2010 DOE Hydrogen Program Review

Hydrogen Delivery Infrastructure Analysis

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Overview

**Timeline**
- Start: FY 2007
- End: Continuous

**Budget**
- 100% DOE funding
- FY09: $400 k
- FY10: $200 k

**Barriers/Challenges**
- Lack of analysis of H2/carrier infrastructure options and tradeoffs
- Cost and efficiency of delivery components
- Lack of appropriate models and tools/stove-piped analytical capability

**Partners**
- Argonne National Lab
- National Renewable Energy Lab
- Pacific Northwest National Lab
Relevance

- Provide platform for comparing alternative component, subsystem and system options to reduce cost of hydrogen delivery
  - Expand Hydrogen Delivery Scenario Analysis Model (HDSAM) to include 350-bar tube trailers and 500-bar cold gas delivery
  - Estimate capital investment, levelized cost, energy and greenhouse gas (GHG) emissions of these options
  - Investigate system and subsystem tradeoffs (e.g., storage vs. peak sizing, boost compression vs. cascade) and strategies for optimization

- Assist in program planning
  - Investigate component performance/efficiency to achieve cost goals
  - Analyze delivery options (e.g., wind-to-LH2)

- Develop new tools that build off existing DOE-sponsored tools (e.g., H2A production, Fuel Cell Power Model, GREET)
  - Collaborate with model developers and lab partners
  - Collaborate with industry for input and review
Approach

- Create **transparent, flexible, user-friendly, spreadsheet-based tool (HDSAM)** to examine new technology, operating and packaging options for hydrogen delivery
- Provide modeling structure to automatically link and size components into **optimized pathways** to satisfy requirements of scenarios, and compute component and **system** costs, energy and GHG emissions
- **Collaborate** to review input assumptions, analyze storage, station, dispensing and conditioning options, and review results
- **Provide thorough QA**
  - Internally via partners
  - Externally, via briefings to Tech Teams, early releases to DOE researchers, industry interaction
HDSAM 2.2 Models Transmission, Distribution & Bulk Storage Needed to Meet Scenario-Defined Supply & Demand

**Liquid H2 Distribution Pathways**
- Bulk geologic or liquid hydrogen storage
- Pipeline or truck transmission
- Urban, interstate or combined markets
- 50-60,000 kg/d GH2 fuel stations
- LH2 storage
  + Cryo-compressed (CcH2) dispensing

**Compressed GH2 Distribution Pathways**
- Bulk geologic or liquid hydrogen storage
- Pipeline or truck transmission
- Urban, interstate or combined markets
- 50-6000 kg/d GH2 fuel stations
- 350-bar dispensing
- 170-bar tube trailer
  + 700-bar dispensing (cascade or boost compressor)
  + 350-bar tube trailer

**Pipeline Distribution Pathways**
- Bulk geologic or liquid hydrogen storage
- Urban, interstate or combined markets
- 50-6000 kg/d GH2 fuel stations
- 350- or 700-bar dispensing (cascade or boost compressor)
  + 700-bar dispensing (cascade or boost compressor)
## FY2010 Accomplishments

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<tr>
<th>Month/Year</th>
<th>Milestone</th>
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<tr>
<td>March 2010</td>
<td>Cold hydrogen gas delivery</td>
</tr>
<tr>
<td>April 2010</td>
<td>Fuel station footprint analysis</td>
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<tr>
<td>May 2010</td>
<td>Posted Version 2.2 of Hydrogen Delivery Scenario Analysis Model (HDSAM 2.2)</td>
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<td>Sept. 2010</td>
<td>Wind-to-LH2 analysis</td>
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<tr>
<td>Continuous</td>
<td>IEA Task 28 support (May 2010 startup)</td>
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<tr>
<td>Sept. 2010</td>
<td>HDSAM 2.3</td>
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COLD GAS PATHWAY
Cold GH2: Sweet Spot between CcH2 and 700-bar?

### 700-Bar with Booster Compression
- Tubes loaded at terminal with cold GH2 (90k) at 350-bar; return at 14-bar (36k) after unloading
- Tube trailer delivered capacity = 1500 kg
- Smaller station compressor → lower power/energy use
- GH2 rises to 130k at 600-bar at full charge in cascade → higher cascade cost
- GH2 dispensed to vehicle at 190k and 500-bar at full charge
- Higher on-board energy density → longer driving range than 350-bar

### 700-Bar with High Pressure Cascade
- Refrigeration
- 180 Bar
- Storage
- Compression
- Cascade
- 700-Bar Dispensing
- 350-Bar Dispensing

### 350-Bar CcH2 with LH2 Delivery
- LH2
- Storage
- Cryo Pump
- 250–350-Bar CcH2 Dispensing

### 500-Bar Cold Gas
- LH2
- Storage
- Compression
- Cascade
- 500-Bar Dispensing
Fuel Stations Can Account for Half of H2 Delivery Cost. CcH2 and Cold Gas Options Cut Station Cost

- Installed capital of equivalent capacity H2 stations = $0.75–$1.8 million.
- With no refrigeration and cascade and less storage, CcH2 stations shift costs upstream.
- Installed capital and levelized cost of CcH2 station is <50% of 700-bar station.
- LH2 storage > 50% CcH2 installed capital cost.
- 700-bar GH2 with high pressure cascade is less expensive than booster-compressed option (not shown).
- 500-bar cold gas station costs ~$0.50/kg more than CcH2 station dispensing but <700-bar GH2 with cascade charging.
- Station cost for 500-bar cold GH2 and 350-bar GH2 ~$1.40/kg.
- But 500-bar cold GH2 provides > energy density and longer driving range.
- All costs are levelized 2005 $ for delivery only.
Levelized Cost of Delivering 500-Bar Cold GH2 Is Slightly Less Than 350-Bar GH2 or CcH2

Sacramento, 15% Market Penetration, 1000 kg/day Station, 62 miles to City

Cost [$/kg of delivered H2]

- Liquid Truck Delivery
- Tube-trailer Delivery

- Gas Dispensing
- CcH2
- 350 bar Cascade
- 700 bar Cascade
- 500 bar cold gas
FUEL STATION FOOTPRINT
HDSAM Approach and Assumptions

- Calculate land area allocated to hydrogen for cost purposes (land rented @ $0.30/ft²/month → $3000/month for 110’ x 130’)
- Hydrogen dispensers displace gasoline dispensers (up to 6 dispensers)
- Gasoline baseline area extended to accommodate H₂ components (e.g., storage, compressors, > 6 dispensers, etc.), and setback/separation distances
- Land area allocated to hydrogen based on relative number of hydrogen dispensers and any incremental increase in station area; area occupied by c-store not allocated to either gasoline or hydrogen (it generates its own revenue)

Comments from industry infrastructure and logistic experts

- Baseline station footprint (130’ x 110’) is small
  - New gasoline stations average 200’ x 200’ with 6-10 dispensers
  - Bigger c-store + car wash
- Mixed risk from dispensing gasoline and hydrogen under the same canopy
- Truck unloading path should be unobtrusive, not require excessive maneuvering to offload product, and permit at least one 90° turn
- Re-examine setback distances based on NFPA requirements
Code Compliance Could Quadruple Station Size (Not All Allocable to H2) and Increase Cost

- Original TIAA-developed station footprint, 110x130 ft, including gasoline dispensing and C-store
- Alternative footprint, 230x250 ft, including gasoline dispensing, C-store, car wash, 2nd tube trailer bay and “full” compliance with current NFPA requirements
- Alternative footprint adds as much as $1/kg to levelized H2 cost for very small stations, less for larger
- Draft report currently under review
But Revisions, Exemptions or Local Restrictions Could Alter Footprints, Particularly for Early Stations

Shell’s 350-bar West LA. station is very compact with H2 storage above a shared gasoline/hydrogen island.

By contrast, their 700-bar Culver City station separates H2 from gasoline dispensing and incorporates additional safety barriers.

Other stations eliminate C-store and other amenities
Key Assumptions/Scope of Wind-to-LH2 Analysis

- Dedicated 252 MW wind farm producing H2 (no electricity export to grid)
- “Generic case study”: wind site in vicinity of Albuquerque supplying LH2 for ~80,000 LD FCVs in LA (~800 mi)
- Evaluate alternative uses of wind power
- Collaborative effort:
  - NREL: Cost contribution of wind turbines, accessories and electrolyzers in H2 production; cost of H2 transport by rail
  - ANL: cost contribution of liquefaction, line-haul truck transportation and distribution to LA H2 fueling stations; energy and GHG assessment
  - PNNL: review and quality assurance
- Joint report will document results (Sept. 2010)

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<thead>
<tr>
<th>Component</th>
<th>Capacity</th>
<th>Other</th>
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<tr>
<td>Turbines (84)</td>
<td>3MW rated 106 MW</td>
<td>42% CF (106 MW output)</td>
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<tr>
<td>Electrolyzer</td>
<td>160,000 kW ac max</td>
<td>55 kWh/kg/1000/kg alkaline</td>
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<tr>
<td>GH2 storage</td>
<td>4,000,000 kg</td>
<td>Saline cavern</td>
</tr>
<tr>
<td>Liquefier</td>
<td>40 tpd</td>
<td>10 kWh/kg</td>
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<tr>
<td>LH2 truck</td>
<td>4200 kg</td>
<td></td>
</tr>
<tr>
<td>H2 fuel stations</td>
<td>400 kg/d</td>
<td>At city gate terminal</td>
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<tr>
<td>LH2 storage</td>
<td>3x daily demand</td>
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Wind-to-LH2 Levelized Cost May Be Higher But GHG Emissions Are Lower Than Selected Alternative H2 Pathways

- Compared 5 pathways: Albuquerque-to-LA via wind-to LH2, SMR-to-LH2 and electrolysis-to-LH2; centralized production in LA via SMR and electrolysis.
- Largest cost is production, followed by liquefaction and fuel station.
- Albuquerque-based production assumes LH2 truck transmission, excluding labor cost for 2nd driver.
- 9g/MJ (18 g/mi) WTW GHG emissions for wind-to-LH2 FCV.
- 446 g/MJ GHG (890 g/mi) WTW for gasoline light-duty vehicle.
## Future Work

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<tr>
<td>September 2010</td>
<td>Post HDSAM 2.3. Enhancements include cold gas tube trailer delivery and revised station and terminal footprints.</td>
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<tr>
<td>December 2010</td>
<td>Complete Phase 2 of wind-to-LH2 analysis. Analyze additional options in report for external review.</td>
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<tr>
<td>June 2011</td>
<td>Investigate advanced compression; geologic and other options for bulk H2 storage; additional markets; incorporate necessary updates to HDSAM.</td>
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<tr>
<td>September 2011</td>
<td>Analyze other renewable hydrogen options using HDSAM and related tools.</td>
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Relevance: Provide platform to evaluate hydrogen delivery (in $, energy and GHG emissions), estimate impact of alternative conditioning, distribution and storage options; incorporate advanced options as data become available; assist Hydrogen Program in target setting.

Approach: Develop models of hydrogen delivery components and systems to quantify costs and analyze alternative technologies and operating strategies.

Collaborations: Active partnership among ANL, NREL and PNNL, plus regular interaction with Fuel Pathways and Delivery Tech Teams, DOE researchers and industry analysts.

Technical accomplishments and progress:
- Version 2.2 of HDSAM completed and posted
- Cold gas pathway defined, analysis and coding begun
- Fuel station and terminal footprints re-evaluated
- Analysis of wind-to-LH2 renewable pathway begun

Future Research: Expand models to include new options (advanced compression, storage) revise/update data and respond to Tech Team recommendations, analyze renewable hydrogen or other options.