

Analysis of H₂ Pipelines and Other H₂ Storage and Delivery Systems

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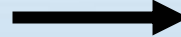
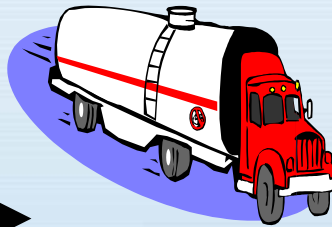
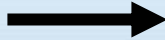
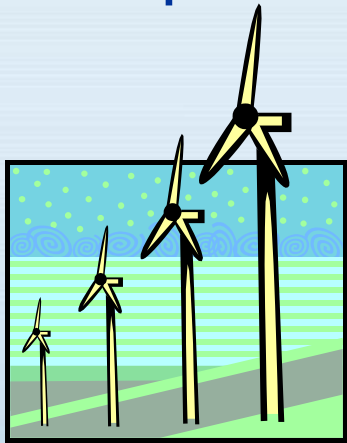
National Renewable Energy Laboratory



- Hydrogen storage and delivery
- Primary components involved in hydrogen storage and delivery
- Hydrogen storage and delivery analysis at NREL
- Pipeline analysis in H₂ delivery component model
- Conclusions

What is Hydrogen Delivery?

- Hydrogen delivery and storage defined as the complete set of equipment and processes used to move hydrogen from the central production plant to the forecourt station or primary usage

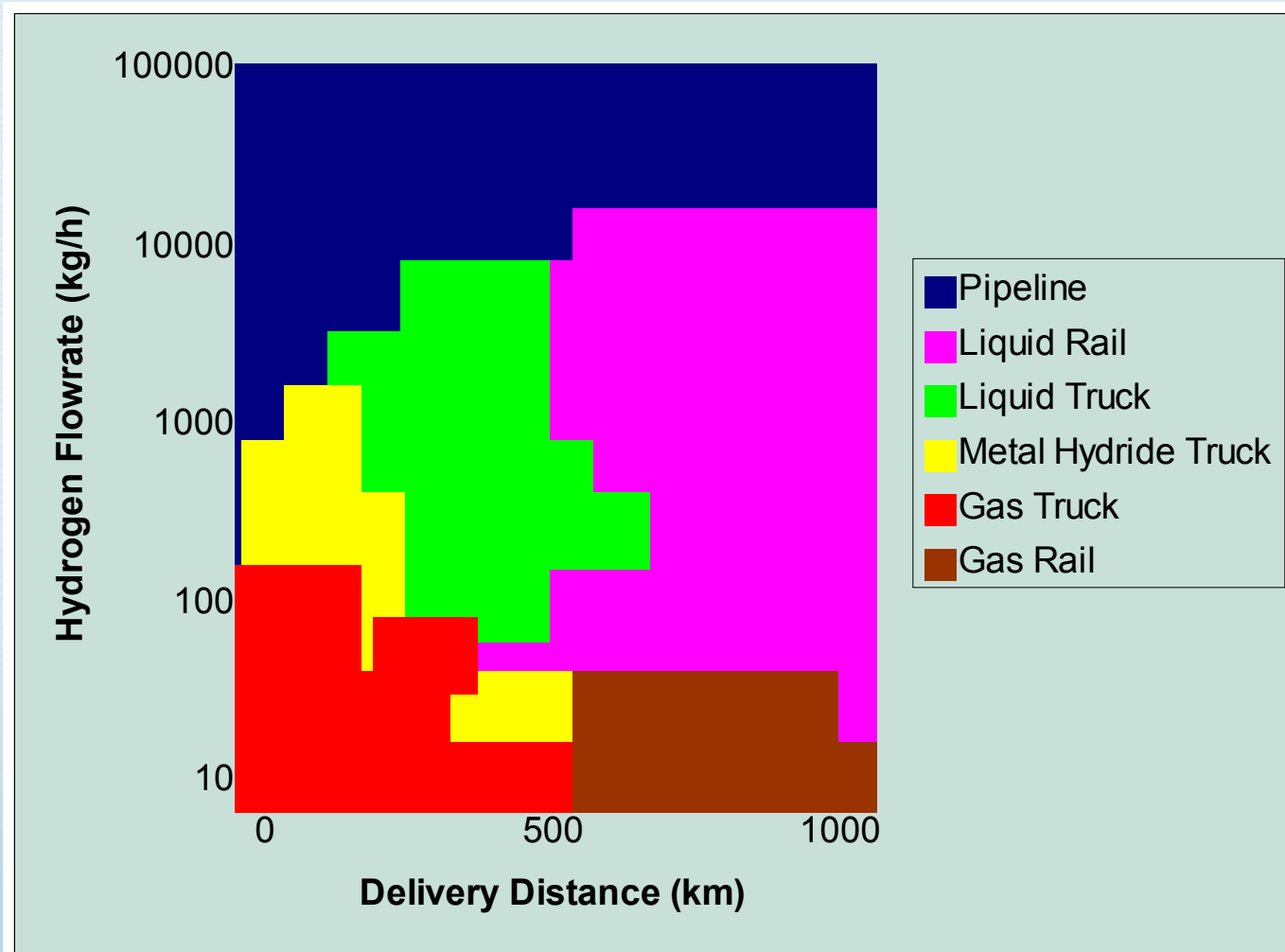


- Hydrogen moved in either liquid or gaseous forms

Delivery Components	Storage Components
<ul style="list-style-type: none">-Compressed gas truck-LH2 truck-Pipeline-Liquefier-Compressor (one-stage and multi-stage)	<ul style="list-style-type: none">-Compressed gas tubes-Bulk Liquid Hydrogen-Geologic storage
<ul style="list-style-type: none">-Terminals (gaseous and liquid)	

- Two Excel-based models developed
 - NOMAHD (NREL Optimization Model for the Analysis of Hydrogen Delivery)
 - Calculates optimum delivery method for given hydrogen flowrate and delivery distance
 - Economic/design calculations based on database
 - Hydrogen Delivery Component model
 - Calculates portion of final delivered hydrogen cost that is attributed to a particular delivery component
 - Calculations based on user input/default process and economic parameters
 - Economic analysis method – fixed charge rate

- Sample result from NOMADH model



- Mixed integer linear program (MILP) to model H₂ fuel deployment and distribution
 - Under development, should be completed by end of FY 05
 - Based on current LP models, GIS capabilities at NREL
 - Will identify optimum installation location and capacity of H₂ production facilities, pipelines
- Integration of hydrogen delivery work with hydrogen production work
 - NREL models and expertise, in combination with H₂A

- Excel-based tool
- Allow the user to determine a “generic” hydrogen cost for a particular component
- Each storage and delivery component has separate tab
- Final hydrogen cost determined using fixed charge rate calculation
 - Final hydrogen cost determined in real dollars (i.e. no inflation assumed)
 - Model assumes MACRS depreciation
 - Truck models include option for replacement

- Allows for manual entry of capital costs, or automatic capital cost entry based on H2A data
 - Land, site preparation, engineering & design, process & project contingency, and licensing and permit fees
- Operation and maintenance costs
 - Labor, property taxes, insurance, overhead and G&A, and operation maintenance and repairs.

- Tab does not design pipeline network for the user
 - Asks for transmission, trunk and distribution details
 - Can calculate diameter or outlet pressure
 - Calculations based on Panhandle B Equation

$$q_{sc} = 737 \left(\frac{T_{sc}}{P_{sc}} \right)^{1.02} \left[\frac{(P_1^2 - P_2^2) d^{4.961}}{\gamma^{0.961} L T_m Z_m} \right]^{0.51} E$$

q_{sc} =flowrate (scfm); T_{sc} =temp at STP (R); P_{sc} =press at STP.; P_1 =inlet press. (psia); P_2 =outlet press. (psia); d =diameter (in); γ =gas relative density; L =length (mi); T_m =mean temp. (R); Z_m =mean compressibility factor; E =pipeline efficiency

- Costs for potential H₂ pipelines difficult to ascertain
- Assumed that natural gas pipeline data, as presented in Oil and Gas Journal, was adequate for preliminary analysis
 - OG&J costs divided into materials, labor, right of way and miscellaneous
 - Cost data from OG&J fit to a curve and multiplied by factor of 1.3 for H₂
- Costs vary significantly based on capacity
 - Pipeline may not be fully utilized at start-up
 - Leads to higher cost
 - Panhandle B equation helps user determine



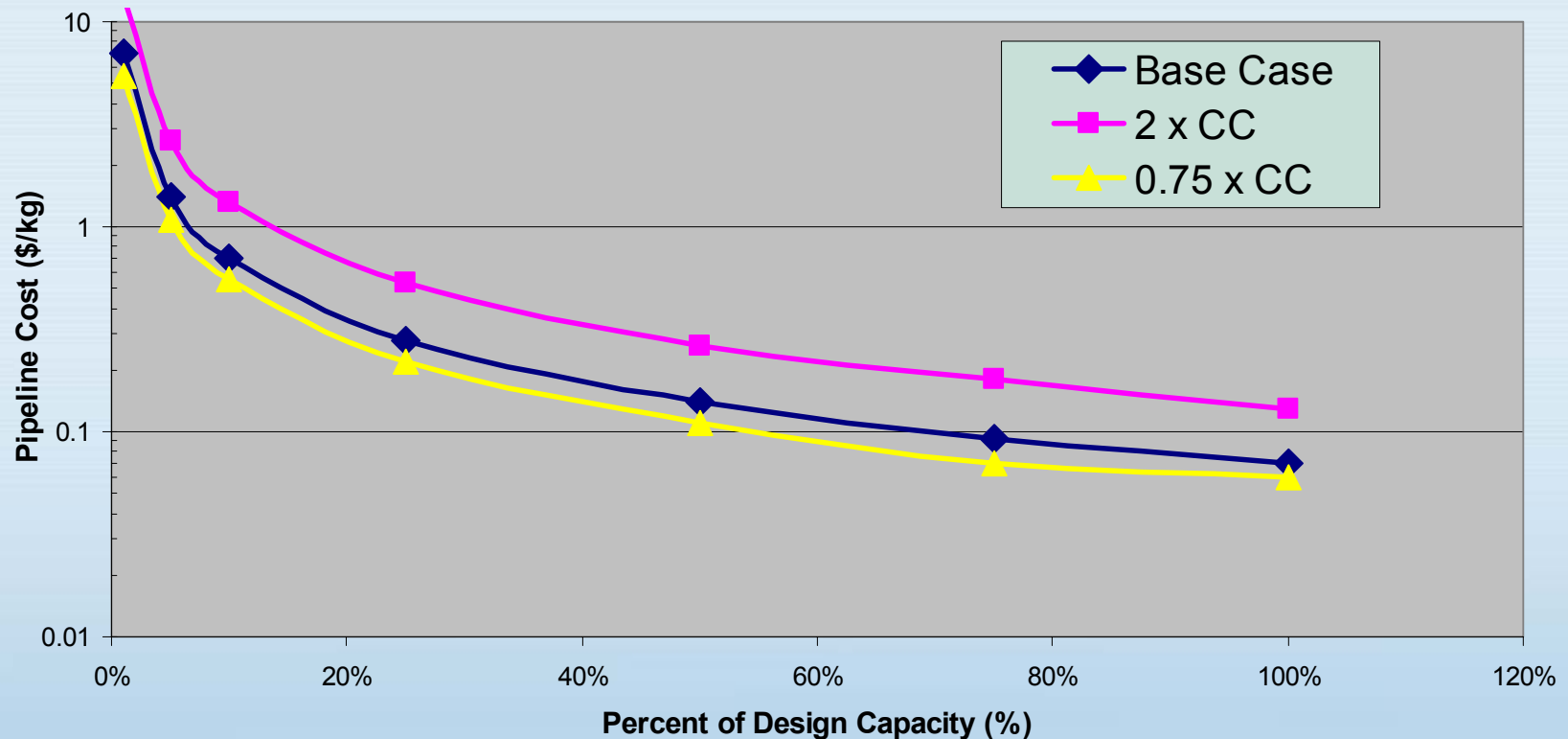
Pipeline Component Analysis (cont.)

Example Calculation – Assuming 50 mi transmission line, 70 mi (7 lengths of 10 mi) of trunk line and 196 mi (98 lengths of 2 mi) of distribution line; no compressors included

Hydrogen Flowrate	1,000,000 kg/day (425 MMscfd)
Transmission Line Diameter	15-inch
Trunk Line Diameter	7-inch
Number Trunk Lines	7
Distribution Line Diameter	2-inch
Number Distribution Lines	98
Transmission Line Pressure	1000 psi inlet
Distribution Line Pressure	250 psi outlet
Pipeline Utilization	95%
Discount Rate	10%
Total Capital Cost	\$140,000,000
Total Cost	\$0.07/kg of H₂

- Effect of pipeline utilization – based on design from previous slide

Pipeline Cost - Effect of Utilization





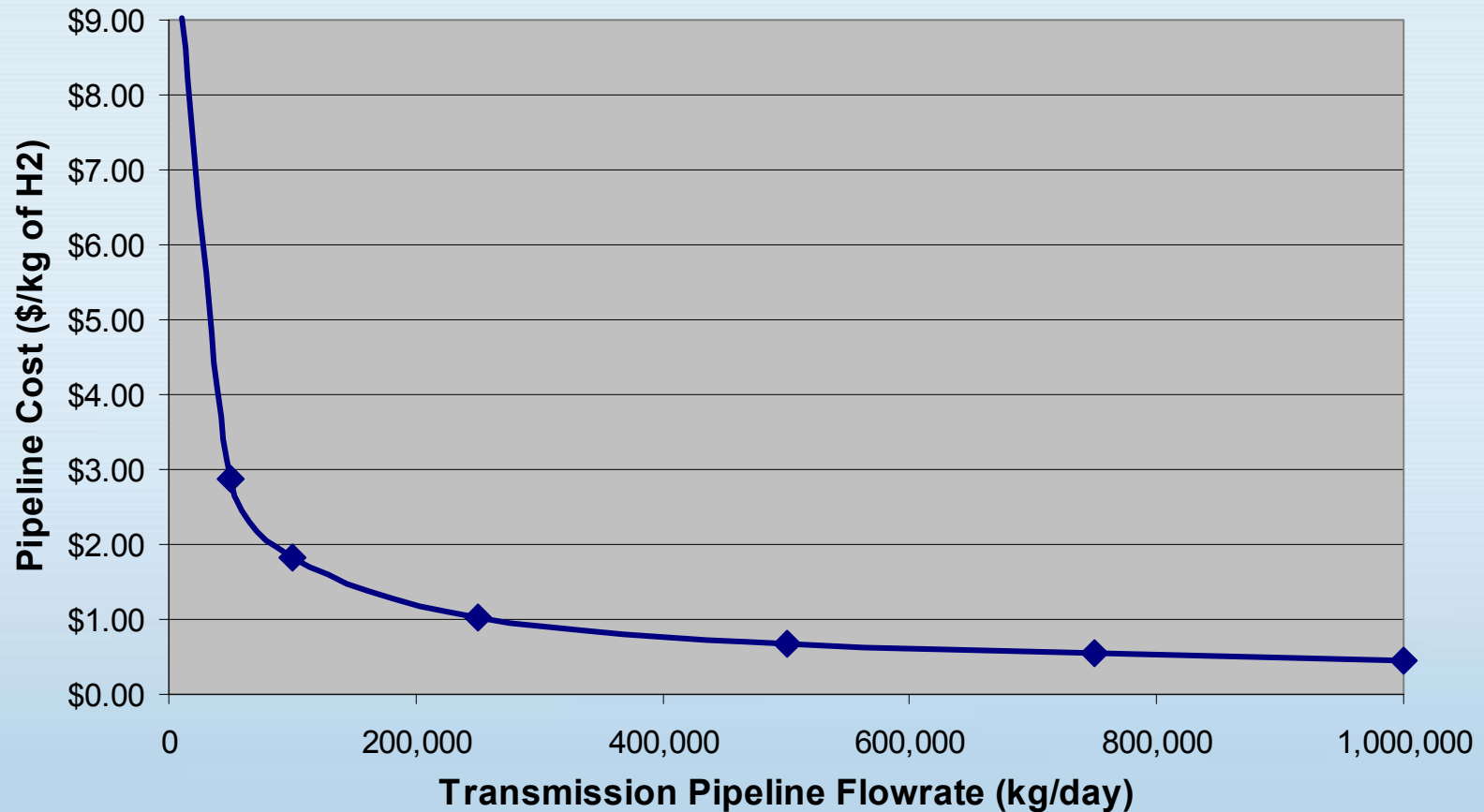
Pipeline Component Analysis (cont.)

Transmission Line Analysis – Sample Calculations; no compressors included

Hydrogen Flowrate	500,000 kg/day (212 MMscfd)
Transmission Line Diameter	18-inch
Transmission Line Length	500 mi (805 km)
Transmission Line Inlet Pressure	1000 psi inlet
Transmission Line Outlet Pressure	700 psi outlet
Pipeline Utilization	95%
Discount Rate	10%
Total Capital Cost	\$685,000,000
Total Cost	\$0.68/kg of H₂

Transmission Pipeline Capacity

Cost for Various Transmission
Pipeline Flowrates (500 mi)



- NREL has two models for analyzing hydrogen delivery and storage
 - NOMAHD optimization model
 - Delivery component model- will be available internet
 - Working to develop MILP model
- Delivery component model predicts pipeline costs based data from Oil and Gas Journal
 - Can be used to determine cost of user-defined design including transmission, distribution and trunk
- Calculations of pipeline cost show capital cost estimations reasonable
 - Pipelines more cost effective at larger flowrate

- Joan Ogden from the University of California at Davis
- Marianne Mintz from Argonne National Laboratory
- Hydrogen, Fuel Cells and Infrastructure Technologies Program: US Department of Energy