Submarine Adiabatic and Isobaric Compressed Air Energy Storage

(SM – AI – CAES)

Jürgen Purtz, IT-Consultant, juergen@purtz.de
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Existing Large Energy Storages

1. Pumped Storage Hydro Power Plant
   - Using potential energy of pumped up water

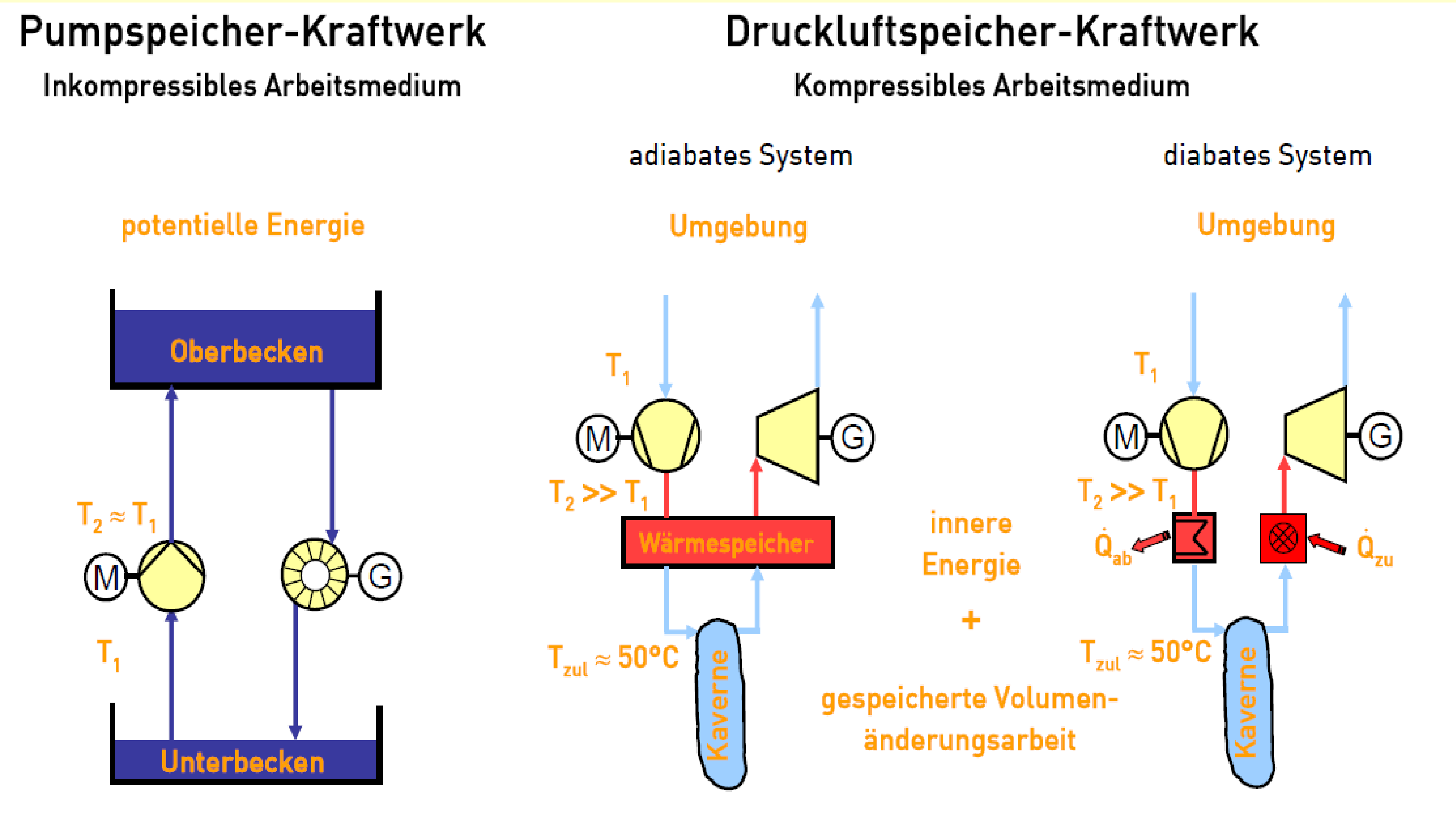
2. Diabatic Compressed Air Energy Storage (CAES)
   - Using volume reduction work of air
   - Loosing a lot of energy by heat loss
   - Low efficiency factor
   - Huntorf (Niedersachsen), McIntosh (Alabama)

Present Development

3. Adiabatic Compressed Air Energy Storage (A-CAES)

   - Enhancement of CAES concept
   - Using volume reduction work of air **in combination** with a heat storage (low heat loss)
   - High efficiency factor: 0.7
   - No CO_2 emission
   - Paper presented by EnBW at the Energietage Hannover, 2007
   - Study *ADELE* coordinated by Federal Ministry of Economics and Technology, Berlin, 2010

Overview



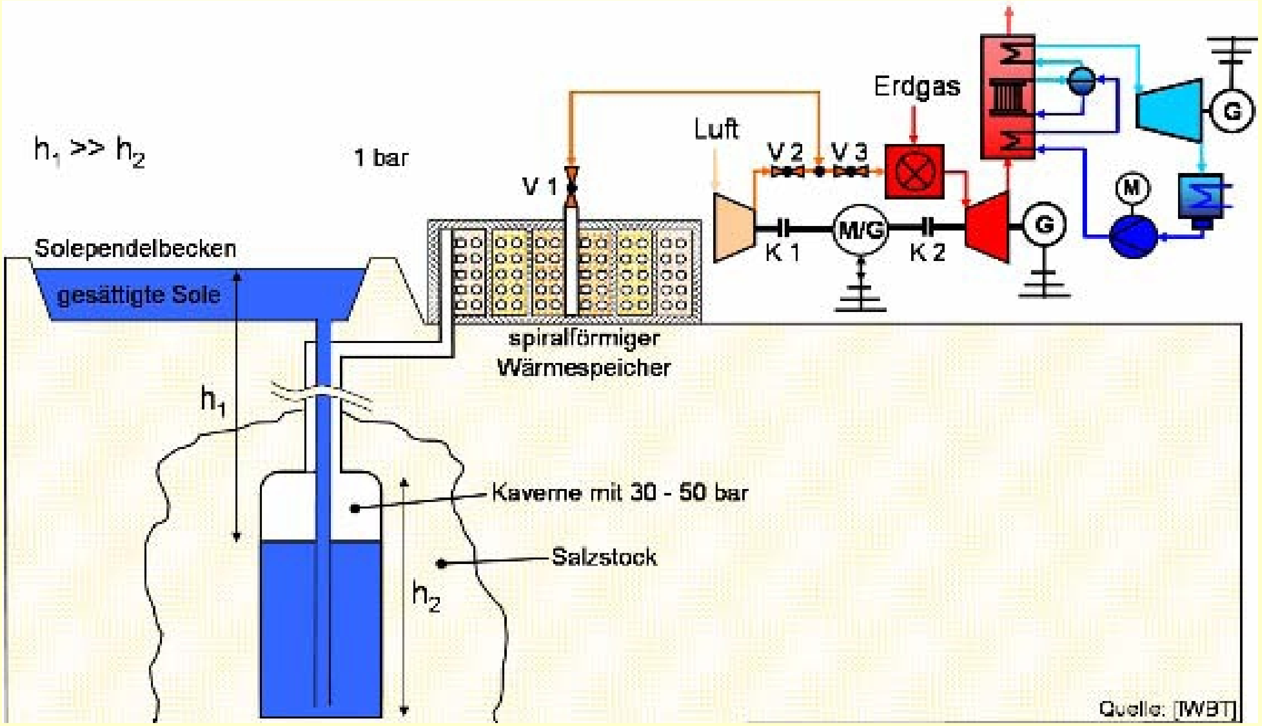
[Source: EnBW]

Present Development, cont.

4. Adiabatic and Isobaric Compressed Air Energy Storage (AI-CAES)

    - Enhancement of A-CAES concept
    - Isobaric characteristic is realized by a hydrostatic head (a lake) over the cavern with a pipe as the junction between the two
    - Study ISACOAST-CC by TU Braunschweig, IWBT, Prof. Leithner
    - Designing as a Combined Cycle Gas Turbine (CCGT; or GuD: Gas und Dampf)

Overview



Isobaric and Adiabatic CAES as a Combined Cycle Gas Turbine (CCGT or GuD) [Source: IWBT]

Present Development, cont.

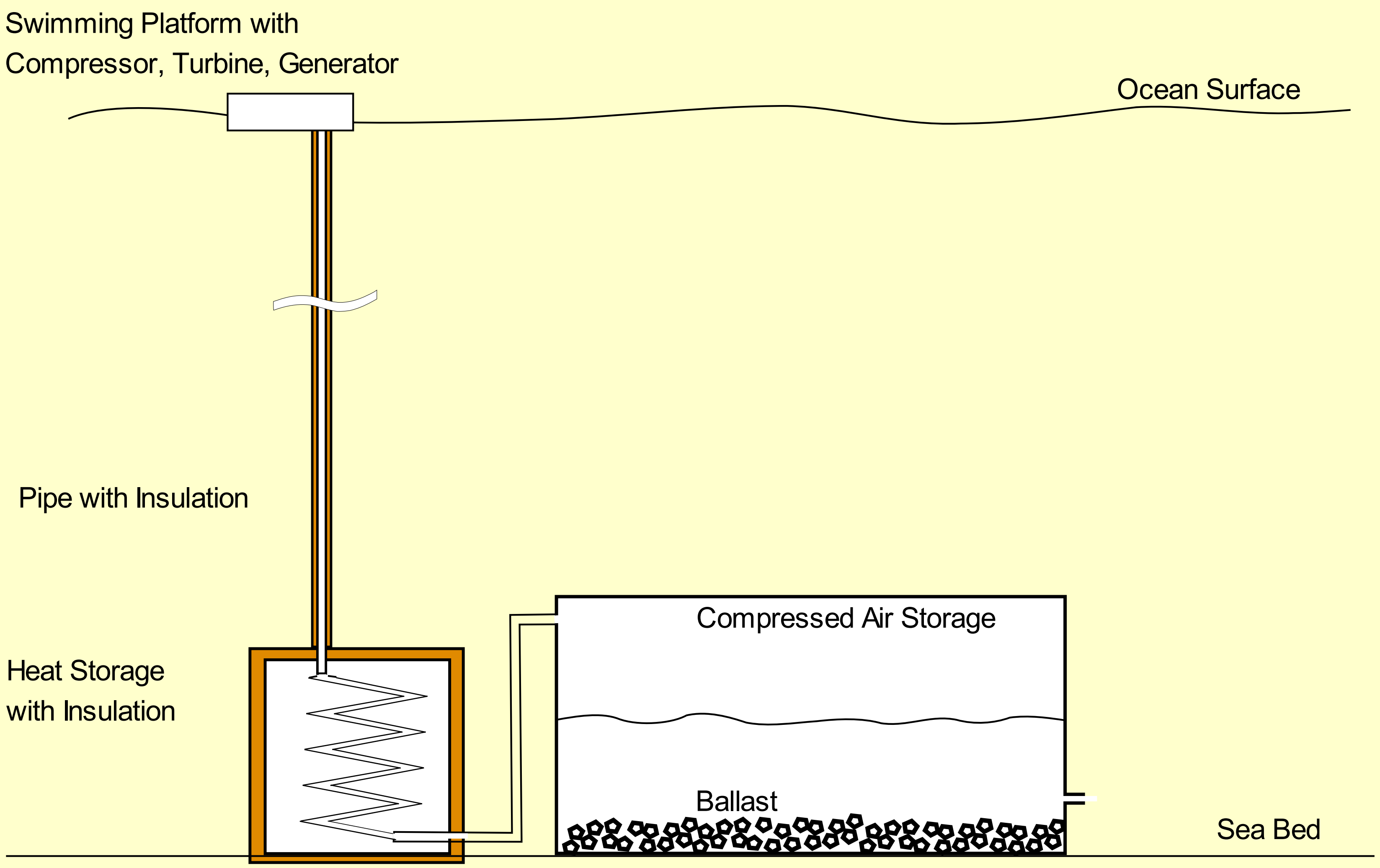
5. “Integrated Compressed Air Renewable Energy System ICARES” also known as “Energy Bag™”

   - Flexible cover positioned under sea level. Its shape is similar to a hot-air balloon.
   - Anchored at seabed or loaded with inside hanging ballast
   - Optimisation of bag's shape
   - About 30 MWh per unit in depth of 500 m; diameter about 20 m
   - (No heat storage, as far as I know. Only few information public available.)
   - Study by Prof. Seamus Garvey, University of Nottingham

Further Development

6. Submarine Adiabatic and Isobaric Compressed Air Energy Storage (SM-AI-CAES). No CCGT or GuD.
   - Enhancement of AI-CAES concept and adoption to offshore situation
   - Position compressed air storage and heat storage under sea level
   - Benefit from natural pressure of water in some depth under sea level
     - Very low pressure difference between inside and outside of compressed air storage and of heat storage: simple and cheap construction
     - Pressure of water 'jails' compressed air
     - Use water as heat storage medium
       - Water has very high heat capacity
       - High temperature without boiling (because of raised pressure)

SM-AI-CAES


Swimming Platform with
Compressor, Turbine, Generator
Ocean Surface
Pipe with Insulation
Heat Storage
with Insulation
Compressed Air Storage
Ballast
Sea Bed

Storing Phase

- Excessive electricity drives electric motor
- Electric motor drives compressor
- Compressor compresses air
- Compressed (and so heated) air streams thru pipe to heat exchanger
- Heat energy is stored in heat storage
- Chilled air streams to compressed air storage and squeezes out its water

Discharge Phase

- Water streams into compressed air storage
- Compressed air streams to heat exchanger within heat storage
- Heat exchanger re-heats air
- Compressed and re-heated air streams thru pipe to turbine
- Turbine drives generator
- Generator generates electricity

Advantage: Large Scale Technology

- Amount of storable energy is comparable with a medium Pumped Storage Hydro Power Plant
- Amount of storable energy is proportional to depth under sea level without modification of the two tanks (there is no pressure difference between inside and outside independent of deepness)
- Free positioning of plant is possible: short distance to offshore wind parks
- Efficiency factor similar to AI-CAES
- No CO_2 emission
- May be, SM-AI-CAES will grow to an optional, standard component for offshore wind parks

Advantage: Low Investment

- Compressed air and heat storage tank need only thin wrappings – maybe old discharged oil tankers can be utilized.
- Heat storage medium *water* is freely available and has ideal physical characteristics: high heat capacity, boiling point over 300°C at 100 bar. You can store another 10 power 12 Joule in a cuboid with edge of 10 meter.
- For the turbine you can use standard equipment as its input pressure is nearly constant.

Disadvantages

- Germans access to see is limited to Nordsee and Ostsee: There we find only very low deepness. The situation is better in Norway, Mediterranean Sea, Ireland, Portugal, complete West Coast of North- and South-America, near New York, … .
- One has to invest into questions about material properties (insulation under high pressure and within salt water, lifetime of steel)
- Swimming platform must be positioned and stabilized at a fix point over tanks
- Pipe must be protected against drift off
- Flexible connection from pipe to platform
- Deconstruction after lifetime
- Environment questions

Typical Usage

Additional component for offshore wind parks

- Deliver electricity in a more constant mode
- Deliver more electricity during peak demands
- Decision depends on short term electricity prize
- Store energy during times of low wind and low demand in public electricity net

Stand alone installation (independent from offshore wind parks)

- Use it like a conventional Pumped Storage Hydro Power Plan

Some Amounts

Typical volume of heat storage	10^3 m^3
Typical volume of compressed air storage (= medium ship size)	10^5 m^3
Typical sinking deepness	About 500 - 1.000 m
Pressure at 1.000 m	About 100 bar
Storable Energy in compressed air storage	> 10^{12} Joule (= 270 MWh)
Storable Energy in heat storage	10^{12} Joule