Heat Transfer Fluids for Concentrating Solar Power

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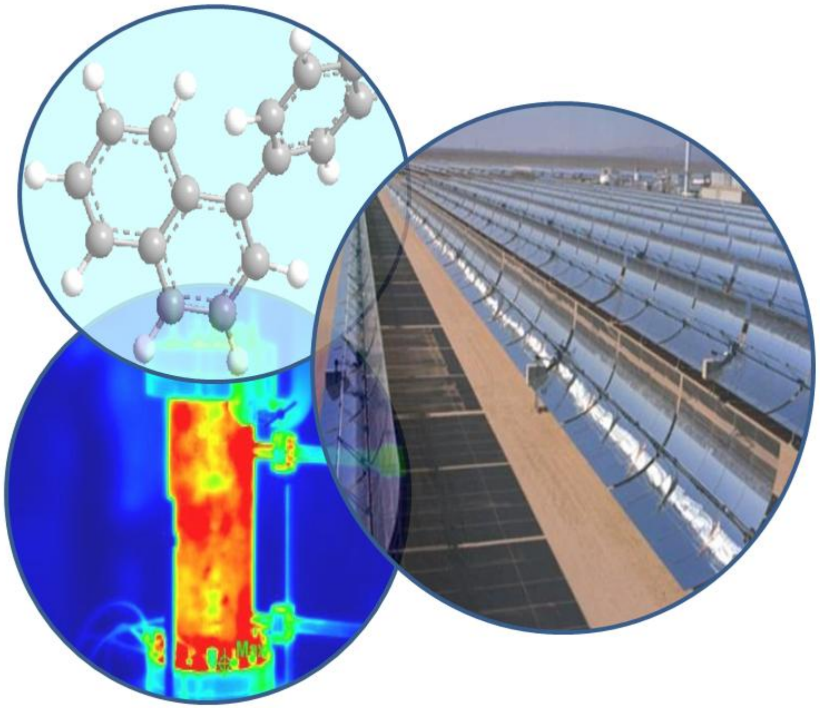
Solar Energy and Energy Storage Workshop

Oak Ridge National Laboratory

September 14, 2010



CSP is deployed worldwide

- **Inherent capacity to store heat, so can be engineered to produce energy even when cloudy or dark**
- **Backup fuels readily incorporated**
- **Enabling for other solar technologies**
- **Integrate with existing fossil plants**

Acciona's Solar One, NV, Parabolic

SES Dish Stirling, CA

PS10 Spain, Power Tower

Fresnel, Ausra, CA

Primary challenges for CSP include:

Sandia test power tower

Cost:

- Now 15-20 ¢/kWh versus baseload natural gas (9 ¢/kWh)
- Desire capital cost of installation of ~1$/W

Production limited to direct normal irradiation:

- Desire 24/7 production of power

Secondary challenges:

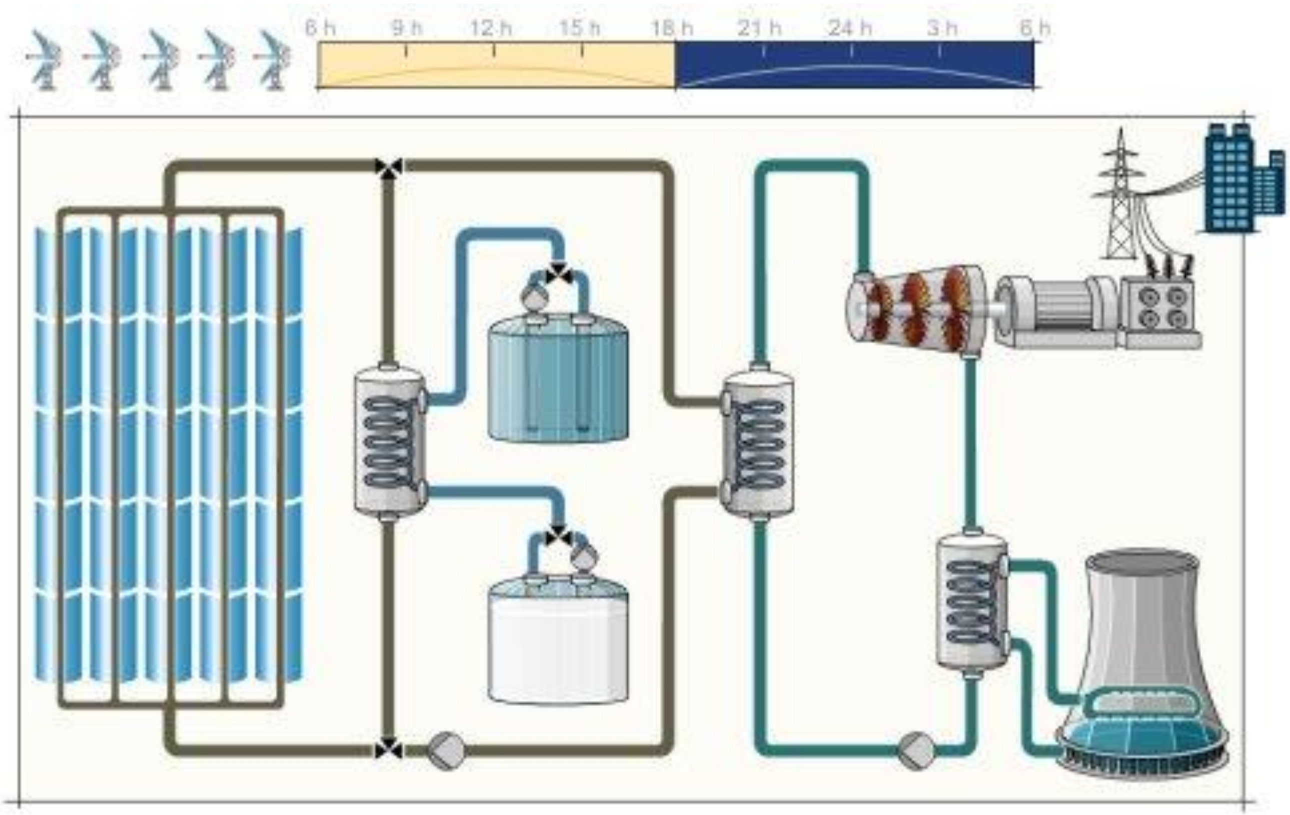
- Transmission from remote fields,
- Water use for cooling,
- Installation in fragile ecosystems,
- Lighter materials,
- Robustness,
- Maintenance.

IEA Technology Roadmaps,
Concentrating Solar Power, 2010

Thermal energy storage is needed for wide-scale adoption of CSP.

Near term (2015) need 8 h – to compete with natural gas

Longer term (2020-2022) need 16 h (overnight) – to compete with coal



DOE Solar Program Office is funding several projects in fluids for HT and TES.

Heat Transfer

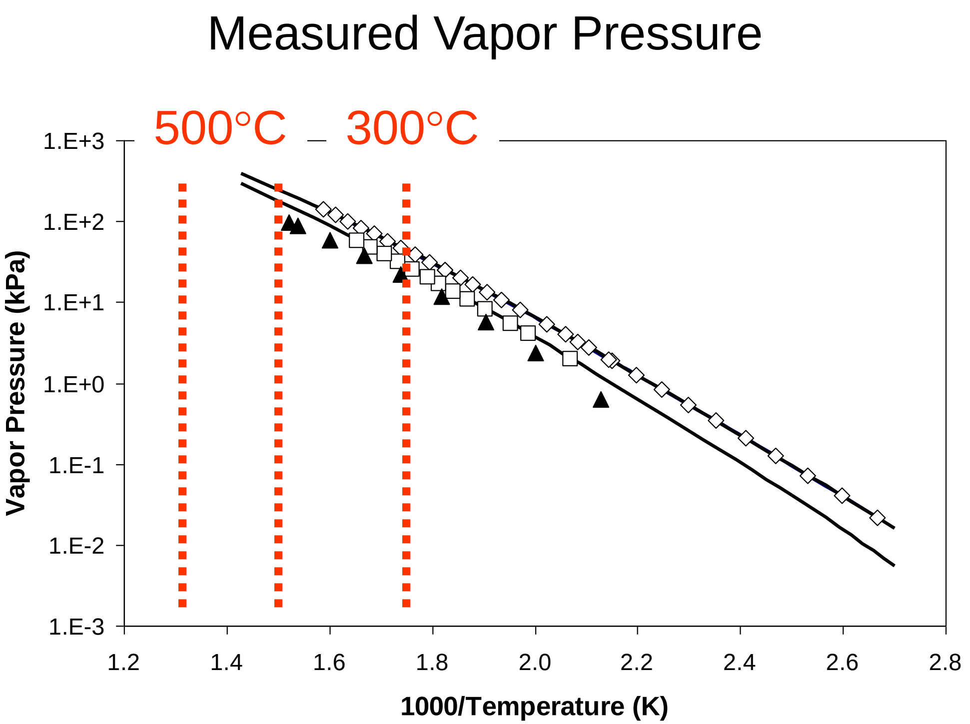
- ***Standard*** **HT fluids for solar collector assembly:**
  - Steam (Solar one, PS-10)
  - Organic: VP1 (Diphenyl oxide + biphenyl). Good to 400ºC.
- ***Molten salts/metals*****: Nitrates or metals as heat transfer fluids deliver heat from receiver to storage**
- ***Non-Newtonian fluids*****: Carbon nanotubes to increase heat transfer, heat capacity; ionic liquids**
- ***Solid particle receiver*****: Moving sand bed**
- ***Combined cycles water*****: Solar preheat before entering coal-fired boiler**

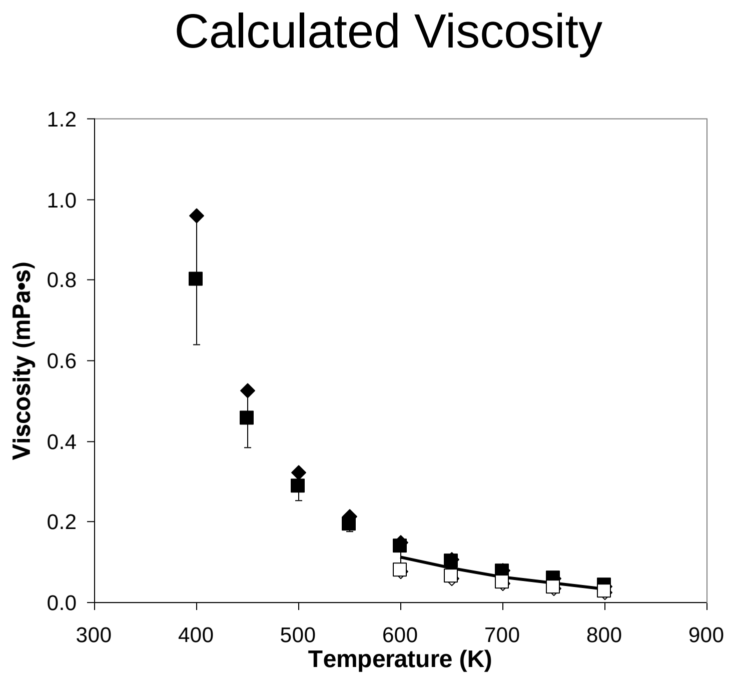
Thermal Energy Storage

- ***Phase-change materials*****: Enthalpy of fusion of eutectic salts with large liquidus region. NaF/NaCl good to 600ºC. Nitrates**
- ***Reversible reactions*****: Silicone polymerization, ammonia decomposition**
- ***Compressed air*****: Brayton cycle with storage in salt dome**

Thermophysical properties have been measured for substituted naphthalenes

These fluids have potential to be used above 500°C in CSP applications.



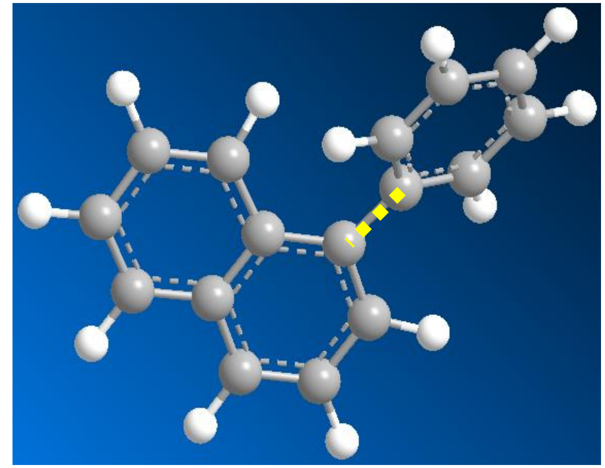


Liquid close to room temperature
Stable almost to critical point, 545°C
Relatively low critical pressure, 7 bar

McFarlane, Luo, Garland, & Steele Separation Science & Technology, 45, 1908-1920 (2010)

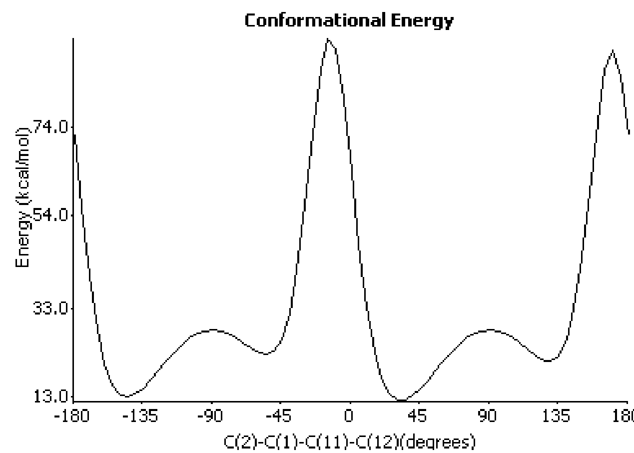
Optimization of cost and performance through chemistry

- **Suzuki-coupling synthesis tested gives > 95% yield**
- **Physical properties prediction through measurement and molecular modeling calculations**
- **Stability testing at high temperatures and pressures in static cell**



Optimized structure of 1-phenylnaphthalene

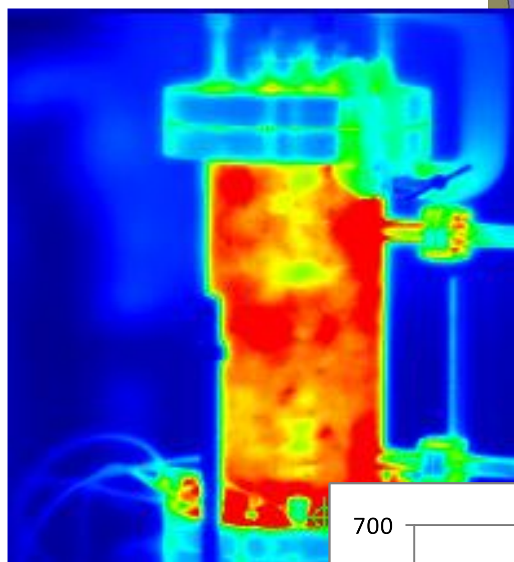
Static Test Chamber

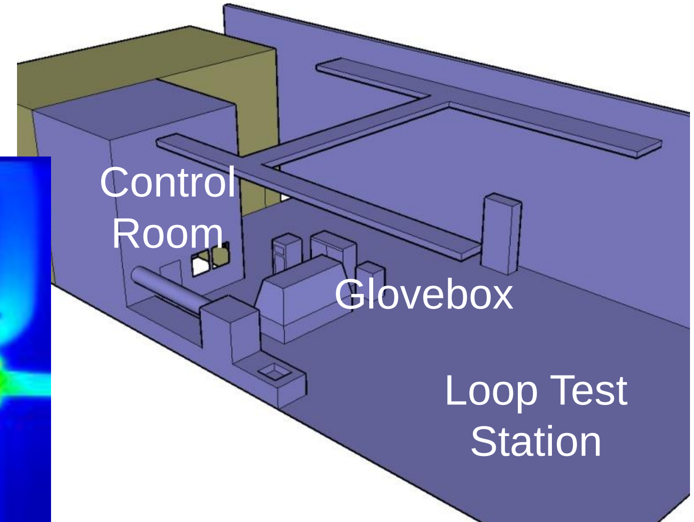


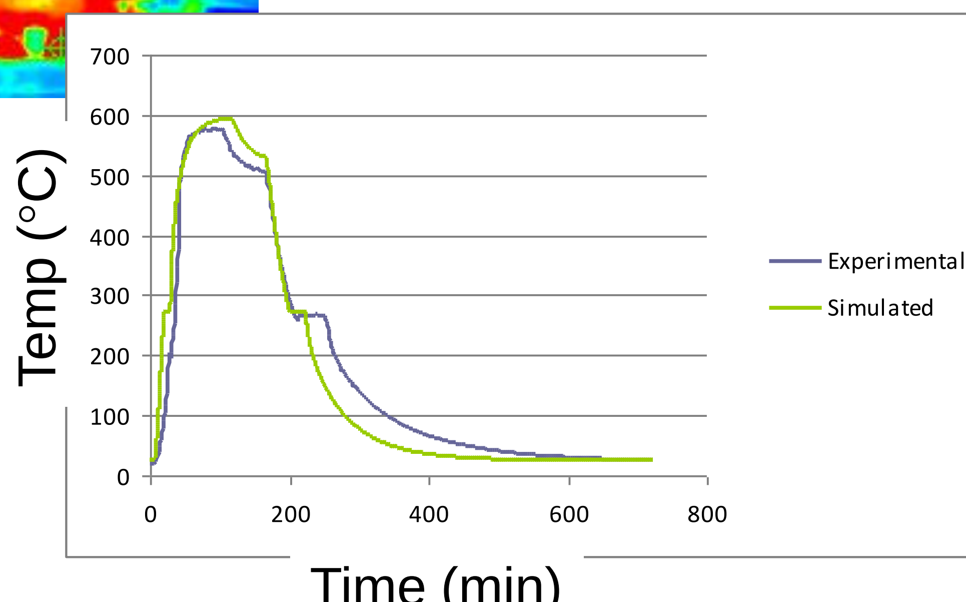
Conformational analysis explains low melting point.

ORNL's Small Power Systems Facility to be used to test fluid performance at high temperatures

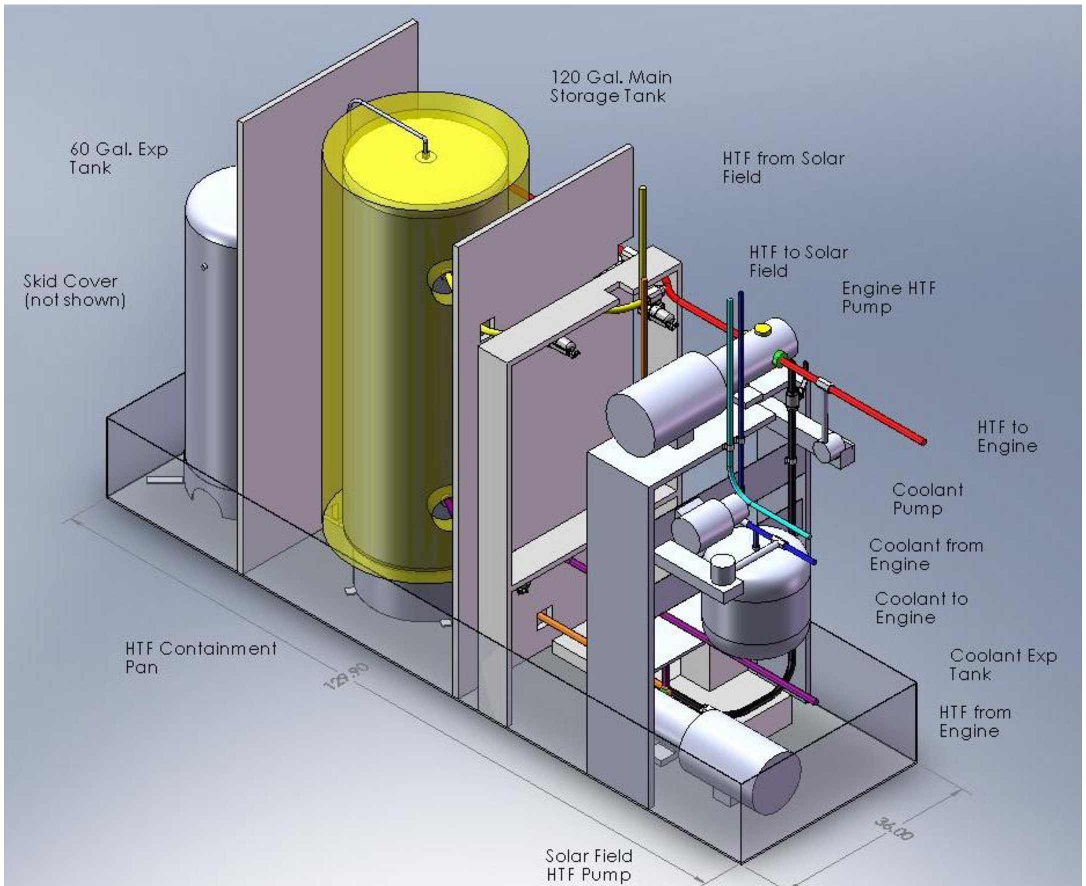
- Facility capability
  - 20 kW(e)
  - Chilled water system
  - Remote control
  - Thermal imaging
- Measurements
  - Heat balance
  - Pump power
- Results to be compared with dynamic models

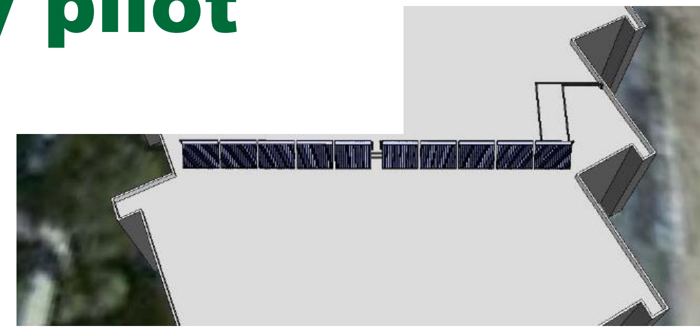




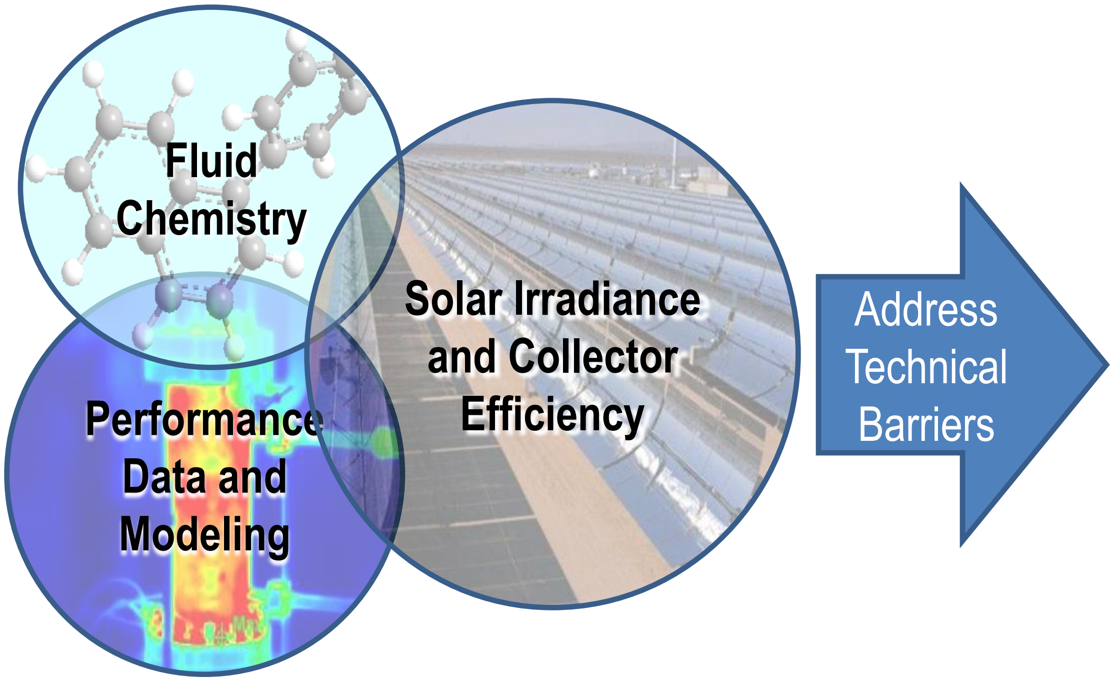


Coolant performance at intermediate temperatures will be tested at Cool Energy pilot plant.





Goal is to develop a conceptual design for high temperature CSP loop using naphthalene derivative heat transfer fluids



Capital cost. *Fluid cost will be reduced by optimizing the synthesis and selection of inexpensive reagents.*

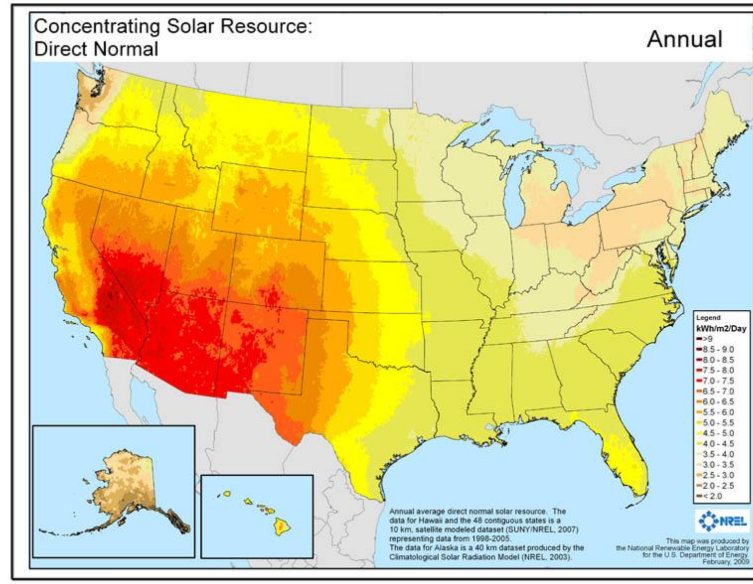
Reliability. *The stability and compatibility of the fluid will be tested at high-T, high-P in contact with loop materials.*

Performance. *The performance of the fluid will be tested by repeated cycling in a high-T test loop at ORNL.*

O&M costs. *Projected operations and maintenance assessed at pilot scale. Stability is key.*

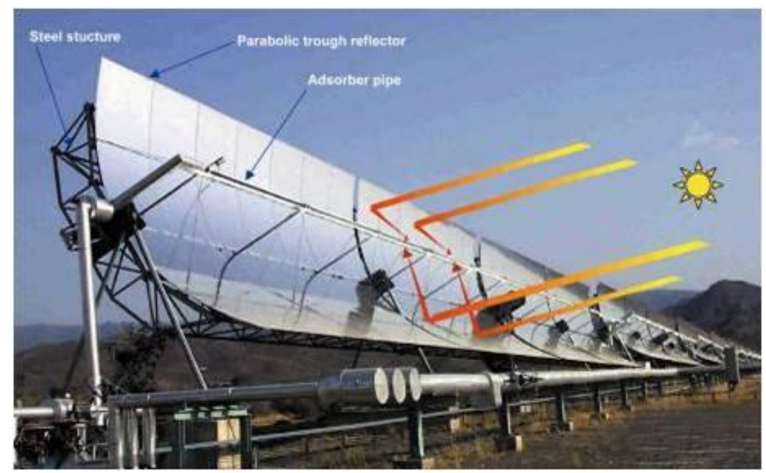
Technology Risk. *The heat transfer fluid will be demonstrated at pilot-scale.*

How to take advantage of solar resources?



Long term funding in R&D needed:

- components: mirrors, heliostats, receivers, heat transfer and working fluids, storage, power blocks, cooling, control and integration,
- applications: power, heat, and fuels, synergistic technologies
- scales: large and small installations



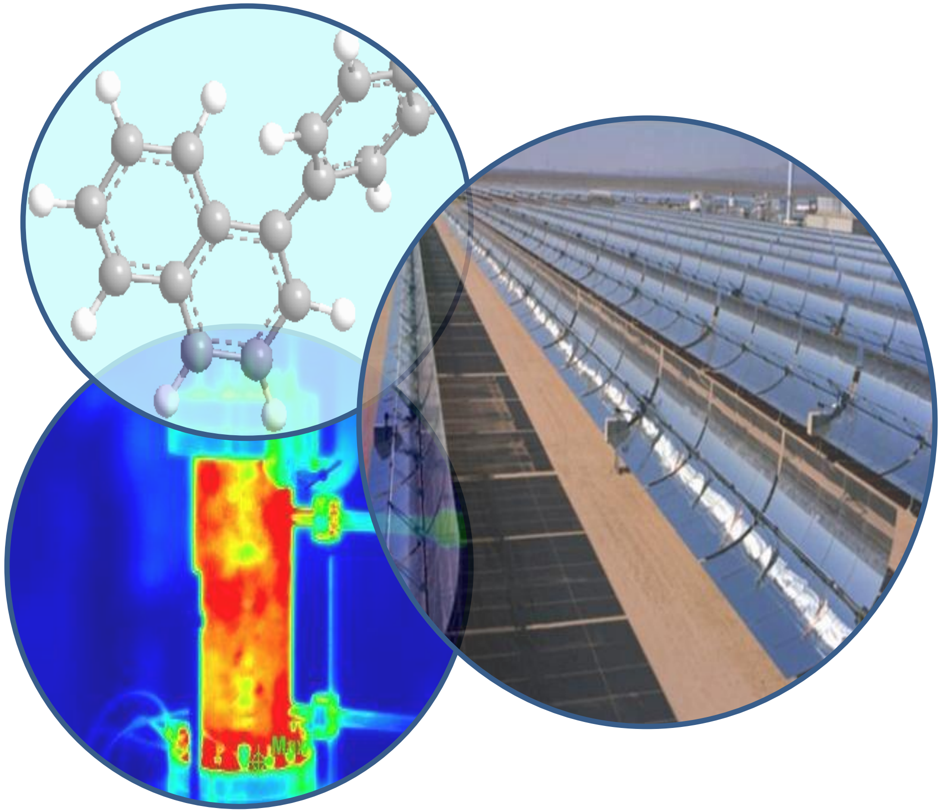
Incentives for Solar

Recommended reading:

- IEA Technology Roadmaps, Concentrating Solar Power, 2010

Funding from DOE EERE Office of Solar Energy

Extra information...



Thermophysical properties show feasiblity for high temperatures

Compound	T_m T_b **(K)**	C_p **(kJ·kg^{-1}K^{-1})**	❐ **(kg·m^{-3})**	T_c **(K)** P_c **(bar)**	**Vp** **(bar)**	● **(W·m^{-1}·K^{-1})**	◆ **(mPa·s)**
Dowtherm A (678 K)	285.2 530.2	2.725	672.5	770 31.34	11.32	0.0771	0.12
Xceltherm 600-C_{20} paraffin oil (588.8 K)	T_b range 574–741	3.001	672.36	768 10.7	0.2499	0.1122	0.252
H_2O (563 K, 7.5 MPa)	273.15 373.15	5.5	732	646.95 220.64	Super-heated	0.56	0.13
Li_2BeF_4 (973 K)	732 1703	2.42	1940	Not available	Not available	1.0	2.9
Na (823 K)	370.95 1156	1.27	820	2503.75 256.4	~10–16	62	0.12
Helium (7.5 MPa)		5.5	3.8	5 2.26	Super-heated	0.29	11.0
Biphenyl (500 K)	342 559	2.03	869	773±3 33.8±1	0.531	0.118	0.32
p-Terphenyl (500 K)	485 623	1.98	947	908+10 29.9±6	0.0199	0.135	0.73
phenylnaphthalene (600K)	**297–318** **598**	**2.6**	**849**	**818** **7.1**	**0.820**	**0.077**	**0.11**

Conceptual design of high temperature loop with naphthalene derivative HT fluid

Cool Energy has done preliminary system performance simulations for a 1.4 kW plant based on a site in Boulder CO (320 sq ft collector, 200 gal tank)