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 and Objectives

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)*

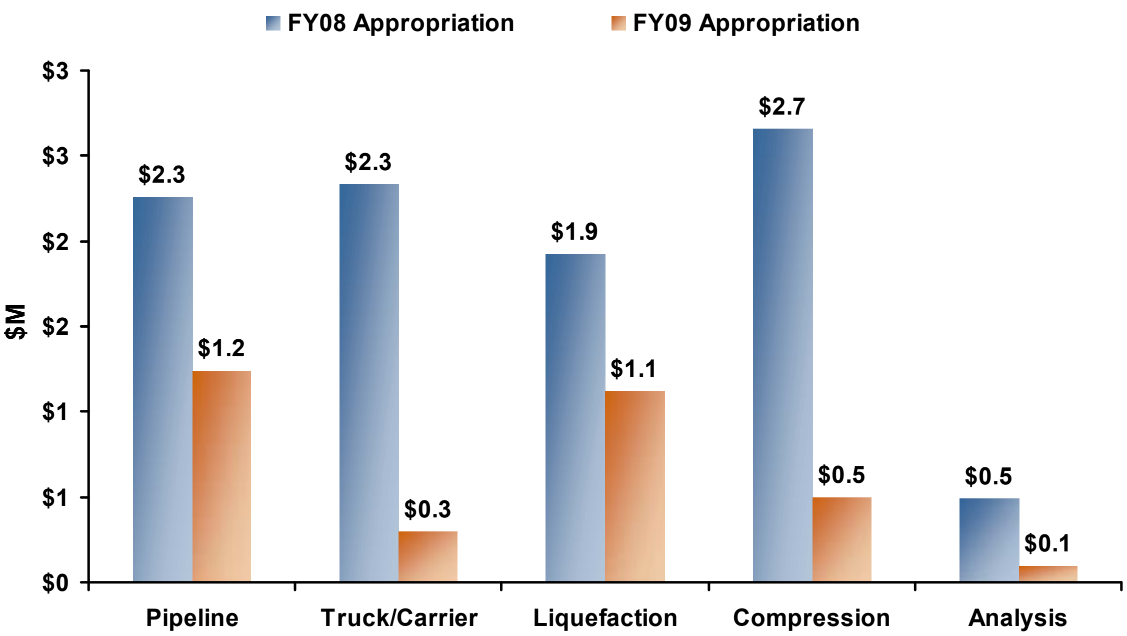
*In the United States, about **9 million tons** of hydrogen are produced annually for industrial purposes, and there are about **1,200 miles** of hydrogen pipelines.*

*** 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

Challenges

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

2009 Progress & Accomplishments

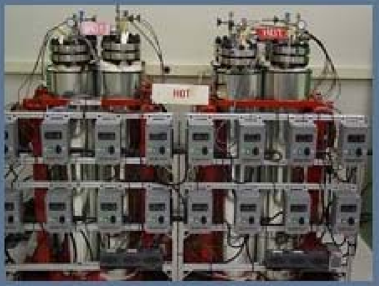
Fiber Reinforced Polymer Pipe (ORNL and SRNL)

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 ≅ 0.5 kg H_2/yr/joint
- Increased joint leakage with flexural loading

– Developed FRP Life Management Research Plan



SRNL Hydrogen Exposure Station

Leakage Measurement at Oak Ridge

2009 Progress & Accomplishments

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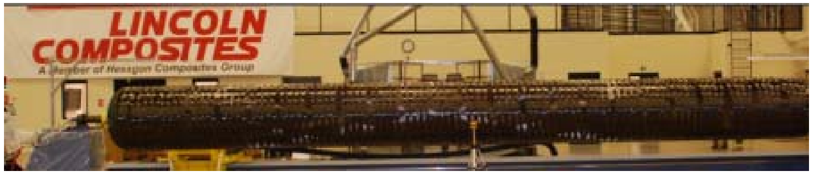
Tube Trailers (Current Status ~300 kg H_2 on board)

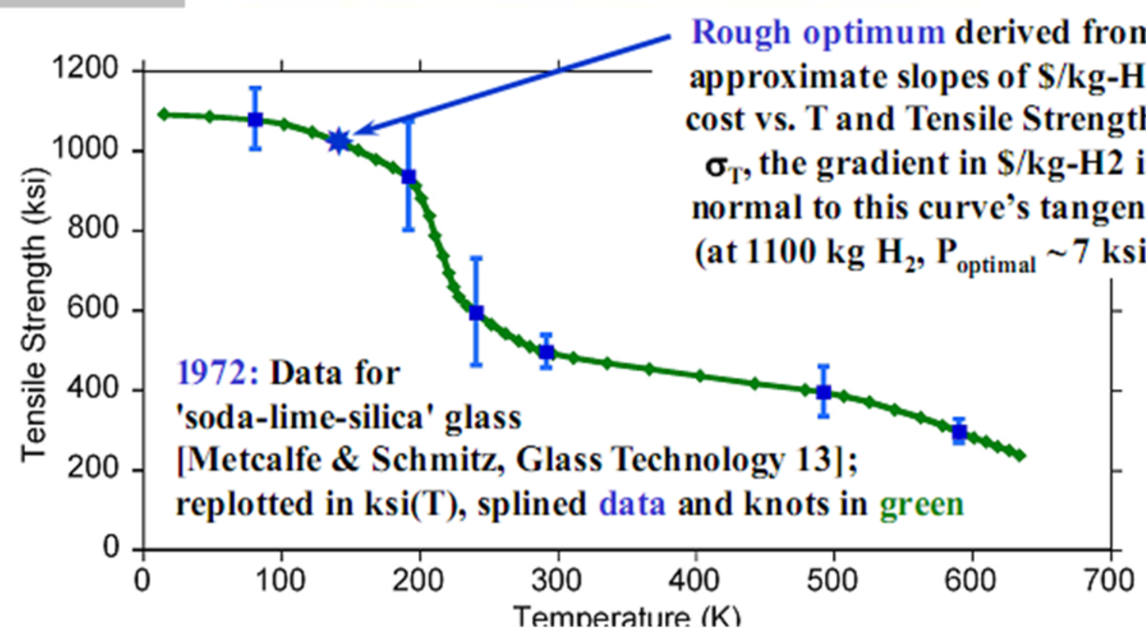


Lincoln Composites

- New system doubles capacity -600 kg H_2
- 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 H_2
- 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)



2009 Progress & Accomplishments

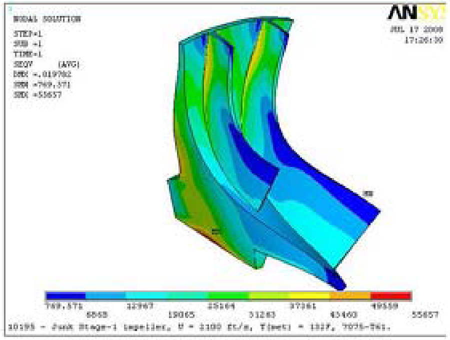
Compression

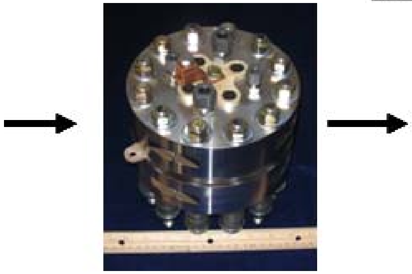
Concepts NREC

- 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

2009 Progress & Accomplishments

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

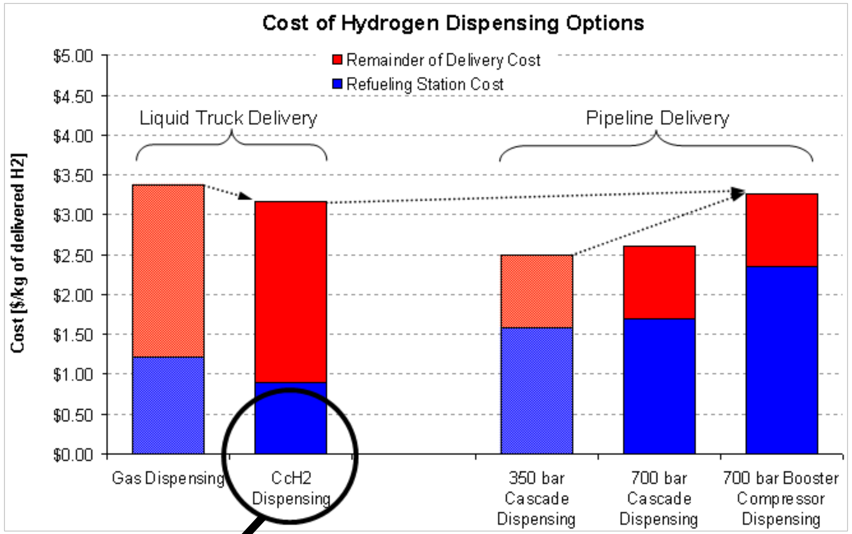
PRAXAIR

2009 Progress & Accomplishments

H2A Component Model and Hydrogen Delivery Scenario Analysis Model- HDSAM

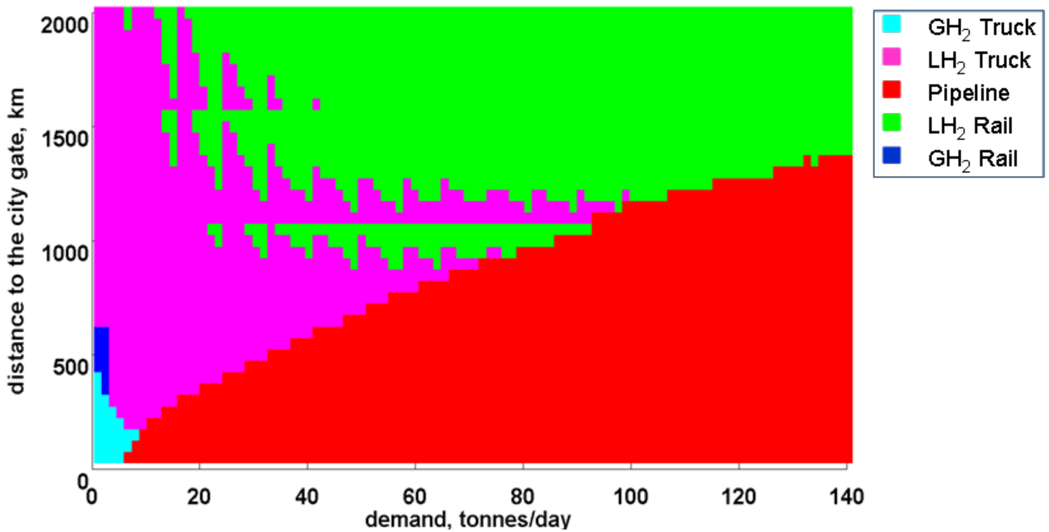
ANL
- Added 700 bar fueling to HDSAM (currently being vetted)
- Added cryocompressed fueling (CcH_2) to HDSAM (currently being vetted)

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



CcH_2 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)



Summary

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

For More Information

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