U.S. Department of Energy Hydrogen Program

Hydrogen Delivery

Monterey Gardiner

2008 DOE Hydrogen Program
Merit Review and Peer Evaluation Meeting

June 11th, 2008

Goal and Objectives

Goal: Research and develop low-cost, highly efficient hydrogen production technologies from diverse domestic resources, including natural gas and renewable sources

- Reduce the cost of hydrogen to $2.00 - $3.00/gge (Untaxed & Delivered)

Near-term: Distributed Production

(produced at station to enable low-cost delivery)

- *Natural gas reforming*
- *Renewable liquid reforming*
- *Electrolysis*

Longer-term: Centralized Production

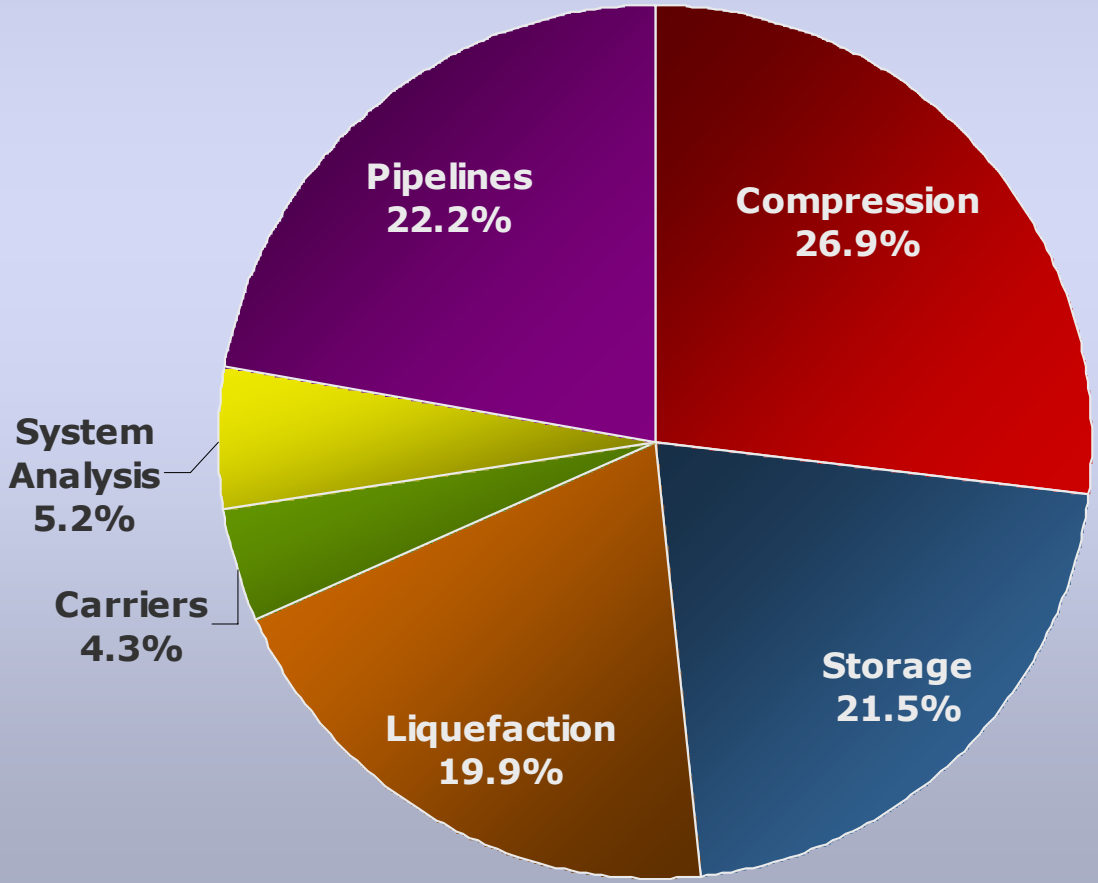
(large investment in delivery infrastructure needed)

- *Biomass gasification*
- *Coal with sequestration*
- *Wind, solar, and nuclear-driven electrolysis*
- *Solar/nuclear high-temperature thermochemical water splitting*
- *Photoelectrochemical, biological production*

- Reduce total hydrogen delivery cost to < $1.00/gge

EERE H_2 Delivery Budget

FY2008 Budget = $10.7 M



FY2008 Emphasis

- Initiate 6 new projects
  - Compression
  - Off-board storage
  - Liquefaction
- Release V2 of H2A and identify V2.5 refinements
- Gather data for eventual pipeline material down selection

Challenges – H_2 Delivery

Pipelines

Liquefaction

Tube Trailers

- Pipelines (Long Term)
  - Capital cost
  - Materials
  - Large centrifugal compressors
- Liquefaction (Long Term/Transition)
  - Capital cost
  - Energy efficiency
- Tube Trailers (Transition)
  - Increased density
  - Maintaining relatively low cost trucks
  - Maintaining energy efficiency
- Other Topics
  - Off-board storage (decrease station foot print)
  - Compression (station, liquefaction, pipelines)

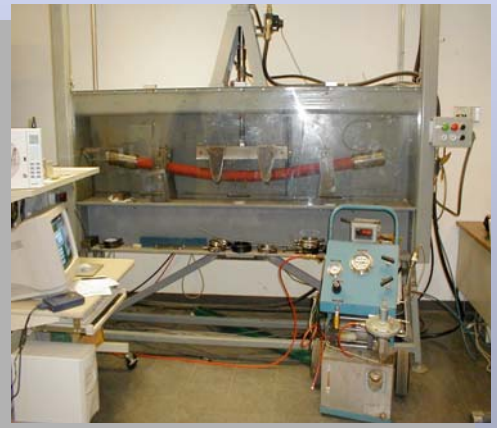
2008 Delivery Accomplishments

Identified Low Cost & Low Permeability Fiber Reinforced Polymer

- 1 psi per day or
  - << 0.1% hydrogen per day
- Developed & verified test bed for ASME compliance testing

(Oak Ridge and Savannah River)

Fiberspar



2008 Delivery Accomplishments

Electrochemical Hydrogen Compressor (EHC)

Developed Prototype Electrochemical Hydrogen Compressor

- Peak compression of 4000 psi
- Continuous operation for 1500 hours
- No seal leakage

(FuelCell Energy)

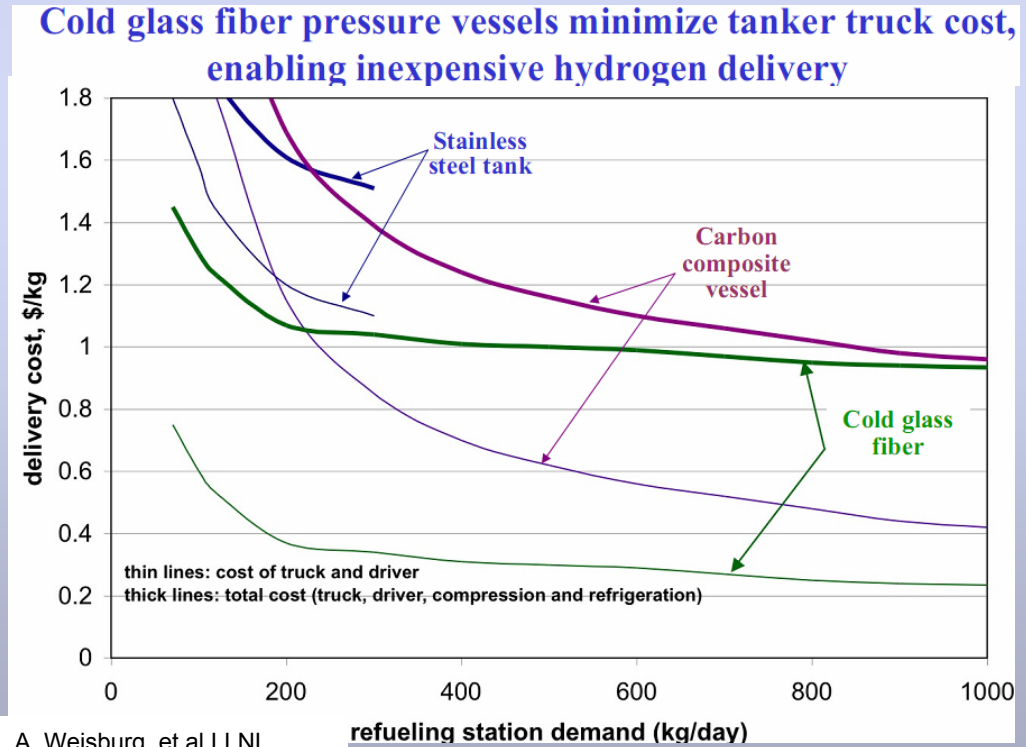
Identified APCI Liquid Hydrocarbon as a Promising Carrier

- Developed novel carrier evaluation and down select tool
- Planned integration into H2A V.3

(TIAX, LLC)

2008 Delivery: Tube Trailers

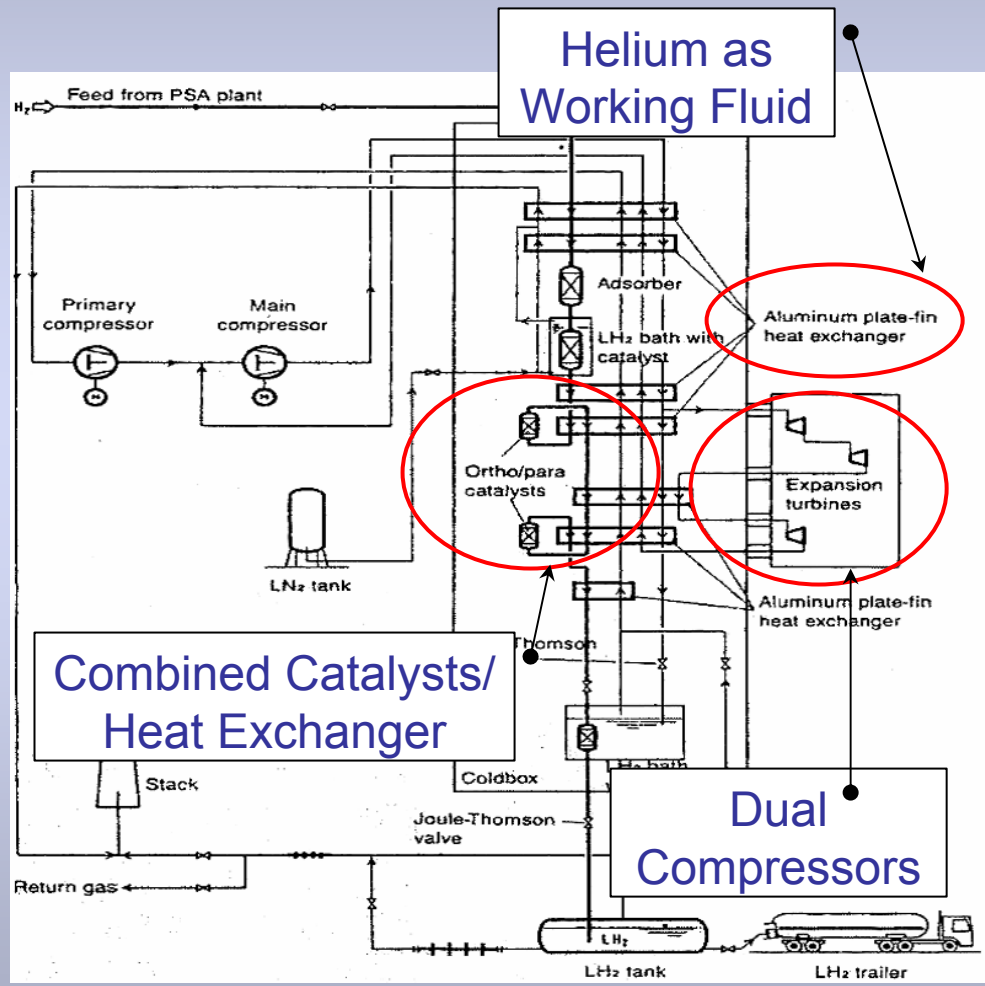
- Best Approach: High pressure, low temperature hydrogen delivery vessels using glass fibers, LLNL
- Cost
  - Reducing trailer capital costs ($300K for 700kg)
  - Availability of glass composites (~$1.50/kg material cost)
  - Potential to hit $1/kg H_2 delivered at 600 kg/day station
- Technical Needs
  - Demonstrate glass fiber strengthening at cold temperatures and/or vacuum (50%) at 200 K vs. 300 K
  - Design new macrolattice/fiber wound vessels that take advantage of the fiber properties
- Other Roadblocks
  - Innovative truck configurations would require the codes and standards community to accept a new technology
- Next Steps
  - Complete cryogenic characterization of glass fibers
  - Demonstrate low cost delivery vessel



A. Weisburg, et al LLNL

2008 Delivery: Liquefaction

- Best Lead: Innovative cycle design, GEECO
- Cost
  - Modeled liquefaction costs are $.76/kg with an increase in efficiency of 30% over state-of-the-art liquefiers
- Technical Needs
  - Efficiency of liquefaction limited by thermodynamics
  - GEECO's innovative liquefaction cycle has not yet been tested at the bench scale
- Other Roadblocks
  - Scaling from the laboratory to a full scale commercial plant (~$400M in capital costs)
  - GHG generation, when not considering renewable energy
- Next Steps
  - Constructing components to test in the coming year



M. Shimko, et al GEECO

Summary

The Program has reduced the cost of producing hydrogen from multiple pathways.

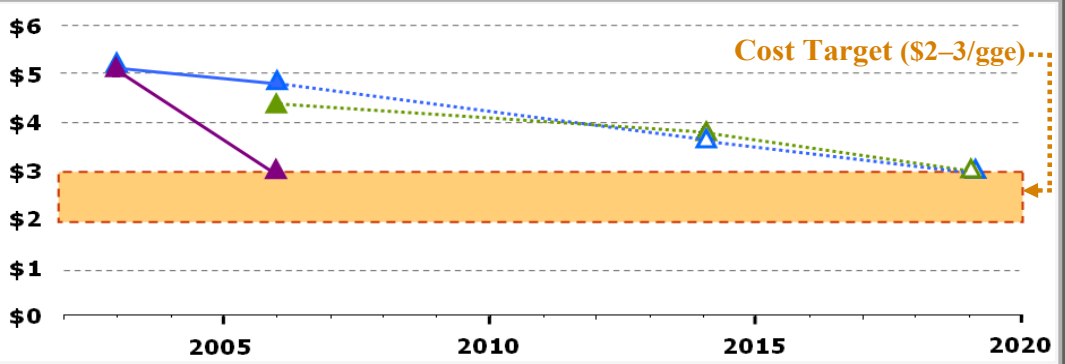
Cost of Hydrogen (Delivered) — Status & Targets

(in $/gallon gasoline equivalent (gge), untaxed)

NEAR TERM: Distributed Production

→ *Hydrogen is produced at station to enable low-cost delivery*

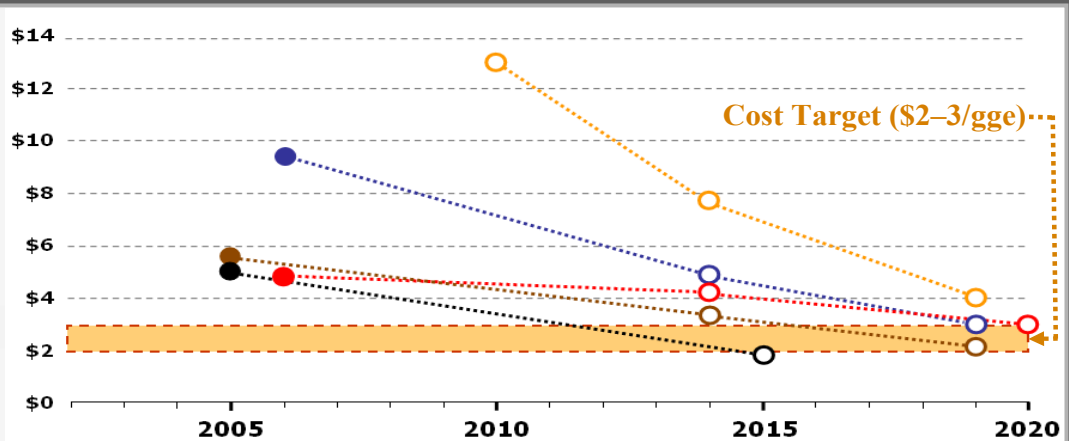
- Distributed Natural Gas
- Distributed Electrolysis
- Distributed Bio-Derived Renewable Liquids



LONGER TERM: Centralized Production

→ *Large investment in delivery infrastructure needed*

- Biomass Gasification
- Coal Gasification with Sequestration
- Solar High-Temperature Thermochemical Cycle
- Central Wind Electrolysis
- Nuclear



For More Information

Hydrogen Delivery

James Alkire
(303) 275-4795
james.alkire@go.doe.gov

Rick Farmer
(202) 586-1623
richard.farmer@ee.doe.gov

Dave Peterson
(303) 275-4956
david.peterson@go.doe.gov

Tim Armstrong
(865) 574-7996
armstrongt@ornl.gov

Monterey Gardiner
(202) 586-1758
monterey.gardiner@ee.doe.gov

Lea Yancey
(303) 275-4944
lea.yancey@go.doe.gov

Paul Bakke
(303) 275-4916
paul.bakke@go.doe.gov

Jill Gruber
(303) 275-4961
jill.gruber@go.doe.gov