Key Technologies, Thermal Management, and Prototype Testing for Advanced Solid-State Hydrogen Storage Systems

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Overview: Project Details

Timeline
• Project start date: February, 2009
• Project end date: January, 2014
• % complete: 3% (Duration)

Budget
• Expected total project funding:
  • $3.195M (DOE)
  • $0.03M (Caltech)
• Funding received in FY08:
  • $0K (DOE)
• Funding received for FY09:
  • $0K (DOE)

Barriers/System Targets (2015)
• A. System Weight and Volume
  – 5.5 %wt_{sys}, 55 gH₂/kg_{sys}, 40 gH₂/L_{sys}
• C. Efficiency
  – 90% on-board/60% off-board
• D. Durability/Operability
  – <1% degradation @ 1500 cycles, etc.
• E. Charging/Discharging Rates
  – 3.3 min fill, 0.02 g/kW·s minimum full flow
• G. Materials of Construction
• H. Balance-of-Plant Components
• I. Dispensing Technology
• J. Thermal Management

Partners
• Caltech (subcontract)
Overview:
HSECoE Organizational Approach

- The organization of HSECoE is built around a modular, hierarchical concept based on Technology Areas/Teams/Tasks

- This organization will help HSECoE meet objectives by:
  - Maintaining effective tasking within a diverse team
  - Managing technology development in an emerging field
**Overview:**

**JPL’s Roles in HSECoE**

### Hydrogen Storage Engineering Center of Excellence

D. Anton, SRNL  
T. Motyka, SRNL

#### Materials Operating Requirements

- D. Herling, PNNL  
  - Materials Centers of Excellence Collaboration – SRNL, LANL, NREL  
  - Reactivity & Compatibility – UTRC  
  - Adsorption Properties – UQTR  
  - Metal Hydride Properties – SRNL  
  - Chemical Hydride Properties - LANL

#### Transport Phenomena

- B. Hardy, SRNL  
  - Bulk Materials Handling – PNNL  
  - Mass Transport – SRNL  
  - Thermal Transport – SRNL  
  - Media Structure - GM

#### Enabling Technologies

- J. Reiter, JPL  
  - Thermal Insulation – JPL  
  - Hydrogen Purity – UTRC  
  - Sensors – LANL  
  - Thermal Devices - OSU  
  - Pressure Vessels - PNNL

#### Performance Analysis

- M. Thornton, NREL  
  - Vehicle Requirements – NREL  
  - Tank-to-Wheels Analysis – NREL  
  - Forecourt Requirements - UTRC  
  - Manufacturing & Cost Analysis - PNNL

#### Integrated Power Plant / Storage System Modeling

- D. Mosher, UTRC  
  - Off-Board Rechargeable - UTRC  
  - On-Board Rechargeable – GM  
  - Power Plant – Ford

#### Subscale Prototype Construction, Testing & Evaluation

- T. Semelsberger, LANL  
  - Risk Assessment & Mitigation – UTRC  
  - System Design Concepts and Integration - LANL  
  - Design Optimization & Subscale Systems – LANL, SRNL, UQTR  
  - Fabricate Subscale Systems Components – SRNL, LANL  
  - Assemble & Evaluate subscale Systems – LANL, JPL, UQTR

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- **Technology Area Lead**  
- **Technology Team Lead**  
- **Technology Task Support**
Relevance:
*Milestones and Task Breakdown*

- JPL Task Plan, including milestones, deliverables, and Go/No-Go points (excerpted from HSECoE Proposal, 2009 Annual Operating Plan, or other materials where appropriate)
Approach:
JPL Task Area 1 - Adv. Technology Development

- JPL is the Technology Area Lead (TAL) for HSECoE’s “Enabling Technologies” strategic technology area (TA)
  - This will be a major effort, dedicated to facilitating the evaluation of key technologies that serve as particular challenges to prototype development
  - As for other Technology Areas within HSECoE, the work will be managed via the Technology Team Leads (TTLs) that will directly interface at the task-level in each case
  - Within each Team, any number of individual tasks may be required to reach objectives

- JPL will also perform as TTL for the “Thermal Insulation” task group, developing approaches for passive thermal management of the storage vessel, thermal devices, and balance-of-plant components of the prototype system

A breakdown of the “Enabling Technologies” TA is provided in the form of Quad Charts for each of the Technology Teams led by JPL and other Center Partners within this structure
## Approach:

### “Enabling Technologies” TAL Quad Chart

<table>
<thead>
<tr>
<th>Technology Area:</th>
<th>Enabling Technologies</th>
<th>Area Lead: J. Reiter, JPL</th>
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<tbody>
<tr>
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<td>March 2009 (v2)</td>
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### Objectives:

- Provides a framework for identifying and addressing technology gaps as well as incorporating new technologies into the Center
- Survey and evaluate existing state-of-art technologies for incorporation into Center design activities
- Provide capabilities as a “technology working group” throughout Center operation
- Identify and recommend approaches to technology development in an ongoing fashion in order to meet technical challenges in key areas

### Accomplishments:

### Key Milestones:

1. Develop technology flow diagram(s) and identify cross-cutting relationships within CoE (5/09)
2. Perform initial criteria evaluations, SOA surveys, gap identification and mitigation approach (8/09)
3. Perform initial testing against trade-space model results for key technologies (3/10)

### Issues:

- Will identify efficient collaborative methods for sharing progress quickly across team
- Must work closely with Center modeling teams/partners in order to accomplish some key goals
# Approach:

“Thermal Insulation” TTL Quad Chart

<table>
<thead>
<tr>
<th>Technology Area:</th>
<th>Enabling Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Team:</td>
<td>Thermal Insulation</td>
</tr>
</tbody>
</table>

Area Lead: J Reiter, JPL  
Team Lead: J. Reiter, JPL

March 2009 (v2)

## Objectives:
- Identify notional requirements, capabilities, and gaps for passive thermal management in storage systems
- Develop high-level trade space performance models \( f(\text{geometry}, \text{material}, \text{temperature}, \text{time}, \text{etc.}) \) as evaluative tool (interface with HSECoE modeling groups)
- Evaluate, recommend, and incorporate candidate approaches for engineered systems (full- and sub-scale)

## Objectives:

<table>
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<tr>
<th>Accomplishments:</th>
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## Key Milestones:
1. Draft CoE info flow/relationships (JPL) (5/09)
2. Complete initial SOA survey/lit search (JPL) (8/09)
3. Initial weighted trade space model results (JPL) (12/09)
4. Initial model validation experiments for MH system (JPL) (3/10)

## Issues:
- Identify model framework for trade space study
## Approach:

**“Hydrogen Purity” TTL Quad Chart**

<table>
<thead>
<tr>
<th>Technology Area: Enabling Technologies</th>
<th>Area Lead: J. Reiter, JPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Team: Hydrogen Purity</td>
<td>Team Lead: D. Mosher, UTRC</td>
</tr>
</tbody>
</table>

**March 2009 (v2)**

### Objectives:
- Develop system methods to improve discharged hydrogen purity / quality for acceptable PEM fuel cell durability.
- Establish procedures for assessing hydrogen purity – moderate level & PEM FC durability level.
- Collaborate with material CoEs to identify existing purity data / concerns & gaps for future testing.
- Evaluate and advance separation method concepts (gas/gas and gas/particulate).
- Incorporate top separation candidate(s) into storage system designs.

### Accomplishments:

### Key Milestones:
1. Determine current purity concerns in materials CoE and select top 2 to 3. (All) (6/09)
2. Compare initial evaluations of separation approaches. (All) (12/09)

### Issues:
- Confirm partner differentiation / roles
  - UTRC: composite Pd membranes
  - HSM: polymer membranes
  - SRNL: metallic membranes
  - TBD: molecular sieves & adsorbants.
- Measurement: LANL & PNNL
- PEM FC can be affected by very low levels of impurities.
- Storage materials & impurities are TBD; performance of some separation methods can be highly influenced.
### Approach: “Sensors” TTL Quad Chart

**Technology Area:** Enabling Technologies  
**Technology Team:** Sensors  

**Area Lead:** J. Reiter, JPL  
**Team Lead:** E. Brosha, LANL  
March 2009 (v2)

<table>
<thead>
<tr>
<th>Objectives:</th>
<th>Accomplishments:</th>
</tr>
</thead>
</table>
| • Identify and evaluate novel devices and methods and for storage system instrumentation (SOC, fluidic, thermal, structural, etc.)  
• Interface with other CoE TAs as necessary for engineering impact of sensor devices (compatibility, etc.)  
• Recommend sensor technologies and instrumentation approaches for engineering design (full- and sub-scale) | |

<table>
<thead>
<tr>
<th>Key Milestones:</th>
<th>Issues:</th>
</tr>
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</table>
| 1. Identify initial criteria matrix: data type, technology class, etc. (LANL) (5/09)  
2. Complete initial SOA survey/lit search (LANL) (8/09)  
3. Provide candidate list for SOC sensors (LANL) (12/09) | • Need to identify additional collaborators/contributors  
• Must be able to rapidly evaluate sensor technologies across a broad tech base by evaluating literature search results |
## Approach:

**“Thermal Devices” TTL Quad Chart**

**Technology Area:** Enabling Technologies  
**Technology Team:** Thermal Devices

**Area Lead:** J. Reiter, JPL  
**Team Lead:** K. Drost, OSU

March 2009 (v3)

### Objectives:

- Evaluate novel heat exchange/transfer technologies and devices required for operation of an H₂ storage system
- Identify/develop tools for assessing performance and fitness of candidate technologies and devices (mass, volume, power, cost, complexity)
- Evaluate, recommend, and incorporate candidate devices for engineered systems (full- and sub-scale)
- Provide ongoing evaluative capability for emergent technologies/requirements

### Accomplishments:

### Key Milestones:

1. Compile initial list of potential implementations (All) (5/09)
2. Complete initial SOA survey/lit search (All) (8/09)
3. Initial weighted trade space model results (SRNL) (12/09)
4. Initial model validation experiments (OSU, JPL) (3/10)

### Issues:

- Must develop an understanding of scale issues with regard to thermal performance at an early stage in the scoping study
## Approach:

**“Pressure Vessels” TTL Quad Chart**

### Technology Area:
- Enabling Technologies

### Technology Team:
- Pressure Vessels

### Area Lead:
- J. Reiter, JPL

### Team Lead:
- K. Simmons, PNNL

### March 2009 (v2)

### Objectives:
- Develop tank designs for retaining storage material structured beds: Absorber (cryogenic), Metal Hydride (pressurized); Chemical hydride (ballast)
- Develop model(s) and evaluate designs for cylindrical and conformal tank concepts
- Assess manufacturability and assembly w/ or w/o integrated thermal management (i.e. heat exchange function), including open/split tank designs
- Identify and test novel resin/fiber/liner systems
- Build and assemble prototype tanks

### Accomplishments:

### Key Milestones:
1. Establish modeling approach and platform(s) (All) (6/09)
2. Determine basic operational parameters (boundary conditions) for each system (PNNL, Lincoln) (9/09)
3. Complete initial design concept analysis w/o internal thermal management function (All) (12/09)

### Issues:
- Availability of high strength low cost fibers
- Toughened resin systems that cures below the liner softening point
- Material compatibility
- Install/recharge tank
- Disposition of draft US standards for H₂ storage vessels
Approach:
JPL Task Area 2 - Media/Material Evaluation

• JPL has a role in the evaluation of material properties under the Technology Area led by Center Partner PNNL
  – Within the context of compatibilities, reactivities, and the engineering properties of candidate materials, JPL can contribute assessments and expertise

• Close collaboration with SRNL, UTRC, and other CoE partners to respond to assessment needs, especially as they shift (Phase 1/2)
  – Some direction from DOE/CoE expected regarding this effort

• Will assess relevant data regarding issues relating to safety, risk, compatibility, etc. as R&D requirements drive the “feedback loop”

• May leverage expertise with metal/complex hydrides as well as hydrogen sorption materials via collaboration with Caltech
Approach:
JPL Task Area 3 - Thermal Modeling & Validation

• JPL will utilize current in-house modeling capabilities to support overall Center activities to evaluate and predict heat-exchange (HX) characteristics of component designs
• SINDA/FLUINT model platform with custom capabilities (charging/discharging, non-equilibrium PCT curves, H2 flow enthalpy accounting, alloy properties, etc.)
  – Originally developed during engineering activities within the Metal Hydrides Center of Excellence (MHCoE)

• Activity includes capabilities for model/sub-model validation via bench-testing of discrete HX/MX components made at JPL with rapid turnaround
  – Can provide validation paths for models developed either at JPL or by other Center Partners
• This is a gated activity; a Go/No-Go milestone exists in Phase 2 for downselecting candidate approaches based on their performance
  – Criteria and candidate list is expected to evolve based on Phase 1 milestoneing
Approach:
JPL Task Area 4 - Prototype Concept Engineering

- Activity focuses on metal/complex hydride and hydrogen sorption systems

- JPL will collaborate with LANL as Technology Area Lead and other Center Partners in Phase 2, in advance of overall DOE/CoE downselect

- Will provide system engineering support:
  - Scale optimizations for candidate system approaches, as well as component designs
  - Risk assessment studies (construction, assembly, test, operation, etc.)
  - Propose risk mitigation in advance of system concept downselect

- Will contribute much of the output of the Enabling Technologies team toward assisting DOE and the Center with the Phase 2 system concept downselect; *much of this activity will be in an emergent/evolving mode*
Approach:
JPL Task Area 5 - Prototype Testing and Evaluation

• This activity is JPL’s main role in Phase 2/3 and supports the entire Center
  – Presupposes the selection of a metal-hydride based prototype demonstrator, although some contributions may be made in the event a sorption system is still selected

• Utilizes a currently active fabrication/testing/characterization laboratory at JPL with available space for ~2 test-stands
  – Hydrogen Storage Engineering Laboratory (HSEL)

• Tasks aligned under this objective are currently scoped to run from Q2FY2012 through Q4FY2013; i.e., 1.5y +

• Selected subtasks:
  – Develop test procedures and test safety plan
  – Build test stand, develop test software
  – Assemble system/fill/closeout hydride storage vessels
  – Integrate system with test facility
  – Analyze and disseminate data
  – Disposition storage prototype at conclusion of testing
Accomplishments

• JPL HSECoE effort is organized and off to a successful start

• Center Kick-Off Meeting held in Washington DC (12/08)

• Tech Team Meeting attended by Center Partners in Washington DC (12/08)

• Initial Center Face-to-Face Meeting held in Golden, CO (2/09)

• JPL Task Plan and draft milestones completed for Phase 1; “100-day” scope finalized during F2F meeting
Proposed Future Work

• JPL efforts on Thermal Insulation task are already underway; the next steps are to complete initial state-of-art assessments and propose approaches to gap determination and mitigation

• Define communications plan and information flow for “Enabling Technologies” TA, as compelled by 100-day plan; obtain initial status of collaborating Center Partners in charge of sub-Teams

• Determine current status of SINDA modeling/validation effort as originally put “on-hold” during the cessation of engineering “Task E” under MHCoE, and adopt plan forward for model efforts during HSECoE Phase 2