Overview of a Cryogenic Capable Pressure Vessel for a (L)H_2 Fueled Toyota Prius

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Agenda

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- Background
- Methodology
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- Demonstration
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- Q/A?

Introduction: Ryan Shelby

- Home: Alabama
- University: University of California at Berkeley
- Department: Mechanical Engineering
- Status: Second year Grad Student
- Focus area: hydrogen storage, strategic product design, energy related user needs analysis

Introduction: US 2005 Carbon Dioxide Emissions

- 84% of total US greenhouse gas emissions came from carbon dioxide emissions

- 33% of U.S. energy-related carbon dioxide emissions in‘05 came from Transportation

• US 2005 Emissions:	Carbon dioxide	Carbon
(Million Metric Tons)	6,008.6	1,638.7
• Transportation Sector:	Carbon dioxide	Carbon
(Million Metric Tons)	1,958.6	534.2

Source: http://www.eia.doe.gov/oiaf/1605/archive/gg06rpt/summary/carbon.html

Introduction: Why Hydrogen?

- Hydrogen, like electricity, is an energy carrier; it is not an energy source.
- 19.6 lbs -- amount of carbon dioxide emitted from burning 1 gallon of gasoline in a car
- 1 kg of hydrogen has the same energy content of 1 gallon of gasoline.
- Heat and water -- the emissions from burning 1 kg of hydrogen in a car
- Hydrogen issues: production, distribution, and storage

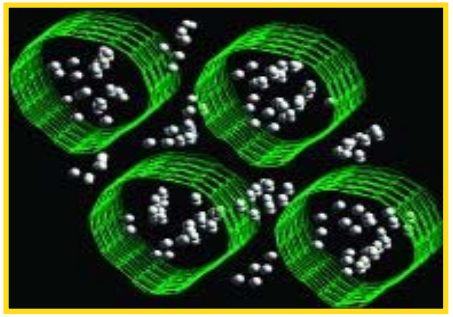
Background: DOE Storage Goals

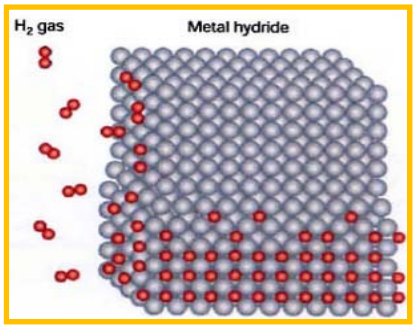
Storage Parameter	Units			
		2007	2010	2015
Gravimetric Capacity	kWh/kg (wt.% hydrogen)	1.5 (4.50%)	2 (6%)	3 (9%)
Volumetric Capacity	kWh/L (kg H_2/L)	1.2 (0.04%)	1.5 (0.045)	2.7 (0.081)
Storage system cost	$/kWh net ($/kg H_2)	6 (200)	4 (133)	2 (67)

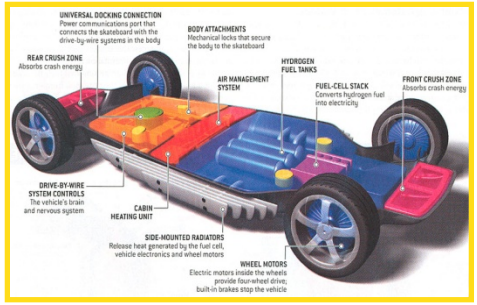
Background: H_2 Storage Options

- There are four automotive H_2 storage technologies:
- compressed gas,
- metal hydride materials,
- carbon-based materials, and
- cryogenic liquid.

- Each technology has its limitation: weight, volume, evaporation losses, or adsorption thermodynamics

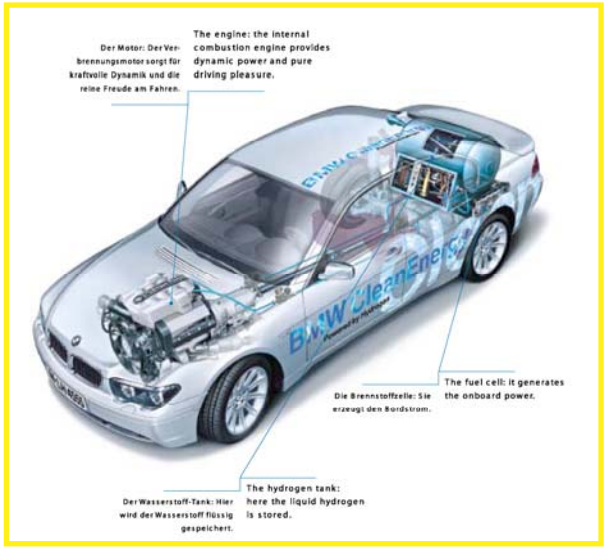






Background: BMW H_2 Storage Research

- BMW's research efforts into vehicular hydrogen storage has resulted in 7 generations of prototyped (L)H_2 cars.



Background: LLNL's H_2 Storage Research History

2003: Demonstration

2001: DOT/ISO cryogenic drop and bonfire tests

Background: LLNL's Recent H_2 Storage Research

- LLNL's cryogenic capable pressure vessel (CCPV) can store
- (L)H_2,
- compressed gaseous H_2,
- compressed gaseous H_2 at 80K.

- CCPV Advantages: long range, compact, elimination of (L)H_2 evaporation, and flexible refueling options.

Methodology: Cryogenic Dormancy Test

- A cryogenic dormancy test of the 151 liter CCPV was performed using (L)N_2 as a surrogate for (L)H_2.
- From the test, equations were generated that describe the vessel's measured pressure and temperature over time.
- Utilizing those equations, a thermodynamic model of the CCPV was created to simulate the test results.
- This model estimates the total heat transferred to the vessel due to both radiation and conduction

Thermodynamic Analysis: Heat leak equations

- The change in temperature of the CCPV was derived in terms of radiation (Q_r), conduction (Q_c), and thermal mass.
- Heat added equations:

$$Radiation(Q_r) = \frac{\left[\varepsilon\sigma A\left(T^4{}_{outside} - T^4{}_{CCPV}(t)\right)\right]}{\left[1 + insulationlayers\right]} \qquad Conduction(Q_c) = \frac{\left[kA\left(T_{outside} - T_{CCPV}(t)\right)\right]}{\Delta x}$$

- Thermal mass equation:

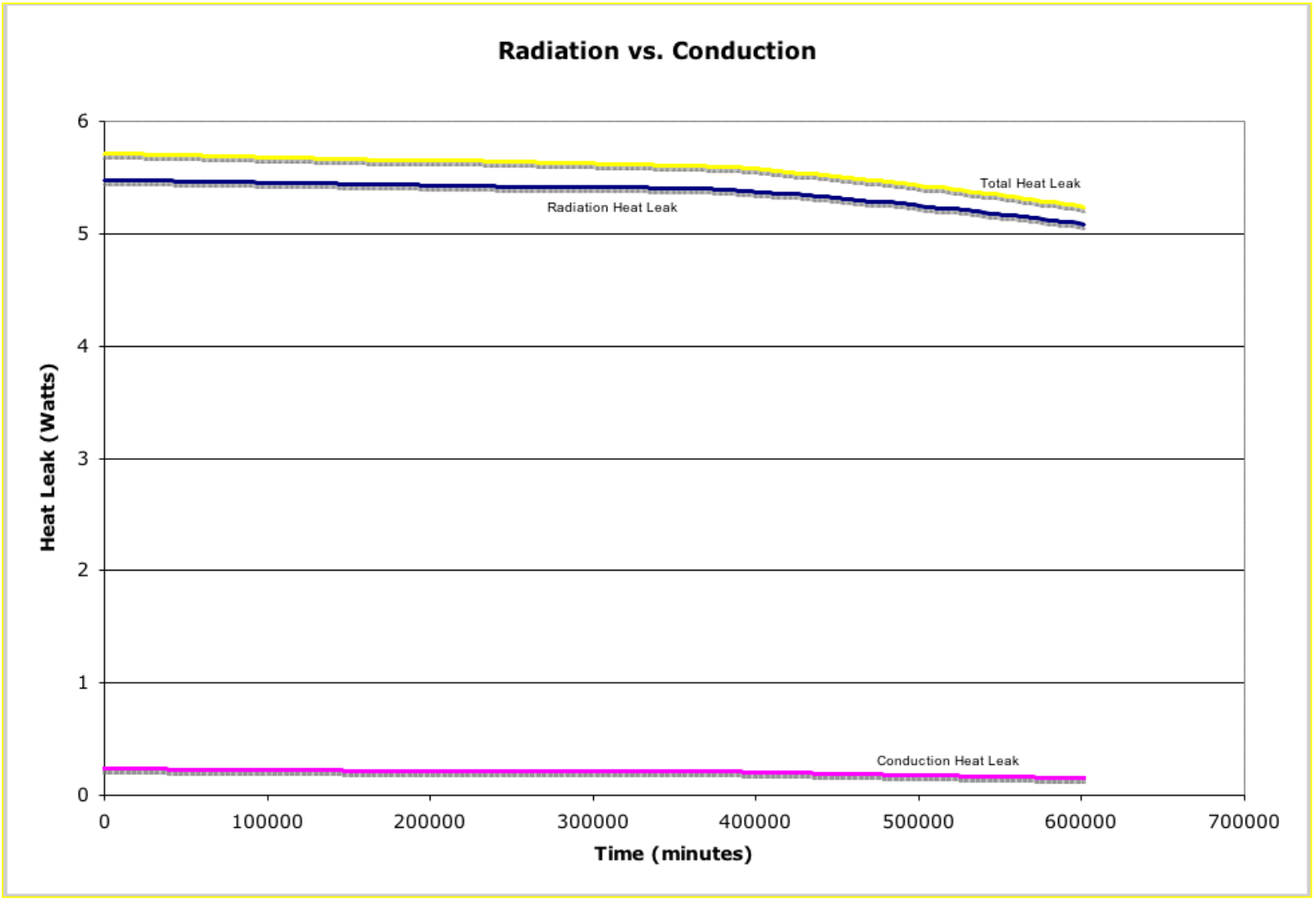
$$Thermalmass = \left[m_{Al}Cv_{Al}(t) + m_{Carbon}Cv_{Carbon}(t) + m_{LN_2}Cv_{LN_2}(t)\right]$$

- Change in temperature:

$$Temperature(\Delta T) = \frac{(Q_r + 2Q_c)}{\left[m_{Al}Cv_{Al}(t) + m_{Carbon}Cv_{Carbon}(t) + m_{LN_2}Cv_{LN_2}(t)\right]}$$

Heat conducts through both the liquid and gas fill pipe

Results: Heat transfer comparison

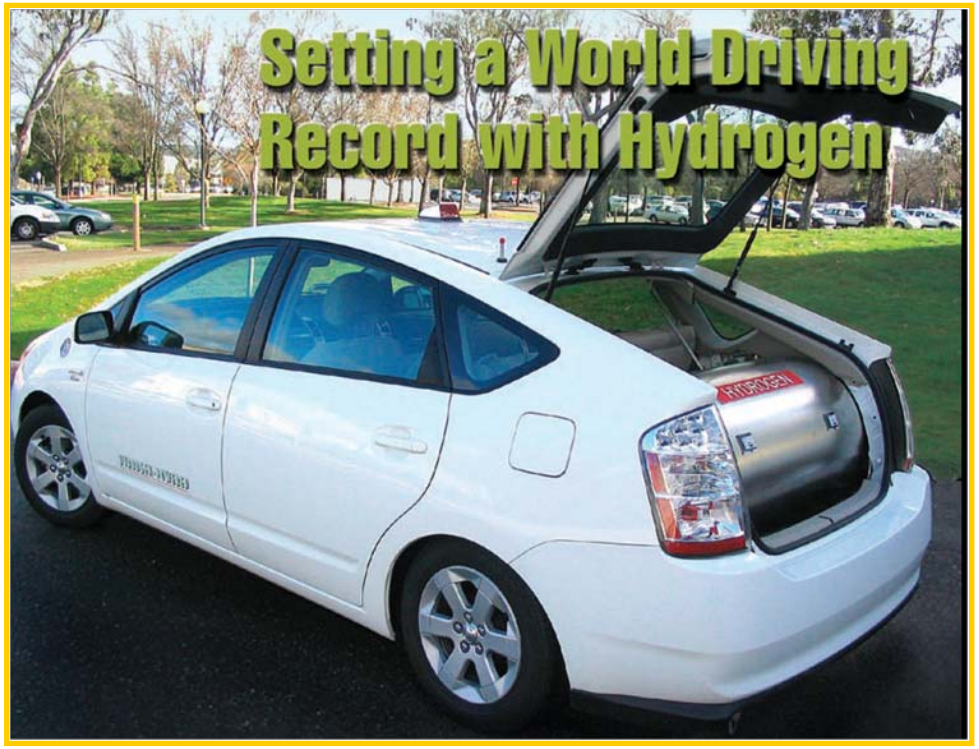


Results of Thermodynamic Analysis

- The temperature generated from the simulation are comparable to the experimental data.
- Radiation is responsible for ~90% of the heat transfer in to the CCPV.
- The average amount of heat transferred into the CCPV during the dormancy test was 5.5 Watts.

Hydrogen Record

- A 653 mile range was obtained using the liquid hydrogen fueled Toyota Prius in January 2007.
- Prius was driven at low speeds and low driving conditions
- Under normal conditions, ~500 mile range is expected



Future Plans

- Create a heat transfer model that will better predict the conversion of the liquid hydrogen to gaseous hydrogen.
- Further refine the design in order to place cryogenic capable pressure vessel (CCPV) under the vehicle
- New design will store 6 kg of H_2; the vehicle will achieve a minimum 300 mile range
- Conduct a user needs analysis to determine the feasibility of a modular hydrogen storage system and its tradeoffs.

Boulders or Pebbles in the River?

- Climate change is a run away train
- It is all our fault
- There is not much we can do about

- Carbon dioxide forms approximately 0.04% of the Earth atmosphere
- Our impact on the environment is negligible
- We don't need to worry climate change

Boulders or Pebbles in the River?

- Climate change is naturally occurring process

- However, human activities contribute to climate change

- Climate change is manageable

- We have the technologies (PHEVs, EVs, FCVs) to address this issue

- One can't force people to change habits

- Engineers must provide tools that will enable people to change

Q/A?