Session I
Large Storage for Bulk Energy Services

Large-scale electricity storage with Adiabatic CAES – The ADELE-ING Project

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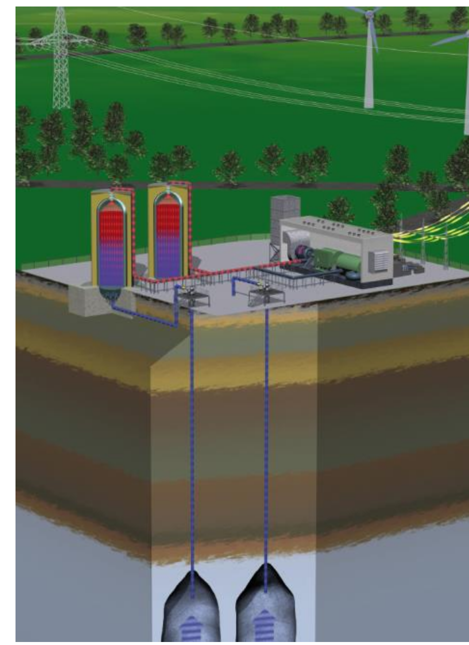
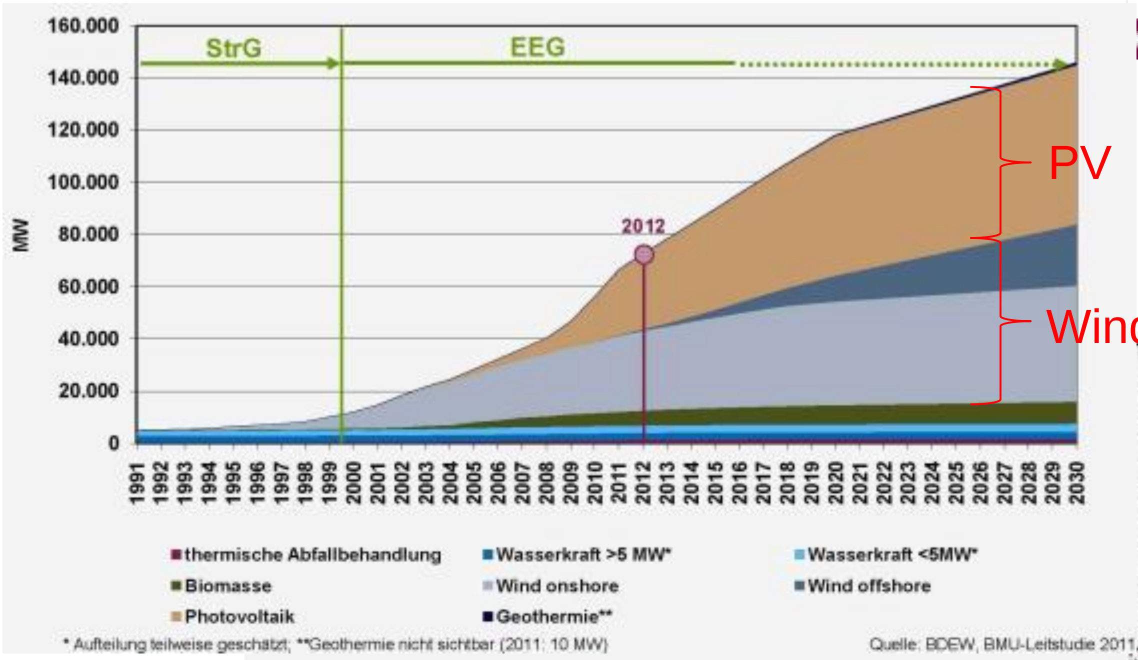


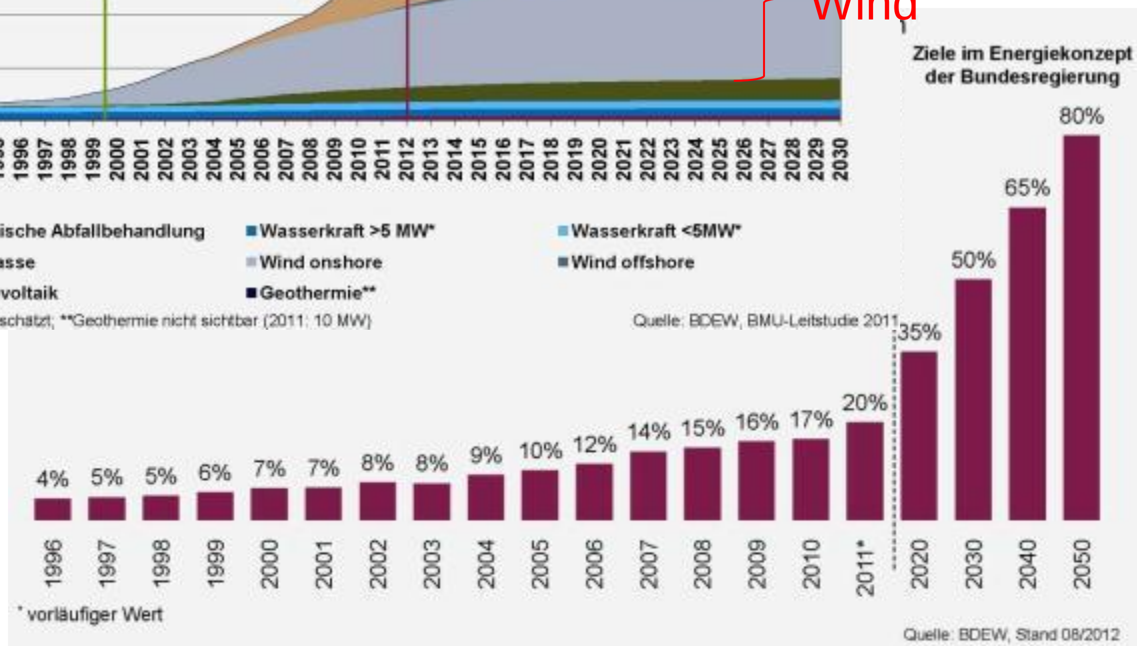
Day 1 – Technology

Energy Storage Global Conference
Explaining I Exchanging I Enabling
Paris | 19th to 21st November 2014

Background

German „Energiewende“: RE Targets





Political targets:

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

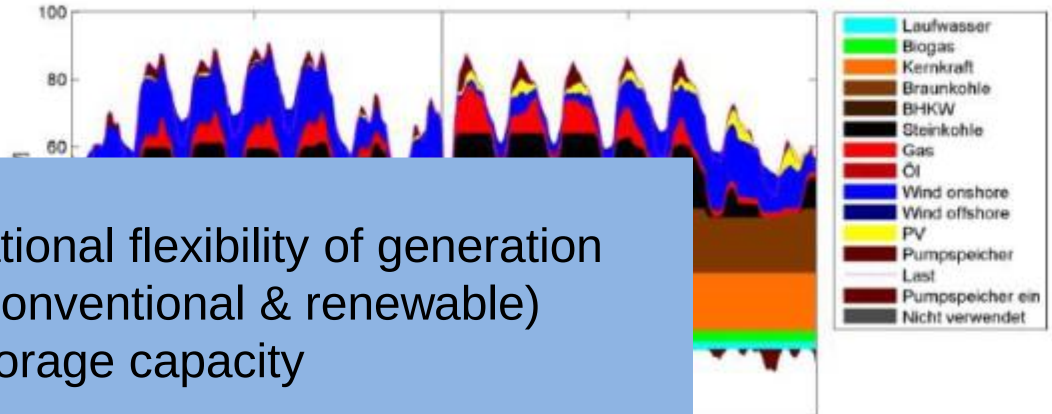
Background

High penetration of RE & grid balancing

Example Germany

Jan+Jul 2009

- High baseload share

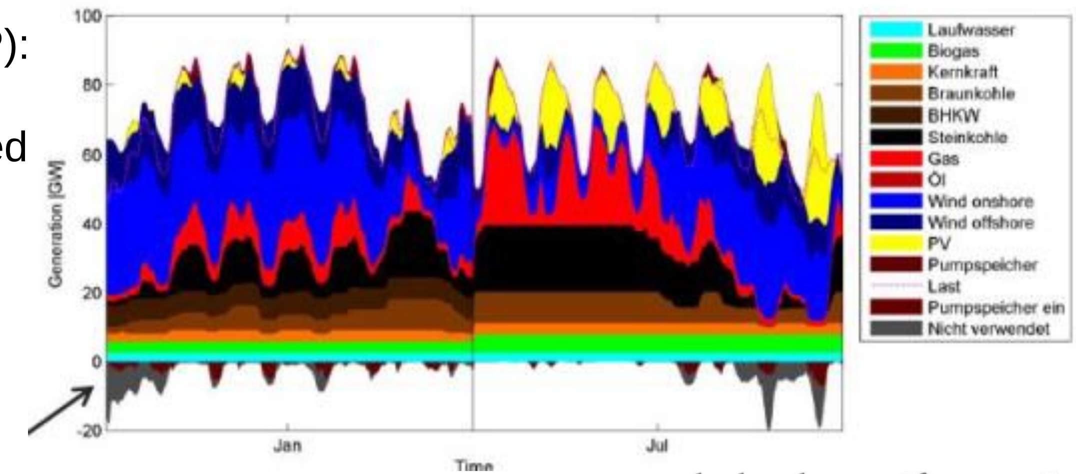


Needed:

- 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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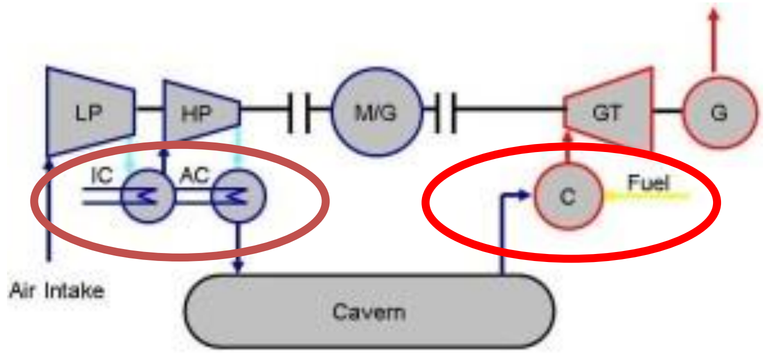
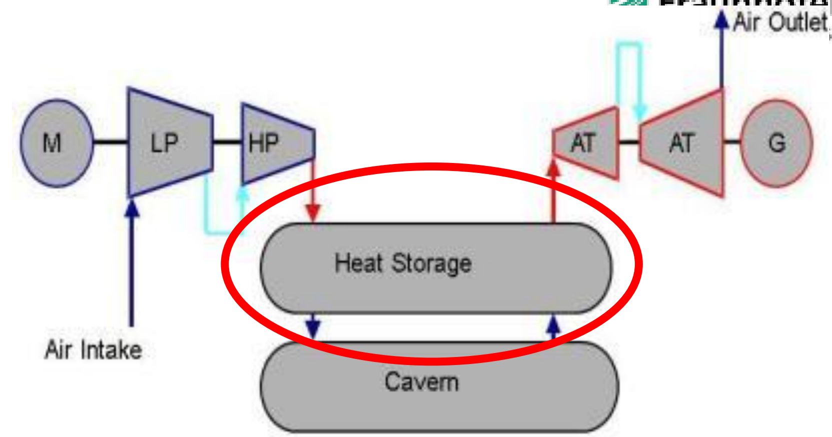
Background

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

Round-trip efficiency ~42%

Adiabatic CAES process:

- Re-use of compression heat during discharge operation

Emission-free

Round-trip efficiency ~70%

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

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imagination at work

DLR

ZÜBLIN

Fraunhofer IOSB

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

Supported by:

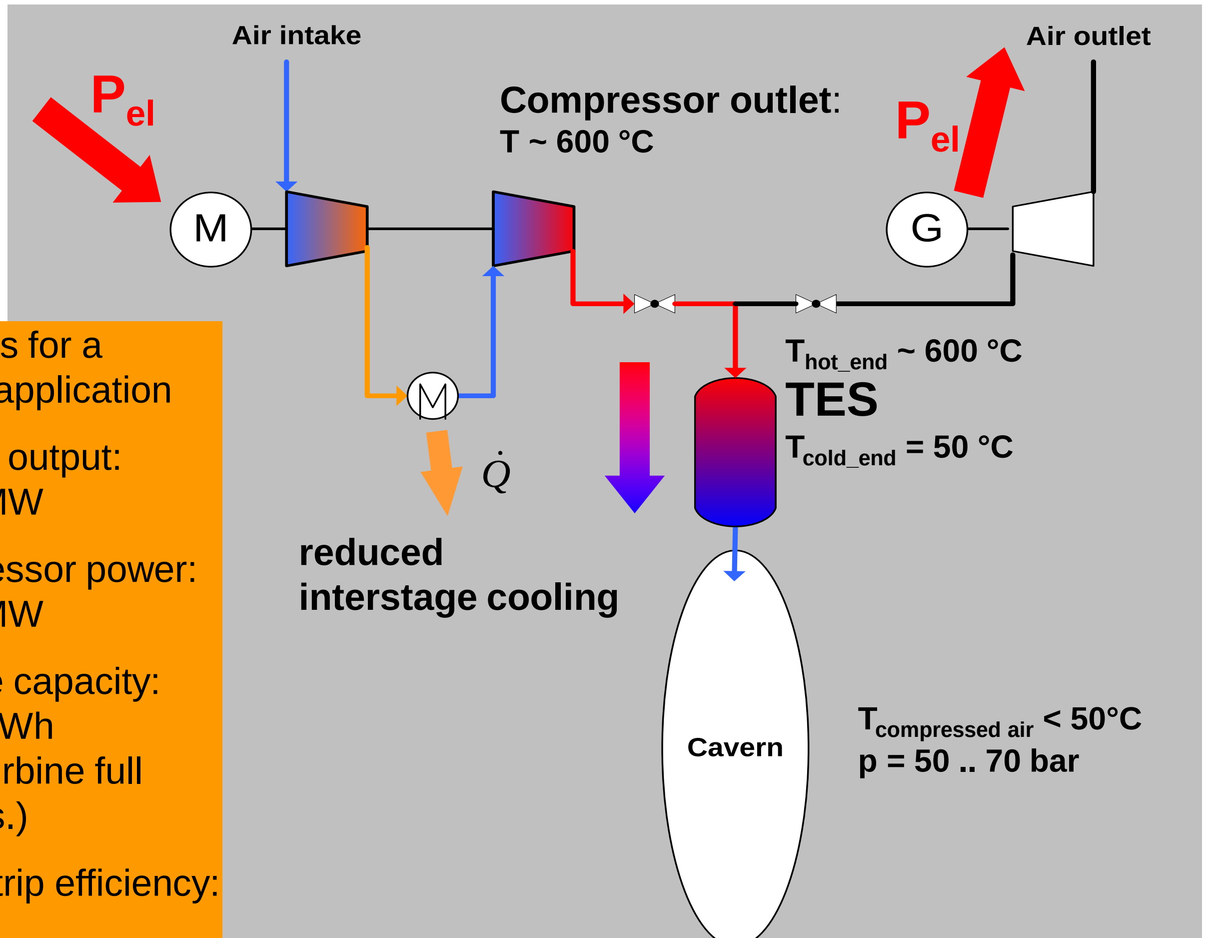
Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

ENERGIESPEICHER Forschungsinitiative der Bundesregierung

ADELE-ING project

System layout (base concept)



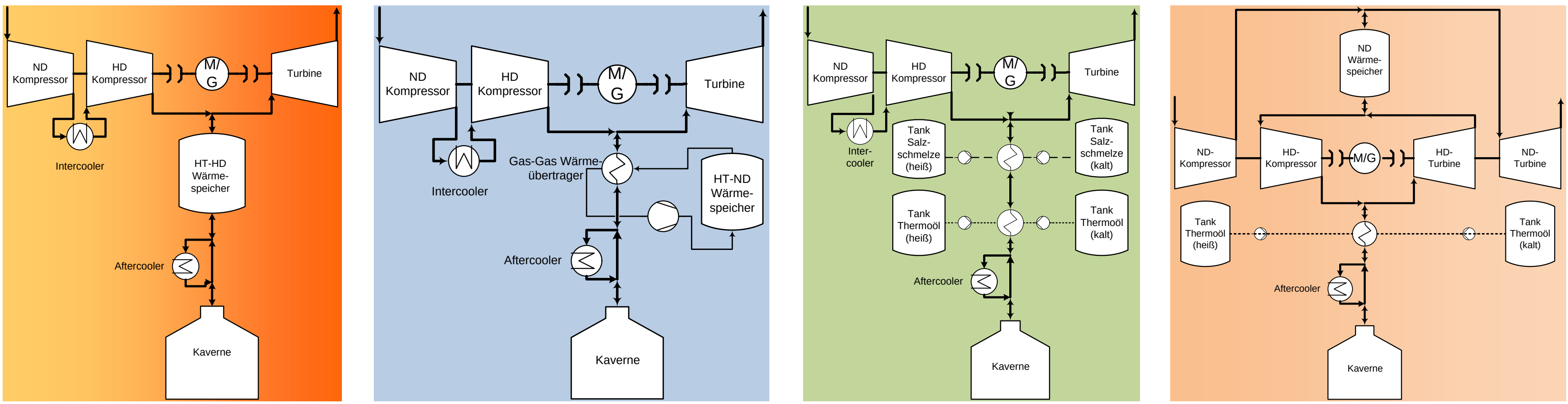
Target figures for a commercial application

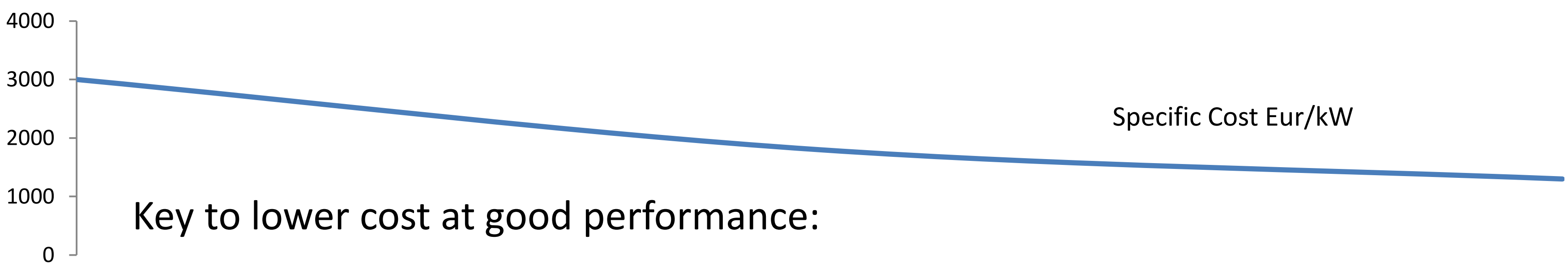
- Turbine output: ~ 260 MW
- Compressor power: ~ 200 MW
- Storage capacity: ~ 1-2 GWh (~4-8 turbine full load hrs.)
- Round trip efficiency: ~ 70%

Challenges & Achievements

ADELE System Technology: Cost Optimization

10 Concept variants jointly developed, techno-economic analysis and risk assessed





Key to lower cost at good performance:

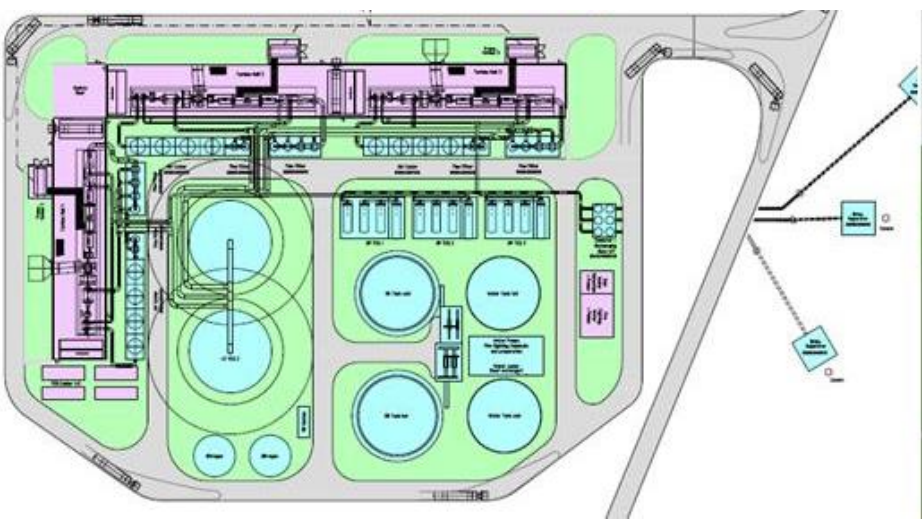
- Multi-stage heat storage
- Standard / commercial technologies, reduced temperature

Challenges & Achievements

ADELE System Technology: Layout

Three final concepts were engineered together with EPC partner
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



Challenges & Achievements

ADELE System Technology: Ongoing Studies

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

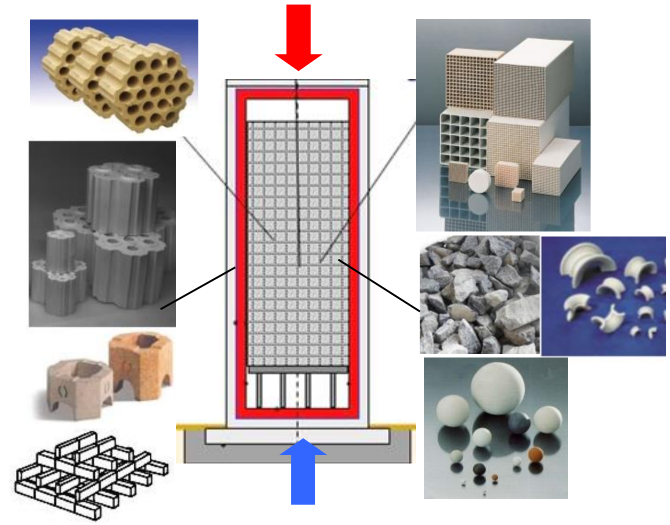
- Down-scaled ACAES
  - ✓ Distribution grid, Industrial "behind-the-meter" (15MW)
  - ✓ Low investment hurdle
- Natural gas co-fired ACAES
  - ✓ Lower specific cost, higher power, more flexibility through limited NG firing (> 100MW)
- ACAES solutions integrating power-to-heat from excess electricity
  - ✓ Lower specific costs
- Gas-turbine integrated CAES (including upgrade solutions)
  - ✓ Waste heat from peaking gas turbine
  - ✓ Low specific cost

Challenges & Achievements

ACAES Heat Storage

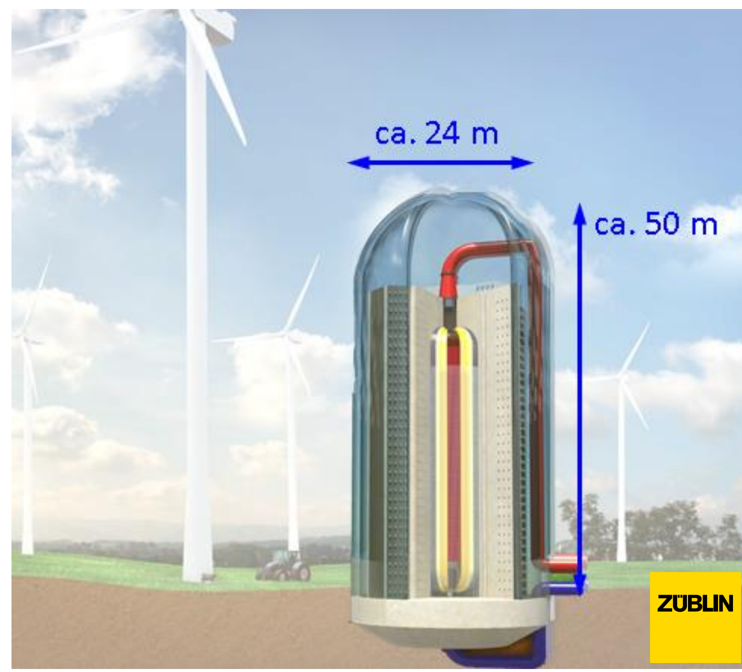
Challenges

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



Development covers ..

- various design options, focus is on solid media storage
- all relevant design aspects (thermal, fluid-dynamics, thermo-mechanics)
- solutions for a pressure vessel from pre-stressed concrete
- material qualification for low-cost inventory media
- experimental validation of concepts

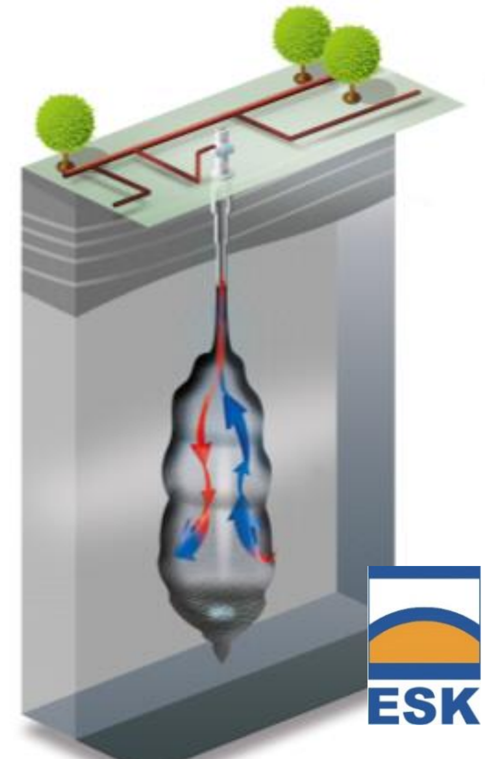


Challenges & Achievements

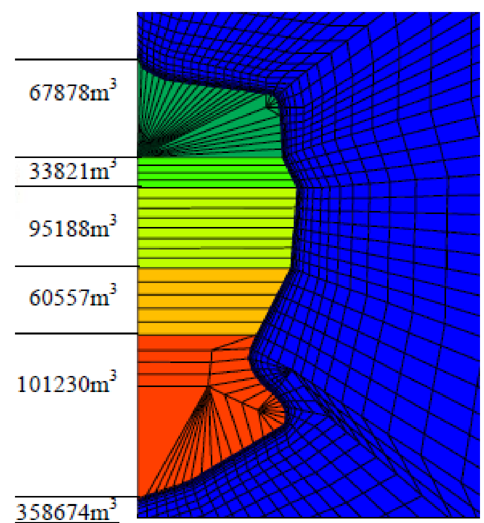
ACAES Cavern

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



Source: ESK GmbH



Challenges & Achievements

ACAES Turbomachinery

Compression Train

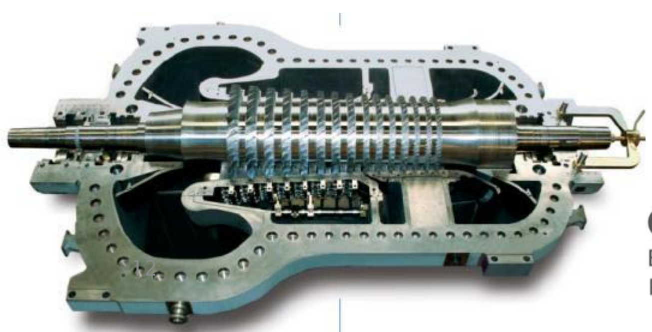
- Axial LP compressor, gas-turbine derived
- Radial HP compressors
- Challenge: high temperatures in last stages

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: Redesign and adapt from current products

Shaft Arrangement

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



Challenges & Achievements

CAES Economics

Cost optimization led to ADELE-Ing plant configurations with Eur1300/kW

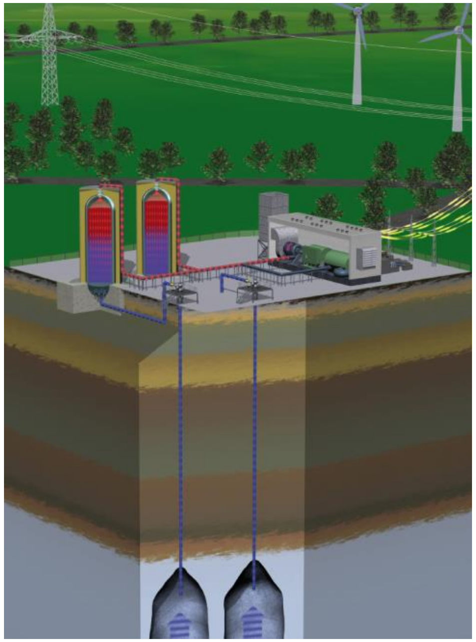
✓ On par with pumped hydro storage!

- ❑ 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

Summary & Conclusions

ADELE-Ing Compressed Air Energy Storage

- Technology offers cost-effective electricity storage, is a promising technology option to increase system flexibility
- ADELE-ING has reached an advanced development stage
  - Design solutions for all components elaborated
  - 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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Thank you for your attention

Backup Slides

ACAES Technology

Current 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