2010 DOE Hydrogen Program Review

Hydrogen Delivery Infrastructure Analysis

Marianne Mintz and Amgad Elgowainy
Argonne National Laboratory

June 9, 2010

Argonne NATIONAL LABORATORY

PD014

Overview

Timeline

- Start: FY 2007
- End: Continuous

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

Budget

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

Partners

- Argonne National Lab
- National Renewable Energy Lab
- Pacific Northwest National Lab

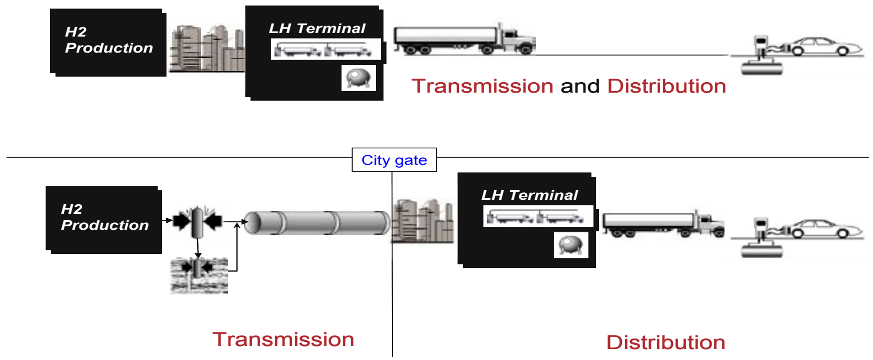
Relevance

- 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

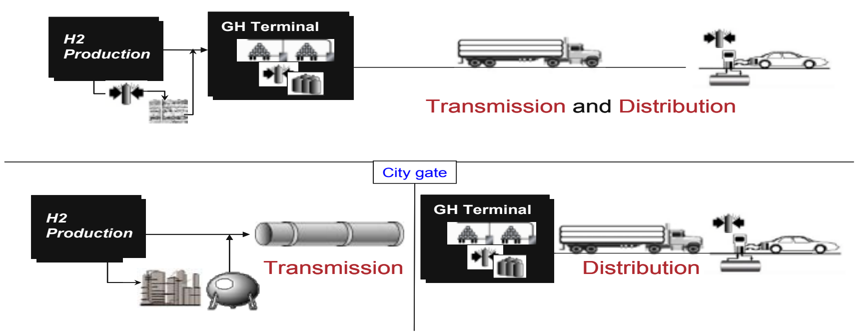
- Create **transparent, flexible, user-friendly, spreadsheet-based tool (HDSAM)** to examine new technology, operating and packaging options for hydrogen delivery
- Provide modeling structure to automatically link and size components into **optimized pathways** to satisfy requirements of scenarios, and 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



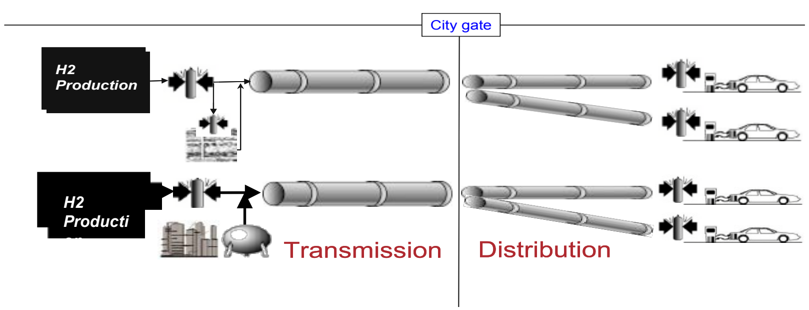
Liquid H2 Distribution Pathways

- Bulk geologic or liquid hydrogen storage
- Pipeline or truck transmission
- Urban, interstate or combined markets
- 50-60,00 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

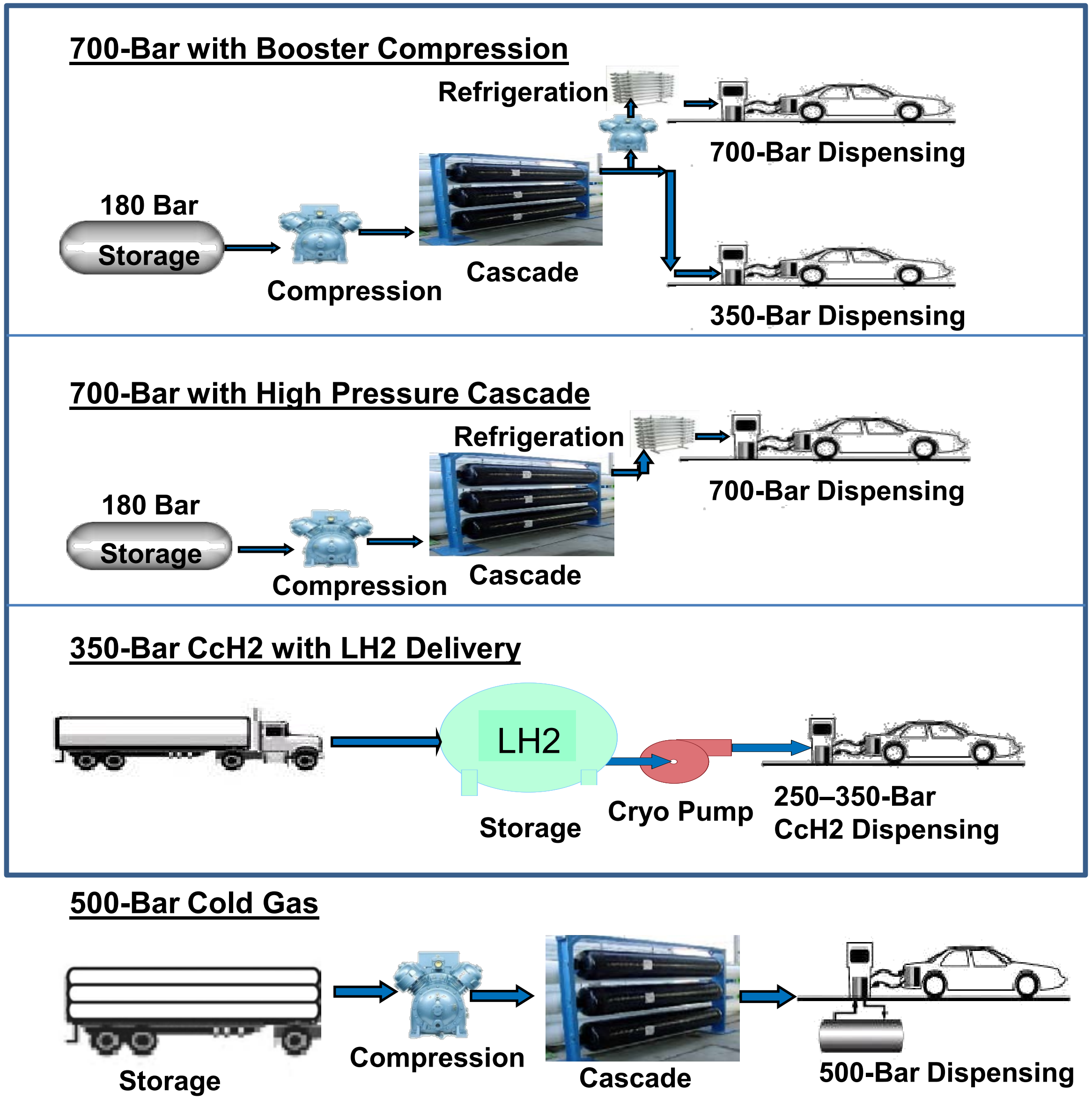
- Bulk geologic or liquid hydrogen storage
- Urban, interstate or combined markets
- 50-6000 kg/d GH2 fuel stations
- 350- or 700-bar dispensing (cascade or boost compressor)
- + 700-bar dispensing (cascade or boost compressor)

FY2010 Accomplishments

Month/Year	Milestone
March 2010	**Cold hydrogen gas delivery**
April 2010	**Fuel station footprint analysis**
May 2010	**Posted Version 2.2 of Hydrogen Delivery Scenario Analysis Model (HDSAM 2.2)**
Sept. 2010	**Wind-to-LH2 analysis**
Continuous	IEA Task 28 support (May 2010 startup)
Sept. 2010	HDSAM 2.3

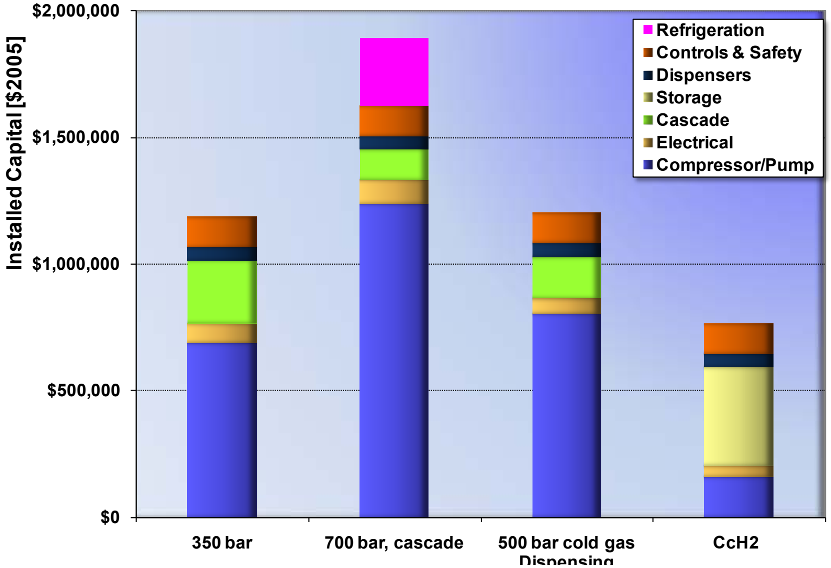
COLD GAS PATHWAY

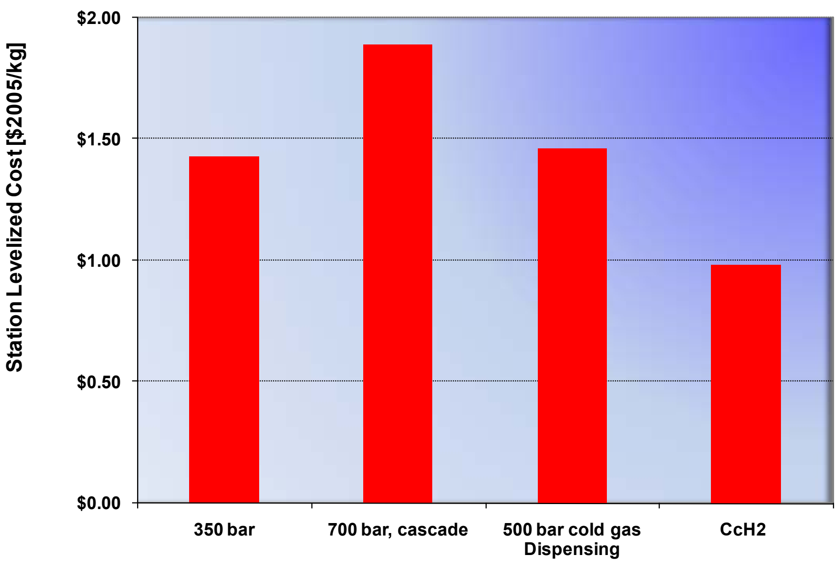
Cold GH2: Sweet Spot between CcH2 and 700-bar?



- 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 to130k 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

Fuel Stations Can Account for Half of H2 Delivery Cost. CcH2 and Cold Gas Options Cut Station Cost

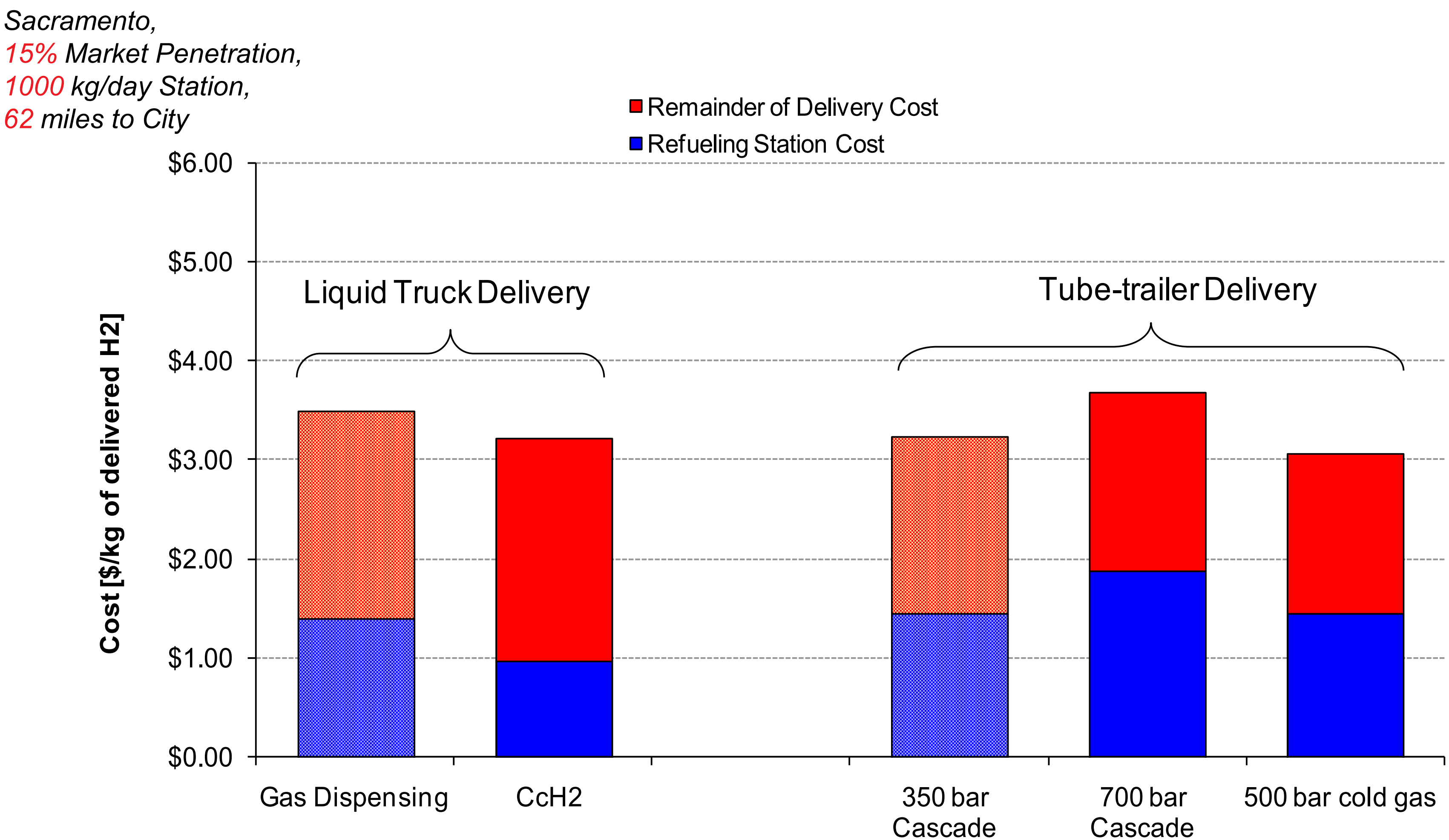




- Installed capital of equivalent capacity H2 stations = $0.75–$1.8 million.
- With no refrigeration and cascade and less storage, CcH2 stations shift costs upstream.
- Installed capital and levelized cost of CcH2 station is <50% of 700-bar station.
- LH2 storage > 50% CcH2 installed capital cost.
- 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



FUEL STATION FOOTPRINT

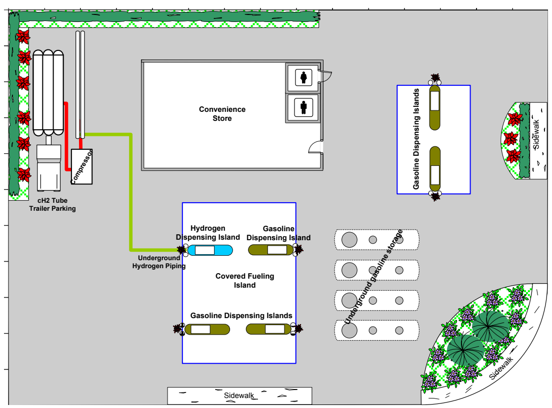
HDSAM Approach and Assumptions

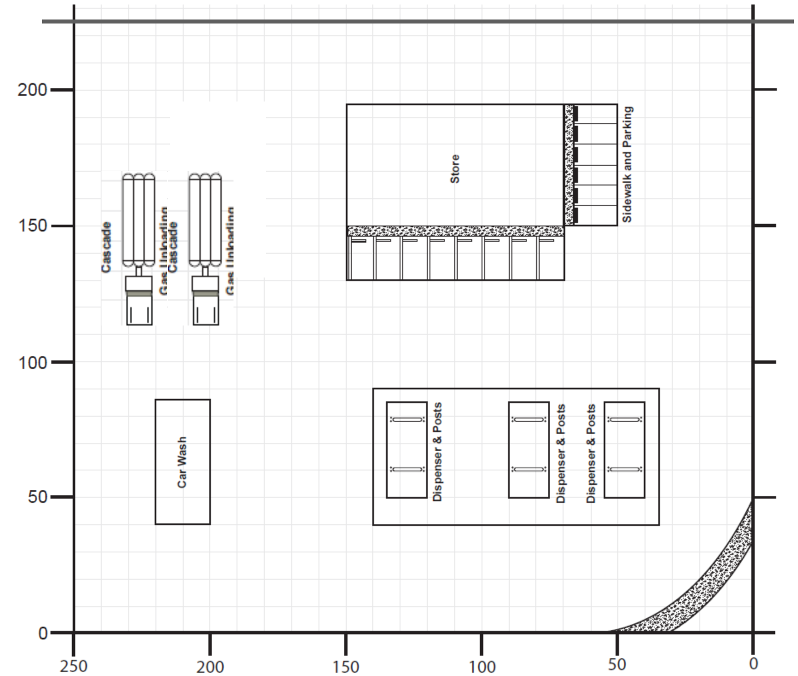
- Calculate land area allocated to hydrogen for cost purposes (land rented @ $0.30/ft^2/month → $3000/month for 110' x 130')
- Hydrogen dispensers displace gasoline dispensers (up to 6 dispensers)
- Gasoline baseline area extended to accommodate H2 components (e.g., storage, compressors, > 6 dispensers, 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^o turn
- Re-examine setback distances based on NFPA requirements

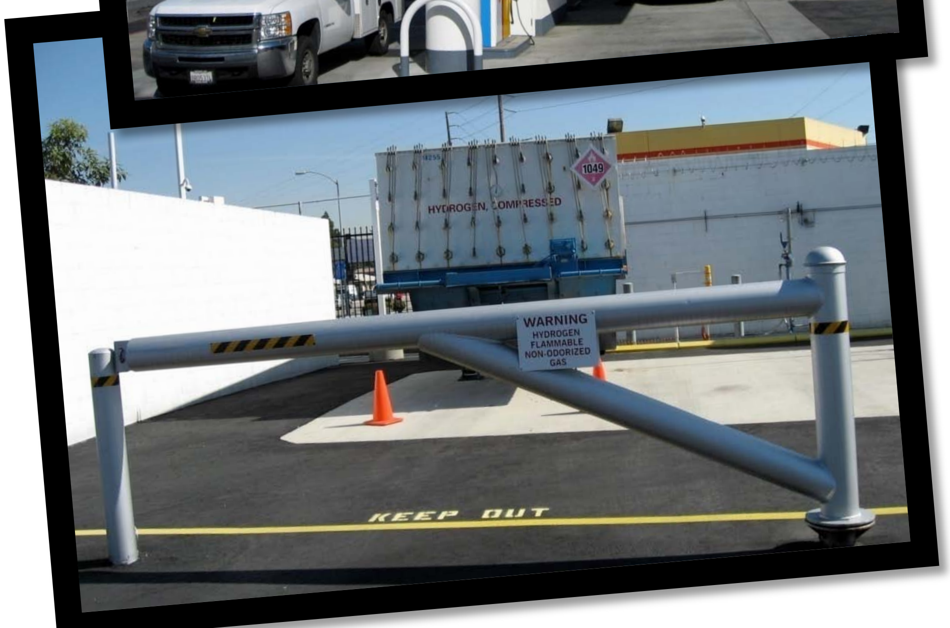
Code Compliance Could Quadruple Station Size (Not All Allocable to H2) and Increase Cost





- Original TIAX-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

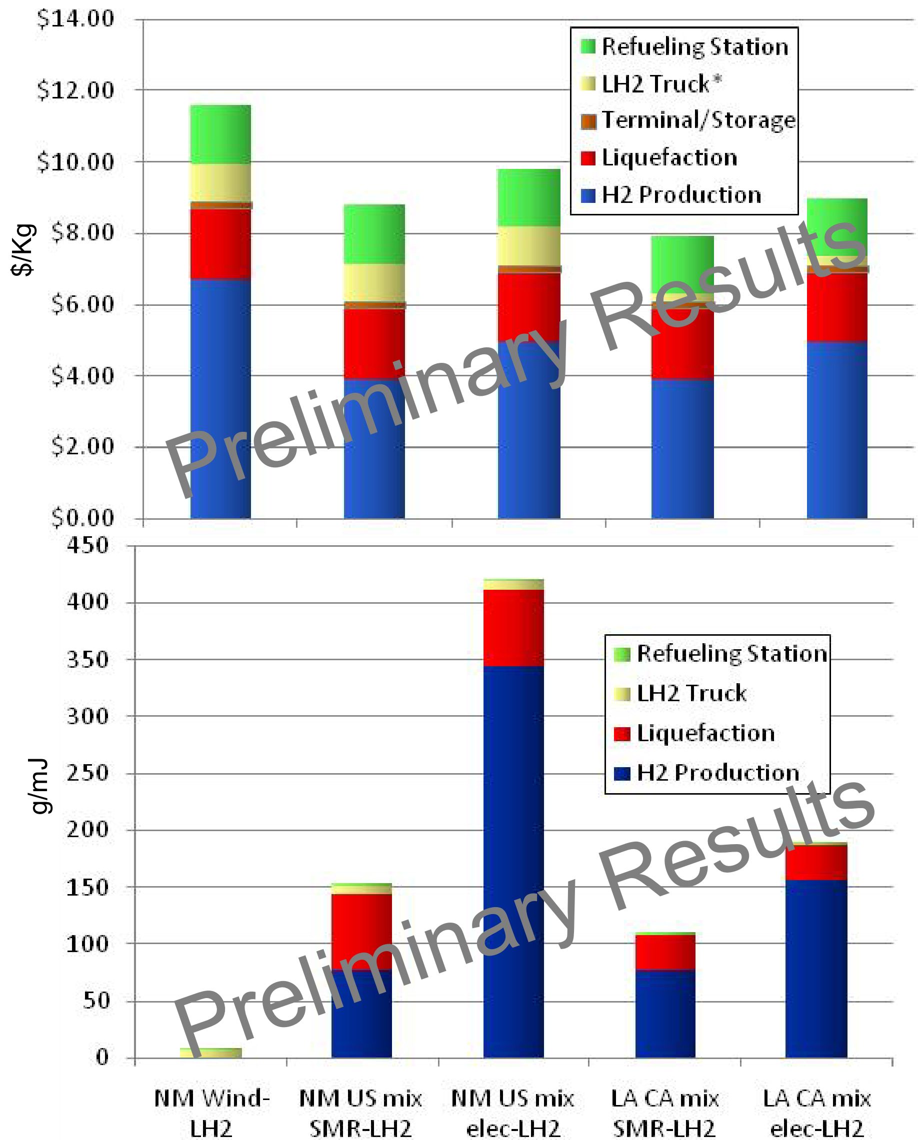
WIND-TO-LH2 ANALYSIS

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)

Assumptions		
Component	Capacity	Other
Turbines (84)	3MW rated 106 MW	42% CF (106 MW output)
Electrolyzer	160,000 kW ac max	55 kWhr/kW alkaline
GH2 storage	4,000,000 kg	Saline cavern
Liquefier	40 tpd	10 kWh/kg $1000/kg
LH2 truck	4200 kg	
H2 fuel stations	400 kg/d	
LH2 storage	3x daily demand	At city gate terminal

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

Month/Year	Milestone
September 2010	Post HDSAM 2.3. Enhancements include cold gas tube trailer delivery and revised station and terminal footprints.
December 2010	Complete Phase 2 of wind-to-LH2 analysis. Analyze additional options in report for external review.
June 2011	Investigate advanced compression; geologic and other options for bulk H2 storage; additional markets; incorporate necessary updates to HDSAM.
September 2011	Analyze other renewable hydrogen options using HDSAM and related tools.

Project Summary

- **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.

Pacific Northwest National Laboratory

NREL

Argonne NATIONAL LABORATORY

Marianne Mintz
mmintz@anl.gov
Project PD014