Cryogenic Capable Pressure Vessels for Vehicular Hydrogen Storage

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May 18, 2007

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Overview

Timeline
• Start date: October 2004
• End date: September 2008
• Percent complete: 70%

Budget
• Total project funding
  – DOE: $765 k
  – SCAQMD: $350 k
• Funding received in FY06:
  – $290 k
• Funding for FY07:
  – $250 k

Barriers
• B. Weight and volume
• H. Sufficient fuel storage for acceptable vehicle range
• L. Hydrogen boil-off

Targets
• 2007 DOE volume target
• 2010 DOE weight target

Partners
• Demonstrated cryotank technology with SCI and SunLine, funded by SCAQMD
• Spencer composites, CRADA with Automotive Composites Consortium, aerospace work funded by DARPA
Rationale: Our Cryogenic Capable Vessels can Store either Gaseous $H_2$ or LH$_2$, Capturing the Advantages of Both

Cryogenic vessels operate across the entire $H_2$ phase diagram.
Cryogenic hydrogen storage behaviors are best analyzed in terms of internal energy and fuel density.
Each square in this phase diagram represents 86 kJ (a watt-day) of thermal endurance.
A conventional tank with 8 kg LH$_2$ has 8 Watt-days of dormancy (warming from 20 K to 28 K and venting at 6 bar)
A cryogenic capable 5000 psi vessel has 56 Watt-days of thermal endurance (when warmed from 20 K to 95 K)
Driving ~ 150 miles (using 2 kg of H₂) cools the remaining 6 kg H₂ to 65 K, 2000 psi, regaining 56 Watt-days of thermal endurance.
Cooling high pressure H₂ can increase safety by removing energy from the gas radically reduces theoretical burst energy at cryogenic temperatures.
Rationale: Why Insulate Pressure Vessels?

- Flexible refueling continuously matches storage method to drivers’ current needs (cost, range, safety)
- Cold (L)H₂ has less stored PV energy
- Liquid hydrogen capability lowers cost (50-75% less fiber than compressed H₂)
- LH₂ boiloff can be eliminated. Vehicle cannot be stranded
- Thermal endurance increases as fuel is used
- Vessel temperature partially self-regulated (cools when driven – more so when fuller and/or warmer)
- Greatly extended dormancy (~5-10x vs. LH₂)
Objective: Demonstrate long range (500+ miles) hydrogen hybrid vehicle with cryogenic capable pressure vessel

The vehicle

- Toyota Prius converted to H₂ fuel by Quantum.
- Originally equipped with 5000 psi 68 L pressure vessels (1.6 kg H₂)
- Est. fuel economy 50 miles/ kg H₂

LLNL Cryotank

- 151 L capacity
- stores 3.5 kg H₂ at 300 K, 5000 psi
- stores 6 kg H₂ at 150 K, 5000 psi
- stores 10.7 kg LH₂ at 20 K, 1 atm
- Meets DOE 2007 weight goal and is within 20% of DOE 2007 volume goal using LH₂ and including all system components
Approach: we are designing, building, testing and demonstrating a compact insulated pressure vessel for long range hydrogen vehicles
Accomplishments: We have designed and built a new cryogenic pressure vessel

1. Attach instrumentation and heater to inner pressure vessel

2. Install mechanical support rings and multilayer insulation

3. Slide insulated vessel into outer vacuum vessel

4. Weld vacuum vessel and install flanges for high pressure lines
We have conducted vessel testing to verify performance and safety.

1. Vacuum test
2. Pressure test
3. Instrumentation and data acquisition test
4. Cryogenic cycling and dormancy test
Thermodynamic analysis confirms adequate thermal endurance in our LN$_2$ dormancy experiments (~5 W)
We have installed our cryogenic capable vessel in a hydrogen fueled hybrid Prius

1. Install cryogenic capable pressure vessel in vehicle

2. Fuel and test vehicle on compressed and liquid H₂

3. Drive test

4. Dormancy test
We drove 650 miles (under atypical conditions) without refueling our cryogenic capable vessel.
Future Work: The two outstanding issues are vacuum stability and cycle life. Our planned experiment can characterize both.
We can efficiently perform all the cyclic tests at our liquid and compressed hydrogen fueling station.
Summary: Cryogenic Capable Vessels can Refuel with Gaseous H₂ or Liquid H₂, Capturing the Advantages of Both

- LH₂ capable vessels can use 2-3x less carbon fiber than conventional vessels
- LH₂ boiloff is eliminated. Vehicle cannot be stranded.
- LH₂ fuel allows maximum range
- Compressed H₂ for urban driving saves energy of cooling and liquefaction
- High pressure vessels make hydrogen insensitive to heat transfer, enabling thinner insulation or lower cost
- Performance figures: 6.0% H₂ weight fraction and 33 grams per liter

Cryogenic pressure vessel installed in Prius hydrogen hybrid vehicle. The vehicle has been driven 650 miles on a single tank with 10 kg LH₂ (under atypical conditions)