Metal Organic Heat Carriers for Enhanced Geothermal Systems

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### Project Overview

<table>
<thead>
<tr>
<th>Award Number</th>
<th>56595</th>
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</thead>
<tbody>
<tr>
<td>Total Project Funding Request</td>
<td>$1,236,432</td>
</tr>
<tr>
<td>Actual Start Date</td>
<td>9/01/2009</td>
</tr>
<tr>
<td>Planned Completion Date of the Project</td>
<td>09/30/2012</td>
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<tr>
<td>FY09 Funding</td>
<td>$456,000</td>
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<tr>
<td>FY10 Funding Expected</td>
<td>$476,432</td>
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<tr>
<td>Actual Costs through 05/7/10</td>
<td>$166,817</td>
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<tr>
<td>Cumulative Percent Spent</td>
<td>13%</td>
</tr>
<tr>
<td>Cumulative Percent Complete Timeline</td>
<td>19%</td>
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</table>

- This project addresses Energy Conversion Barrier N - Inability to lower the temperature conditions under which EGS power generation is commercially viable.
- PNNL is partnering with Ormat Technologies, Inc. for loan of a portable ORC unit to support full cycle testing.
Relevance/Impact of Research

- Develop nanophase materials that interact at the molecular level with various working fluids
- Improve ORC efficiency by 10 to 20%
  - Boost the heat carrying capacity of the working fluid
  - Increase thermal conductivity
- Equal or potentially exceed molar density of the liquid or vapor phase states of the pure working fluid.

\[
\frac{q_3^M}{q_3} = 1 + x_M \left( \frac{\Delta H_d}{\Delta H_v} - 1 \right)
\]
Metal Organic Heat Carriers

- Synthesis under mild conditions and templating techniques available to produce nanophase forms
- Many combinations of metal ions and organic linkers
- High structural and thermal stability >500 °C
- Surface area 25 to 6000 m²/g
- Tunable pore size, shape and chemical functionality
Highlights to Date

• Successfully synthesized several MOHC’s with different organic linkers for initial evaluation, including nanophase form
• In depth characterization work underway (porosity, thermal stability, structure)
• Confirmed large uptake capacity (>30 wt%) using IGA-100 for various working fluids including a commercial product (Dow J) with Cu-BTC
• Using TG-MS, peak desorption temperatures are consistently 1.5 to 2X above standard boiling point of working fluid
Adsorption of Butane with Cu-BTC

![Graph showing adsorption of butane with different temperatures ranging from 25°C to 110°C. The x-axis represents pressure in mbar, and the y-axis represents the percentage of butane uptake.](image)
Adsorption of Cyclohexane

Cu-135BTC Vapor Sorption Isotherm: Cyclohexane @ 34°C
Desorption Behavior of Cyclohexane

- Mass Change: -4.47% for m/z 41; Cyclohexane
- Mass Change: -30.72% for m/z 69; Cyclohexane
- Mass Change: -30.72% for m/z 55; Cyclohexane

Temperature (°C) vs. TG (%)

- m/z 41; Cyclohexane
- m/z 69; Cyclohexane
- m/z 39; Cyclohexane
- m/z 55; Cyclohexane
# Preliminary Adsorption Thermodynamics of Various Alkanes on Cu-BTC

<table>
<thead>
<tr>
<th>Working Fluid</th>
<th>Heat of Desorption (J/g)</th>
<th>Heat of Vaporization (J/g)</th>
<th>Peak Desorption Temp (°C)</th>
<th>Standard Boiling Point (°C)</th>
<th>Weight Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclohexane</td>
<td>1217</td>
<td>356</td>
<td>145</td>
<td>81</td>
<td>50</td>
</tr>
<tr>
<td>Hexane</td>
<td>670</td>
<td>365</td>
<td>125</td>
<td>69</td>
<td>45</td>
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<tr>
<td>Pentane</td>
<td>186</td>
<td>357</td>
<td>75</td>
<td>36</td>
<td>40</td>
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<tr>
<td>Cyclopentane</td>
<td>350</td>
<td>407</td>
<td>95</td>
<td>49</td>
<td>35</td>
</tr>
<tr>
<td>Butane</td>
<td>180</td>
<td>386</td>
<td>35</td>
<td>-0.5</td>
<td>35</td>
</tr>
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</table>
Test Loop System Development

• Test loop system design and procurement was implemented a full year ahead of original schedule
  – The 1.5 kW test loop system to be operational early in FY11
  – Microturbine will provide a needed bridge prior to testing with commercial equipment

• MOHC Performance Evaluation
  – Calculate cycle performance
    • Cycle efficiency and turbine power output
      – Compare cycle performance with and without MOHC’s
        ▪ Dependence on low, medium and high source temperatures
        ▪ Evaluate MOHC’s solids loading influence on optimization

• Instrumentation Plan
  – Cycle state pressures and temperatures
  – Gas, hot and chilled water loop mass flow rate
  – Turbine power output measurement system
Accomplishments, Expected Outcomes and Progress

- **Milestones**
  - Demonstrate synthesis of at least one candidate MOHC at nanoscale, 3/31/2010 (Complete)
  - Complete physical and thermodynamic property measurements for at least one MOHC with multiple working fluids, 9/30/2010 (On Schedule)
  - Biphasic fluid test loop system operational performance tests complete, 3/31/2011 (Ahead of Schedule)

- **Performance Outcomes and Measures**
  - Demonstrate achievement of a minimum 15 wt% loading for at least one organic working fluid with at least one MOHC candidate material (Exceeded Performance Requirements)
  - Demonstrate at least 20% greater heat capacity of at least one biphasic fluid candidate (Complete)

- **Deliverables**
  - Issue journal article on synthesis and properties of MOHCs, 7/30/2010, (On Schedule)
  - Issue PNNL report on biphasic fluid test loop system design, development, and testing, 12/31/2010 (On Schedule)
Project Management/Coordination

- Project Management Plans
  - Managing press and business/venture capital interest in MOHCs technology has been the most significant and unexpected management challenge
    - Project has been highlighted in numerous technical magazines including: *Scientific American, Popular Science, Technology Review, Discover Magazine*
    - Over 100 business inquiries
  - MOHCs patent application filed

- Schedule
  - Project is either on or ahead of schedule in meeting all planned milestones and deliverables

- Application of Resources and Leveraged Funds
  - PNNL investments in microturbine and facility modifications to accommodate Ormat loaned equipment have been leveraged to accelerate and expand testing over original plan
• MOHC nanomaterials synthesized to date are meeting or significantly exceeding performance requirements in terms of mass loading and binding energies with selected working fluids

• Aggressive steps have been taken to accelerate cycle performance testing and leverage non-EERE funding opportunities for facilities and equipment support

• Submission of peer reviewed publications and presentations at technical conferences to occur shortly
Supplemental Slides