National Renewable Energy Laboratory
Innovation for Our Energy Future

# H2A Delivery Analysis and H2A Delivery Components Model


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*National Renewable Energy Laboratory*


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Project ID # PD015




NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# 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

U.S. DEPARTMENT OF ENERGY Hydrogen Program hydrogen.energy.gov

**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<br>Expected completion: end of April 2010 |
| Hydrogen rail delivery<br>cost analysis | 50% complete<br>Expected completion: end of FY10 |
| Multi-node delivery scenario model development, stage 1 and 2 | 50% complete<br>Expected completion: end of June 2010 |
| Review: go/no go decision on delivering hydrogen via natural gas pipelines | 10% complete<br>Expected completion: end of FY10 |

# Technical Accomplishments and Progress

## Outline

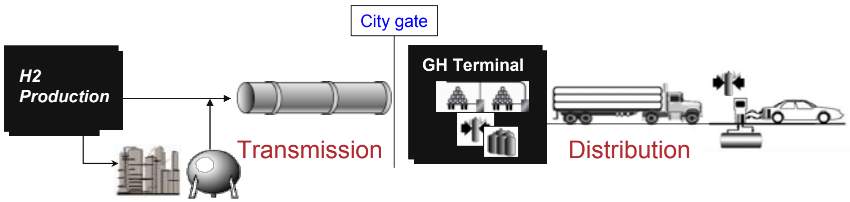
- H2A Components Model upgrade and cost analysis
- Rail components development and cost analysis
- Building new components for GH2 delivery using composite tubes
- Building multi-node delivery scenario model

# Technical Accomplishments and Progress

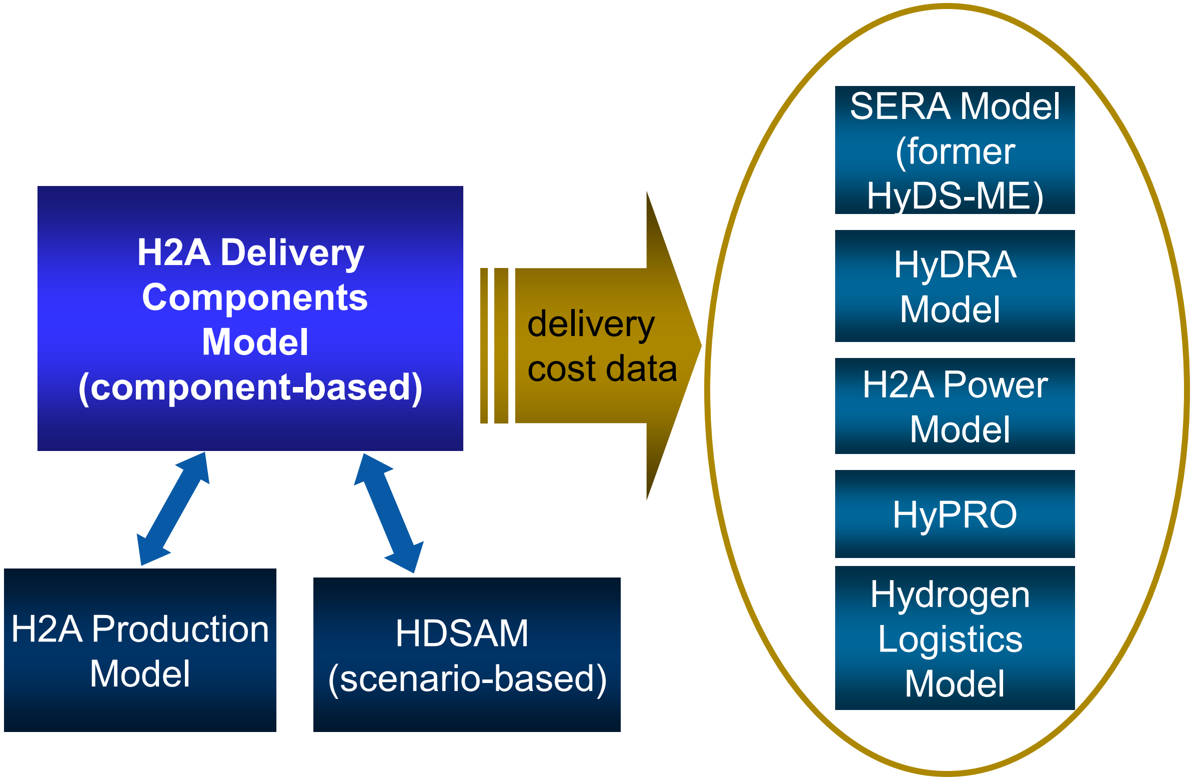
## H2A Components Model Upgrade and Cost Analysis

# 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**
- **Dispensing type:** cascade
  - **Tube pressure:** 180 atm
  - **Tube pressure:** 480 atm

**Dispensing pressure** — **700 bar**
- **Dispensing type:** cascade
  - **Tube pressure:** 180 atm
  - **Tube pressure:** 480 atm
- **Dispensing type:** booster compressor
  - **Tube pressure:** 180 atm
  - **Tube pressure:** 480 atm

### LH2 Refueling Station Upgrade

**2 dispensing options:**

- gas
- liquid or cryo-compressed

**Simple Design**
**Storage**
**Cryo-Pump**
**Dispenser**

### GH2 Tube-Trailer Upgrade

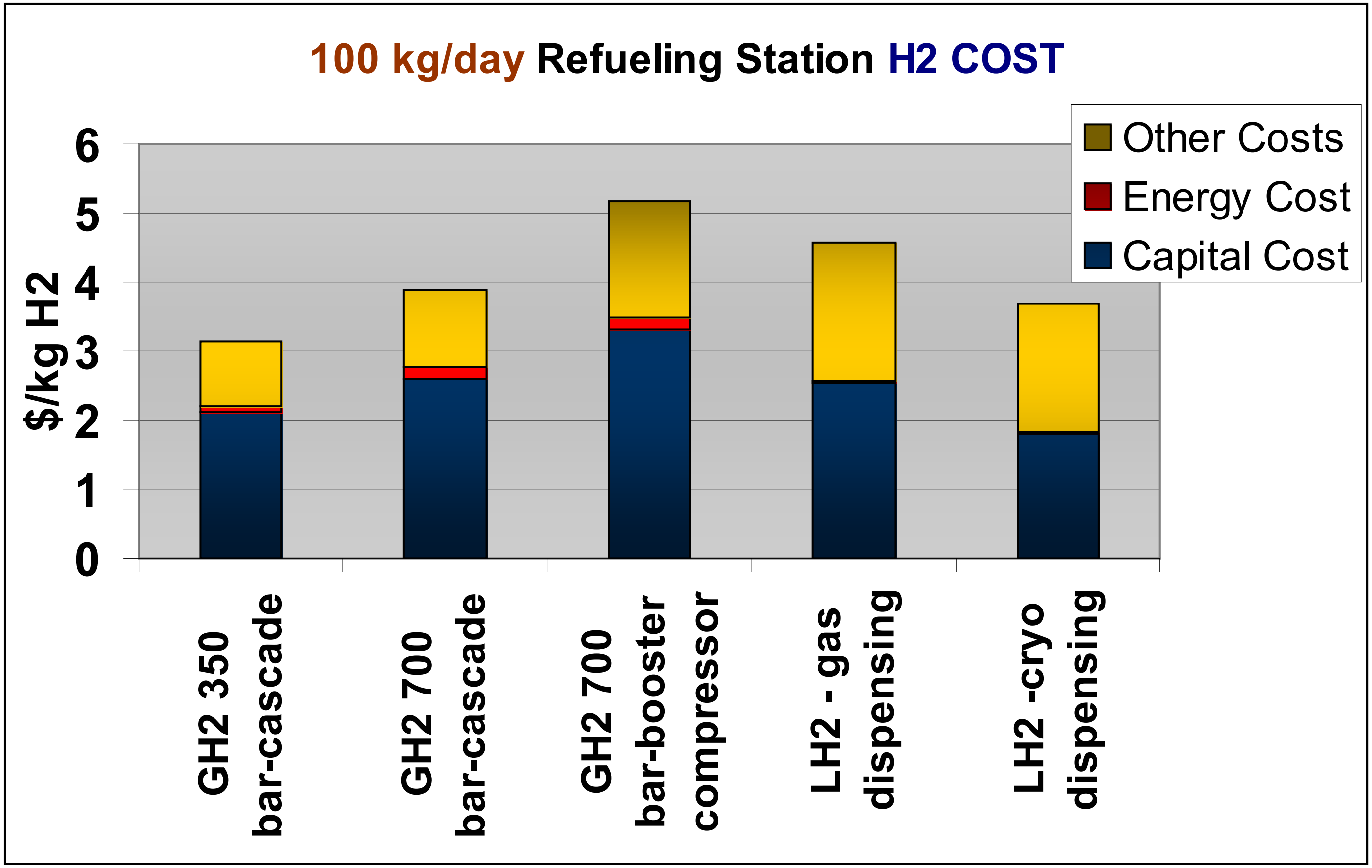
**2 options for tube pressure:**

- 180 atm
- 480 atm

# Technical Accomplishments and Progress

## H2A Delivery Components Model Upgrade

### Impact on Refueling Station Upgrade

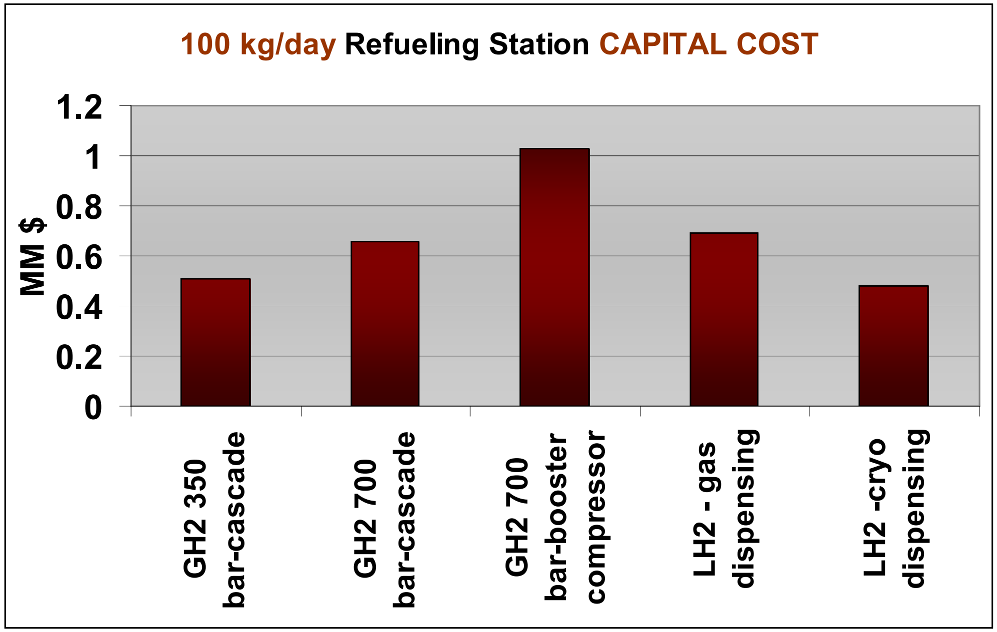


# Technical Accomplishments and Progress

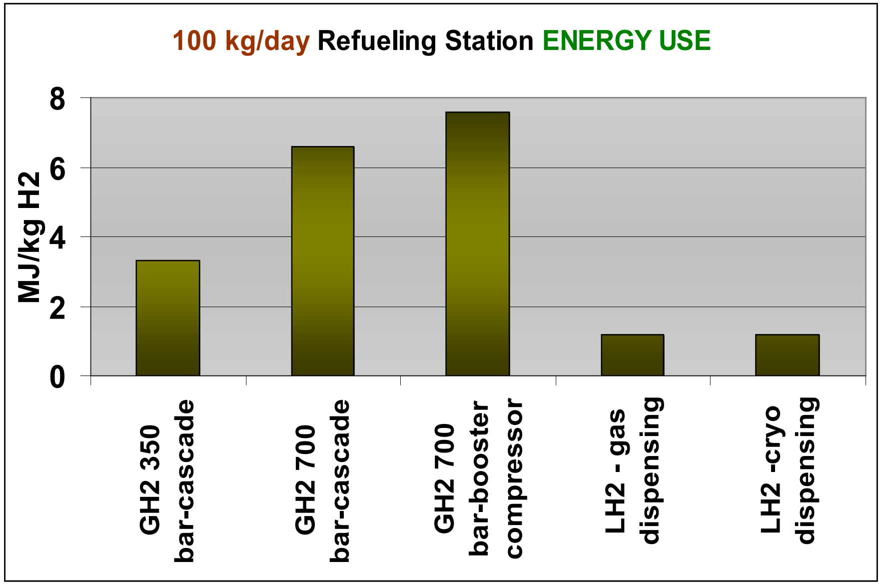
## H2A Delivery Components Model Upgrade

### Impact on Refueling Station Upgrade

How much initial investment needed?



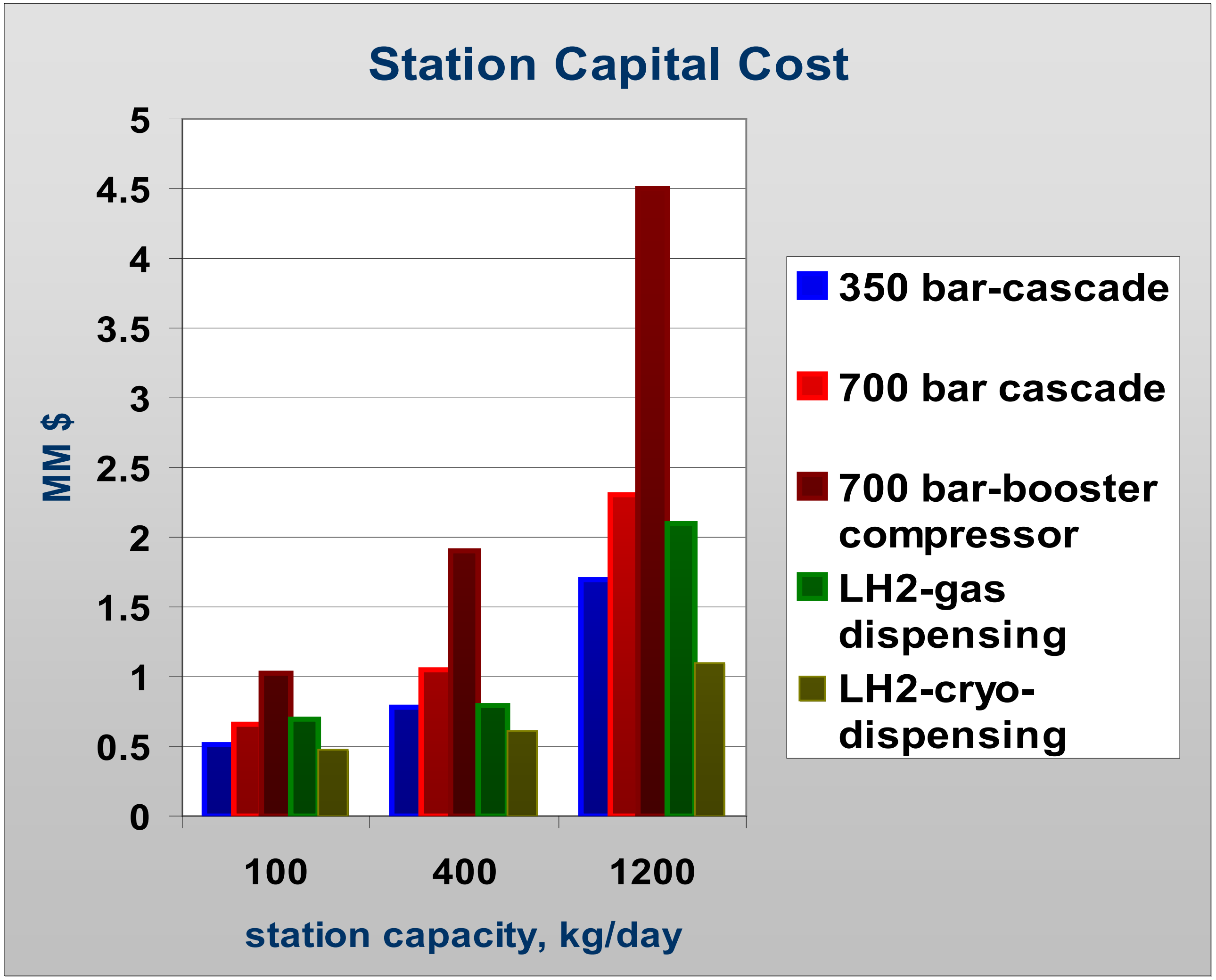

How energy-effective?



## 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

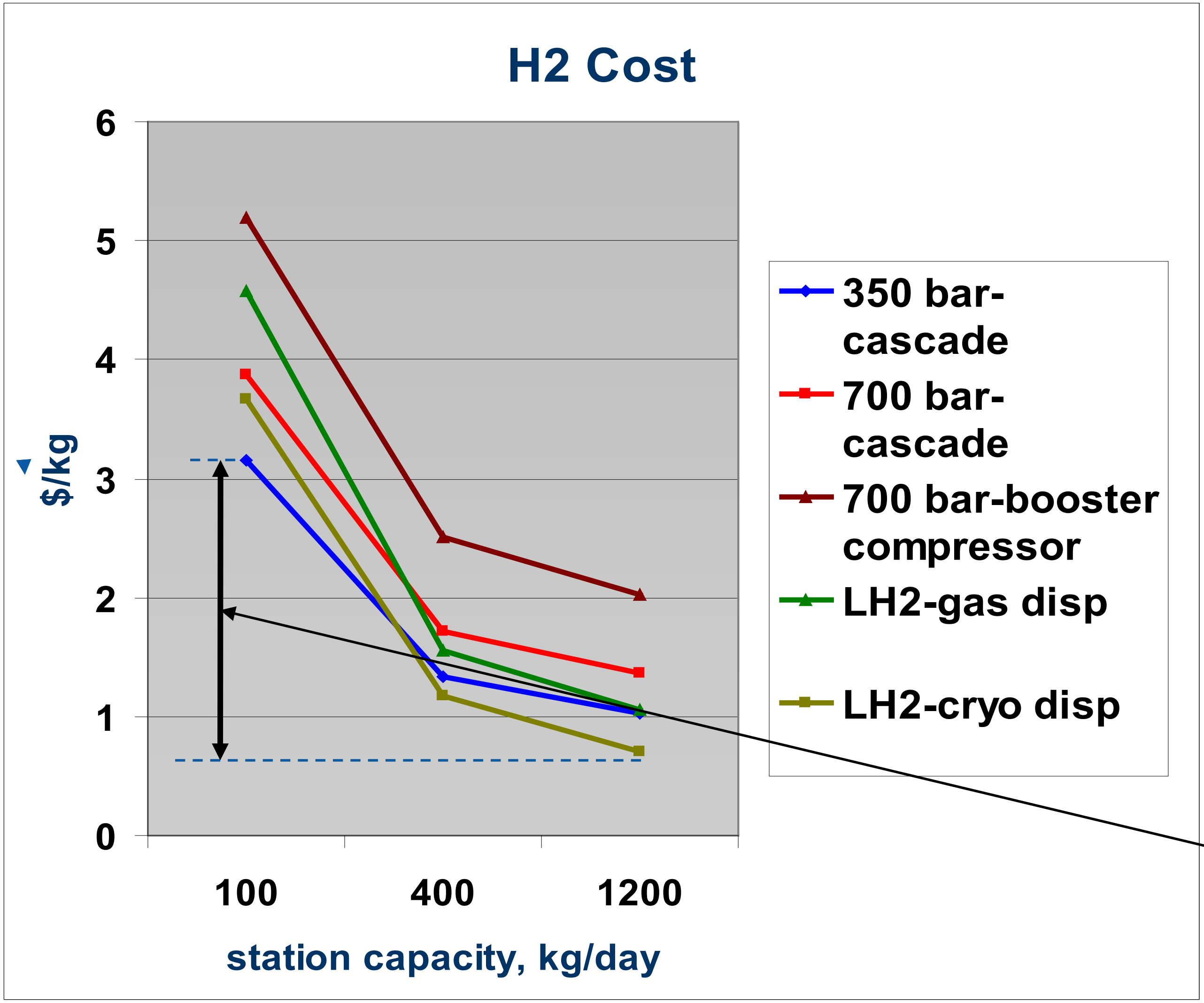
Cryo-compressed station is the cheapest and has the simplest design

# 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

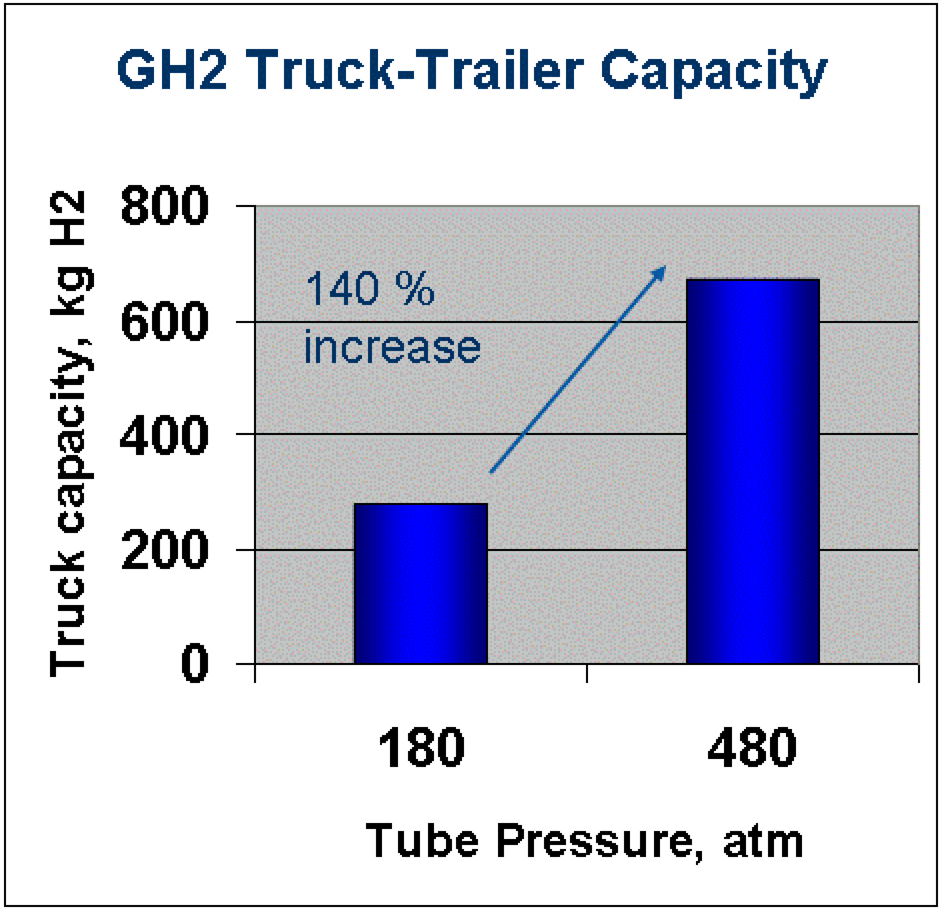
Long-term: 1200 kg/day

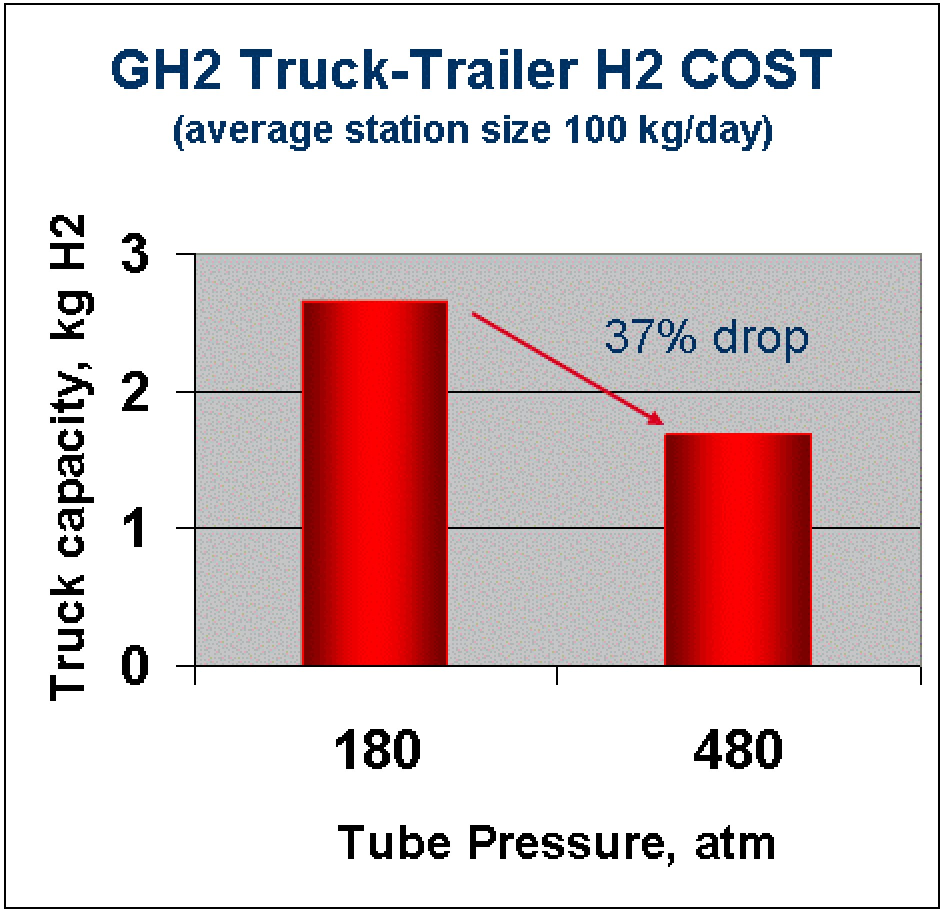
H2 cost drop by $\Delta$=$2.5/kg

# Technical Accomplishments and Progress

## H2A Delivery Components Model Upgrade

### Gaseous H2 Tube Trailer



# Rail Components Development and Update

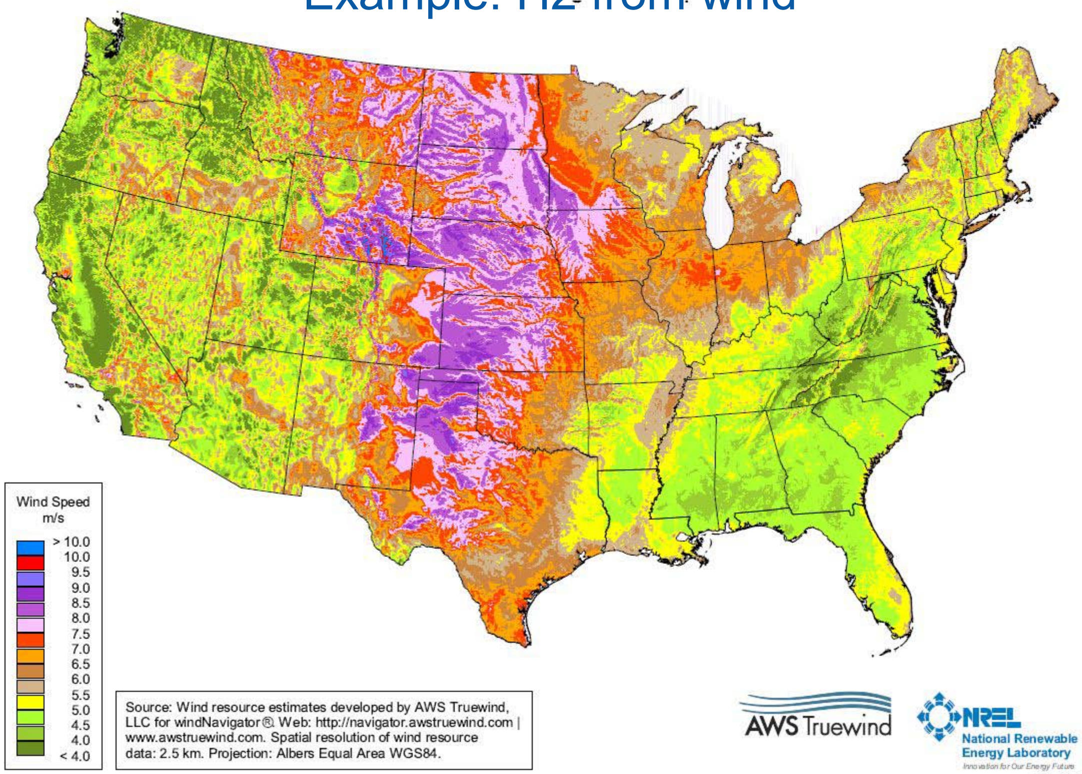
# Technical Accomplishments and Progress

## 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: $H_2$ 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

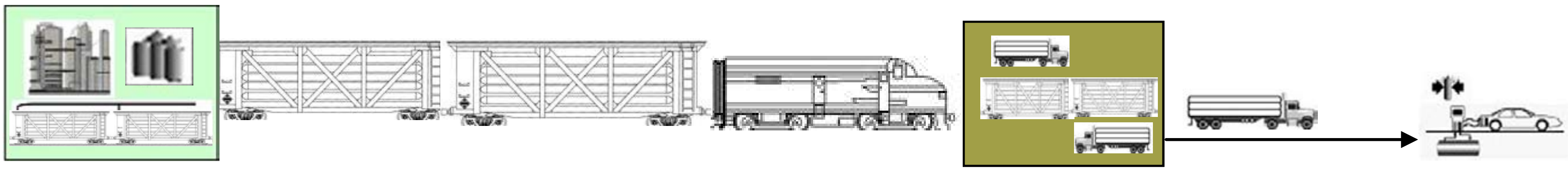
* * 30% capacity factor at 80 m above ground, assumes 5 $MW/km^2$ of installed nameplate capacity

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

# Technical Accomplishments and Progress

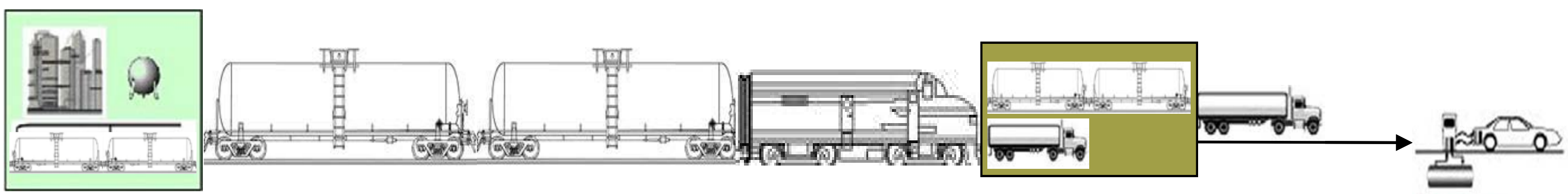
## H2 Rail Delivery Pathways

### 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)

## New Components Using Composite Tubes Development

## and

## Comparative Delivery Cost Analysis

## 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

## Rail Components Upgrade

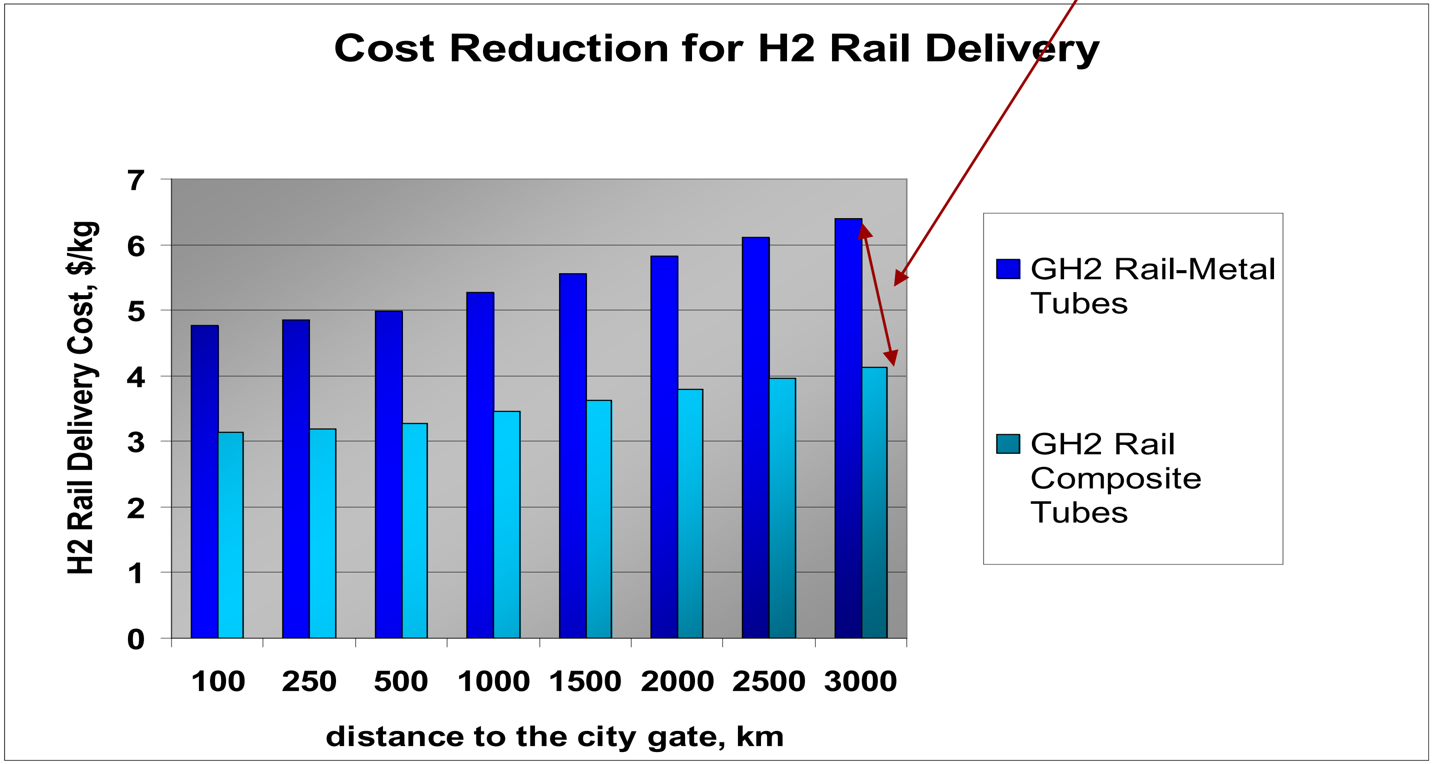
# Rail: From **metal** tubes to **composite** tubes

**Increased railcar capacity:**

Metal tubes – 2680 kg of $H_2$

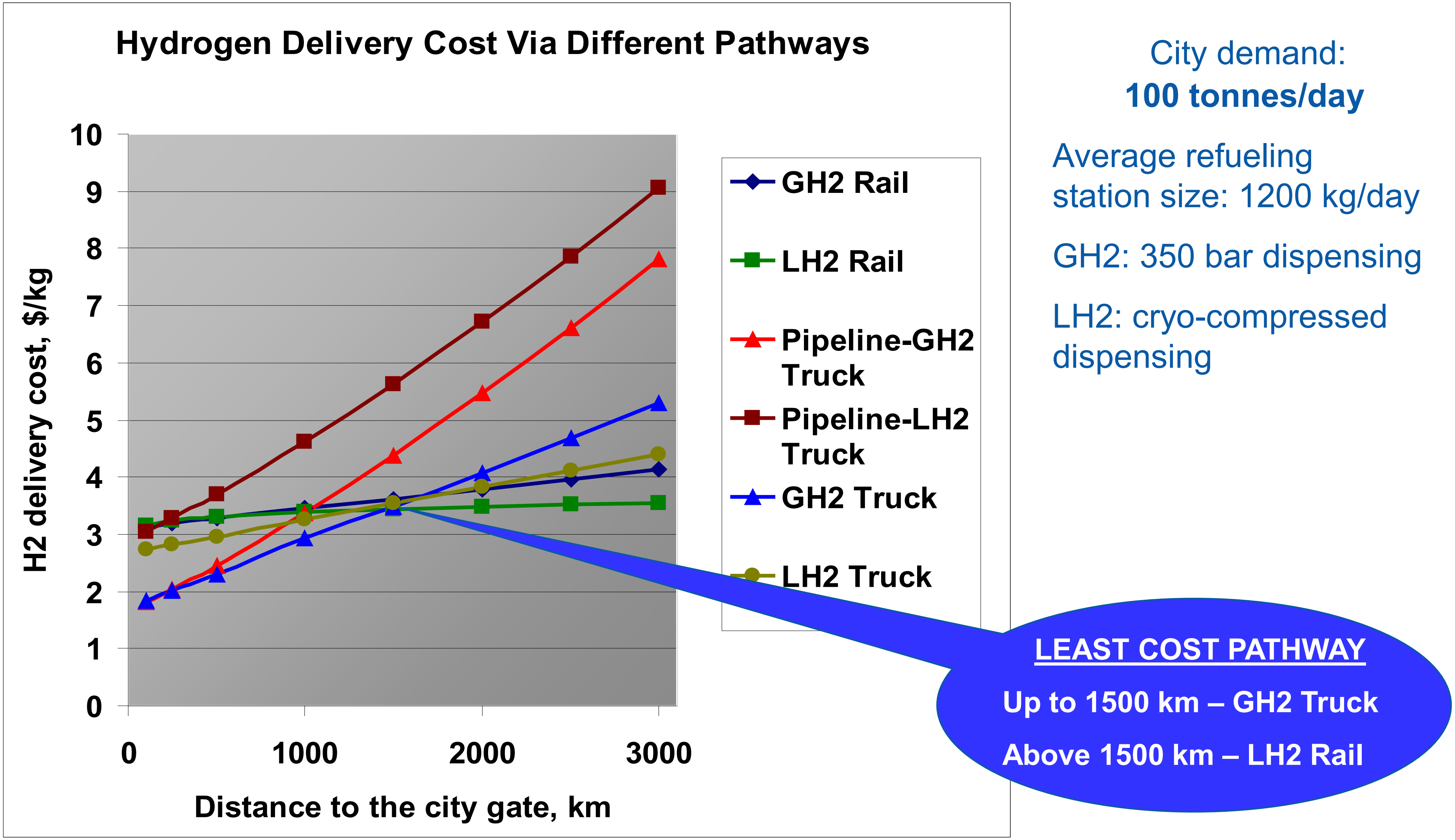
Composite tubes – 4400 kg of $H_2$

**33 % $H_2$ cost reduction for $GH_2$ Rail Delivery**



## 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

## 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

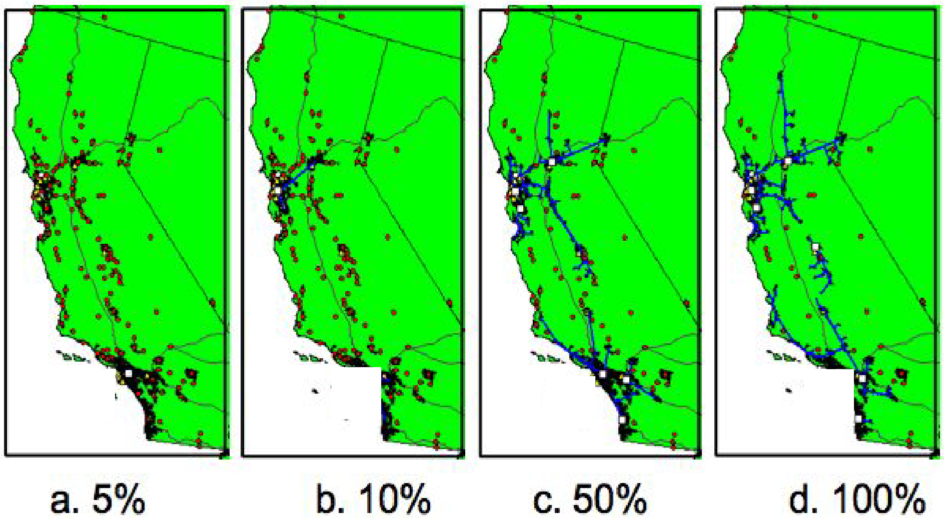
- Using SERA Model (former HyDS-ME) – geo-resolution and optimization
- Substitute cost curves with the delivery component build-ups inside of SERA
- By applying the above, get the flexibility to place components at different geographical locations
- Calculate optimal network and storage
- Trace network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

# Technical Accomplishments and Progress

## Building Multi-Node Scenario Model

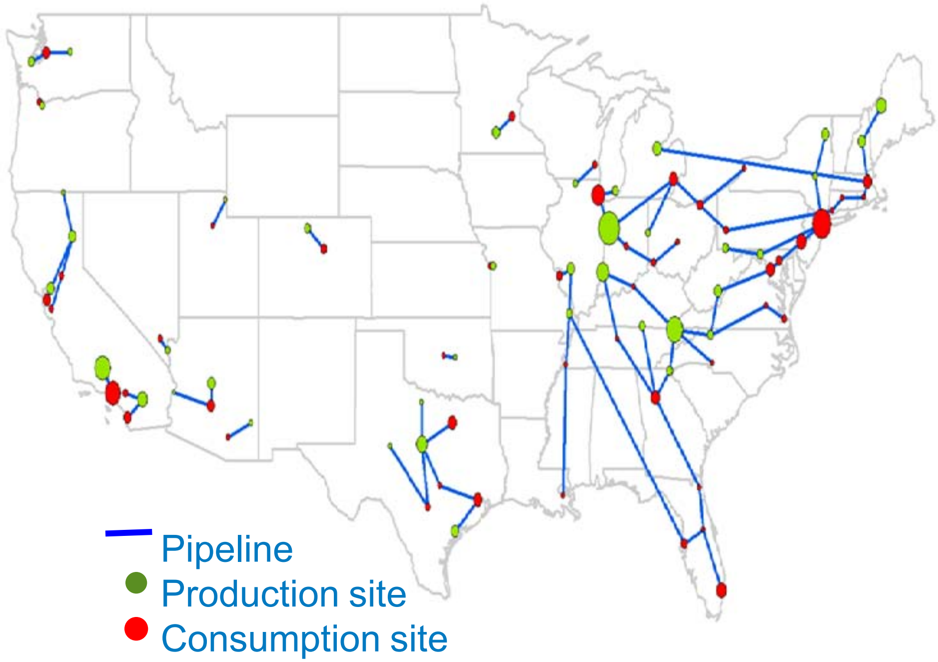
### What is SERA Model?

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




**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.**

## 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

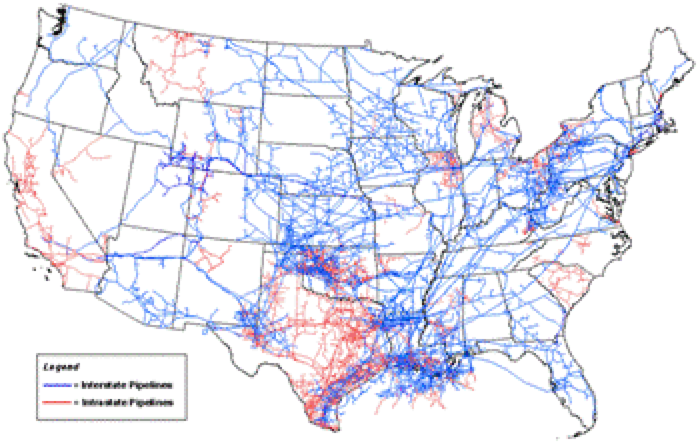
- Use the learning curve from Stage 3 to develop multi-node delivery scenarios

# 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