H2A Delivery Models and Results

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Presentation Outline

- DOE Delivery Goals
- H2A Project
  - Background
  - Approach & key assumptions
- Delivery Scenarios Model
  - Objectives & conceptual overview
  - Current & future pathways
  - Key variables
- Initial results

H2A Delivery

OFCHIT Hydrogen Delivery Goal

- Develop hydrogen delivery technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power

Scope

- From the end-point of central or distributed production (300 psi H2) to and including the dispenser at a refueling station (forecourt) or stationary power site

OFCHIT Technical Objectives

- By **2007**, define the criteria for a cost-effective and energy-efficient hydrogen delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.
- By **2010**, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to ***<$0.90/kg*** of hydrogen.
- By **2010**, develop technologies to reduce the cost of compression, storage, and dispensing at refueling stations and stationary power sites to less than ***<$0.80/kg*** of hydrogen.
- By **2015**, develop technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to ***<$1.00/kg*** of hydrogen in total.
- By **2015**, develop technologies to reduce the cost of hydrogen delivery during the transition to ***<$xx/kg*** of hydrogen.

Background of H2A Project

- Mission:
  - Improve the transparency and consistency of analysis
  - Improve the understanding of the differences among analyses
  - Seek better validation from industry
- Purpose
  - R&D portfolio development
  - Input to research direction
  - Not to be used to pick winners
- History
  - Initiated February 2003
  - Team of eleven analysts from labs, industry, consulting firms
  - H_2 Production Cash Flow Model & Case Studies
  - H_2 Forecourt Model
  - H_2 Delivery Components & Delivery Scenarios Models
  - Group of Key Industrial Collaborators (KIC)

H2A Approach

- Discounted cash-flow rate-of-return analysis
- Estimate levelized selling price of hydrogen required to attain a specified internal rate of return
  - Result is *minimum hydrogen price*
  - Cash flow calculation includes debt payments, taxes, depreciation, construction, working capital, capital replacement, equity capital, H2 revenue, byproduct revenue, operating costs, inflation
- Models meant to be a means of *reporting assumptions* as well as calculating hydrogen selling price
- Assumptions transparent, easy to identify and change

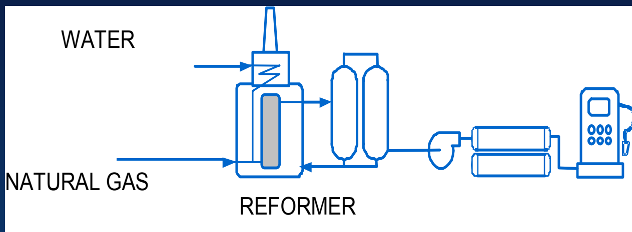
Financial Inputs: Central, Delivery & Forecourt

- Reference year (2005 $)
- Debt versus equity financing (100% equity)
- After-tax internal rate of return (10% real)
- Inflation rate (1.9%)
- Effective total tax rate (38.9%)
- Design capacity (varies)
- Capacity factor (central 90%, excl. wind; forecourt 70%; delivery varies)
- Construction period (central 0.5 – 3 yrs; forecourt 0 yrs; delivery varies)
- Production ramp up (central varies with case, delivery by component)
- Depreciation: MACRS (central 20 yrs; forecourt 7 yrs; delivery varies)
- Economic analysis (central 40 yrs; delivery & forecourt 20 yrs)
- Land (central & delivery $5,000/acre; rented in forecourt)
- Burdened labor (central $50/hr; forecourt $15/hr; delivery $20-25/hr)

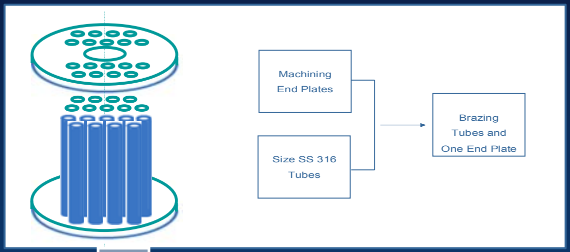
H2A Delivery

Analytical Inputs to H2A Cost Modeling

Process Flow Analysis



Manufacturing Cost Modeling



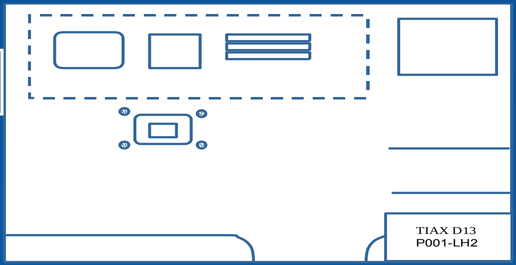
H2A Cost Analysis

FIXED O&M COSTS (Inputs REQUIRED in Year 2005 Dollars)	Base Case:	H2A Guidelines:
Production Unit Labor required (Hours/year)	0.0	
Production Unit Labor cost ($/man-hr)	$15.00	$15.00
Production Unit Labor cost ($/year)	$0	
Storage/Dispensing Labor required (Hours/Year))	1,231.9	410
Storage/Dispensing Labor cost ($/man-hr)	$15.00	$15.00
Storage/Dispensing Labor cost ($/year)	$18,478	
Overhead and G&A rate (% of total labor costs)	20.00%	20%

Equipment Specifications

Item	Specification
System Power Supply	• 480 V, 3-Phase, 60 HZ • Power 325 kVA
Electrolyzer Cells	• 10 cell stack • Design Current 620 A DC • Cell Voltage 1.9V • Operating Temperature 63°C Max. • Operating Pressure 150 psig • Electrolyte 34% KOH • Feedwater Flowrate Total 4 GPH
Feedwater Supply	• Demineralized • Flowrate 4 GPH

Site Planning



Scope of H2A Delivery Modeling

- Develop spreadsheet model for delivery system component costs and performance: Hydrogen Delivery Components Model
- Develop delivery scenario model for set of well defined "base cases" that span major markets and demand levels: Hydrogen Delivery Scenario Analysis Model (HDSAM)
- Estimate the cost of H_2 delivery for base cases.
- Assume 2005 delivery technologies

Delivery Scenarios Model Builds on Past Efforts and Common Analytical Tools

- Microsoft EXCEL based
- Designed to “synchronize” with improvements to Delivery Components Model
- Uses building blocks from the H2A Program
  - Delivery Components Model
  - “Forecourt” model
  - Discounted cash flow analysis
  - Common financial and energy assumptions

Delivery Components

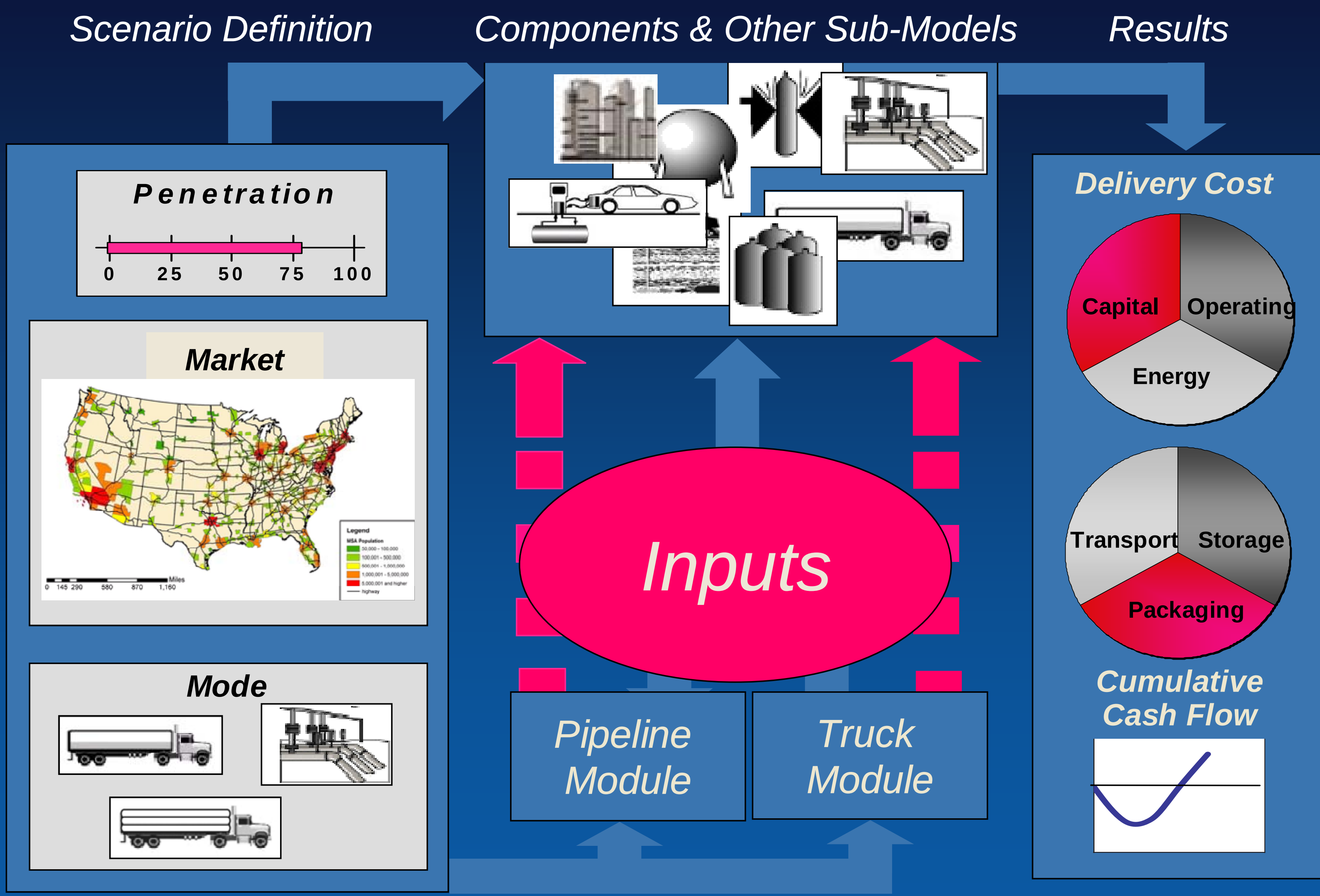
- Compressed Hydrogen (CH) Truck (3k psi tube trailer)
- Compressed Hydrogen (CH) Truck (7k psi tube trailer)
- Compressed Hydrogen Gas Truck Terminal
- Liquid Hydrogen (LH) Truck
- Liquid Hydrogen Truck Terminal
- H2 Transmission Compressor
- H2 Forecourt Compressor
- Hydrogen Pipelines
- H2 Liquefier
- LH2 Storage Tank
- Gaseous H2 Storage “Tank”
- Gaseous H2 Geologic Storage
- Gaseous H2 Dispenser
- Gaseous Forecourt
- Liquid Hydrogen Forecourt

Version 1.0 of Hydrogen Delivery Scenario Analysis Model (HDSAM)

- Predefined demand based on
  - Market (urban or interstate/rural)
  - Penetration of hydrogen-fueled LDVs (%)
  - Single delivery mode
  - 100 kg/d or 1500 kg/d forecourts
- Delivery mode defined by user
  - Pipeline with geologic storage
  - Liquid hydrogen (LH2) via terminal and truck
  - Compressed hydrogen (CH2) via terminal and truck (2650 or 7000 psi)
- Components tabs linked so pathway capacities reflect losses and availabilities

H2A Delivery

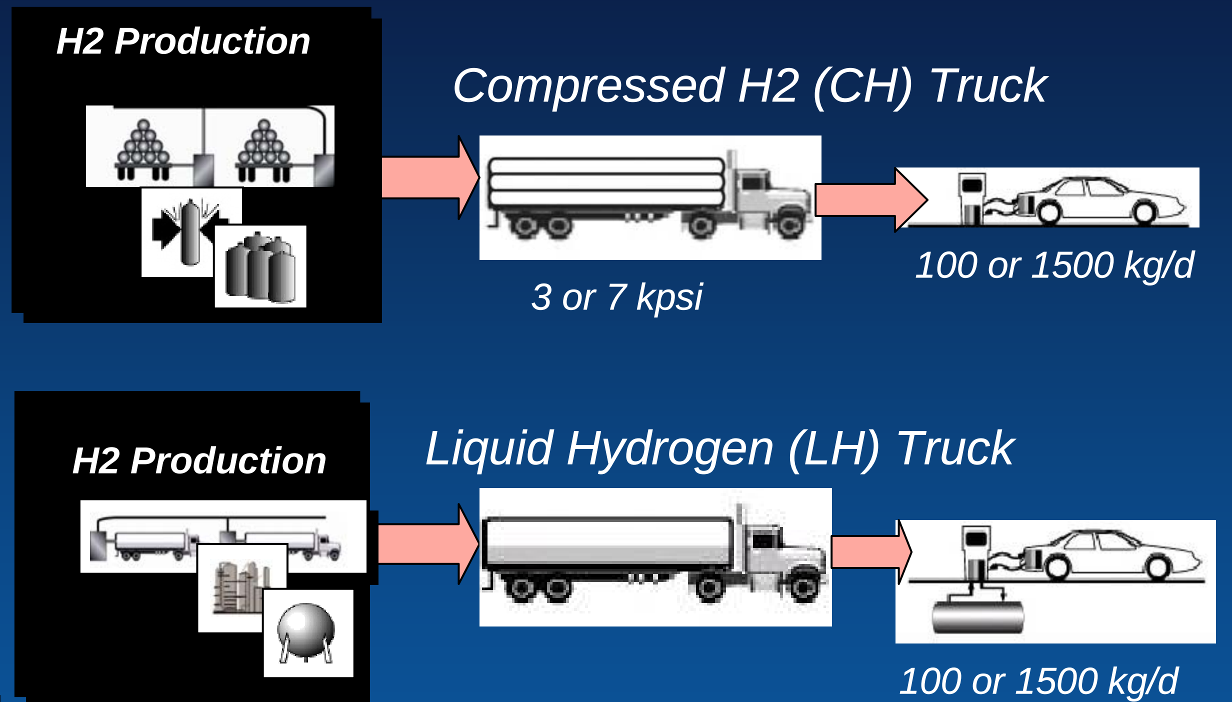
Overview of HDSAM

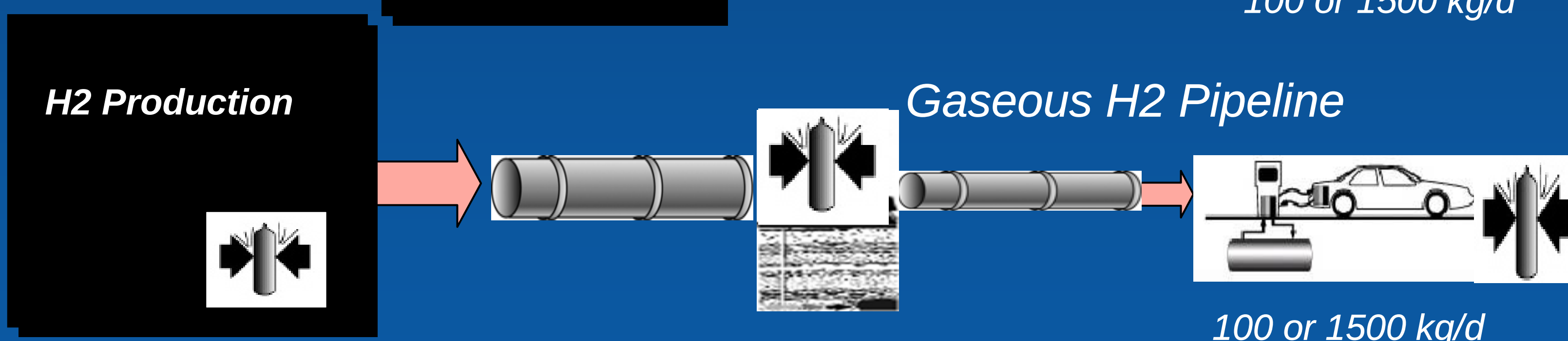


H2A Delivery

HDSAM Estimates Delivery Cost for 3 Pathways

V1.0 characterizes components for 3 pathways with delivery by a single mode. Loading, conditioning and storage are at or adjacent to the plant





HDSAM Capabilities Have Grown Over Time

Pathways	Penetration	Markets
LH Truck	Fixed (1, 10, 30, 70%)	Generic large urban (1 M)
GH Truck		Generic small urban (100 K)
Pipeline		Short intercity segment (100 mi)
+ HPGH Truck (7000 psi)	Variable (1%-100%)	Long intercity segment (200 mi)
+ GH Forecourt (100, 1500 kg/d)		>450 urbanized areas
+ LH Forecourt (100, 1500 kg/d)		Variable population, generic urban area
+ Pipeline & GH Truck		Variable # and length intercity segments
+ Pipeline & LH Truck		
Variable Capacity Forecourt		
+ Distributed Production		Combined urban & intercity
+ Hydrogen Carriers		

Key Delivery Scenario Variables

Urban areas
- Population, land area, vehicle density
- Distance from central H2 production

Intercity/rural travel
- Highway miles
- Travel density, fuel demand

H2-fueled vehicles
- Number, fuel economy, utilization

H2 fuel stations (forecourts)
- Number, capacity, avg. kg dispensed
- Distance between stations
- Ratio to gasoline stations

LH2 and CH2 trucks
- Fuel economy, losses (e.g., boiloff)
- Capacity, avg. load
- Speed, load/unload time, drops/trip
- Physical & economic life

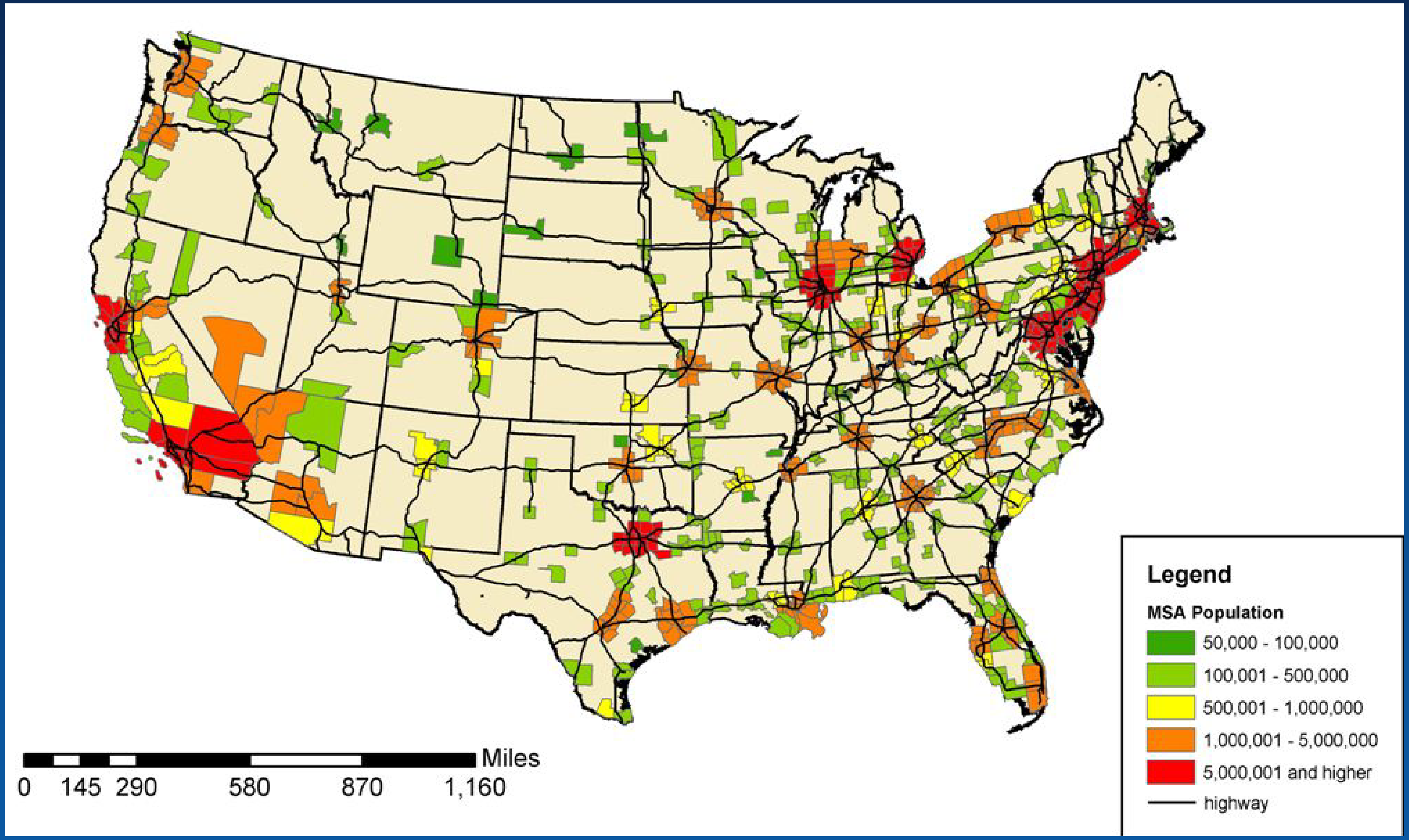
Terminals
- Size & fill rate of truck bays
- Compressor design requirements

Pipelines
- Inlet, city gate, forecourt pressure
- Transmission, distribution, service length
- Circuity factors
- Physical & economic life
- Ratio to capital cost of NG pipelines

H2A Delivery

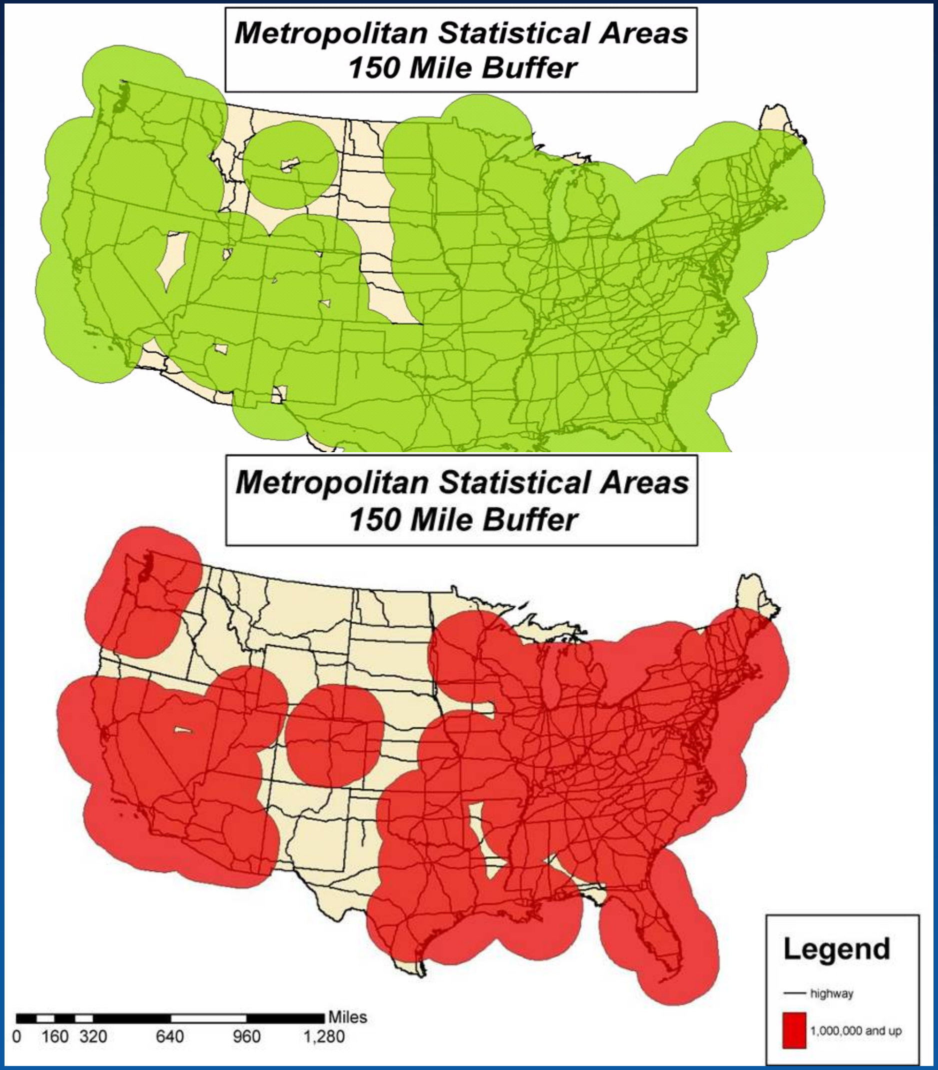
Three-Quarters of the US Population Reside in Urbanized Areas

East of the Mississippi urban areas are large and clustered. In the West urban areas tend to be smaller, fewer and more dispersed.



H2A Delivery

Rural/Interstate Markets May Be Served Via Urban and Interstate Highway Infrastructure

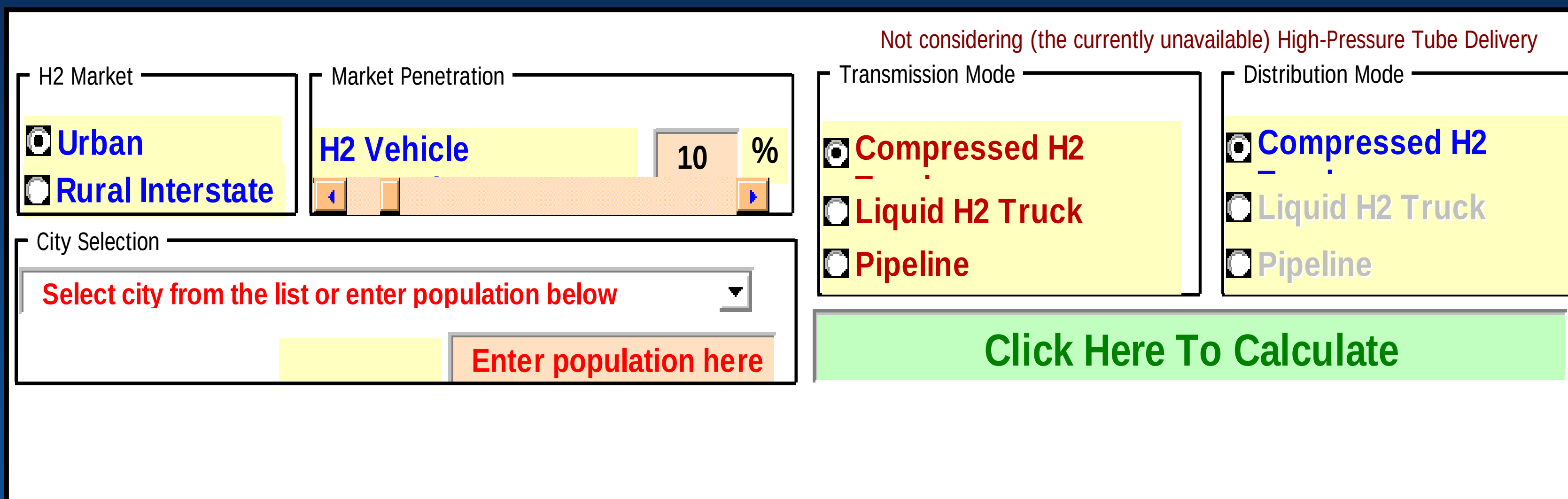


Most of the Great Plains and Mountain States are within 200 highway miles (320 km) of smaller urban areas (100k-500k people)

Nearly all areas East of the Mississippi and West of the Rockies are within 200 highway miles (320 km) of large urbanized areas (>1M people)

H2A Delivery

GUI Simplifies User-Selection of Market Type and Size, Penetration and Delivery Mode



H2A Delivery

Scenario Definition & Results Tabs (50% Urban Penetration, LH2 Truck, Indianapolis)

H2 Market
- (•) Urban
- ( ) Rural Interstate

Market Penetration
H2 Vehicle Penetration: 50 %

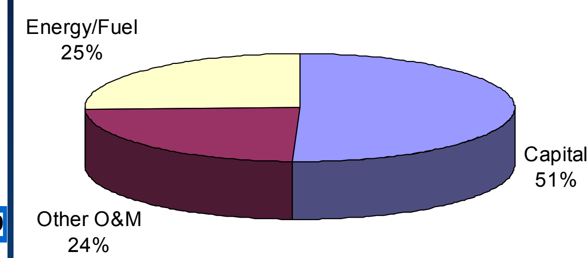
City Selection
Indianapolis, IN
1,218,919

Delivery Mode
- ( ) Compressed H2 Truck
- (•) Liquid H2 Truck
- ( ) Pipeline

Calculate

Delivery Costs

Total Cost [$/kg]	2.49

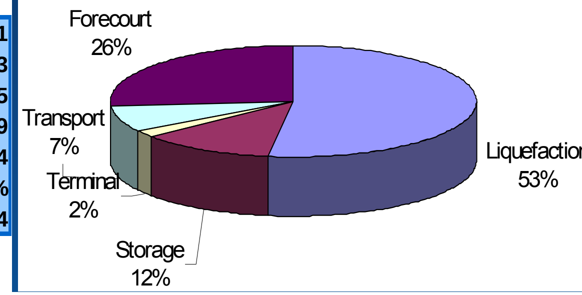


Key Delivery Inputs and Assumptions

City population	1,218,919
City area (mi2)	553
Population density (people/mi2)	2,205
Vehicles/person	0.85
Miles driven per year/ vehicle	13,748
Distance from production to city (km)	100
Actual refueling station capacity factor	0.7
H2 refueling station ave. H2 dispensed daily (kg/d)	1049
H2 Vehicles fuel economy equivalent (mi/gge)	57.50

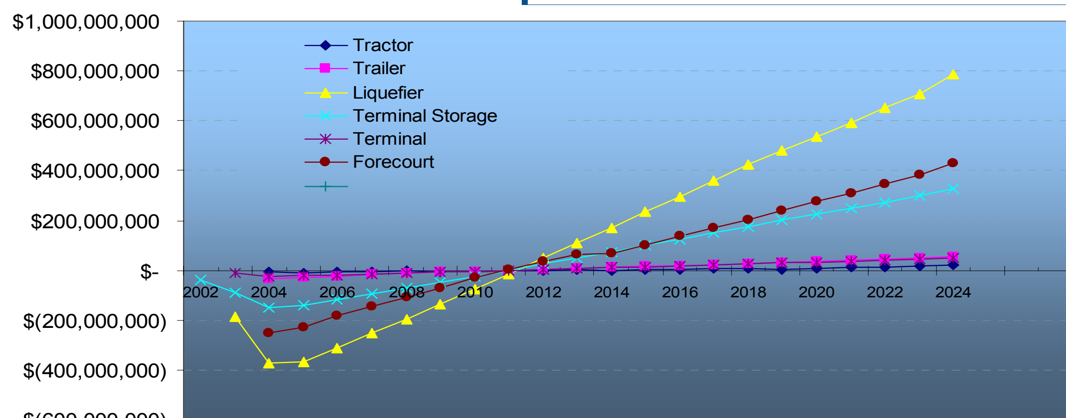
Demand Calculations

H2 use per LDV per year (kg/y)	231
H2 use per LDV kg H2/day (ave)	0.63
Number of H2 vehicles in city	520,985
City H2 daily use (kg/d)	329,229
Number of H2 refueling stations in city	314
Number of H2 stations/Number of gasoline stations	60%
Average distance between stations (km)	2.14

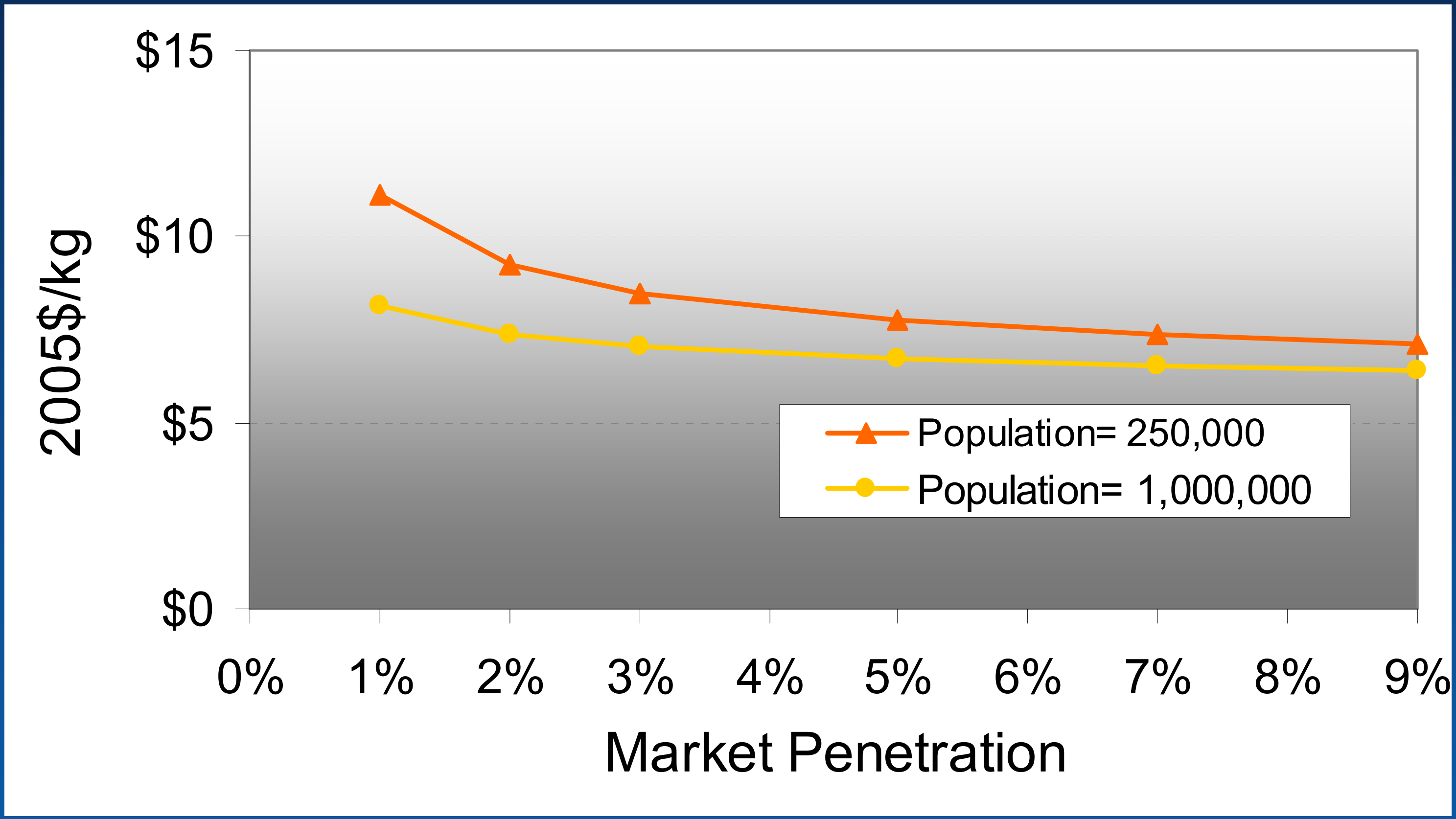


Delivery Mode Calculations

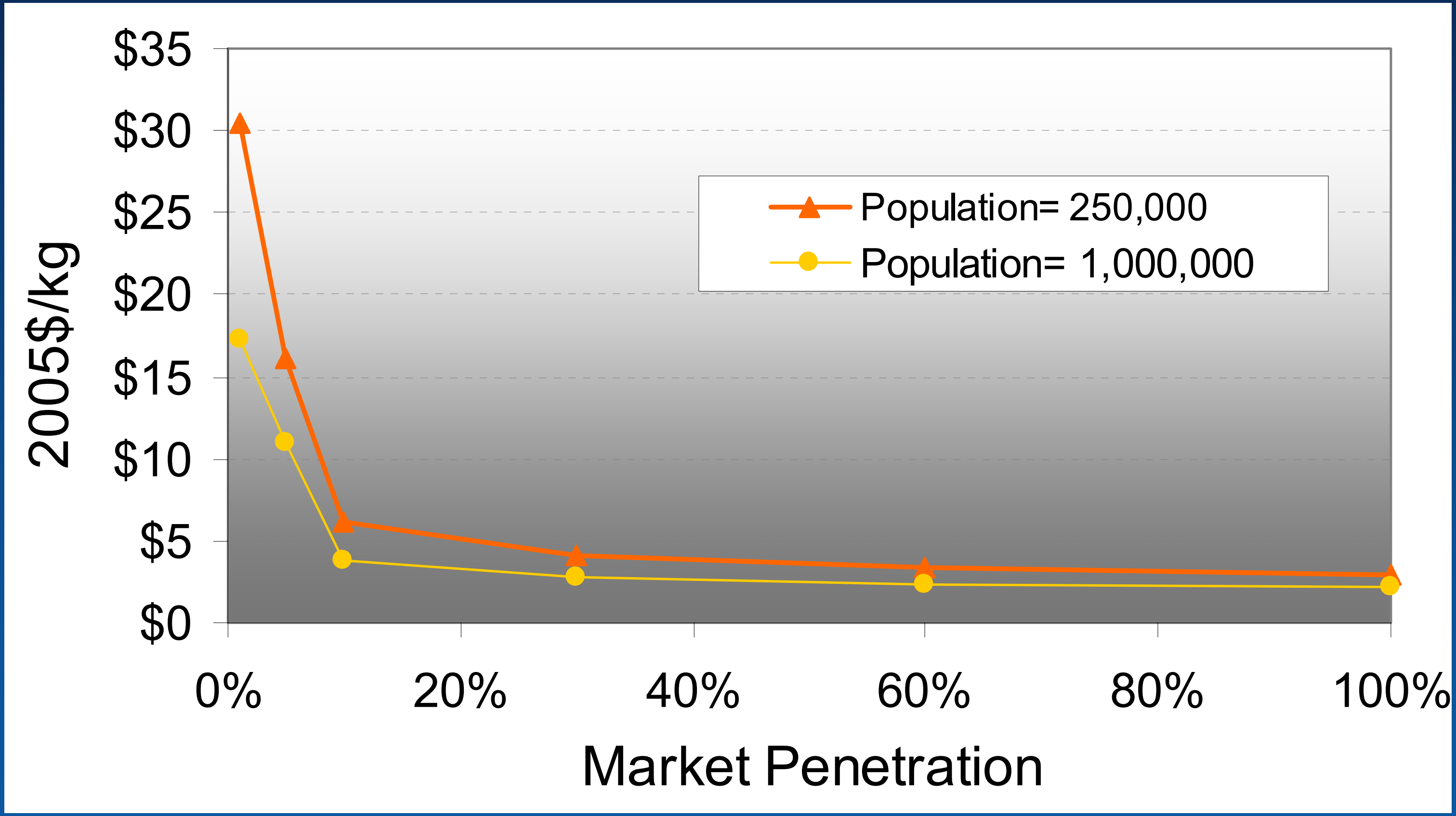
Average round-trip time (h)	12.20
Total number of deliveries per day	84.7
Possible number of round-trips per truck /day	2.0
Maximum number of deliveries per day	120.9
Number of trucks required to provide H2 to city	62



Conventional Tube Trailers Are Limited to Scenarios with Relatively Low H2 Demand

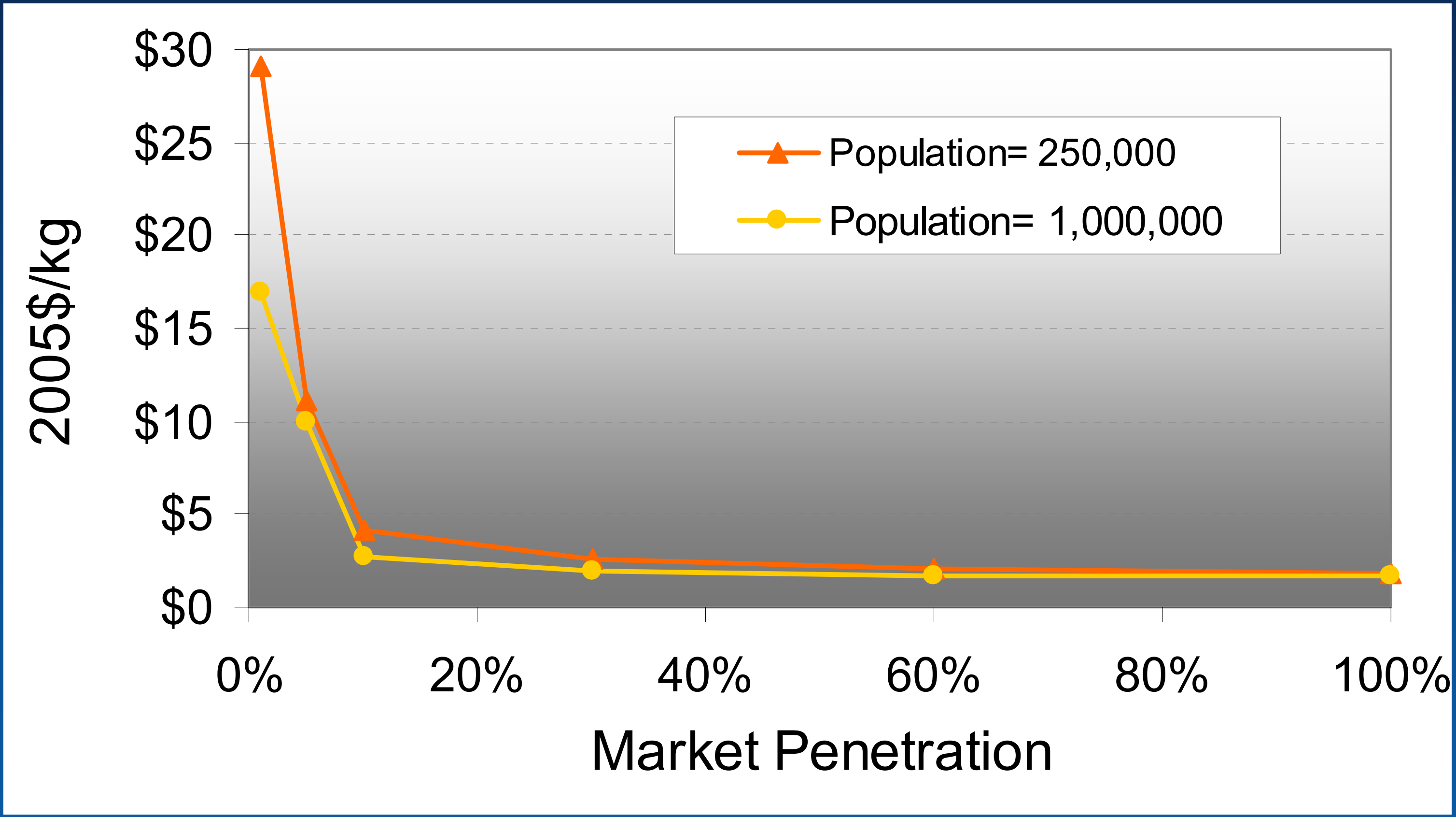


Liquid Delivery Cost Also Depends on Demand (Market Size & Penetration)



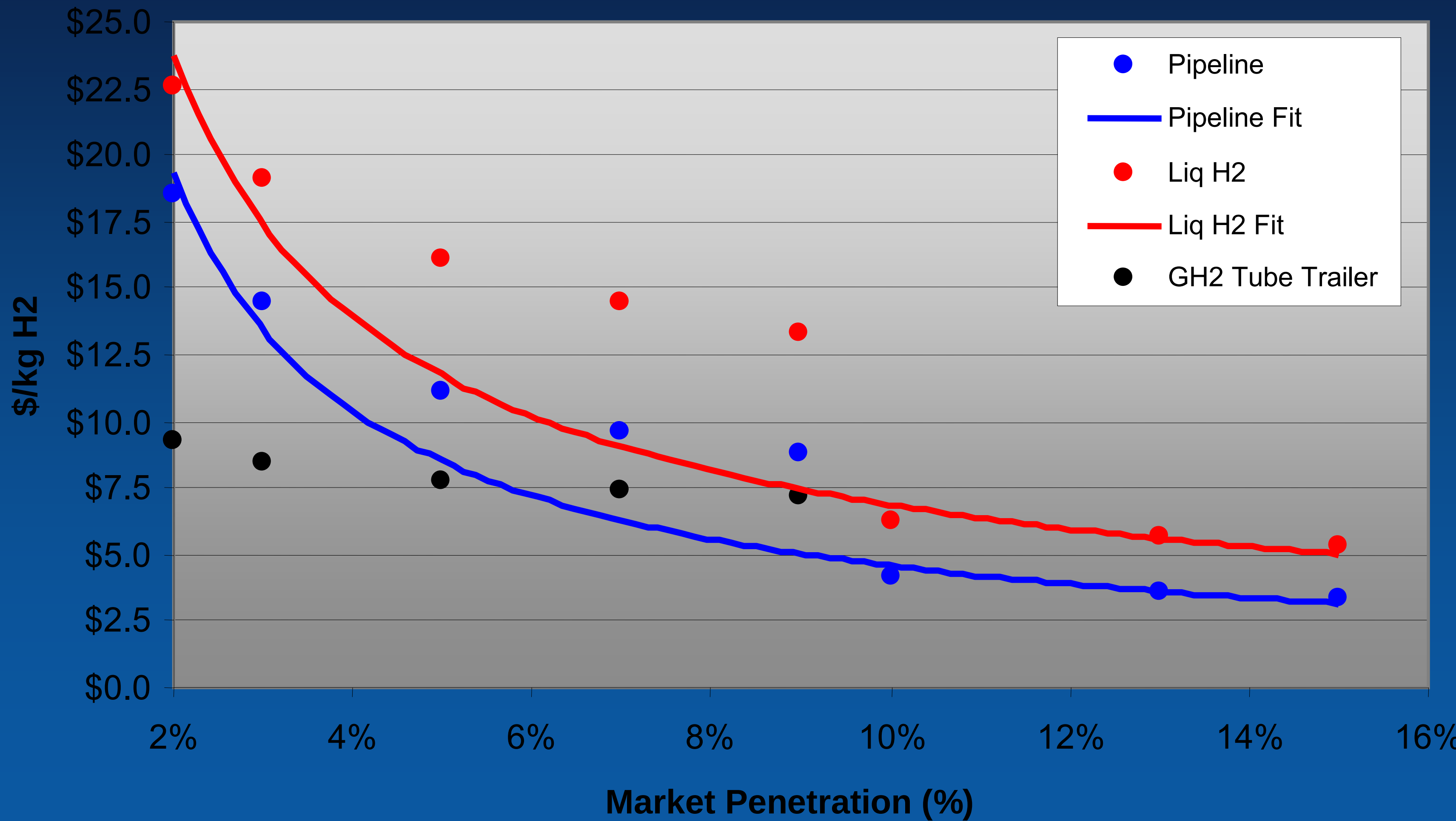
H2A Delivery

Pipeline Delivery Is Attractive above 10% Penetration in Urban Markets



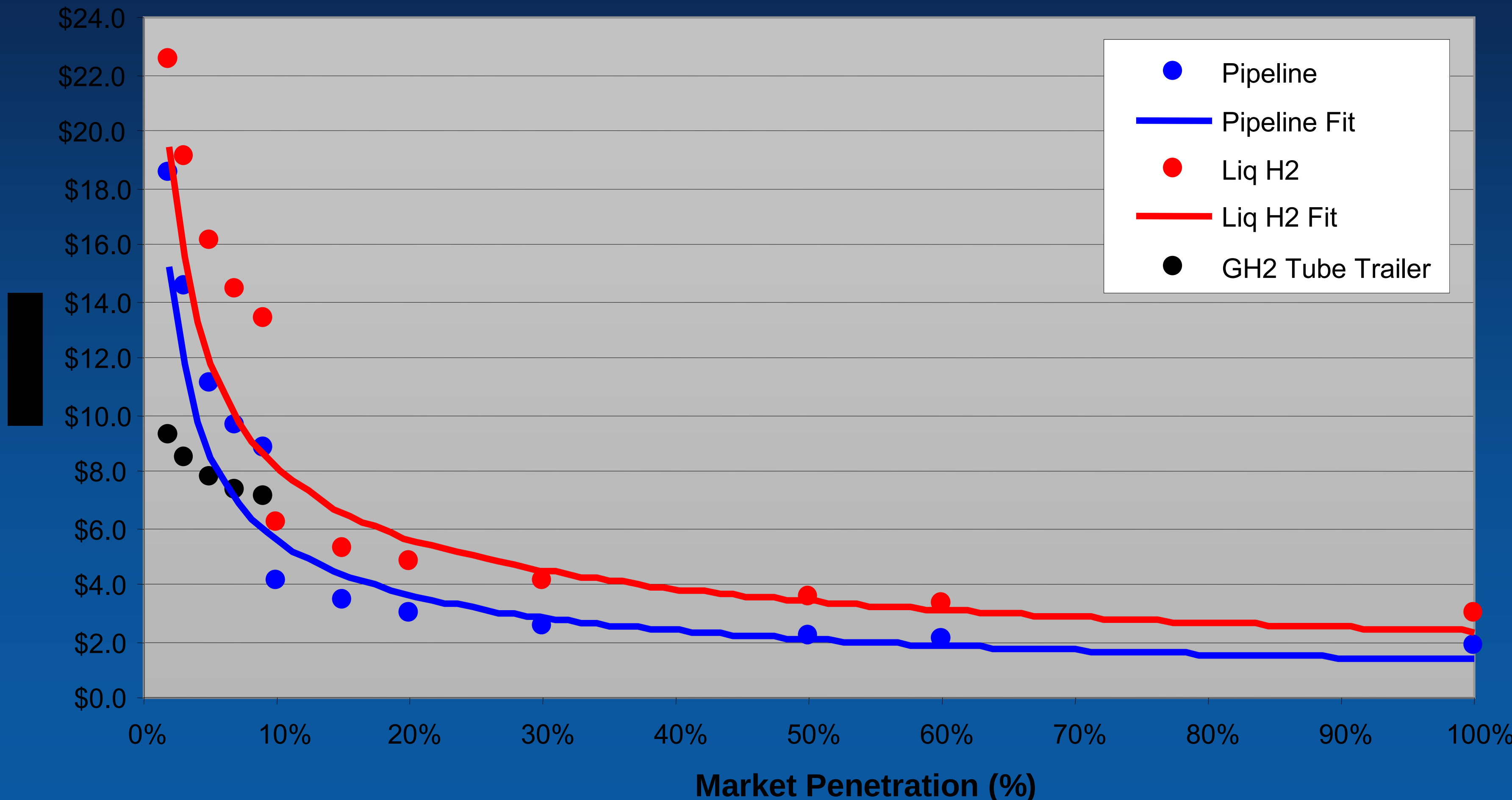
H2A Delivery

Urban Delivery Cost Declines with Increased Market Penetration and Forecourt Size (250,000 case)



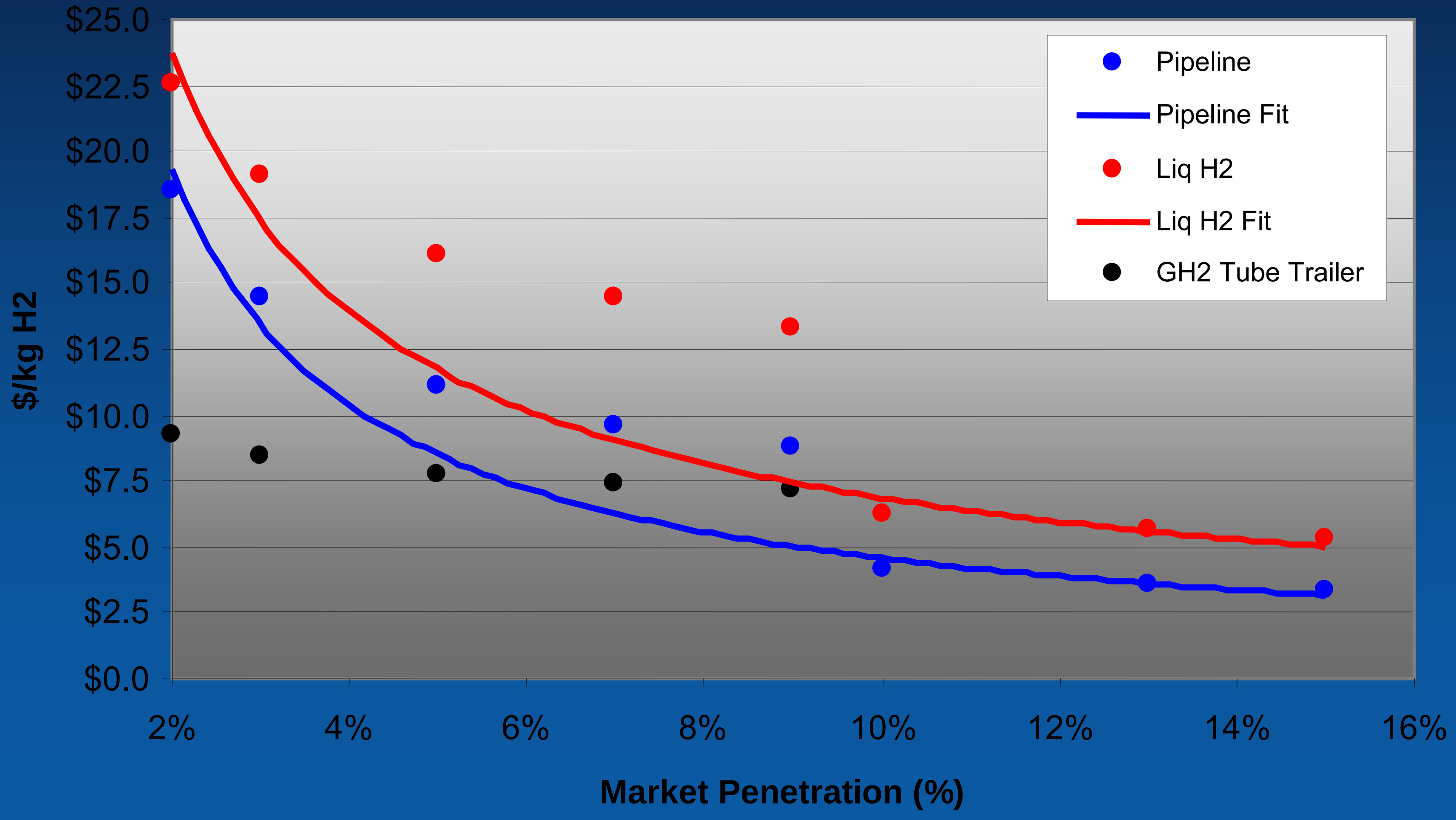
H2A Delivery

Urban Delivery Cost by Mode and Market Penetration (250,000 population, 100 & 1500 kg/d forecourts)



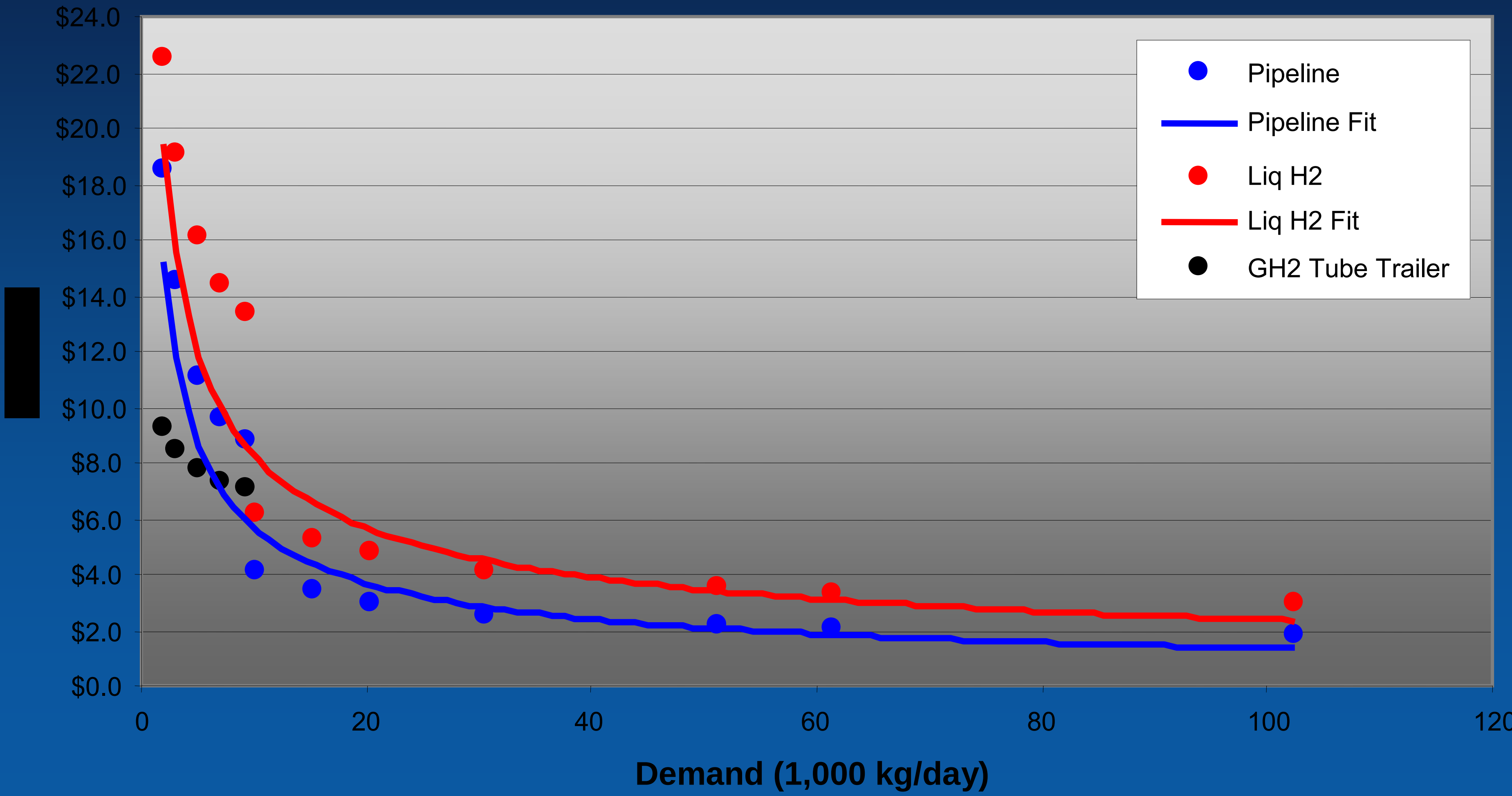
H2A Delivery

Urban Delivery Cost at Low Market Penetration (250,000 population, 100 & 1500 kg/d forecourts)



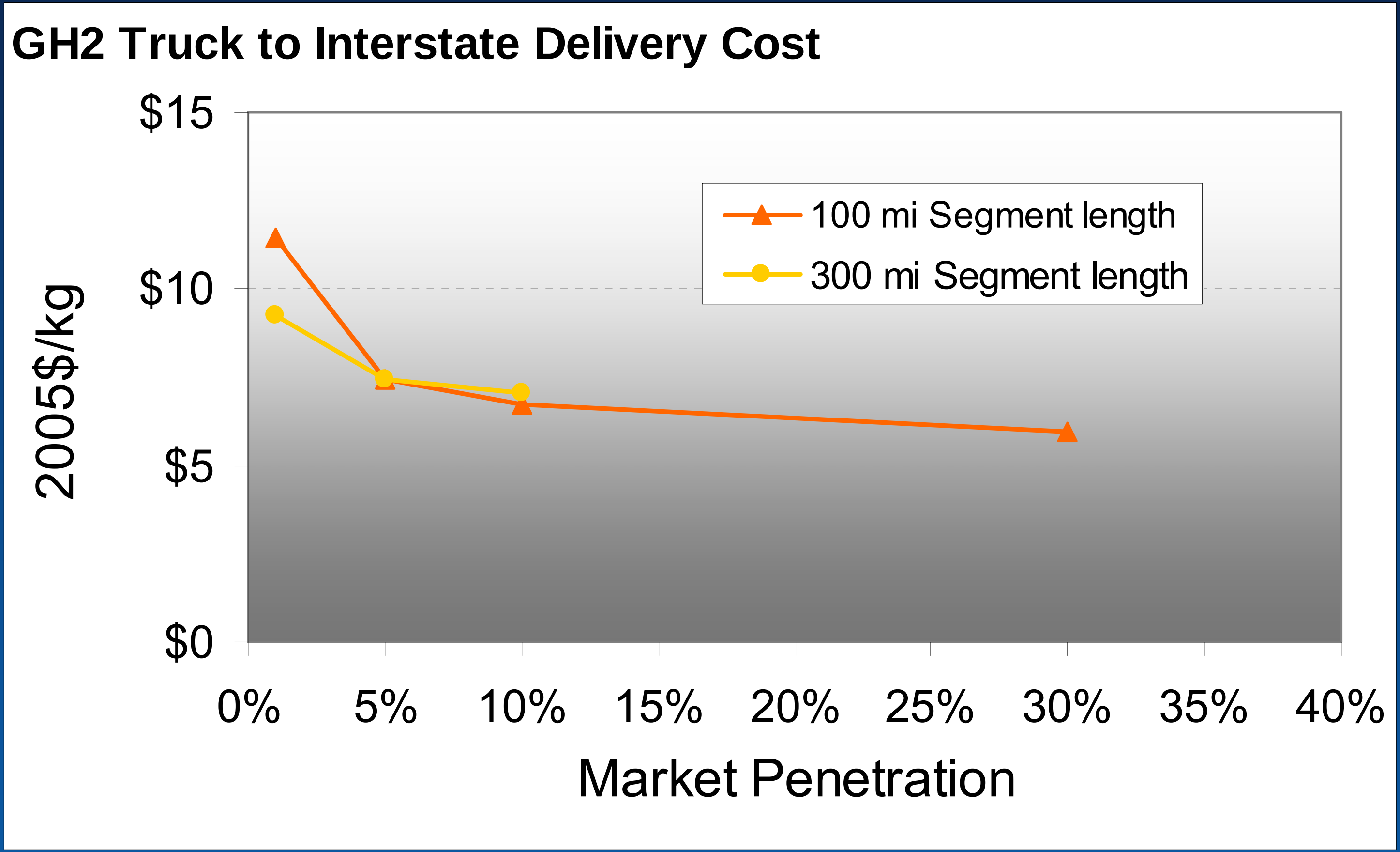
H2A Delivery

Urban Delivery Cost by Mode and Demand (250,000 population, 100 & 1500 kg/d forecourts)



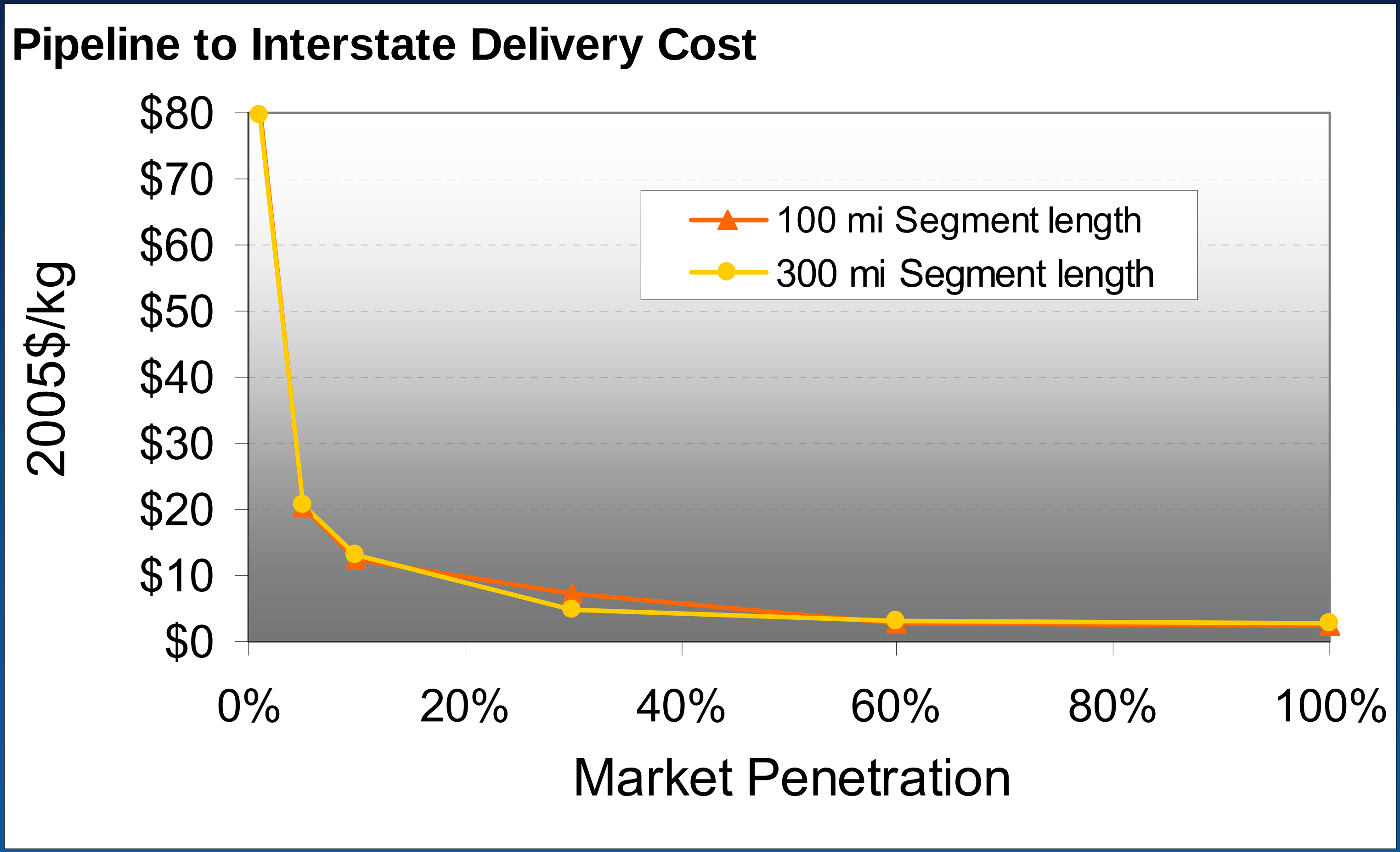
H2A Delivery

Rural/Interstate Delivery Cost Consistently Exceeds Urban; Scale Effects Limited for Tube Trailers



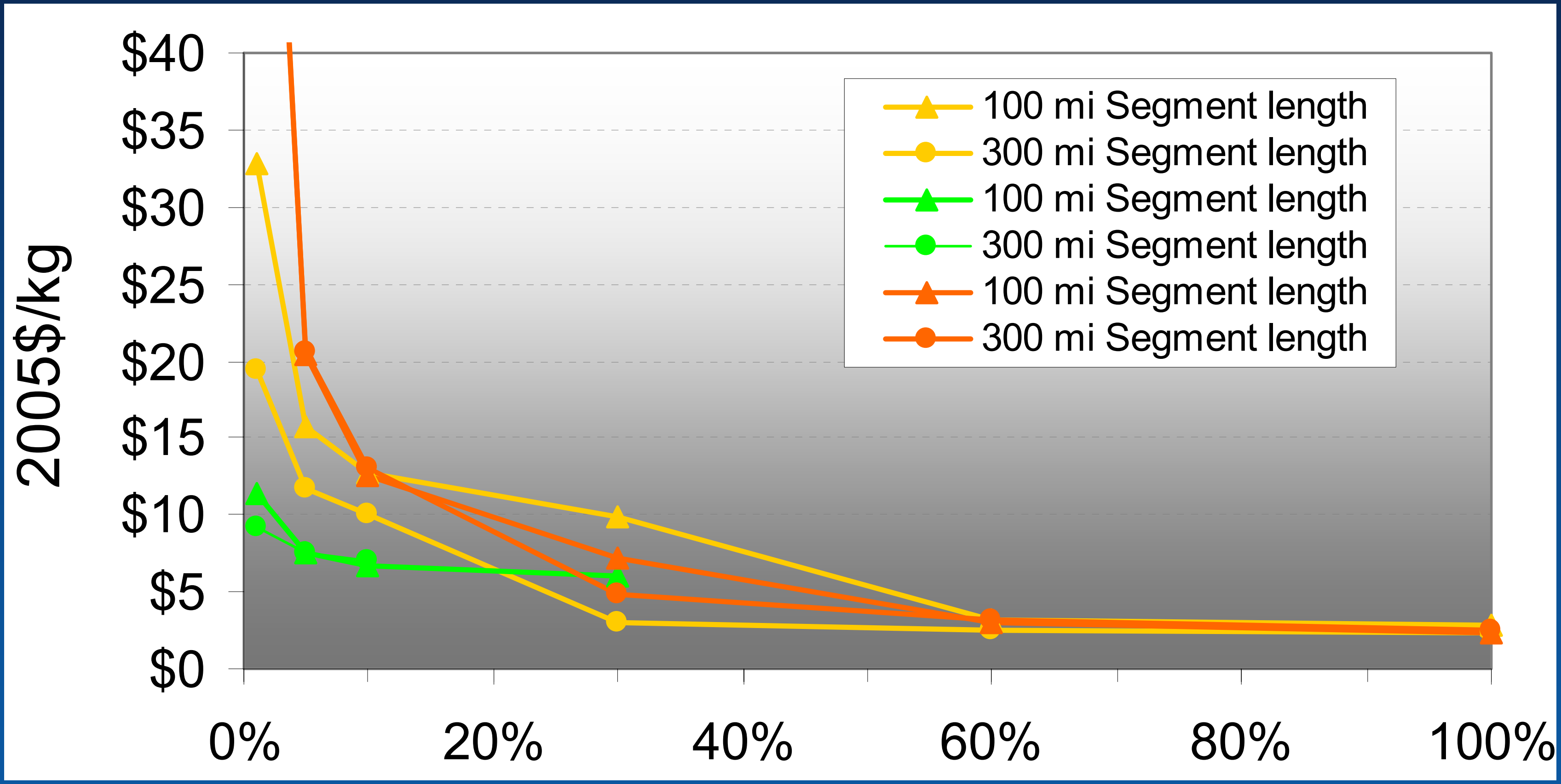
H2A Delivery

Pipeline Delivery to Interstate Markets Becomes Attractive above 30% Market Penetration



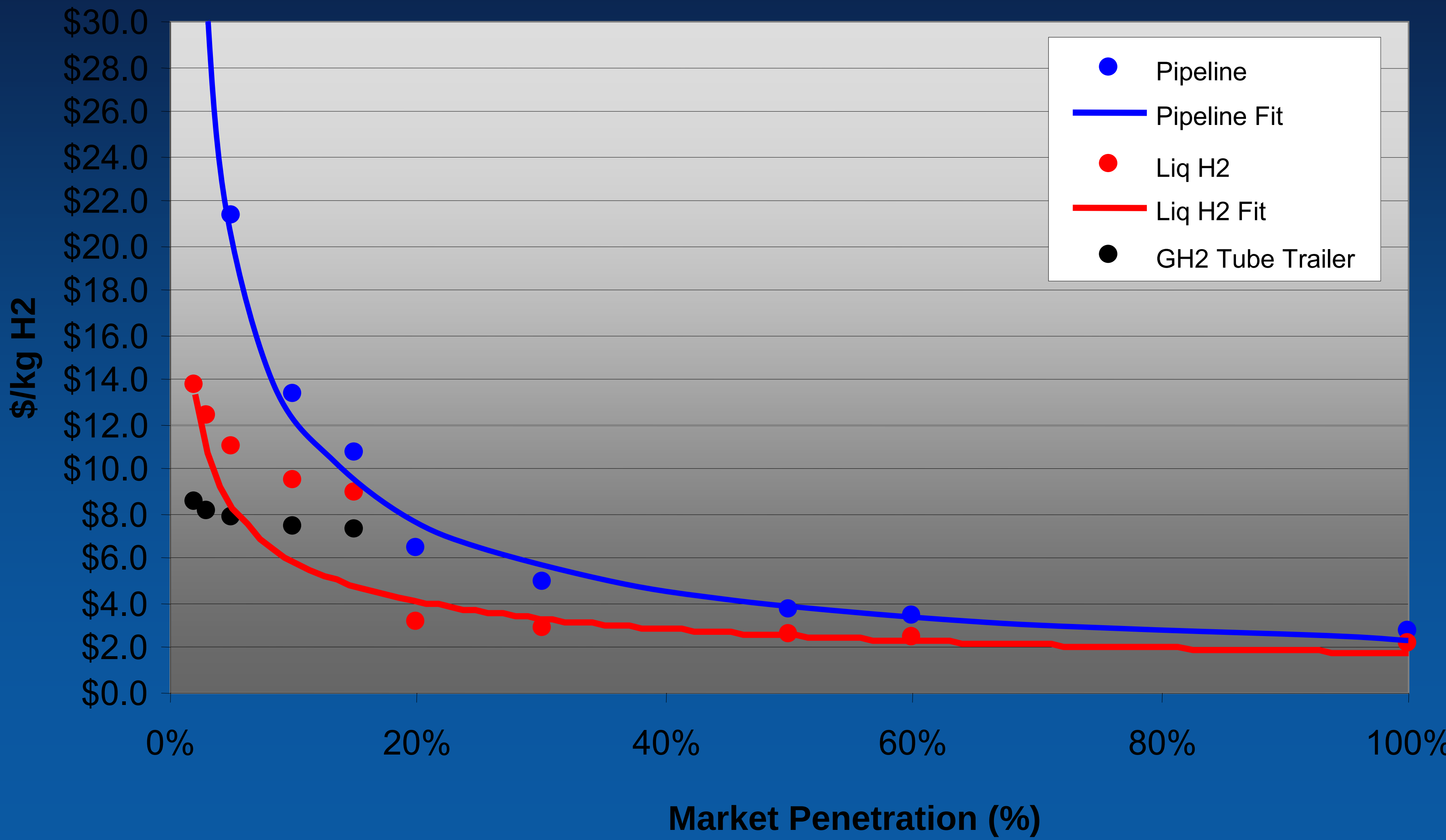
H2A Delivery

Rural/Interstate Delivery Cost Exceeds Urban; Pipeline More Costly Below 60% Penetration



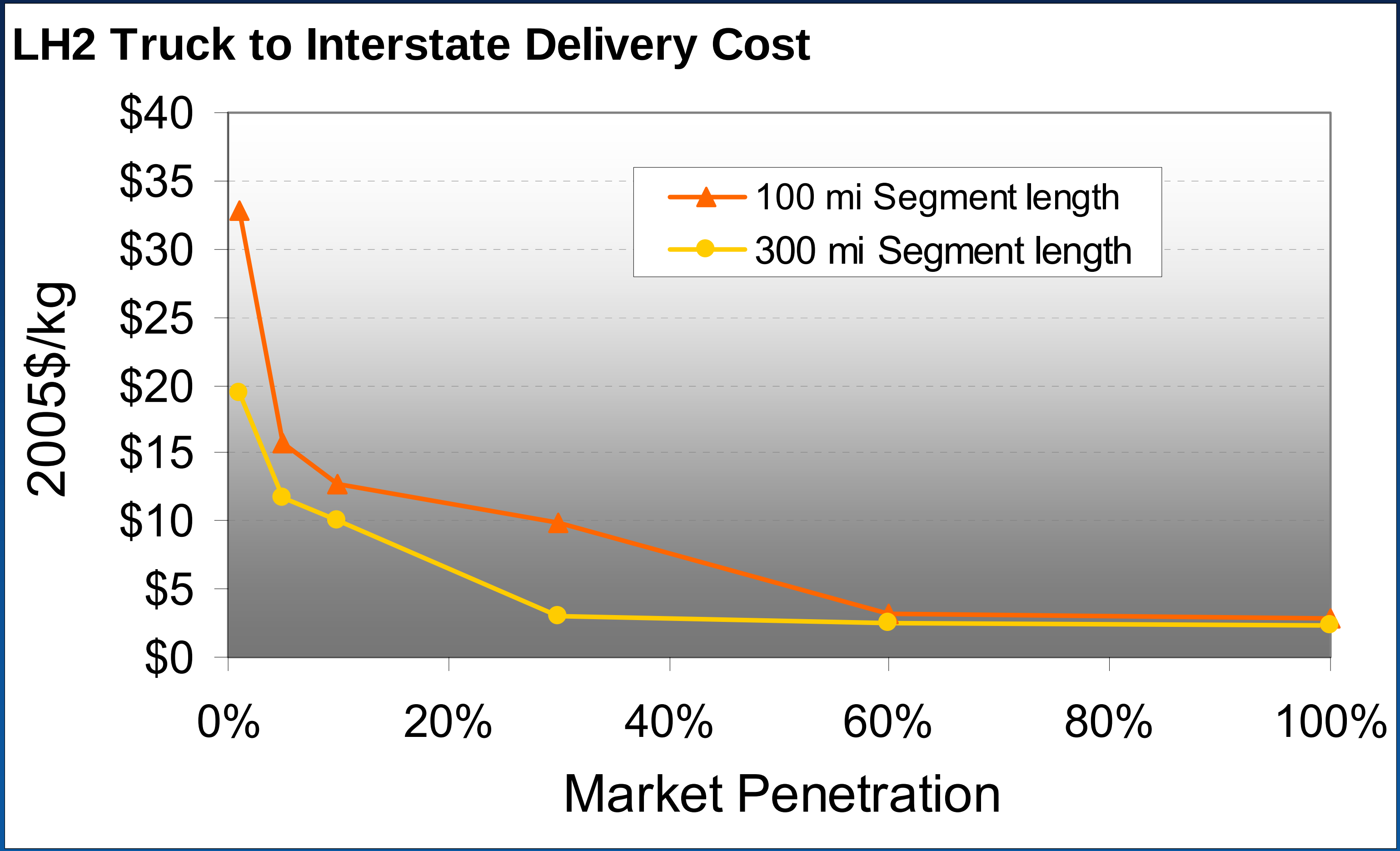
H2A Delivery

Rural/Interstate Delivery Cost by Mode and Market Penetration (400-mi segment)



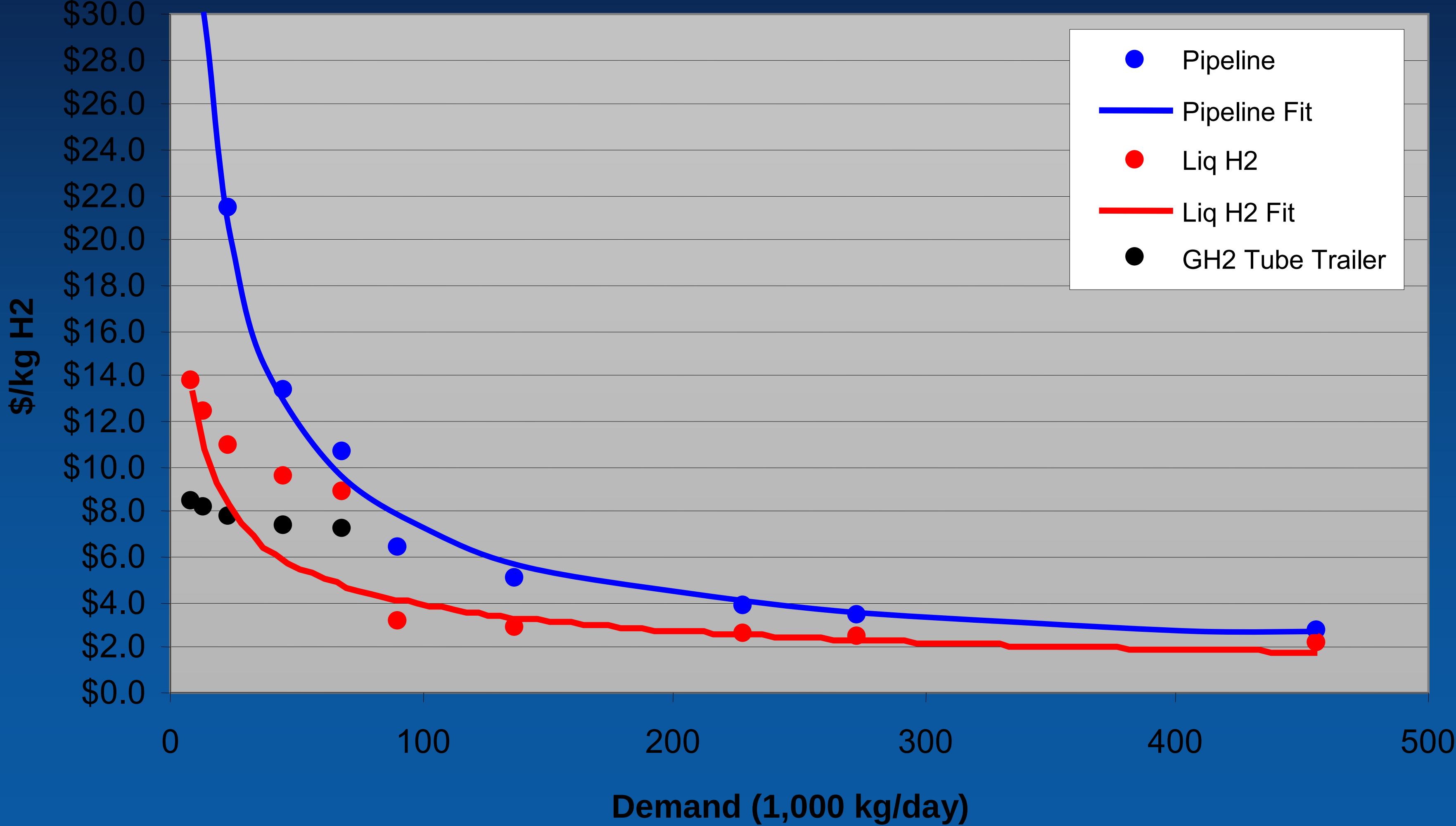
H2A Delivery

LH2 Delivery to Interstate Forecourts Becomes Attractive above 20% Market Penetration



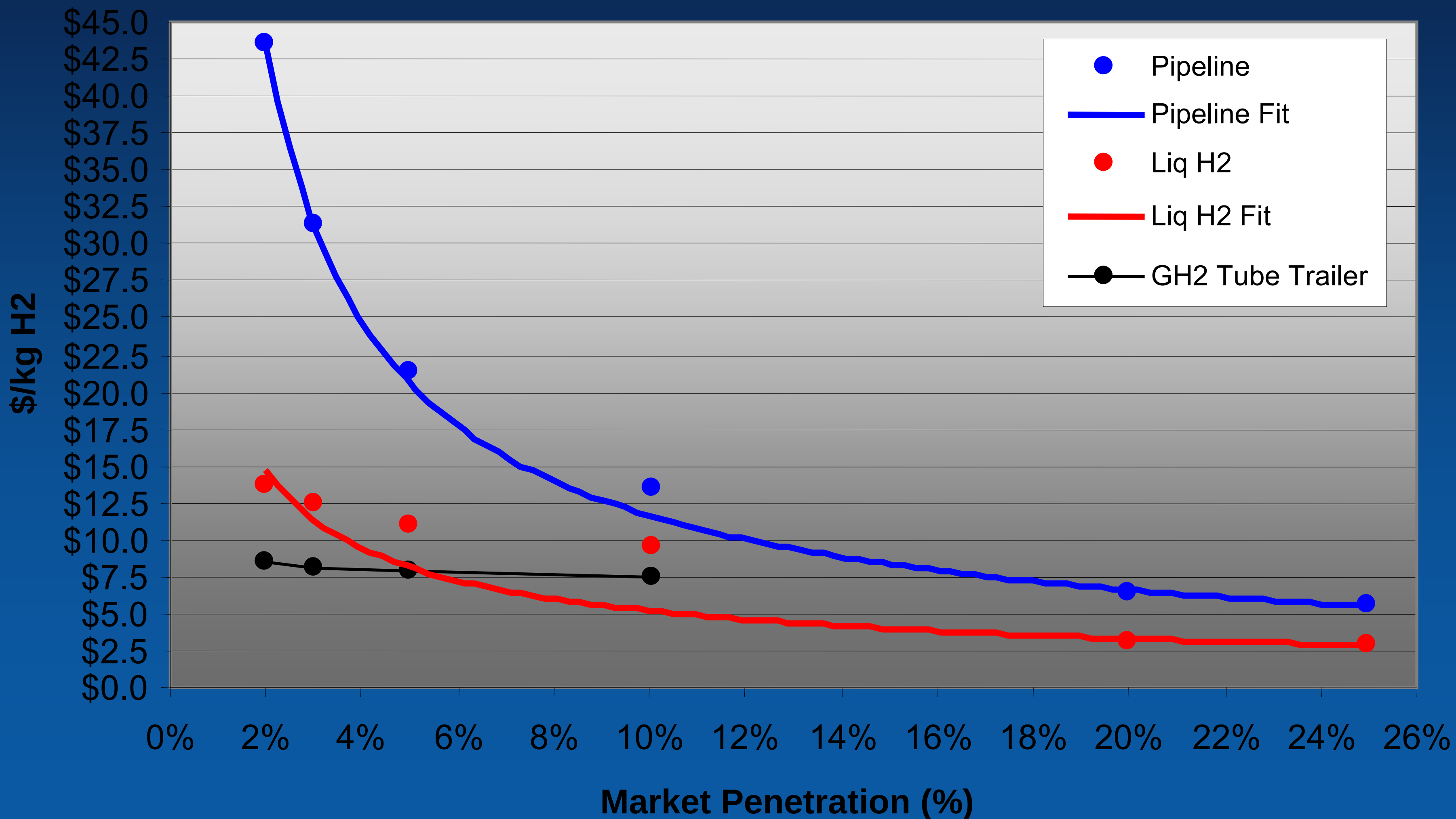
H2A Delivery

Rural Delivery Cost by Mode and Daily Demand (400-mi segment, 100 & 1500 kg/d forecourts)



H2A Delivery

Rural Delivery Cost at Low Market Penetration (400-mi segment, 100 & 1500 kg/d forecourts)

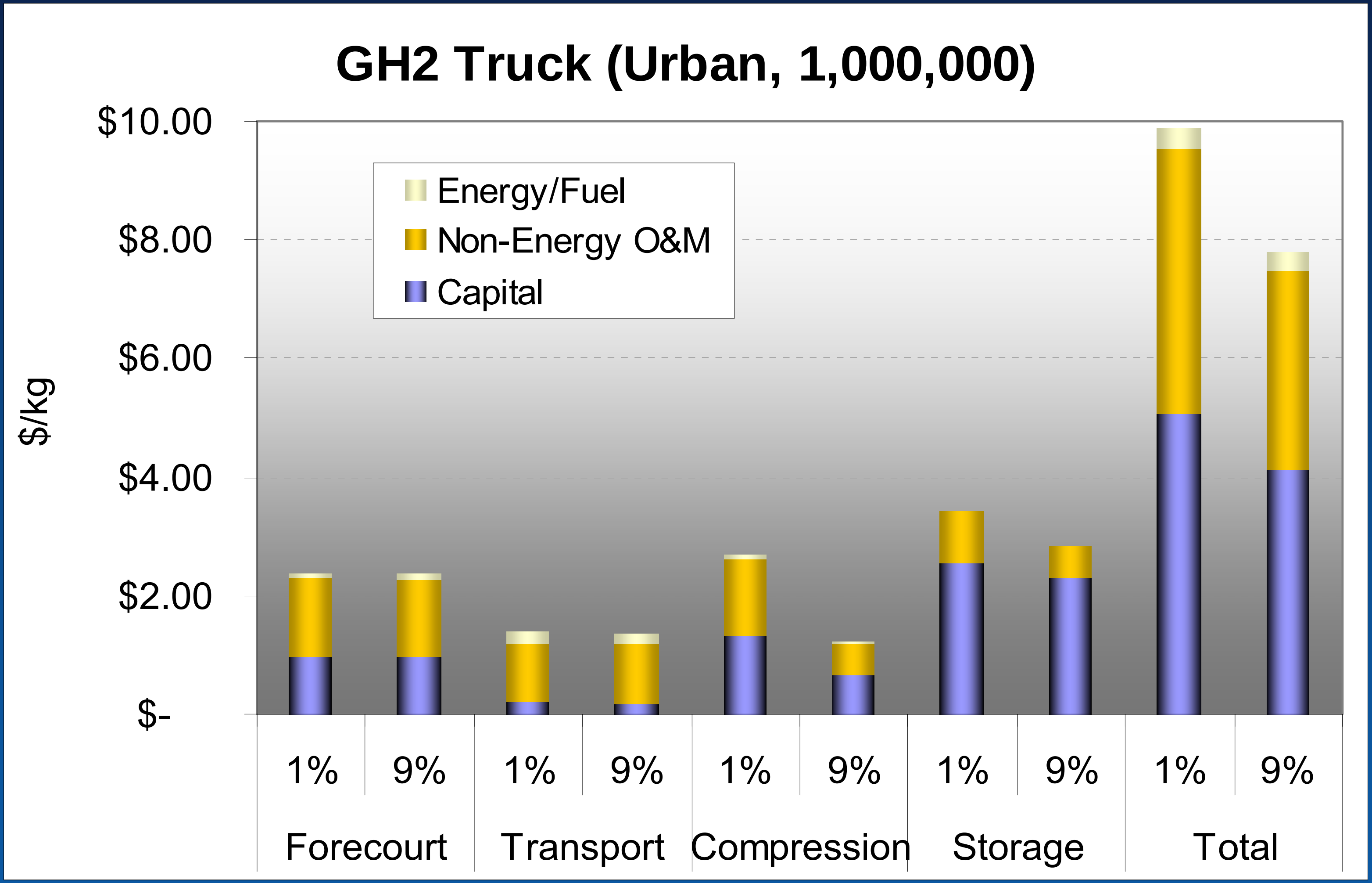


H2A Delivery

- Cost Details

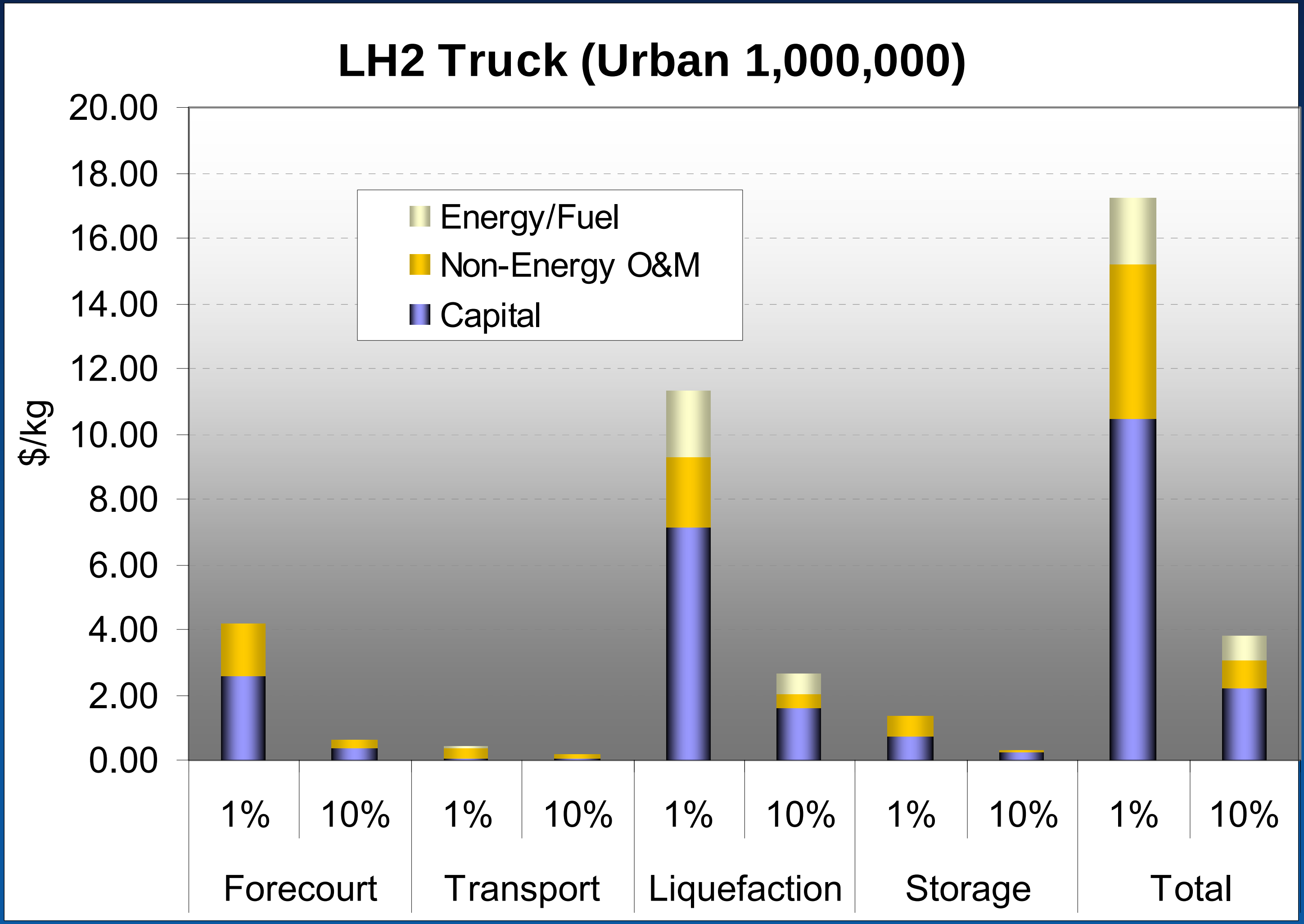
H2A Delivery

Conventional CH2 Truck Delivery Is Capital & Labor Intensive, Low Scale Economy (100 kg/d forecourt)



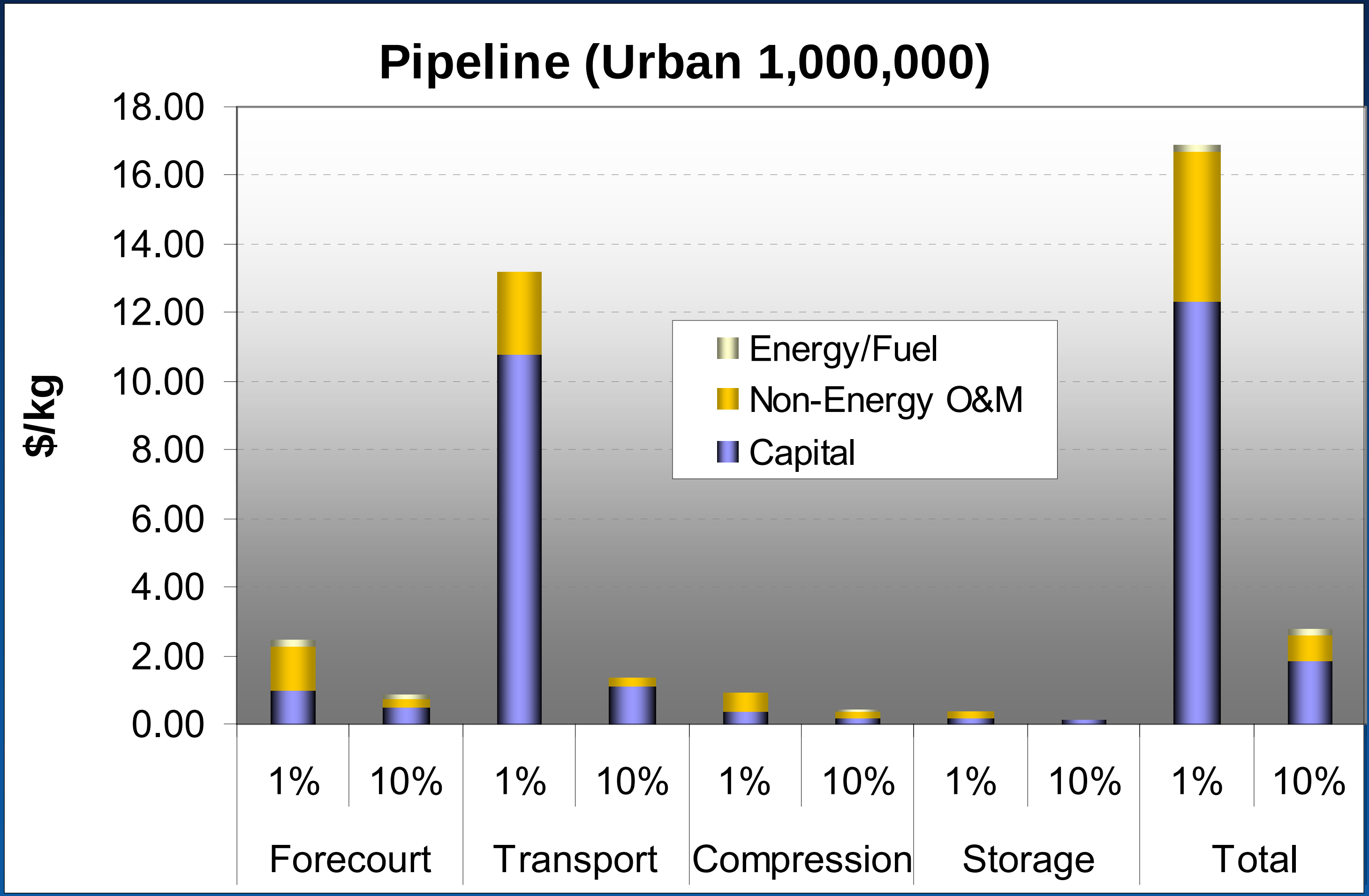
H2A Delivery

LH2 Truck Delivery Requires More Energy; Large Forecourt & Liquefier Scale Economies



H2A Delivery

Pipeline Delivery Is Capital Intensive and Has Significant Scale Economies

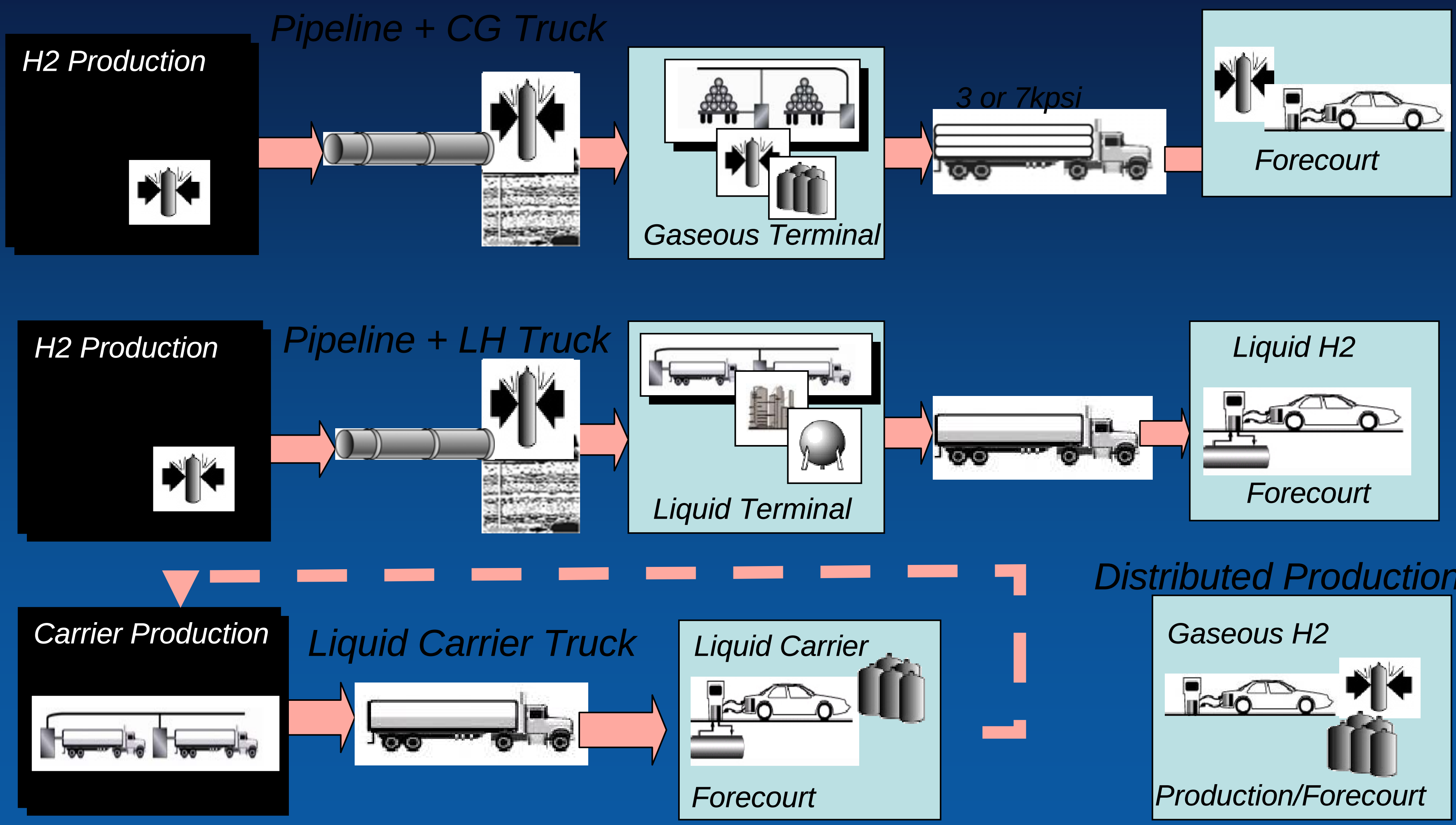


Improvements in HDSAM Version 2.0

- Additional pathways (e.g., pipeline to GH2 terminal, hydrogen carriers)
- Mixed demands/markets (e.g., combining urban with interstate demand)
- Variable capacity forecourts
- Distributed production
- Initial overbuilding of delivery infrastructure
- Energy efficiencies and CO_2 emissions
- Sensitivity analyses (service ratio, service lines, storage/compression tradeoffs, etc.)

H2A Delivery

HDSAM V2.0 Will Characterize 4 Additional Pathways, Estimating Delivery Cost for 7 Potential Options



H2A Delivery

This work has benefited from the input of many individuals, especially:

John Molburg, ANL

Joan Ogden, UCD

Mike Nicholas, UCD

H2A KIC

Delivery Tech Team

Thank You All!

Marianne Mintz

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Extra Slides

H2A Delivery Inputs Tab: (50%, LH2, Indianapolis)

General Economic Assumptions

Assumed start-up year	2005
Reference year dollars	2005
Real After-tax Discount Rate (%)	10.0%
Analysis period (years)	20
State Taxes (%)	6.0%
Federal Taxes (%)	35.0%
Total Tax Rate (%)	38.9%

Liquid H2 Delivery Market Assumptions

Distance from production to city (mi)	62

Refueling Station Data

Ave. Light Duty Vehicles (LDV) per gasoline station (US ave)	2,000

Truck-LH2 Assumptions

Truck-LH2 Economic Assumptions

Tractor MACRS Depreciation Schedule Length (years)	5
Tank Trailer MACRS Depreciation Schedule Length (years)	5
Tractor Lifetime (years)	5
Tank Trailer Lifetime (years)	20
Inflation Rate (%)	1.9%

Truck-LH2 Design Inputs

Tank Water Volume (ft3)	2295.5
Tank Loading Losses (% of Tank Volume)	0.0%
Tank Unloading Losses (% of Tank Volume)	6.0%
Tank Boil-off Rate (% per day)	0.5%

Truck-LH2 Delivery Scenario Inputs

Tanker Useable Delivery Capacity (%)	90%
Round-Trip Distance (mi)	195
Average Station Hydrogen Demand (kg/day)	1,049
Number of Stations per Trip	1
Total Time for Load Truck (hours)	3.0
Total Time to Unload Truck at each Station (hours)	3.5
Average Truck Speed (mph)	43.5
Average Truck Gas Mileage (mpg)	6.0
Truck Yearly Availability (%)	98%

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor cost ($(2005)/man-hour)	$20.00
Percent of Total Labor Costs Allocated to Tractor (%)	100%

Fuel Cost

Use the H2A Feedstock Cost Projections?	yes
	$0.00
Percent of Total Fuel Costs Allocated to Tractor (%)	100%

Other Fixed Cost

Insurance ($(2005)/mi)	$0.097
Percentage of Insurance Costs Allocated to Tractor (%)	75%
Property Taxes (% of total capital investment)	1.5%
Licensing and permits ($(2005)/mi)	$0.113
Percentage of Licensing and Permits Allocated to Tractor (%)	75%
Operating, Maintenance and Repairs ($(2005)/mi)	$0.080
Percentage of Operating, Maintenance and Repairs Allocated to Tractor (%)	75%
Overhead and G&A (% of Total Labor Cost)	50%
Other Fixed Operating Costs ($(2005)/year)	$5,000
Percentage of Other Fixed Operating Costs Allocated to Tractor (%)	50%

Truck-LH2 Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	1
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

Liquid H2 Terminal Assumptions

Terminal Economic Assumptions

MACRS Depreciation Schedule Length (years)	15
Liquid Hydrogen Terminal Lifetime (years)	20
Inflation Rate (%)	1.9%
Unit installed cost of piping ($(2005)/ft)	$503
Cost of plumbing, electrical, and instrumentation at each individual bay (Year 2005 $)	$25,000

Terminal Design Assumptions

Terminal capacity (kg/day)	506,856
Useable Percent of Liquid Storage Unit (%)	90.0%
Boil-off (%/day)	0.25%

Terminal Delivery Assumptions

Liquid H2 Terminal Availability	98.6%
Time required per fill, connected time (hours)	2.0
Time required for parking, connection, disconnection, and removal of trailer (hours)	1.0
Number of Days of Storage (days)	5.0
Width of individual bay (ft)	16.4
Distance from storage to pump (ft)	100.1
Distance from pump to fill header (ft)	100.1

Capital Investment Assumptions

Land Cost

Land Cost ($(2005)/ft2)	$0.12

Other Capital Cost

Site Preparation (% of Initial Capital Investment)	12.0%
Engineering & Design (% of Initial Capital Investment)	32.0%
Project Contingency (% of Initial Capital Invesment)	25.0%
One-time Licensing Fees (% of Initial Capital Investment)	1.5%
Up-Front Permitting Costs (% of Initial Capital Investment)	4.0%
Other capital ($(2005))	$0

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor required (hrs/year)	17,520
Labor cost ($(2005)/man-hr)	$24.20

Other Fixed Cost

Insurance (% of Total Capital Investment)	1.0%
Property Taxes (% of Total Capital Investment)	1.5%
Licensing and Permits (% of Total Capital Investment)	1.0%
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%
Overhead and G&A (% of Total Labor Cost)	50.0%
Other Fixed Operating Costs ($(2005)/year)	$0

LH2 Terminal Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	3
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

H2 Liquefier Assumptions

Liquefier Economic Assumptions

MACRS Depreciation Schedule Length (years)	15
Liquefier Lifetime (years)	20
Inflation Rate (%)	1.9%

Liquefier Design Assumptions

Hydrogen Flowrate into Liquefier (kg/day)	519,799
Use Liquefier Electrical Efficiency Calculation?	yes
	0.0%
Use Default Inlet Hydrogen Temperature?	yes
	0
Use default outlet hydrogen temperature?	yes
	0

Liquefier Scenario Assumptions

Hydrogen Loss During Liquefaction (%)	0.5%
Liquefier Availability (% per year)	98%

Capital Investment Assumptions

Land Cost

Land Cost ($(2005)/ft2)	$0.12

Other Capital Cost

Site Preparation (% of Initial Capital Investment)	12.0%
Engineering & Design (% of Initial Capital Investment)	32.0%
Project Contingency (% of Initial Capital Invesment)	25.0%
One-time Licensing Fees (% of Initial Capital Investment)	1.5%
Up-Front Permitting Costs (% of Initial Capital Investment)	4.0%
Other capital ($(2005))	$0

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor required (hrs/year)	15,768
Labor cost ($(2005)/man-hr)	$24.20

Electricity Cost

Use the H2A Commercial Electricity Cost Projection?	yes, industrial
Electricity Cost ($(2005)/kWh)	$0.05
	$0.00

Other Fixed Cost

Insurance (% of Total Capital Investment)	1.0%
Property Taxes (% of Total Capital Investment)	1.5%
Licensing and Permits (% of Total Capital Investment)	1.0%
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%
Overhead and G&A (% of Total Labor Cost)	50.0%
Other Fixed Operating Costs ($(2005)/year)	$0

LH2 Liquefier Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	2
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

H2A Delivery

Scenario Definition & Results Tabs (50% Urban Penetration, Pipeline, Indianapolis)

H2 Market
- (●) Urban
- ( ) Rural Interstate

Market Penetration
H2 Vehicle Penetration: 50 %

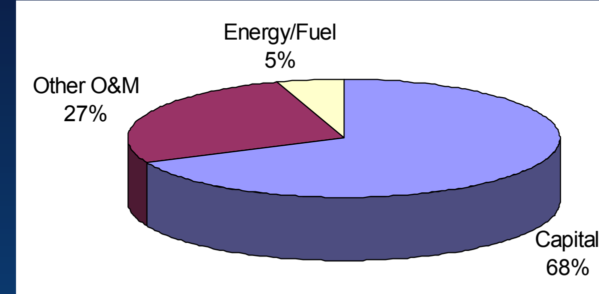
City Selection
Indianapolis, IN
1,218,919

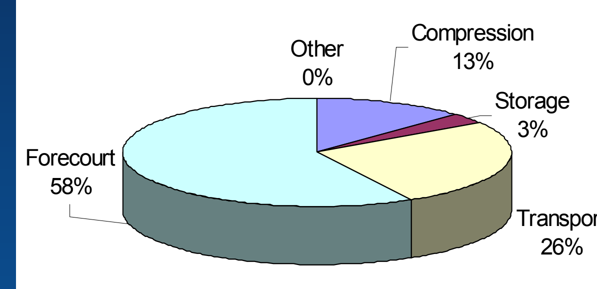
Delivery Mode
- ( ) Compressed H2 Truck
- ( ) Liquid H2 Truck
- (●) Pipeline

Calculate

Delivery Costs

Total Cost [$/kg]	1.82





Key Delivery Inputs and Assumptions

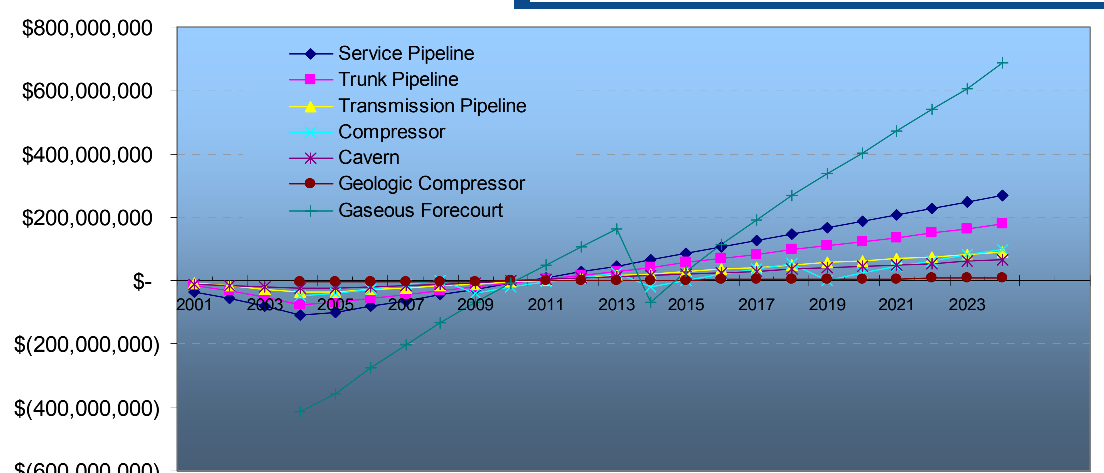
City population	1,218,919
City area (mi2)	553
Population density (people/mi2)	2,205
Vehicles/person	0.85
Miles driven per year/ vehicle	13,748
Distance from production to city (km)	100
Actual refueling station capacity factor	0.7
H2 refueling station ave. H2 dispensed daily (kg/d)	1049
H2 Vehicles fuel economy equivalent (mi/gge)	57.50

Demand Calculations

H2 use per LDV per year (kg/y)	231
H2 use per LDV kg H2/day (ave)	0.63
Number of H2 vehicles in city	520,985
City H2 daily use (kg/d)	329,229
Number of H2 refueling stations in city	314
Number of H2 stations/Number of gasoline stations	60%
Average distance between stations (km)	2.14

Delivery Mode Calculations

Number of trunk rings	2
Pipeline ring1 (trunk) peak flow rate [kg/day]	222,265
Pipeline ring2 (trunk) peak flow rate [kg/day]	248,057
Pipeline transmission length [km]	100
Pipeline ring1 (trunk) length [km]	62
Pipeline ring2 (trunk) length [km]	124
	1217
Pipeline ring1 (trunk) radius [km]	8
Pipeline ring2 (trunk) radius [km]	16
Transmission pipe diameter [in]	12.25
Ring1 (trunk) pipe diameter [in]	10.50
Ring2 (trunk) pipe diameter [in]	14.50
Pipeline service diameter [in]	1.00



H2A Delivery

Inputs Tab: (50%, Pipe, Indianapolis)

General Economic Assumptions

Assumed start-up year	2005
Reference year dollars	2005
Real After-tax Discount Rate (%)	10.0%
Analysis period (years)	20
State Taxes (%)	6.0%
Federal Taxes (%)	35.0%
Total Tax Rate (%)	38.9%

Pipeline Delivery Market Assumptions

Distance from production to city (mi)	62

Refueling Station Data

Ave. Light Duty Vehicles (LDV) per gasoline station (US ave)	2,000

H2 Pipeline Assumptions

H2 Pipeline Economic Assumptions

MACRS Depreciation Schedule Length (years)	15
H2 Pipeline Lifetime (years)	20
Inflation Rate (%)	1.9%

H2 Pipeline Design Inputs

Hydrogen Flowrate to System (kg/day)	479,865
Use H2A calculations, using the Panhandle B Pipeline Equation, to calculate pipeline diameter?	yes
Transmission Pipeline Inlet Pressure (psi)	999
Desired Transmission Pipeline Outlet Pressure (psi)	705
Transmission Pipeline Temperature (degrees F)	77
Transmission Pipeline Length (mi)	62.1
	0.00
Trunk (ring1) Pipeline Inlet Pressure (psi)	588
Desired Trunk (ring1) Pipeline Outlet Pressure (psi)	441
Trunk (ring1) Pipeline Temperature (degrees F)	68
Number of Trunk Pipelines	2
Length of Trunk (ring1) Pipeline (mi)	38.5
	0.00
Hydrogen Flowrate to Trunk (ring2) (kg/day)	253,087
Trunk (ring2) Pipeline Inlet Pressure (psi)	514
Desired Trunk (ring2) Pipeline Outlet Pressure (psi)	441
Trunk (ring2) Pipeline Temperature (degrees F)	68
Length of Trunk (ring2) Pipeline (mi)	77.3
	0.00
Service Pipeline Inlet Pressure (psi)	397
Desired Service Pipeline Outlet Pressure (psi)	294
Service Pipeline Temperature (degrees F)	77
	0.00

H2 Pipeline Delivery Scenario Inputs

Hydrogen Lost During Pipeline Delivery (%)	0.50%
Pipeline Availability (%/year)	99%

Capital Investment Assumptions

Land Cost

Use H2A right of way/land costs, based on data for natural gas pipelines from the Oil and Gas Journal	yes
	$0
	$0
	$0

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor required (hrs/year)	8,320
Labor cost ($(2005)/man-hr)	$15.05

Other Fixed Cost

Insurance (% of Total Capital Investment)	1.0%
Property Taxes (% of Total Capital Investment)	1.5%
Licensing and Permits (% of Total Capital Investment)	1.0%
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%
Overhead and G&A (% of Total Labor Cost)	50.0%
Other Fixed Operating Costs ($(2005)/year)	$0

H2 Pipeline Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	4
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

GH2 Geologic Storage Assumptions

Geologic Storage Economic Assumptions

Compressor MACRS Depreciation Schedule Length (years)	5
Cavern MACRS Depreciation Schedule Length (years)	15
Compressor Lifetime (years)	10
Cavern Lifetime (years)	20
Inflation Rate (%)	1.9%
Cost of Hydrogen Cushion Gas ($(2005)/kg)	$2.50

Geologic Storage Design Assumptions

Enter Demand Hydrogen Flowrate for the System that the Geologic Storage Cavern Provides Surge Capacity for (kg/day)	332,546
Cavern Maximum Pressure (psi)	1837
Cavern Minimum Pressure (psi)	294
Cavern Temperature (degrees F)	50
Pipeline pressure in feeder to cavern (psi)	999
Inlet Hydrogen Temperature to Compressor (F)	68
Cp/Cv ratio	1.4
Design Compressor Based on Compression Ratio?	yes
Enter Compression Ratio Per Stage	1.7
	0
Isentropic Compressor Efficiency Available?	yes
Isentropic Compressor Efficiency (%)	70.0%
	0.0
	0.0
Use Isentropic Compressor Efficiency to Calculate Power Requirement?	yes
	0.0
Compressor Yearly Availability (%)	100%

Geologic Storage Delivery Assumptions

% Above Peak System Demand Required for Surges	10.0%
Maximum Number of Days for Surges	120
Number of Surges per Year	1
Maximum allowable daily hydrogen withdrawal rate (% of total cavern capacity)	10%
Maximum allowable injection Rate (as Percentage of Withdrawal Rate)	66%
Cavern Availability (%/year)	98.6%

Capital Investment Assumptions

Land Cost

Use H2A correlation for land cost to calculate total land cost?	yes
	0
	0

Other Capital Cost

Site Preparation (% of Initial Capital Investment)	12.0%
Engineering & Design (% of Initial Capital Investment)	32.0%
Project Contingency (% of Initial Capital Invesment)	25.0%
One-time Licensing Fees (% of Initial Capital Investment)	1.5%
Up-Front Permitting Costs (% of Initial Capital Investment)	1.0%
Other capital ($(2005))	$0

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor required (hrs/year)	8,760
Labor cost ($(2005)/man-hr)	$24.20
Percentage Allocated to Compressor (%)	50%

Electricity Cost

Use the H2A Commercial Electricity Cost Projection?	yes, industrial
Electricity Cost ($(2005)/kWh)	$0.06
	$0.00
Percent Allocated to Compressor (%)	100.0%

Other Fixed Cost

Insurance (% of Total Capital Investment)	1.0%
Property Taxes (% of Total Capital Investment)	1.5%
Licensing and Permits (% of Total Capital Investment)	1.0%
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%
Overhead and G&A (% of Total Labor Cost)	50.0%
Other Fixed Operating Costs ($(2005)/year)	$0
Percent Allocated to Compressor (%)	$0

Geologic Storage Compressor Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	4
Startup Time	1
Salvage Value	5%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

Pipeline Compressor Assumptions

Pipeline Compressor Economic Assumptions

MACRS Depreciation Schedule Length (years)	5
Compressor Lifetime (years)	5
Inflation Rate (%)	1.9%

Pipeline Compressor Design Assumptions

Hydrogen Design Capacity Flowrate (kg/day)	482,276
Inlet Pressure (psi), no vacuum pressure allowed	294
Outlet Pressure (psi), no vacuum pressure allowed	999
Inlet Hydrogen Temperature (degrees F)	77
Cp/Cv ratio	1.4
Design Compressor Based on Compression Ratio per Stage?	yes
Enter Compression Ratio Per Stage	1.7
	0
Isentropic Compressor Efficiency Available?	yes
Isentropic Compressor Efficiency (%)	70.0%
	0.0%
	0.0%
Use Isentropic Compressor Efficiency to Calculate Power Requirement?	yes
	0.0
Hydrogen Lost During Compression (% of Feed H2)	0.50%
Compressor Yearly Availability (%)	100%

Capital Investment Assumptions

Equipment Cost

Use H2A compressor costs, based on data for natural gas compressor stations from the Oil and Gas Journal (factor of 1.3 higher than natural gas pipelines). Plots shown in sheet entitled "Large Comp. Costs" end of this workbook.	yes

Land Cost (No inputs are required for this table)

	0
	$0.00

Other Capital Cost (No inputs are required for this table)

	0.0%
	0.0%
	0.0%
	0.0%
	0.0%
	$0

O&M Costs (Monetary Inputs REQUIRED in Year 2005 $)

Labor Cost

Labor required (hrs/year)	1,740
Labor cost ($(2005)/man-hr)	$24.20

Electricity Cost

Use the H2A Electricity Cost Projection?	yes, industrial
Electricity Cost ($(2005)/kWh)	$0.06
	$0.00

Other Fixed Cost

Insurance (% of Total Capital Investment)	1.0%
Property Taxes (% of Total Capital Investment)	1.5%
Licensing and Permits (% of Total Capital Investment)	1.0%
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%
Overhead and G&A (% of Total Labor Cost)	50.0%
Other Fixed Operating Costs ($(2005)/year)	$0

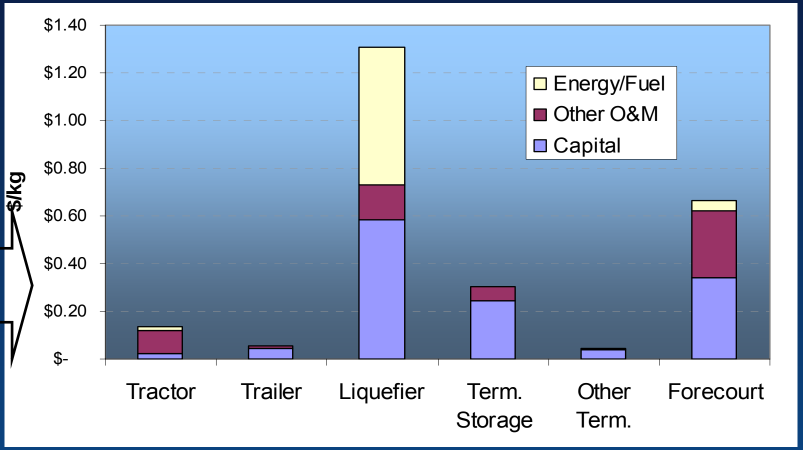
Pipeline Compressor Components Financial Assumptions

Debt Ratio	0%
Debt Interest	10%
Debt Period	10
Construction Period	1
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	50%

H2A Delivery

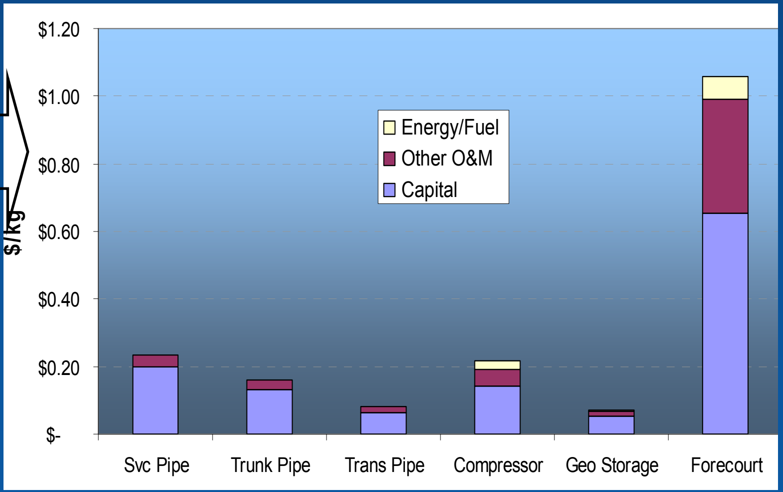
Liquefier Is Biggest Contributor to LH2 Cost; Pipeline & Forecourt Are Greatest for Pipeline-Delivered GH2

Component	Liquefier	LH Truck	LH Term	Forecourt
Design capacity	520 t/d	3900 kg	507 t/d	1500 kg/d
Initial capital ($2005)	225 M	725k/unit	105 M	707k/unit
Land ($/acre)	5000	NA	5000	Rented
Site prep	12%	NA	12%	6.5%
E&D	32%	NA	32%	3%
Contingency	25%	NA	25%	10%
Other	5.5%	NA	5.5%	3%
Economic life (yrs)	15	5/5	15	7/7
Physical life (yrs)	20	5/20	20	10/20
Non-labor O&M	4% cap	$225k/unit	4% cap	4% cap



LH2 Truck Delivery

Component	Compressor	GeoStorage	Pipeline	Forecourt
Design capacity	482 t/d	333 t/d	480 t/d	1500 kg/d
Initial capital ($2005)	55 M	13 M	203 M	1.2 M
Land ($/acre)	5000	5000	ROW	Rented
Site prep	12%	12%	In pipe $	6.5%
E&D	32%	32%	In pipe $	3%
Contingency	25%	25%	In pipe $	10%
Other	5.5%	2.5%	In pipe $	3%
Economic life (yrs)	5	5/15	15	5/7/7
Physical life (yrs)	NA	10/20	20	10/10/20
Non-labor O&M	4% cap	4% cap	4% cap	4% cap



Pipeline Delivery