Development of a Compressed Hydrogen Gas Integrated Storage System (CH2-ISS) for Fuel Cell Vehicles

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Objectives

Advance the technology elements required to develop a semi-conformal, Compressed Hydrogen Gas Integrated Storage System (CH2-ISS) for light-duty fuel cell electric vehicles (FCEV) by conducting engineering research as follows:

- Develop materials and treatments to reduce hydrogen gas permeation through tank liners
- Develop an optimized carbon fiber/epoxy resin tank overwrap to support storage tank design with improved gravimetric energy density construction
- Determine alternative methods and materials for manufacture of the integrated storage system

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Cost
- B. Weight and Volume
- H. Sufficient Fuel Storage for Acceptable Vehicle Range
- I. Materials
- K. Balance-of-Plant (BOP) Components

Approach

- Develop baseline CH2-ISS design consistent with packaging and driving range requirements
- Develop tank liner materials and surface treatments and measure hydrogen gas permeation
- Build and performance test all-carbon overwrap tanks with alternative toughened epoxy resin formulations
- Evaluate alternative materials and designs for production of the ISS shell and unitary gas control module
- Develop CH2-ISS vehicle packing interface design for notional FCEV applications

Accomplishments

- Continued evaluation of low permeation tank liner materials and developed a test unit for accurately measuring gas permeation

- Continued work on improving tank gravimetric energy density through development of toughened epoxy resins
- Continued evaluation of alternative materials for constructing the CH2-ISS outer shell; purchased material coupons and developed preliminary design of test fixture
- Continued work on the unitary gas control module (UGCM); downselected one of two alternative designs for prototype development
- Initiated storage system-vehicle interface technology task; developed idea of storage-to-vehicle attachment system (Crash Management System) that both preserves vehicle "crumple zone" while reducing impact load to the storage unit; established CH2-ISS size and operating pressure to support FCEV with 300+ mile driving range

Future Directions

- Build and evaluate performance of storage tanks with improved gravimetric energy density
- Conduct flammability and impact tests on alternative CH2-ISS outer shell materials; select optimum
- Design, build, test and evaluate unitary gas control system
- Design the CH2-ISS with sufficient fuel storage for 300+ mile driving range
- Detail storage-to-vehicle interface Crash Management System design

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Introduction

The storage of compressed hydrogen gas (CH2) poses challenges in the areas of relatively low energy density, system cost, crashworthiness, and vehicle packaging. A solution to these challenges is offered by the Integrated Storage System (ISS) technology (U.S. Patent No. 6,257,360 issued July 2001) jointly developed by Johns Hopkins University Applied Physics Laboratory (JHU/APL) and General Dynamic Armaments and Technical Products (GDATP) (formerly Lincoln Composites). Under DOE Cooperative Agreement DE-FC36-01G011003, the ISS technology is being advanced to support development of a 5,000 and/or 10,000 psi service pressure semi-conformal gas storage system that provides sufficient fuel storage for 300+ mile driving range without impacting passenger and cargo space or compromising vehicle safety, and that is able to be mass produced at DOE target storage cost.

Approach

ISS uses Type IV all-composite tanks constructed with a high-density polyethylene (HDPE) thermoplastic liner structurally overwrapped with carbon fiber and epoxy resin. The tanks are encapsulated within a high-strength outer shell unitizing the individual cylinders into a single container and providing protection from environmental exposure. Additional physical protection of the tanks is provided by urethane foam surrounding the tank dome region (location of highest stress concentration during impact). A unitized gas control module (UGCM) is incorporated into the ISS package and provides all necessary gas flow control and safety features. Figure 1 is a

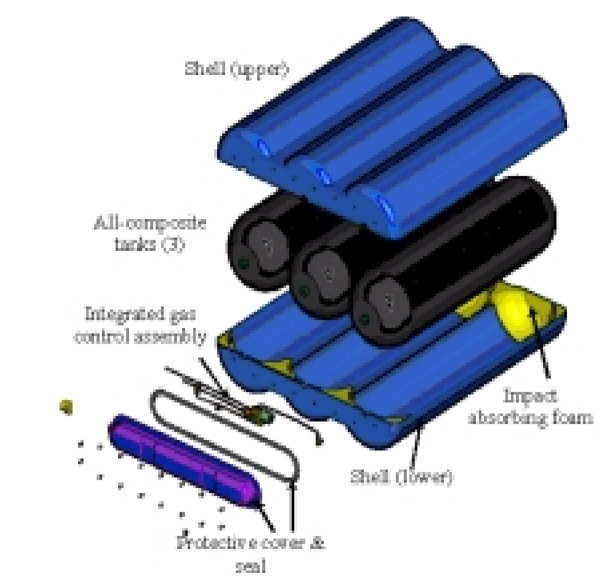

Figure 1. Assembly View of the CH2-ISS

computer-aided design (CAD) image of the CH2-ISS design. The objective of the DOE Cooperative Agreement is to advance the technologies needed to support developing and safety certifying a CH2-ISS.

There are five specific tasks: (1) HDPE treatment and alternative tank liner materials for hydrogen gas permeation reduction; (2) epoxy resin toughness enhancement to improve tank gravimetric energy density; (3) materials and process evaluation for manufacturing the ISS protective shell; (4) engineering of an optimized unitary gas control module; and (5) development of vehicle interface technologies to support storage system packaging requirements and system crashworthiness objectives. Within the timeframe covered in this report, JHU/APL had only received 35% of DOE committed FY 2003 funding. The progress reported herein therefore represents only approximately 35% of the plan activities. As a result of the delayed commitment of funds, the completion date for FY 2003 tasks was negotiated to March 31, 2004.

Results

Task (1): ISS uses Type IV high-pressure gas storage tanks constructed with a thermoplastic liner overwrapped with carbon fiber and epoxy resin. The liner serves as a permeation barrier, mechanical interface to aluminum bosses, and a stable mandrel for the filament winding process. The main focus of the permeation task has been to quantify and control the hydrogen gas permeation rate through the thermoplastic liner. In addition, two alternative secondary seal designs at the plastic liner/metal boss interface were explored. To accurately measure gas permeation, GDATP developed a test unit. This unit utilizes a hydrogen mass spectrometer in combination with a 2500 L vacuum chamber. A mass spectrometer as the instrument of measurement provides real-time data acquisition and evaluation. Permeation testing to date has been performed using a non-flammable 5% H_2 / 95% N_2 (by volume) gas composition. A proprietary surface treatment on the existing HDPE (High Density Polyethylene) lined tanks reduced permeation by 80% compared to the untreated HDPE. Two alternative proprietary liner materials were also tested, and they showed a 90% reduction in the permeation rate over untreated HDPE. More materials have been prepared but had not been tested at the time of this report.

Task (2): Decreasing tank weight (to improve gravimetric density) and reducing tank fabrication cost are key technology advancement goals. In FY 2002, GDATP established that increasing epoxy resin toughness with toughening agents formulated into GDATP's standard resin led to successful gunfire test for an all-carbon fiber overwrap at a 2.25 factor of safety (FOS) design. However, the specific toughening agents tested also modified the resin by lowering its glass transition temperature (impacting tank service temperature) and increasing its viscosity (impacting the tank winding process). Despite these shortcomings, the work was very encouraging and led to the hypothesis that if the right additive(s) was found, tanks could be manufactured without any loss in performance or higher fabrication cost. In addition, further tank weight reduction might be achieved if built with a factor of safety less than the regulatory 2.25 minimum. Current federal and international standards for Type IV tanks dictate the minimum allowable factor of safety 2.25. The minimum FOS was derived by industry and the government for natural gas vehicle tanks and accounts for material and manufacturing variations and physical/environmental abuse tolerance. In the ISS application, the tanks are fully protected by an unstressed outer shell and impact protection foam; consequently, the 2.25 FOS may not be needed to field a fully safe system. To explore this, we are embarking on a systematic examination of modern epoxy resin toughening agents and screening them for their effect on toughness, tank service temperature, the tank winding process, cost and other factors. During this reporting period, plans have been developed to have Dr. Giuseppe Palmese at Drexel University perform the resin screening study. There was insufficient DOE funding, in the timeframe covered by this report, to initiate the resin study.

Task (3): The ISS uses a high-strength, lightweight shell/cover in conjunction with flexible urethane impact-absorbing foam to encapsulate and protect the individual tanks into a single unitized container. In FY 2002, a manufacturing study was performed addressing alternative means for constructing, at low-cost and in high volume, the CH2-ISS outer shell and protective cover. The study identified a number of candidate materials and manufacturing processes used for high volume automotive reinforced plastic parts. These included compression molding with sheet molding compound

(SMC), structural reaction injection molding (SRIM), injection molding, and resin transfer molding (RTM). Both SMC and SRIM were determined to be good candidates. There remained, however, issues of part strength in the required bonfire test and impact strength for the drop test, that needed to be fully answered before making the final selection. To that end, material coupon tests are planned, and representative SMC and SRIM coupons were purchased. A special coupon test fixture is being devised that incorporates a load applied to the shell coupons under the conditions of the bonfire test simulated with heat lamps. Load bearing capability and qualitative condition of the coupons will be used to assess the results of the test for each sample. There was insufficient DOE funding, in the timeframe covered by this report, to initiate the test panel testing.

Task (4): The CH2-ISS is treated as a single, inseparable container, requiring only one manual service valve, one solenoid, and one thermally activated pressure relief device (PRD), all incorporated into a unitary gas control module (UGCM). The added cost and complexity of redundant components when using multiple separable tanks in a vehicle installation is avoided by this approach. The gas control system is safeguarded from physical damage with impact absorbing foam within a high-strength protective cover. In FY 2002, two alternative UGCM notional designs were developed with differing approaches to transferring heat, from a potential under-vehicle fire, to the thermally activated PRD. In FY 2003, work continued with particular focus on system crashworthiness, and the heat pipe option of heat transfer was selected as the safest design. For added safety, the UGCM design was refined to eliminate hard-mounting to a tank for added crashworthiness isolation. A non-disclosure agreement was established between JHU/APL and Circle Seal Inc. to allow interface information to be shared for commercial off-the-shelf component integration into the UGCM. There was insufficient funding available over the timeframe covered by this report to start work on finalizing the UGCM design and building a prototype unit for service, safety and reliability testing.

Task (5): With the need to develop FCEVs with driving ranges comparable to today's ICE (internal combustion engine) vehicles, work began on a vehicle interface technology task to explore options to increase hydrogen capacity at practical temperatures and pressures without compromising cargo and passenger space. The focus of this work has been a point design on a class of light-duty vehicles (i.e., car-based sport utility vehicles) to increase space in the vehicle under chassis to house a larger capacity CH2-ISS unit, without impacting passenger or cargo volume or reducing ground clearance, all while notionally meeting vehicle crashworthiness goals. The point design study led to the idea of a breakaway, four-bar linkage Crash Management System (CMS) to secure the CH2-ISS and to tip and guide the unit into the under carriage in the event of a high-speed rear end collision. This is done to preserve the all-important vehicle "crumple zone," thus protecting the passengers, and to control the impact energy imparted to the CH2-ISS to reduce the likelihood of physical damage. A patent disclosure for the CMS concept was developed and filed. A scaling analysis was performed that included the parameters of storage unit size and service pressure. The analysis showed that the 300+ mile driving range goal is possible with a properly sized and packaged CH2-ISS unit while meeting all other vehicle utility and safety objectives.

Conclusions

Some progress has been made in developing a high energy density, near-rectangular, safety-certified and affordable container for the onboard storage of compressed hydrogen gas for use in fuel cell electric vehicles. The work has focused on hydrogen tank gravimetric energy density improvement and permeation reduction, refining the design of a unitary gas control module and exploring means of achieving driving ranges comparable to today's vehicles without compromising vehicle utility or safety. Due to the slow dispersion of DOE funding, the FY 2003 planned work will not be completed until the revised phase completion date of March 31, 2004.

FY 2003 Publications/Presentations

1. "Development of a Compressed Hydrogen Gas Integrated Storage System (CH2-ISS) for Fuel Cell Vehicles - Peer Review Presentation CD/ ROM Report", May 20, 2003