2008 Solar Annual Review Meeting

Session: Thermal Storage - Advanced Fluid Development
Company or Organization: NREL
Funding Opportunity: Concentrating Solar Program

Greg Glatzmaier, Dan Blake, Joongoo Kang

Relationship to Solar Program Goals

"…to make CSP cost competitive in the intermediate power markets by 2015 (~7¢/kWh with 6 hours of storage) and in baseload power markets (~5¢/kWh with 16 hours of storage) by 2020."

1. Project Overview

a) Description

- near-term & long-term R&D activities relating to heat transfer & thermal storage fluids

b) Major FY08 Activities

- near-term analysis and modeling of organic HTF decomposition within parabolic trough power plant
- long-term exploration of properties of nanoscale particles
- preparation of advanced fluids & thermal storage solicitation
- testing & evaluation support of FOA work

Relationship to Solar Program Goals

Project overview (continued)

c) Planned Milestones

- prepare & review advanced fluids/thermal storage solicitation, March 2008
- complete organic HTF decomposition modeling, September 2008
- initiate nanofluids modeling work & submit progress report, September 2008

Agreement	FTEs	$(K)	Subcontract $(K)
Advanced fluids	1.6	169	0
HTF decomposition modeling	0.3	83	0
FOA storage support	1.0	300	0
HTF/TES solicitation	1.0	300	0

Relationship to Solar Program Goals

Project overview (continued)

e) Personnel

- solicitation support: Greg Glatzmaier, Mark Mehos, Chuck Kutscher, Tom Mancini
- Nanofluids R&D: Dan Blake, Yong-Hyun Kim, Calvin Curtis, Joongoo Kang (post-doc), Greg Glatzmaier and Luc Moens
- HTF decomposition modeling: Greg Glatzmaier

2. Relevance to Program Plans & Goals

MYPP & Program Goals

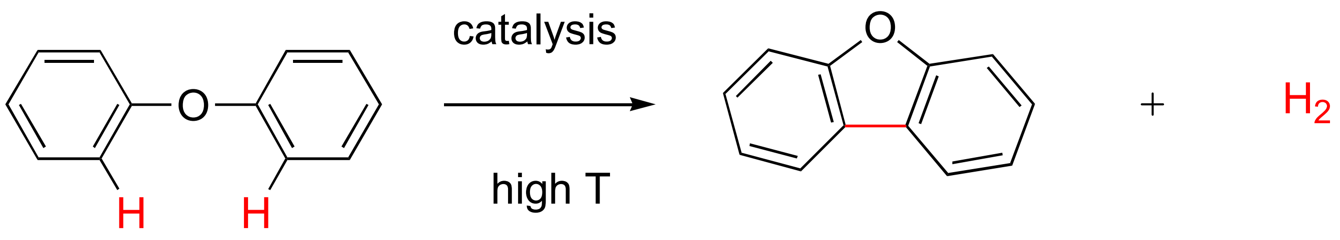
- Advanced fluids with enhanced heat capacities directly impact thermal storage costs ($20/kWh) and plant LCOE
- Higher temperature advanced fluids will increase turbine efficiency, annual solar efficiency and reduce LCOE

FY08 Progress Report

Organic HTF decomposition: mechanisms

1. What has been accomplished thus far?

- **Goal:** determine organic HTF decomposition reaction mechanisms
- **Status**
    - o work on reaction mechanisms complete
    - o results published in NREL technical report **TP-510-42468**



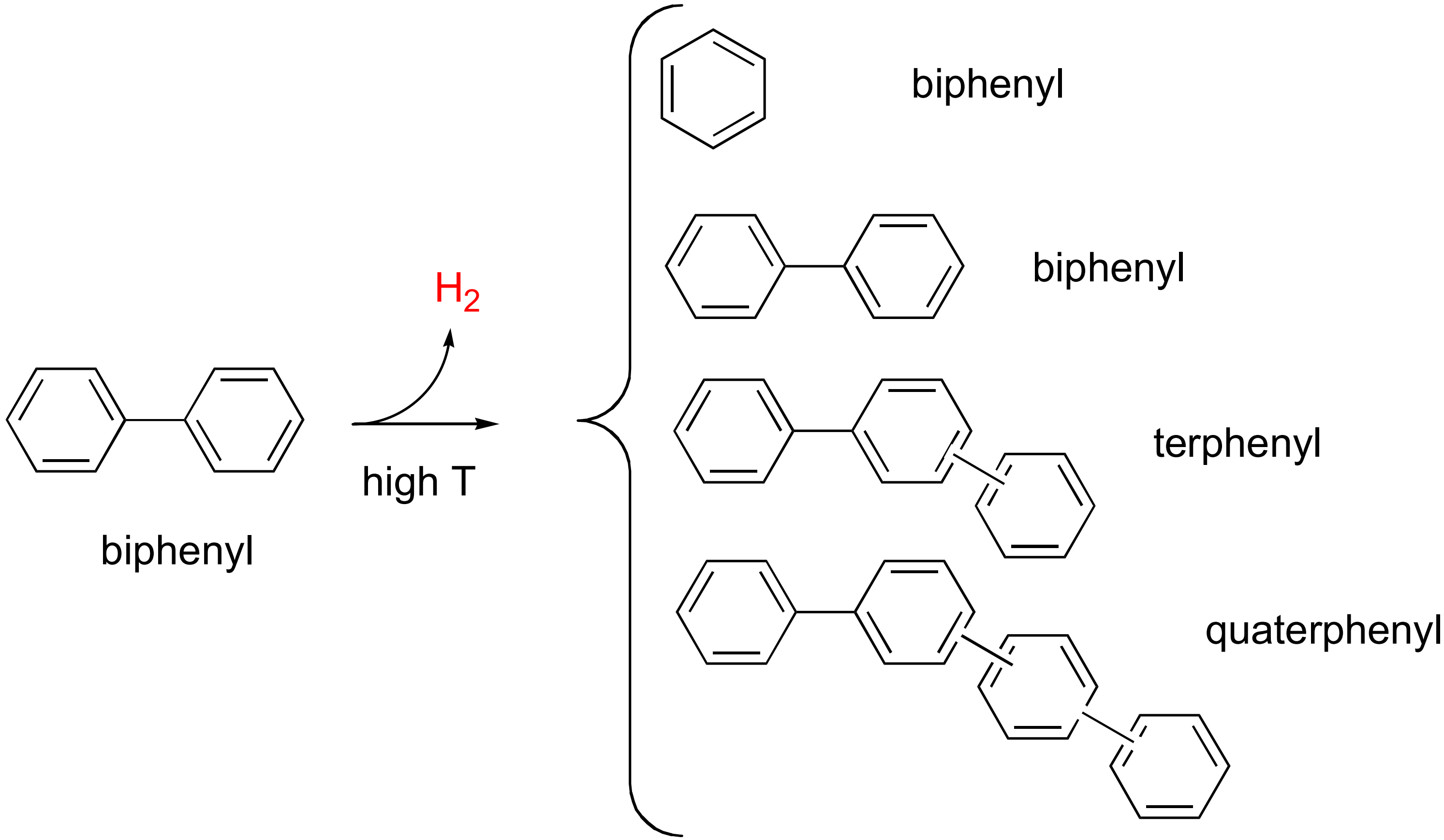
diphenyl oxide

dibenzofuran

Diphenyl oxide ring closure

FY08 Progress Report

Organic HTF decomposition: mechanisms



Free-radical polymerization of biphenyl

FY08 Progress Report

Organic HTF decomposition: modeling

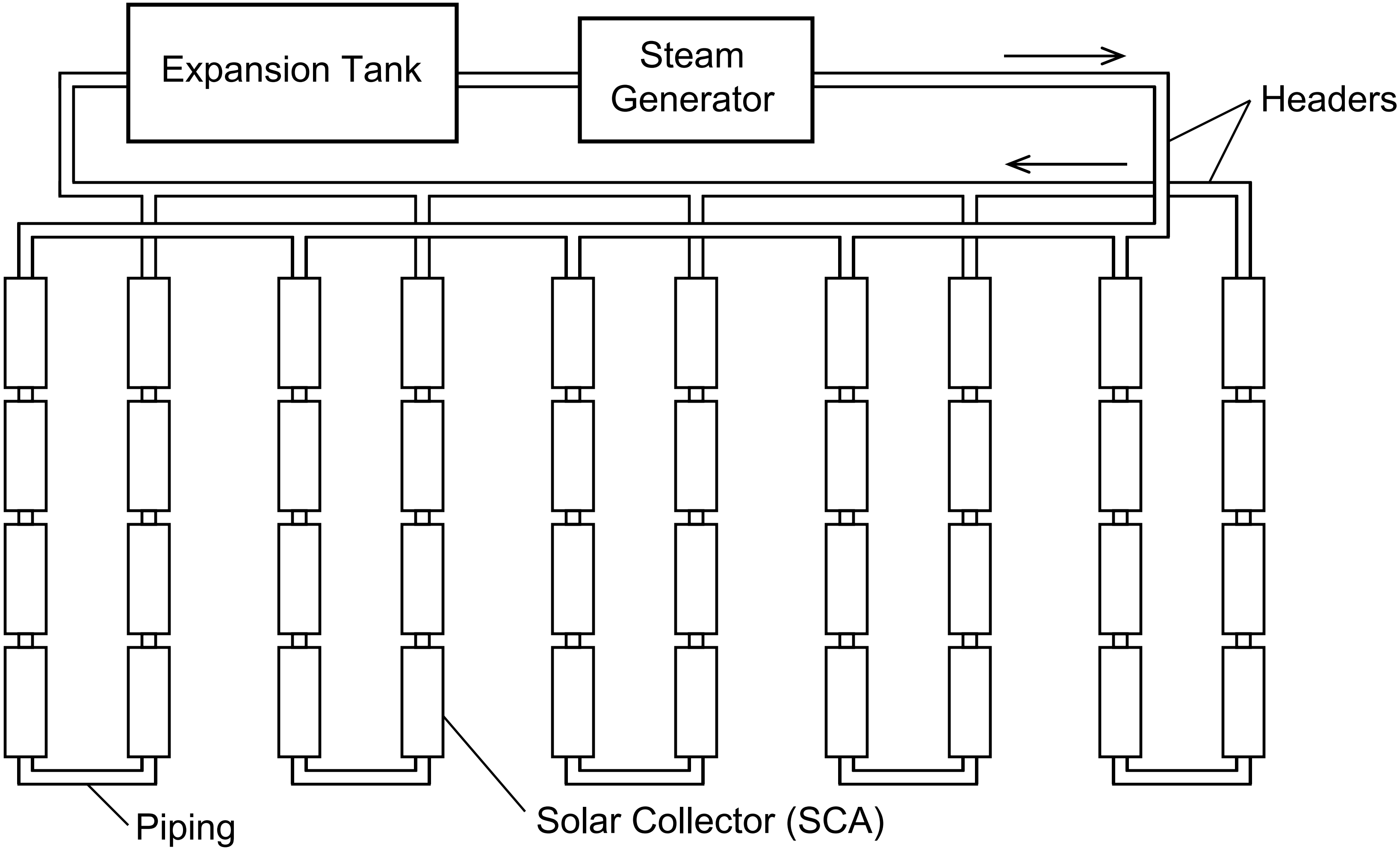
1. What has been accomplished thus far?

- **Goals**
  - understand the occurrence of hydrogen within parabolic trough power plants due to organic HTF decomposition - hydrogen degrade the thermal performance of the heat collection elements (HCEs)
  - evaluate promising mitigation methods

- **Approach**
  - model hydrogen generation and transport within a parabolic trough power plant
  - develop a steady-state hydrogen material balance within each major plant component including expansion tank, steam generator, headers, solar collectors and piping connections

FY08 Progress Report

Organic HTF decomposition: modeling



FY08 Progress Report

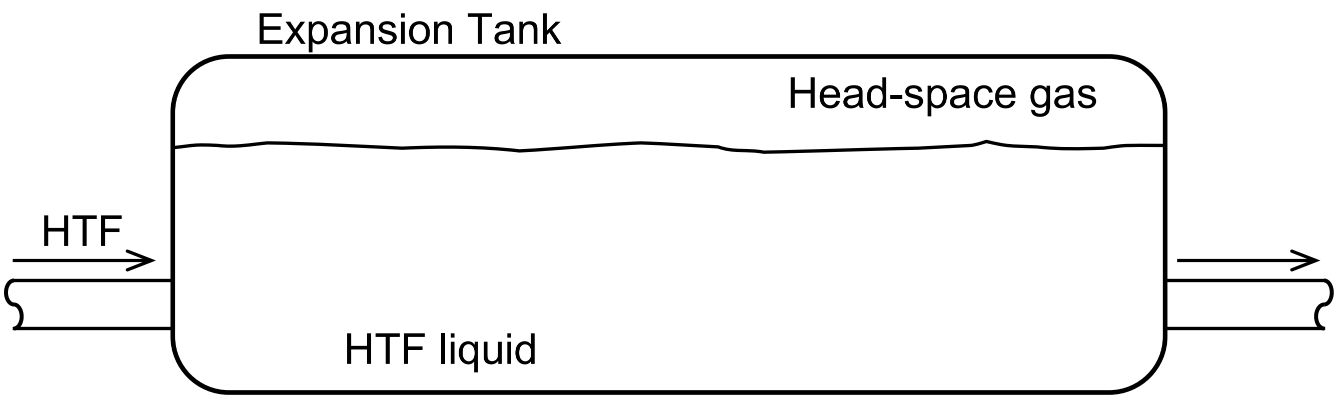
Organic HTF decomposition: modeling

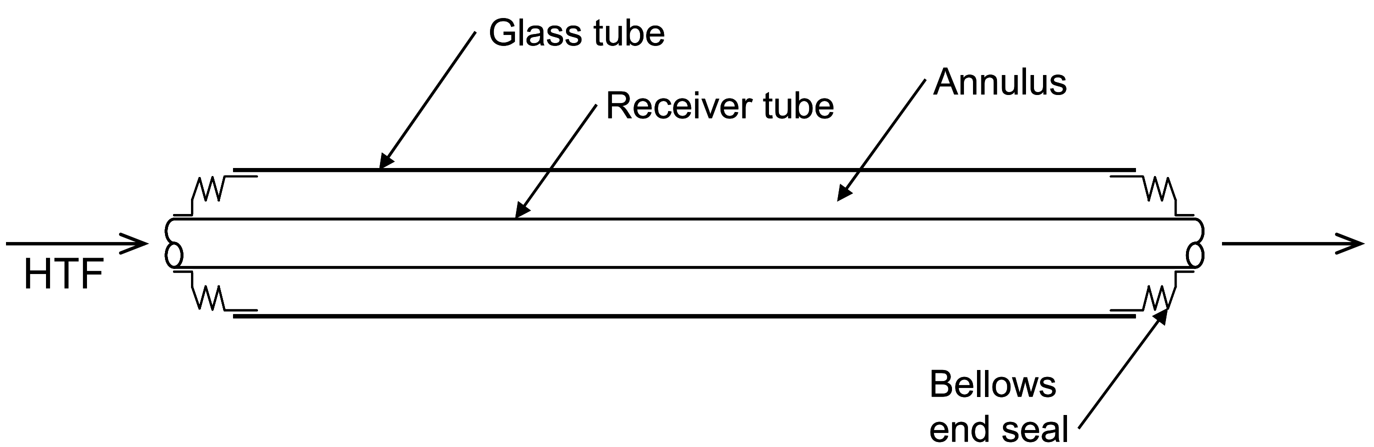
1. What has been accomplished thus far?

- each material balance accounts for hydrogen generation due to HTF decomposition & transport in and out of the component due to HTF flow & gas permeation
- material balances on HCEs model hydrogen concentrations in both the receiver tube and the annulus
- material balance on the expansion tank models gas-phase & liquid-phase hydrogen concentrations

FY08 Progress Report

Organic HTF decomposition: modeling





FY08 Progress Report

Organic HTF decomposition: modeling

1. What has been accomplished thus far?

- **Status**
  - software was written in Engineering Equation Solver (EES)
  - software is functioning, modeling work is next

c) Costing (spending on track)

NREL			
Project Beginning Date	**FY07 Budget**	**FY08 Budget**	**Total Budget**
10/1/2008	83K	0	83K

FY08 Progress Report

Organic HTF decomposition: modeling

2. Plans for the 3rd and 4th Quarters

- analyze generation and transport of hydrogen in typical parabolic trough power plant
- use model to evaluate promising methods to reduce or remove hydrogen from HTF loop and the HCE annulus

a) Status of milestone: on track

Future Activities

Organic HTF decomposition: modeling

1. FY09 Planned Activities

   a) Follow-on efforts

      - implement and test a promising method to remove hydrogen at a SEGS plant
      - FPL/Kramer Junction expressed interest in this work

   c) Budget Table (FTEs, $FTE, Subcontract Info)

      - 0.75 FTEs, 225K $FTE

   d) Projected Milestone

      - complete a field test

Future Activities

Organic HTF decomposition: modeling

2. FY10 and Beyond Ideas

   a) Future Work

      - on-going monitoring and modeling of the field tests

   c) Vision: a parabolic trough power plant with no hydrogen

FY08 Progress Report

Nanofluids R&D

Goal: develop a new class of heat transfer & storage fluids that possess enhanced heat capacities & conductivities

Approach: use nanoscale "encapsulated" structures (50 – 500 atoms) capable of solid/solid, solid/liquid, or solid/gas phase transitions (nanoPCMs)

sensible heating ($\Delta T = 100\ ^{o}C$): ΔH = 85-230 kJ/kg (VP-1, nitrate salts, concrete)

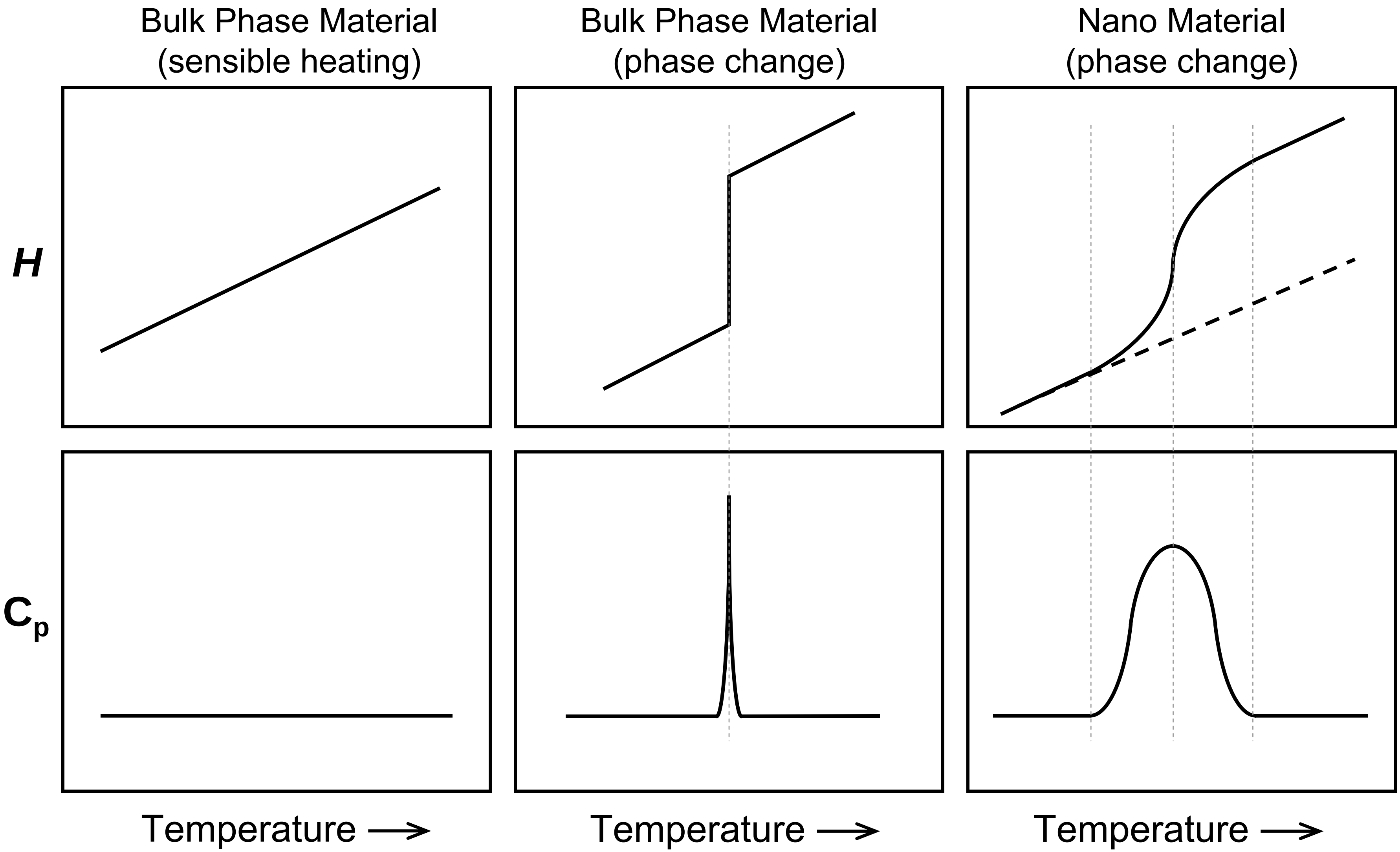
phase change: ΔH = 200-1400 kJ/kg (melting & sublimation)

Nano-scale particles vs. bulk materials

- bulk materials
  - phase change occurs at single temperature
- nano particles
  - phase transitions occur over a temperature range that is tunable

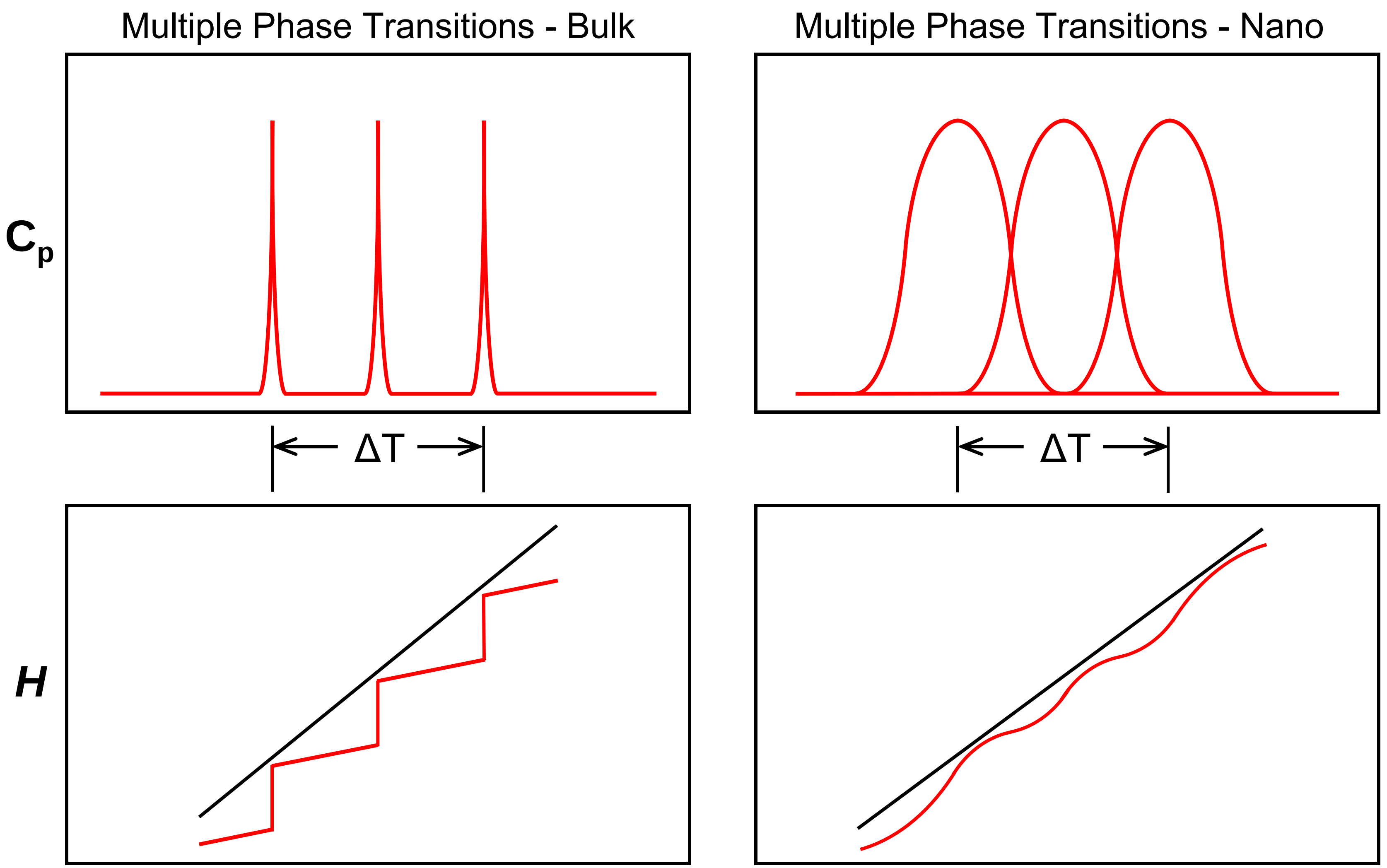
FY08 Progress Report

Nanofluids R&D



FY08 Progress Report

Nanofluids R&D



FY08 Progress Report

Nanofluids R&D

1. What has been accomplished thus far?

- nanoscale fluids project started using internal NREL funding
- initial molecular modeling of thermal properties of aluminum clusters shows encouraging results

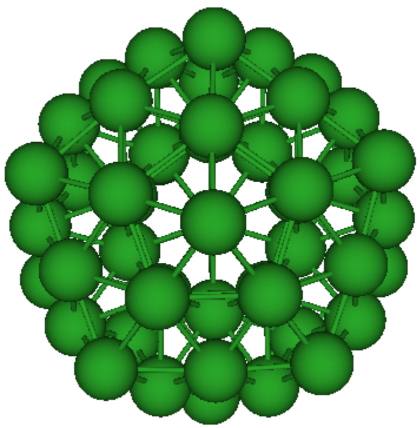
FY08 Progress Report

Nanoparticle Experimental Results

G.A. Breaux *et al.*, PRL (2005)

55 Atom Aluminum Clusters

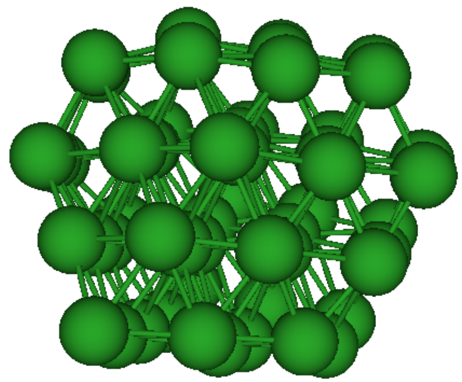
icosahedron (I_h)



E = +3.95 eV

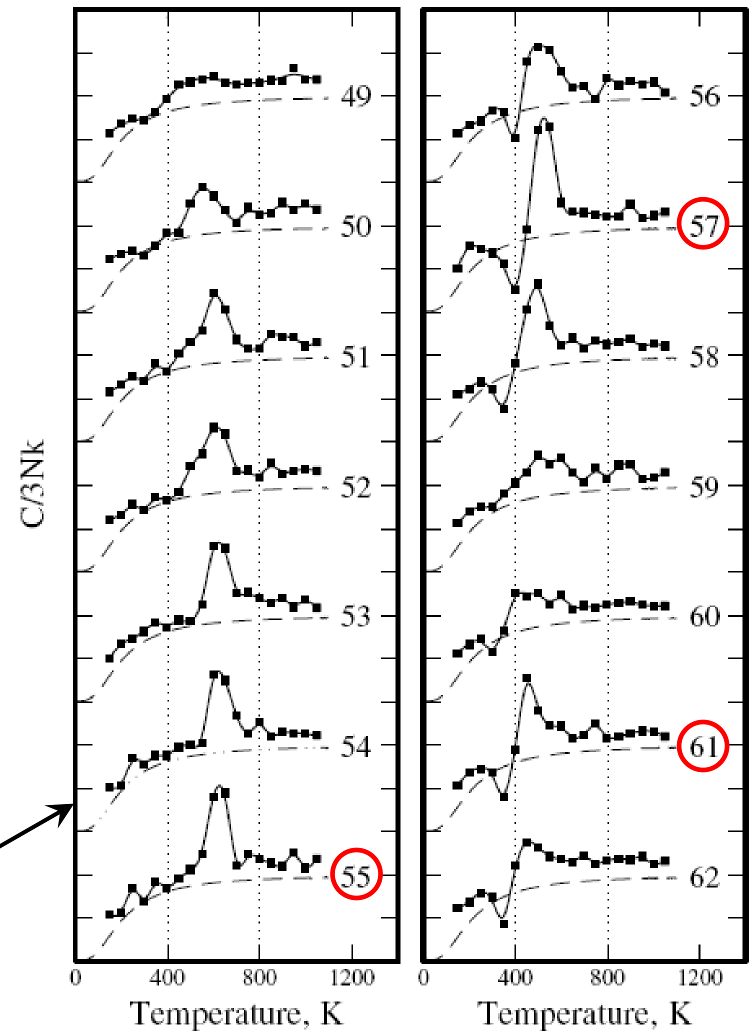
Z. H. Li *et al.*, JACS (2007)

ordered structure



E = 0 (most stable)

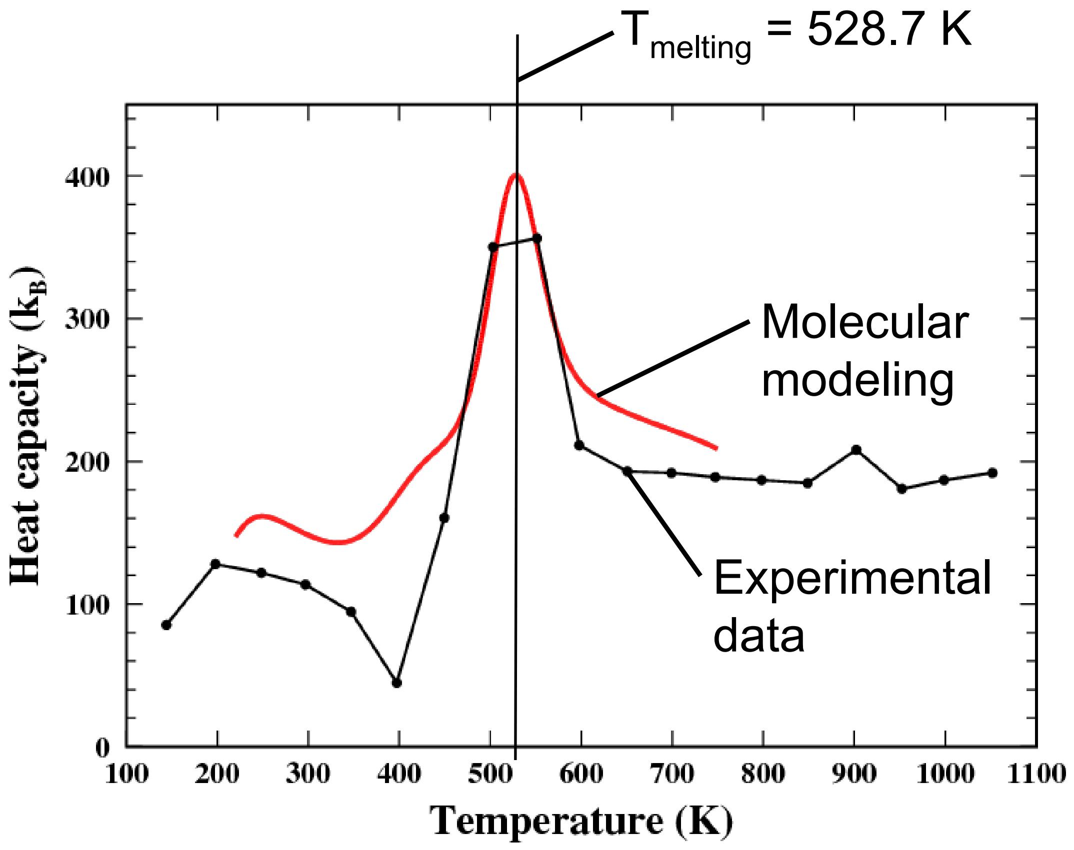
- melting phase transitions
- variation in aluminum nanoclusters' T_{melt}
- bulk aluminum T_{melt} = 933 K (660 ^{o}C)



FY08 Progress Report

Nanofluids R&D

Al 57



FY08 Progress Report

Nanofluids R&D

c) Costing (funding on track)

NREL			
Project Beginning Date	**FY07 Budget**	**FY08 Budget**	**Total Budget**
10/1/2008	59K	110K	169K

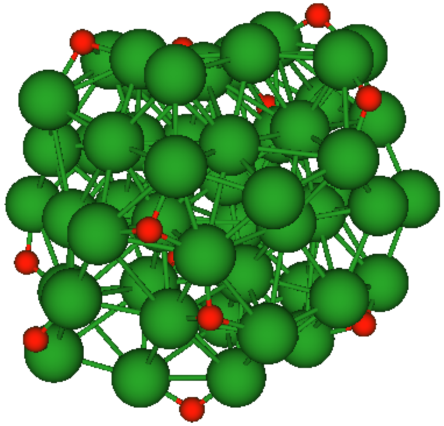
FY08 Progress Report

Nanofluids R&D

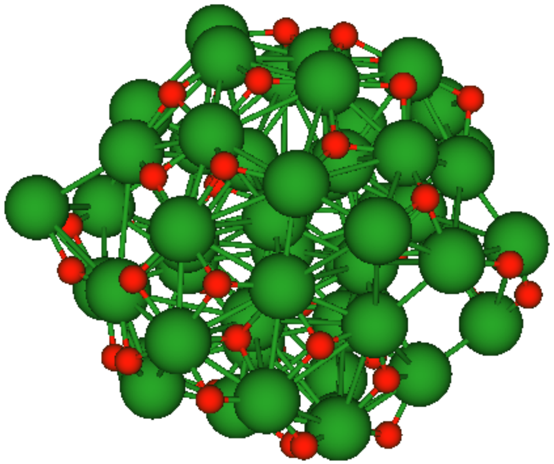
2. Plans for the 3rd and 4th Quarters

- Encapsulate nanostructure to stabilize particles using partial oxidation to form core-shell structures

Al 55 + 12 O



Al 55 + 42 O



a) Status of milestone: R&D on track

Future Activities

Nanofluids R&D

1. FY09 Planned Activities

   a) Follow-on efforts

   - continue work on modeling, synthesis, and characterization of nanocluster storage materials
   - tune phase transition temperature as a function of material and cluster size
   - evaluate other elements (metals, carbon)

   b) New directions

   - model larger metal atom clusters (>200 atoms)
   - requires significantly more computing power

   c) Budget

   - 2.2 FTEs (1 post doc), $360K

   d) Projected milestone

   - progress report on modeling & directed synthesis of phase-change materials

Future Activities

Nanofluids R&D

2. FY10 and Beyond Ideas

   a) Future Project: complementary work effort using nanoscale particle features & properties to develop a metal-based fluid with a proper liquid-phase temperature range (10 ^{o}C – 500 ^{o}C)

   b) Outside the Box: tune nanoscale properties to develop a set of nanofluids that has an effective phase transition over a 100 ^{o}C ΔT

   b) Vision: an inexpensive, noncorrosive combined HTF/storage fluid with a 10 ^{o}C – 500 ^{o}C liquid temperature range