



U.S. DEPARTMENT OF
ENERGY

Hydrogen Delivery

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**2009 DOE Hydrogen Program & Vehicle
Technologies Program**

Merit Review and Peer Evaluation Meeting

May 21, 2009

Goal: Reduce the delivered cost of hydrogen to <\$1.00/gge (gallon gasoline equivalent)*

Near-term: Low Investment Needs

- Existing Pipeline Infrastructure
- Gaseous Hydrogen Delivery by Truck
- Liquid Hydrogen Delivered by Truck
- High Pressure Low Temperature by Truck
- Railway

Longer-term: Lowest Delivered Cost

(large investment in delivery infrastructure needed)

- Pipelines
 - Steel
 - Fiber Reinforced Polymer
- Specialized Carriers
 - N-ethylcarbazole “like” liquid carrier
- Compression
 - Electrochemical
 - Centrifugal
- Low Cost Bulk Storage
 - At Station
 - Near Production (Geologic Storage)

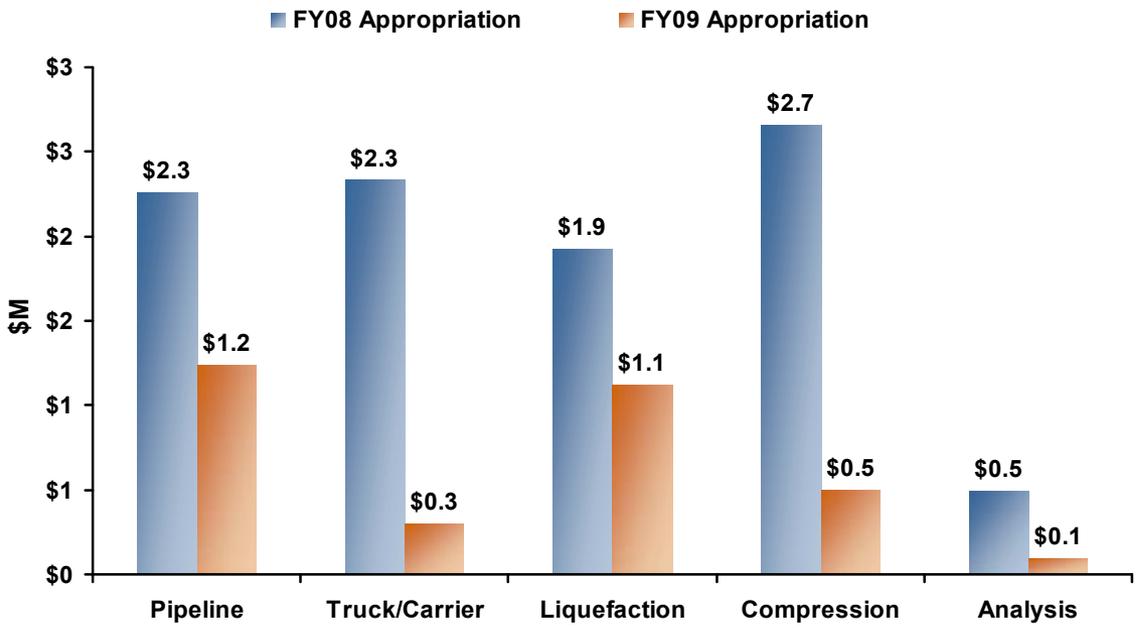
In the United States, about 9 million tons of hydrogen are produced annually for industrial purposes, and there are about 1,200 miles of hydrogen pipelines.

* Delivery costs and target currently under review.



Delivery Budgets Focus on Key Technologies

FY 2009 Appropriation = \$2.8M
FY 2008 Appropriation = \$9.5M



EMPHASIS

- **Reducing Compression Cost**
 - Centrifugal compression system design using “off-the-shelf” parts
 - High RPM system to reduce size and cost
 - High pressure/temperature Test Bed to develop coatings and materials
 - Electrochemical -SBIR
- **Higher Capacity Truck Delivery**
 - Large volume/high pressure gas
 - High pressure, low temperature using glass fibers
- **Advanced Liquefaction**
 - Leveraging Ortho-Para conversion
 - Helium cycle with novel heat exchanger configuration
- **Analysis**
 - Adding 700 bar and cryocompressed costs
 - Evaluating pathways and largest cost contributors
 - Evaluating purification costs



Hydrogen Delivery via Three Existing Options & Supporting Technologies

1. Hydrogen Pipelines

- Embrittlement issues
- Capital equipment and labor cost
- New materials such as fiber reinforced pipe for wider use
- Potential quality concerns

2. Gaseous Hydrogen via Tube Trailer Truck

- Limited capacity
- Capital equipment cost
- Regulatory acceptance

3. Liquid Hydrogen via Truck

- Energy penalty
- Boil-off
- Capital equipment cost

Supporting Technologies

Hydrogen Carriers

- Energy and material cost for regeneration
- Cycle life
- Increased hydrogen capacity
- Environmental issues

Compression and Storage

- Compression for pipelines and stations
- Bulk storage for winter maintenance, summer peak and at the station



Fiber Reinforced Polymer Pipe (ORNL and SRNL)

Fiber Reinforced Polymer (FRP) Pipe

– Completed Test Regimen

- Accelerated-aging showed no degradation
- Completed Hydrogen Compatibility Testing in Fiberspar FRP Pipeline Specimens
- Fiberspar specimen passed blow-down testing
- Predicted leakage rate $< 0.02\%$ per day
- Measured leakage rate $\cong 0.5$ kg H₂/yr/joint
- Increased joint leakage with flexural loading

– Developed FRP Life Management Research Plan



Leakage Measurement at Oak Ridge



Tube Trailers (Current Status ~300 kg H₂ on board)



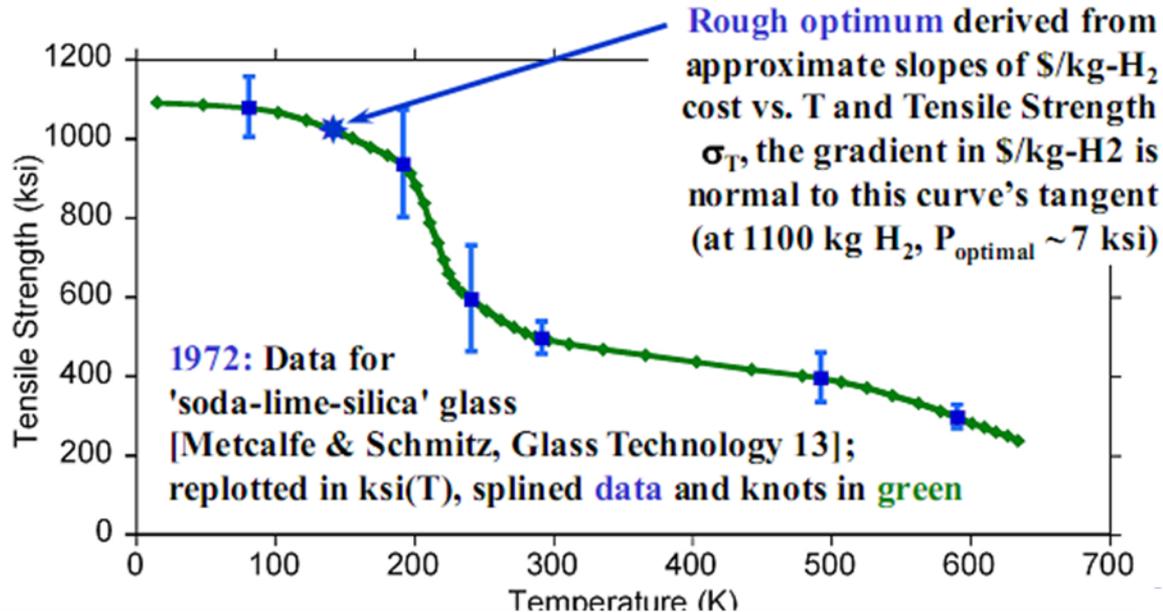
Lincoln Composites

- New system doubles capacity -600 kg H₂
- Achieved large scale dome molding & tubular welding of tanks
- Completed large scale filament winding of tanks



Lawrence Livermore National Lab

- Designed for triple capacity -1100 kg H₂
- Verified 80% higher glass fiber strength at 140 K compared to 300 K
- ~\$6/kg glass fiber vs. ~\$23/kg carbon fiber
 - 50% trailer cost reduction (~\$400K to ~\$200K)





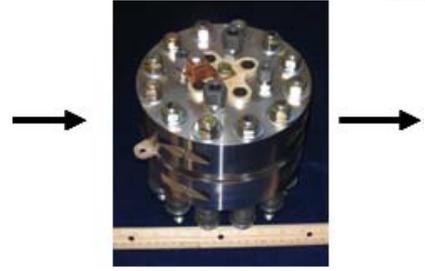
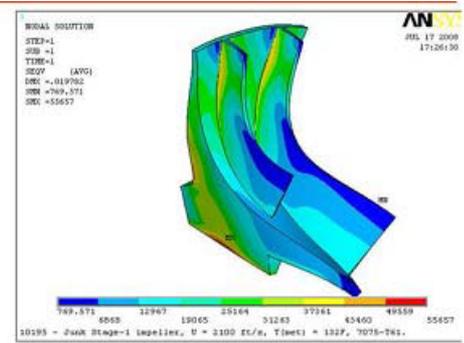
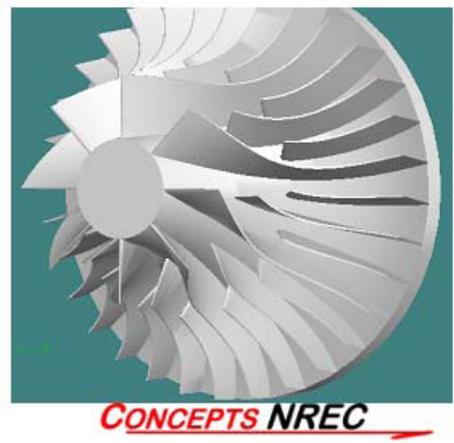
Compression

Concepts NREC

- Create a hydrogen centrifugal compressor using “off-the-shelf” parts
- Develop design criteria and performance specifications

Fuel Cell Energy

- Increased compression ratio reduces # of stages & associated capital costs
- Increased operating hours supports reduced maintenance requirements
- Increased pressure cycling validates progress from proof of concept to a viable technology



Electrochemical Hydrogen Compressor



Liquefaction

Prometheus: Active Magnetic Regenerative Liquefier (AMRL)

- Completed test lab-prototype specifications for 290 K to 120 K cooling operation

Praxair: Ortho-Para Approach to Liquefaction

- Developed new model
- Developed large and small test systems

The AMRL cold box on the left is a double walled dewar. The AMRL cryocooler on the right is a proven two-stage GM model



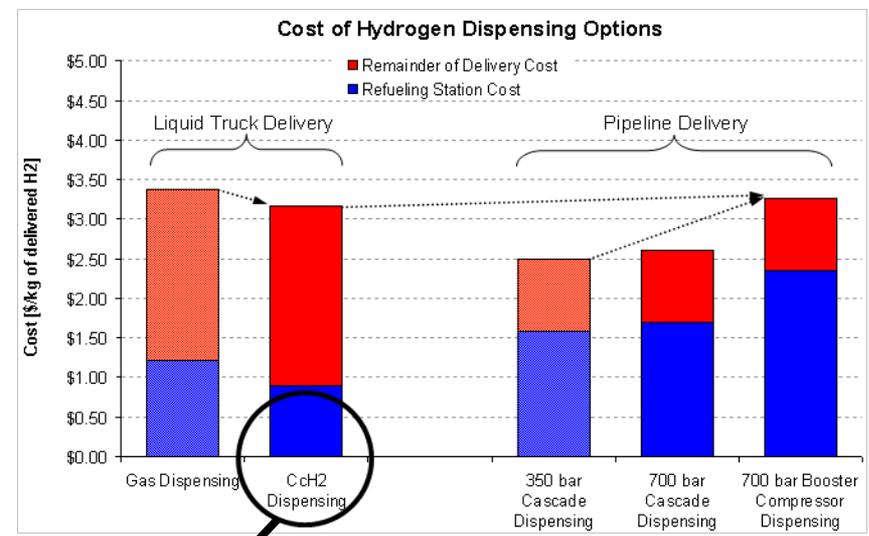
H2A Component Model and Hydrogen Delivery Scenario Analysis Model- HDSAM

ANL

- Added 700 bar fueling to HDSAM (currently being vetted)
- Added cryocompressed fueling (CCH₂) to HDSAM (currently being vetted)

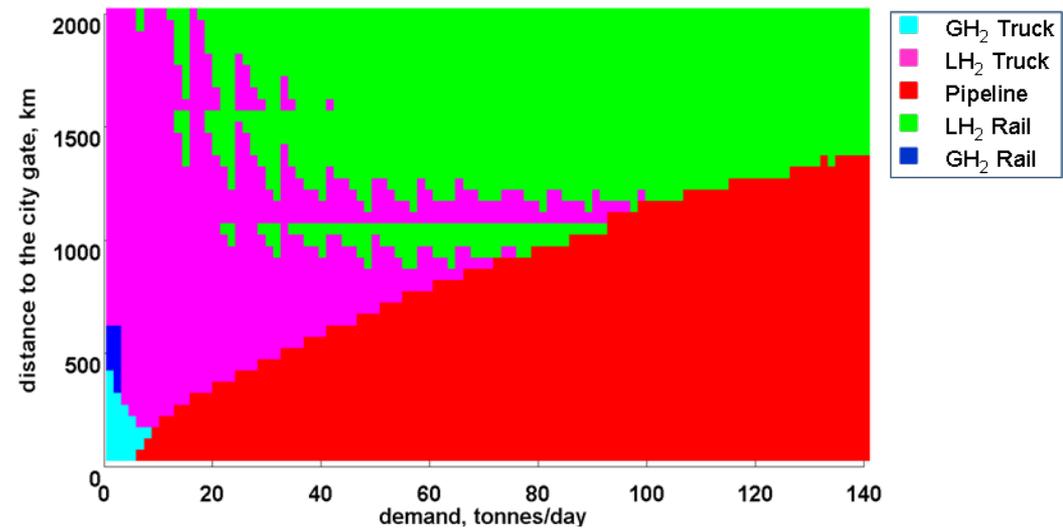
NREL

- Designed preliminary version of Hydrogen Rail Component Model
- Rail delivery appears to be a viable low-cost option for long distances and large demands



CCH₂ onsite cost is up to 30% of the onsite cost of a 700 bar station

Lowest Delivery Cost Pathway Map (station capacity is 1,000 kg/day)





Hydrogen Delivery Progress in FY 2009

- Significant progress was achieved in all delivery technologies
- Continue hydrogen delivery systems analysis development
 - Added 700 bar and cryocompressed refueling
 - Updating component tab, including Rail delivery information
 - Assessing geologic storage costs and purification needs
- Continue pipeline R&D assessment



Hydrogen Delivery Team

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