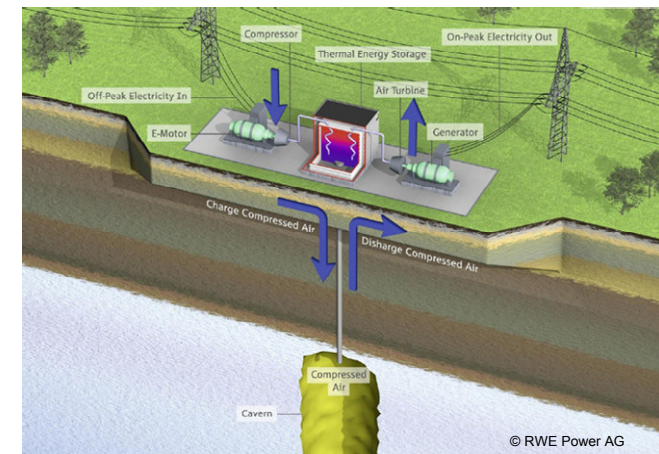


Status and Technical Challenges of Advanced Compressed Air Energy Storage (CAES) Technology

Matthias Finkenrath (GE Global Research Europe)
Simone Pazzi, Michele D'Ercole (GE Oil & Gas)
Roland Marquardt, Peter Moser (RWE Power AG)
Michael Klafki (ESK GmbH)
Stefan Zunft (DLR)



2009 International Workshop on Environment and Alternative Energy

Organized by C3P and NASA, Nov 10 - 13, 2009

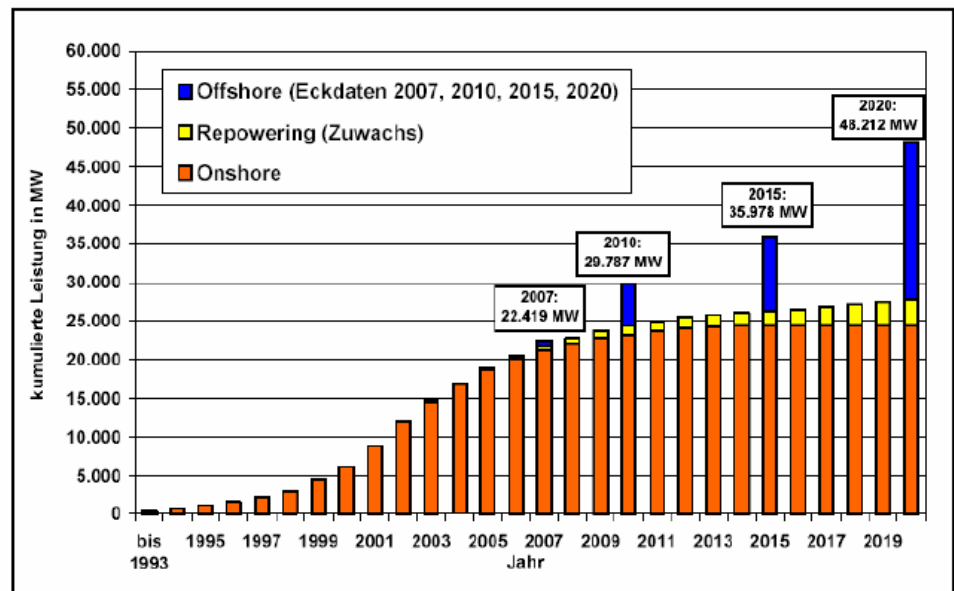
GE Global Research, Garching n. Munich, Germany



Motivation for Large-Scale Energy Storage

- Substantial increase of non-demand oriented power generation
- **New-built regenerative power generation** in particularly off-shore
- Forecast Germany: **48 GW in 2020 vs. 23 GW today**
- **Demanded increase of CHP Units** (25% of power generation From CHP in 2020)

Example: Offshore Wind Power in Germany (DENA)



Rapid Growth in Renewables Impacts Technical Requirements for Conventional Power Generation

Alternatives for Large-Scale* Energy Storage

Pumped Hydroelectric Energy Storage

- + very high efficiency (75 ... 78%)
- + extremely fast availability
- low extension potential
- long permitting processes

* "100+MW power
for hours"

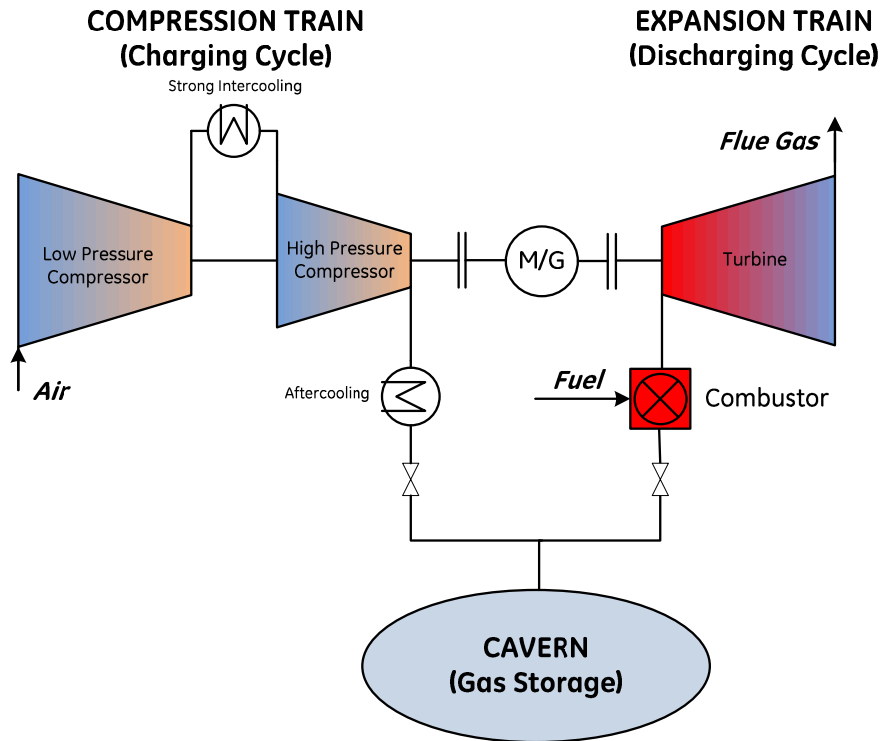
Compressed Air Energy Storage (CAES)

- + low above-surface space requirements and impact
- + installation close to off-shore wind parks possible
(example: North Sea Coast of Germany)
- low efficiency of commercially available concepts (54%)

**CAES Concepts with Higher Efficiency Technically Feasible
Significant Development Needed Prior to Commercialization**

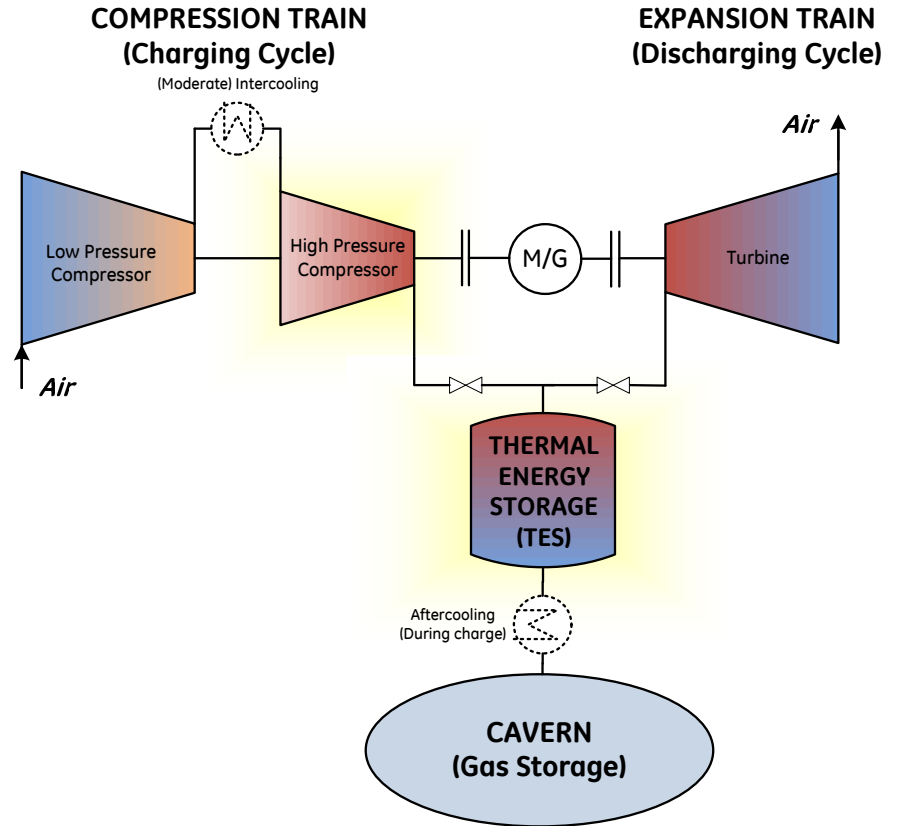
Compressed Air Energy Storage Concepts

Conventional CAES System



Only two commercial units installed
Efficiency max. 54 % with recuperation

Advanced Adiabatic System (AA-CAES)



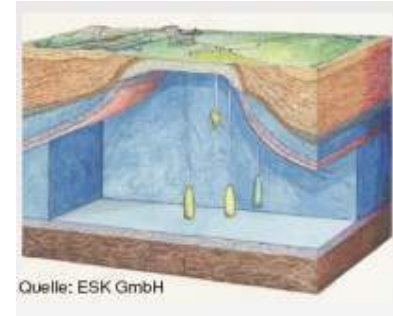
Advanced, zero-emission concept
Efficiency target 70 %

Key Technical Challenges of Adiabatic CAES



Thermal Energy Storage (TES)

- Inventory
- Insulation
- Active cooling
(600...650 °C, 50 ... 100 bar)
- Condensation



Adiabatic Compressor

- Requires specific redesign
- Simultaneous challenge wrt
 - temperature
 - pressure
 - load change stresses



Cavern

Known technology from natural gas storages, but

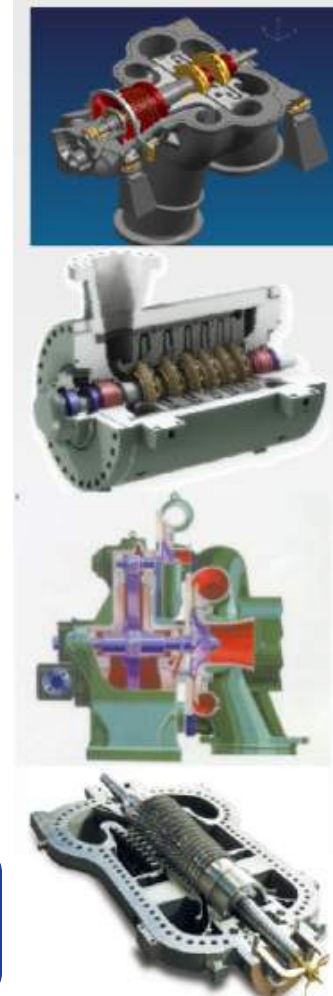
- Higher discharge rate
- Larger drilling diameter
- Larger volume

TES & Compressor: Substantial Development Need
Turbine & Cavern: Moderate Development Need

Example: Compressor Considerations

- Compression requires combination of at least two casings
- Comparison of alternative turbomachinery options
- Aerodynamic selection and thermodynamic evaluation of compressor stages
- Thermomechanics at > 600 °C biggest challenge:
 - material selection
 - thermal expansion and thermostresses
 - sealing concepts
 - max. temperatures for bearings, lubrication

Compressor Development for Aggressive Environment

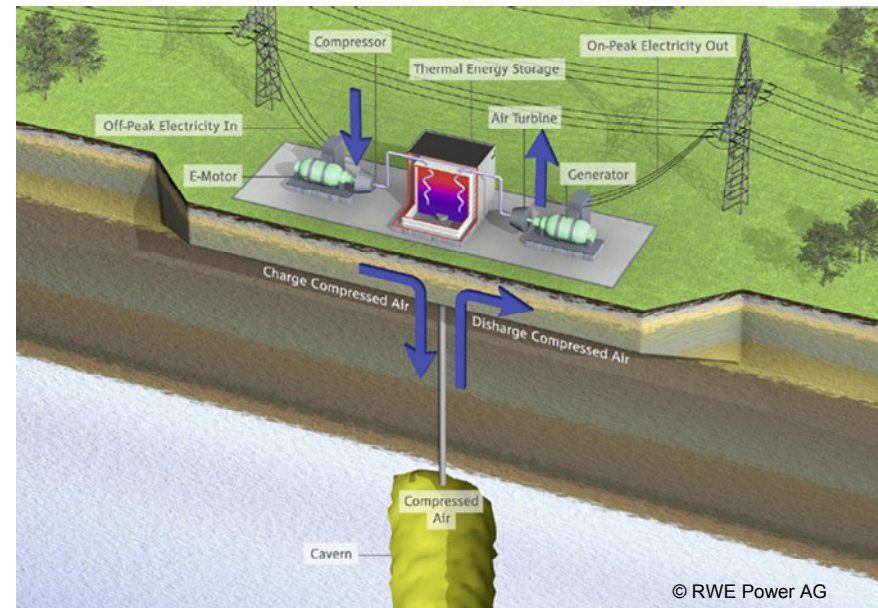


Example: Boundary Conditions of Joint RWE & GE Feasibility Study

Project Phases



- ~ 260 MW Turbine
- ~ 200 MW Compressor
- Daily Cycle
- ~ 70 % Target Efficiency
- 4 ... 6 h Turbine Operation
- 8 ... 12 h Compressor Operation
- 1040 ... 1560 MWh Capacity
- Add. Revenue: Minute grid reserve



Conclusions

- Increasing need for large-scale storage driven by non-demand oriented power generation
- AA-CAES without alternative in many geographical areas, in Germany in particular at the coastline
- AA-CAES development needs to be started now for large-scale implementation in the next decade
- Most substantial R&D need related to
 - Turbomachinery and
 - Thermal Energy Storage
- Results of feasibility study of RWE and GE show promising results

**Increasing Interest in Advanced Adiabatic CAES,
but Still Substantial R&D Needs**