Energy Storage – the Future of Renewables?

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TECNOLOGÍAS E INFRAESTRUCTURAS
PARA EL DESAFÍOENERGÉTICO EUROPEO
Universidad International Menéndez Pelayo
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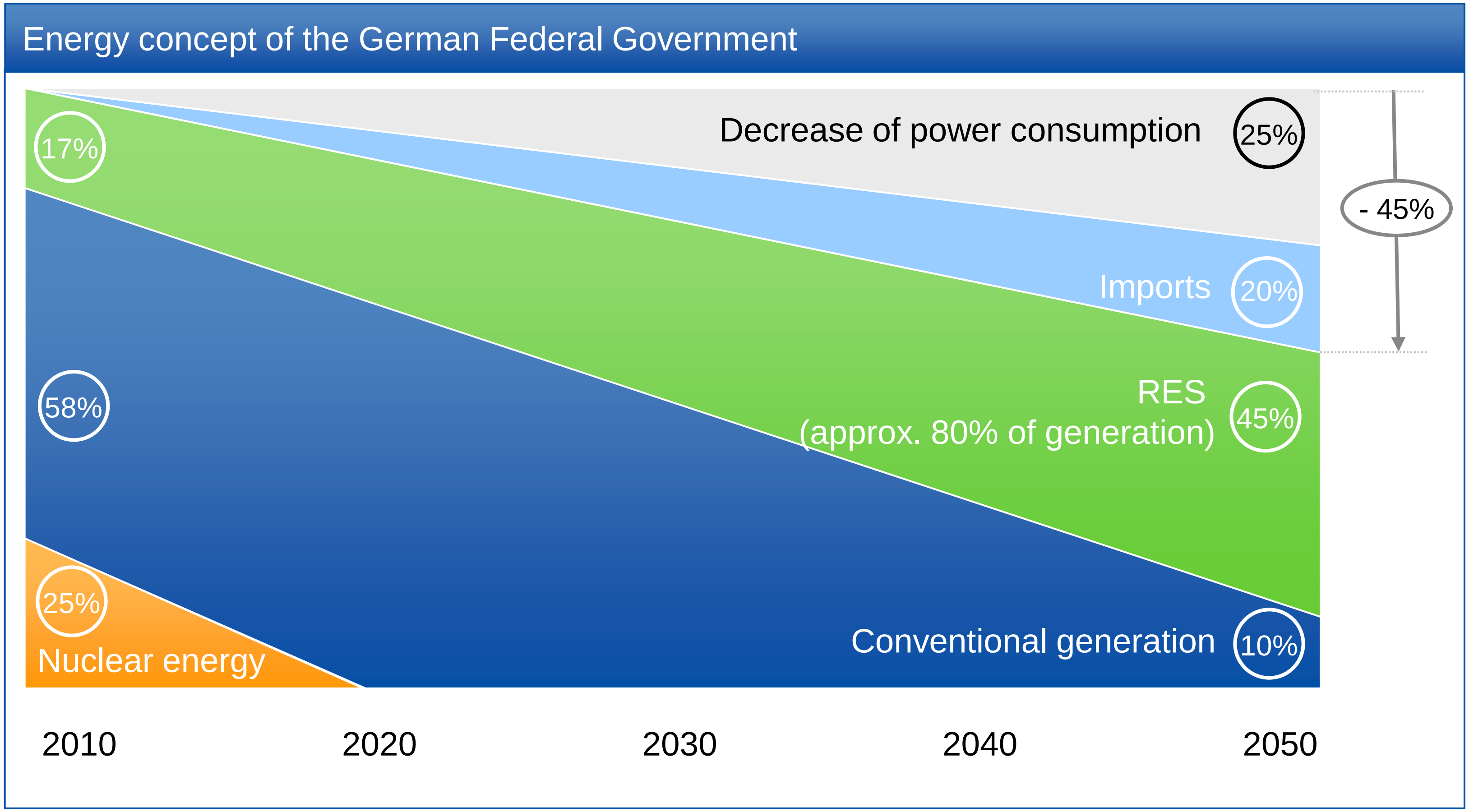
Agenda

1. **initial situation of the German "Energiewende" (paradigm change towards renewables)**
2. central storage within the transmission grid / ADELE technology development
3. economics of bulk storage

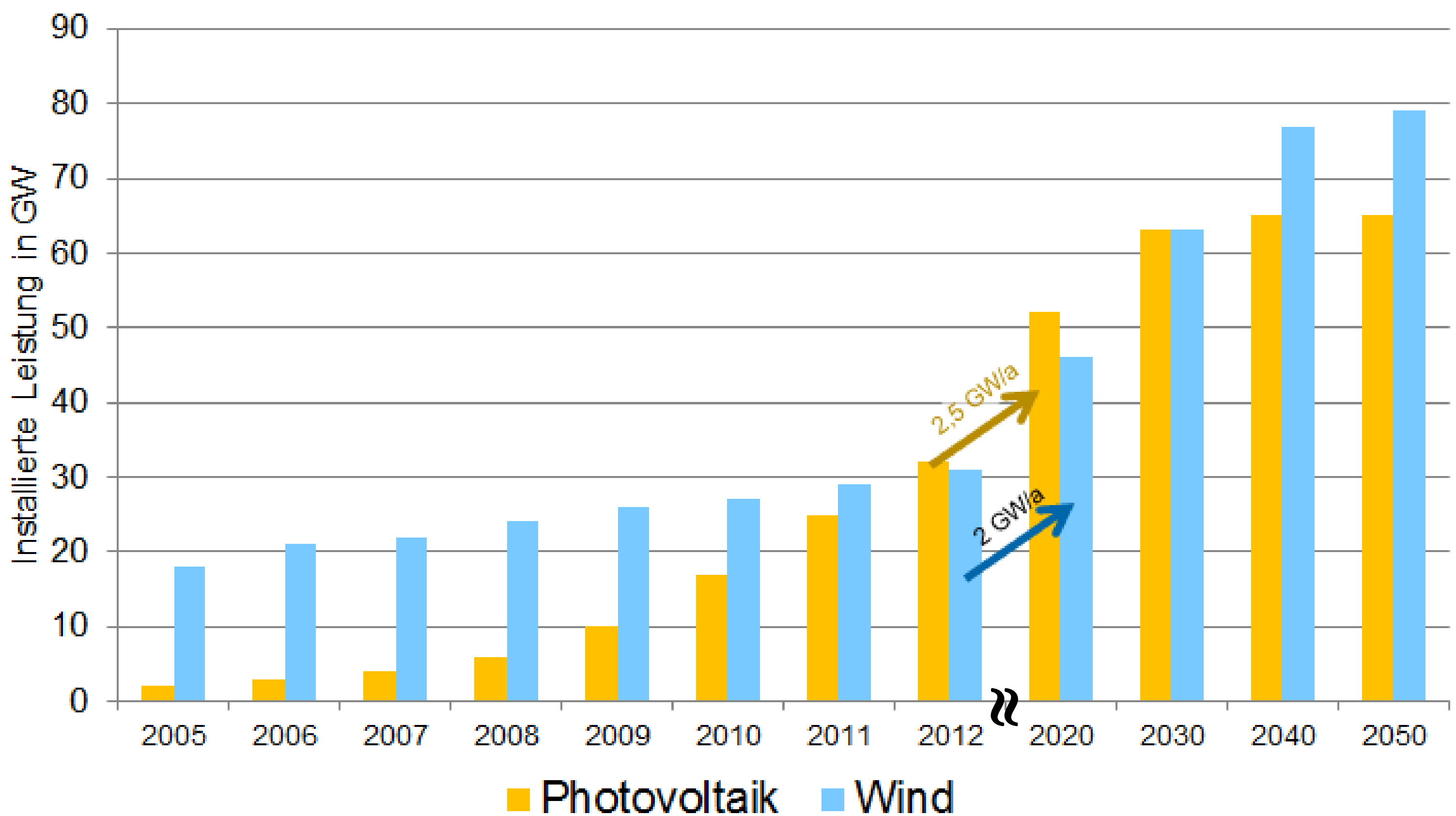
The German Federal Government assumes a decrease of power generation of 45 % until 2050



Source: EWI/Prognos/GWS Studie

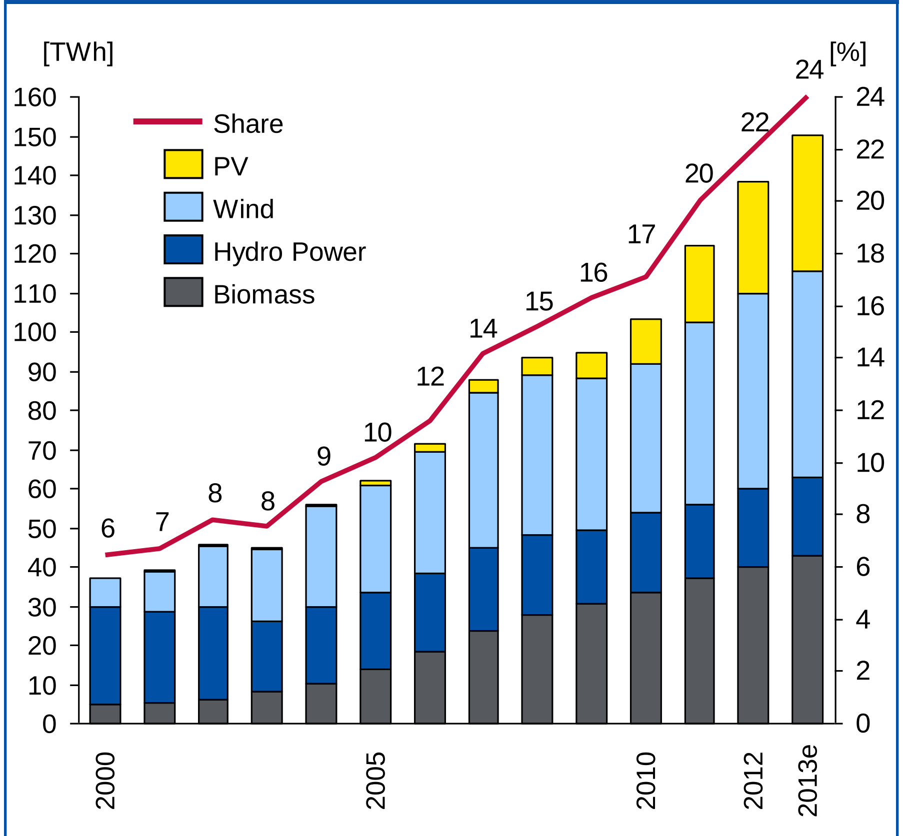
Fluctuating power generation will continue to increase

Development of installed capacity of generation by wind and PV

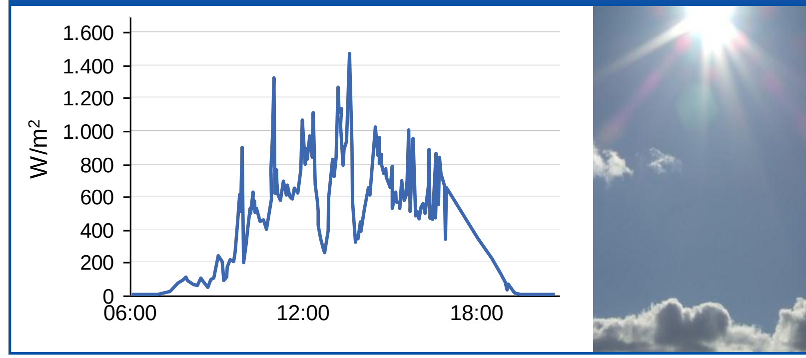


Fluctuating power generation will continue to increase

Contribution of renewable energy to the gross power generation Germany (2000 to 2013)

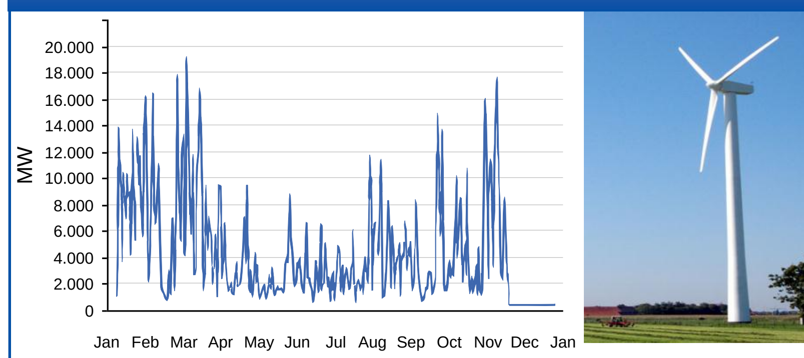


Variation of the solar irradiation



Source: Alfred Wegener Institute

Wind power feed-in



Source: own assessment; BMU, July 2011;
Fraunhofer ISE, July 2012;

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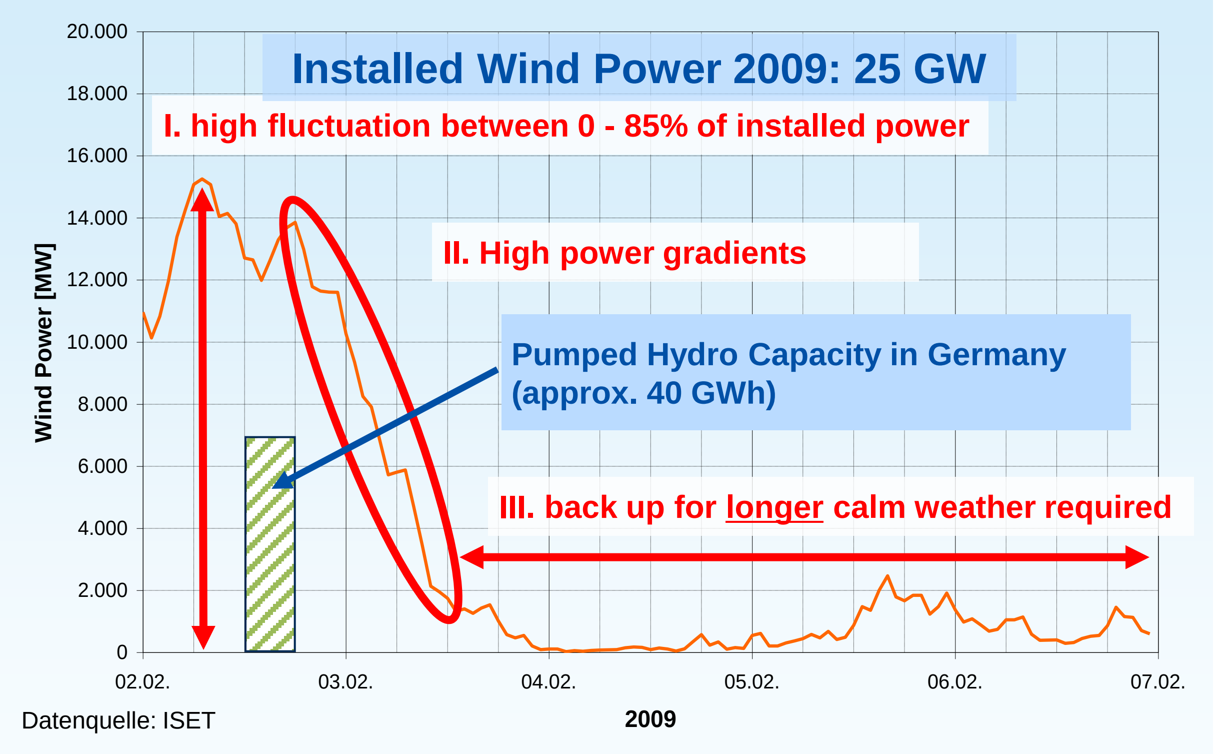
Dramatic Changes of Wind Power Output



Feb 2009

- Initial strong wind phase
- Several days of calm & foggy weather with very low temperatures (inversion weather)
- Peak residential heating demand
- Whole Germany was affected

When doubling installed capacity until 2020 to 50 GW:

- grid enforcement required, but alone not sufficient to solve the problem
- existing storage capacity too low
- at least 90% of demand as back-up required by conv. power plants
- focus on NG (CC & OCGT) appears to be very risky

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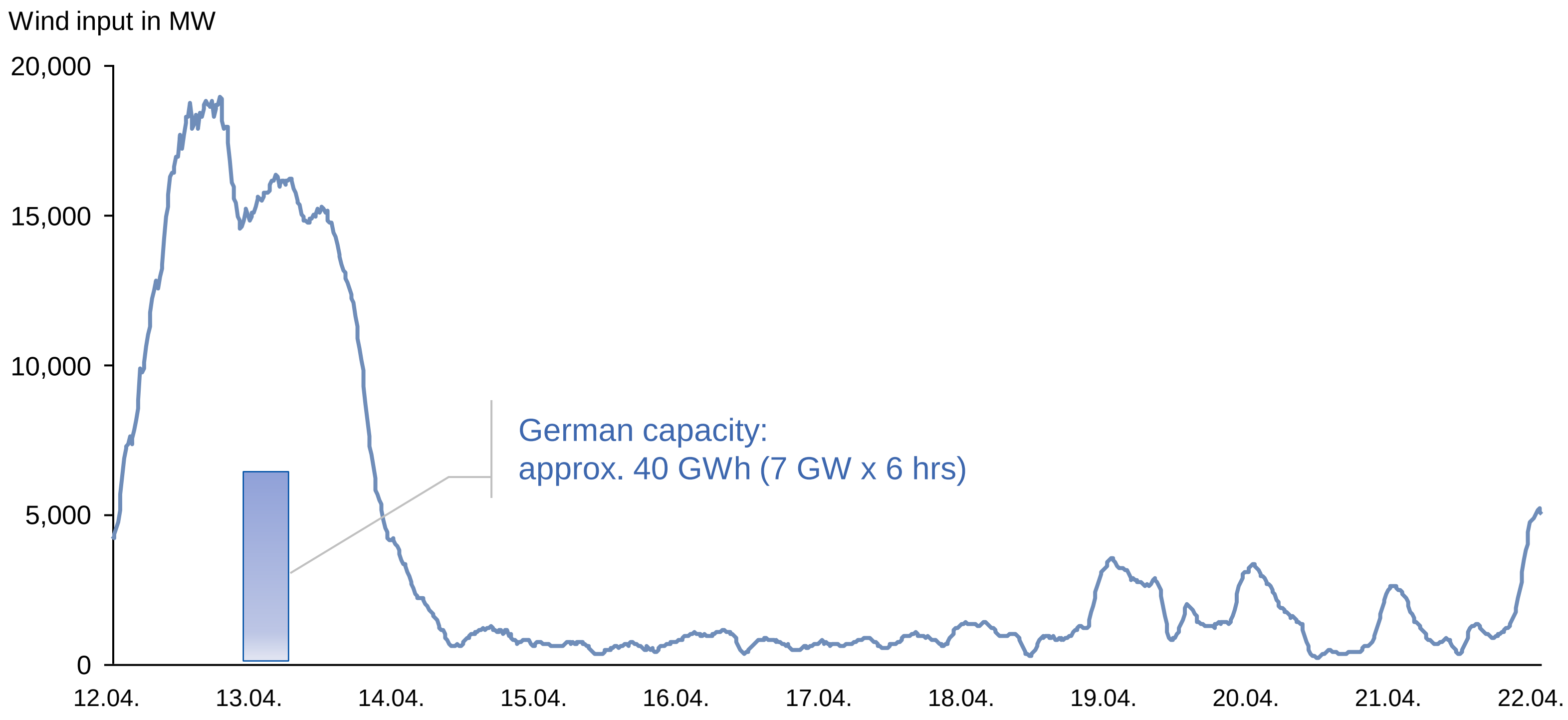
Integration of Fluctuating Power Generation is a Challenge in Many Respects

German wind energy production at selected days in April 2011



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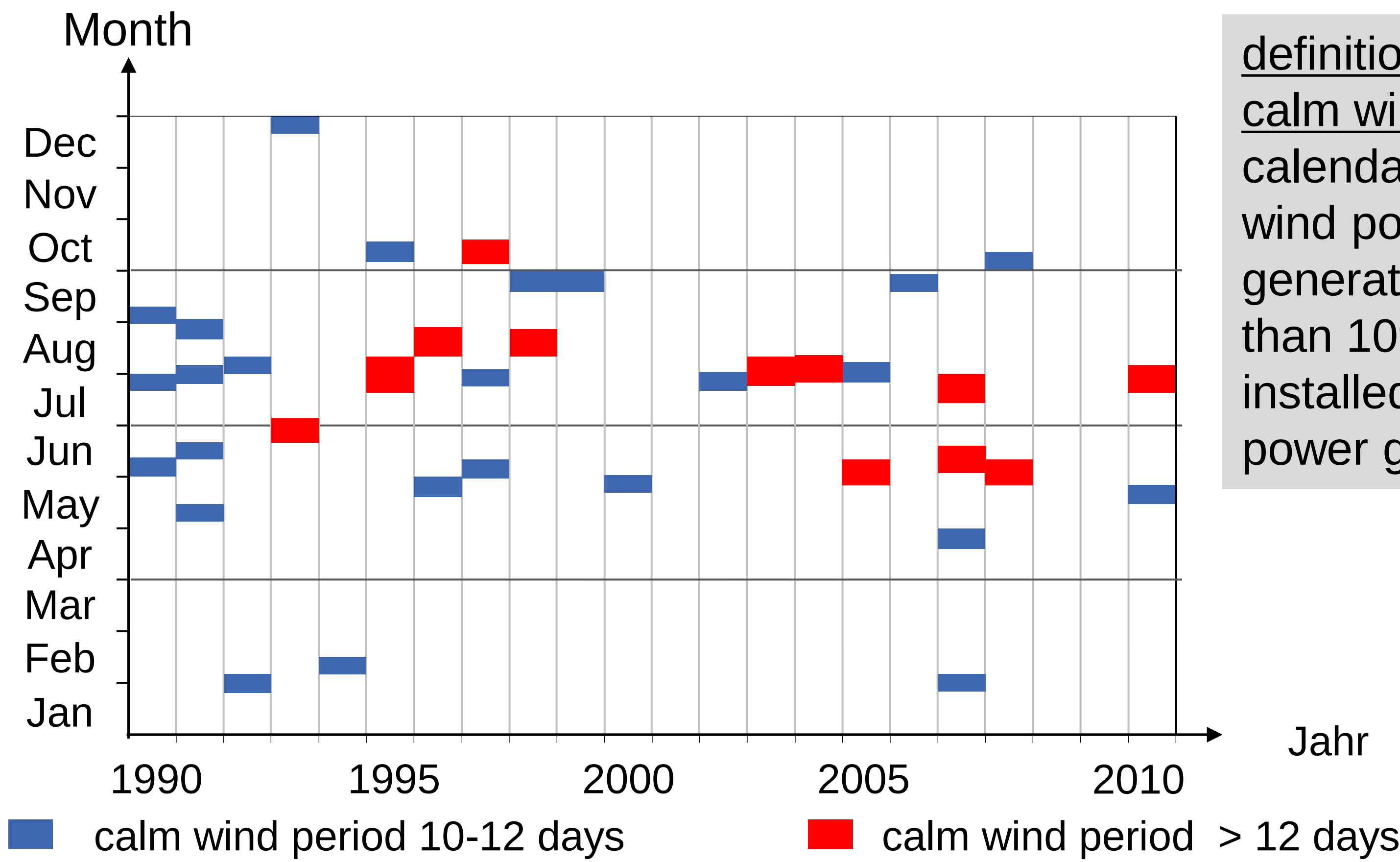
Periods of Calm Wind happen regularly ($P_{el\_wind}<10\%P_{inst}$)

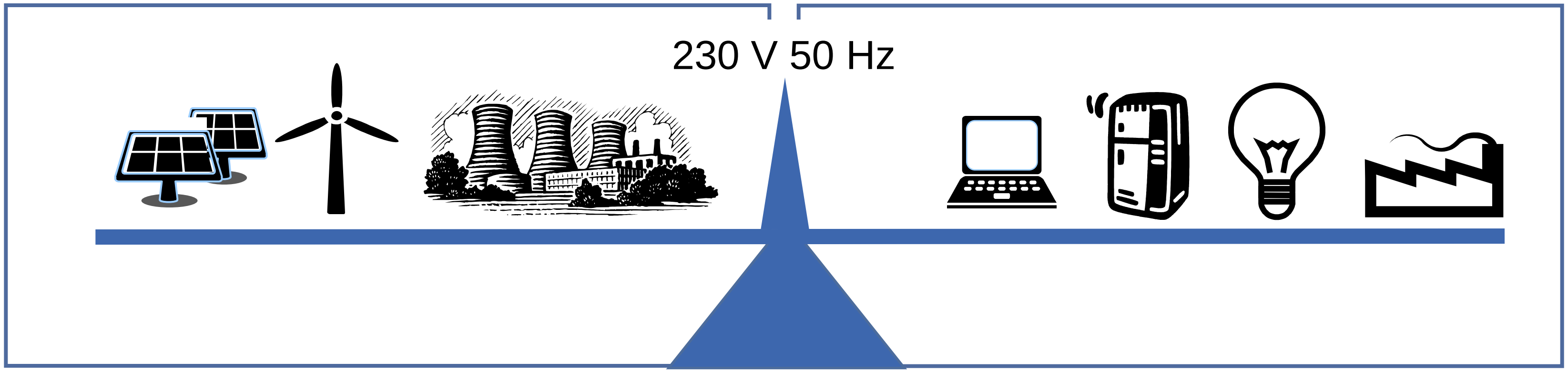
Experience made during more than 20 years (1989 to 2010)



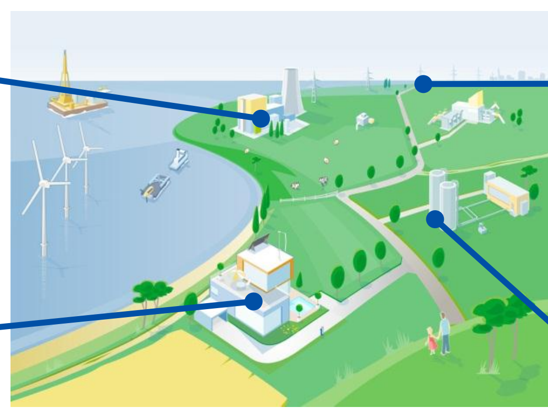
<u>definition of</u>
<u>calm wind day</u>:
calendar day with wind power generation of less than 10% of installed wind power generators

Energy storage is just one of four major measures to balance power generation and consumption continuously

Power generation | **Power consumption**



Possible technical measures



1. Flexible power generation
2. Expansion of electricity grids
3. „Smart“ Technologies to control demand side
4. Energy storage

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Federal Ministry
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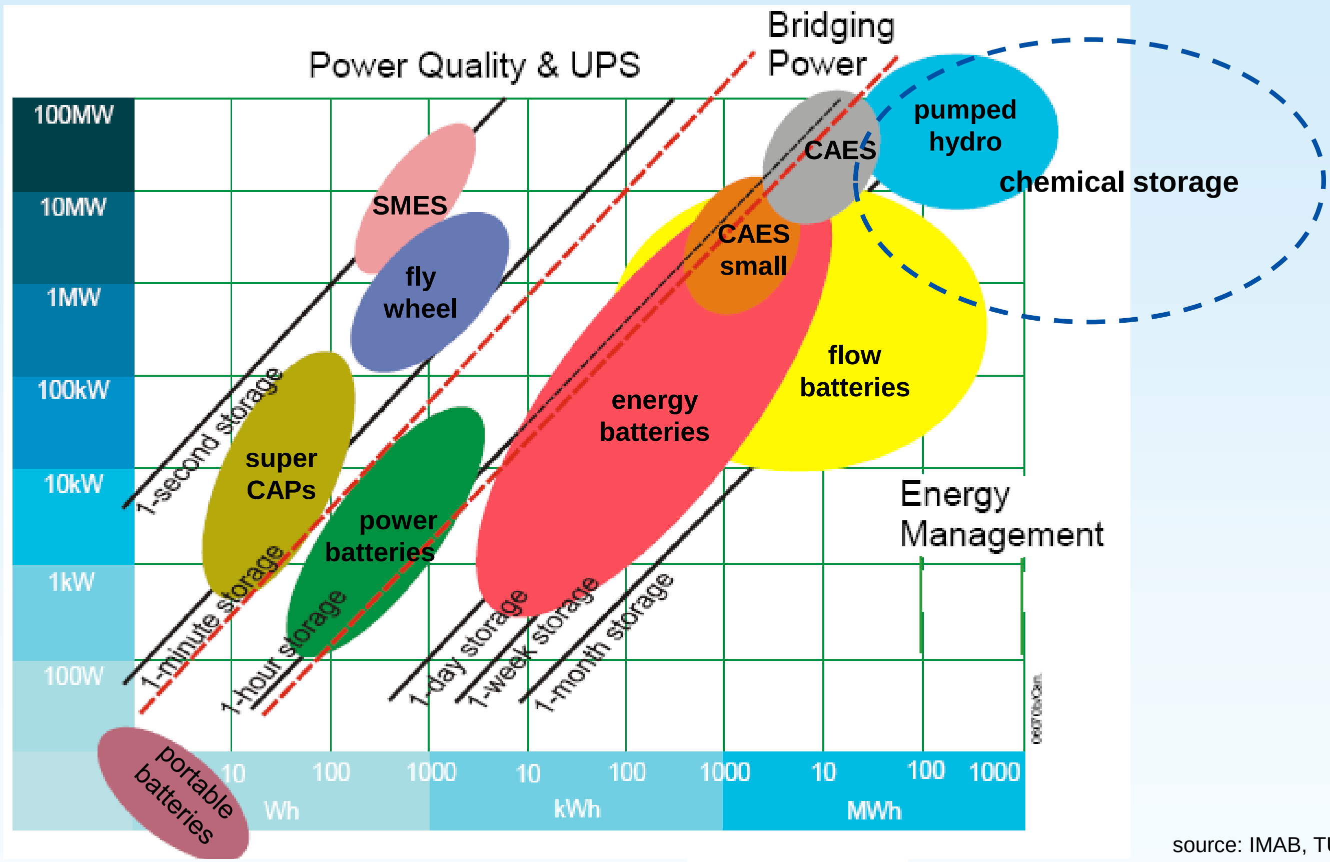
Power Rating and Energy Capacity Determine the Selection of the Suitable Energy Storage Technology



source: IMAB, TU Braunschweig

only pumped hydro and CAES (compressed air energy storage) provide both: large energy capacity and high charge/discharge power rating

Options for Large-Scale Storage of Electric Energy

Pumped Hydro

+ high efficiency (75 … 80%)
+ fast activation and response time
– limited potential of additional deployment (approx. 2 GW by 2030 in Germany)
– impact on landscape, long permitting procedure

CAES – <u>C</u>ompressed <u>A</u>ir <u>E</u>nergy <u>S</u>torage

+ small impact on landscape
+ option of deployment in North and Middle Germany
– low efficiency of both currently operated plants (42% and 54%)
– today's CAES concepts require natural gas combustion, CO_2 emissions

New Option: Adiabatic CAES

+ efficiency goal 70% (η at least in the range of pumped hydro)
+ no combustion of fuel, no CO_2-emission

- **Pumped hydro will remain the preferred technology**
- **CAES concepts with higher efficiency are technological feasible**
- **Need for significant techno-economical enhancement before application**

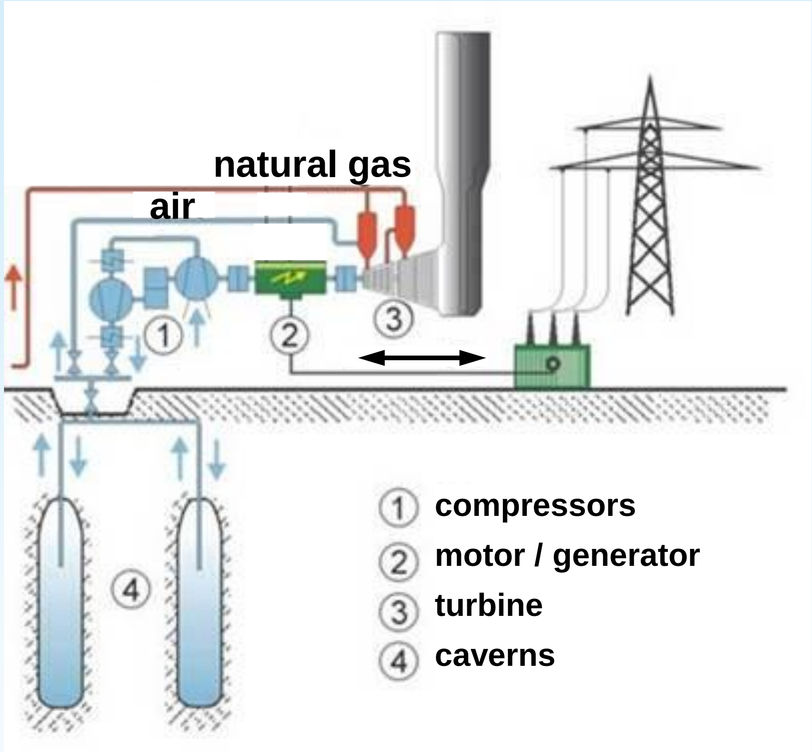
Conventional Compressed Air Energy Storage (I) Huntorf

E.ON Plant Huntorf (Lower Saxonia)

- in operation since 1978
- w/o use of compression heat
- w/o recuperation of hot GT flue gas

efficiency approx. 42%

Input:	**0,83 kWh electrical energy**
	1,56 kWh fossil energy
Output:	**1,00 kWh electrical energy**



Quelle: E.ON, KBB Underground

Process economically not very attractive

Conventional Compressed Air Energy Storage (II) McIntosh

McIntosh, Alabama, USA

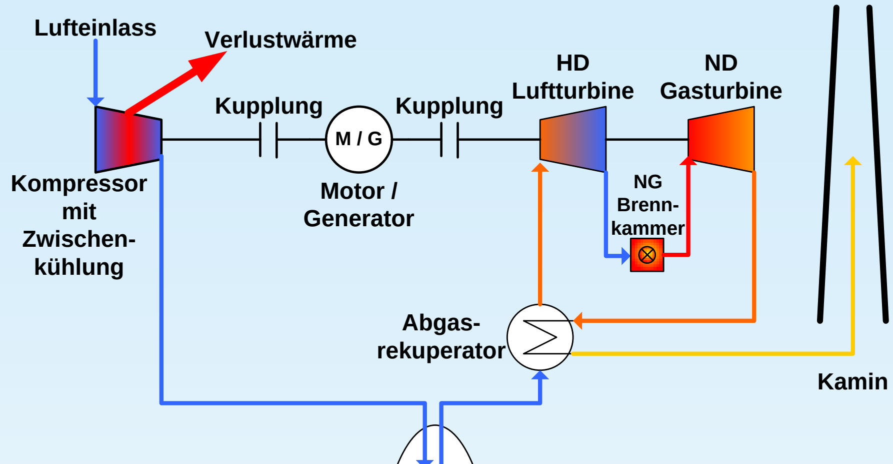
In operation since 1991

w/o use of compression heat

<u>With</u> recuperation of GT flue gas

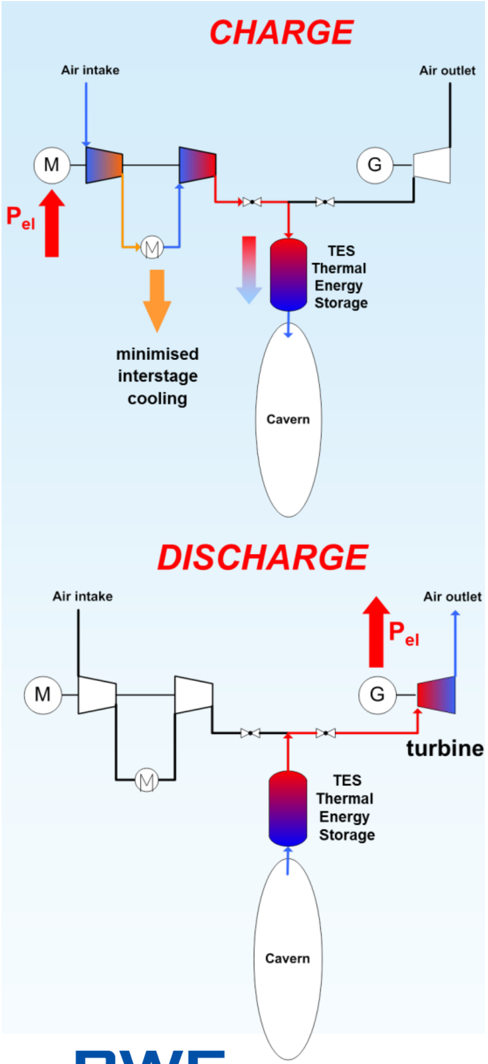
Efficiency approx. 54%

Input:	**0,69 kWh electrical energy**
	1,17 kWh fossil energy
Output:	**1,00 kWh electrical energy**



Efficiency better, but not yet sufficient

ADELE – The Adiabatic Concept: pure electricity storage – minimised losses



ADELE Joint Development Programme

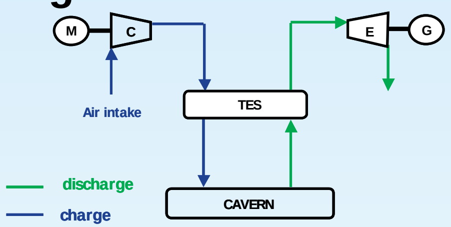
VORWEG GEHEN | ESK | imagination at work | DLR | ZENTRALE TECHNIK | ZÜBLIN

2008	2009	2010	2011	2012	2013 +

feasibility study → R&D-programme ADELE → demo project

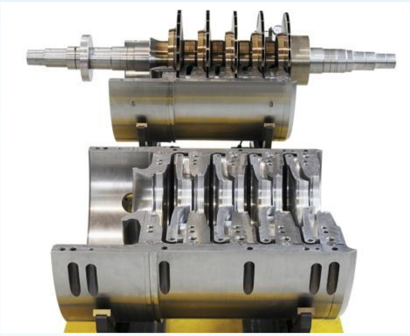
Development Programme Adiabatic Compressed Air Energy Storage

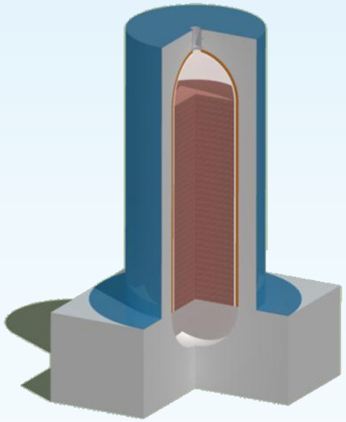
- approx. 240 MW compressor power, 260 MW turbine power
- approx. 1 …2 GWh capacity (≙ 4 … 8 full load hours)
- 70 bar, 600 … 650 ° C



Project Partners:

- RWE Power (coordination)
- ESK (RWE Group)
- GE Oil & Gas and GE Global Research
- DLR
- Ed. Züblin
- Züblin Chimney & Refractory





Goal: Development of core components of an A-CAES system, solve related technical / economical issues, conceptual layout of first demo plant

Turbomachinery and Overall Plant Design
General Electric O&G Nuovo Pignone und GRC

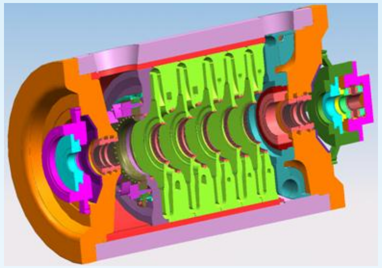
imagination at work

overall plant concept

- el. efficiency goal of approx. 70%
- dynamic simulations to optimise the concept
- engineering of instrumentation, first estimate on piping, balance of plant components and foot print

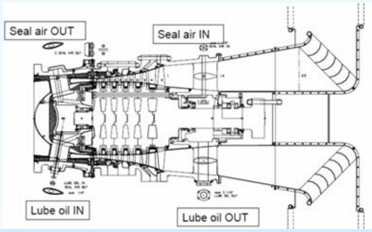
compressor train design

- LP axial-compressor derived from gas turbine compressor
- HP radial compressor :
  - thermal expansion: clearances, impeller/shaft, lube oil, …
- part load behaviour, start-up procedures, secondary air flows



turbine design

- gas turbine or steam turbine derivative (velocity vs. robustness)
- investigation concerning use of inlet guide vanes (IGVs), trip valve, control valves, particle filters

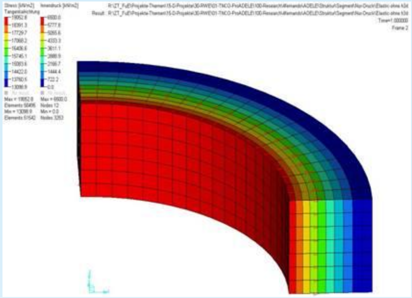


Numerous details need to be designed due to completely new requirement profile

TES - Thermal Energy Storage
Züblin, DLR

Pressure Vessels

- pre-stressed concrete pressure vessel design
- even flow distribution
- active cooling system to keep concrete at low temperatures
- condensate handling system



Insulation

- material testing: fibre material, sponges, refractory bricks
- condensation of air humidity at/inside the insulation layer under investigation; two concepts: dry/wet insulation
- Interaction of insulation and active cooling

Inventory Material

- Accelerated live time and stability testing with material samples:
  - chemical (powders) → crystal structure,
  - mechanical tests of standardised sample cubes
- Small scale cycle testing of an entire vessel-insulation-bed assembly concept in the “HOTREG” test rig at DLR

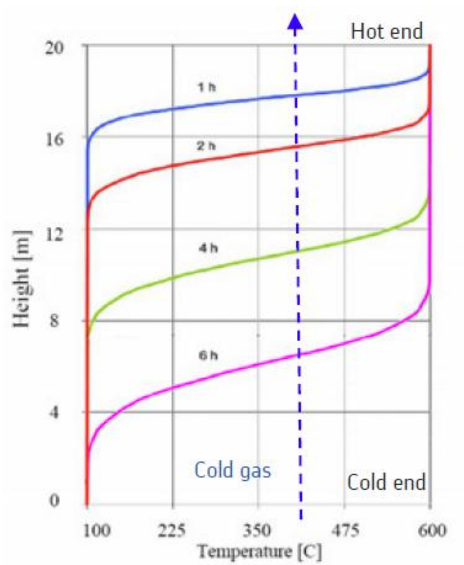
➢ **design goal: one heat storage per machine train**
➢ **techno-economical evaluation: pebble bed vs. ceramic bricks**

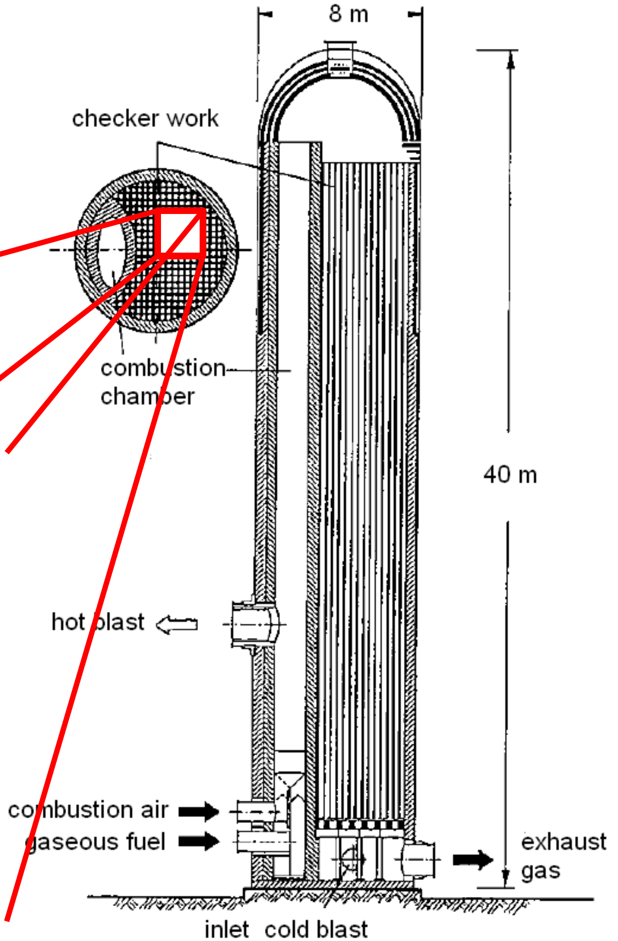
ADELE – Thermal Storage
Functional Principle Thermal Energy

Gefördert durch:
Bundesministerium für Wirtschaft und Technologie
aufgrund eines Beschlusses des Deutschen Bundestages

Regenerator type of storage

- Direct storage of thermal energy in a solid material (ceramics, natural stones)
- No use of a heat "exchanger" and a secondary heat carrier media (e.g. like thermo-oil or molten salt as used in CSP (concentr. solar power) technologies)
- No "delta t" needed as driver in heat exchangers





analogy: cowper, hot blast stoves
source: VDI Wärmeatlas

Gefördert durch:

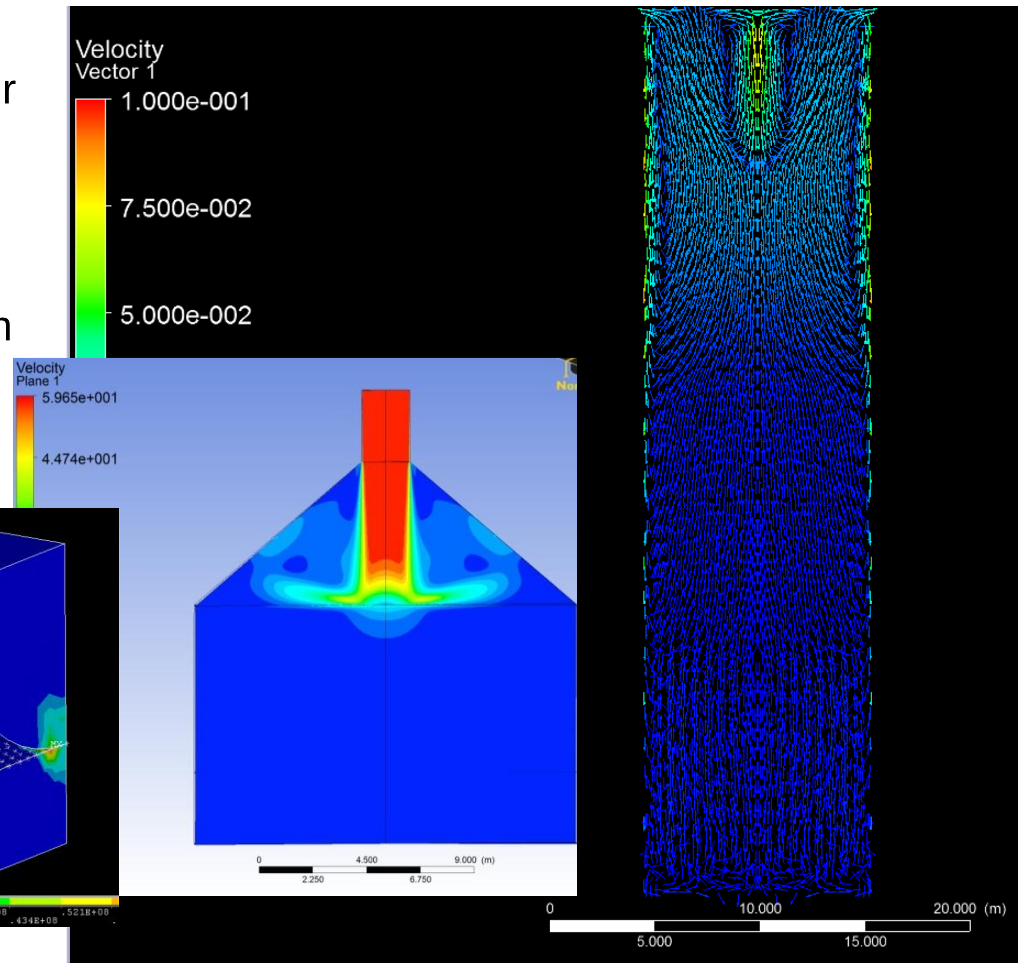
Bundesministerium für Wirtschaft und Technologie

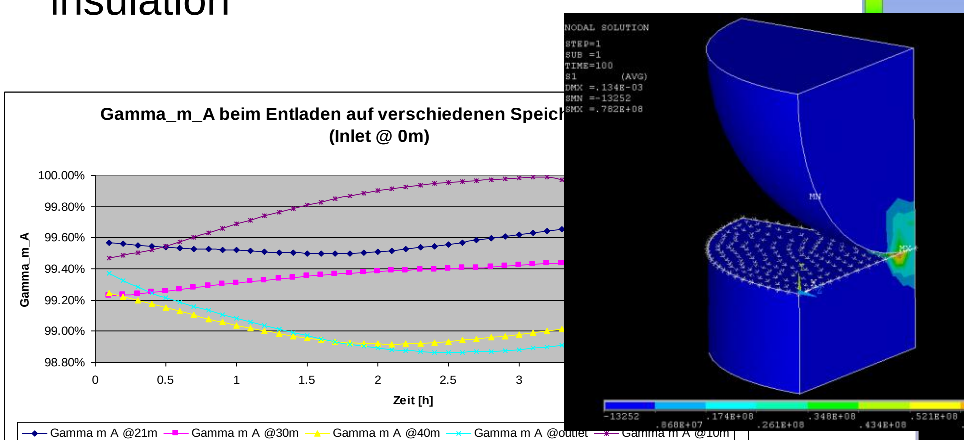
aufgrund eines Beschlusses des Deutschen Bundestages

ADELE – Thermal Energy Storage Design- and Simulation-Studies

Design aspects:

- Thermal expansion und dynamic behaviour of inventory
- Fluid dynamic studies to estimate losses and inventory usage
- 3D calculation of temperature for insulation and active cooling
- Thermo-mechanics for inventory and insulation





ADELE – Thermal Energy Storage TES
Lab and Test Rig Investigations

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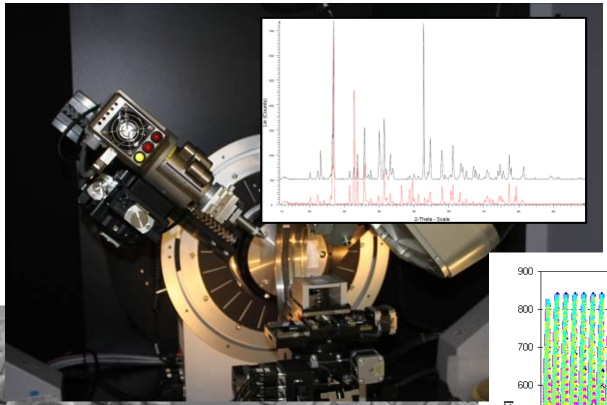

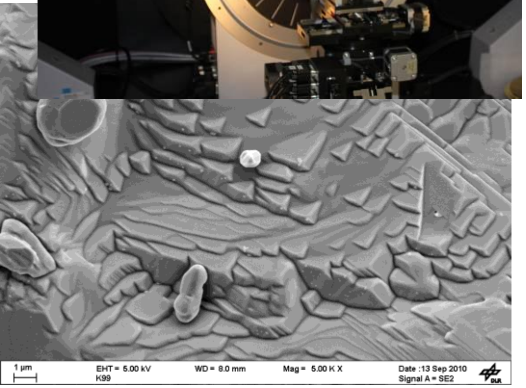

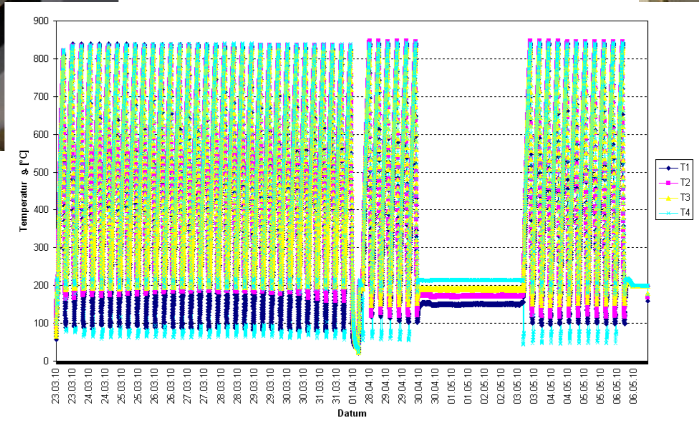

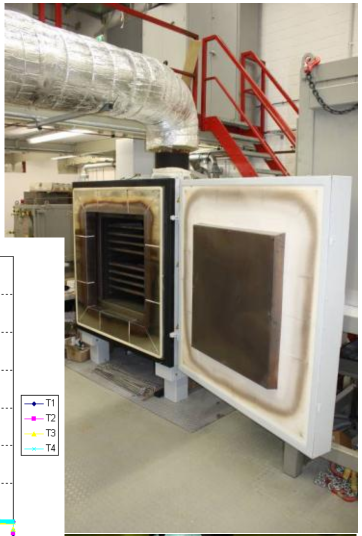

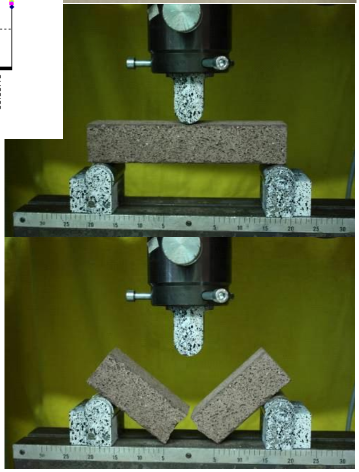

Test rig “HOTREG” for high-temperature regenerator storage at DLR Stuttgart

Experimental work:

- Thermal cycling as closed as possible to real conditions, accelerated life time testing
- Investigation on sub-component behaviour in test rig scale

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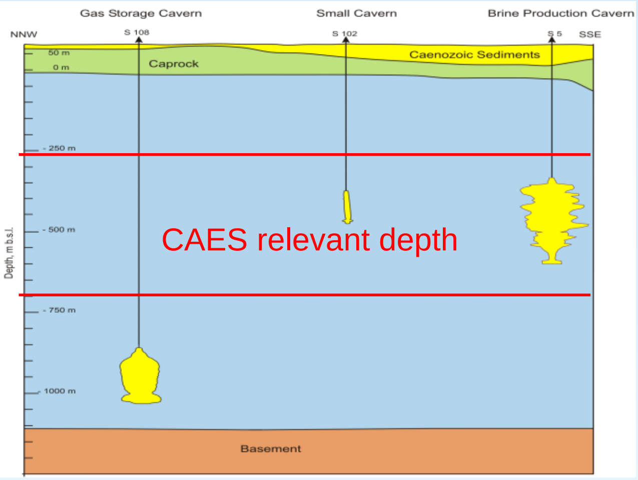
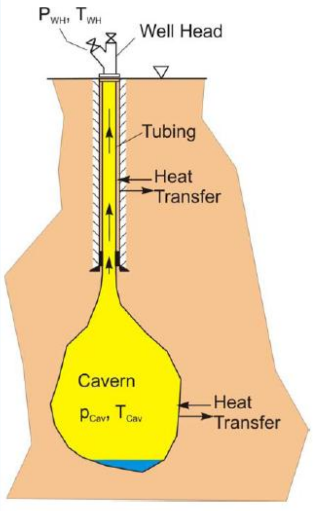
ADELE – Caverns
Adaption of Natural Gas Storage Technology

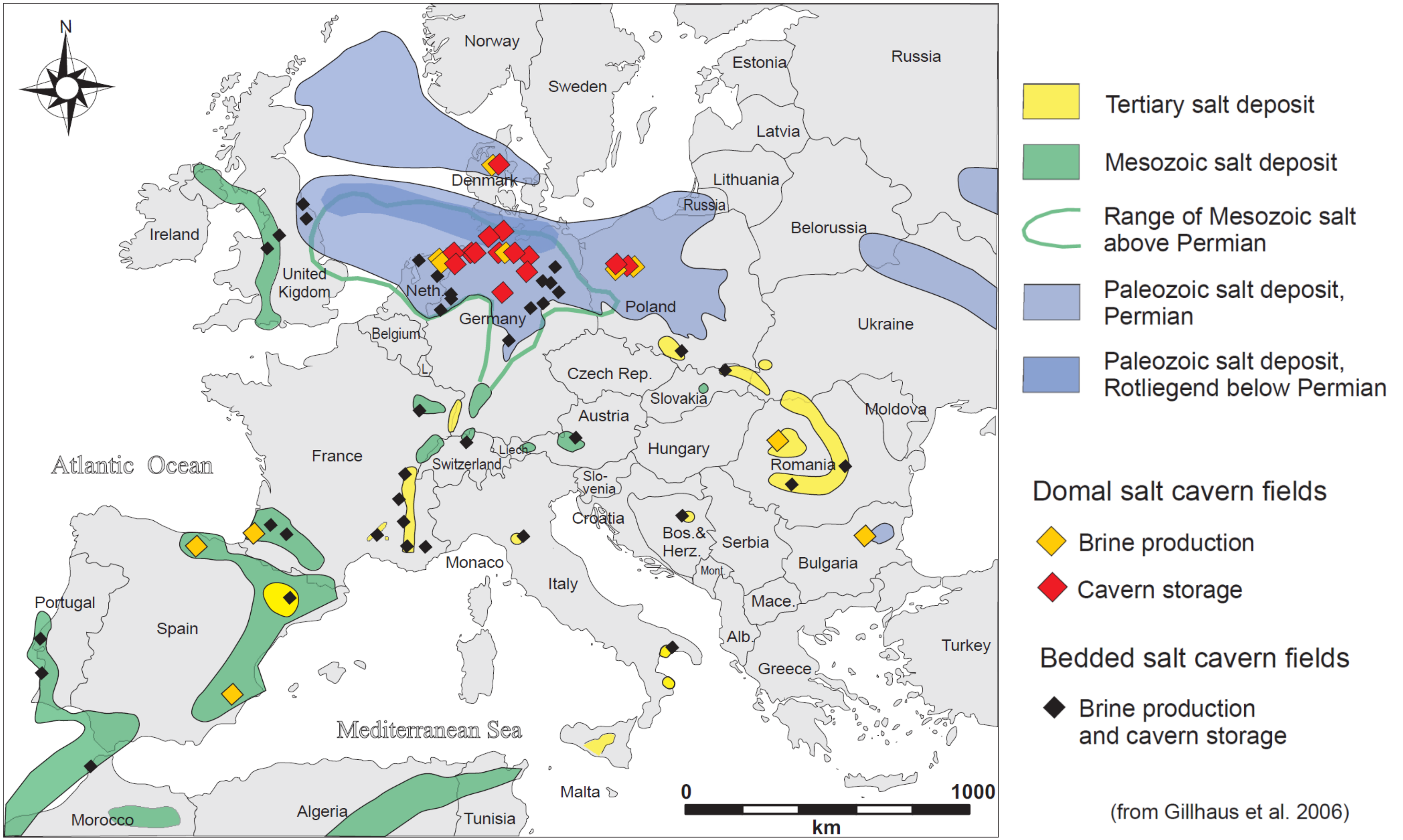
ESK

- rock mechanics: geomechanical modelling, lab tests concerning material stress and deformation behaviour
- adaption of well completion and wellhead equipment (material, Ø)
- thermodynamic process modelling deals as input for overall process design (@ GE GRC); parameter studies: volume, shape, geometry, depth
- site screening and ranking (D, Benelux, UK, …), site specific salt properties





Salt deposits in Europe

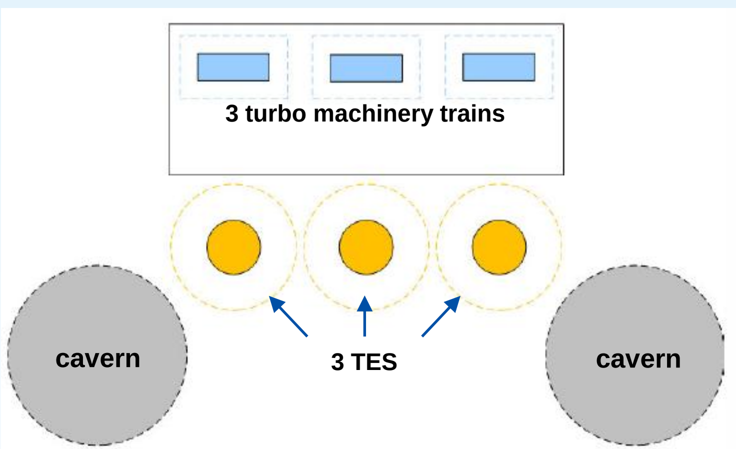


(from Gillhaus et al. 2006)

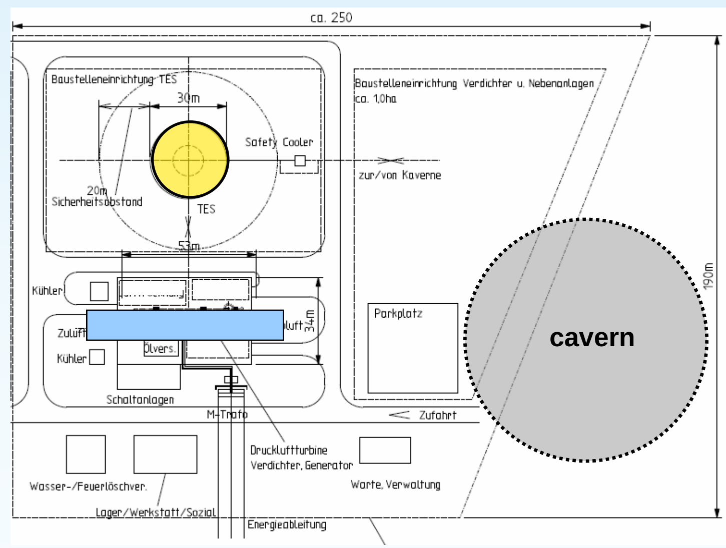
Demonstration is needed to reach market maturity

- **Demonstration of down-scaled components not meaningful:**
  - smaller TES requires different design principles
  - intensive turbo machinery engineering would need to be repeated

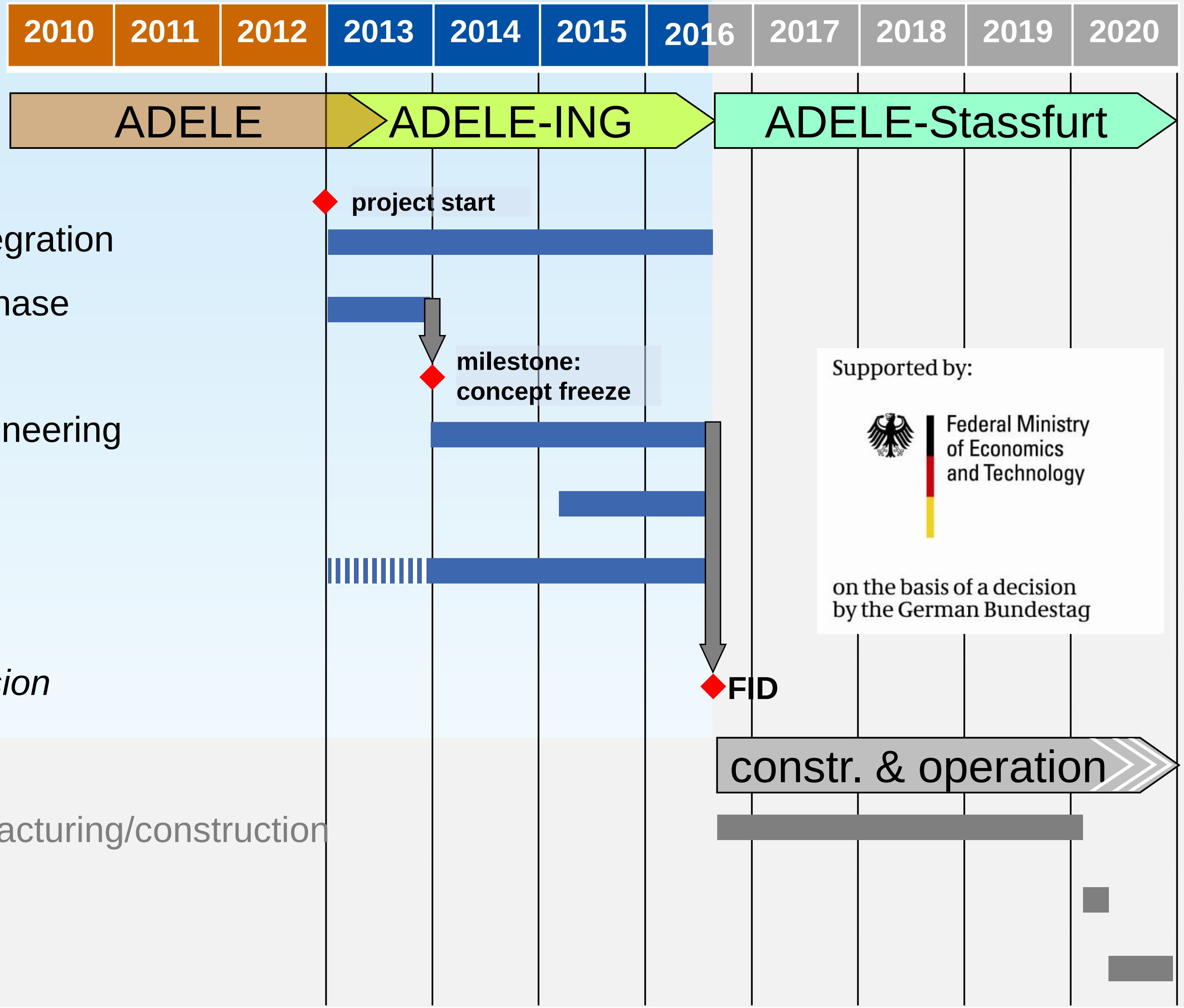
ADELE:
aimed size: 260 MW, 1 GWh



single-train ADELE-Demo:
90 MW, 360 MWh, required area ~ 4 ha



Next Stepps ADELE-ING & ADELE-Staßfurt



ADELE-ING

> grid- and market integration

> conceptual review phase

Concept Freeze

> basic und detail engineering

> procurement

> permits

Final Investment Decision

ADELE-Stassfurt

> procurement, manufacturing/construction

> commissioning

> start test operation

Supported by:

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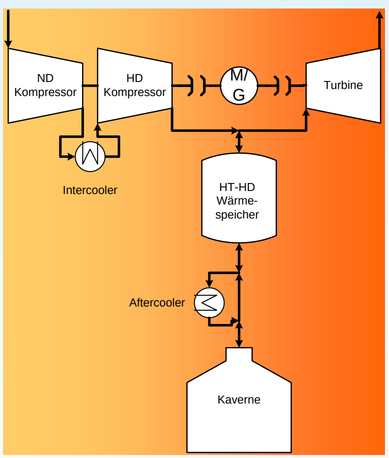
ADELE-ING
Phase 1 – Conceptual Review Phase

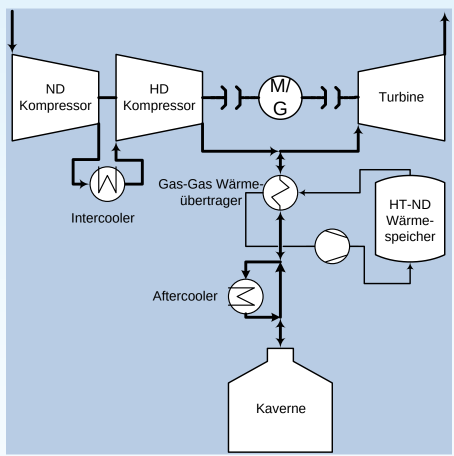
Fundamental review of different adiabatic concepts:

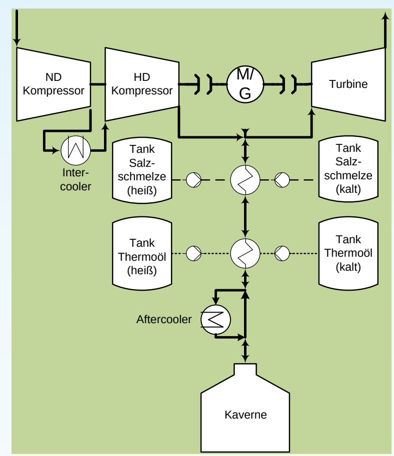
- plant concepts, heat storage concepts, temperature levels

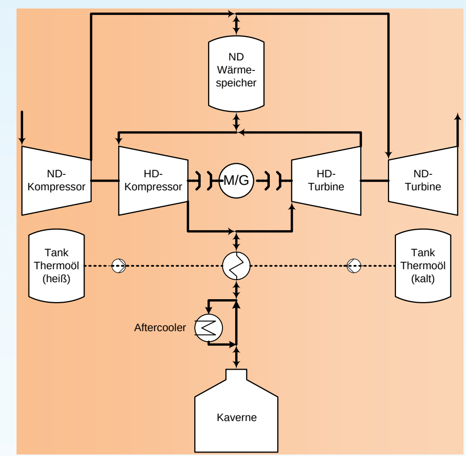
→10 plant variations were investigated in terms of achievable performance and costs

HT-HP regenerator thermal energy storage (TES)	**HT-LP regenerator TES in secondary loop**	**molten salt - thermal oil TES**	**LT multi stage TES**









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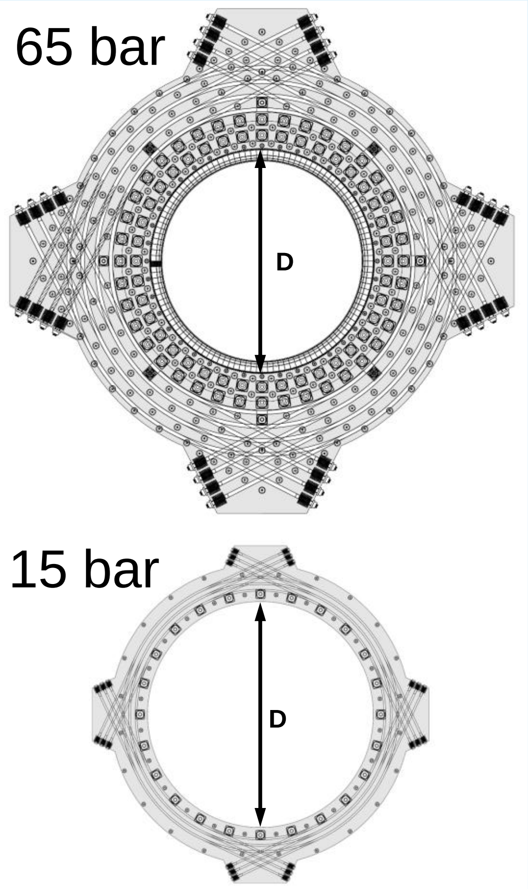
ADELE-ING Phase 1 – Conceptual Phase
Example: TES cost reduction by lowering pressure and temperature

concept	validation in full scale testing	TES design



- ← **reducing costs is development driver #1**
- **cost reduction potential by reducing pressure level**
- **risk mitigation potential by reducing temperature level**

Gefördert durch:

Bundesministerium für Wirtschaft und Technologie

aufgrund eines Beschlusses des Deutschen Bundestages

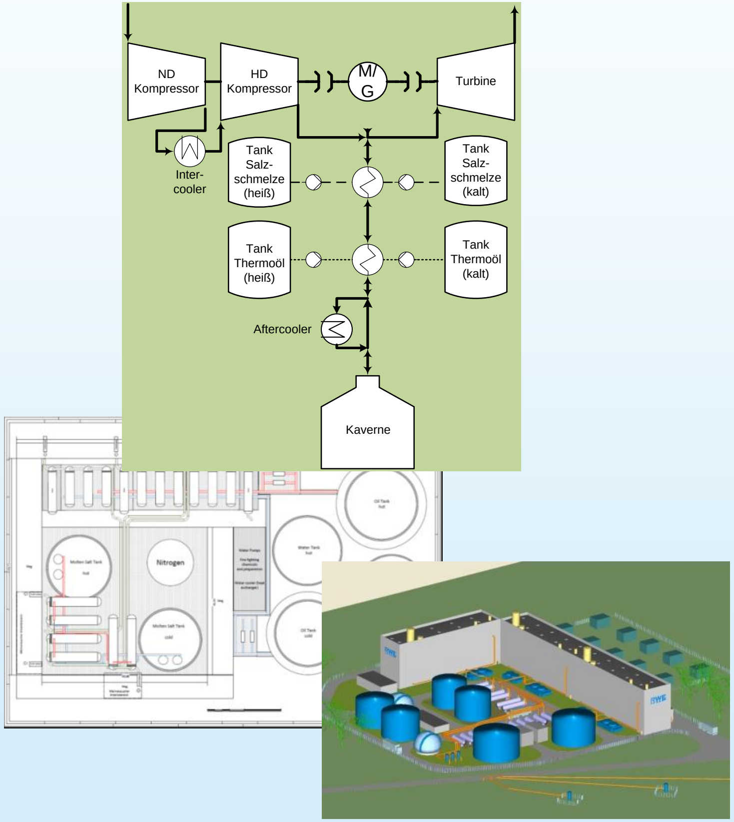
Pre-stressed Concrete Pressure Vessel
TES Full Scale Lab Test

ZÜBLIN ZENTRALE TECHNIK | ZÜBLIN DLR

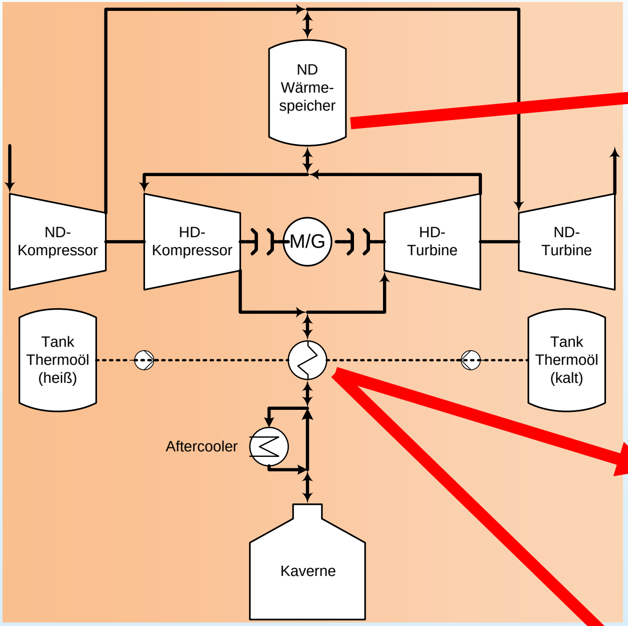
full scale lab test during construction of concrete reinforcement

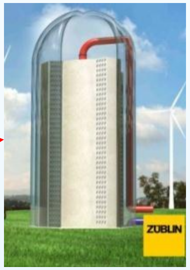
Surprising Result:
Three Systems Perform Very Similar

a) molten salt – thermal oil TES



b) & c): low temperature multi stage TES





Low pressure: solid TES inventory

High pressure TES:

Specific investment costs: approx. 1.300 €/kW at efficiencies of 66 to 68 %

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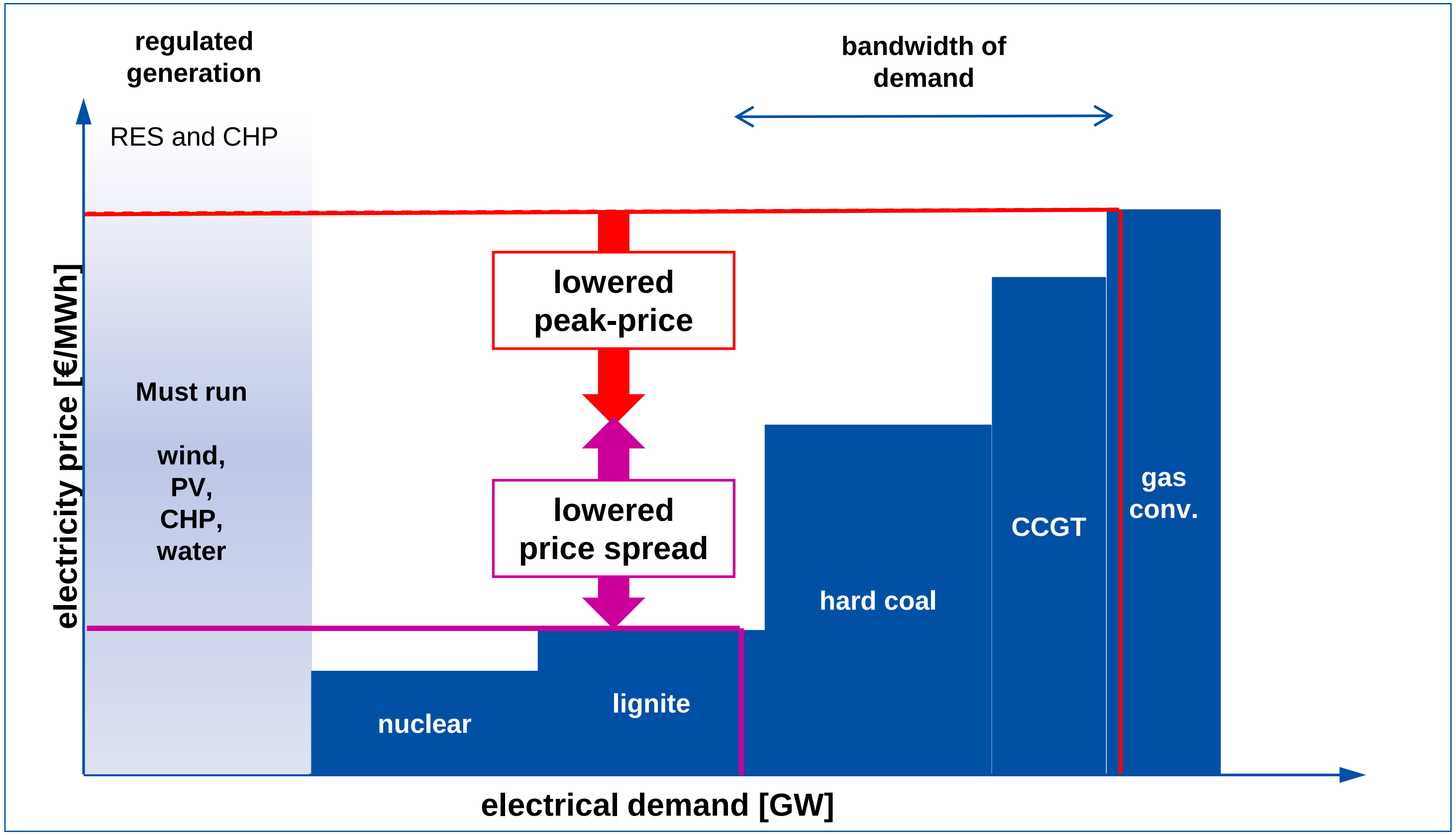
2. central storage within the transmission grid / ADELE technology development
3. **economics of bulk storage**

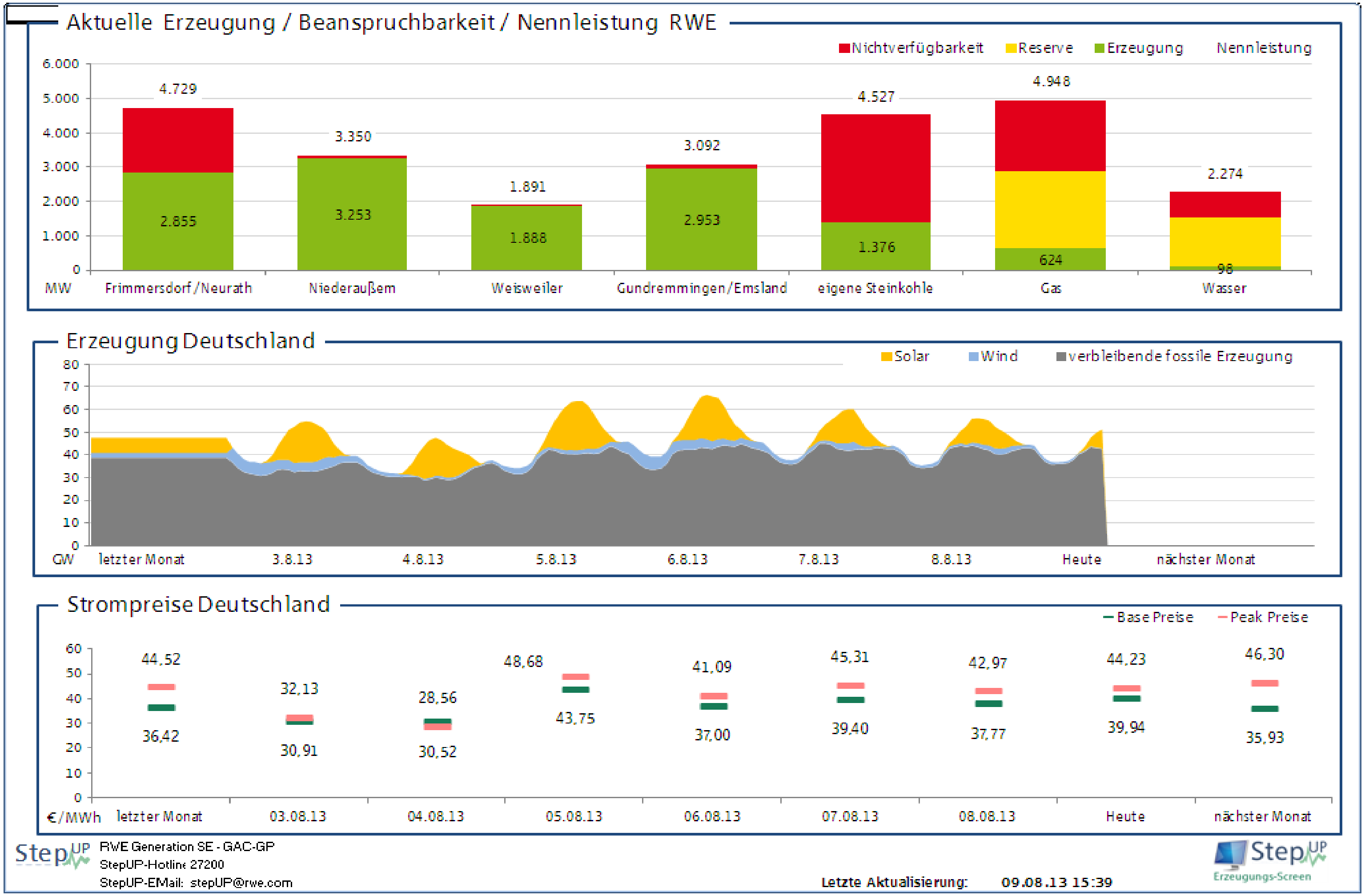
Increased not-demand-driven generation does not automatically lead to enhanced economics for storage



price mechanisms influenced by regulatory measures
⇒ incentives for investing in storage have been disappeared already

storage always has to compete with other flexibility measures (conv. pp)

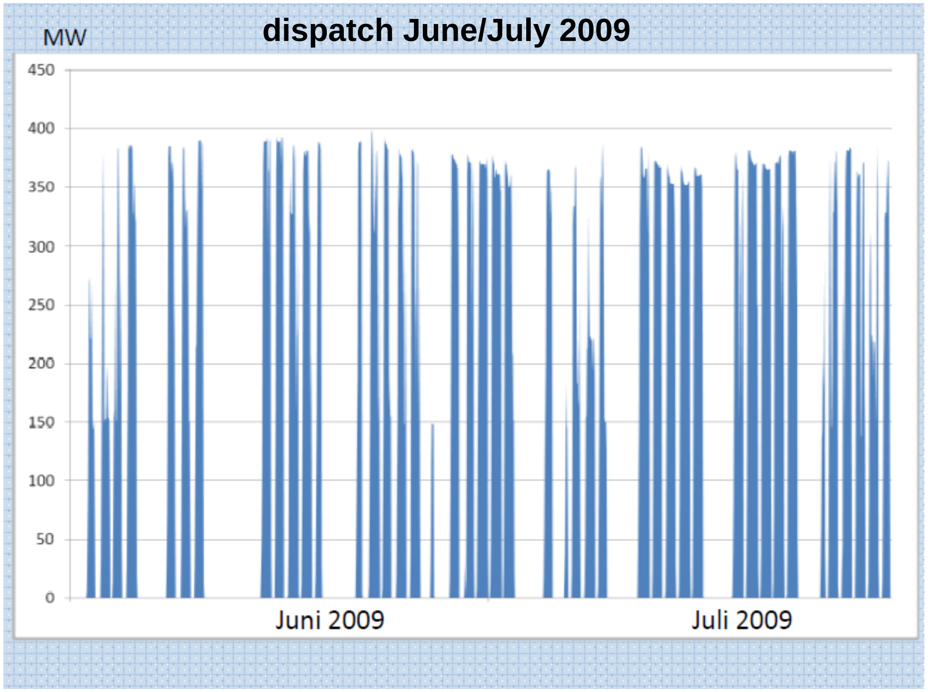
summer: PV cuts at noon peak of residual load and price

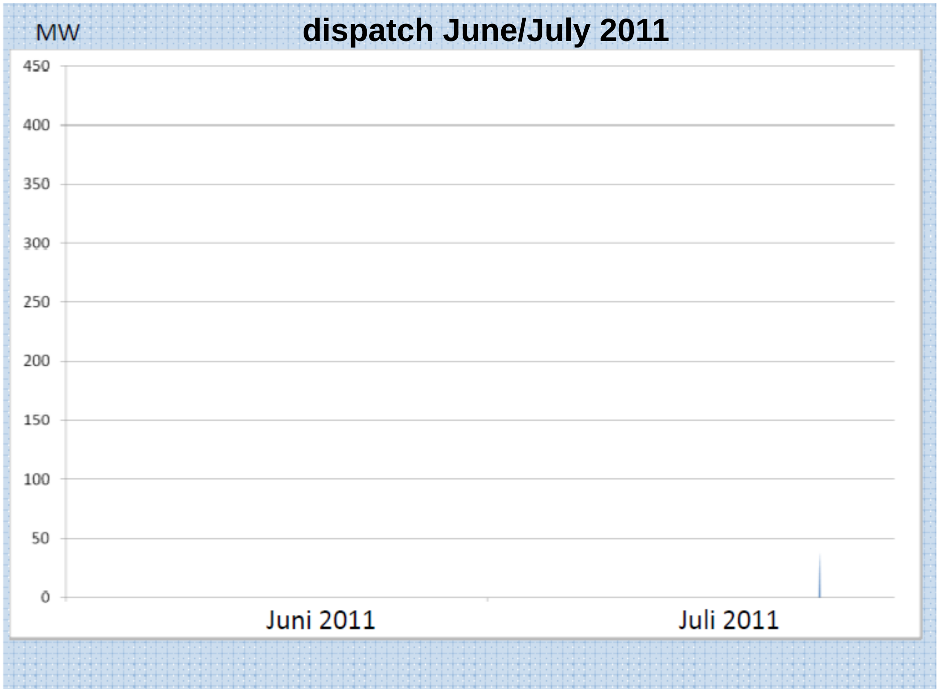


- **In summer time residual load is more even due to PV → price drop, low price spread**

Consequence for natural gas power plants: Dramatically reduced operation

Comparison of the dispatch of a 400 MW NG-combi-plant (topping GT + gas fired boiler) 2009 vs 2011





- **NG power plants first to be decommissioned**
- **Though: Due to lower CO_2 foot print, NG plants planned to be complementary to RES in the government's Energy Concept**

Only with a share of RES exceeding 50 % significant storage increase on system level will be required

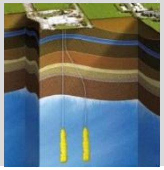
With the "Energiewende" increasing share of RES power generation

20 to 25%	35 to 40%	50 to 60%	75% to 100%	(R&D) action

New Pumped Hydro

➢ Keep future options open

Compresssed Air



➢ Pursue R&D projects

Power-2-Gas

➢ Pursue R&D projects

Heute | 2020 | 2030 | 2050

Relevance of new Storage

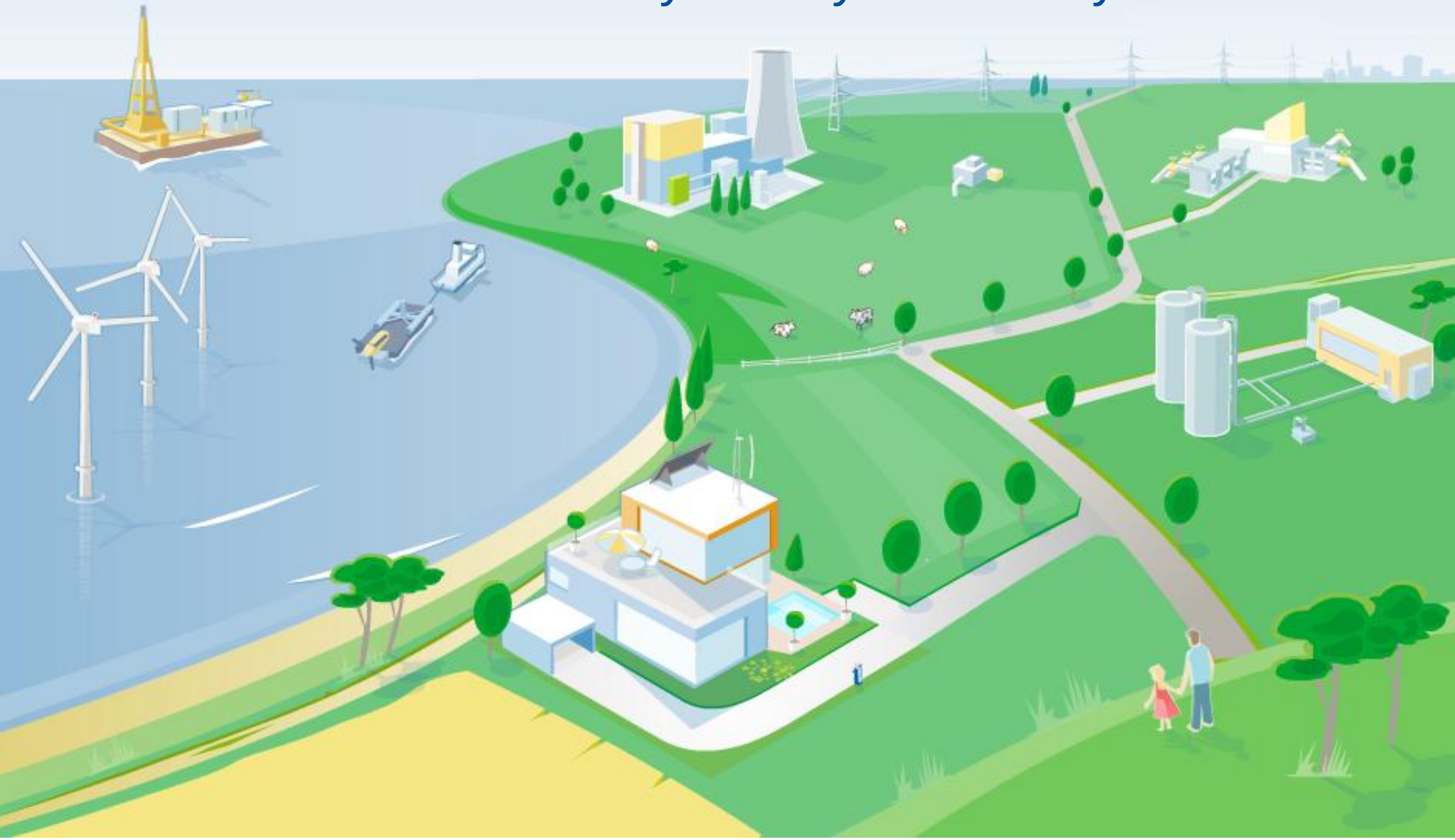
RWE
The energy to lead

Summary

- Massive deployment of electricity generation by renewable energy sources as well as not-demand driven CHP generation call for
  - grid extension measures,
  - flexible operation of the conventional power plant fleet,
  - extension of electricity storage capacity
- Adiabatic compressed air energy storage is the most favourable alternative to pumped hydro and provides large potential for suitable sites in Europe.
- The adiabatic concept is not available yet. Demonstration is still needed to reach market maturity of the technology
- Cost reduction endeavours (CAPEX and OPEX) are needed, but won’t be sufficient to generate a positive business case
- Revenue situation has to improve to allow for investment into “grid-size” storage

➢ **Regulator decides which technologies will be competitive**

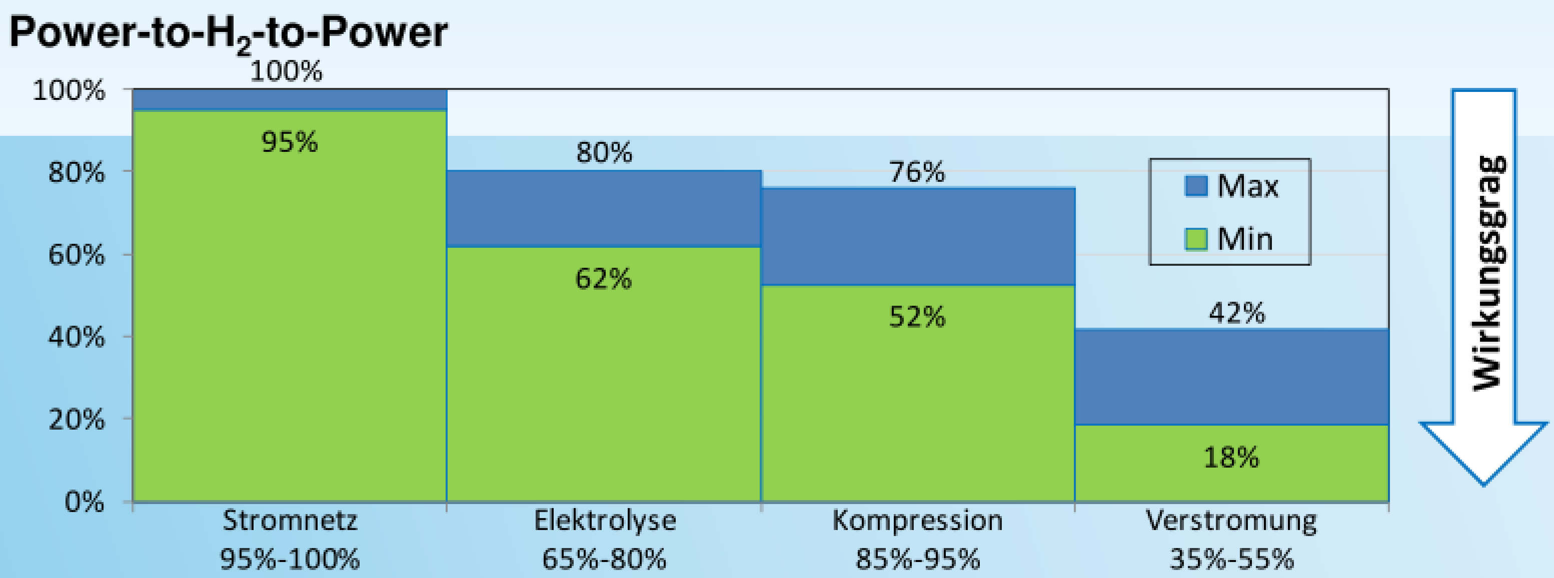
Thank you very much for your attention!

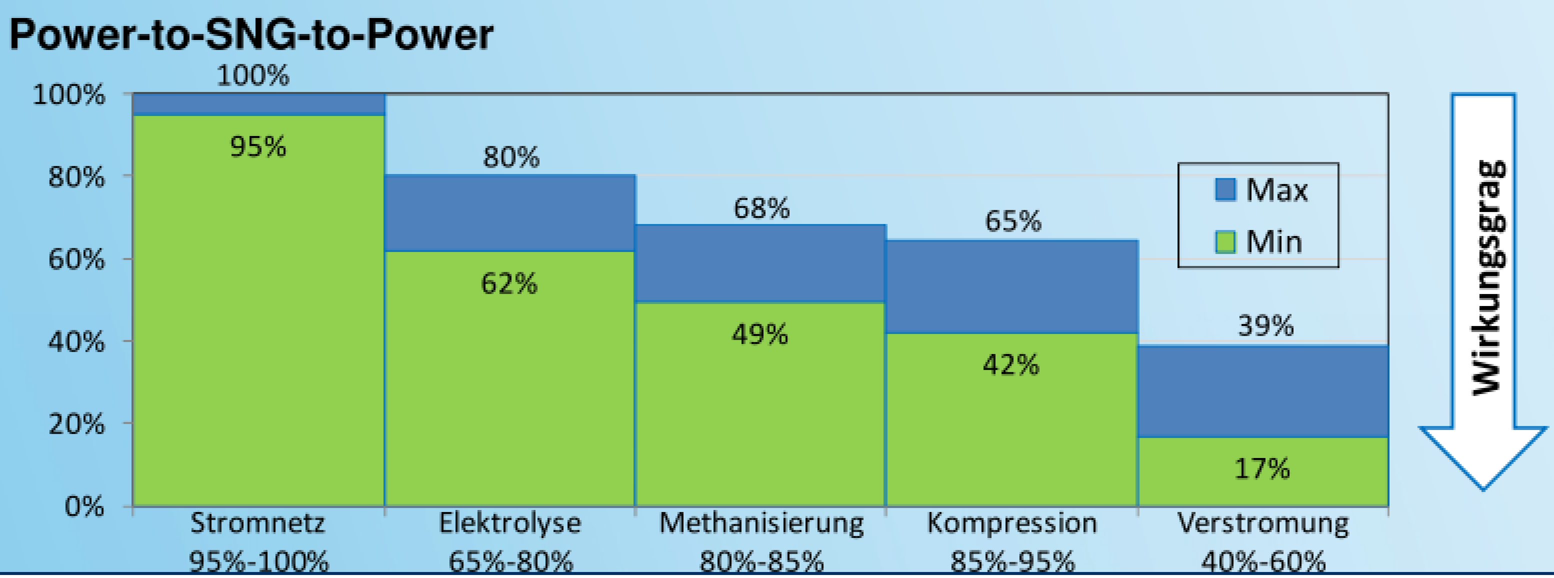


If you want to know more: www.RWE.com > Innovation

Additional Information

Efficiency of energy storage via Power-to-Gas





Storage in Norway is not a first priority option

The physical potential is huge…

- Currently installed: about 30 GW hydro power, why is seasonally operated
- Pumping power is only 1 GW leaving a huge potential
- The actual PHS costs are comparable to Germany, Grid connection costs come on top
- For Germany big dependence on foreign storage devices, thus price risks exist
- Also in Norway environmental issues exist

Functional Storage seems an alternative

- Analysed in 2012 by PROGNOS for WEC
- Base load in NO and SE amounts to17 GW
- In past years reservoirs in NO and SE had a spare capacity of ~12 GWh never used
- Shifting generation from Scandinavia to Europe and back creates a long term store
- Until 2050 5-12 GW of this rather cheap functional storage could be exploited

In any case European grid interconnection is the real issue

- HVDC-Grid connection to continental Europe is expensive
- Currently until 2020 only 2 cables are planned (limited to 1.4 GW, long lead times)
- The infrastructure investment is indirectly charged to Norwegian public, which would solve foreign problems not nationally known
- According to RWE analysis, grid costs per MWh transported are at least levelised PHS storage costs, hence local sites should be prioritised

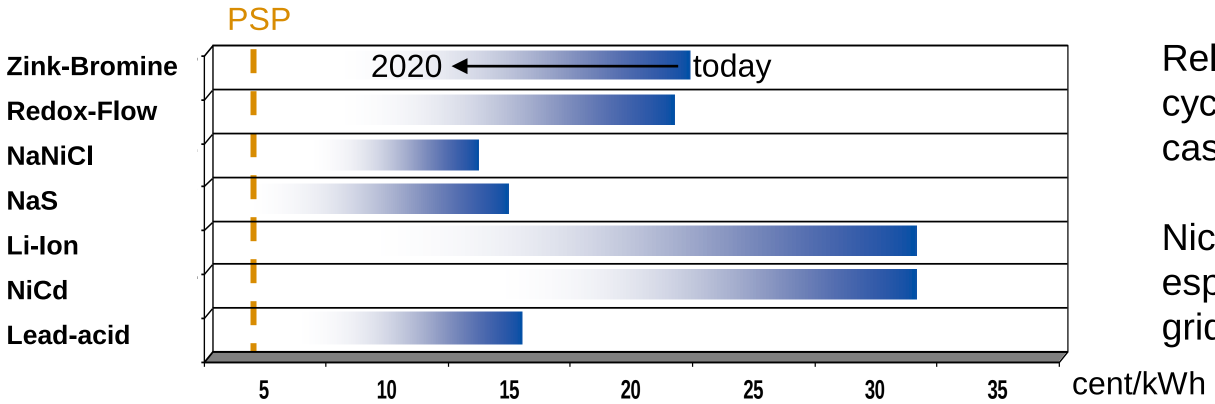
> The Scandinavian option is risky and no silver bullet

Decentralised Batteries may become an important solution

There are several applications for batteries. The requirements are different.

Application	**E-Mobility**	**PV-Systems**	**Reducing grid load**
Efficiency	Competition with fossil fuels Locally zero emissions	Local generation vs. grid service UPS applications	Avoidance of Invest in grid assets Security of supply
Battery types	Li-Ion NaNiCl	Li-Ion Lead acid Redox-flow	NaS Redox-flow NaNiCl

For a broader application the battery costs have to decrease significantly



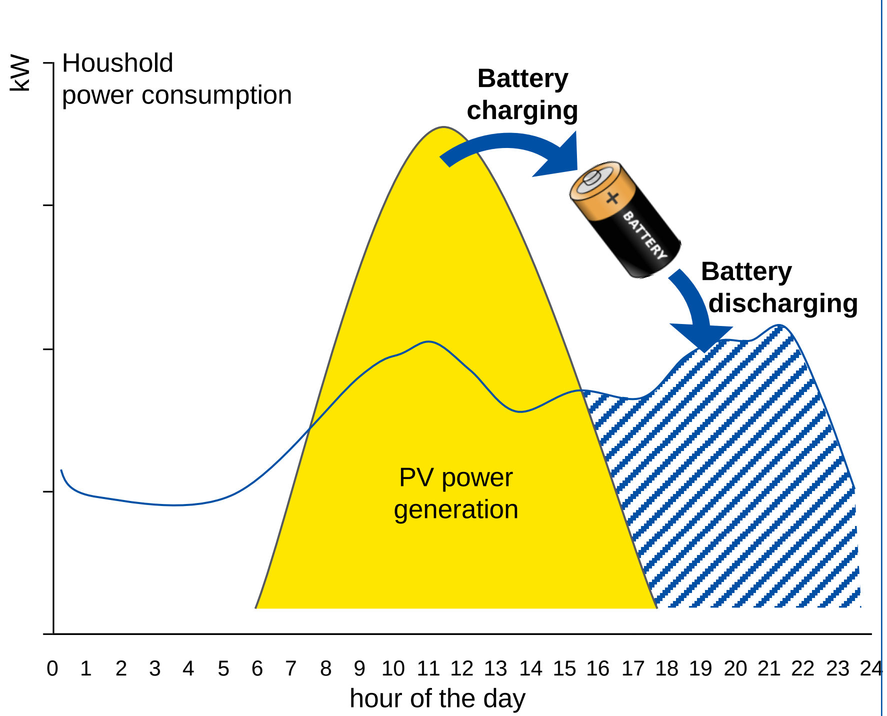
Relatively high costs per storage cycle challenge the business case for battery systems.

Niche market applications exist, especially in regions with weak grids.

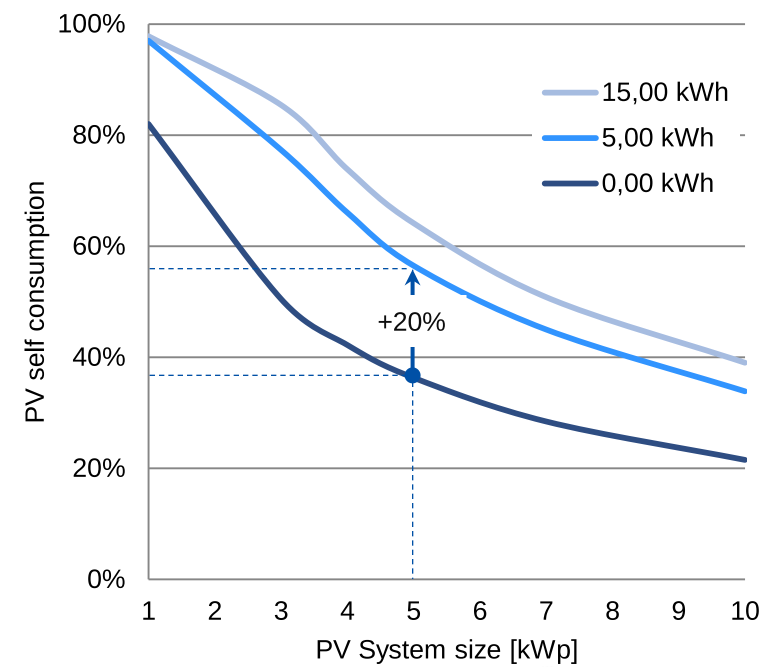
Source Costs: VDE Storage Study 2009 (Application Peak Shaving)

Batteries allow for an increase of the local consumption of the PV power generation

Local PV power generation and consumption will be decoupled time-wise



For a typical*) B2C customer a battery will increase the self consumption by about 20 %



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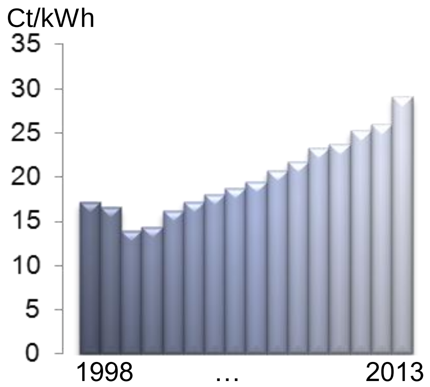
- The economics of batteries rely on the avoided power purchases
- Business case depends on avoided grid fees, taxes, …
- With decreasing battery prices home-storage will be profitable for the investor

Business depends on regulation

*) Family household, 4.500kWh annual consumption, 5 kWh Battery, 5 kWp PV

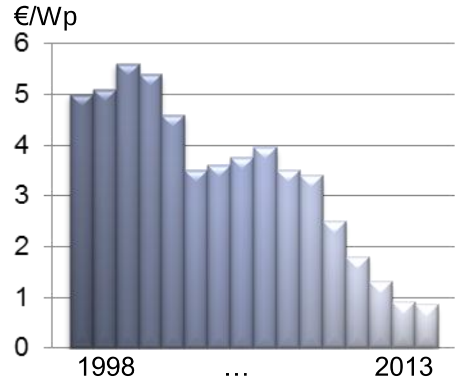
Recent developments of the energy system are very much in favour of battery home storage systems

End customer prices[1)]



Stable trend to higher prices driven by „EEG“ and other fees and taxes

PV modul prices[2)]



Unprecedented decrease in PV system prices led to system parity even in GER

Mainstream believes

- Concerns about rising electricity prices
- Personal independence and autarky are desirable
- Security of grid supply is not an issue, even in winter after shut down of nuclear
- “Get rid of the big utilities”

Push to develop and use local storage systems

> Biggest uncertainties for local storage business:

a) future stationary battery characteristics and prices
b) future regulatory framework (related to social consent on the “Energiewende”)

[1)] bdew: “Haushaltsstrompreis” D, 1998 – 2013 in ct/kWh
[2)] Fraunhofer Institut ISE, Freiburg, 2013