Overview on Thermal Storage Systems

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Workshop on Thermal Storage for Trough Power Systems

February 20 - 21, 2002

FLABEG Solar International GmbH

Why storage?

- Cost reduction for solar generated electricity
- Improve availability of solar power plants

Tasks of Storage

- Buffering during transient weather conditions
- Dispatchability or time-shifting
- Increase of annual capacity factor
- More even distribution of electricity production
- Achieve full load operation of the steam cycle at high efficiency

Technical Requirements for Storage Systems

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- High energy density (per-unit mass or per-unit volume) in the storage material
- Good heat transfer between heat transfer fluid (HTF) and the storage medium
- Mechanical and chemical stability of storage material
- Chemical compatibility between HTF, heat exchanger and/or storage medium
- Complete reversibility for a large number of charging/discharging cycles
- Low thermal losses
- Ease of control

Design Criteria: Cost

- The cost of the storage material itself
- The heat exchanger for charging and discharging the system
- The cost for the space and the enclosure for the TES

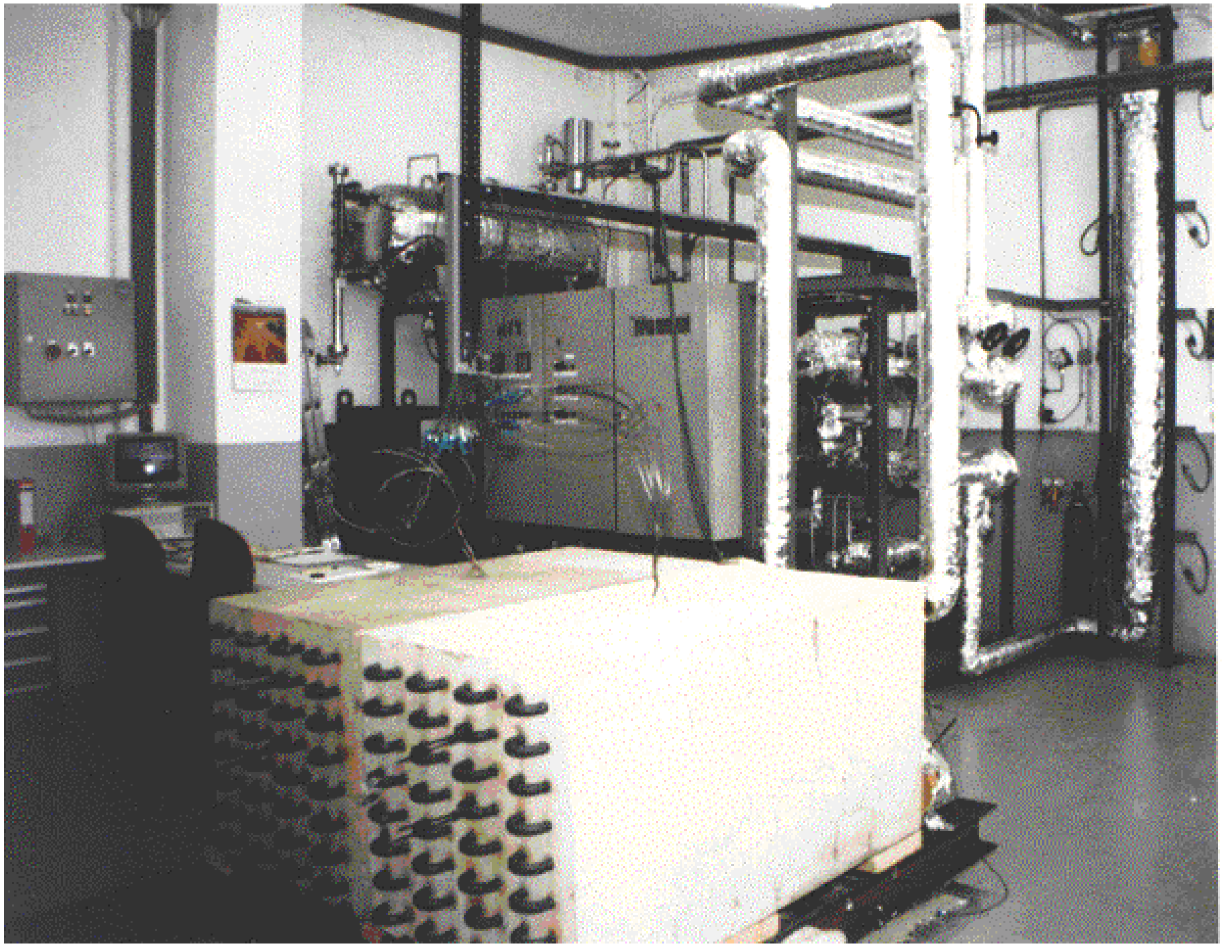
Storage Mechanism

- Sensible heat storage (solid of liquid)
- Latent heat storage
- Chemical Storage

Solid Storage Materials

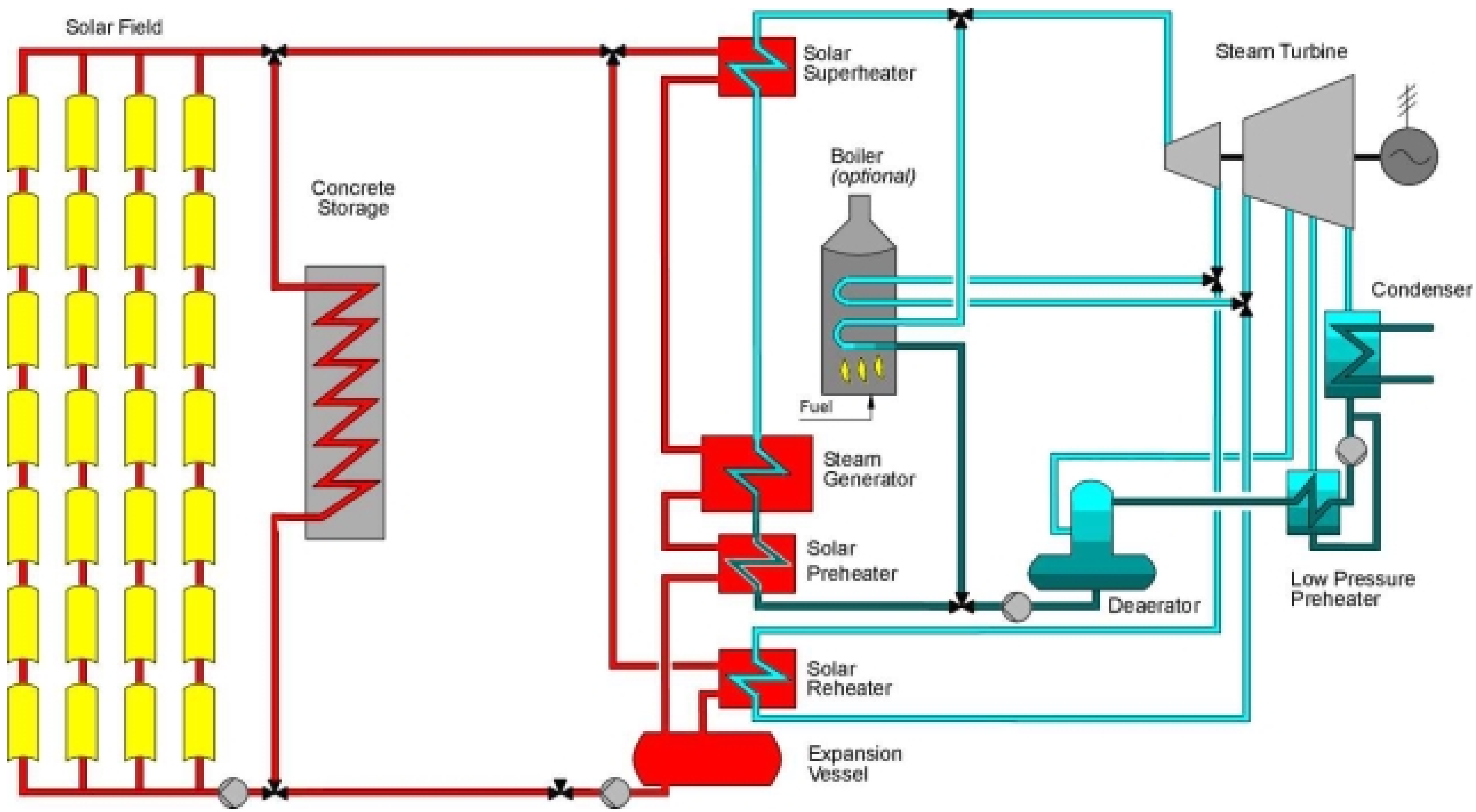
Storage Medium	Temperature Cold (°C)	Temperature Hot (°C)	Average density (kg/m³)	Average heat conductivity (W/mK)	Average heat capacity (kJ/kgK)	Volume specific heat capacity (kWh_t/m^3)	Media costs per kg (US$/kg)	Media costs per kWh_t (US$/$kWh_t$)
Solid media								
Sand-rock-mineral oil	200	300	1,700	1.0	1.30	60	0.15	4.2
Reinforced concrete	200	400	2,200	1.5	0.85	100	0.05	1.0
NaCl (solid)	200	500	2,160	7.0	0.85	150	0.15	1.5
Cast iron	200	400	7,200	37.0	0.56	160	1.00	32.0
Cast steel	200	700	7,800	40.0	0.60	450	5.00	60.0
Silica fire bricks	200	700	1,820	1.5	1.00	150	1.00	7.0
Magnesia fire bricks	200	1,200	3,000	5.0	1.15	600	2.00	6.0

Concrete Storage



- tested at small scale
- low cost
- long-term stability?

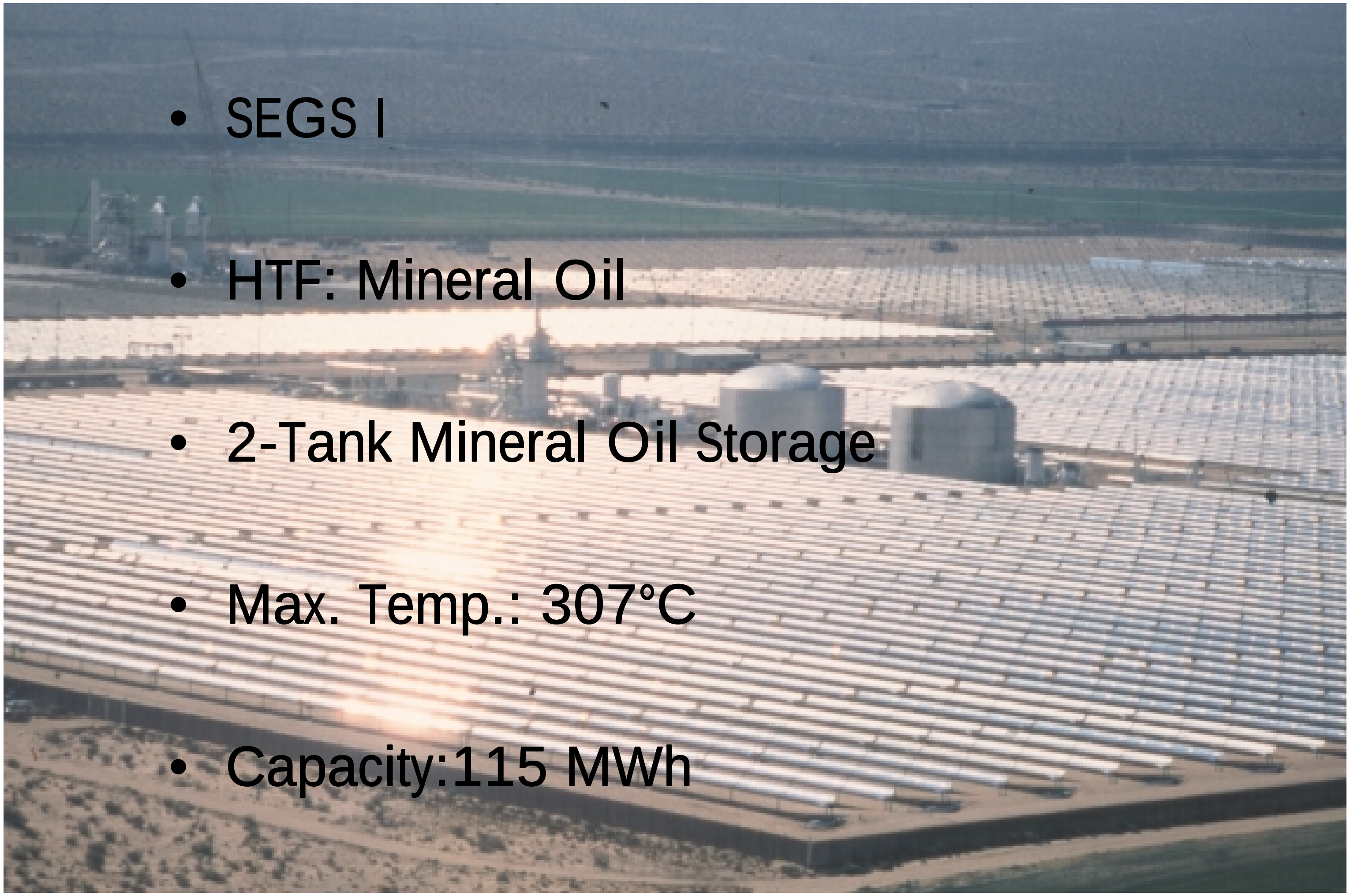
Process Integration of Concrete Storage



Liquid Material

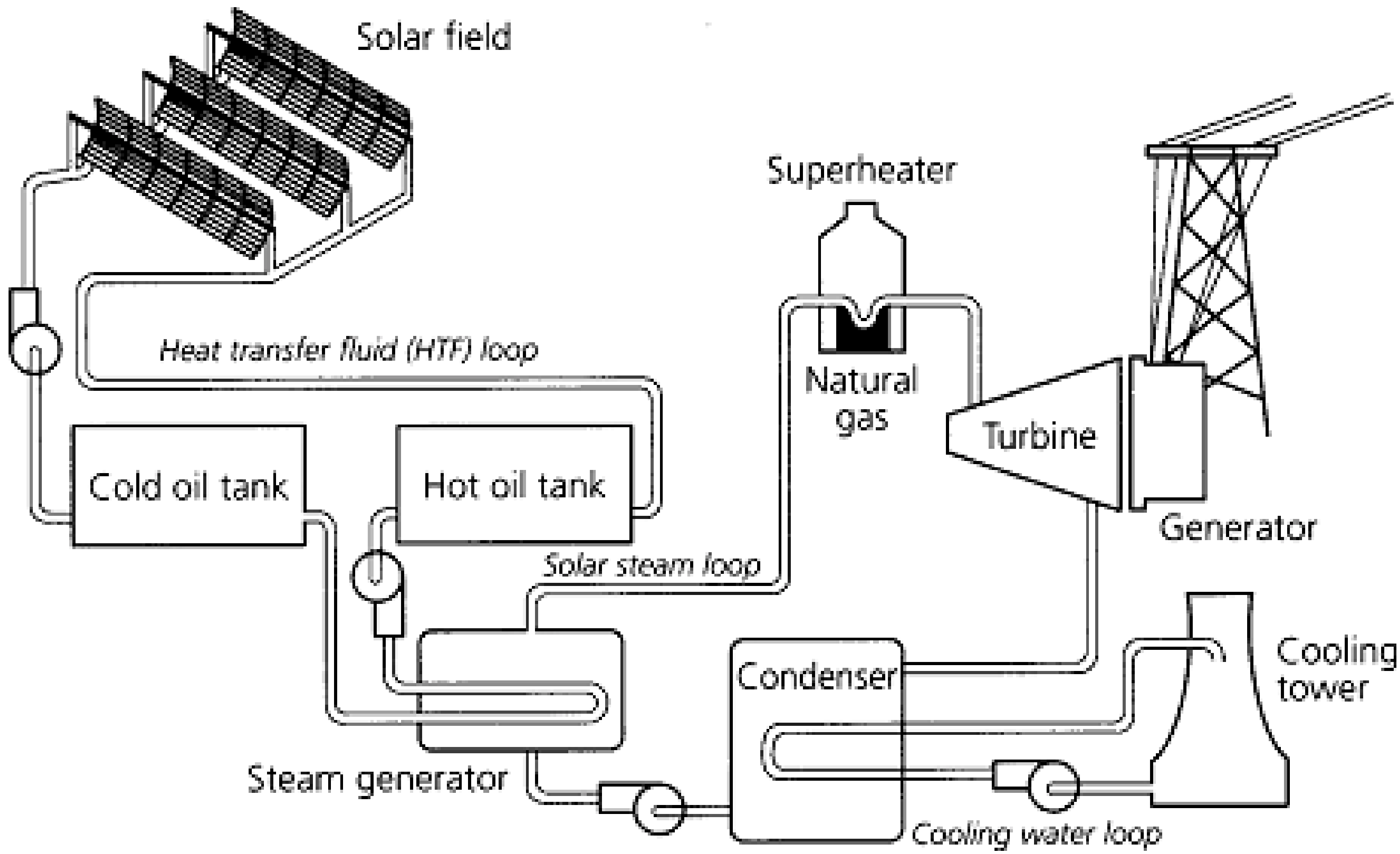
Storage Medium	Temperature Cold (°C)	Temperature Hot (°C)	Average density (kg/m³)	Average heat conductivity (W/mK)	Average heat capacity (kJ/kgK)	Volume specific heat capacity (kWh_t/m^3)	Media costs per kg (US$/kg)	Media costs per kWh_t (US$/$kWh_t$)
Liquid media								
Mineral oil	200	300	770	0.12	2.6	55	0.30	4.2
Synthetic oil	250	350	900	0.11	2.3	57	3.00	43.0
Silicone oil	300	400	900	0.10	2.1	52	5.00	80.0
Nitrite salts	250	450	1,825	0.57	1.5	152	1.00	12.0
Nitrate salts	265	565	1,870	0.52	1.6	250	0.50	3.7
Carbonate salts	450	850	2,100	2.0	1.8	430	2.40	11.0
Liquid sodium	270	530	850	71.0	1.3	80	2.00	21.0

Mineral Oil Storage



- SEGS I
- HTF: Mineral Oil
- 2-Tank Mineral Oil Storage
- Max. Temp.: 307°C
- Capacity:115 MWh

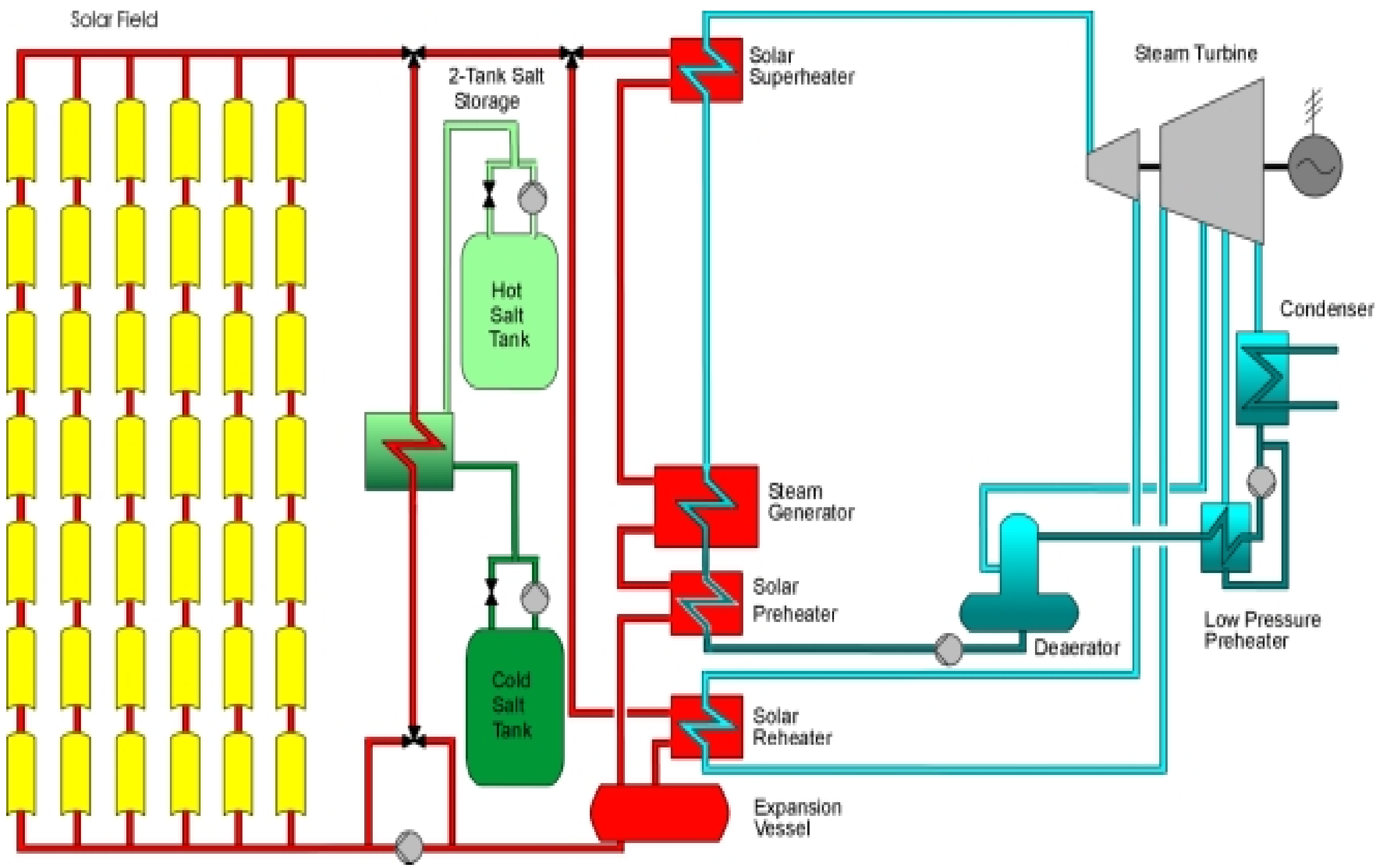
Process Scheme of SEGS I



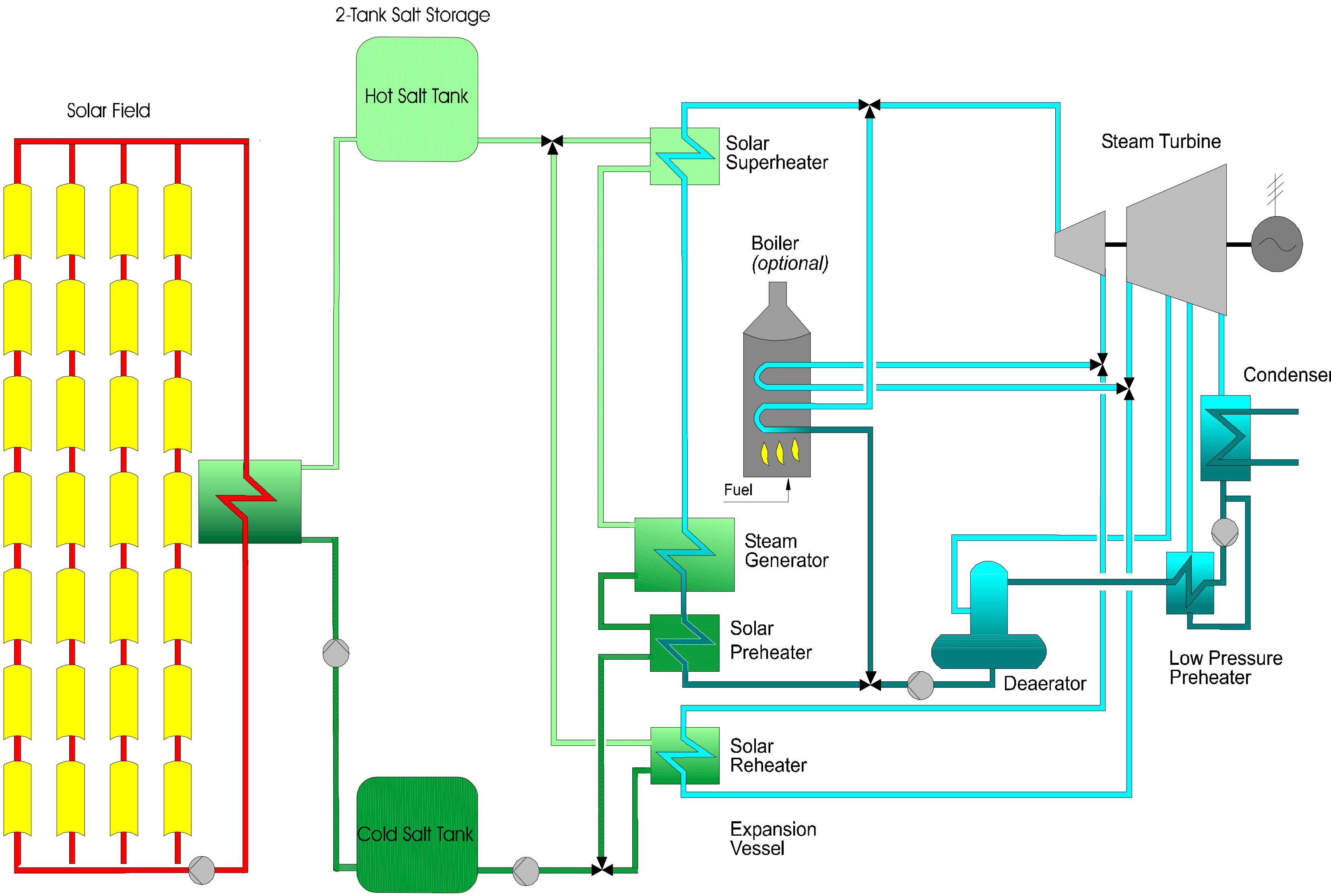
Molten Salt Storage

- 2 Tank Molten Salt
- Nitrate Salt Mixture
- Salt was also HTF
- Max. Temp. 565°C
- Capacity: 105 MWh

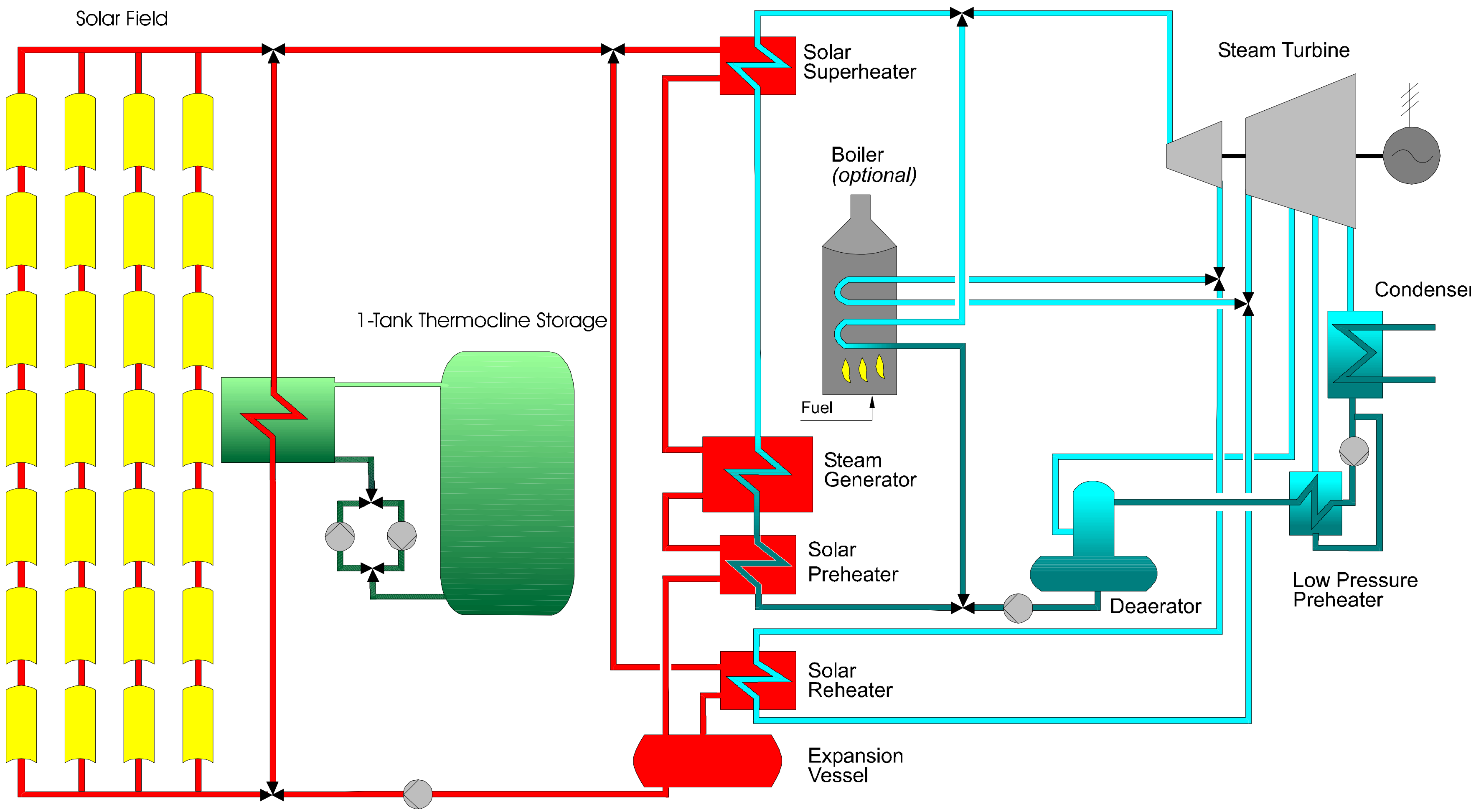
Process Scheme for SEGS plant with 2 Tank TES



Process Scheme: Option 2



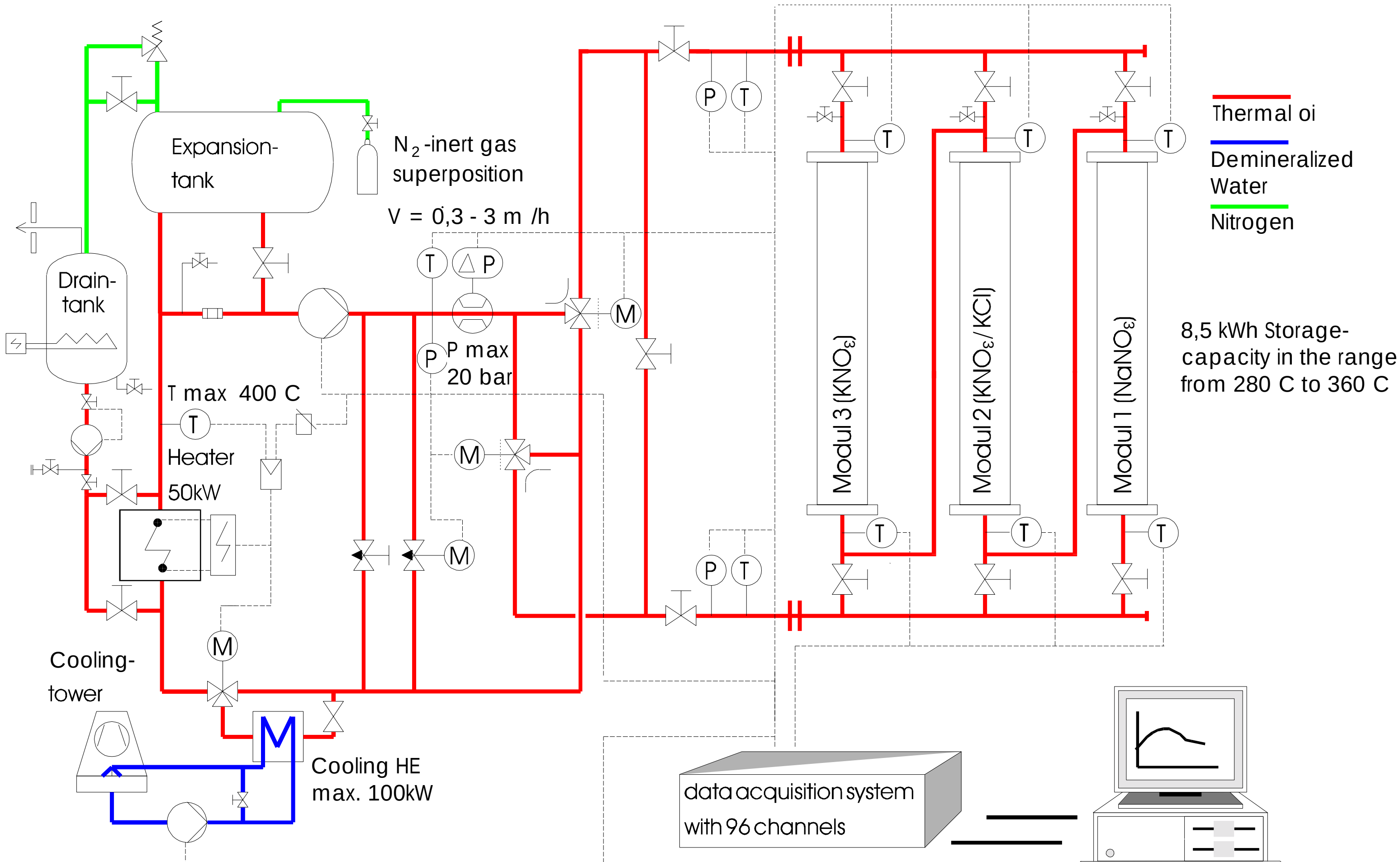
Next Step Thermocline Storage



Phase Change Material

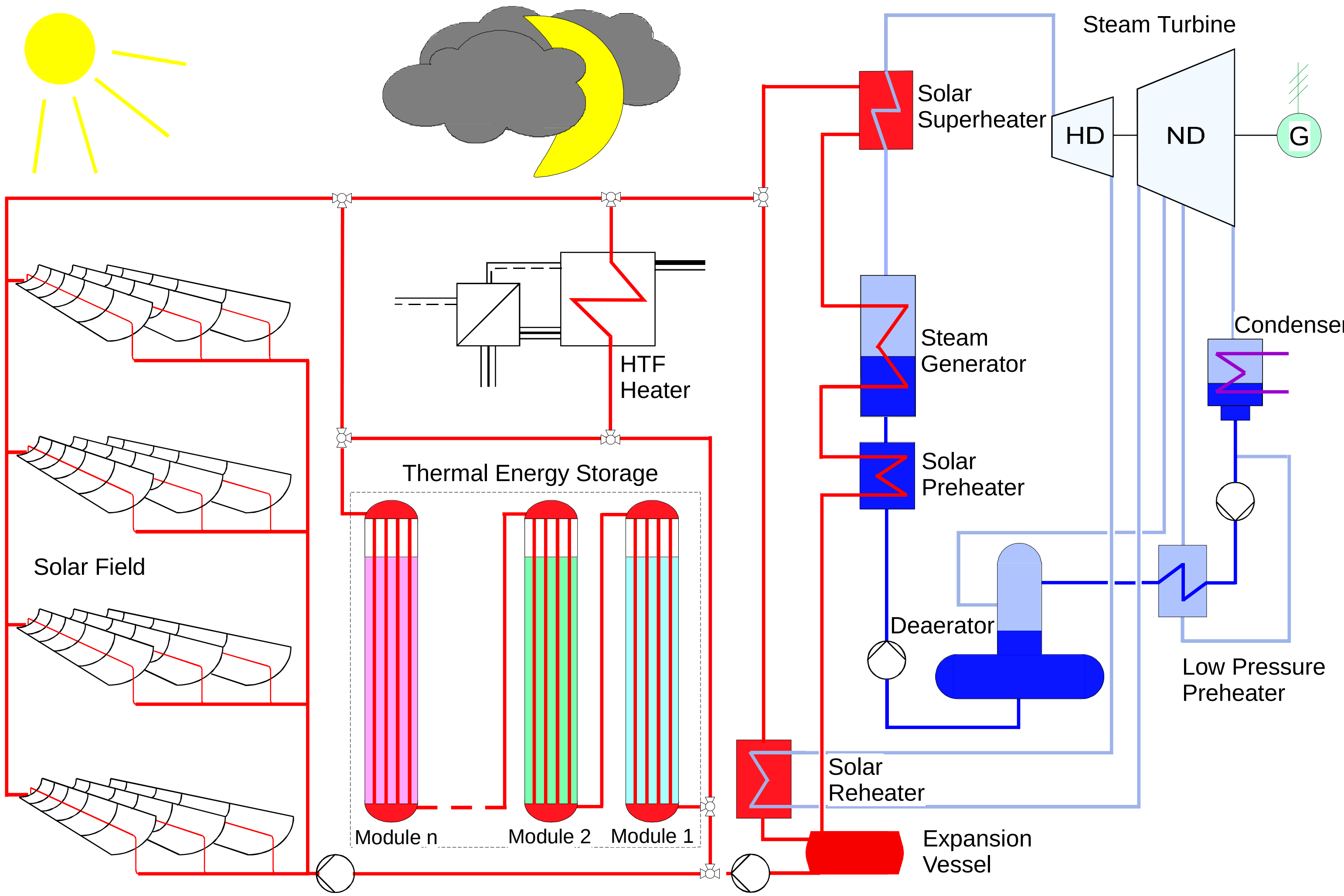
Storage Medium	Temperature Cold (°C)	Temperature Hot (°C)	Average density (kg/m³)	Average heat conduct-ivity (W/mK)	Average heat capacity (kJ/kgK)	Volume specific heat capacity (kWh_t/m^3)	Media costs per kg (US$/kg)	Media costs per kWh_t ($US\$/kWh_t$)
Phase change media								
$NaNO_3$		308	2,257	0.5	200	125	0.20	3.6
KNO_3		333	2,110	0.5	267	156	0.30	4.1
KOH		380	2,044	0.5	150	85	1.00	24.0
Salt-ceramics ($NaCO_3$-$BaCO_3$/MgO)		500-850	2,600	5.0	420	300	2.00	17.0
NaCl		802	2,160	5.0	520	280	0.15	1.2
Na_2CO_3		854	2,533	2.0	276	194	0.20	2.6

Phase Change Material Experiments

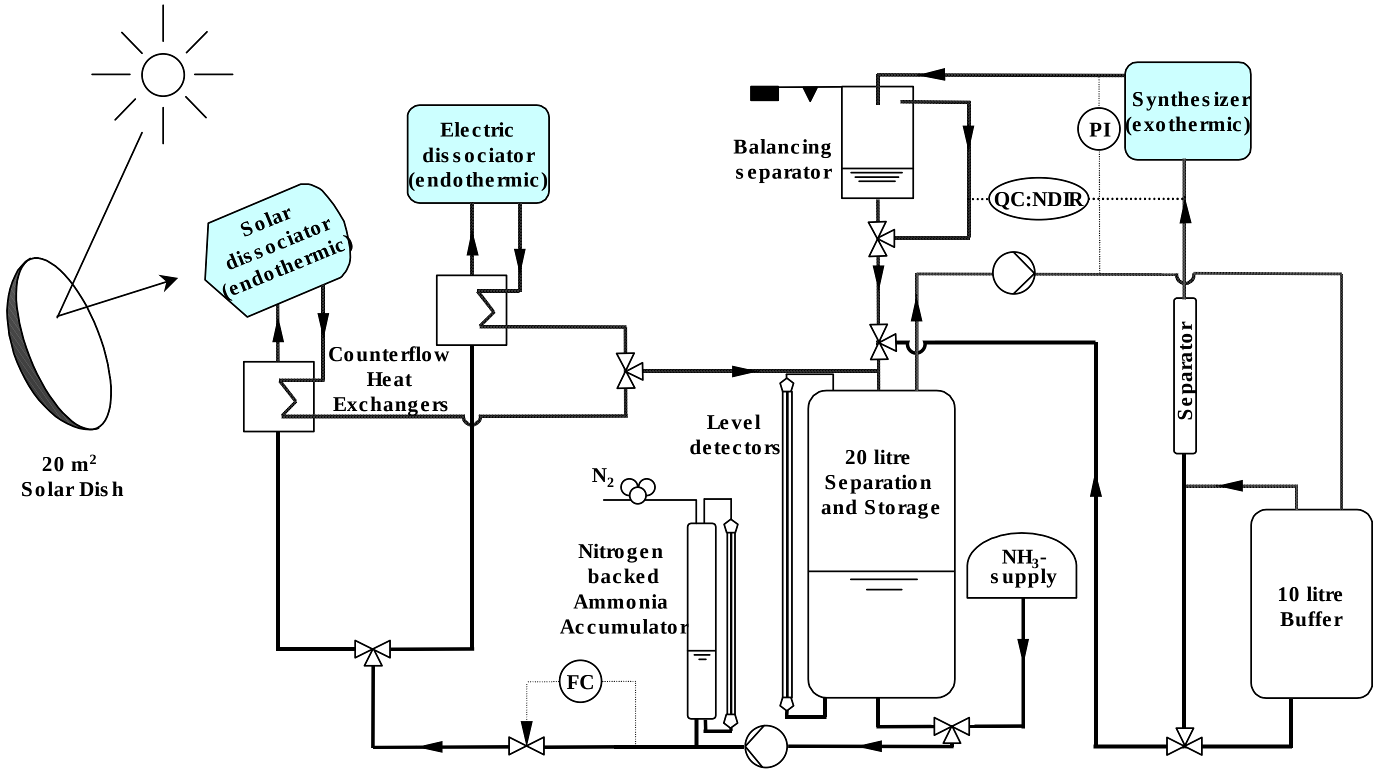


- only lab scale experiments

Process Scheme for SEGS with PCM-Storage



Chemical Storage

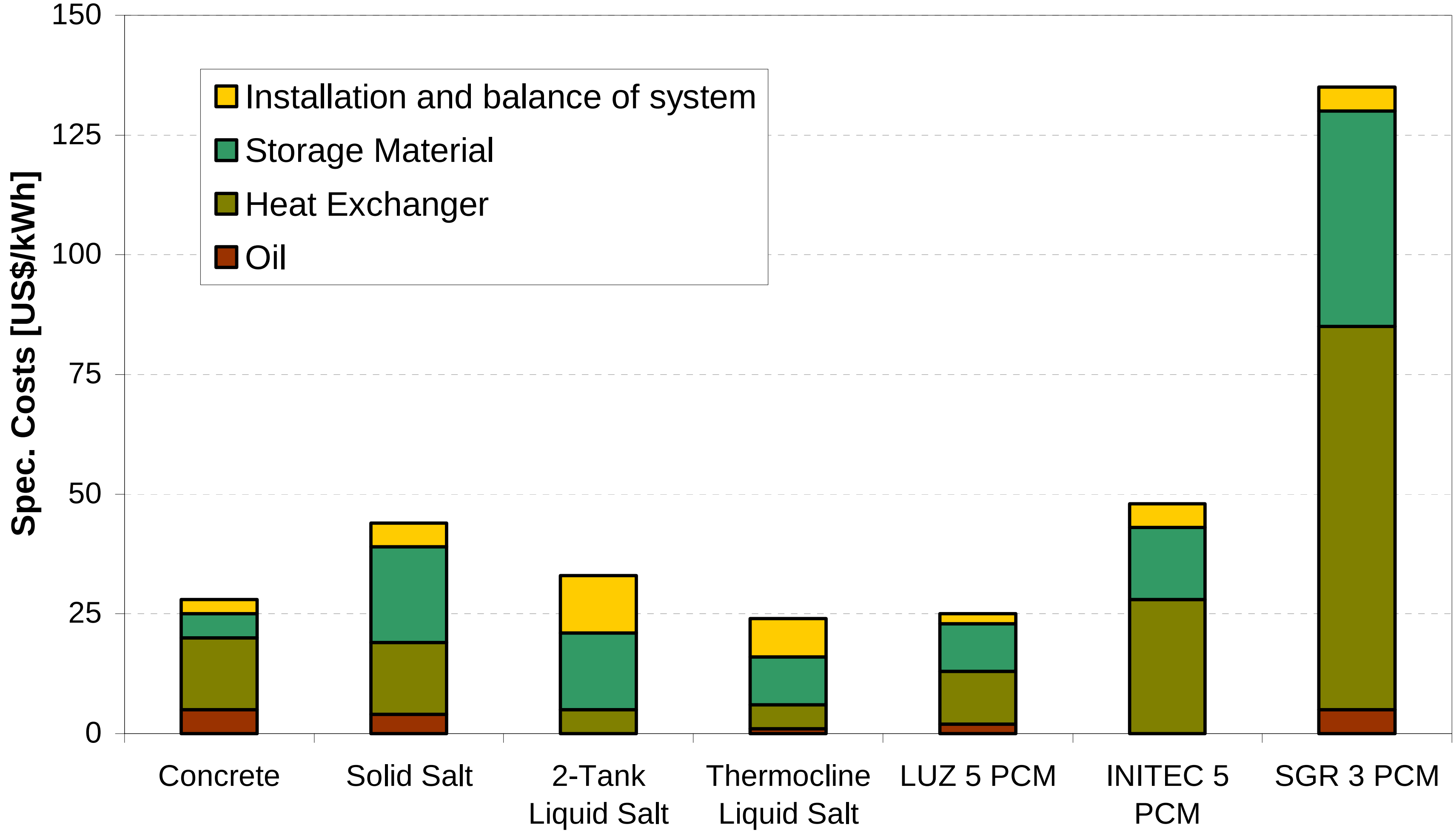


- only lab scale experiments

or

- for different applications (Dish)

Specific Cost of Storage Concepts



Summary

- Three storage options offer favourable cost
  - Salt Storage (2-Tank and Thermocline)
  - Concrete (or compound material)
  - Phase change material

- No reliable information available about cost of chemical storage

- 2-Tank molten salt storage seems to be most advanced system and ready for realization

Overview on Current European Work

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- 2-Tank Molten Salt Storage
  AndaSol-Project Herrmann/Geyer/Kistner

- Concrete or Compound Material
  Update on the European concrete TES program
  Tamme

- Phase Change Material
  Phase Change Storage/Storage for DISS
  Tamme/Pitz-Paal