Energy Storage
Key Technology for Sustainable Development

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Outline

- Rational for energy storage
- Storage of electricity
    - electro-chemical storage / batteries
    - pumped hydro
    - compressed air energy storage
    - chemical storage /hydrogen
- Thermal energy storage
    - sensible, latent, thermo-chemical heat storage
    - waste heat storage, flexible power generation, solar thermal applications
- Summary and conclusions

Energy Landscape of the Future - The European View

2008/2009 – European Parliament and the European Council agreed upon so-called „Climate and Energy Package“ – known as 20/20/20 targets

- reduction in EU greenhouse gas emissions of at least 20% below 1990 levels by 2020
- Increasing the share of renewable energy to 20% in EU’s energy consumption by 2020
- Improving the EU’s energy efficiency by 20% by 2020 compared to business as usual

2011- EC published its Energy Roadmap 2050

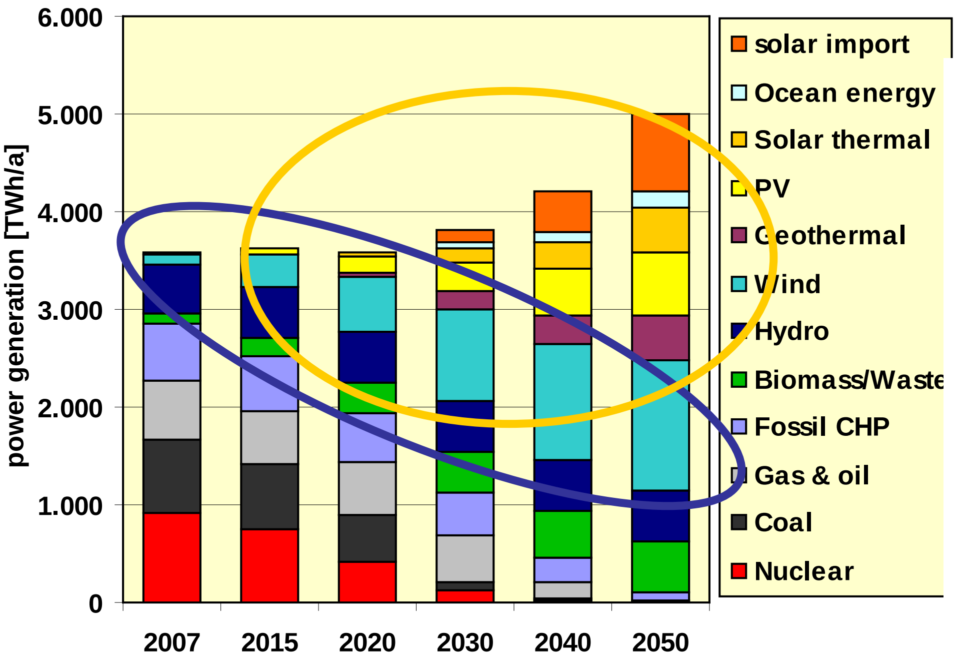
- long term views for the energy policy based on different energy mix assumptions
- the share of renewable energy sources (RES) in gross final energy consumption will achieve at least 55% in 2050

Source: *http://ec.europa.eu/clima/policies/package/index_en.htm*
EC Energy Roadmap 2050

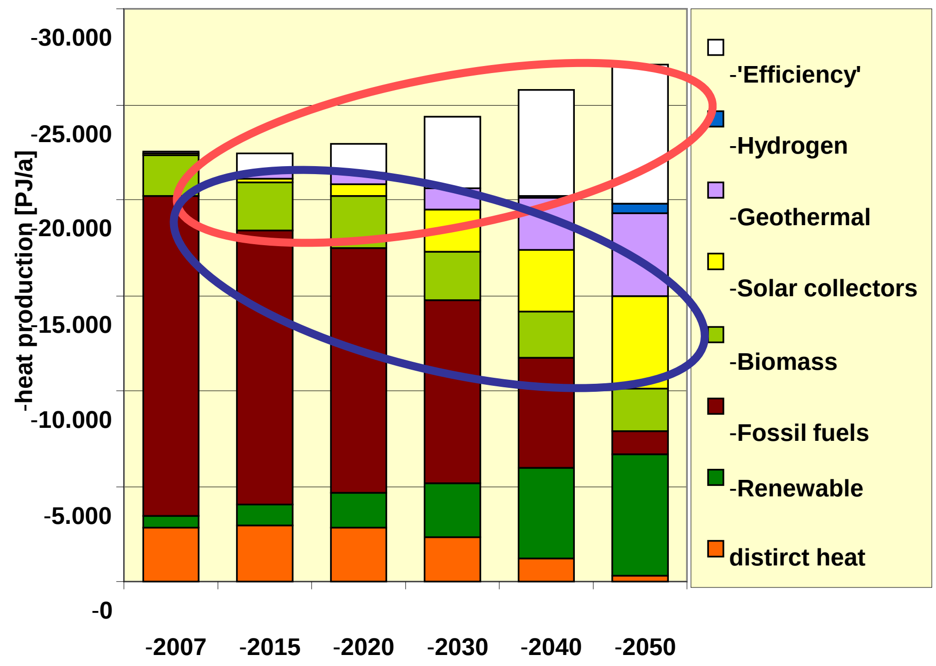
The European View

Results of the Advanced Energy [R]evolution scenario for EU27
(DLR, Greenpeace, EREC, Ecofys 2010)

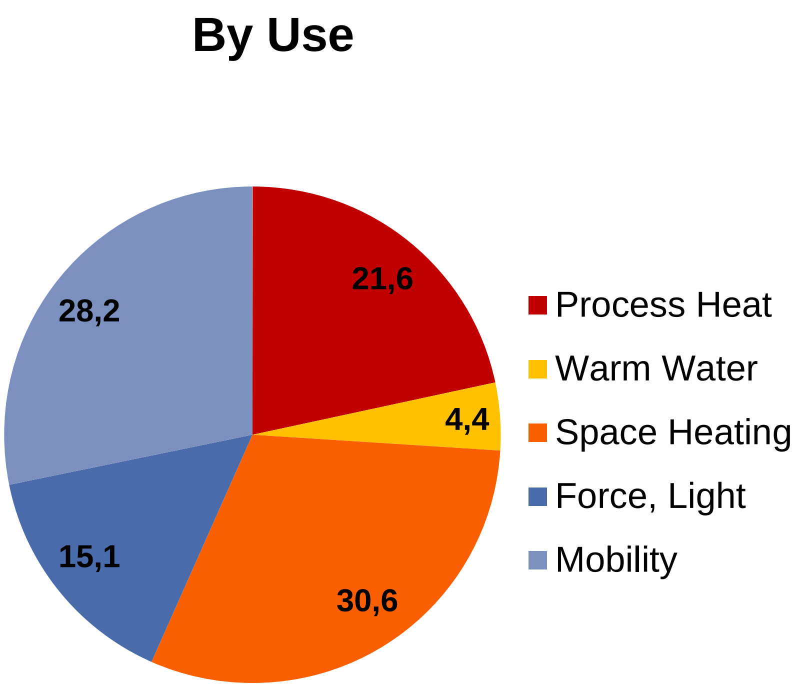
Future electricity generation ?

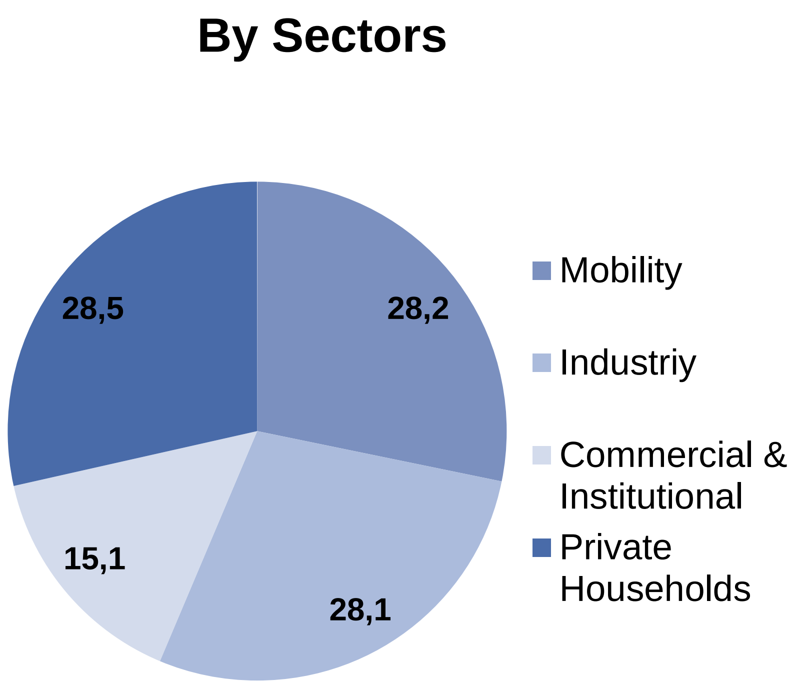


Future heat supply ?



German Gross End Energy Consumption in 2008





:Auswertungstabellen der AGEB, Stand: Juli 2011; BDEW-Endenergieverbrauchsstruktur, 2008

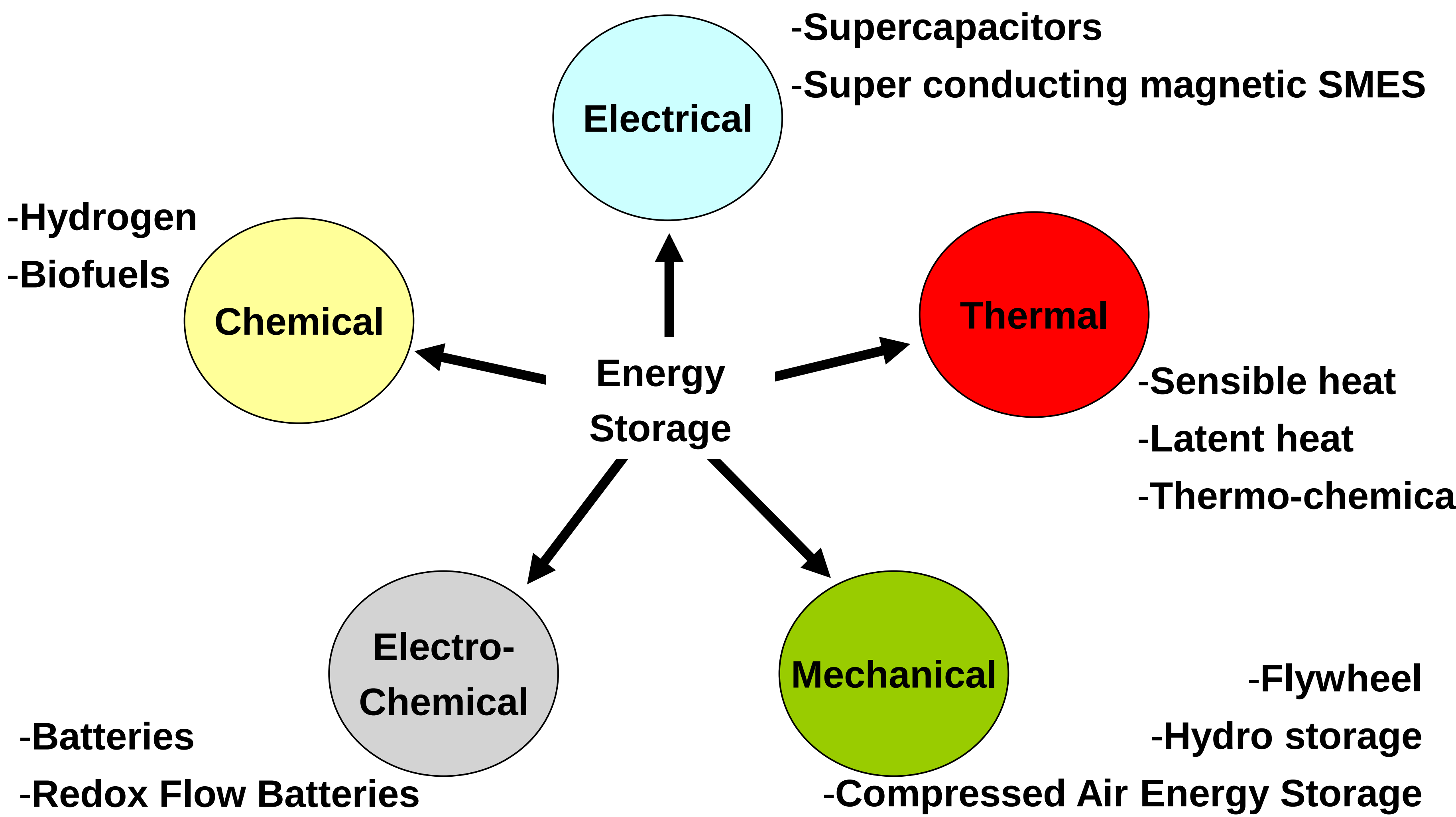
Source: BMU Leitstudie 2011

- About **57 % of the gross end energy** is consumed for supply of heat

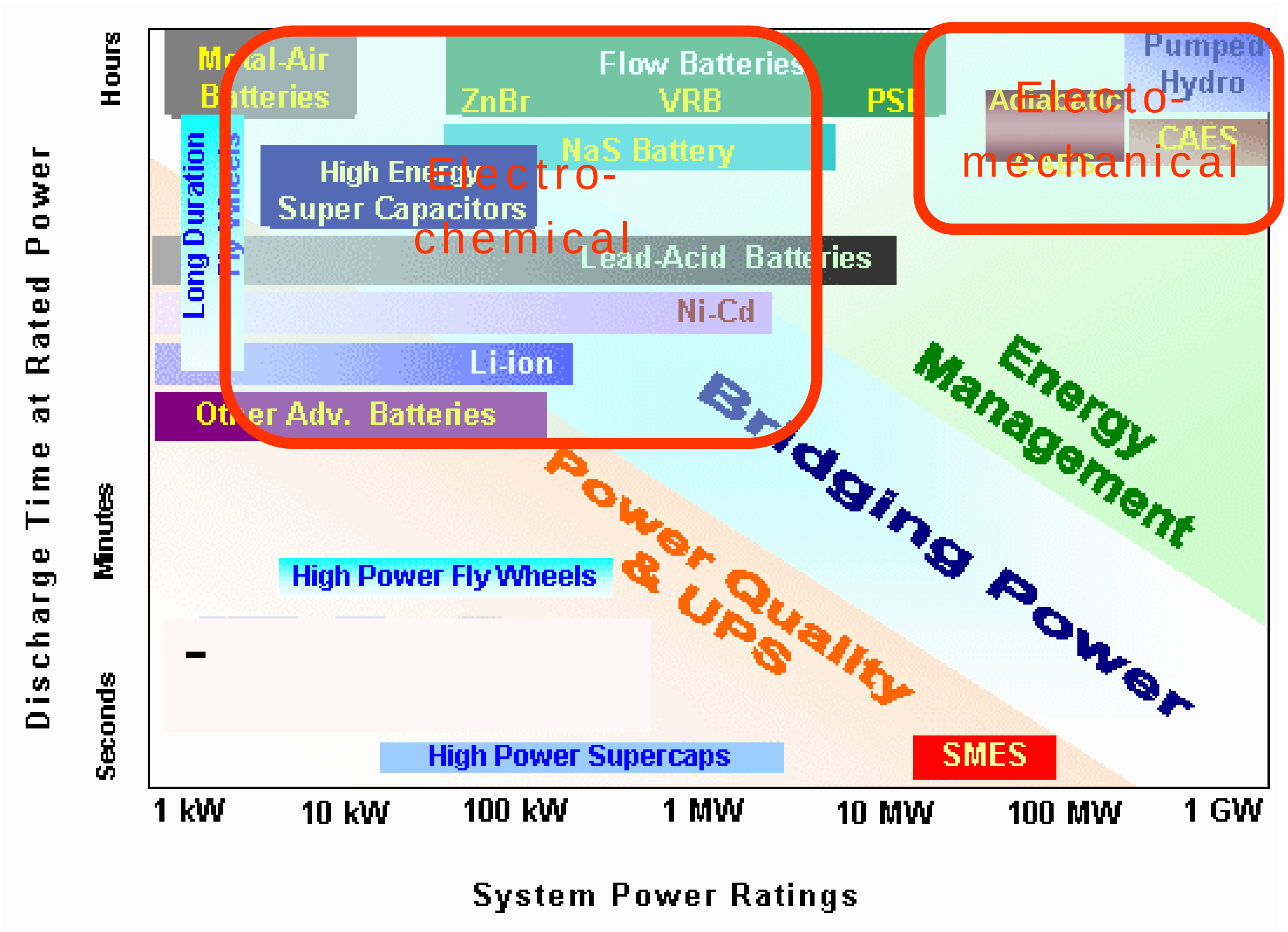
Conclusions from existing projections

- In all scenarios of the Roadmap 2050, the share of renewable energy sources (RES) in gross final energy consumption will achieve at least 55% in 2050
- Growing penetration of RES, in particular non-dispatchable generation such as wind and solar - photovoltaic (PV) and solar thermal
- Energy storage – in combination with other measures – is a key issue to respond to this challenge and to ensure a continued security of energy supply at any time
- Storage technologies will play a key role into a growing deployment of Electric Vehicles and low-energy buildings
- Energy storage contributes to manage local electricity and heat generation and consumption
- Storage enables more efficient design of heat and power generation to be sized closer to average energy flows, instead of to peak power requirements

Energy Storage Technologies



Storage for Electricity Generation



Source: Electricity Storage Association

Electro-chemical Storage – Batteries

Preferred for decentralized application and transportation sector

- Batteries are electro-chemical storage of direct current electric power networks
- Currently used as "off-the-grid" domestic systems or uninterrupted power supply systems (UPS)
- Today the most commonly used technologies on the market available are lead-based, lithium-based, nickel-based and sodium-based batteries.
- Batteries are still too expensive and have limited lifetime
- Commercial and R&D activities on Li-ion batteries are focused on consumer electronics and electro-mobility
- Possible technology for scale-up: flow batteries and liquid metal batteries
- Sodium-sulfur batteries have been used for grid storage in Japan and in the United States
- Vanadium redox batteries and other types of flow batteries are also beginning to be used for energy storage

Source: Joined EASE/EERA Energy storage Roadmap
http://www.ease-storage.eu/Technical_Documents.html

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Electro-chemical Storage with Na-S Batteries
Sodium–sulfur battery

- As of 2008, Na-S batteries are only manufactured by NGK/TEPCO consortium, which is producing 90 MW of storage capacity each year
- Already 165 MW of installed capacity in Japan, world-wide 365 MW
- 1-Megawatt Na-S Battery installed at Younicos test plant in Berlin

Na-S battery at NGK/TEPCO in Japan


Na-S battery at Younicos test plant in Berlin

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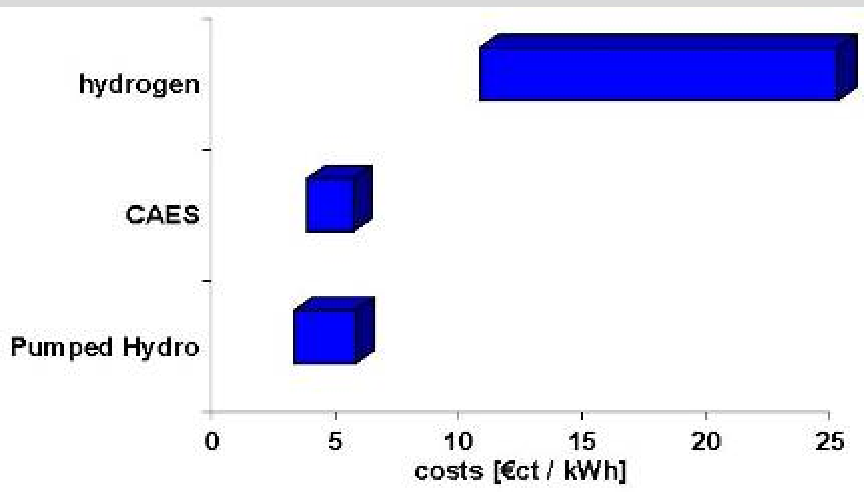
Options for Large Scale Storing of Electricity

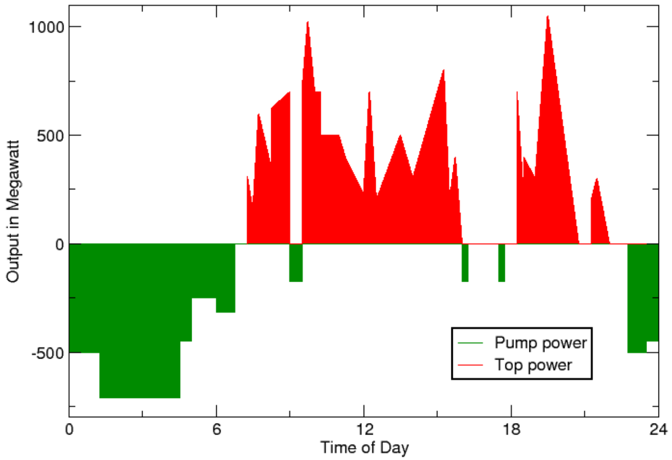
	X-Large Scale	Large Scale	Medium Scale
Response time	> 15 min	< 15 min	1 s -30 s [1)]/ 15 min [2)]
Typical discharge times	days to weeks	hours to days	minutes to hours
Storage technologies	Hydrogen storage systems	Compressed air storage (CAES) Hydrogen storage systems Pumped hydro	Batteries (Li-Ion, lead-acid, NiCd) High-temperature batteries Zinc-bromine batteries Redox-flow batteries
Suited applications	reserve power compensating for long-lasting unavailability of wind energy	secondary reserve minute reserve load levelling	primary reserve [1)] secondary & minute reserve [2)] load levelling, peak shaving

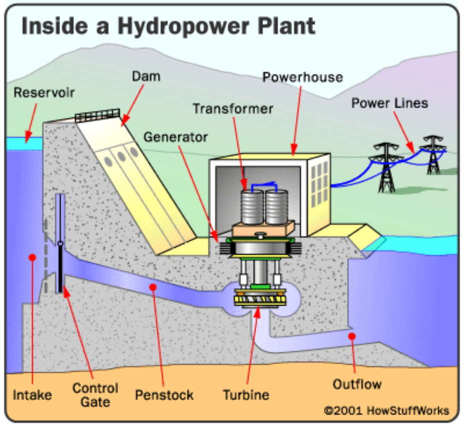


Source: Kleimaier M.; Zunft S. et al.: Energy storage for improved operation of future energy systems. In: 2008 CIGRE Session, Paris, France, 24-26 August 2008

Large Scale Electricity Storage – Pumped Hydro

Two reservoirs at different altitudes are required. Energy is created by the downflow water released from the upper reservoir
Motors to pump back the water to the upper reservoir are powered by electricity from the Grid - Cycle efficiency 70-75 %





Total world pumped hydro storage generating capacity 104 GW (2008)

EU:	38.3 GW net capacity (2008) - 36.8% of world capacity
Japan:	25.5 GW net capacity (2008) - 24.5% of world capacity
USA:	21.5 GW net capacity (2009) - 20.6% of world capacity

Potential for pumped hydro storage in Europe, US and Japan limited in Germany geographically more less terminated

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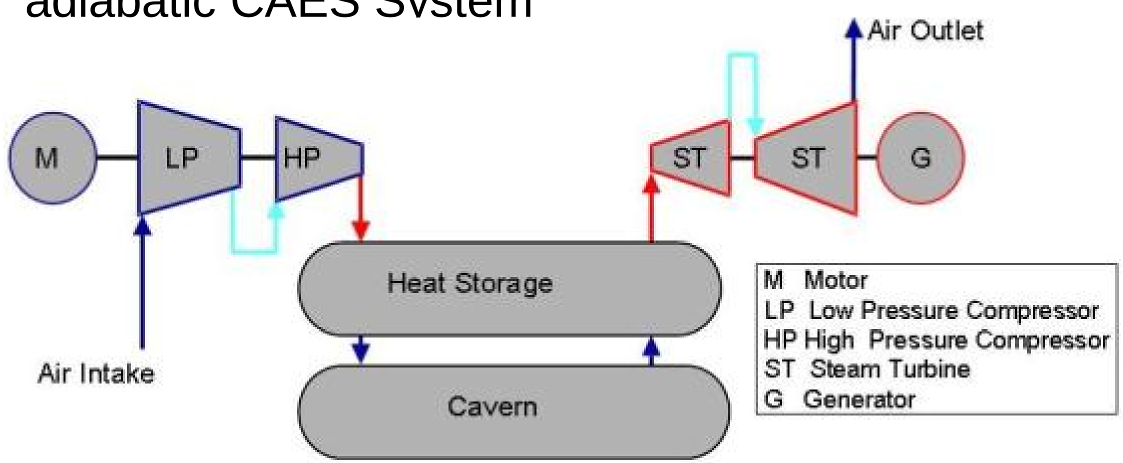
Large Scale Storage for Electricity - Compressed Air Energy Storage - CAES

- CAES plants present alternative option for future energy systems
- World wide are 2 plants in operation – USA + Germany
  Germany: 290 MW plant in Huntorf, since 1978 operated by E.ON; Connected with coal-fired plant in Bremen-Farge, efficiency approx. 42 %
  USA: 110 MW plant, since 1991 operated by Alabama Electric Corporation in McIntosh, Alabama, efficiency approx. 54 %.
- Increase of efficiency to 70-75 % by recovering the heat of compression

adiabatic CAES System



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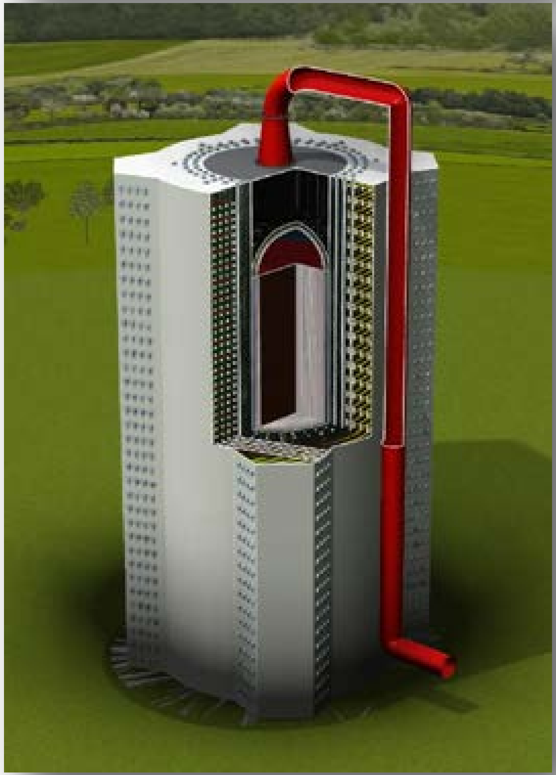
Adiabatic Compressed Air Energy Storage

- Electrical storage in power plant scale (300 MW)
  → integration of renewable energy sources

- Increased efficiency by integration of thermal energy storage
  → ~70 % power-to-power (instead of 50 %)

- Thermal energy storage specifications:
  - Maximum temperature: ca. 400-550 °C
  - Heat transfer fluid: compressed air (65 bar)
  - Power output ca. 300 MW_{th}
  - Capacity: ca. 1,2 GWh (4 turbine hours)
  - Constant power level for discharge



Large Scale Electricity Storage - Hydrogen

Possible long term role of Hydrogen in the energy sector

- **Energy storage for electricity from fluctuating renewable energy sources (Wind + PV)**
- Energy carrier for solar energy from desert regions to urban centers
- Alternative fuel for transportation and heat and power generation

-Electricity from wind/PV

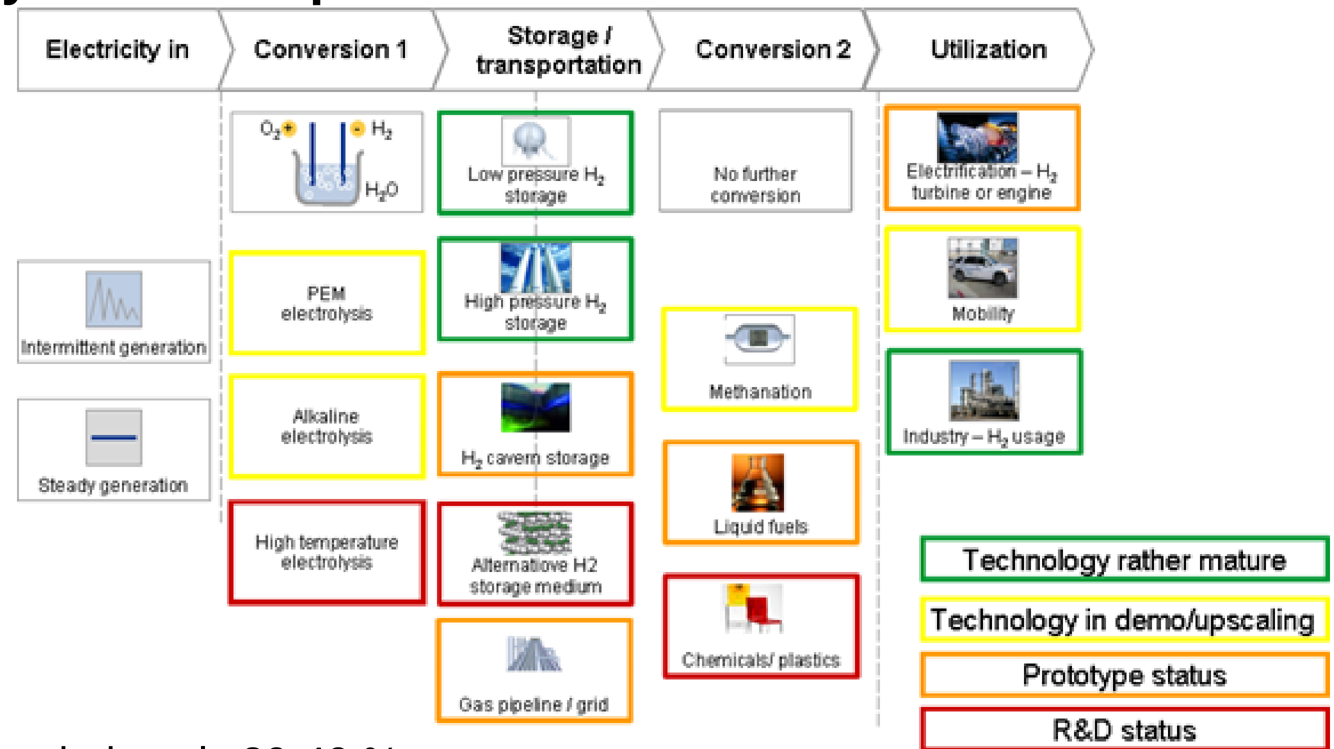
-Electrolysis of water

-Underground storage
of compressed H2

-Electricity generation FC
-Combustion engine

Chemical Storage via Hydrogen

Maturity of technology chain components

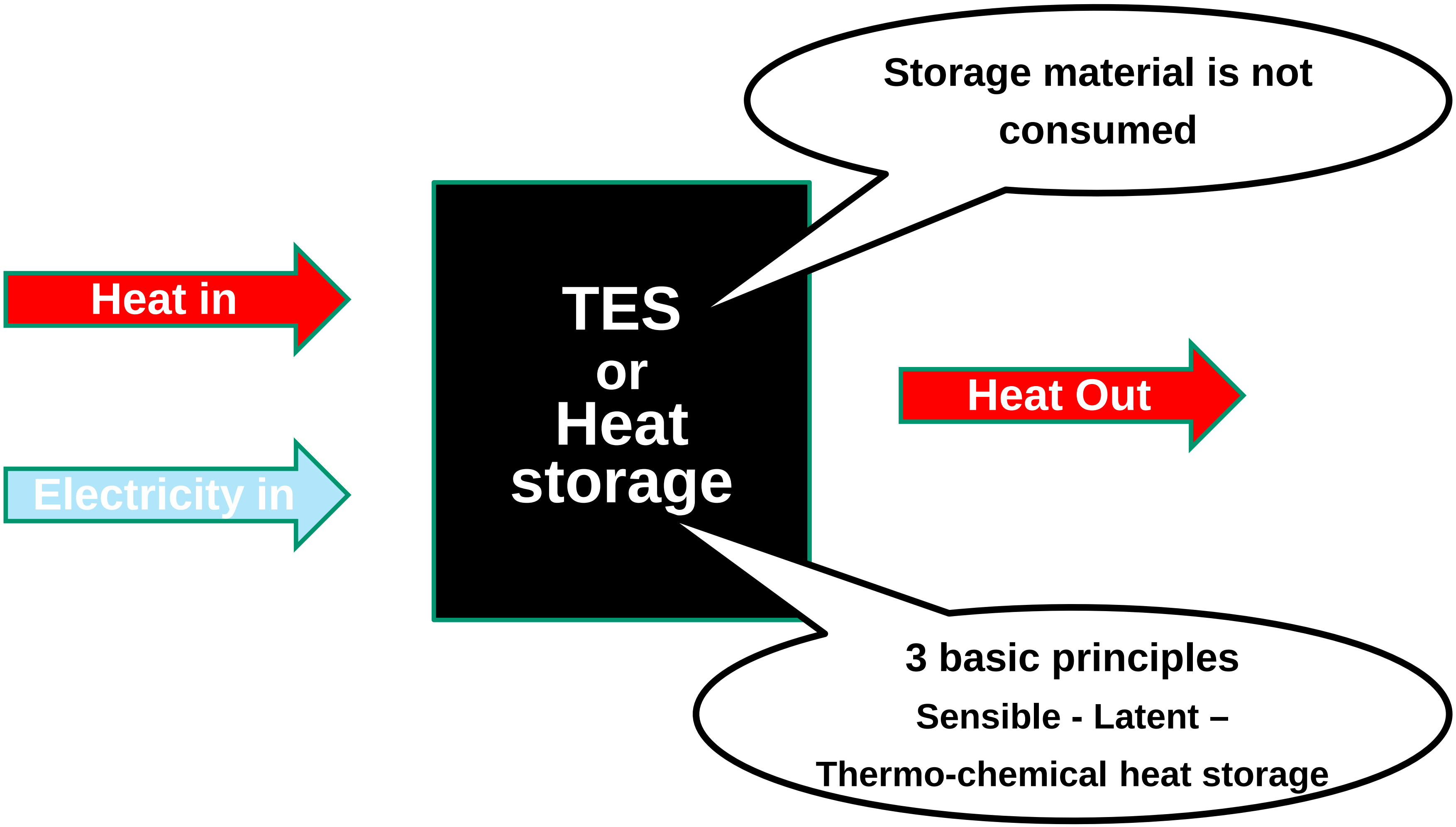


Limitations

- High investment cost
- Efficiency of total conversion chain only 30-40 %
- Heat utilization from conversion process is essential to reach efficiency < 70 %
- Preference for decentralized systems - island (non grid connected applications)

Source: Joined EASE/EERA Energy storage Roadmap
http://www.ease-storage.eu/Technical_Documents.html

Thermal Energy Storage - Definition



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Thermal Energy Storage as a Cross-cutting Technology

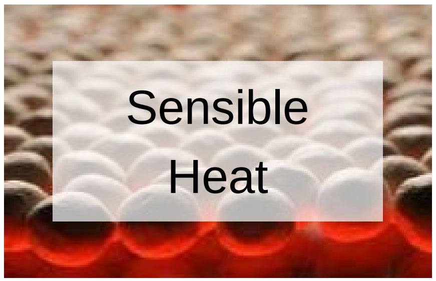
1. Increase **efficiency** of industrial processes by utilization of waste heat streams

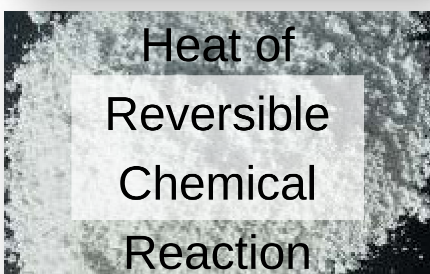
2. Add operational **flexibility** to power plants and establish a stronger link between renewable power production and heat applications (power-to-heat)

3. Increasing the **share of renewable energies** by utilization of solarthermal technologies

Requirements for Thermal Energy Storage

Storage Principle





Requirements

- o Temperature level
- o (Dis-) Charging characteristics
- o Storage capacity

ONE single solution will not meet all requirements!

Application

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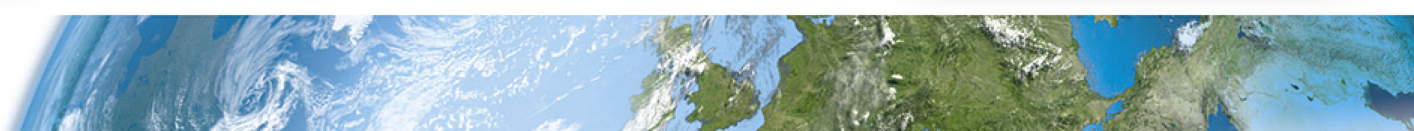
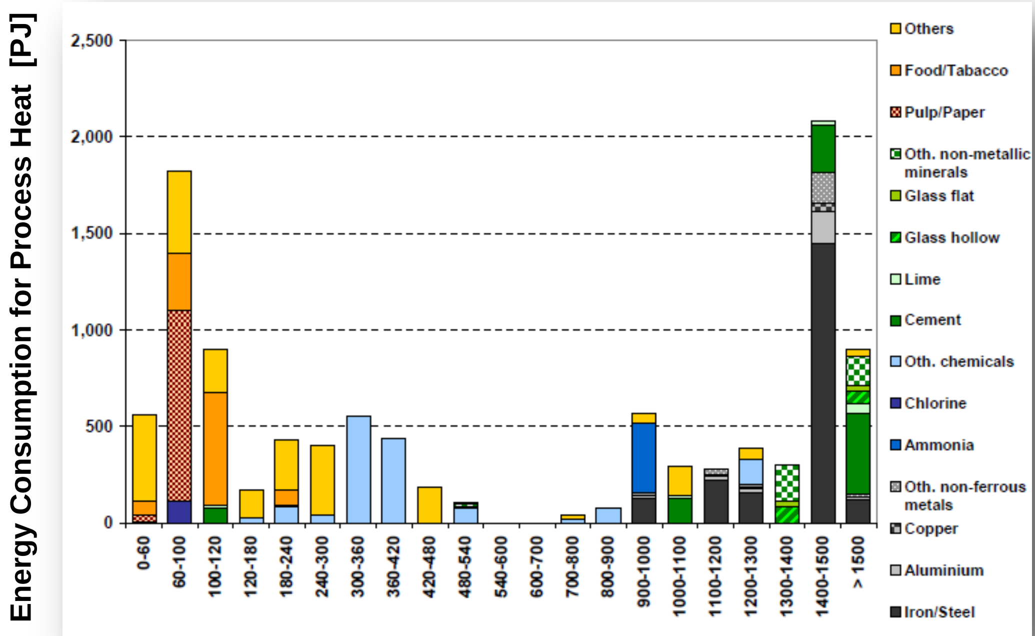


Utilization of Waste Heat in Industrial Processes



Integration of thermal energy storage reasonable if:

- Level of thermal process integration is fully exploited
- Sufficiently high amount of waste heat available
- Local demand for thermal energy
- Supply and demand for process heat are differing in time

Scenario for Germany (BMU Leitstudie 2011):

- **Reduction of process heat utilization** by **27 %** until 2050

Source: Technology orientated analysis of the emission reduction potentials in the industrial sector in the EU-27 Ralf Kuder, 23.06.2010, Stockholm

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Established Technologies

Regenerator Storage/ **Cowper-Storage**

- Gaseous heat transfer fluids in direct contact
- High temperatures

→ Steel industry (hot blast stove for furnaces)

Ruths-Storage (Accumulator)

- Steam as heat transfer fluid
- Moderate pressures

→ Steam supply in building industries, pulp and paper or food industries, etc.

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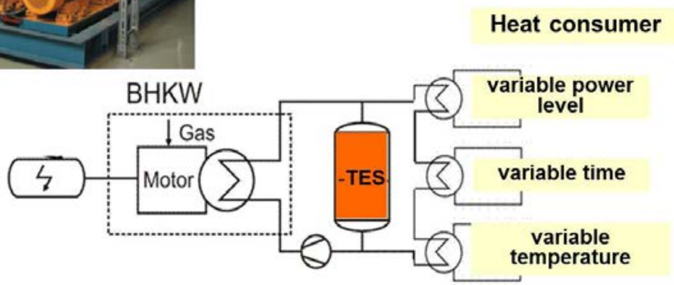
New Approach
Increased Operational Flexibility of Power Plants

To support decentralised CHP implementation

TES integration into CHP systems

- decoupling of power and heat generation
- supply of heat at variable
  - power level
  - time
  - temperature level

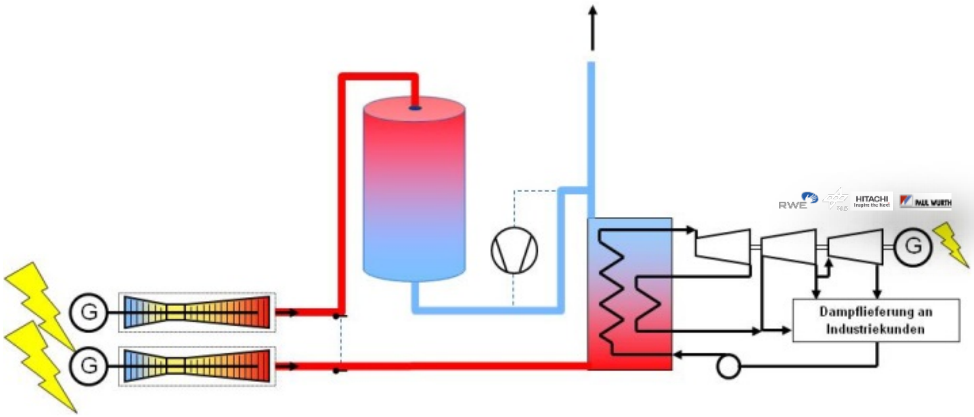


Decoupling of heat and power production

→ demand oriented CHP power production

Fast load changes in power production

→ Contribution for grid stabilization



Storage requirements:

- Temperature max: ca. 300 °C
- Heat transfer fluid: water/steam, oil
- Heat flux 100 kW- 10 MW_{th}
- Capacity: 1-48 full load hours

Storage requirements:

- Temperature max: ca. 600 °C
- Heat transfer fluid: flue gas
- Heat flux ca. 300 MW_{th}
- Capacity: 8-12 full load hours

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New Approach – Thermal Upgrade of Waste Heat

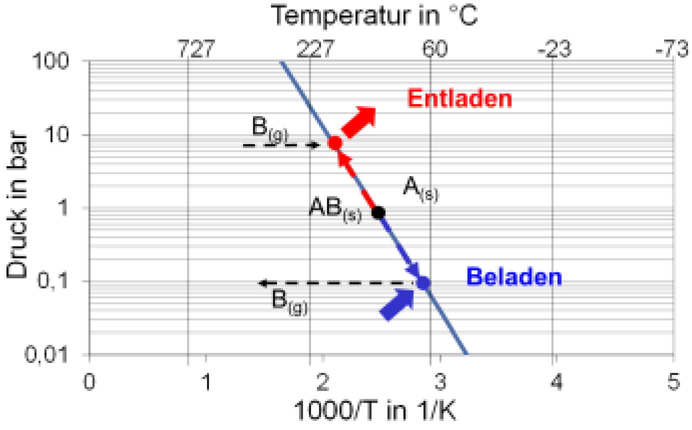
Heat Transformation with Thermochemical Systems

- Reversible gas-solid-reactions

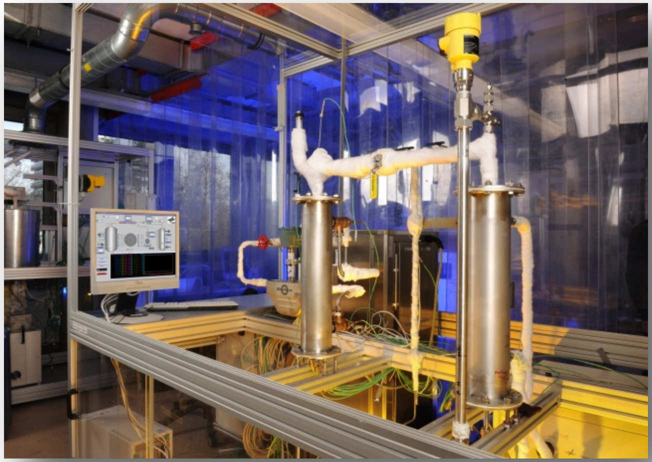
exothermal

$$A_{(s)} + B_{(g)} \rightleftharpoons AB_{(s)} + \Delta H$$

endothermal



- Utilization of pressure and concentration differences (i.e. waste steam vs. ambient air)
- Proof-of-concept in lab-scale
- 50 K temperature upgrade realized



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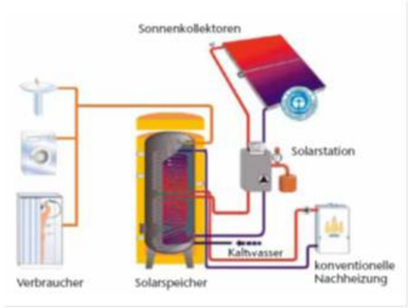
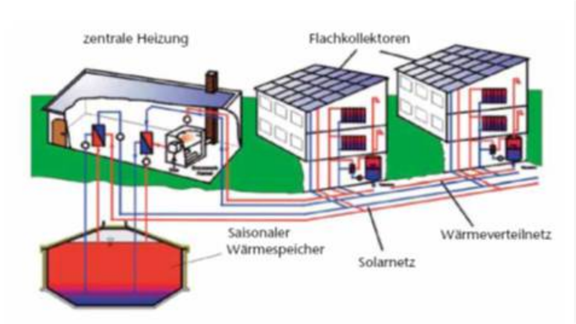
Increased implementation of solar thermal systems

Dispatchable solar heat and power generation

Small scale and centralised solar cooling and heating in buildings





solar process heat generation

solar thermal power plants

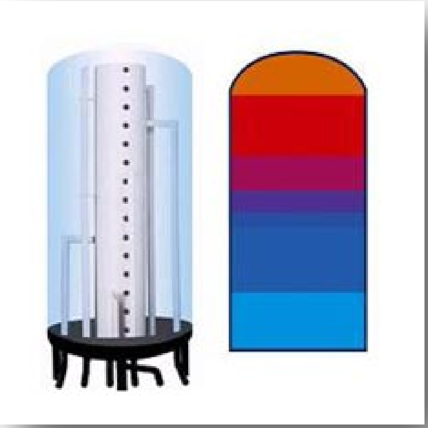
Hot Water Storage

The predominant and multi million business is currently
Hot Water Thermocline Storage for domestic heating systems

All further commercially available heat storage technologies currently cover only niche markets

Pressurized water tank for distric heating (till 130/150 ° C)

Ice storage for cooling in combination with heat pumps



Hot Water Thermocline Storage

Source: Sonnenhaus-Institut e.V.

District heating storage Theiß, Austria

Ice storage for energy management

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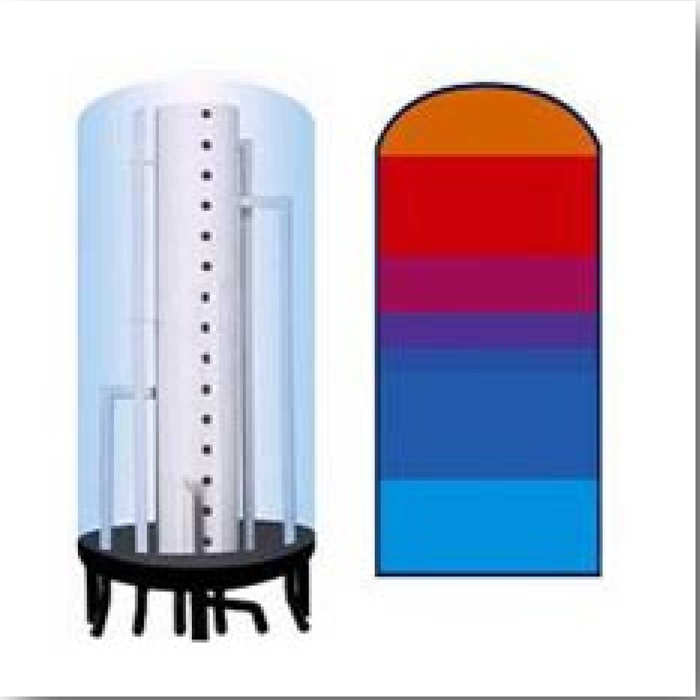
Commercially Available Hot Water Thermocline Storage

- Large storage needed for high solar shares
  (up to 40 m^3 for single familiy homes)

- Slim design for sufficient layering
- Multi-stage (dis-) charging with several heat exchangers
- Integration into the living area for reintegration of storage losses
- Storage for days or weeks
- Little seasonal storage

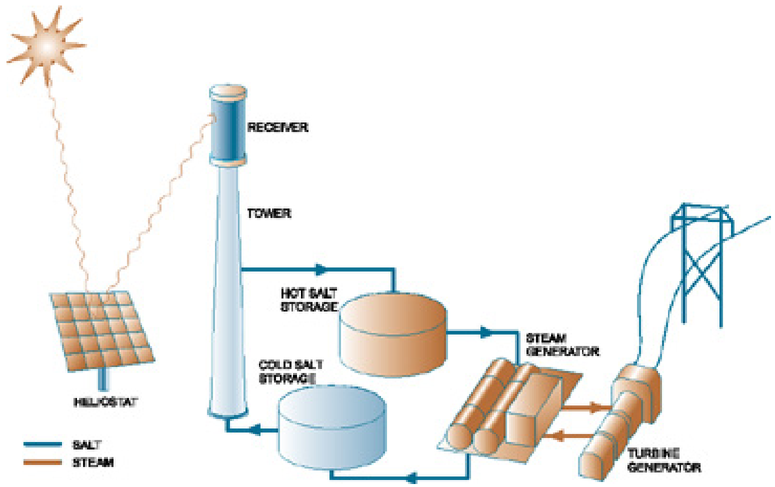


Quelle: Sonnenhaus-Institut e.V.

Molten Salt Storage for Solar Thermal Power Plants

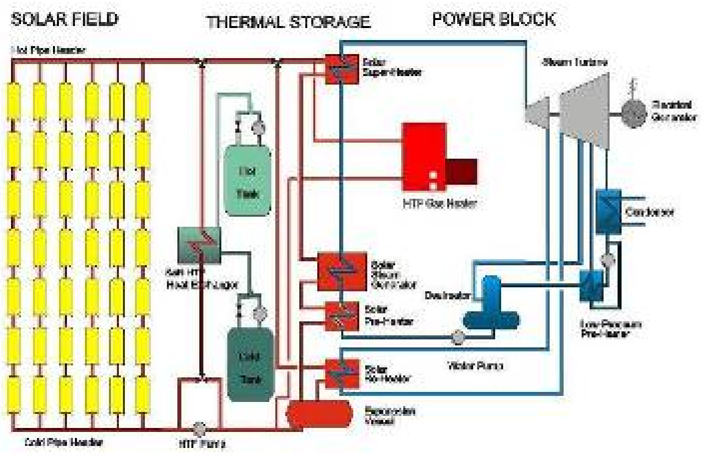
Direct systems (tower technology)

- Heat transfer fuild is also storage medium
- Temperatures up to 560°C
- Large systems in the US (90 MWh) and in Spain (700 MWh) with salt nitrates



Indirect systems (trough technology)

- Thermal oil in the solar collector
- Various systems in Spain with 50 MW_{el} power and 1.000 MWh storage capacity



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Latent Heat Storage for CSP Plants

Combined with Direct Steam Generation

- Identification and characterization of suitable phase change materials with melting temperatures between 140 °C and 300 °C

- Demonstration of a pilot-scale storage system and integration into a steam plant in Spain:
  - 700 kWh latent heat storage with 14 tons of sodium nitrate salt
  - 300 kWh concrete storage
  - 3.000 hours of operation, 100 cycles

- Improvement of heat transfer structures
- Optimization of (dis-) charging characteristics

New Approach – Thermo-chemical Systems

Calcium Hydroxide

$Ca(OH)_2 + \Delta H \leftrightarrow CaO + H_2O$

T_{eq} = 507°C at 1 bar

ΔH = 100 kJ/mol

Storage density*) = 410 kWh/m³

Metall Oxide

$6\ Mn_2O_3 + \Delta H \leftrightarrow 4\ Mn_3O_4 + O_2$

T_{eq} = 980°C at 1 bar

ΔH = 31.8 kJ/mol

Storage density*) = 126 kWh/m³

*) solid only, Bulk porosityt $\varepsilon = 0.5$

Conclusions

- Energy storage
  - .. a key element of **sustainable energy systems** with increasing amount of fluctuating Wind and PV plants
  - .. essential for **rational use of fossil resources** in the industrial sector
  - .. mandatory for intensified **utilization of CHP** systems
- Hydro power is state-of-the-art, but has limited possibilities for strong expansion
- Advanced ACAES and Hydrogen are promising option for future implementation
- With integrated thermal energy storage CSP plants have the capability to provide firm dispatchable power
- High temperature thermal energy storage is a key element for efficient heat management and heat integration of CHP systems
- Existing energy storage technologies and new approaches are still too expensive for large scale implementation – strong R&D effort required
- To meet the national and international targets to reduce fossil fuel consumption all different types and options for energy storage technologies are needed

Thank you for your attention!

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