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
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

FY2008 Budget = $10.7 M

- Pipelines 22.2%
- Compression 26.9%
- Liquefaction 19.9%
- Storage 21.5%
- System Analysis 5.2%
- Carriers 4.3%
Challenges – H\textsubscript{2} Delivery

- **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 footprint)
  - 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)
2008 Delivery Accomplishments

**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

![Diagram](cold-glass-fiber-pressure-vessels-minimize-tanker-truck-cost-enabling-inexpensive-hydrogen-delivery.png)
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
The Program has reduced the cost of producing hydrogen from multiple pathways.

**Summary**

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
### Hydrogen Delivery

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