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

Joseph W. Reiter (Primary Contact),
Alex Raymond, Jason A. Zan,
Channing C. Ahn (Caltech)
Jet Propulsion Laboratory (JPL)
4800 Oak Grove Drive, Mail Stop 79-24
Pasadena, CA 91109-8099
Phone: (818) 354-4224
E-mail: Joseph.W.Reiter@jpl.nasa.gov

DOE Technology Development Manager:
Monterey Gardiner
Phone: (202) 586-1758
E-mail: Monterey.Gardiner@ee.doe.gov

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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 Hydrogen Storage section of the Fuel Cell 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 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

The efforts at JPL during the previous year have centered on a technology development role in the Enabling Technologies area of the Center, specifically the identification, analysis, and characterization of thermal insulating materials for hydrogen storage systems. This effort will extend into Fiscal Year (FY) 2011, featuring the testing of thermal materials in order to inform the modeling/validation effort ongoing within the Center.

JPL has also taken on the role of System Architect for Adsorbent System technology development. In this role, JPL provides oversight and coordination of the various technology areas within the Center that have responsibility for developing credible paths toward satisfying the DOE hydrogen storage targets (2010/2015/ultimate). JPL will also have direct responsibility for a notional "system engineering" role, providing guidance and oversight for conceptual system design.

Specific Accomplishments:

- Initial "insulative materials" database has been developed and deployed within the Center; database contains thermal performance parameters, mass, volume, and cost where possible. Candidate materials continue to be added as they are identified, or as potential vendors/technologies are found.
- Preliminary plans for a low-k material thermal characterization facility are complete; this facility will be used to fully characterize candidate insulative materials across a large temperature range; the potential also exists for this facility to be

used to analyze the thermal characteristics of bulk hydrogen storage materials, especially cryosorbents. The facility will be hosted in JPL's Hydrogen Storage Engineering Laboratory.

- JPL hosted the Center's Face-to-Face Meeting 4 in Pasadena, CA (March, 2010). This meeting solidified the System Architect roles and reviewed the first calendar year of Center activity (start date February, 2009). Crucial teaming activities were accomplished between JPL and other Center partners; first high-level system designs shown and preliminary performance numbers reviewed.

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Introduction

Activities at 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 Center; the present effort at JPL is divided into several tasks:

- **Advanced Technology Development.** JPL has a lead role in the Center as a technology area lead 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 Center's duration, and involves collaborations with a majority of the Center's partners and a responsibility at the center coordinating council level.
- **System Architect/System Engineer.** JPL provides technical guidance and engineering oversight to the Adsorbent System design team in its Center role as System Architect/System Engineer. Additionally, and in coordination with the Center's conceptual design effort, JPL will provide assistance with overall system design, component selection, and design review for the adsorbent system, especially as it applies to cryogenic system design and operation.
- **Material/Media Evaluation.** JPL is contributing to the evaluation of the engineering properties of candidate hydrogen storage materials. A subcontract with Caltech allows assistance with evaluation of hydrogen sorption materials (cryosorbents).
- **Thermal Modeling & Validation.** JPL will provide modeling support to the Center via parametric and other types of analysis for hydrogen storage systems. This effort includes thermal/thermodynamic/performance modeling of cryogenic storage vessels and associated hardware, both specific to and independent of storage material type. This task is integrated into the overall Center modeling effort. JPL will collaborate with partners Savannah River National Laboratory (SRNL) and United Technologies Research Center (UTRC). This task may involve validation of model results via bench-top testing of novel designs and configurations.
- **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 will be led by Center 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 Center, and will be led by LANL.

Via the task breakdown summarized here, JPL will mix management and direct engineering in a three-phase project of roughly 1.5 years per phase. Much of this effort is being accomplished in an "emergent" manner, allowing for changes to scope, approach, and technology basis. The Center's technology area lead structure is designed to account for this type of operation.

Approach

Within the HSECoE, JPL's participation covers a wide variety of tasks and activities, spanning technology management and active research and development. In the latter case, JPL relies on in-house expertise in the areas of thermal engineering, cryogenic system design, systems engineering, and hydrogen storage system testing and evaluation. The overall approach involves well-organized and managed communication pathways and closed loops among the other Center partners collaborating with JPL as well as with the Center lead at SRNL. This management approach is built around the technology area concept, wherein key Center partners

– including JPL – are responsible for sub-management and direction of agile technical teams, each charged with a particular task in the engineering scope. Within this structure, JPL 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.

The Center has also developed the System Architect model for managing the development and configuration of individual storage system designs; as such, there are three Center partners responsible for the guidance and oversight of the design teams assigned to the metal hydride design, the cryo-adsorbent design, and the chemical hydride design, respectively. JPL is the Center partner responsible for the adsorbent system overall design and architecture. The System Architect relationship to the Center is as a matrix organization, utilizing the analytical products of the technology areas in order to reach a system design that credibly satisfies the appropriate DOE Hydrogen Storage targets. This relationship is illustrated schematically in Figure 1.

HSECoE is a widespread effort technically, geographically, and with regard to expertise. JPL maintains a central cognizance within the Center by virtue of its status as an System Architect and technology area lead, working closely with Center partners SRNL, LANL, Pacific Northwest National Laboratory, and UTRC, as well as with Oregon State University, General Motors, Ford, and, via subcontract, Caltech.

Results

Key results of the work during the reporting period are summarized as follows:

- Insulative materials literature/vendor search has resulted in the categorization of potential materials by temperature range (elevated, ambient, and cryogenic) and material type (rigid, blanket, loose-fill). Such materials are considered "physical" or "bulk" insulation, typified by low thermal conductivity and (occasionally) low density. Considering as an example a design for storing a cryogenic (77 K) material, performance of these insulators would be compared to the "standard" approach of using multi-layer vacuum insulation, with regard to cost, mass, and volume. A first-step algorithm for measuring performance in this way has been developed.
- Key material parameters for solid-aerogel insulation has been obtained internally from JPL where this material is manufactured. These parameters have been included in initial scoping models of tank/storage vessel thermal performance, but data are required for radiative transmissivity and temperature-dependent thermal conductivity data. The means to acquire this information for aerogel and other insulative materials is being developed at JPL in the form of a novel test facility.

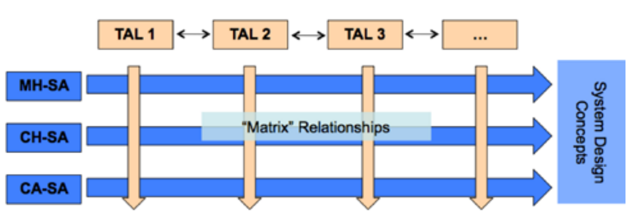

FIGURE 1. Graphic representation of the System Architect concept, showing the flow-down and cross-reporting paths as well as hierarchical responsibilities within the Center. This concept maintains the goal of aligning notional system design concepts with the overall storage targets as set by DOE.

Conclusions and Future Directions

The overall HSECoE effort will be continuing through early 2014. At the time of this writing, Center efforts are focused on the near-term goal of demonstrating the performance of several conceptual systems against the 2010 DOE Storage targets; a Center-wide milestone for this achievement is set for the end of the second quarter of FY 2011. With this in mind, there are several broad areas in which JPL plans specific accomplishments:

- Additional physical/bulk insulative materials will be added into the Insulative Materials Database, which continues to be available internally to the Center. It is planned that the database, along with analytical tools, results, and general metrics, will be made publicly available at some point in the future.
- The low-k material thermal characterization facility will be brought on-line and used to validate literature values for several candidate materials in the database. In addition, the facility will allow JPL to acquire temperature-dependent data for these materials, which in many cases is not otherwise available elsewhere. The facility will also be used to directly validate the thermal material properties of storage materials; superactivated carbon and certain candidate metal-organic frameworks are good examples of such materials. Figure 2 shows the current status of the hardware being assembled for this effort.
- Initial scoping models for determining thermal performance of the storage vessel will be integrated into the Center model framework. The models will address issues for cryogenic vessels such as low-temperature dormancy, parasitic heat loads, and passive thermal design approaches. These models will initially be designed for the cryo-adsorbent

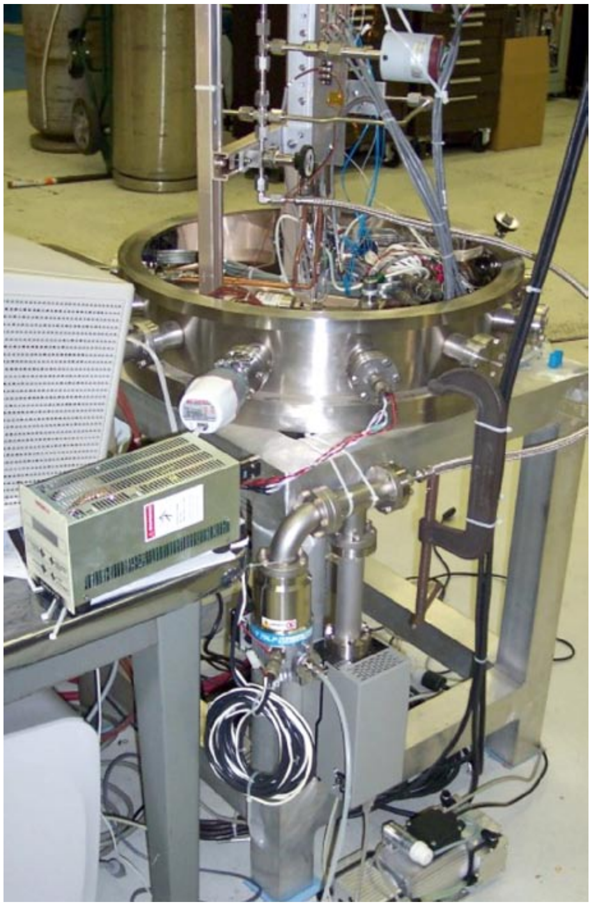

FIGURE 2. In-process photo of the hardware being assembled for the low-k material thermal characterization facility being developed for testing/validation of both insulative materials and low-temperature storage materials. The facility will be a JPL/Center asset capable, for example, of obtaining temperature-dependent data from low-conductivity materials.

system, but will be extensible for the metal hydride and chemical hydride systems as well. Parametric data from the insulative materials search/analysis will feed directly into this effort.