# IV.D.1f Key Technologies, Thermal Management, and Prototype Testing for Advanced Solid-State Hydrogen Storage Systems

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## Objectives

- Develop and apply an understanding of storage system requirements for light-duty vehicles.
- Develop innovative on-board system concepts for materials-based storage technologies.
- Develop and test innovative concepts for storage subsystems and component designs.
- Develop multi-level engineering models to address storage subsystem and fuel cycle.
- Design, fabricate, and test subscale prototypes for each material-based technology.

## Technical Barriers

This project addresses the following technical barriers from the Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan (referenced to 2015 targets, as revised 2009):

(A) System Weight and Volume: 5.5 $\%wt_{sys}$, 55 $gH_2/kg_{sys}$, 40 $gH_2/L_{sys}$

(C) Efficiency: 90% on-board/60% off-board

(D) Durability/Operability: <1% degradation @ 1,500 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 (BOP) Components

(I) Dispensing Technology

(J) Thermal Management

## Technical Targets

Regarding the technical barriers addressed by JPL's activities within the Hydrogen Storage Engineering Center of Excellence (HSECoE), the main areas that would be the focus of technical efforts would be the nature of Thermal Management, Balance of Plant Components, and Durability/Operability; the last of these will be evaluated directly by a phased effort of testing and analysis at JPL.

## Accomplishments

It should be noted that complete Fiscal Year 2009 funding for HSECoE efforts at JPL was not received/available until September 2009. The immediate impact of this delay was of course the inability to make any progress in earnest for the entirety of the period covered by this report. Any achievements listed in this section have been funded so far via JPL-internal sources and/or accomplished in parallel with other DOE-funded activities at JPL. For example, JPL attended the 2009 Annual Merit Review as a participant in the Metal Hydrides Center of Excellence (MHCoE), a parallel effort, while also providing a poster presentation citing HSECoE progress under this effort.

- HSECoE kick-off meeting held in Washington, D.C. (12/08). Although this meeting and subsequent organizational efforts took place outside the scheduled HSECoE period (start: 2/09), the result was significant, as it allowed a key re-scope of the proposed HSECoE approach. JPL attended this meeting via teleconference.
- Tech Team meeting attended by HSECoE partners in Washington, D.C. (12/08).
- Initial HSECoE face-to-face meeting held in Golden, CO (2/09). During this meeting, considered the "official" start to DOE-funded HSECoE activities, the concept of technology areas/teams/tasks was finely tuned. Important teaming activities were accomplished between JPL and HSECoE partner Oregon State University (OSU) in the area of novel heat-exchange devices; the "thermal devices" technology area was created. JPL's task plan and draft milestones completed for Phase 1; "100-day" scope finalized during face-to-face meeting.

- HSECoE face-to-face meeting held in Arlington, VA, during the DOE Annual Merit Review (6/09).

## Introduction

Activities at the JPL under the auspices of DOE's HSECoE have been designed to contribute to the development of advanced automotive solid-state hydrogen storage systems that meet or exceed the DOE/FreedomCAR technical targets for on-board hydrogen storage. JPL performs in several different roles in the HSECoE; the present effort at JPL is divided into several tasks:

- **Advanced Technology Development.** JPL has a lead role in the HSECoE as a Technology Area Lead (TAL) in the area of "Enabling Technologies". This role encompasses the coordination of other partners in the development of technologies for novel thermal devices, fuel sensors, pressure vessels, and gas purity and separation. In addition, JPL has a direct charge under this task of evaluating and developing technologies for passive thermal management for the hydrogen storage system, in both cryogenic and elevated temperature regimes. This role will extend through the entirety of the HSECoE's duration, and involves collaborations with a majority of the HSECoE's partners and a responsibility at the HSECoE Coordinating Council level.
- **Material/Media Evaluation**. As led by Center partner Pacific Northwest National Laboratory (PNNL), JPL will contribute to the evaluation of compatibilities, reactivities, and the engineering properties of candidate metal hydride materials. A subcontract with Caltech will allow assistance with evaluation of hydrogen sorption materials.
- **Thermal Modeling & Validation.** JPL will provide support by preparing and testing thermal hardware as validations of thermal models prepared by other HSECoE partners; this effort will be led by partner Savannah River National Laboratory (SRNL). This testing/validation will be performed at JPL on the "benchtop" and will be in collaboration with other partners.
- **Prototype Concept Engineering.** During the development of the prototype storage system(s) for the various material storage concepts, JPL will provide engineering expertise and oversight in various areas, including but not limited to mechanical design, thermal efficiency, system engineering, control and data acquisition, and materials compatibility. This task are will be led by HSECoE partner Los Alamos National Laboratory (LANL).
- **Prototype Testing and Evaluation.** JPL will be responsible for the design, construction, and operation of the test stand used for evaluating the subscale prototype storage system based on metal hydride materials, as well as for the final assembly of the prototype itself. JPL will also acquire, reduce, and analyze the data from the prototype and prepare summary reports. This task is the largest portion of JPL's contribution to the HSECoE, and will be led by LANL.

By means of this breakdown, JPL plans to mix management and direct engineering in a three-phased project of roughly 1.5 years per phase. The nature of technology development implies that much of this effort is being accomplished in an "emergent" manner, allowing for changes to scope, approach, and technology basis. The HSECoE's TAL structure is designed to account for this type of operation.

## Approach

JPL's participation in the HSECoE comprises a broad sweep of activities, balanced between technology management on one hand and active research and development on the other. In the latter case, JPL relies on in-house expertise in the areas of thermal engineering, systems design, and hydrogen storage system testing and evaluation. The overall approach involves well-organized and managed communication pathways and closed loops among the other HSECoE partners collaborating with JPL as well as with the HSECoE lead at SRNL. This management approach has a distinctive gestalt derived from the nature of the *Technology Area* concept, wherein key HSECoE partners – including JPL – are responsible for sub-management and direction of agile technical teams, each charged with a particular task in the engineering scope. Figure 1 illustrates this principle. JPL, in this structure, is responsible – via its own work as well as the work of the partner organizations managed within the "Enabling Technologies" technology area – for shepherding the development of key technologies considered necessary for the design and operation of a successful hydrogen storage system.

HSECoE is a widespread effort technically, geographically, and with regard to expertise. JPL maintains a central cognizance within the HSECoE by virtue of its status as a TAL, working closely with HSECoE partners SRNL, LANL, PNNL, and United Technologies Research Center, as well as with OSU, General Motors, Ford, and, via subcontract, Caltech.

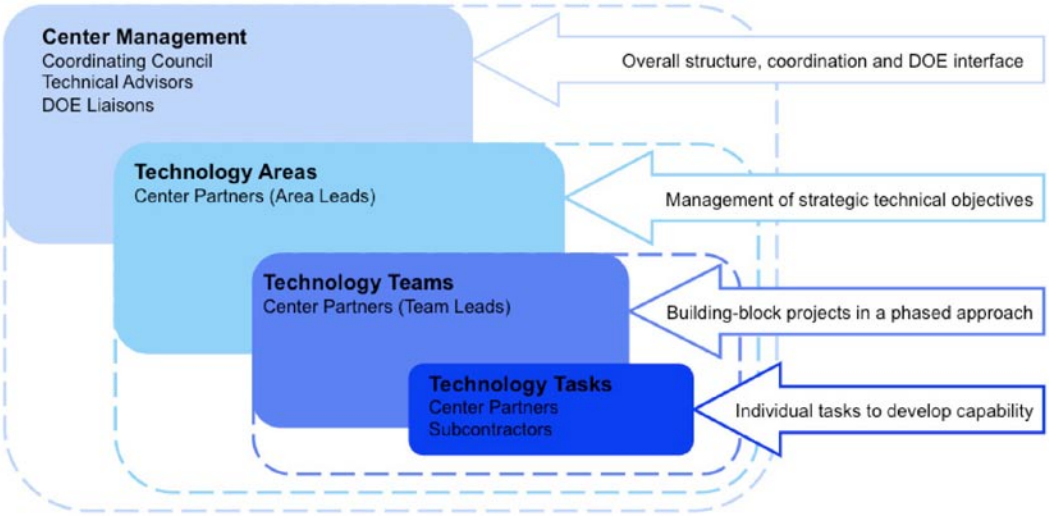


**FIGURE 1.** Graphic representation of the Technology Area concept, showing the flow-down and up-reporting paths as well as hierarchical responsibilities within the HSECoE. In this structure, JPL has cognizance at the Area, Team, and Task level.

## Results

As stated above in *Accomplishments*, difficulties with direct funding from DOE have prevented any significant progress during FY 2009. Nevertheless, JPL has been able to accomplish important organizational and management goals, allowing work within the Enabling Technologies TAL to progress, mostly by virtue of the excellent efforts of the HSECoE partners charged with the technical work. In addition, JPL has a vested interest in adding value to HSECoE in order to "make up" for lost time; see *Conclusions* below for specific means by which JPL plans to infuse additional technical accomplishments into future HSECoE efforts.

## Conclusions and Future Directions

As currently planned, the HSECoE project will be continuing through early 2014; however, the uncertainty raised by recent Federal budget discussions has led the HSECoE Coordinating Council to discuss an alternate scope for completing work in FY 2009. As a result, much of the planning is centered on creating a "technology footprint", writing white papers and summarizing the progress of technical and management efforts this far. With this in mind, JPL has considered several near-term goals that will likely be achievable; indeed, now that FY 2009 funding for JPL's effort is available, rapid progress may be made. There are several broad areas in which JPL plans specific accomplishments:

- JPL efforts on its Thermal Insulation task are now underway; the first steps are to complete initial state-of-the-art assessments and propose approaches to technology gap determination and mitigation.
- During FY 2009, several alternate activities were undertaken at JPL in the area of hydrogen storage system design; these activities ranged from internally-funded research and development "seed" projects to proposal-type designs of working systems. If HSECoE efforts proceed, JPL plans to make efforts to merge its accomplishments in these independent areas into HSECoE as much to gain ground lost during budget downtime as to potentially enhance JPL's value to both HSECoE and DOE.
- Define communications plan and information flow for "Enabling Technologies" technology area, as compelled by 100-day plan; obtain initial status of collaborating HSECoE partners in charge of sub-teams.
- Determine current status of Systems Improved Numerical Differencing Analyzer modeling/validation effort as originally put "on-hold" during the cessation of engineering "Task E" under the MHCoE, and adopt plan forward for model efforts during HSECoE Phase 2.
- Discuss options for publication, either in refereed journals or direct to DOE for archival purposes, should HSECoE be placed on-hold in FY 2010 due to current Federal budget constraints.