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Adiabatic CAES: The ADELE-ING project

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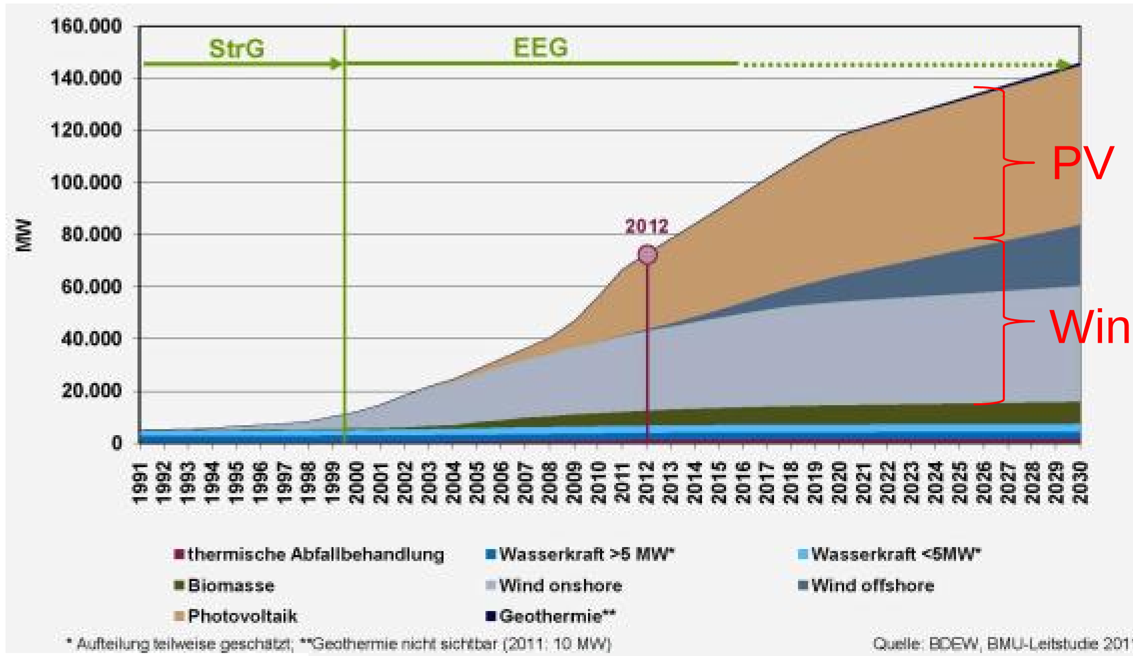
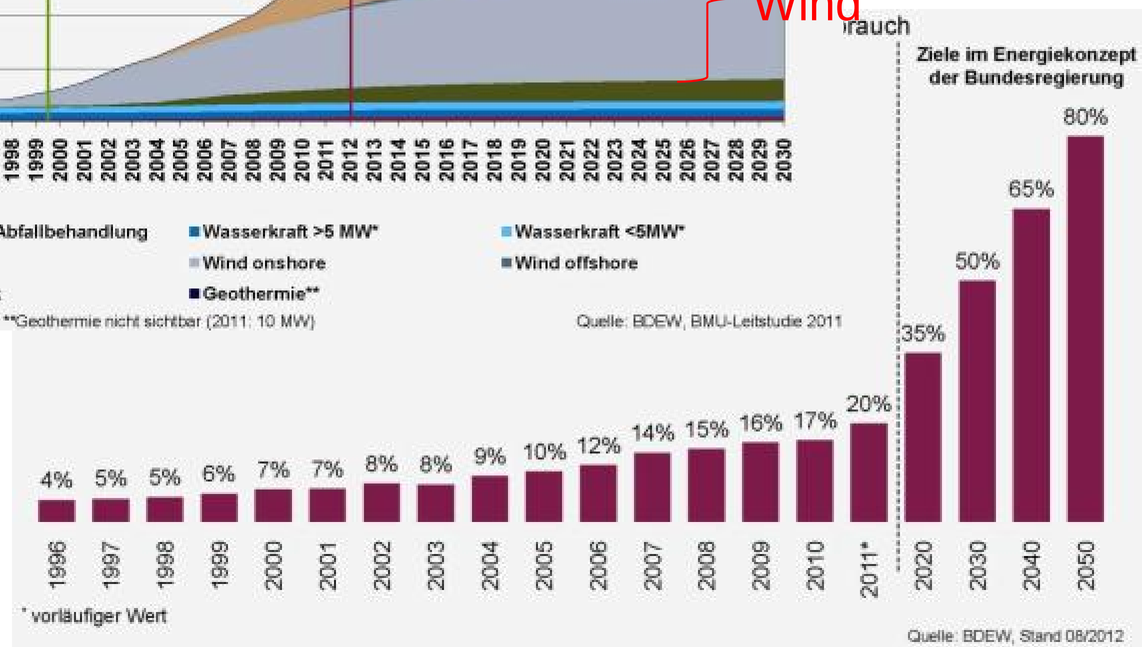
Background
German „Energiewende“: RE Targets

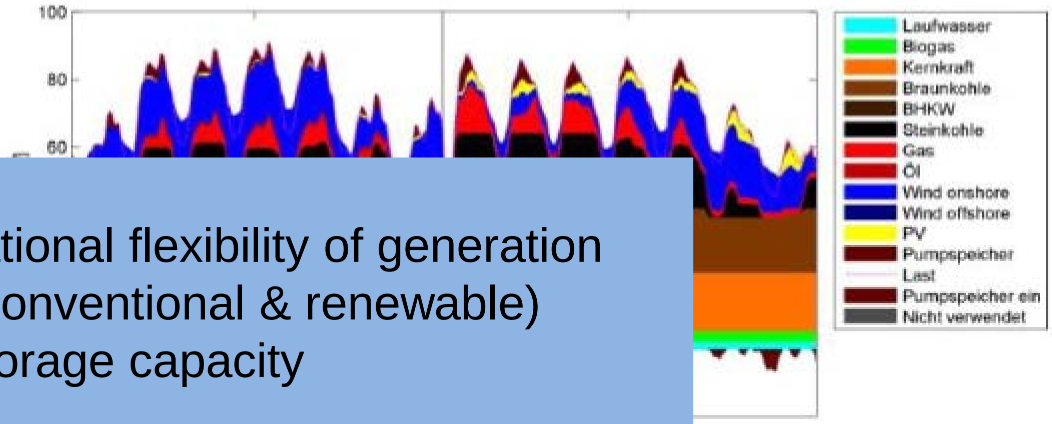




Political targets:
- 50% of gross electricity production from RE by 2030
- Mostly by PV und Wind

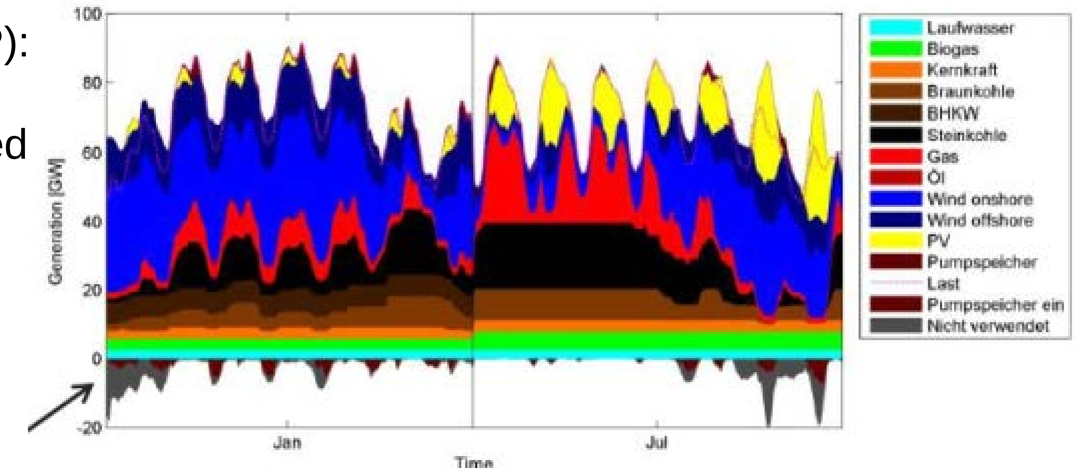
Background
High penetration of RE & grid balancing

Jan+Jul 2009
- High baseload share



Needed:
- Improved operational flexibility of generation capacity (both conventional & renewable)
- Expansion of storage capacity
- … and more

Jan+Jul 2020
- Planned: 35%RE by 2030 (NREAP): 51.8 GW PV, 45.8 GW Wind
- Share of baseload power decreased & significant share of fluctuating power from RE
- → variation of residual load 30..45 GW
- → pronounced gradients



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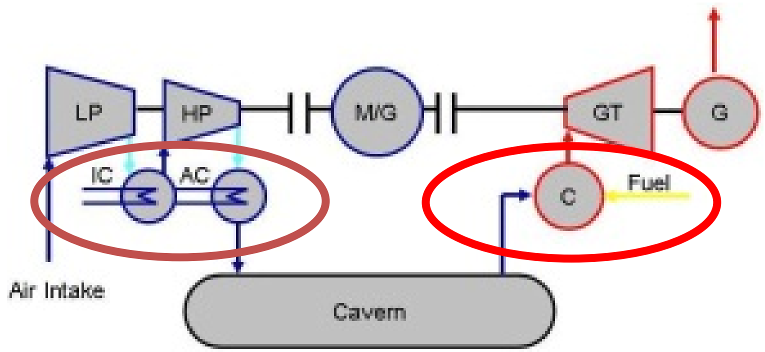
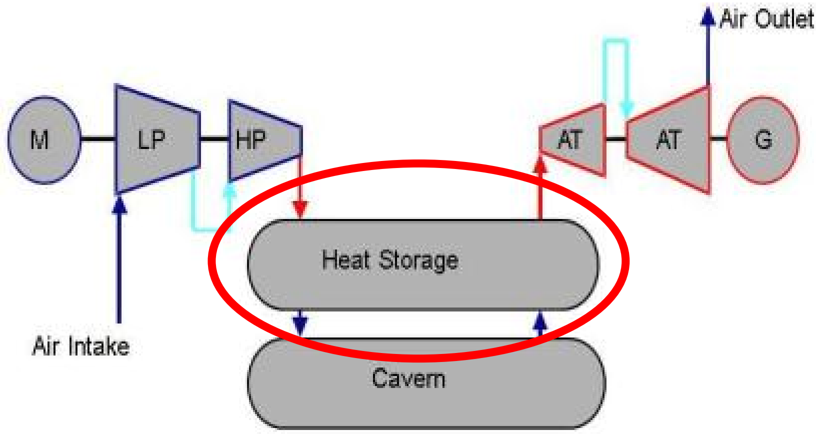
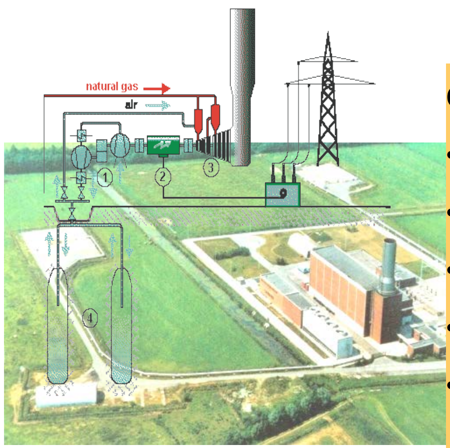
Background
Flexibility through Compressed Air Energy Storage (CAES)







Conventional CAES process:

- Huntorf, Germany (E.ON)
- 321 MW (2h)
- 310000 m^3
- 46 – 66 bar
- Operation since 1978, turbine refurbishment in 2007

Efficiency ~42%

Adiabatic CAES process:

- Re-use of compression heat during discharge operation

Emission-free

Round-trip efficiency ~70%

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VORWEG GEHEN

ADELE-ING Project

ADELE-ING Consortium

- **RWE**: Operator, Cavern, Grid & Economics
- **GE**: Turbomachinery, system design
- **DLR** (Coord.): Heat storage, system design
- **Züblin**: Heat storage, concrete pressure vessels
- **Fraunhofer IOSB**: Economics, Grid modeling
- **Universität Magdeburg**: Economics, Grid modeling

Scope:

- ADELE (2009-2013): Feasibility, concept studies, component development
- ADELE-ING (2013-2016): Engineering aspects, Assessment of system variants

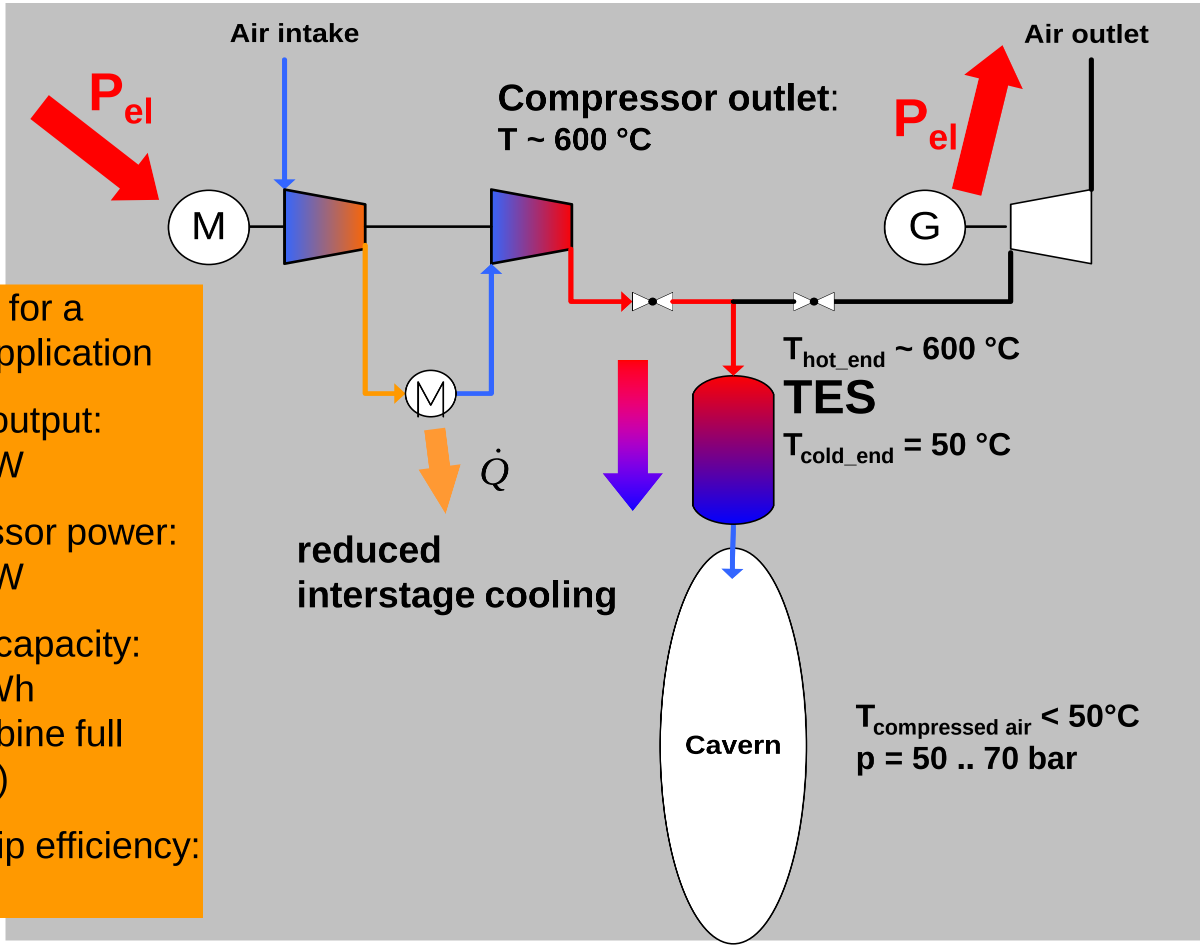
Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

ENERGIESPEICHER
Forschungsinitiative der Bundesregierung

ADELE-ING Project
System layout (base concept)

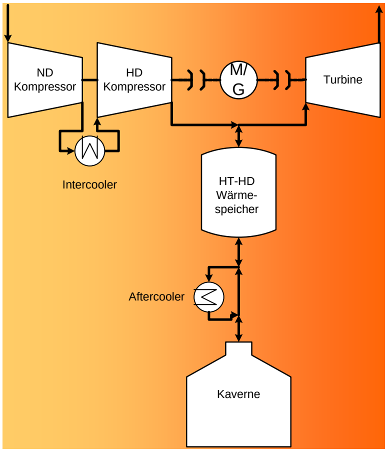


Target figures for a commercial application

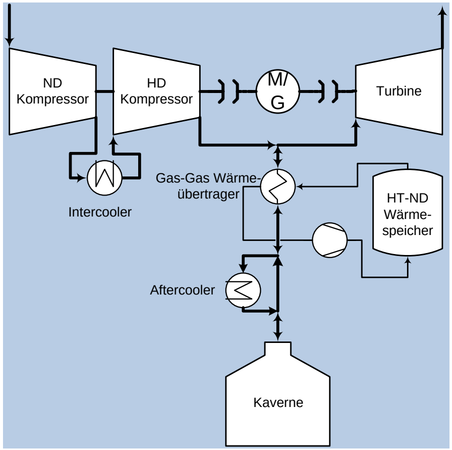
- Turbine output: ~ 260 MW
- Compressor power: ~ 200 MW
- Storage capacity: ~ 1-2 GWh (~4-8 turbine full load hrs.)
- Round trip efficiency: ~ 70%

Challenges & Achievements
ADELE System: Cost optimization of 10 variants

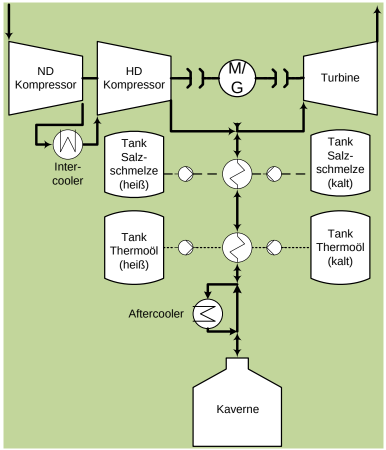
HT Regenerator storage



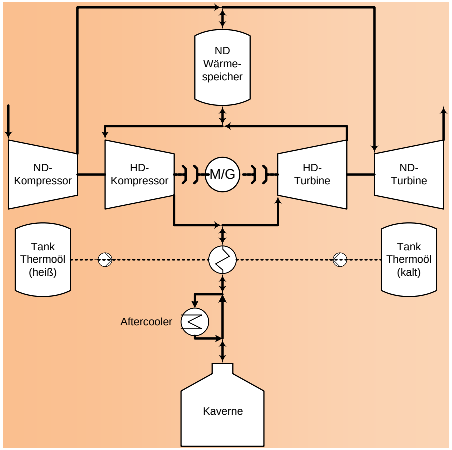
HT Regenerator storage in secondary loop



Molten salt heat storage & thermal oil storage



Multistage process with low temperature heat storage



- Comparative assessment, based on
- Conceptual designs, jointly developed P+I diagrams
- Techno-economic assessment, availability analysis, risk analysis

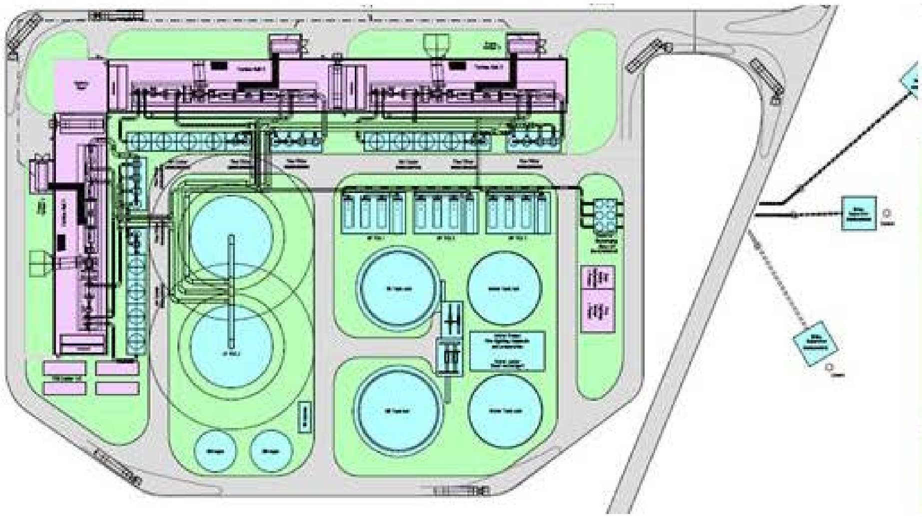
→ Advantages for 2-stage systems with reduced temperature level

Challenges & Achievements
ADELE System: Layout, lead options

Three concepts engineered in depth together with EPC partners
Different heat storage options:

- High-temperature molten salt HX and tank
- Low-temperature 2-stage LP and HP solid regenerators
- Low-temperature 2-stage, LP regenerator/ HP thermal oil HX

→ Capital costs comparable to pumped hydro plants: ~1300 €/kW_{el}



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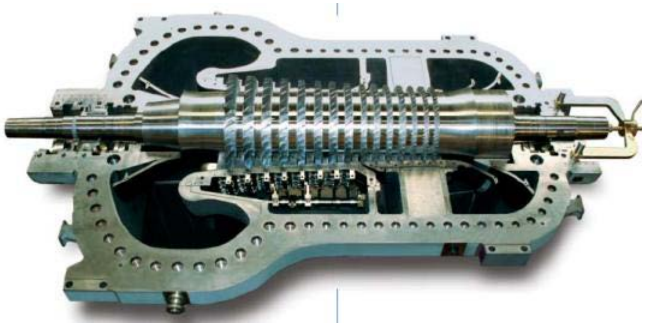
Challenges & Achievements
Turbomachinery

Compression Train
- Axial LP compressor, gas-turbine derived
- Radial HP compressors
- Challenge: high temperatures in last stages



Expansion Train
- Full-scale 100 MW: Axial turbines,
  HP based on steam, LP on gas turbine technology from GE O&G
- Small-scale: Radial HP expander and LP axial turbine
- Challenge: Broad operation range, Redesign and adapt from current products

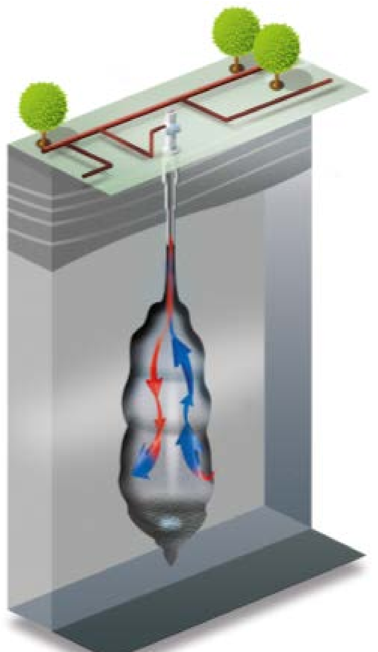
Shaft Arrangement
- Single-shaft with motor/generator and SSS clutches, gear boxes for compressors

imagination at work

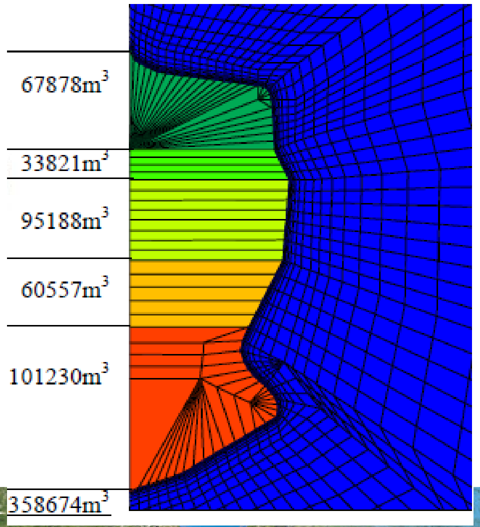
Challenges & Achievements
Cavern

Air storage in caverns

- Mature technology for natural gas
- Technical challenges for air:
  - significant higher flow rates → larger well diameter
  - frequent cycling → comply with safety/durability requirements
  - lower pressure spread → large volume
  - increased corrosion risk → advanced completition materials
- On-going investigations:
  - Re-use of existing caverns
    → cost saving potential
  - Sites studies (salt caverns, saline aquifers)
    → high potential, well correlated with wind sites
  - Simulation studies (geo-mechanics, assessment of operation strategies)



Source: ESK GmbH



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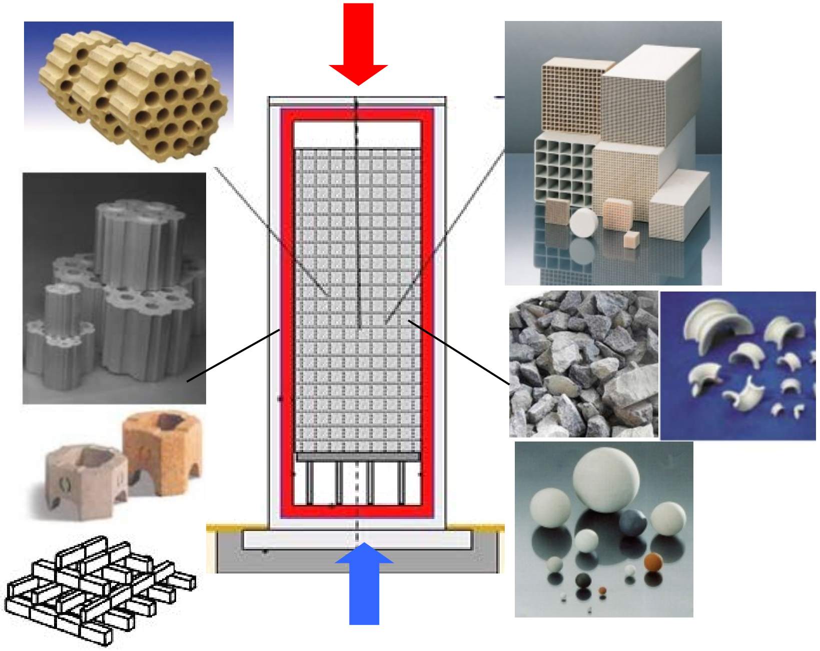
Challenges & Achievements
Heat storage technology

Challenges
- Large storage capacity (1-2 GWh)
- Large (& constant) discharge heat rates …
- … @~600°C, 50-70 bar
- Without existing industrial examples

Technology: Regenerator storage
- Direct contact of storage material & pressurised air
- Inventory material: oxide ceramics, natural stones
- Pressurised containment
- Inner HT-insulation



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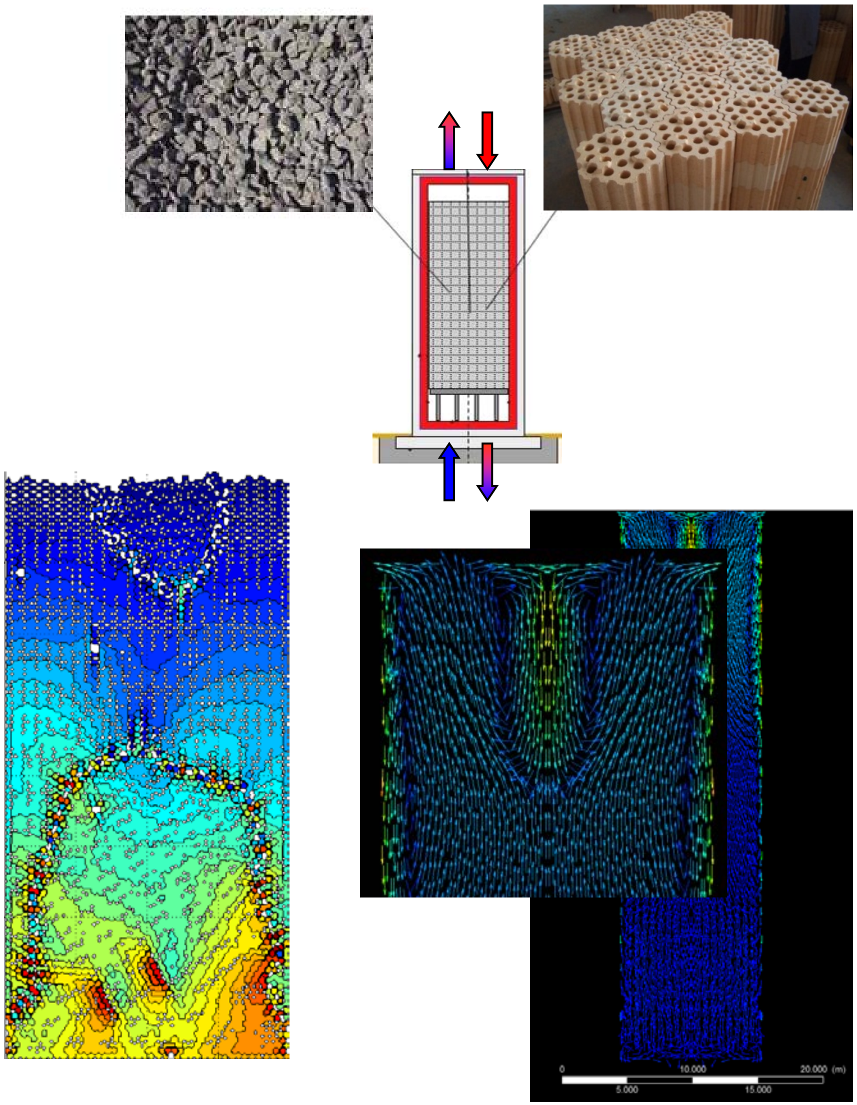
Challenges & Achievements

Heat storage design aspects

Development has covered all open design questions:

- Inventory arrangement? Typically shaped bricks, cost reduction potential with packed beds
- Thermal design: How to best deploy existing design freedoms for a cost-effective design?
- Fluid-dynamics: Pressure loss & flow quality?
- Thermo-mechanics: Mechanical loads (thermal ratcheting) & lifetime?
- Pressure vessel: solutions with pre-stressed concrete. Feasibility? Costs?
- Material qualification for low-cost inventory media & lifetime assessment
- Experimental validation of concepts

→ Cost reduction is the main target!

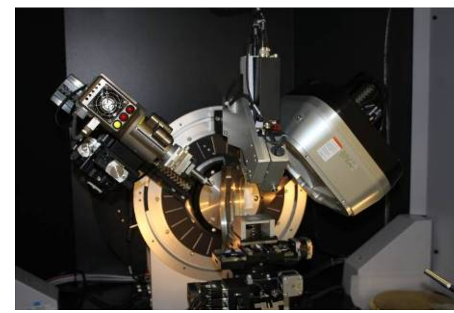


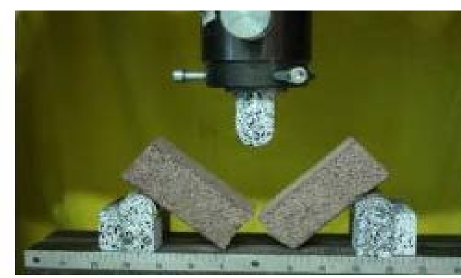
Stillstandsberechnungen für Schüttspeicheraufbau

Challenges & Achievements
Pilot-scale validation & material qualification

- Material qualification for low-cost inventory media in cyclic tests, lifetime assessment
- Experimental validation of inventory concepts in 5 tons scale

Teststand „TM-Speicher“ am DLR Stuttgart





Challenges & Achievements

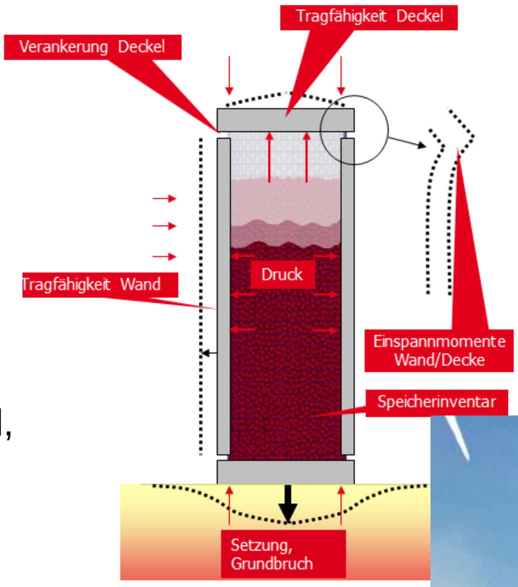
Structural engineering of TES pressure vessel

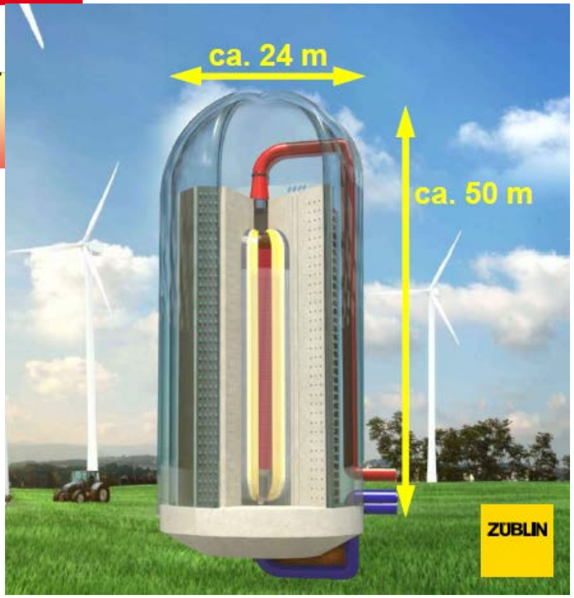
Challenges

- Mechanical working load of lid with openings
- Working load of wall with inner pressure & inventory-induced mechanical loads
- Working load at joint restraints @lid, @foundation
- foundation

Solution

- Containment from pre-stressed concrete
- Tightening, Insulation, integrated active cooloing





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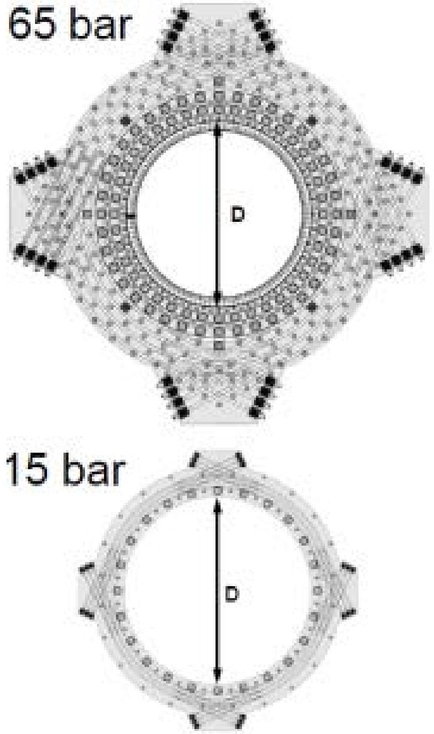
Challenges & Achievements
Structural engineering of TES pressure vessel

Concept: layout of pre-stressing elements



Experimental validation in 1:1 large-scale experiment

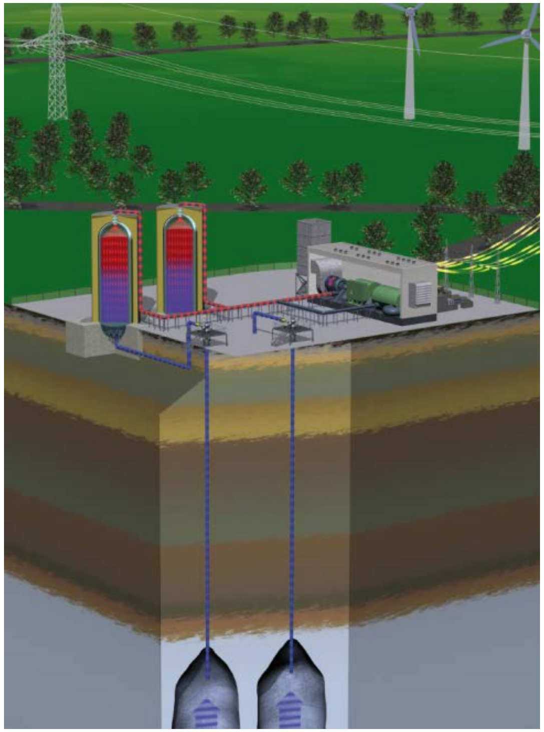
Ongoing work

Challenging and uncertain economic environment:
requires additional solutions with even lower costs, tailored to different markets:

- Down-scaled ACAES:
  - Distribution grid, Industrial “behind-the-meter” (15MW)
  - Low investment hurdle
- Hybrid (partly adiabatic) schemes:
  - Natural gas co-fired ACAES (lower specific cost, higher power, more flexibility through limited NG firing
  - Integration of power-to-heat from excess electricity (lower specific costs)
- Gas-turbine integrated CAES (including upgrade solutions)

Summary & Conclusions

- Adiabatic CAES offers cost-effective electricity storage, is a promising technology option to increase the energy system‘s flexibility
- ADELE-ING has elaborated an advanced development stage
  - Design solutions for all components available
  - Some configurations cost-optimised
  - High round-trip efficiency 66..70%
  - Since 2010 Capex brought down to level of pumped hydro
- Economics: difficult economic environment
- On-going work seeks to further improve the opportunity to market entry (downscaling to 10-30MW, hybrid schemes using low-tariff electricity or natural gas)



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Challenges & Achievements
ACAES Economics

Cost optimization led to ADELE-Ing plant configurations with Eur1300/kW
→ On par with pumped hydro storage!

- Revenues in current German market not sufficient for economic viability of storage plants
- Challenging and uncertain economic situation requires solutions with even lower cost tailored to different markets

Today's CAES Plants

Type	Simple CAES process, two-stage NG combustors	2nd generation CAES, recuperator, two-stage NG combustors
Location	Huntorf, Niedersachsen	McIntosh, Alabama
Commissioning	1978	1991
Turbine power	320 MW_{el}	110 MW_{el}
Generation capacity	~1 GWh	2.6 GWh
Thermal round trip efficiency	~42 %	~52 %
Specific cost	320 DM/kW_{el}	$\$591/kW_{el}$
Turbine start-up time	>9 min.	14 min.
Images Sources: BBC, Operating Experience with the Huntorf Air Storage GT Power Station, 1986; Daly, CAES reduced to practice, ASME 2001; http://www.pennenergy.com	 	 

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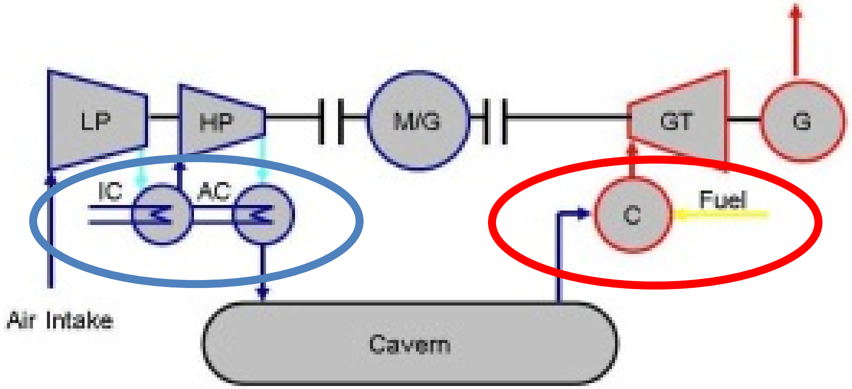
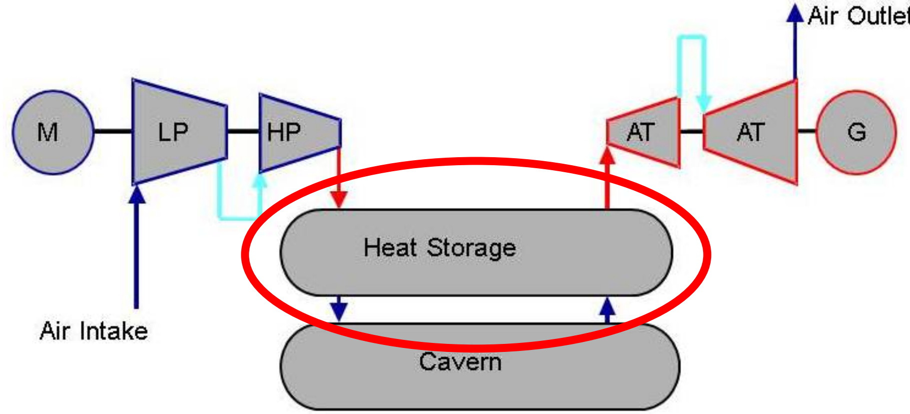
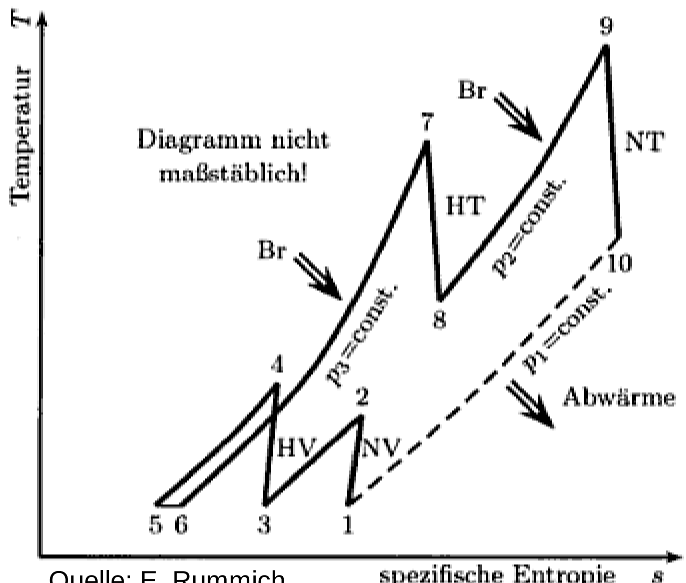
Technologieoption Druckluftspeicher







Quelle: E. Rummich

Adiabater Prozess:

- „Reiner“ Speichertechnologie, lokal emissionsfrei
- Hoher Speicherwirkungsgrad ~70%