VI.E.2 Advanced Concepts for Containment of Hydrogen and Hydrogen Storage Materials

Salvador M. Aceves (Primary Contact), Andrew Weisberg, Francisco Espinosa-Loza, Scott Perfect, Gene Berry
Lawrence Livermore National Laboratory
7000 East Avenue, L-644
Livermore, CA 94551
Phone: (925) 422-0864; Fax: (925) 423-7914: E-mail: saceves@llnl.gov

DOE Technology Development Manager: Sunita Satyapal
Phone: (202) 586-2336; Fax: (202) 586-9811; E-mail: Sunita.Satyapal@ee.doe.gov

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Objectives

- Select optimum designs for continuous fiber pressure vessels
- Select optimum designs for replicant conformable pressure vessels
- Design, build and test conformable and cryo-compressed pressure vessels
- Develop innovative forms of hydrogen storage

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 Research, Development and Demonstration Plan:

- B. Weight and volume
- D. Durability
- E. Refueling Time
- H. Sufficient Fuel Storage for Acceptable Vehicle Range
- I. Materials
- K. Balance of Plant Components
- M. Hydrogen Capacity and Reversibility

Technical Targets

Table 1. Lawrence Livermore Cryo-Compressed Storage Progress Toward Meeting DOE On-Board Hydrogen Storage Targets

Storage Parameter	Units	2007 Target	2010 Target	2004, 1st generation	2005, 2nd generation
Specific Energy	kWh/kg	1.5	2	1.67	2.32
Energy Density	kWh/L	1.2	1.5	0.77	1.22
Storage System Cost	$/kWh	6	4	–	–

Approach

- Build prototype continuous fiber conformable containers
- Build and test cryo-compressed hydrogen containers
- Build demonstration model of selected lattices
- Analyze and test innovative hydrogen storage in liquid nitrogen

Accomplishments

- Designed and built prototype macrolattice conformable vessels
- Analyzed and designed continuous fiber conformable container
- Installed insulated pressure vessel in pickup truck and demonstrated flexible refueling with liquid and compressed H_2
- Designed a new insulated pressure vessel that works in the horizontal position and meets the 2010 DOE weight goal and the 2005 DOE volume goal
- Characterized absorption of hydrogen in nitrogen at low temperatures with anticipated safety and delivery advantages
- Identified supercritical hydrogen as an operating condition that has potential for meeting the 2015 DOE goals
- Wrote 2 patents, 5 invited papers, 2 contributed papers, 1 technical report, 1 set of safety standards and delivered 2 invited presentations

Future Directions

- Continue conceptual analyses and begin detailed analyses
- Begin application analysis
- Analyze thermal management capability of macrolattice
- Conclude conceptual design by creating computer-aided design (CAD) models of the elements
- Develop engineering requirements for macrolattice components
- Finalize design of second-generation insulated pressure vessel
- Pressure test newly built macrolattice conformable container
- Build and pressure test new insulated pressure vessel
- Build and pressure test continuous fiber conformable container

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Introduction

One of the fundamental hurdles limiting the broad applicability of hydrogen vehicles is storing enough hydrogen on-board for a reasonable range (300-400 miles). Several approaches are being tried, including physical storage (liquid or compressed hydrogen), chemical storage, hydrogen absorption in metallic hydrides, and hydrogen adsorption in carbon compounds. All these approaches present fundamental limitations in weight and volume densities. Some forms of storage (hydrides and carbon structures) also require thermal management (heating during desorption and cooling during absorption or adsorption). Regardless of which form of hydrogen storage is ultimately selected by the vehicle manufacturers, there is a great need to develop high-performance containers for hydrogen or hydrogen storage materials. For best performance, these containers should be conformable, meet the pressure and temperature requirements for the different forms of hydrogen storage, and provide efficient means for thermal management.

Approach

We are working on many approaches for high-performance containers. For continuous fiber (filament winding) conformable containers, we have identified an optimum geometry and are currently planning a detailed design and experimental testing of small-scale components. For macrolattice conformable vessels, we have built and tested two zero-generation prototypes and are planning to move into engineering prototypes next year. We are also designing, testing and demonstrating cryo-compressed containers, which achieve the high density of liquid hydrogen (LH_2) without the evaporative losses typical of LH_2 containers. All our container work can efficiently be applied to all forms of hydrogen storage, including hydride and carbon storage in addition to physical storage. Finally, we have developed a new concept for hydrogen storage: absorption of hydrogen in fluids, where we have focused on liquid nitrogen as the storage medium. This storage technique has refueling advantages, and it is light, compact and intrinsically safe.

Results

In FY 2005 we were able to build and test the first ever macrolattice conformable container (Figure 1). This is a cubic container with polycarbonate surfaces held together by metallic struts. The arrangement of the struts is inspired by the crystallography space groups and was selected to facilitate manufacture and improve volumetric efficiency. The container was pressure tested in our high pressure laboratory to 170 psi and then demonstrated in the poster session at the DOE Hydrogen Program Review meeting. The strut arrangement has the additional advantage of providing heat transfer paths for efficient thermal management of hydrogen storage materials (hydrides). If more intense thermal management is required, the metallic struts can be made hollow, allowing the circulation of a coolant fluid into the vessel. This is the design used in our current vessel prototype (Figure 1).

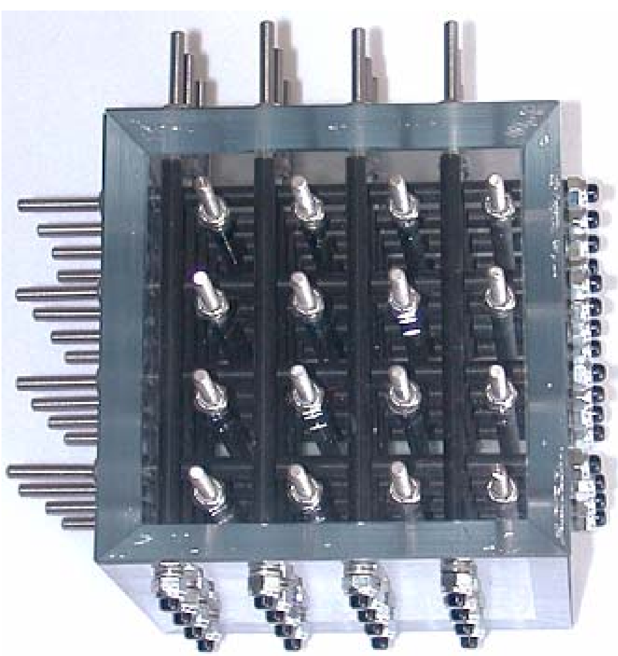

Figure 1. Prototype Generation-Zero Conformable Macrolattice Container

We have also been working on continuous fiber (filament wound) conformable pressure vessels. Last year we developed three conceptual designs and, through finite element analysis, selected the optimum. This year, we have conducted more analysis and design and are planning to build two small-scale segments for testing at our high pressure lab (Figure 2). The segments will be tested between two parallel plates for replicating the results that would be obtained if segments with hemispherical ends were added to our design.

This year we also demonstrated a cryogenic compatible container in a pickup truck. The truck was refueled multiple times with both compressed and liquid hydrogen, demonstrating the flexible refueling capability. The truck was driven for six months with no failures or major issues. The container meets the 2007 DOE target for weight (see Technical Targets table above).

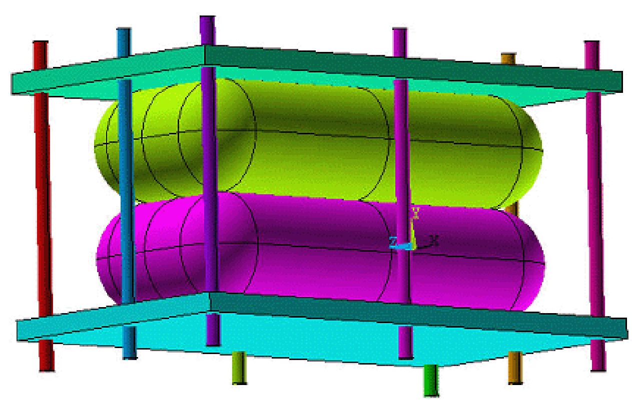

Figure 2. Design for Filament Wound Conformable Container to Be Tested in High Pressure Laboratory

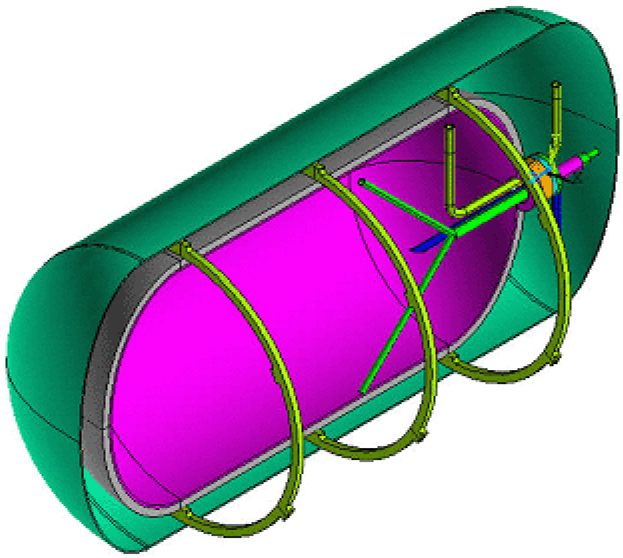

Figure 3. New Design of Cryogenic Compatible Container with Level Sensor Working in the Horizontal Position

We have designed and are building a new generation of cryogenic compatible container. The new design is projected to meet the DOE 2010 weight target and the 2007 volume target. It will also work in the horizontal position due to a new level sensor design that was developed for this application (Figure 3).

Our work for this year also included analysis of innovative hydrogen storage approaches. We identified cryogenic fluids (especially liquid nitrogen) as a storage medium that offers safety and refuelability advantages compared to conventional approaches. We conducted experiments to determine optimum pressures and temperatures of operation as well as infrastructure issues.

Conclusions

- We have built and pressure tested the first ever macrolattice conformable container. This container promises optimum utilization of available space in a vehicle and high-performance thermal management of hydrogen storage materials.
- We are planning to build two small-scale continuous fiber (filament wound) segments for testing at our high pressure lab.
- We have demonstrated a cryogenic compatible container in a pickup truck. The truck was refueled multiple times with both compressed and liquid hydrogen, demonstrating the flexible refueling capability. The container meets the 2005 DOE target for weight.
- Our second-generation cryogenic compatible container will have multiple improvements with respect to the previous design. The new design will meet the DOE 2010 weight target and the 2005 volume target. It will also work in the horizontal position.
- We identified liquid nitrogen as a storage medium that offers safety and refuelability advantages compared to conventional approaches. We conducted experiments to determine optimum pressures and temperatures of operation as well as infrastructure issues.

Special Recognitions & Awards/Patents Issued

1. Lightweight Cryogenic-Compatible Pressure Vessels for Vehicular Fuel Storage, Salvador M. Aceves, Gene Berry, Andrew H. Weisberg, U.S. Patent 6,708,502 B1, March 23, 2004. World Patent WO 2004/029503 A2, April 8, 2004.
2. Storage of H_2 by Absorption and/or Mixture within a Fluid, Gene Berry and Salvador Aceves, World Patent WO 2005/015076 A1, February 24, 2005.

FY 2005 Publications/Presentations

1. Hydrogen Storage and Transportation, Gene Berry, Joel Martinez-Frias, Francisco Espinoza-Loza, Salvador Aceves, Invited chapter, Encyclopedia of Energy, Volume 3, pp. 267-281, Elsevier Academic Press, New York, 2004.
2. Hydrogen Production, Gene Berry, Invited chapter, Encyclopedia of Energy, Volume 3, pp. 282-294, Elsevier Academic Press, New York, 2004.
3. The Case for Hydrogen in a Carbon Constrained World, Gene D. Berry and Salvador M. Aceves, Invited discussion paper, ASME Journal of Energy Resources Technology, Vol. 127, pp. 89-94, 2005.
4. Vehicular Storage of Hydrogen in Insulated Pressure Vessels, Salvador M. Aceves, Gene D. Berry, Joel Martinez-Frias, Francisco Espinosa-Loza, Submitted to the International Journal of Hydrogen Energy, 2005.

5. Liner Materials for Composite Tanks, Andrew Weisberg, Invited paper for "Materials for the Hydrogen Economy," CRC Press, 2005.
6. Development and Demonstration of Insulated Pressure Vessels for Vehicular Hydrogen Storage, Salvador M. Aceves, Gene D. Berry, Proceedings of the 15th World Hydrogen Energy Conference, Yokohama, Japan, June 27-July 2, 2004.
7. Hydrogen Absorption in Fluids: An Unexplored Solution for Onboard Hydrogen Storage, Gene D. Berry, Lawrence Livermore National Laboratory Report UCRL-TR-209650, Livermore, CA, February 2005.
8. Proposed Standards for Hydrogen and Liquefied Natural Gas Insulated Pressure Vessels, Report to the South Coast Air Quality Management District, August 2004.
9. Advanced Hydrogen Containers, Andrew Weisberg, Invited presentation, American Physical Society, March 2005.
10. Cryogenic Hydrogen Storage, Salvador Aceves, Invited Presentation, Materials for the Hydrogen Economy, September 2005.