High temperature storage
- Solar thermal application

Outline of the talk

- Selection criteria for heat transport and heat Storage mediums
- Comparative study of various such mediums
- Technological progress achieved worldwide
- Why molten salt as a storage option
- Clarification/elaboration for the need of high temperature
- Our plants design points ??

Need for Storage

- Output management tool to prolong operation after sunset, to shift energy sales from low revenue off-peak hours to high revenue peak demand hours, and to contribute to guaranteed output
- internal plant buffer, smoothing out insolation changes and provide freeze protection
- A surge capacity of thermal energy is also required to protect the steam generator section from receiver transients due to cloud cover.

Thermal energy can be stored as

- Latent heat in Phase Change Phenomenon
- sensible heat
  - In SOLIDS require use of charge discharge fluid
  - In LIQUIDS can be stored in the heat transport fluid itself
- Heat of reaction
- A combination of above methods

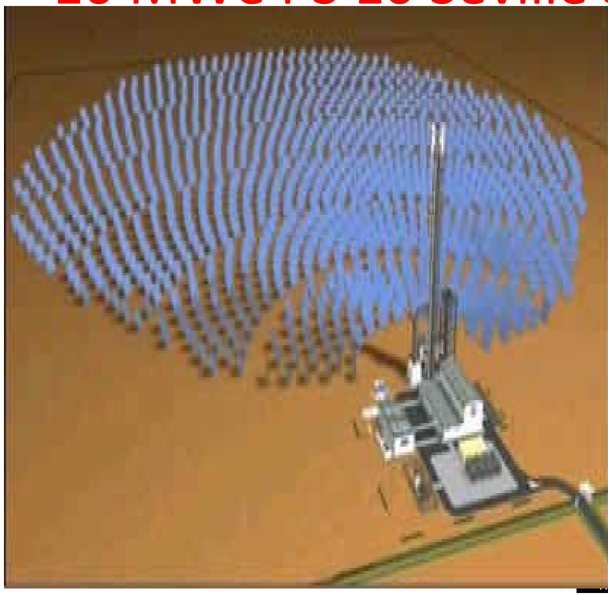
Power towers

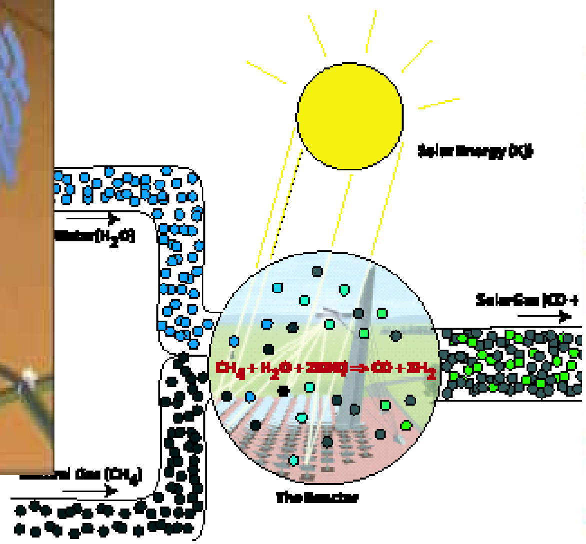
Project	Country	Power Output(MWe)	Heat Transfer Fluid	Storage Medium	Began Operation
SSPS	Spain	0.5	Liquid Sodium	Sodium	1981
EURELIOS	Italy	1	Steam	Nitrate Salt/Water	1981
SUNSHINE	Japan	1	Steam	Nitrate Salt/Water	1981
Solar One	USA	10	Steam	Oil/Rock	1982
CESA-1	Spain	1	Steam	Nitrate Salt	1983
MSEE/Cat B	USA	1	Molten Nitrate	Nitrate Salt	1984
THEMIS	France	2.5	Hi-Tec Salt	Hi-Tec Salt	1984
SPP-5	Russia	5	Steam	Water/ Steam	1986
TSA	Spain	1	Air	Ceramic	1993
Solar Two	USA	10	Molten Nitrate Salt	Nitrate Salt	1996
Solar gas	AUS	0.5	Steam- methane	Solar gas	2007

Source:

Technological progress achieved worldwide

10 MWe PS 10 Seville Spain





- Water-steam heat storag
(15MWh)
- supply 50 minutes of plant operation at 50% load

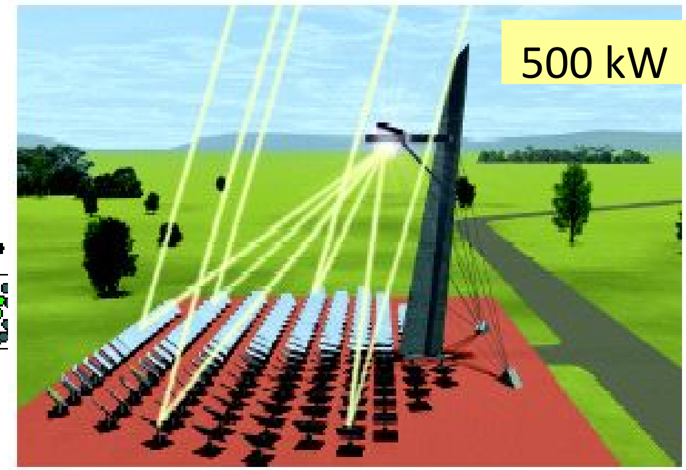
Solar – 2 10 MWe Pilot Plant

- 2*12-m diameter by 8-m high storage tanks
- 1,400 tonnes of molten sodium/potassium nitrate salt

Source: http://www.eren.doe.gov/sunlab
http://www.eren.doe.gov/csp.

Solar gas project

(New Castle, Australia)



Source: www.csiro.au

1MWe Japan (sunshine project) 1981

- 5 steam accumulators 60 m^3 each
- Pressure range 13-40 Kg/cm^2 abs
- 229 deg C inside accumulator
- Approx. 12 MWh each

PHOEBUS international 30 MWe Solar tower plant (proposed)

A storage capacity of 3 hours full-load operation.

Design follows rather conventional technologies as used in the steel industry.

The storage medium is a refractory ceramic material Al_2O_3

Charge cycle: hot air at 700°C enters & exits at 240° C. During a Discharge cycle: the flow is reversed

The conceptual design requires a useable storage capacity of 250 MWht.

10 MWe Solar One

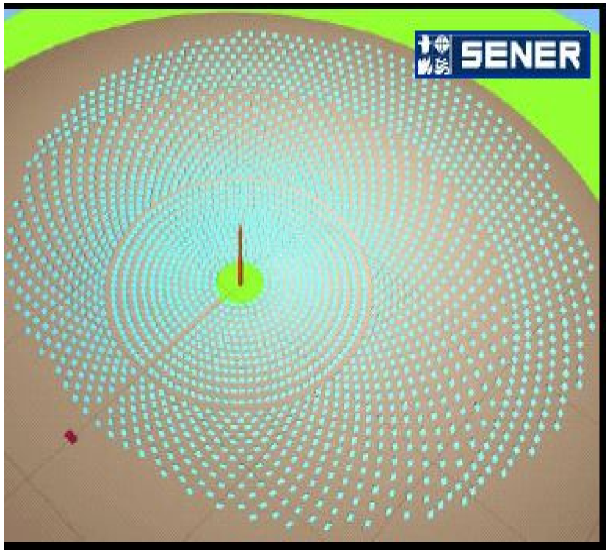
Solar-produced steam in a tank filled with rocks and sand using oil as the heat-transfer fluid

Storage system was complex and thermodynamically inefficient

Intermittent operation of the turbine due to cloud transience and lack of effective thermal storage.

Source: http://www.freetechpapers.com/mechpapers/solar%20power%20tower.doc

16 MWe Solar Tres



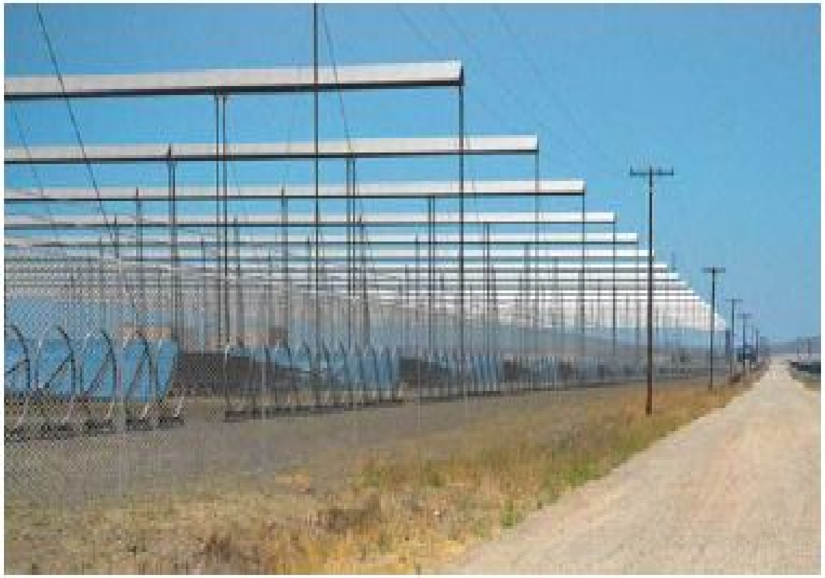
15 Hours Storage, generate electricity 24 hrs a day

12-15% fossil fuel

96 GWh annual production

Receiver now under tests at PSA

Continuation of solar-2 molten salt technology



SEGS-I

The plant initially had 3 hours of thermal energy storage that was used to dispatch to peak period. The storage system was damaged by fire in 1999 and was not replaced.

Visualization of the proposed 177 MW plant atthe Carrizo Plain, California.

Tracking Compact linear reflectors focus solar energy on elevated boiler tubes to produce steam

Very low cost water-based thermal storage is expected to be commercialized within two years using own technology under development

Closed loop thermo-chemical energy storage system using ammonia

Proposed by ANUM

david.mills@Ausra.com

Selection criteria for heat transport and heat Storage mediums

Important criteria for selection of media

- Investment cost
- Operation cost
- Safety and reliability

- Non pressurized
- Thermally Stable at operating range
- Non corrosive
- Cost effective

Comparative study of various such mediums

- High boiling point organic liquid

  Decomposes at the temperature reached at CRS plant servotherm, thermic oil

- Liquid Metals

  better heat transfer characteristics, stable at operating temp. range

  - Mercury (toxic, expensive)
  - Lead Bismuth (Bi toxic, expensive)
  - Na-K(highly reactive, better heat transfer)

- Molten salts

  1. Carbonates
     - high melting points (>380°C)
     - Stable at high temperature (700-900°C)
  - Fluorides (corrosive to most metals at high temperature)
  - Chlorides (corrosive to most metals at high temperature)
  - Sodium hydroxide
    - used in the range 320°C-800°C
    - Highly Corrosive, difficult to hold at high temp. (S.P.Sukhatme p208)
  5. Nitrates and Nitrites
     - least expensive Rs. 25-35/Kg

Nitrates and Nitrites salt systems

- $NaNO_3$ (307°C) KNO_3 (335°C) $NaNO_2$ (282°C)

- K-Na-Ca Nitrate Mixture eutectic mixture (46:24:30) has a melting point of 160°C

- K-Na-Li Nitrate Mixture melting points as low as 120°C. More expensive than K-Na-Ca nitrates.

- HiTEC 7% $NaNO_3$,53%KNO_3 and 40% $NaNO_2$(142°C-480°C)

  Popular in Chemical and petrochemical industry

Nitrates and Nitrites salt systems

- Max. reported temp. usage 480°C
- More thermally stable molten salt
  - 46%$NaNO_3$ & 54%KNO_3 melts at 223°C
  - KNO_3 lowers melting point
  - $NaNO_3$ improves thermal conductivity
- Alkali nitrate decomposes to give oxygen
- Decomposition rate vary with presence of impurity

Study

- Locally available Salt's deterioration study
- Thermal cycling study is also to be studied

Molten Salt Safety Study, SAND80-8179 done by Martin Marietta
Experimental data indicate that HITEC is not explosive. … Draw salt or any other mixtures of sodium nitrate and potassium nitrate is expected to act similarly to HITEC.

Mixture of 60 % $NaNO_3$ and 40 % KNO_3, commonly called saltpeter

- **A variety of fluids was tested to transport the sun's heat, including water, air, oil, and sodium, before molten salt was selected as best.**
- **Molten salt is used in solar power tower systems because it becomes liquid at atmosphere pressure**
- **It provides an efficient, low-cost medium in which to store thermal energy**
- **Operating temperatures compatible with today's high-pressure and high-temperature steam turbines,**
- **Non-flammable and nontoxic.**
- **In addition, molten salt is used in the chemical and metals industries as a heat-transport fluid, so experience with molten-salt systems exists for non-solar applications**

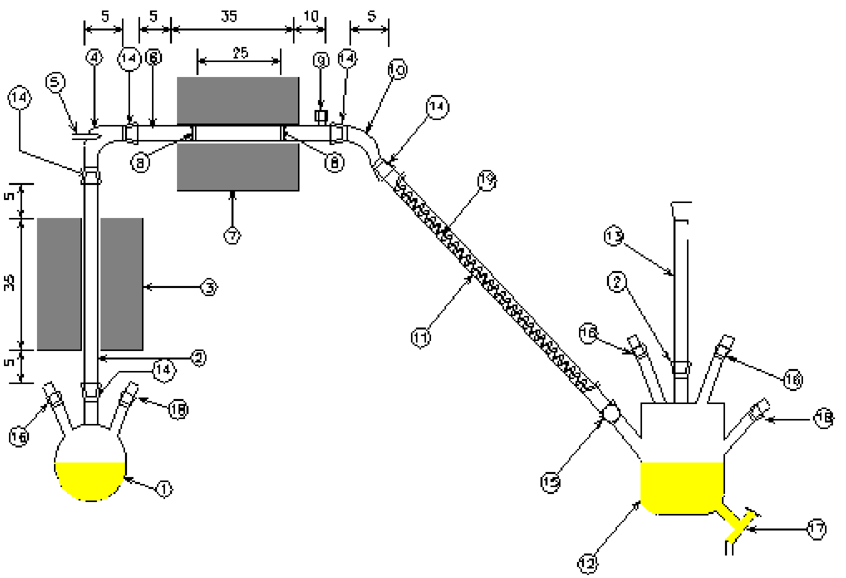
Need for higher temperature

Higher temperature required to
support hydrogen generation program

Sulfur-Iodine process (800 deg C)

UT-3 (Ca-Br process) (727 deg C)

Cu-Cl low temperature process (530 deg C)



H_2SO_4 decomposition unit

Sulfur-Iodine Process
Highest efficiency quoted for any
water-splitting process
Efficiency 52%

- Bunsen Reaction (ChTD)
- HI Decomposition (HWB)
- H_2SO_4 Decomposition (RD&DG)

Laboratory Scale Glass Unit (LSGU)
LSGU has been designed for 30 lit/hr
of H_2 production
operational at Hall-7

Some topics addressed by recent studies are

- Evaluation of novel processes for fuel synthesis (Möller et al. 2002; Dahl etal. 2004) and material production (Murray et al. 1995; Wieckert et al. 2004);

- Development of novel solar reactors (Anikeev et al. 1998; Osinga et al. 2004);

- Catalyst development for solar-driven high temperature gas-gas reactions(Berman and Epstein 1997).

The development of fuel production using solar energy is in a relatively early stage

http://www.sc.doe.gov/bes/reports/abstracts.html#SEU

Sensible heat storage materials	Thermal conductivity	Density*Sp.heat (kJ/kg-m^3)	Operating Temp range	Remark
Water	0.683	4040		
Servotherm	0.126	4341		
NaOH (320^oC)	1.2	3685		
Hitec (400^oC)	0.54	2653	140-480^oC	
Rock	0.13	1818		
Pebbles	0.85	1215		
Mg. Oxide	10.5	3790		
Aluminum Oxide	6.3	4080		
Silicone Oxide	2.3	3276		

SOTEF design points

Conclusion