National Renewable Energy Laboratory
Innovation for Our Energy Future

H2A Delivery Analysis and H2A Delivery Components Model

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Overview

Timeline

- *Start date:* FY 2004
- *End date:* FY 2012

Budget

- Funding: 100% DOE Funded
- FY09: $200K
- FY10: $150K

Barriers

- Lack of hydrogen/carrier and infrastructure option analysis (3.2 A)
- Gaseous hydrogen storage and tube trailer delivery costs (3.2 F)

Partners

- Argonne National Lab
- Pacific Northwest National Lab
- Nexant, Inc.
- TIAX
- GTI
- Chevron
- Air Liquide
- Linde
- DTI

Relevance: Objectives

Project Objectives

- Update and maintain the H2A Delivery Components Model
- Provide cost analysis on hydrogen delivery infrastructure
- Support other models and analysis that include delivery costs
- Expand H2A Components Model by designing new components

MYPP

Activities: Development of the H2A Delivery Components and Scenario Models, MYPP, 2007, p. 3.2-9

Analysis: Comprehensive cost and environmental analyses for all delivery options as function of demand, MYPP, 2007, p. 3.2-9

Outputs: D3. Output to System Analysis and System Integration: Hydrogen delivery infrastructure analysis results, MYPP, 2007, p. 3.2-29

Approach

Since 2004 – the project introduction – we have followed the general H2A approach and guidelines:

- ✓ Collaborating closely with industry to get and update costs and tech specs in the models
- ✓ Keeping consistency of the cost inputs across all H2A models
- ✓ Employing H2A standard assumptions *
- ✓ Maintaining models as publicly available

* http://www.hydrogen.energy.gov/h2a_analysis.html#h2a_project

Approach: Barriers Addressed

Barrier 3.2 A: Lack of Hydrogen/Carrier and Infrastructure Option Analysis
"Additional analysis is needed to better understand the advantages and disadvantages of the various possible approaches." (p. 3.2-18)

Barrier 3.2 F: **Gaseous Hydrogen Storage and Tube Trailer Delivery Costs** "Approaches include increasing the storage pressure, utilizing cold hydrogen gas, and/or utilizing a solid carrier material in the storage vessel. The same technology approaches could be utilized for gaseous tube trailers making them much more attractive for hydrogen transport and distribution." (p. 3.2-20)

Milestone 12
"By 2017, reduce the cost of hydrogen delivery from the point of production to the point of use at refueling sites to < $1/gge" (p. 3.2-26)

APPROACH

- Developing new H2 delivery option: rail delivery components
- Analyzing a possibility to deliver H2 via existing CNG infrastructure
- Building the model capable of calculating delivery costs from multiple sources to multiple demand centers
- Multi-node delivery model will also include storage sharing capability between demand centers, providing overall storage cost decrease
- Analyzing a possibility for delivering H2 by truck-trailer in composite tubes instead of metal tubes – increased capacity

Approach: Milestones

Milestone	% of completion, as of March 31, 2010
H2A Delivery Components Model update: finalize changes to the 700 bar and cryo-compressed dispensing options	95% complete Expected completion: end of April 2010
Hydrogen rail delivery cost analysis	50% complete Expected completion: end of FY10
Multi-node delivery scenario model development, stage 1 and 2	50% complete Expected completion: end of June 2010
Review: go/no go decision on delivering hydrogen via natural gas pipelines	10% complete Expected completion: end of FY10

Technical Accomplishments and Progress

Outline

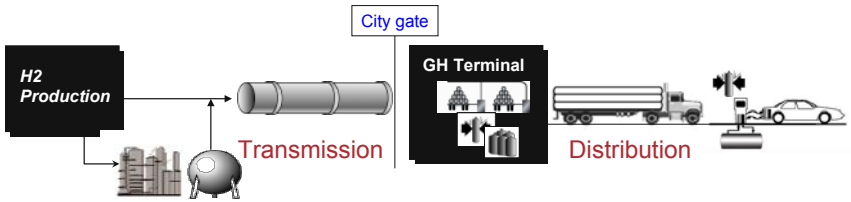
- H2A Components Model upgrade and cost analysis
- Rail components development and cost analysis
- Building new components for GH2 delivery using composite tubes
- Building multi-node delivery scenario model

Technical Accomplishments and Progress

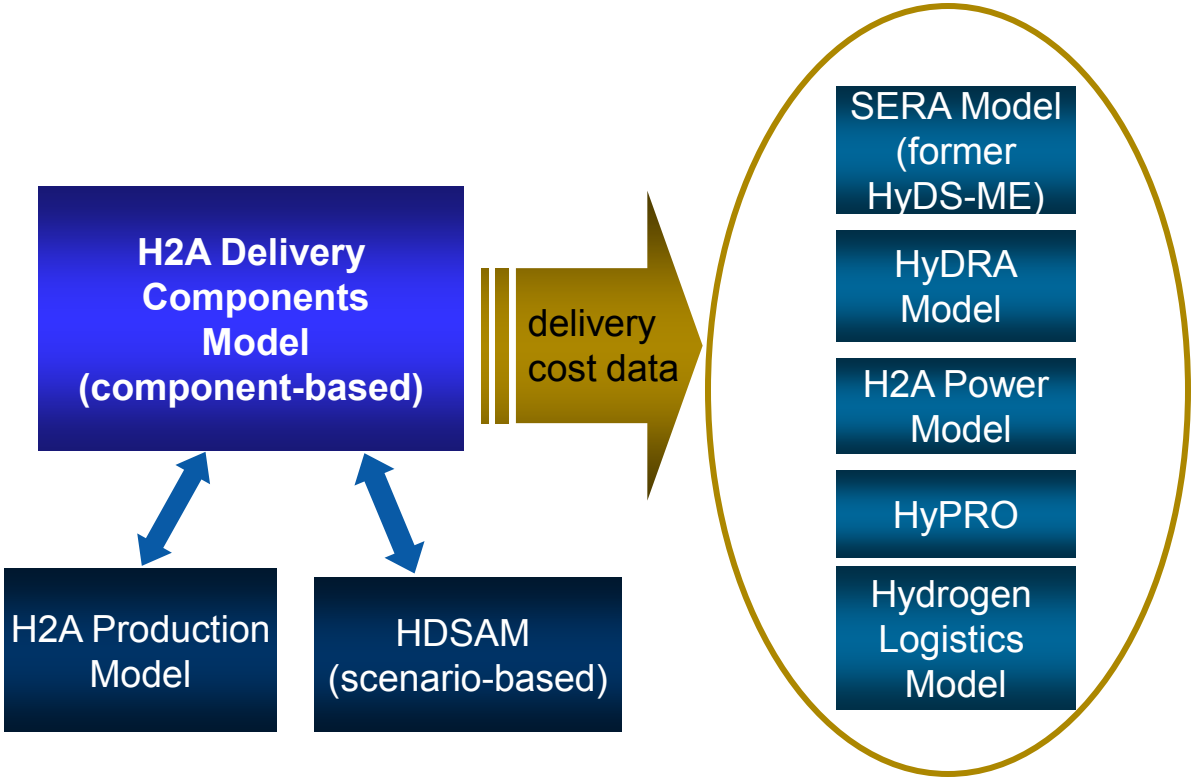
H2A Components Model Upgrade and Cost Analysis

Technical Accomplishments and Progress

H2A Delivery Components Model Overview



Relation to Other Models



H2A Delivery Components Model provides costs for hydrogen delivery components

- Excel based (available to public)
- Flexible
- Can be used to provide inputs for spatially and temporally detailed models

Technical Accomplishments and Progress

H2A Delivery Components Model Upgrade

GH2 Refueling Station Upgrade

Dispensing pressure **350 bar** **700 bar**

Dispensing type cascade cascade booster compressor

Tube pressure 180 atm 480 atm 180 atm 480 atm 180 atm 480 atm

LH2 Refueling Station Upgrade

2 dispensing options:

- gas
- liquid or cryo-compressed

Simple Design
Storage
Cryo-Pump
Dispenser

GH2 Tube-Trailer Upgrade

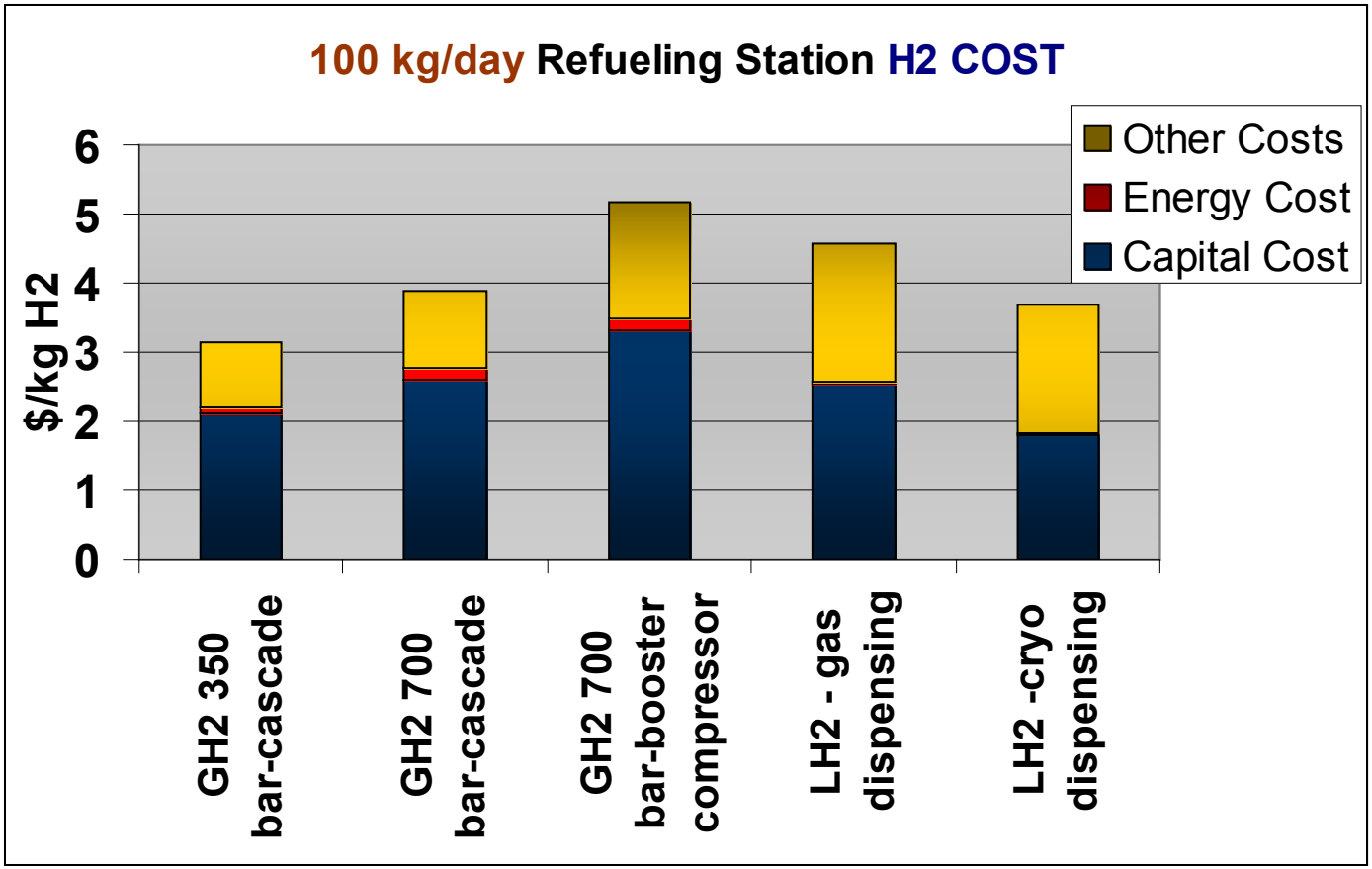
2 options for tube pressure:

- 180 atm
- 480 atm

Technical Accomplishments and Progress

H2A Delivery Components Model Upgrade

Impact on Refueling Station Upgrade

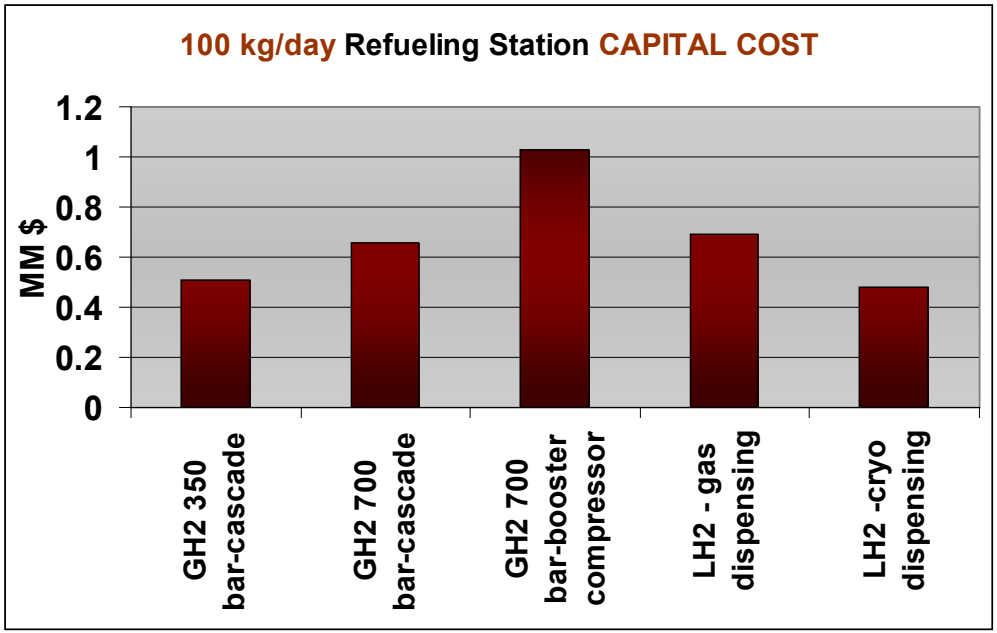


Technical Accomplishments and Progress

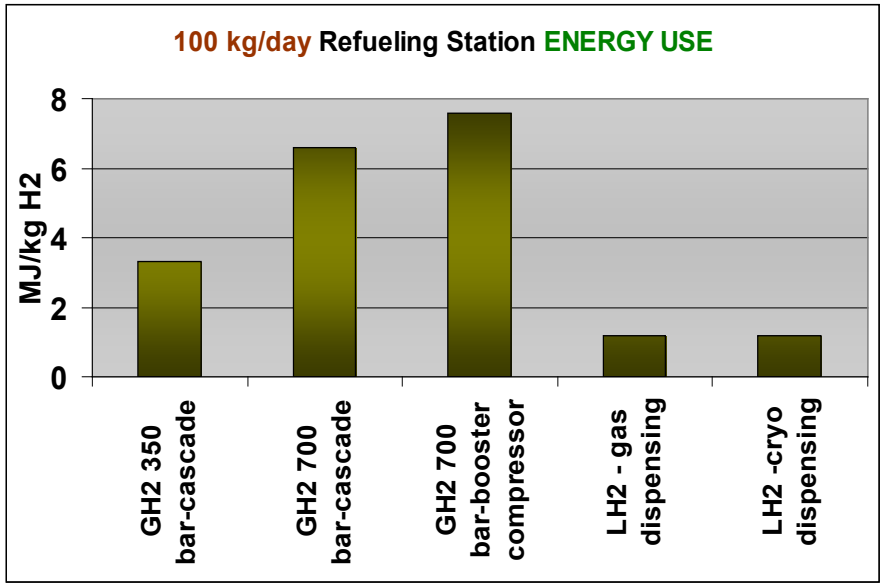
H2A Delivery Components Model Upgrade

Impact on Refueling Station Upgrade

How much initial investment needed?



How energy-effective?

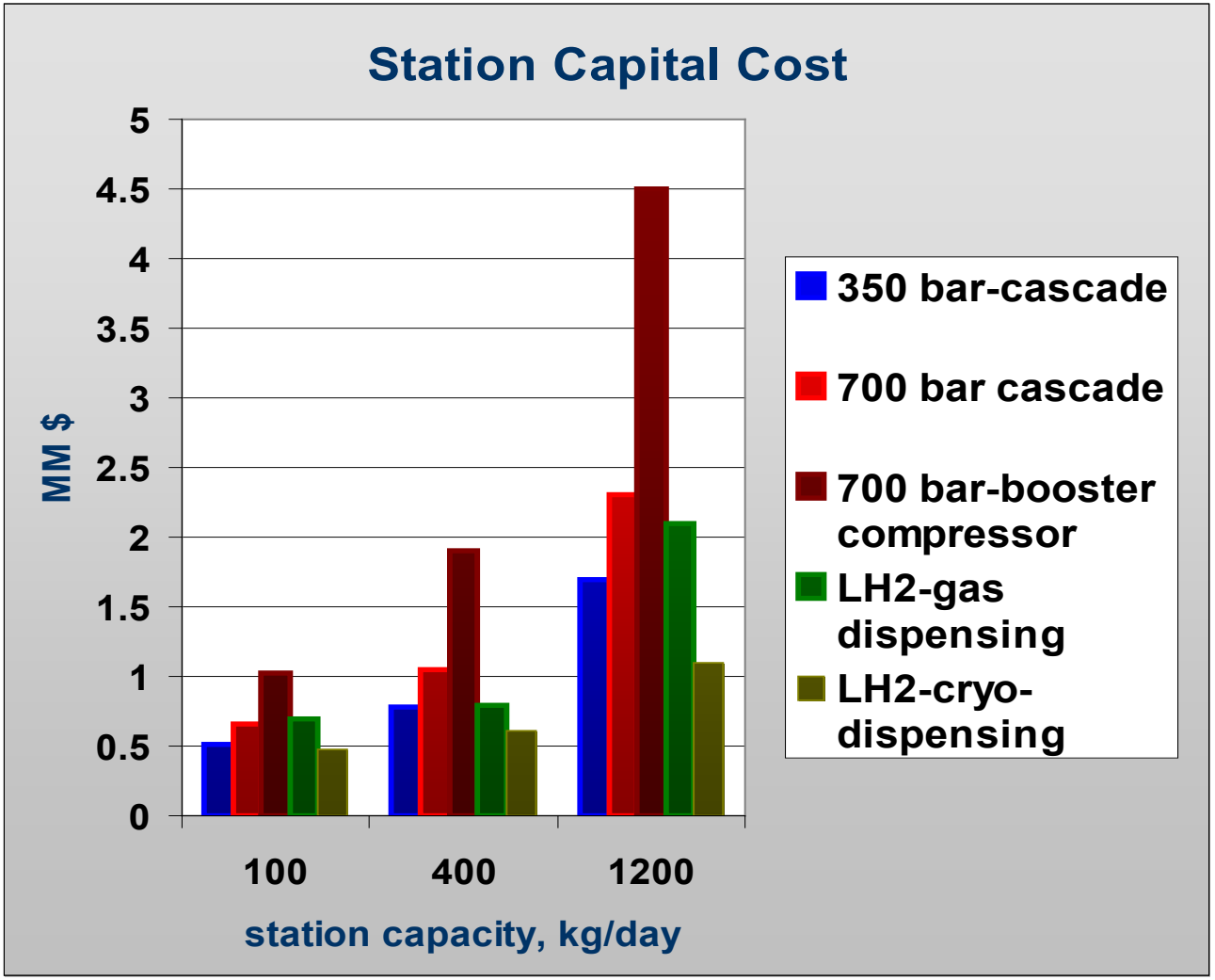


Technical Accomplishments and Progress

H2A Delivery Components Model Upgrade

Larger Station – Bigger Investment

Station Size Comparison



Near-term: 100 kg/day

Mid-term: 400 kg/day

Long-term: 1200 kg/day

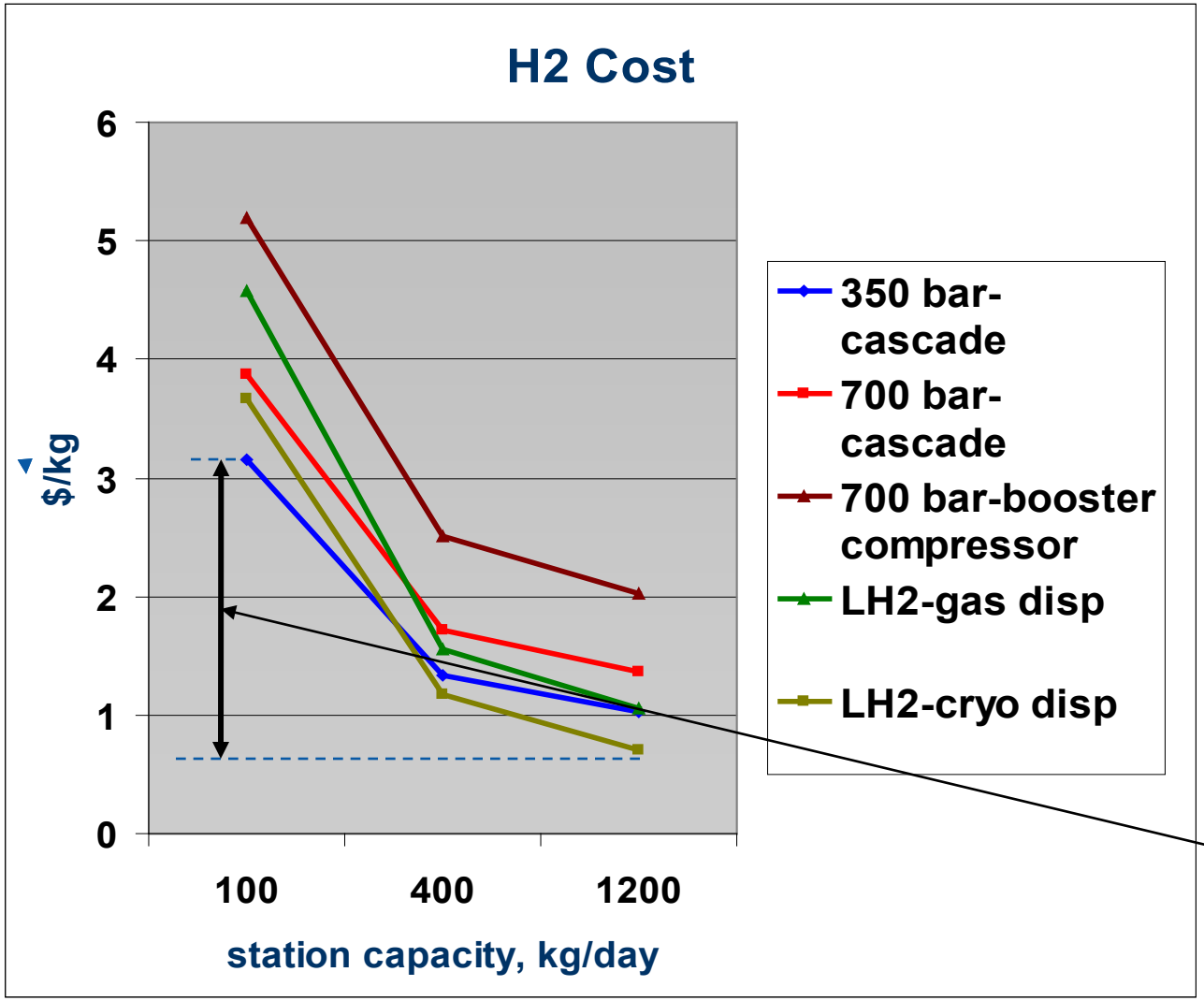
Cryo-compressed station is the cheapest and has the simplest design

Technical Accomplishments and Progress

H2A Delivery Components Model Upgrade

The larger the station – the cheaper the H2

Station Size Comparison



Near-term: 100 kg/day

Mid-term: 400 kg/day

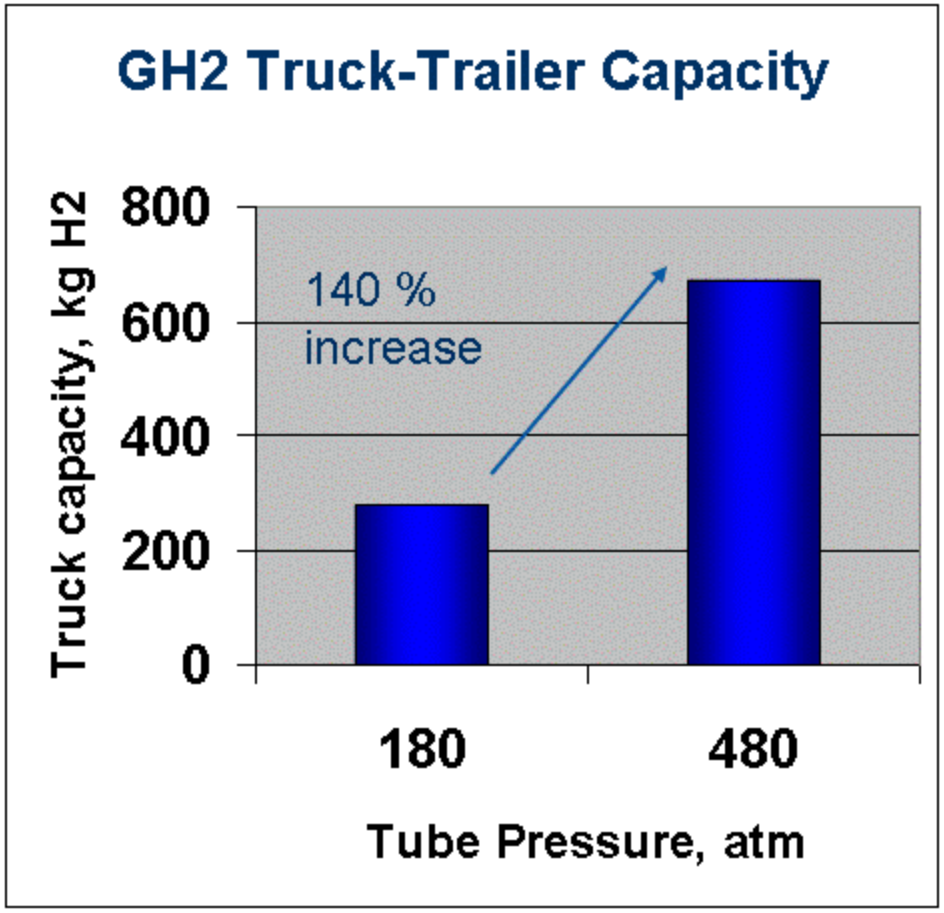
Long-term: 1200 kg/day

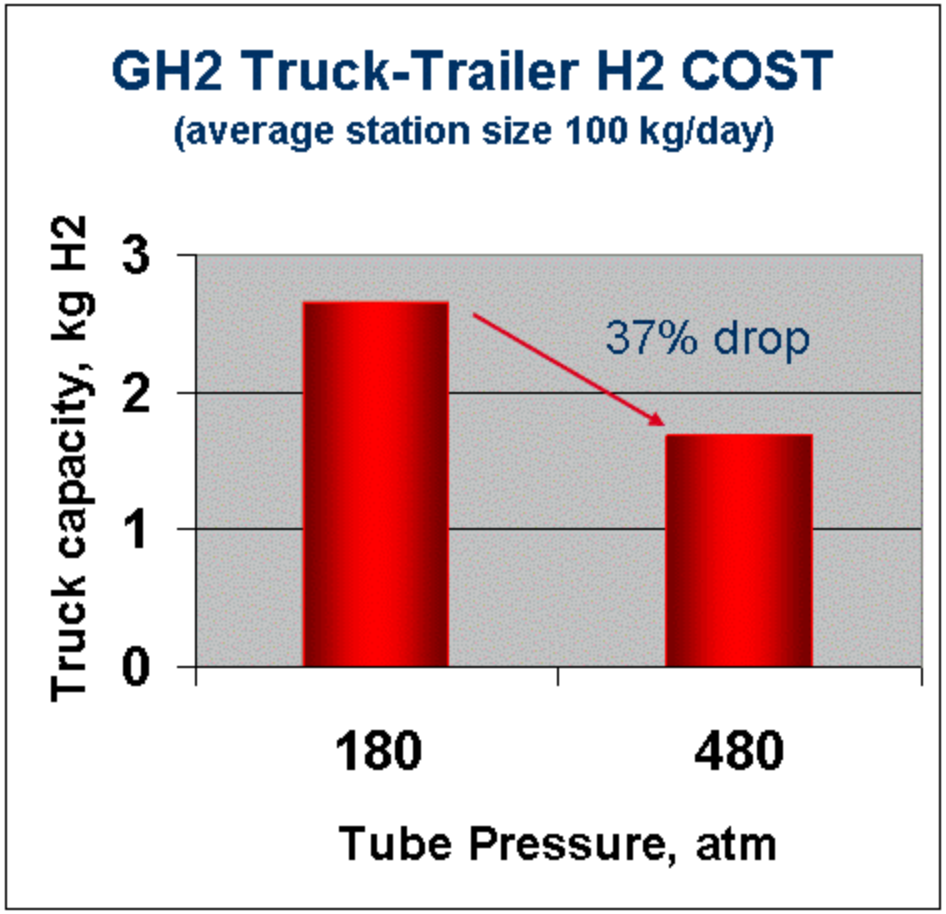
H2 cost drop by Δ=$2.5/kg

Technical Accomplishments and Progress

H2A Delivery Components Model Upgrade

Gaseous H2 Tube Trailer





Rail Components Development and Update

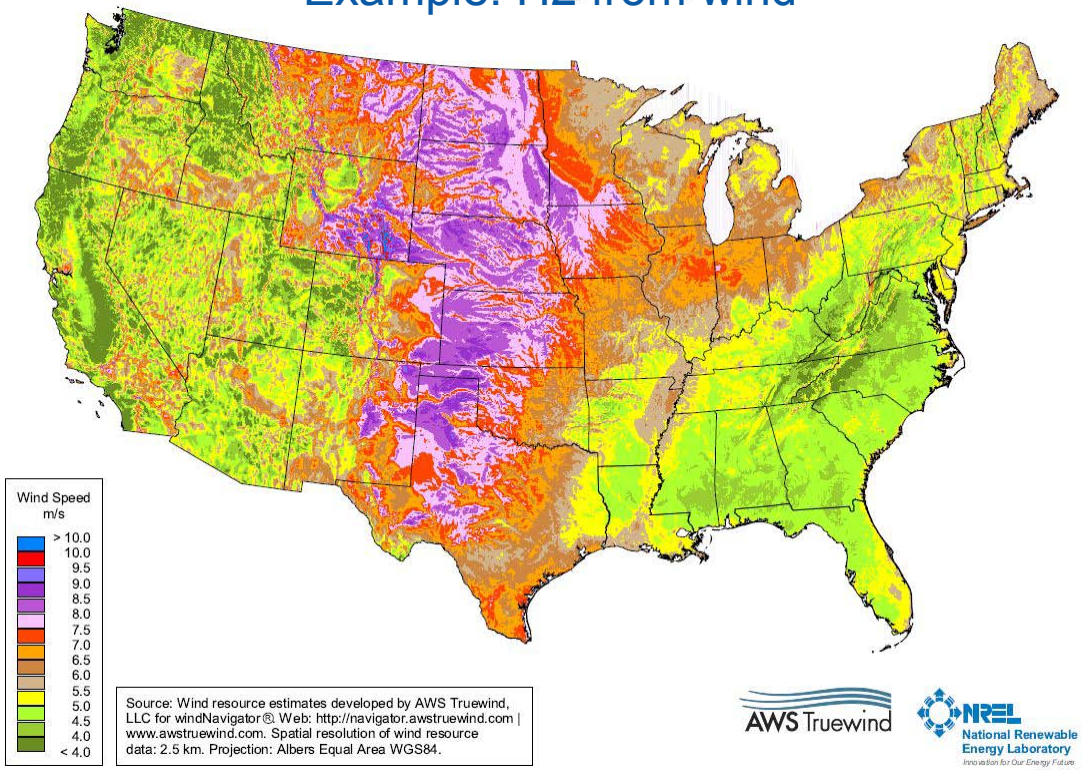
Technical Accomplishments and Progress

H2 Rail Delivery

WHY RAIL?

Rail delivery may be the most economical option for delivering hydrogen made from renewable sources (long distances + high demand)

Example: H2 from wind



Estimates of wind energy potential in purple/red band states* :

86% of total U.S. installed capacity** (8,989 GW)

Estimated annual generation:

32.4 millions GWh

* IA, KS, MN, MT, NE, NM, ND, OK, SD, TX, WY

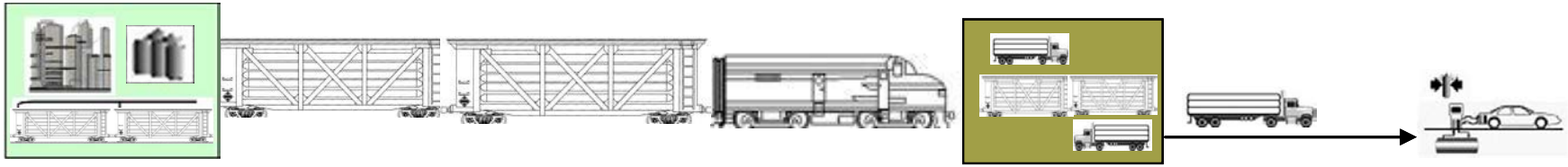
* * 30% capacity factor at 80 m above ground, assumes 5 MW/km^2 of installed nameplate capacity

Source: http://www.windpoweringamerica.gov/pdfs/wind_maps.asp

Technical Accomplishments and Progress

H2 Rail Delivery Pathways

Gaseous Hydrogen Rail Delivery

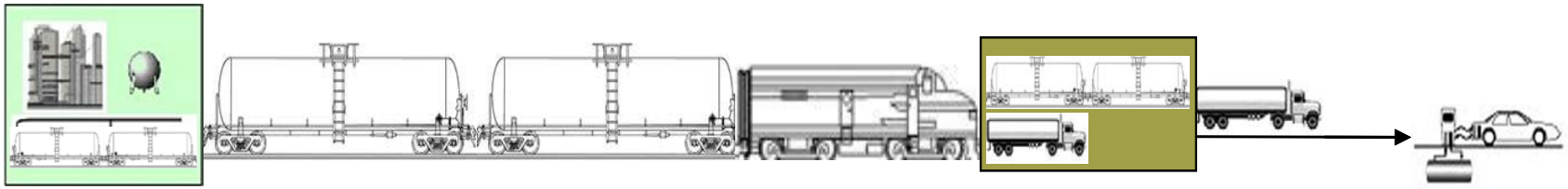


Gaseous Production Site Terminal

Gaseous City Gate Terminal

Gaseous Refueling Station

Liquid Hydrogen Rail Delivery



Liquid Production Site Terminal

Liquid City Gate Terminal

Liquid Refueling Station

Technical Accomplishments and Progress

H2 Rail Delivery Components Update

- ✓ Two independent reviews (by DTI and PNNL) of the H2 rail delivery components were conducted. The comments and suggestions were incorporated in the updated model.

- ✓ NREL delivery team collaborated with multiple industry companies in order to refine the input cost and technical data, and to get a better understanding of the logistics of rail delivery:

  - Freight data, logistics (Union Pacific Railroads)
  - Railcar leasing costs (GE Rail Leasing)
  - Intermodal rail crane cost and technical specs (Konecranes Heavy Lifting Company, Paceco)

Technical Accomplishments and Progress

New Components Using Composite Tubes Development

and

Comparative Delivery Cost Analysis

Technical Accomplishments and Progress

New Components: Composite Tubes

To estimate delivery costs using composite tubes, 7 new components were added to the H2A Delivery Components Model

1. **GH2 Rail Production Plant Terminal-Composite Tubes** (filling up composite tubes)
2. **GH2 Rail Transport-Composite Tubes** (delivering composite tubes with H2)
3. **GH2 Rail City Gate Terminal-Composite Tubes** (reloading composite tubes to the truck trailer)
4. **Pipeline-GH2 Truck City Gate Terminal-Composite Tubes** (pumping H2 into composite tubes)
5. **GH2 Truck-Trailer Terminal-Composite Tubes** (filling up composite tubes)
6. **GH2 Truck Transport-Composite Tubes** (accommodating composite tubes delivery)
7. **GH2 Refueling Station-Composite Tubes** (accommodating changes in tube pressure and truck capacity)

All pathway costs involving composite tubes are preliminary

Technical Accomplishments and Progress

Rail Components Upgrade

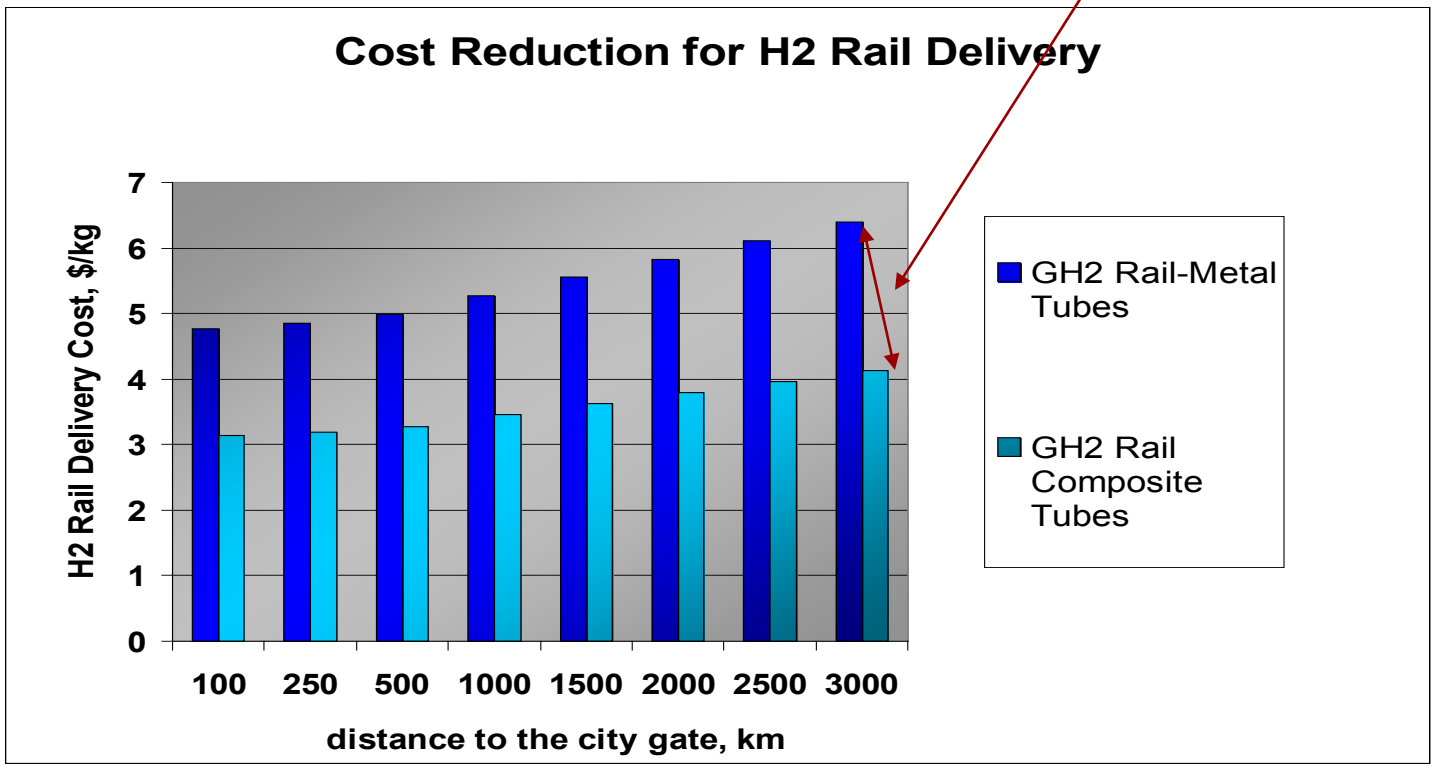
Rail: From **metal** tubes to **composite** tubes

Increased railcar capacity:

Metal tubes – 2680 kg of H2

Composite tubes – 4400 kg of H2

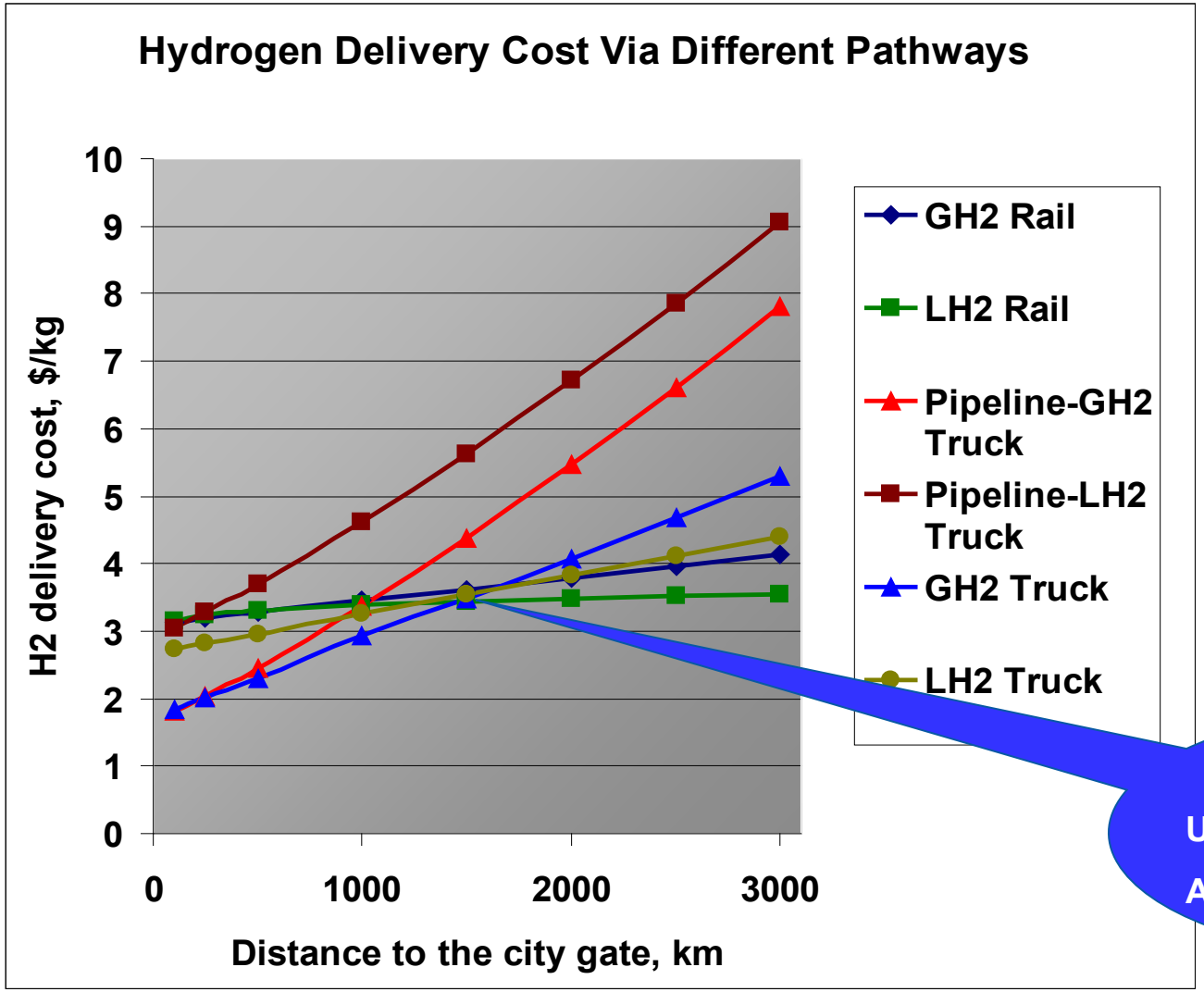
33 % H2 cost reduction for GH2 Rail Delivery



Technical Accomplishments and Progress

Cost Analysis

Distance sensitivity to the delivery cost: composite tubes



City demand:
100 tonnes/day

Average refueling station size: 1200 kg/day

GH2: 350 bar dispensing

LH2: cryo-compressed dispensing

LEAST COST PATHWAY

Up to 1500 km – GH2 Truck

Above 1500 km – LH2 Rail

Building Multi-Node Delivery Scenario Model

Technical Accomplishments and Progress

Building Multi-Node Scenario Model

Multi-Node Delivery

from	*to*
multiple plants	single city
multiple plants	multiple cities
single plant	multiple cities

Flexibility

- Storage sharing
- Branched pipeline networks

Approach

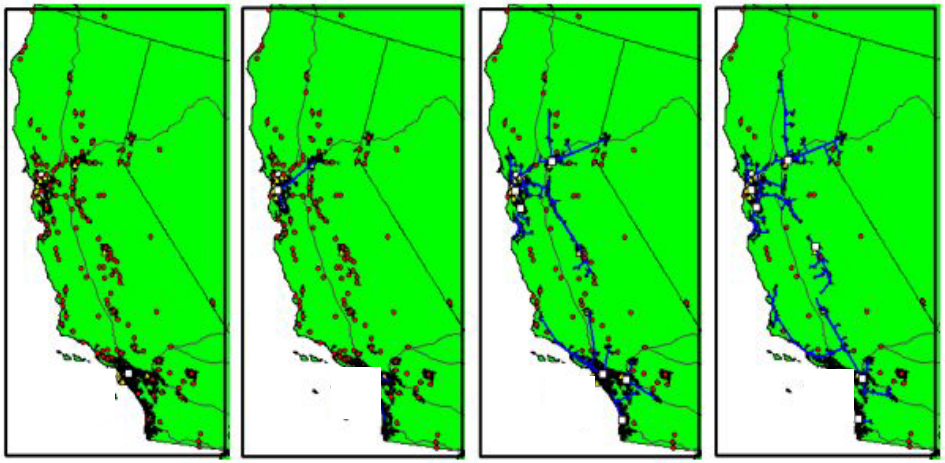
- Using SERA Model (former HyDS-ME) – geo-resolution and optimization
- Substitute cost curves with the delivery component build-ups inside of SERA
- By applying the above, get the flexibility to place components at different geographical locations
- Calculate optimal network and storage
- Trace network evolution
- Develop optimal multi-node scenarios

Technical Accomplishments and Progress

Building Multi-Node Scenario Model

What is SERA Model?

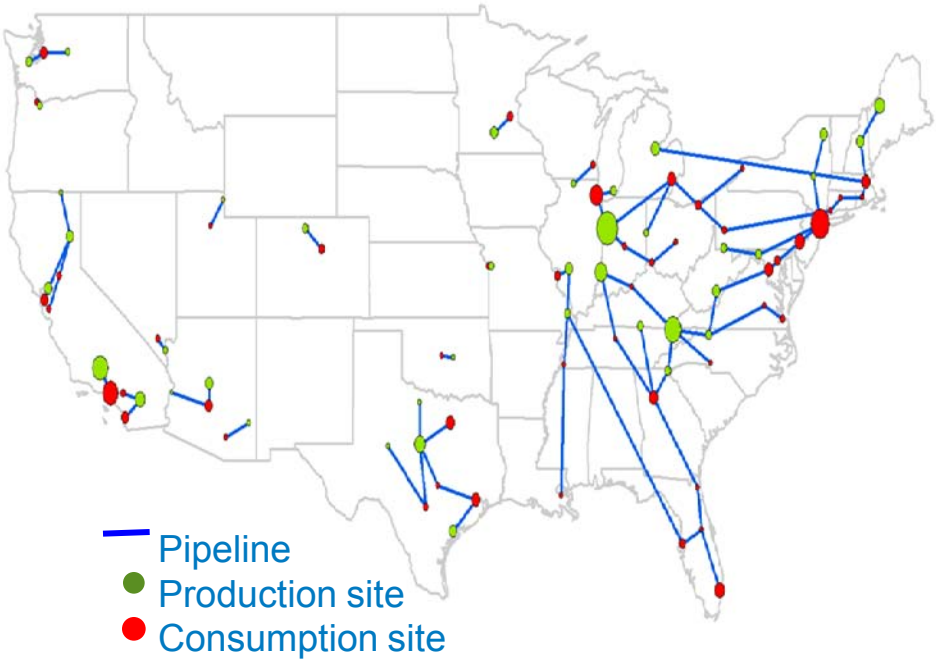
GIS-based DYNAMIC optimization model determines the optimal production and delivery infrastructure build-outs for hydrogen, given resource availability and technology cost.



a. 5% b. 10% c. 50% d. 100%

Hydrogen infrastructure at various demand levels

Optimal H2 pipeline network build-out example: H2 from Wind Study



– B. Bush, M. Melaina, O. Sozinova, "Optimal Regional Layout of Least-Cost Hydrogen Infrastructure," National Hydrogen Association Conference & Expo 2009.

Technical Accomplishments and Progress

Building Multi-Node Scenario Model

Stage 1: Build delivery components inside SERA

Four components were coded:

- Pipeline Compressor
- Pipeline Transport
- Geological Storage
- Pipeline-GH2 Truck City Gate Terminal.

Future Work

Building Multi-Node Scenario Model

FY10

Stage 2: Restructure SERA for allowing branched pipelines

FY11

Stage 3: Optimize delivery networks

- Use restructured SERA Model to perform calculations for identifying optimal infrastructure layout
- Identify possible pipeline branching points and storage sharing points

Stage 4: Develop multi-node delivery scenarios

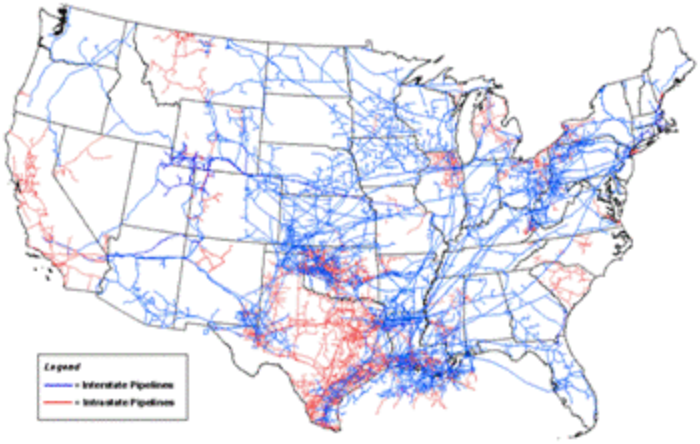
- Use the learning curve from Stage 3 to develop multi-node delivery scenarios

Future Work

Go/ No Go Decision on using Natural Gas Pipelines for Delivering Hydrogen

Is it feasible to use NG pipelines for delivering hydrogen?

Target: Review available studies on adding hydrogen (pure or as a mixture with other gases) to the natural gas pipelines



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Focus:

- Life cycle assessment
- Safety
- Leakage assessment
- Durability
- Integrity
- End use: separation, quality
- Impacts: environmental and macroeconomic benefits

Milestone Due: Completion expected by the end of FY10

Future Work

FY10 – FY11

On-going efforts

- Update and maintain H2A Delivery Components Model
- Update rail delivery components
- Refine delivery components involving composite tubes

Build-up Hydrogen-From-Wind Scenarios

- Identify near term largest demand centers
- Identify potential wind production sites with maximized capacity pertinent to the above demand areas
- Evaluate storage capacity and locations based on actual wind profiles
- Optimize wind farm size for allowing electricity-from-wind use to liquefy hydrogen
- Analyze delivery options for H2 from wind

Collaborations

Industry

- Linde
- Air Products
- GE Rail Leasing
- Lincoln Composites
- Union Pacific Railroad
- Konecranes Heavy Lifting Company
- Paceco Corporation

(technical and cost inputs)

National Labs

- Marianne Mintz - ANL (Delivery Analysis)
- Amgad Elgowainy - ANL (HDSAM)
- Brian Bush - NREL (SERA)
- Daryl Brown - PNNL (Model Review)
- Darlene Steward - NREL (H2A Production Model)
- Mike Penev - NREL (H2A Power Model)

(data exchange and review)

Other Companies

- DTI (HyPro Model) *(data exchange and review)*
- TIAX (Logistics Model) *(data exchange and review)*
- GTI *(subcontract)*

Summary

Relevance

- Project activities follow the DOE H2 Program targets

Approach

- Project follows H2A general approach and guidelines

Accomplishments

- Rail delivery components update with new freight and cost input data
- H2A Components Model upgrade with 700 bar and cryo-compressed dispensing
- Designed seven new delivery components for using composite tubes
- Performed comparative cost analysis for various delivery pathways
- Built up four pipeline delivery components into SERA for multi-node scenarios development

Collaborations

- Linde, Air Products, GE Rail Leasing, Lincoln Composites, Union Pacific Railroad, Konecranes Heavy Lifting Company, Paceco Corporation, ANL, PNNL, DTI, TIAX, GTI

Future Work

- Continue developing multi-node delivery scenarios: network optimization and scenarios draft
- Assist DOE in developing go/no go decision on the use of CNG infrastructure for delivering hydrogen
- Build up hydrogen-from-wind scenarios