Thermal Storage Development

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CSP Review Meeting

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Team Members:

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Representing:

SunLab (NREL & Sandia), Kearney & Associates, Nexant, Univ. Nevada – Las Vegas, Univ. of Alabama

Background: Thermal Storage Development Project

Status in 1999:

Two-Tank Molten-Salt Thermal Storage Proven at Solar Two

- High temperature range (290 C to 570 C $\Rightarrow \Delta T$=280 C)
- 99% measured efficiency
- Levelized energy cost decreases with increased storage
- Receiver working fluid integral with storage media
- Capital cost = \$10/kWh$_t$

No thermal Storage Options for Current Technology Trough

- SEGS plants meet dispatching needs with natural-gas fired boilers

DOE Program Objectives

- Develop thermal storage options that:
  - Expand the dispatchability potential of CSP technologies using solar
  - Reduce the levelized energy cost
  - Improve the plant overall performance
- Development required for trough technology because:
  - Lower temperature range (290 C to 390 C $\Rightarrow \Delta T=100$ C)
  - Requires intermediate heat exchanger to transfer heat to storage media (near-term option)
  - Research required to develop integral storage options and improve economics / plant performance

Focused on Storage for Parabolic Trough Plants

- **Near-Term:** Current State of Technology Trough Plants (SEGS type with VP-1 oil heat transfer fluid)
  - Two tank molten-salt
  - Molten salt thermocline
- **Mid-Term:** Advanced Molten-Salt HTF Trough System
- **Long-Term:** New Heat Transfer Fluids
  - Organic nitrate salt

Long-Term Road Map Goal:

Thermal-Storage Capital Cost = $10/kWh$_t$

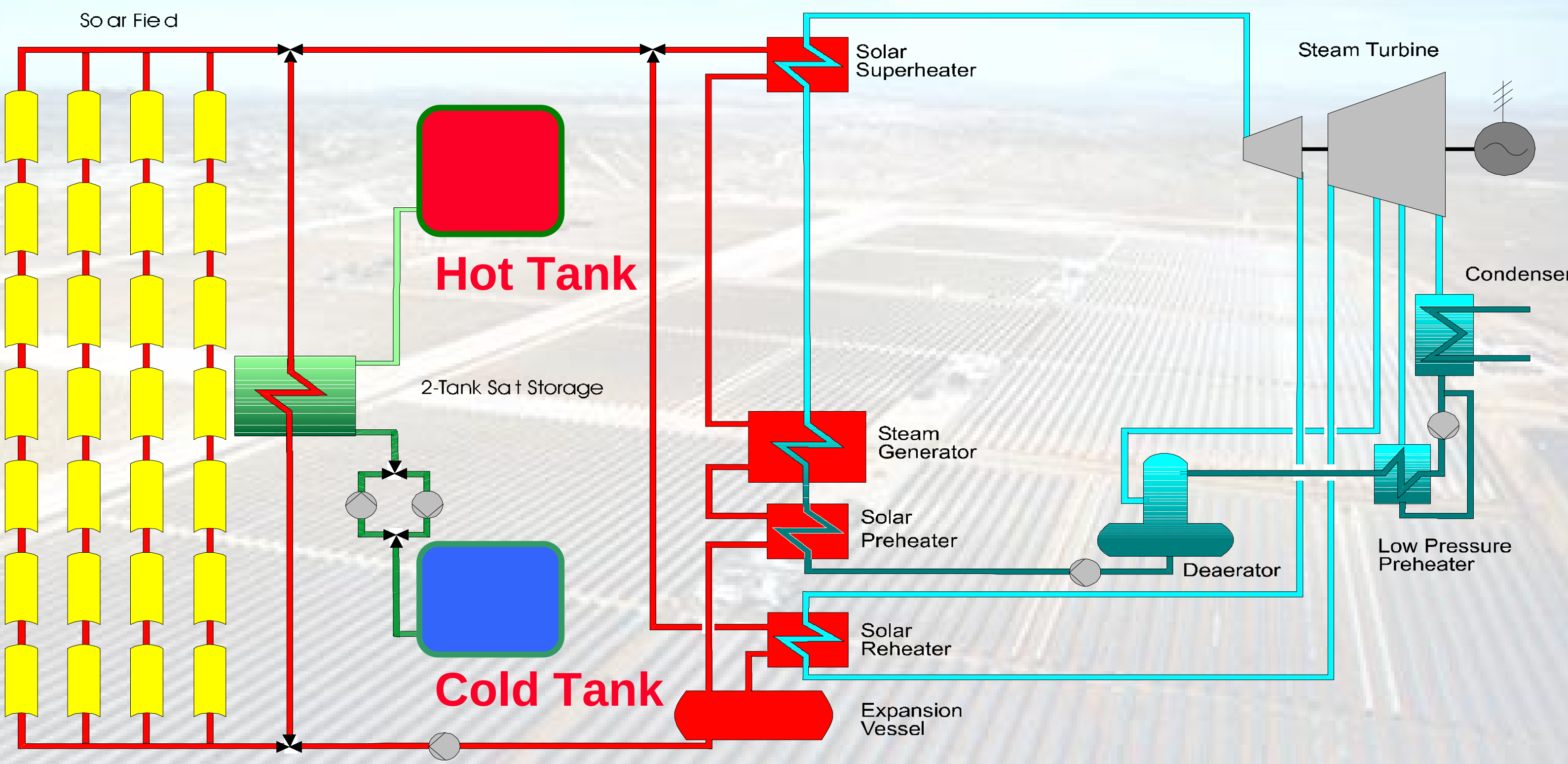
Near-Term Development

- **Two Tank Molten Salt Storage**
  - Leveraged experience from Solar Two's thermal storage system.
  - Heat transferred via an oil-to-salt heat exchanger.
  - Approach: Contract with Nexant to design conceptual storage system for 80 MWe SEGS
- **Thermocline Molten Salt System**
  - Single tank. Hot and cold potential separated with thermal gradient.
  - Low-cost filler material used to displace higher-cost molten salt
  - Approach: SunLab development effort

Solar Two Molten Salt Thermal Storage

Prototype Thermocline Storage

Trough Plant with Two Tank Molten Salt Storage System



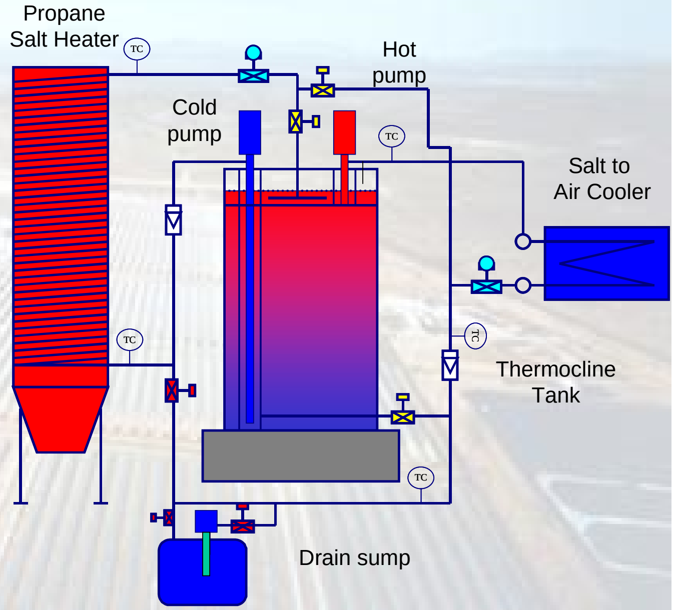
Nexant study shows two-tank storage capital costs for 80 MWe plant to cost \$27 – 40 /kWh$_t$.

Thermocline Development

Table 3. Cost of two-tank and thermocline molten-salt thermal storage systems each 688 MWh.

Component	Two-Tank Molten Salt	Thermocline with Quartzite
Nitrate Solar Salt, $k	11800	3800
Filler Material, $k	0	2200
Tank(s), $k	3800	2400
Salt-to-oil Heat Exchanger, $k	5500	5500
Total, $k	21100	13900
Specific Cost, $/kWh	31	20

Assumptions: Tank delta T=84ºC, Mixed filler cost=$72/tonne, Salt cost=$0.45/kg, Tank cost =$155/m³, Thermocline practical capacity = 69%



Pilot-Scale System Schematic

Thermocline Molten-Salt System is 65% the cost of a Two-tank Molten-Salt System. Feasibility demonstrated with 2 MWh pilot-scale system at NSTTF.

Mid-Term: Advanced Trough Storage

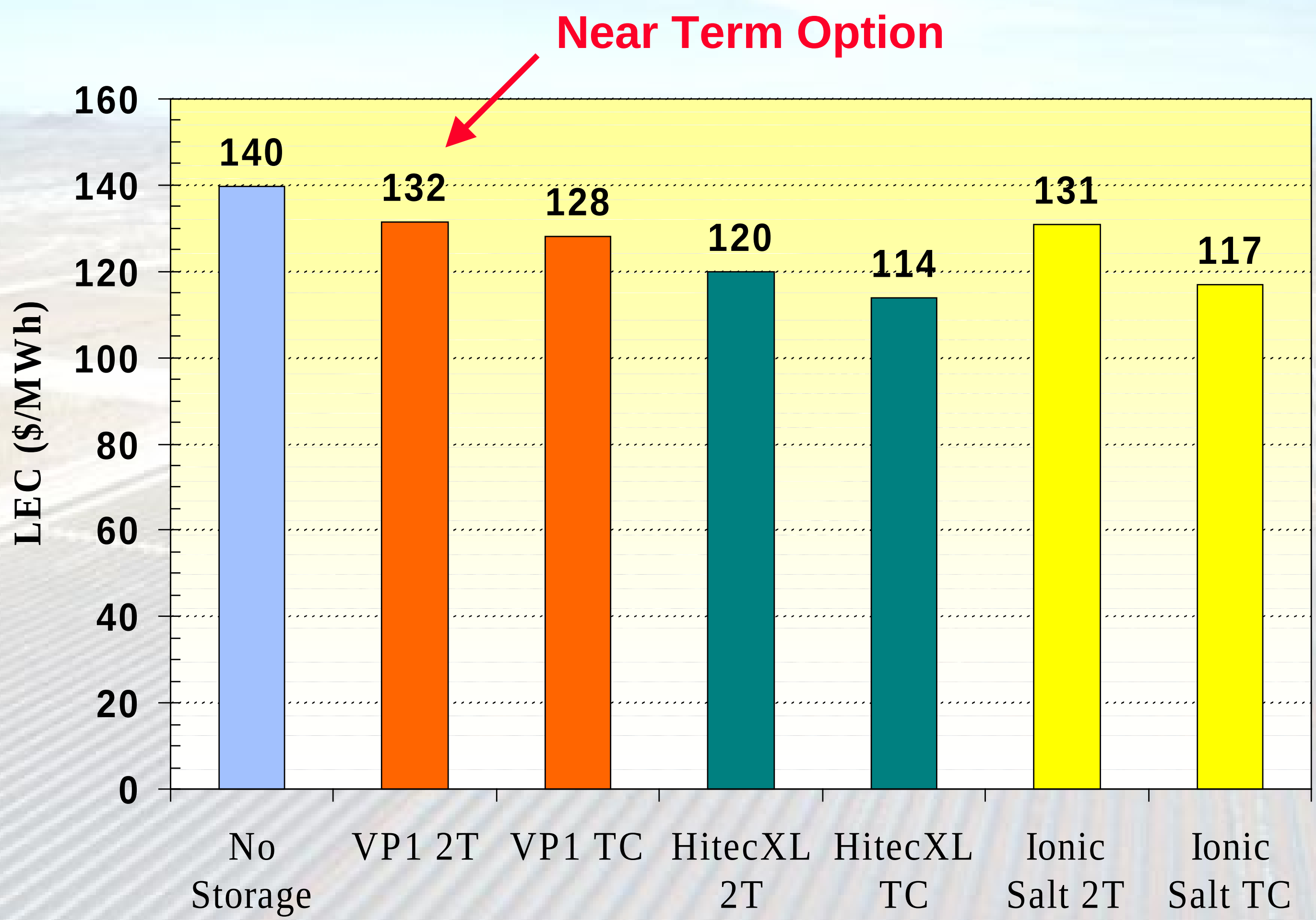
Molten Salt Heat Transfer Fluid

- **Objective:**
  - Evaluate use of a molten salt as the heat transfer fluid in a parabolic trough solar field to improve system performance and to reduce the LEC
- **Using nitrate salts directly as the HTF allows:**
  - Storage media and HTF to be the same. No intermediate HX.
  - Higher outlet temperatures to be achieved
  - High efficiency turbines to be used
  - Reduces LEC
  - Selected HiTech XL (Three-Component Nitrate Salt)
  - 2-tank and single tank thermocline designs considered
- **Freeze protection and heat loss are a major issues**
  - Adds additional risk. Accounted for in system model.
- **Approach: Contract with K&A, Flabeg, and Nexant to evaluate the feasibility**

Cases Analyzed

Case ID	HTF in SF	max. Temp. [°C]	Storage	HTF in Sto	Steam P [bar]	Emissivity at 350°C
VP1-NoSto	VP-1	393	-	-	100	0.1
VP1-2T	VP-1	393	2-Tank	SolarSalt	100	0.1
VP1.66-2T	VP-1	393	2-Tank	SolarSalt	**66**	0.1
VP1-TC	VP-1	393	Thermocline (14x39m)	SolarSalt	100	0.1
VP1.66-TC	VP-1	393	Thermocline (14x34m)	SolarSalt	**66**	0.1
S7-2T	HitecXL	450	2-Tank	HitecXL	100	0.1
S33-2T	HitecXL	450	2-Tank	HitecXL	**66**	0.1
S7-2TSS	HitecXL	450	2-Tank	**SolarSalt**	100	0.1
S7SS-2TSS	**SolarSalt**	450	2-Tank	SolarSalt	100	0.1
S7-TC	HitecXL	450	**Thermocline (14x27m)**	HitecXL	100	0.1
S14-2T	HitecXL	500	2-Tank	HitecXL	100	0.1
S14-TC	HitecXL	500	Thermocline (14x23m)	HitecXL	100	0.1
S7-TC-b	HitecXL	450	Thermocline **(14x28m)**	HitecXL	100	0.1
S7-TC-c	HitecXL	450	Thermocline **(14x40m)**	HitecXL	100	0.1
S7-TC-d	HitecXL	450	Thermocline **(17x25m)**	HitecXL	100	0.1
S7-TC-e	HitecXL	450	Thermocline **(17x38m)**	HitecXL	100	0.1
VP1.66-2T-hiE	VP-1	393	2-Tank	SolarSalt	66	**0.15**
S7-2T-hiE	HitecXL	450	2-Tank	HitecXL	100	**0.15**
S14-2T-hiE	HitecXL	500	2-Tank	HitecXL	100	**0.15**
IF-2T	**Ionic Fluid**	450	2-Tank	Ionic Fluid	100	0.1
VP1-Sto	VP-1	393	2-Tank	**VP-1**	66	0.1

Flabeg Cost/Performance Analysis



Long-Term: Advanced Heat Transfer Fluids Development

- **Objective:**
  - Develop advanced organic heat transfer fluid that will also work as a direct thermal storage media
- **Desirable heat transfer fluids properties:**
  - Low freezing points (< 0 deg C)
  - Low vapor pressure (< 1 atmosphere)
  - High thermal stability (>450 deg C)
  - Compatible with common materials
  - Low cost
- **Approach: Contract with Univ. of Alabama**

Imidazolium Salts Are First Candidates

- **Wide usable temperature range**
  - Freezing point: -75 deg C
  - Decomposition temperature: 416 deg C
  - Low vapor pressure: < 1 atmosphere
  - Raw material cost: $10/kg
- **Thousands of other organic salts under consideration**
  - Cost is a key issue
  - Potentially lower cost
  - Some could easily be mass produced

Summary of Thermal Storage Activities

- Thermal storage activities have made tremendous progress in the past two years.
- Two-tank molten salt system integrated into the current state of technology trough is feasible and has low perceived risk. Capital cost is $27-40/kWh.
- Thermocline systems offer potential to reduce this cost by 1/3. Feasibility of concept has been demonstrated through testing.
- Evaluations of using salts directly as an HTF have shown that LECs can be reduced further as a results of more efficient system performance and use of direct thermal storage.
- Advanced fluid develop offers the potential to simplify the integration of storage and improve performance.

Next Steps

- Support industry in evaluating and designing thermal storage for near term projects
- Improve the cost effectiveness of trough thermal storage technologies
- FY02 Tasks include:
  - Reducing the risk of thermocline storage
  - Resolution of key issues for using an inorganic molten-salt as the HTF in a trough solar field
  - Continued development of new heat transfer fluids and storage media for trough solar plants