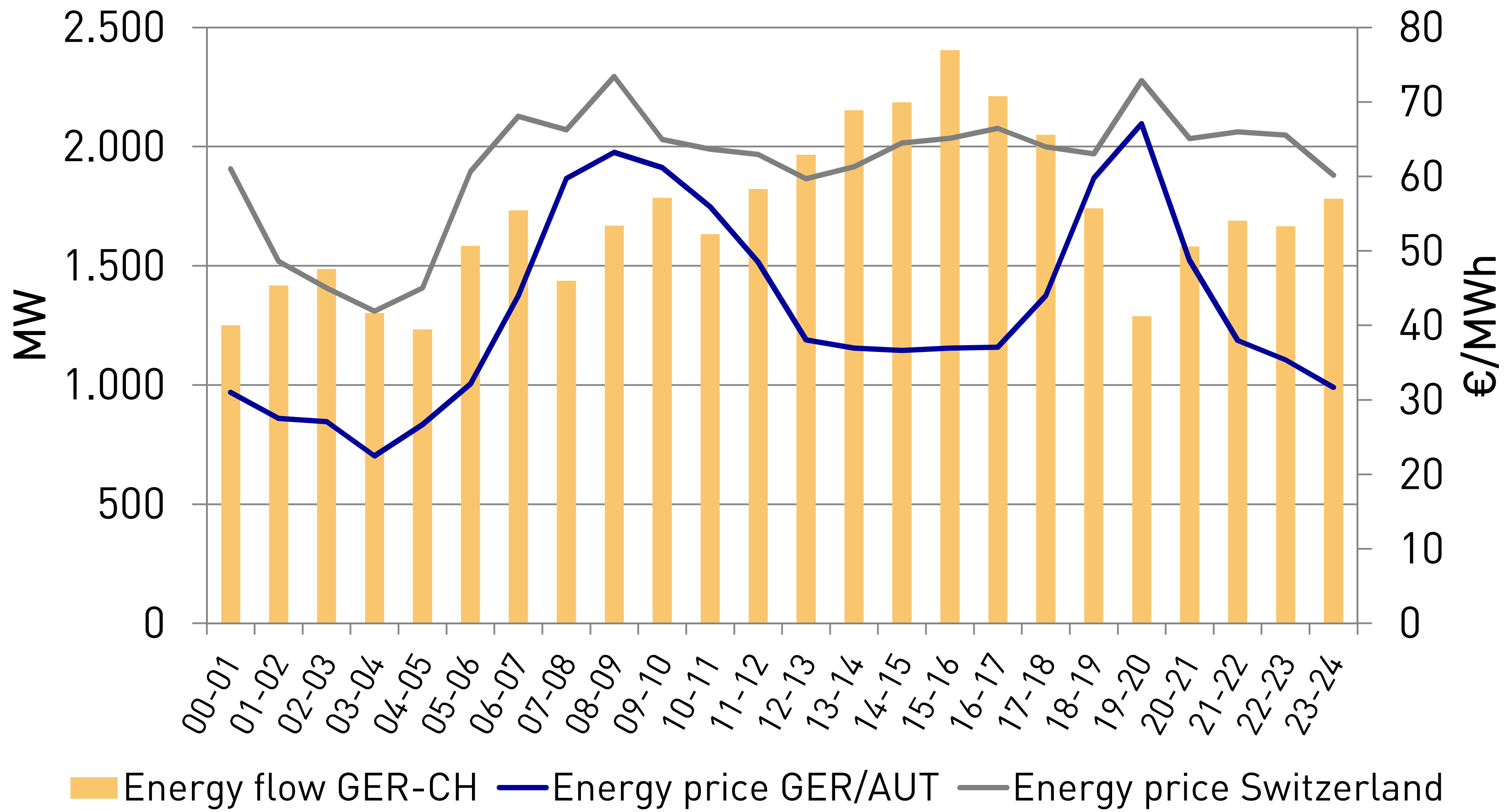
Export vs. Import



Source: entso-e

Physical power flows between Germany and Switzerland 17.10.2012

EnBW



Source: entso-e; EEX

Transport capacity – a more and more scare good
Challenges for the network operation in Europe

EnBW

Example: TenneT-control zone

- Currently there is a high burden through wind energy and trade flows from Scandinavia
- 6.200 MW transport capacity/ 3.500 MW min. demand

- Additional wind capacity
- Integration of new power plants
- Expansion of transport capacity with Scandinavia is demanded

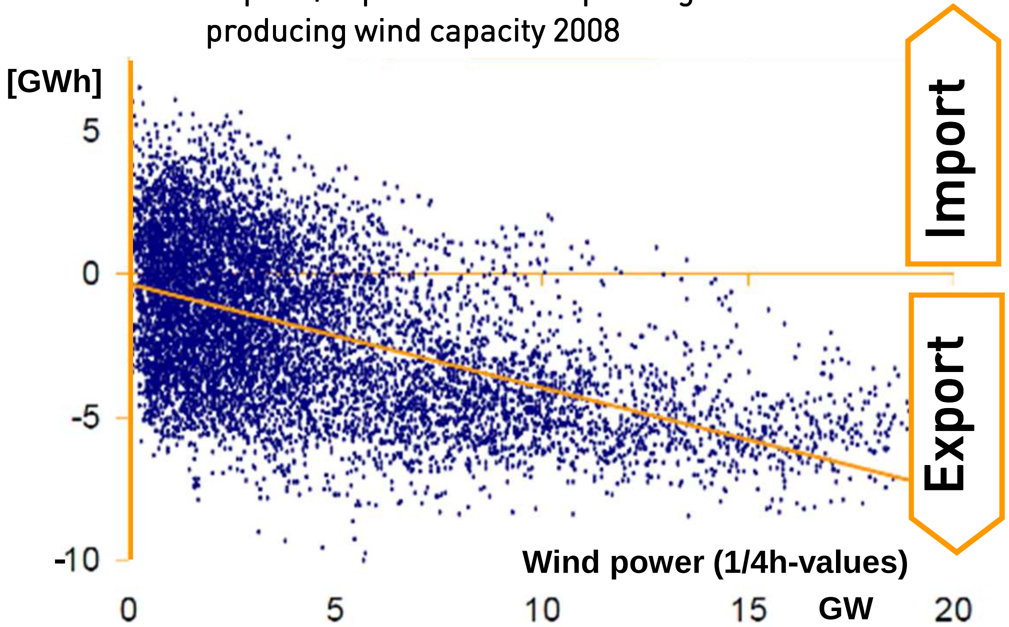
Example:

- Central Europe at the 22.12.04, 17:30 h, phys. Load flows
- Wind feed-in: 11,461 MW
- Export balance: ca. 6200 MW

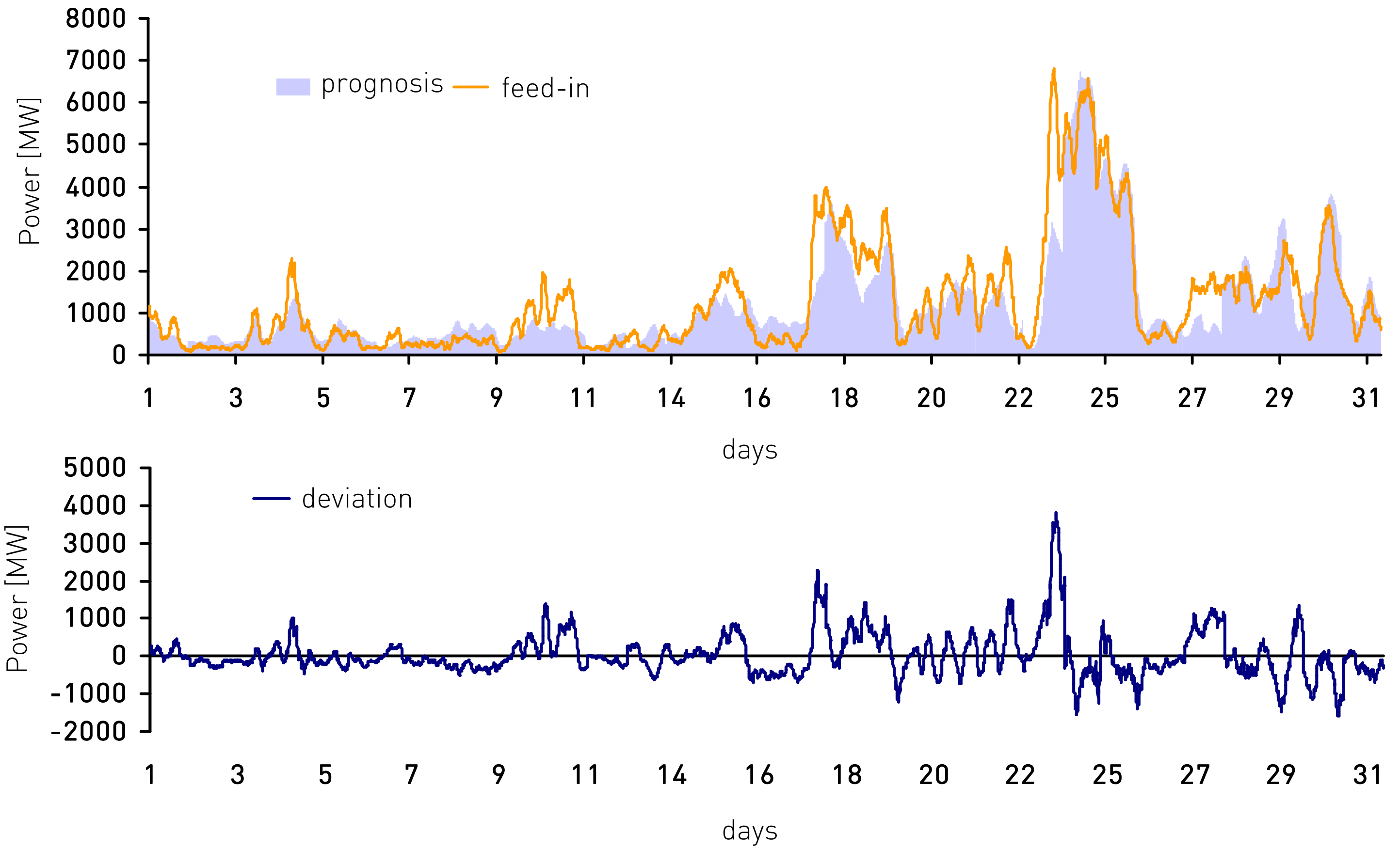
Result:

- With a growing wind feed-in the electricity is pushed in the neighbouring countries
- Growing stress on the cross-border transfer capacity
- Overloading of the neighbouring networks

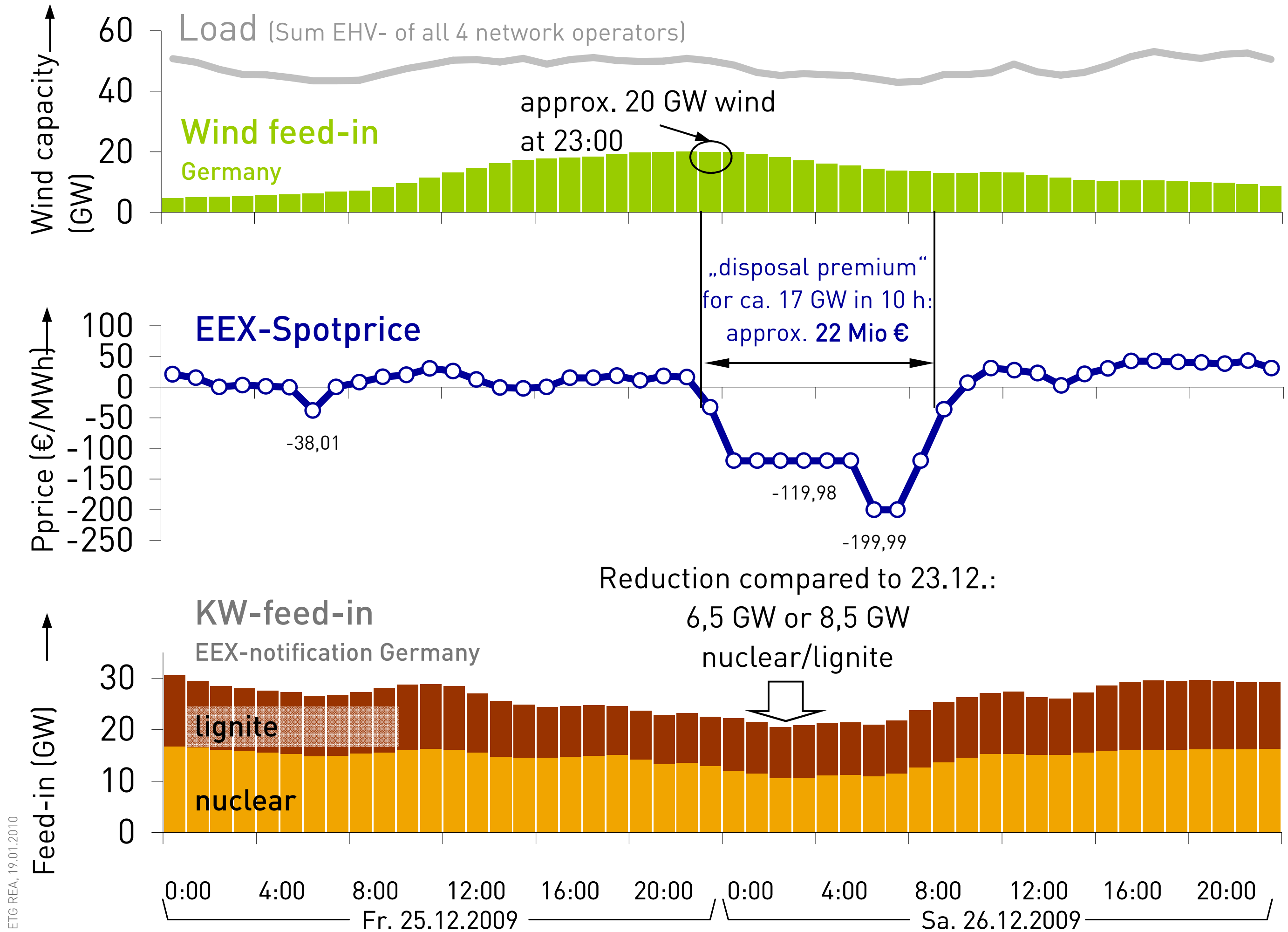
Import-/Export balance depending on the producing wind capacity 2008



Wind energy feed-in in the TenneT-network, Aug. 2010
prognosis and real feed-in



Market reaction strong wind situation 25./26.12.2009:

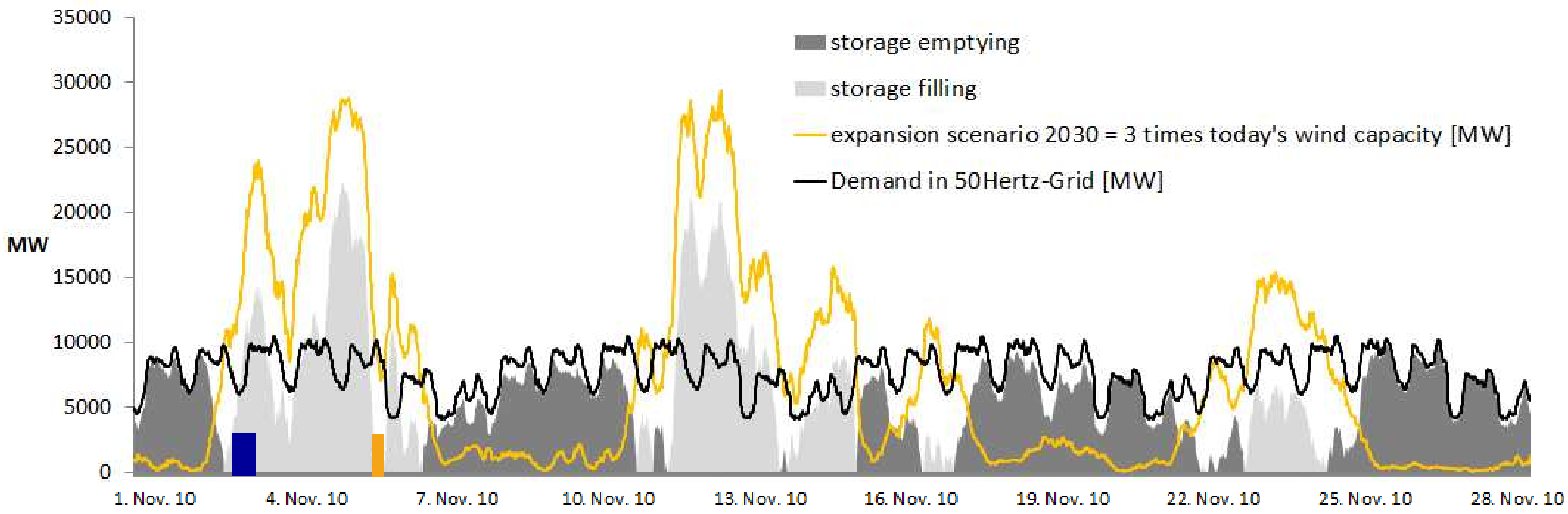


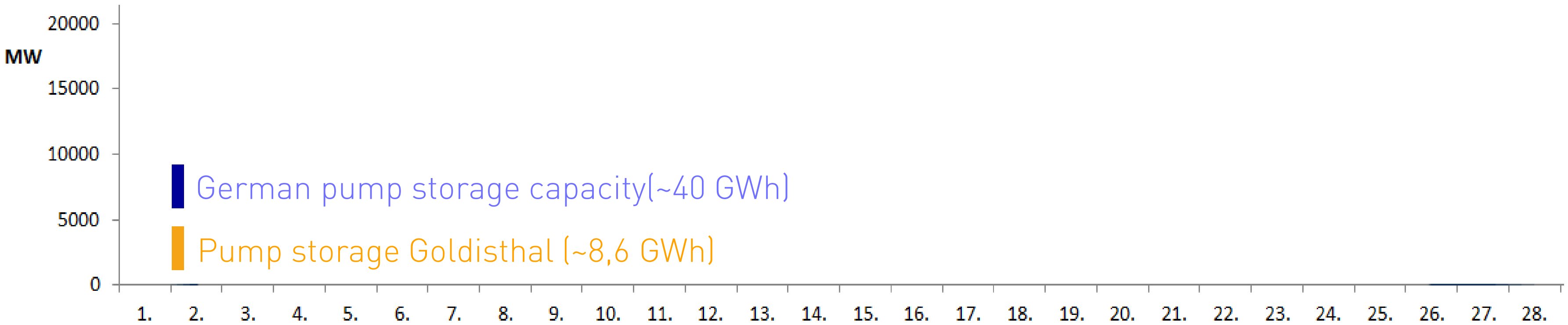
September 2012:

29.6 GW installed wind capacity in Germany

The Challenge

Difference between electricity demand and operating wind capacity





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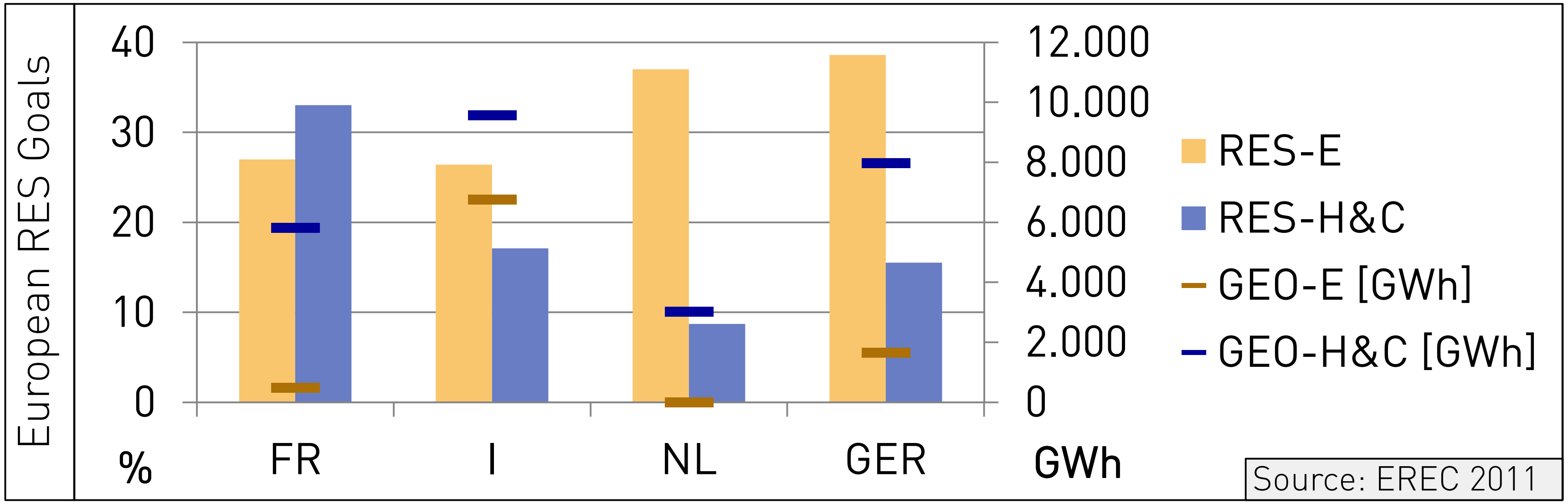
European directives and goals concerning renewable/geothermal energy sources

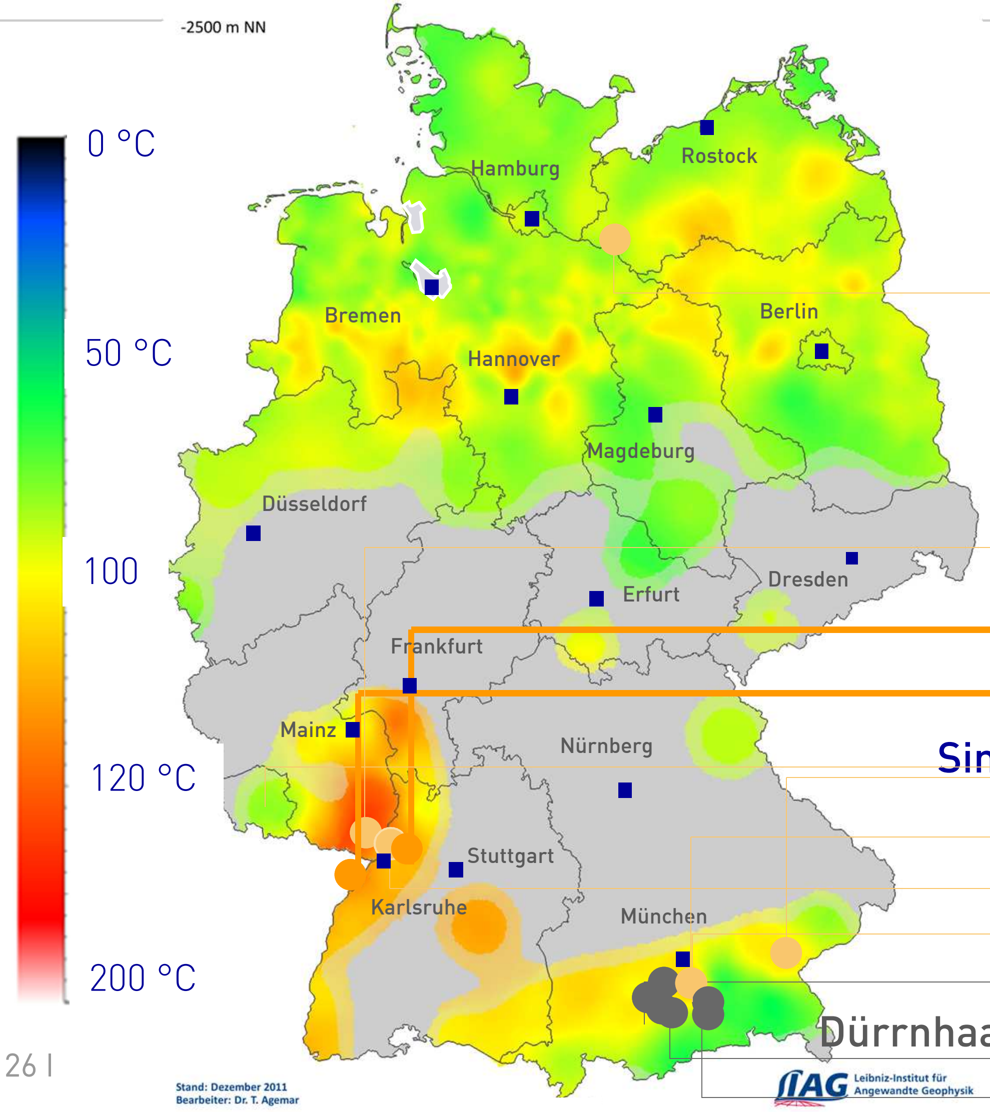
- European directive 2009/28/EC
  - Article 2a: "energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, … "
  - Article 2c: "geothermal energy' means energy stored in the form of heat beneath the surface of solid earth;"



Source: EREC 2011

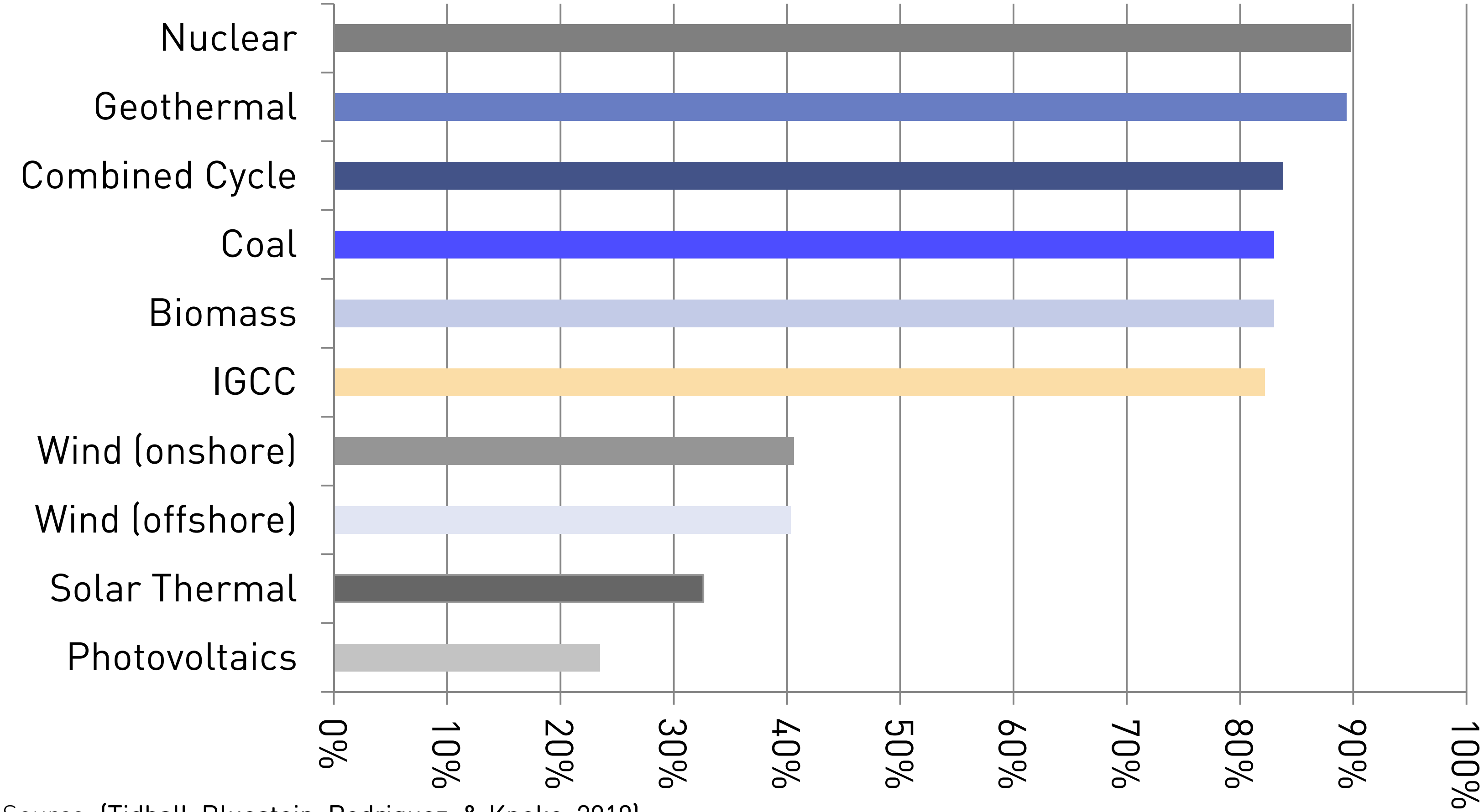
Geothermal power plants in Germany

*existing *planned



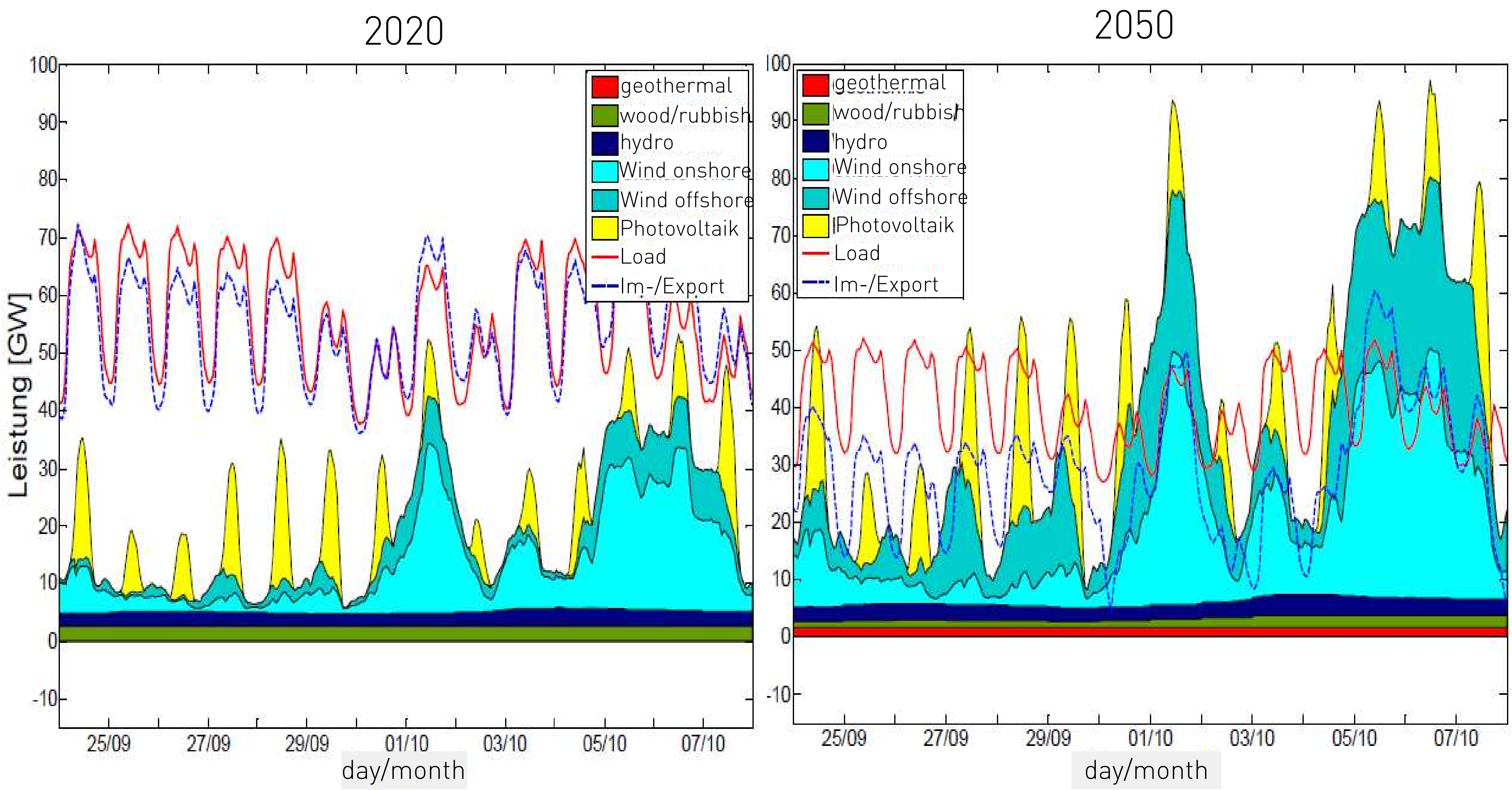
Neustadt-Glewe
Landau
Bruchsal
Soultz-sous-Forêts
Simbach-Braunau
Unterhaching
Insheim
Sauerlach
Kirchstockach
Dürrnhaar, Taufkirchen
Kirchweidach, Traunreuth

Capacity factors for electricity production
Availability of power plants



Source: (Tidball, Bluestein, Rodriguez, & Knoke, 2010)

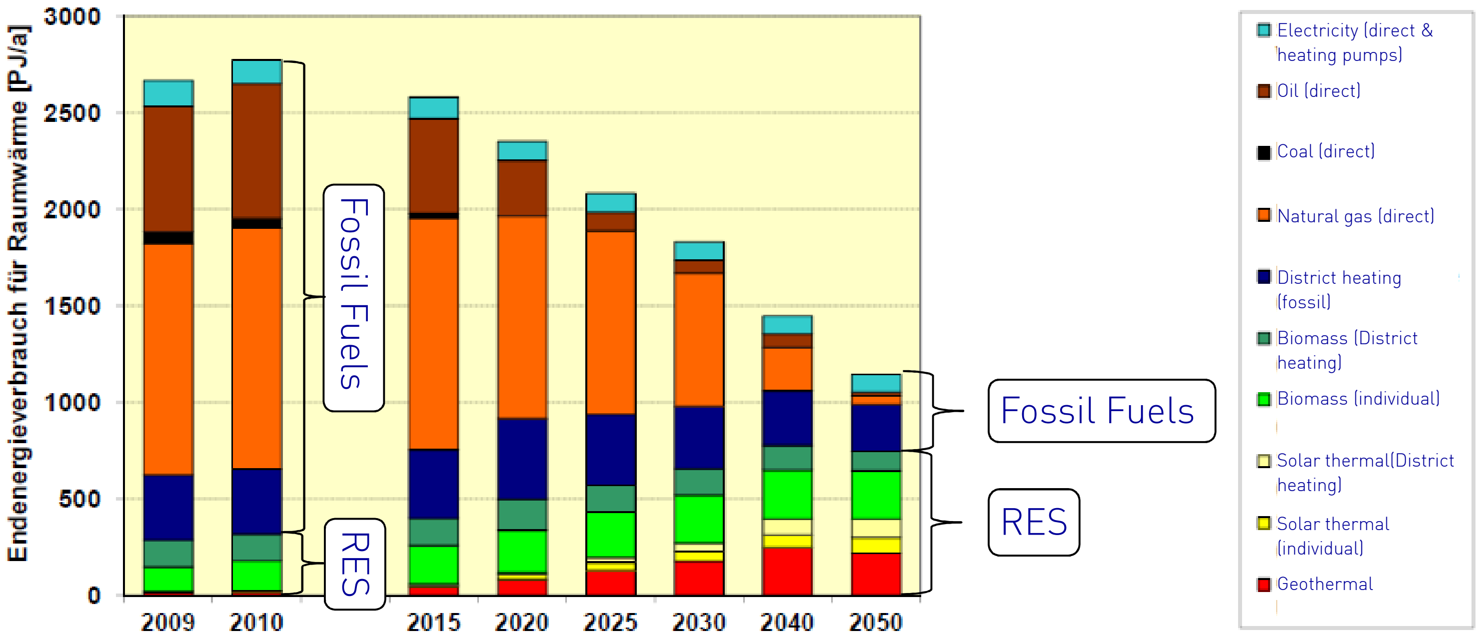
Future demand for base load power



Source: Nitsch et. al 2012

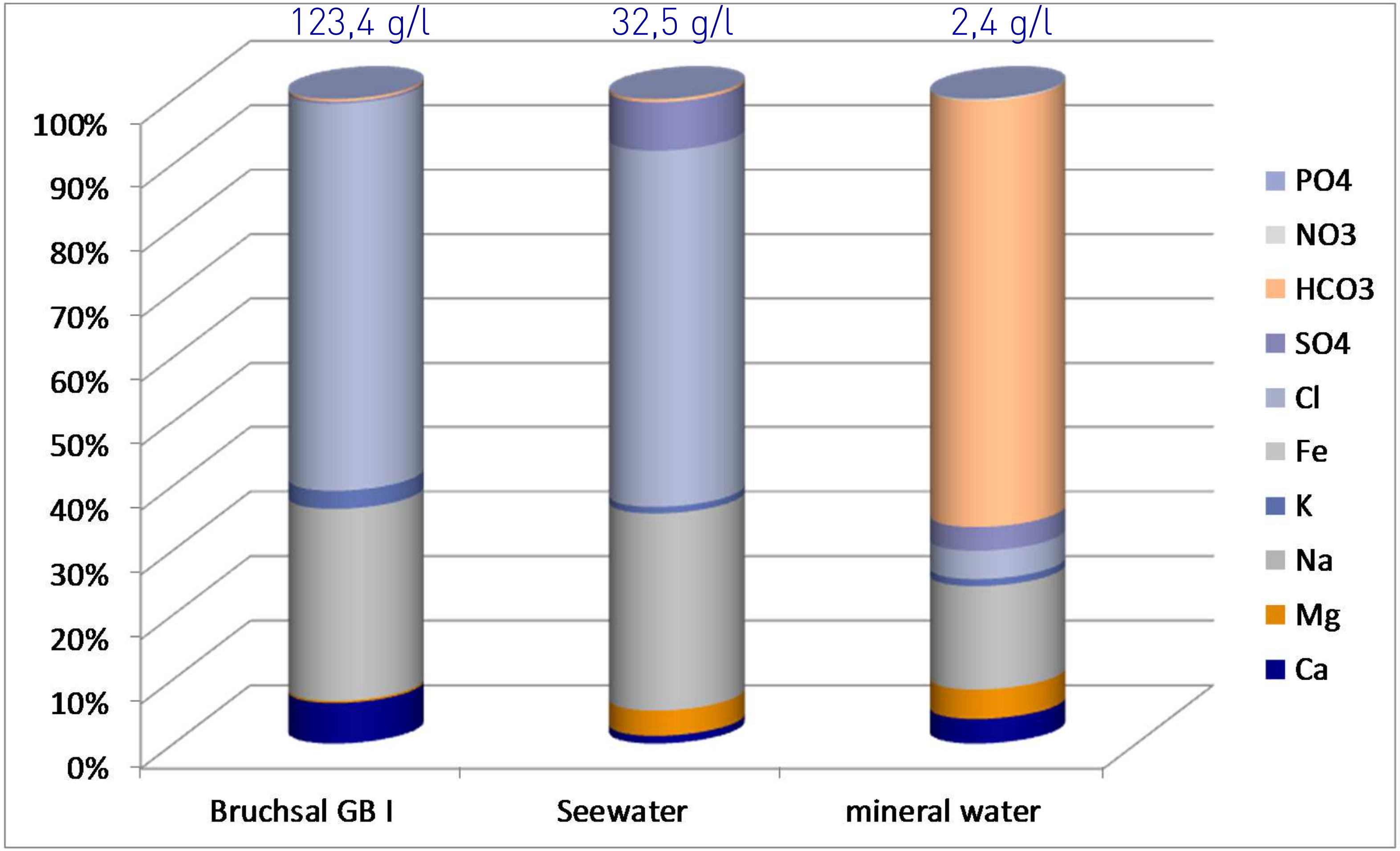
Renewable heat production – the sleeping giant of climate protection

- Ambitious goals for renewable heating in Europe
- 10.2 % of German heat demand (heating; warm water) comes From RES (2011)
- In Germany around 90 % of a households energy demand is used for heating
- Only 3 renewable Sources



Source: Nitsch et. al 2012

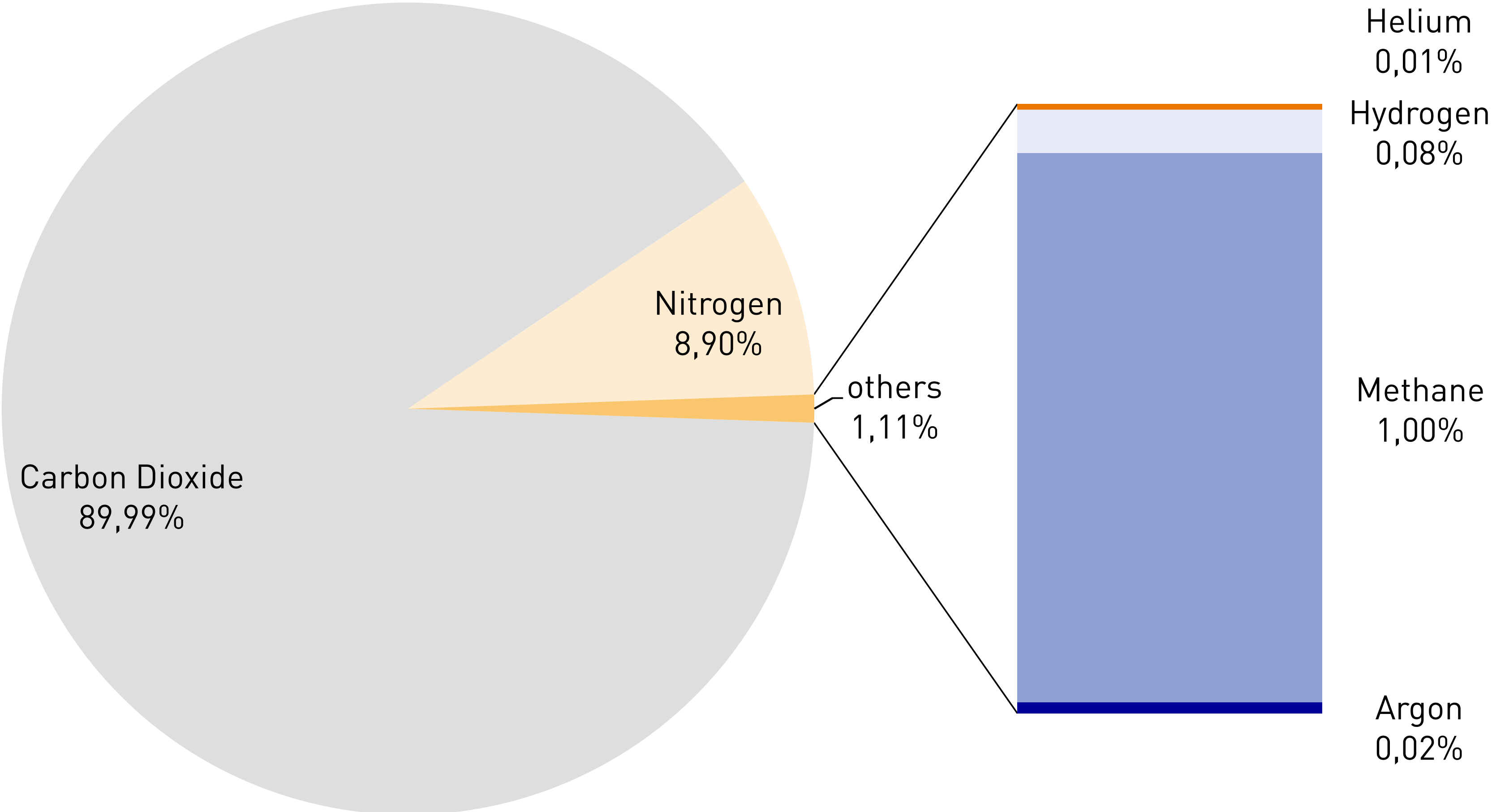
Mineralisation of the brine (Bruchsal)



Scaling - Bruchsal

Source: ewb Bruchsal

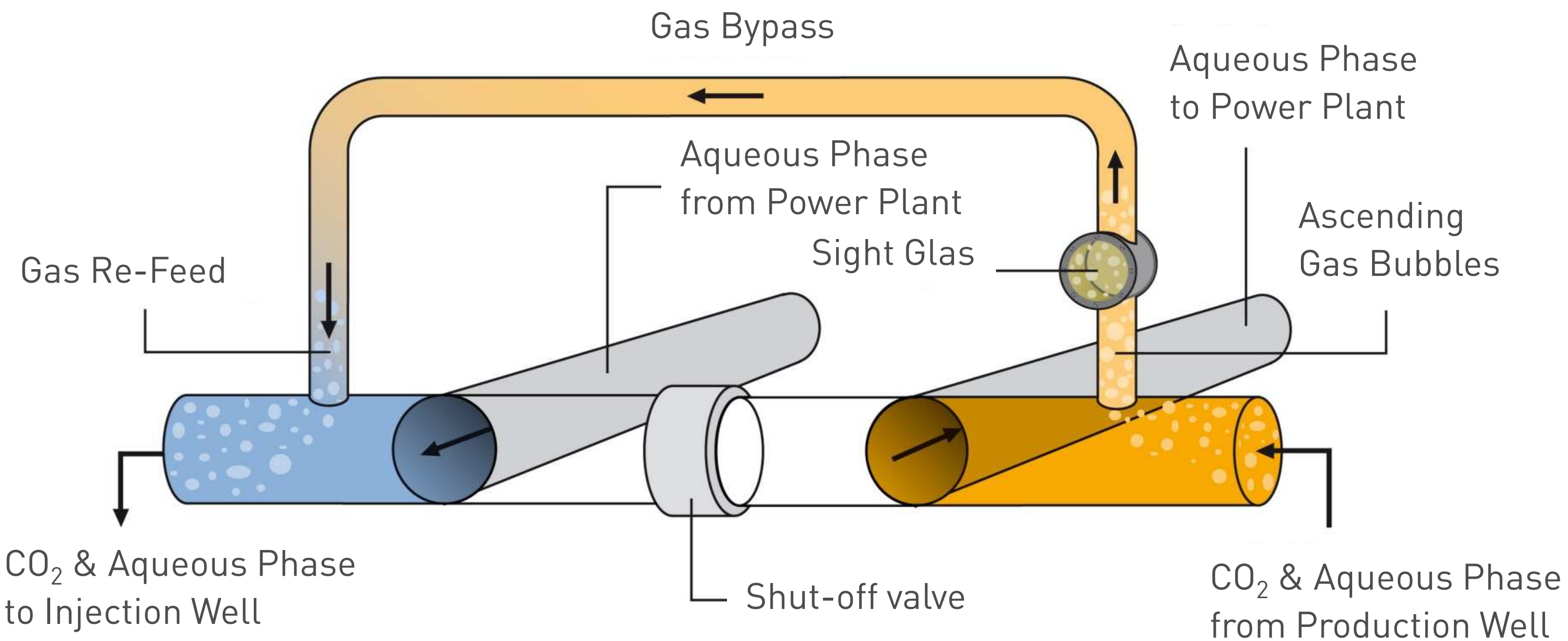
Gas Composition - Bruchsal



Gases in the geothermal brine

Two Phase Flow: CO_2 and Aqueous Phase

- Technical measures to prevent precipitations and low efficiency of heat exchange:
  - Pressure maintenance
  - Acidifying
  - Application of inhibitors



Pumping technologies applied and tested in Soultz

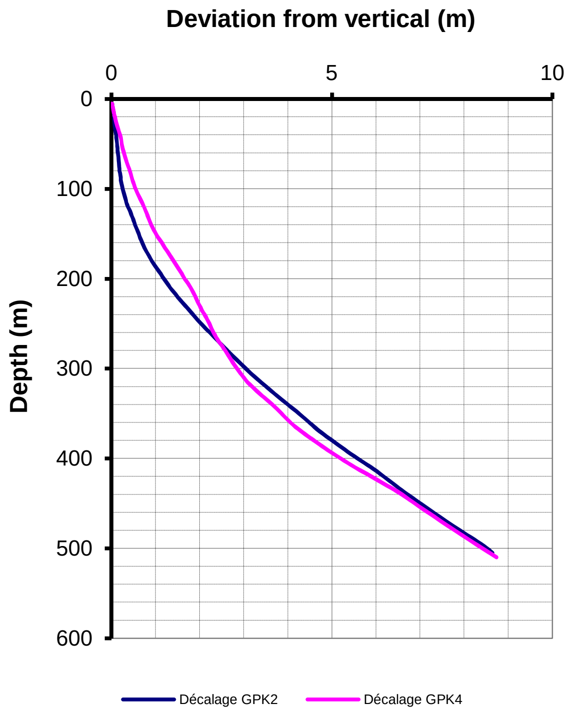
Three different kind of pumps are used in the geothermal loop

- Line Shaft Pump (LSP): the hydraulic pump is down-hole, the motor drive is at surface, connection being done through a line shaft
  ⇨ mechanical risk
- Electric Submersible Pump (ESP): both electrical motor and pump are down-hole, the motor drive is fed by a MV cable
  ⇨ electrical risk
- Injection pumps : horizontal, multistage high pressure pump (surface equipment)

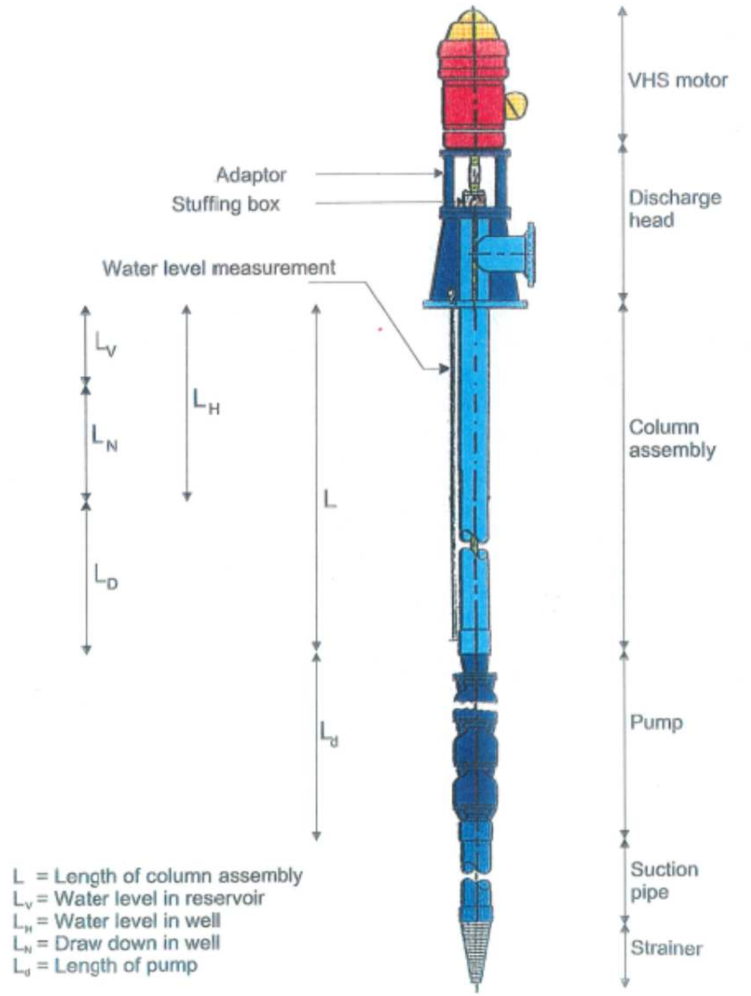
Key data LSP - located in well GPK2

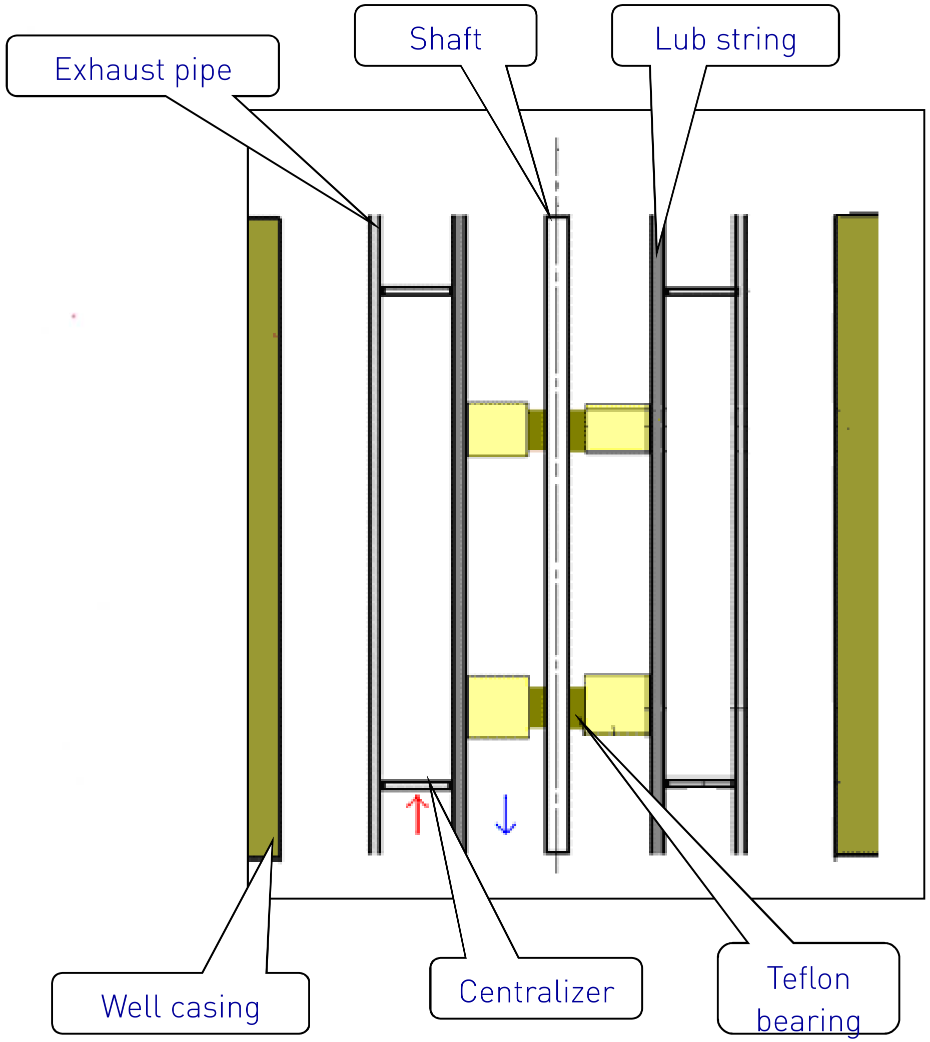
- Design data:
- Ordered in June 2006 (Manufacturer: IGE Ltd.)
- Initial shaft length of 350 m
- Max. volume flow 40 l/s
- Surface motor 350 HP, Variable Frequency Drive
- Lubrication by demineralized tap water

- operation conditions:
- Initial productivity of GPK2 was 1 l/s/bar
- Productivity improved during operation time
- The LSP is now installed at 270 m depth due to verticality issue
- ~ 25 l/s, ~170 °C and a TDH of 300 - 400 m



Working principle and general configuration of LSP





Ref: IGE Ldt.

Working principle and general configuration of LSP

riser, enclosing tube, shaft

Teflon bearings

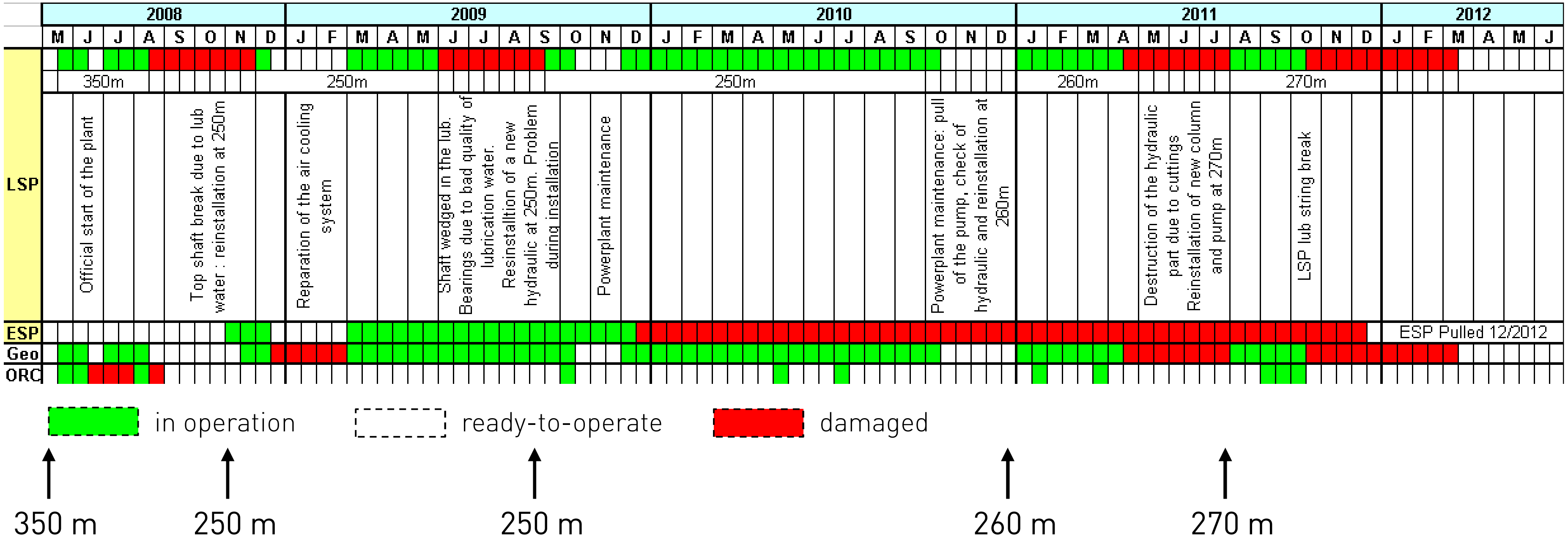
hydraulic part, 17 stages

installation

motor/shaft coupling

view at well head/motor

Operating time and maintenance of LSP



- The LSP pump has been installed/removed 5 times at different depth
- ~23 month of operation, ~15 to 20 start ups
- All installations have been carried out by the GEIE team.

Dismantling one and two due to lubrication problems

- Failure mode
- Shaft wedged in enclosing tube and broke
- Caused by bad quality of lubricant (demineralized tap water)

- Problem solving
- Re-engineer of water treatment plant

Dismantling due to hydraulic problems

- Failure mode
- Damage of impellers (all stages), bearings, centralizers and enclosing tube
- Caused by abrasion, corrosion, local cavitation?
- Problem solving
- Material selection, adapted operation conditions (to be proven!)



Design and operation improvements done for the restart in March 2012

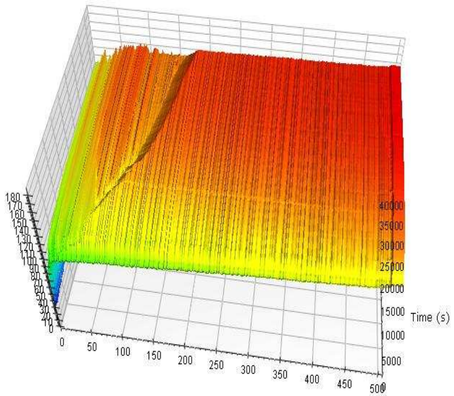
- Test of new bearing material (lub string): Bronze
- Increase the number of stages in order to decrease the rotation speed of the pump ⇨ avoid vibration problems
- Replacement of damaged parts (hydraulic part, piping)
- Adjustment of shaft diameter ⇨ reduce sleeve diameter from 47,5 to 47mm
- Renew surface connection (shaft/motor coupling)

Key data ESP - located in well GPK4

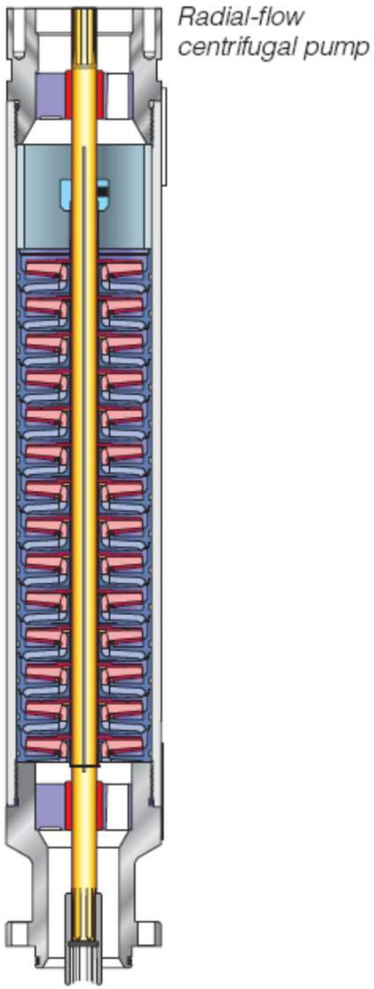
- Design data:
- ESP REDA Schlumberger ordered in June 2007
- 339 kW, max. 40 l/s, min. 20 l/s, total ESP length of 20 meters
- Specific high temperature design for brine temperatures of 185 °C; Motor is cooled by hot geothermal brine why oil temperature can reach up to 260 °C
- Noble materials due to specific working conditions
- Temperature monitoring along ESP

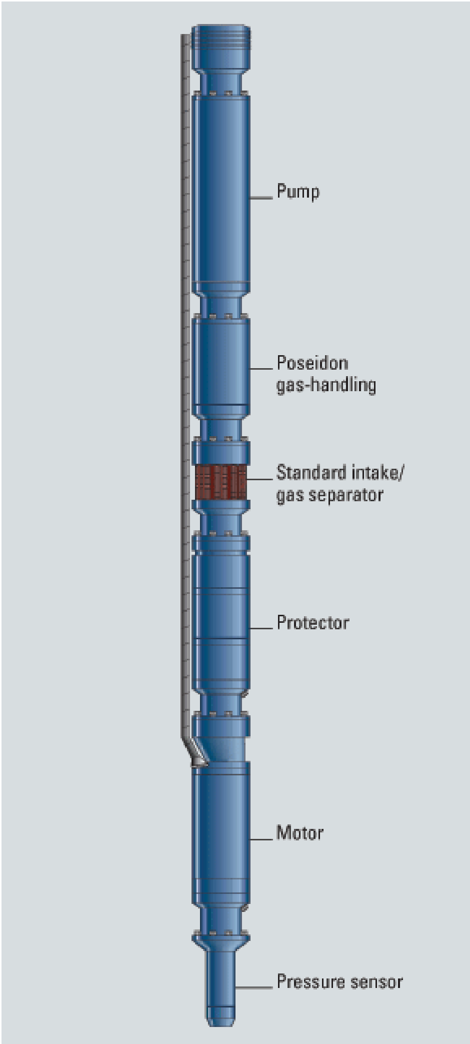
operation conditions:

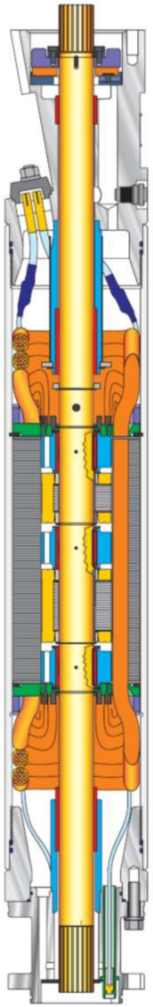
- Installed at 500 meter depth in GPK4
- ~ 25 l/s, ~170 °C and a TDH of 400 to 600 m



Working principle and general configuration of ESP

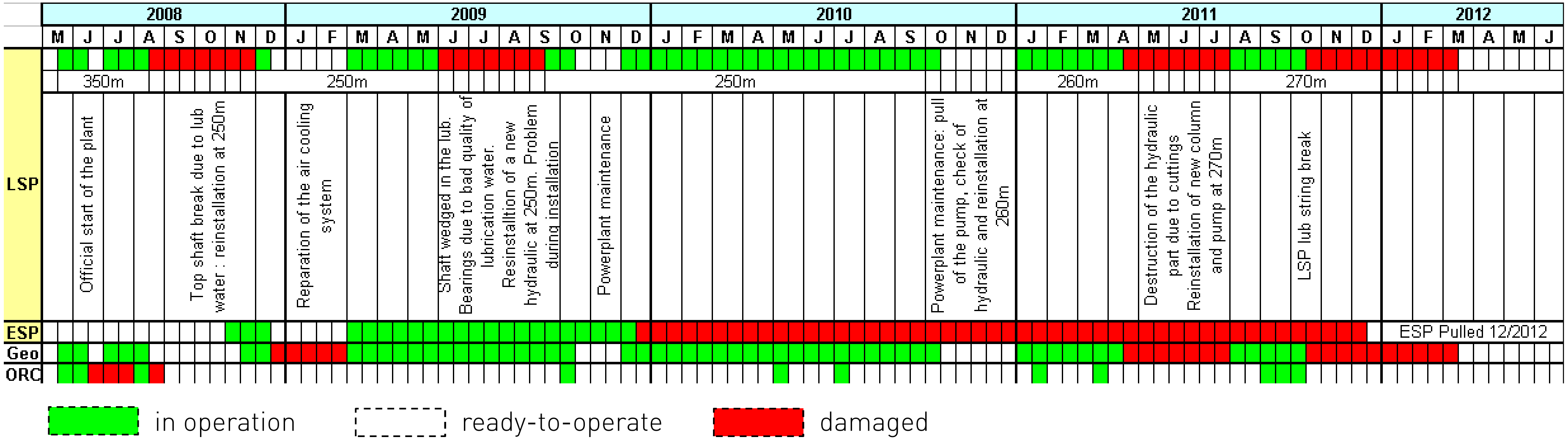






Ref: Reda/Schlumberger

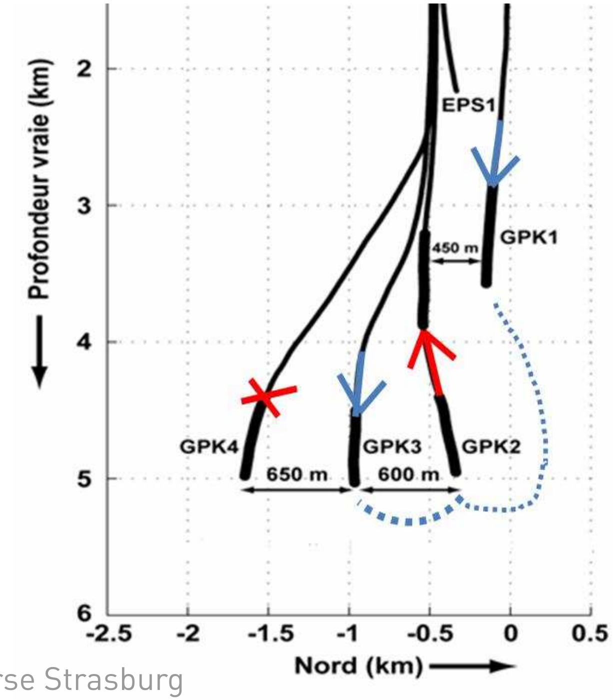
Operating time of ESP



- The ESP was installed from November 2008 to December 2011
- 10 month of operation, 12 start ups
- Operation outside operating range, as GPK4 is no good producer
- Tear down analysis is still in progress

Injection pumps

- Injection pumps were used in 2008, 2009 and beginning of 2010 to re-inject the brine into GPK3
- Since 2010, trial of a new strategy without reinjection pump
- Today brine is re-injected in GPK3 (deep reservoir) and GPK1 (upper reservoir) without pumps
  - ⇨ System is working
  - ⇨ Temperature decrease of ~7 °C due to new concept



Comparison ORC and Kalina

ORC

Commercial available

Organic, pure fluid as working fluid

Isotherm evaporation and condensation

Higher exergetic loss

Less complex, no separators

Source G.E.I.E, 2010

Kalina

Currently only few power plants

Zeotropic mixture of Ammonia/water as working fluid

non.- isotherm evaporation and condensation

Better adaption of the cycle to the heat source

Separators necessary

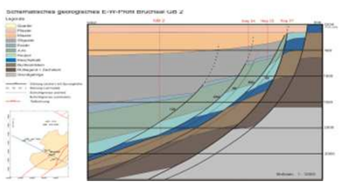
Experience: operation is manageable

Engineering and design seems to be challeging

Outlook: Research in the field of deep geothermal energy

Environmental influences

- noise
- Natural radioactivity
- Optical influences
- etc.



Quelle: AGW am KIT

Power plant technology

- corrosion
- scaling
- Aqueous chemistry
- Plant operation
- etc.

Reservoir

- Reservoir management
- seismicity
- Hydraulic behaviour of bore holes
- etc.


Geothermal Power...
...inexhaustible!
EnBW
Thanks for your kind attention!