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

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.

H2A Delivery 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
 - H₂ Production Cash Flow Model & Case Studies
 - H₂ Forecourt Model
 - H₂ Delivery Components & Delivery Scenarios Models
 - Group of Key Industrial Collaborators (KIC)

H2A Approach

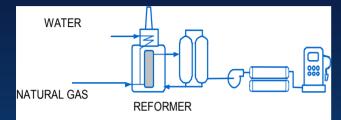
- Discounted cash-flow rate-of-return analysis
- Estimate levelized selling price of hydrogen required to attain a specified internal rate of return
 - Result is minimum hydrogen price
 - Cash flow calculation includes debt payments, taxes, depreciation, construction, working capital, capital replacement, 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

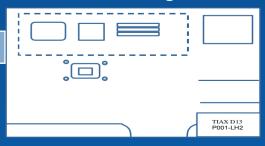
FIXED O&M COSTS (Inputs

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)					
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	DemineralizedFlowrate 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 H₂ 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

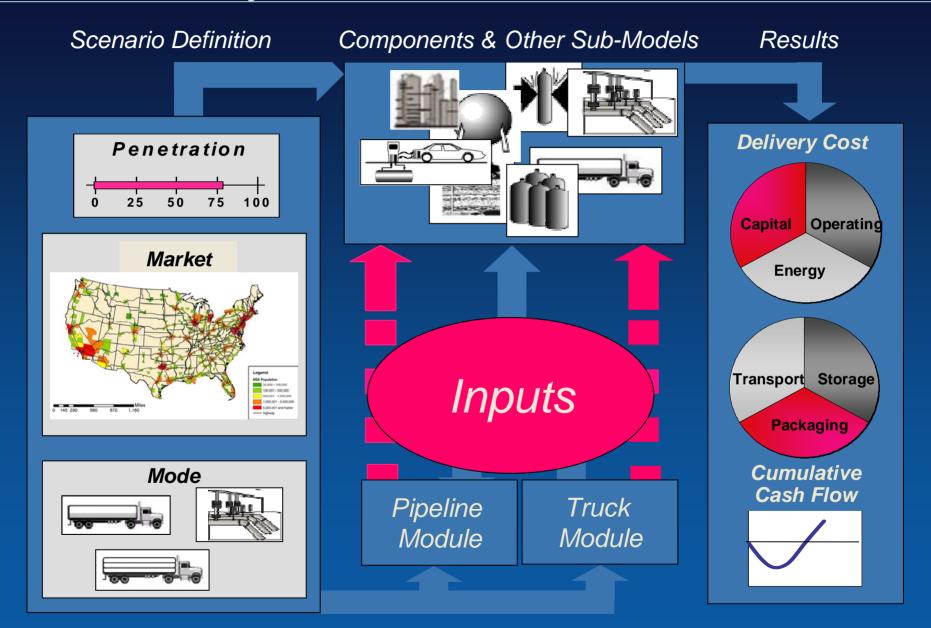
Delivery Components

- 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

Overview of HDSAM

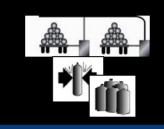


HDSAM Estimates Delivery Cost for 3 Pathways

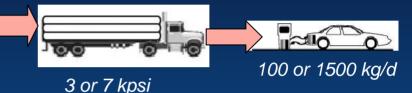
V1.0 characterizes components for 3 pathways with delivery by a single mode. Loading, conditioning and storage are at or adjacent to the plant

H2 Production

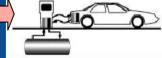
H2 Production



Compressed H2 (CH) Truck







100 or 1500 kg/d

Gaseous H2 Pipeline



100 or 1500 kg/d

HDSAM Capabilities Have Grown Over Time

Pathways	Penetration	Markets
LH Truck	Elizad	Generic large urban (1 M)
GH Truck	Fixed (1, 10, 30, 70%)	Generic small urban (100 K)
Pipeline	(1, 10, 30, 7070)	Short intercity segment (100 mi)
+ HPGH Truck (7000 psi)		Long intercity segment (200 mi)
+ GH Forecourt (100, 1500 kg/d)	Variable	>450 urbanized areas
+ LH Forecourt (100, 1500 kg/d)		Variable population, generic urban area
+ Pipeline & GH Truck	(1%-100%)	
+ Pipeline & LH Truck		Variable # and length intercity segments
Variable Capacity Forecourt		ocginento
+ Distributed Production		Combined urben ⁸ inter city
+ Hydrogen Carriers		Combined urban & intercity

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

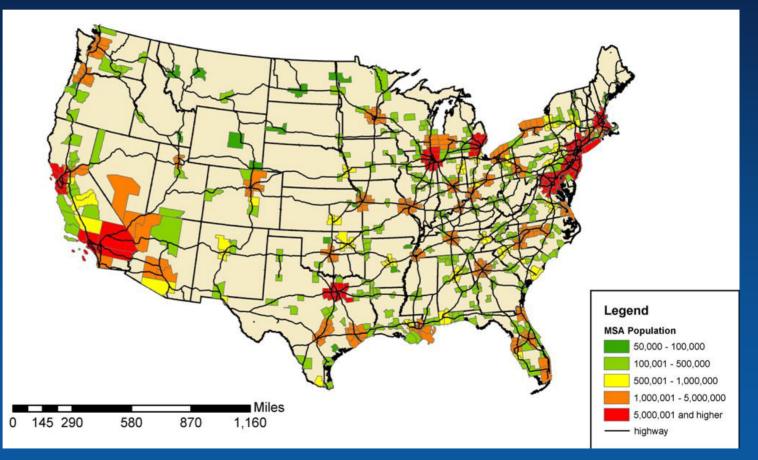
- Size & fill rate of truck bays
- Compressor design requirements

Pipelines

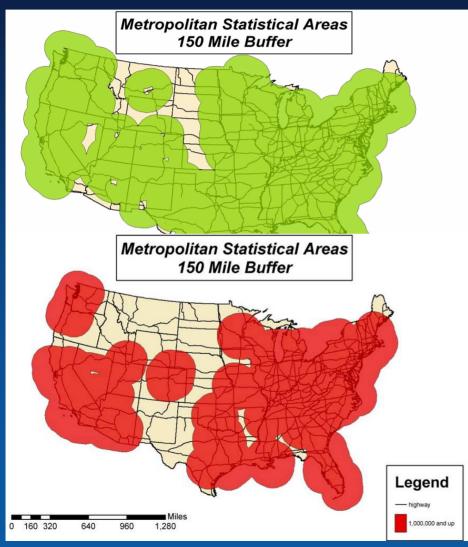
- Inlet, city gate, forecourt pressure
- Transmission, distribution, service length
- Circuity factors
- Physical & economic life
- Ratio to capital cost of NG pipelines

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.



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)

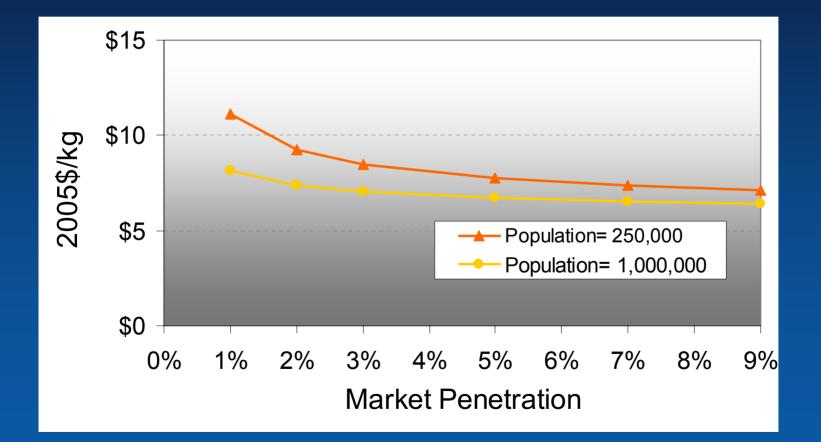
GUI Simplifies User-Selection of Market Type and Size, Penetration and Delivery Mode

H2 Market	Market Penetration —	Not considering (the currently Transmission Mode	unavailable) High-Pressure Tube Delivery Distribution Mode
City Selection	H2 Vehicle 10 %	Compressed H2	Compressed H2 Liquid H2 Truck Pipeline
Select city from the lis	st or enter population below Enter population here	Click Here	e To Calculate

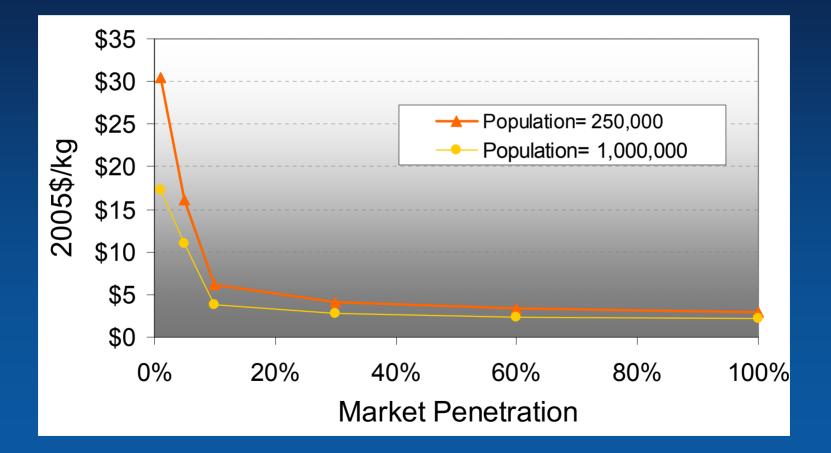
Scenario Definition & Results Tabs (50% Urban Penetration, LH2 Truck, Indianapolis)

H2 Market Penetration Warket Penetration H2 Vehicle City Selection Indianapolis, IN 1,218,919	50 % ▶	Delivery Mode Compressed H2 Liquid H2 Truck Pipeline Delivery Costs Total Cost [\$/kg]		ergy/Fuel 25% Capital 51% 24%
Key Delivery Inputs and Assumptions		Demand Calculations		
City population	1,218,919	H2 use per LDV per year (kg/y)	231	Forecourt
City area (mi2)	553	H2 use per LDV kg H2/day (ave)	0.63	26%
Population density (people/mi2)	2,205	Number of H2 vehicles in city	520,985	
Vehicles/person	0.85	City H2 daily use (kg/d)	010,110	nsport
Miles driven per year/ vehicle	13,748	Number of H2 refueling stations in city	314	7% Liquefaction
Distance from production to city (km)	100	Number of H2 stations/Number of gasoline stations	60% T	Terminal 53%
Actual refueling station capacity factor	0.7	Average distance between stations (km)	2.14	2%
H2 refueling station ave. H2 dispensed daily (kg/d)	1049			Storage
H2 Vehicles fuel economy equivalent (mi/gge)	57.50			12%
Deliver / Made Cale Jatiena		\$1,000,000,000		
Delivery Mode Calculations	12.20	\$800,000,000 Trailer		
Average round-trip time (h)				
Total number of deliveries per day Possible number of round-trips per truck /day	84.7 2.0	\$600,000,000 Termin ————————————————————————————————————	al Storage	
Maximum number of deliveries per day	2.0 120.9	\$400,000,000 Foreco		
· · · ·		4400,000,000		
Number of trucks required to provide H2 to city				
Number of trucks required to provide H2 to city	62	\$200,000,000 -		and the second s

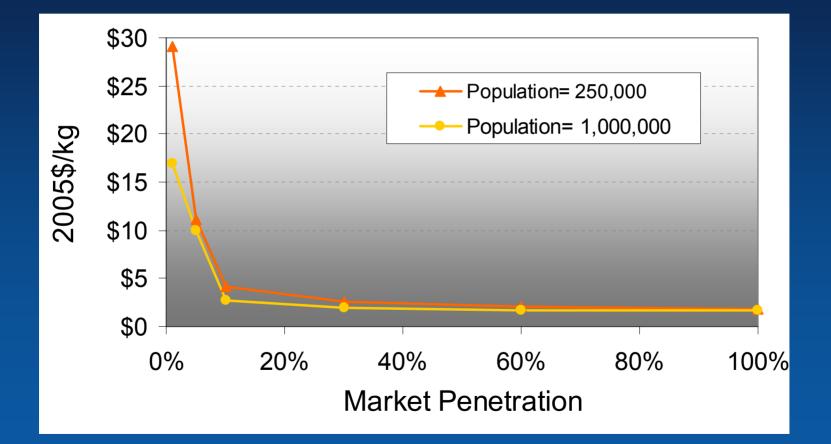
Conventional Tube Trailers Are Limited to Scenarios with Relatively Low H2 Demand



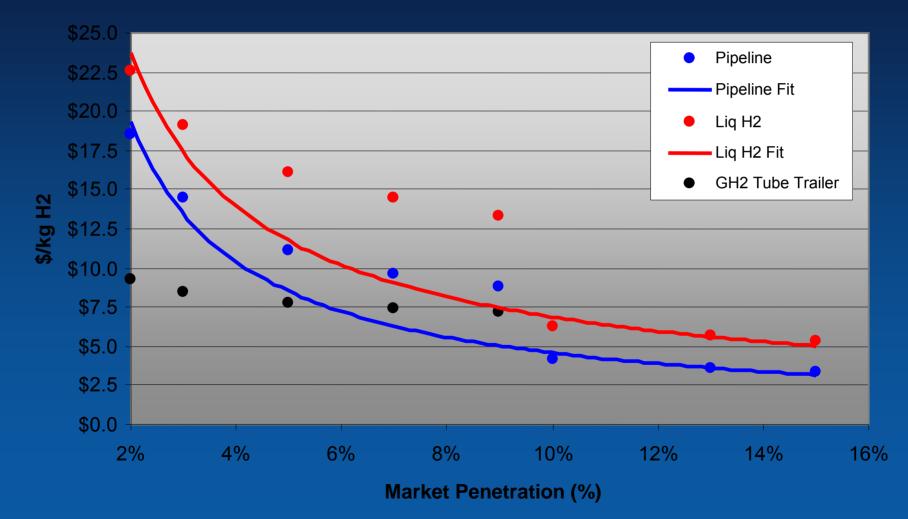
Liquid Delivery Cost Also Depends on Demand (Market Size & Penetration)



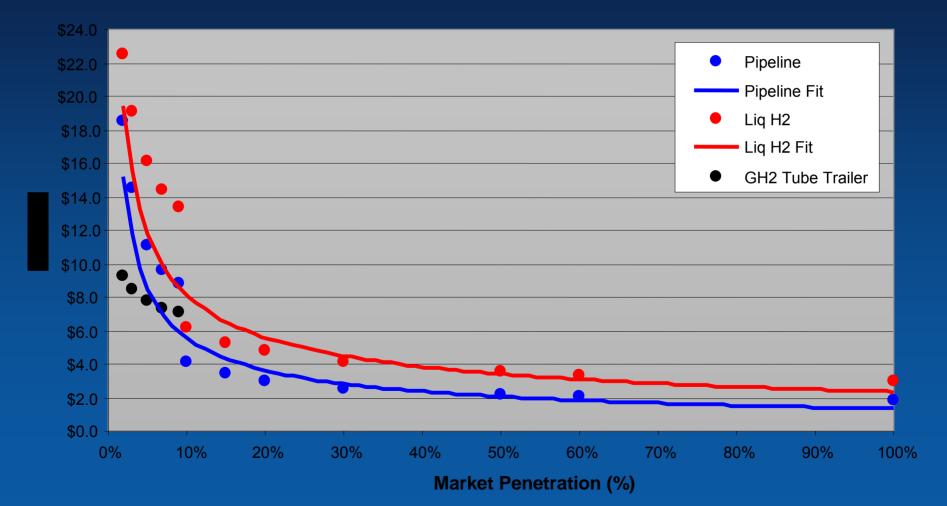
Pipeline Delivery Is Attractive above 10% Penetration in Urban Markets



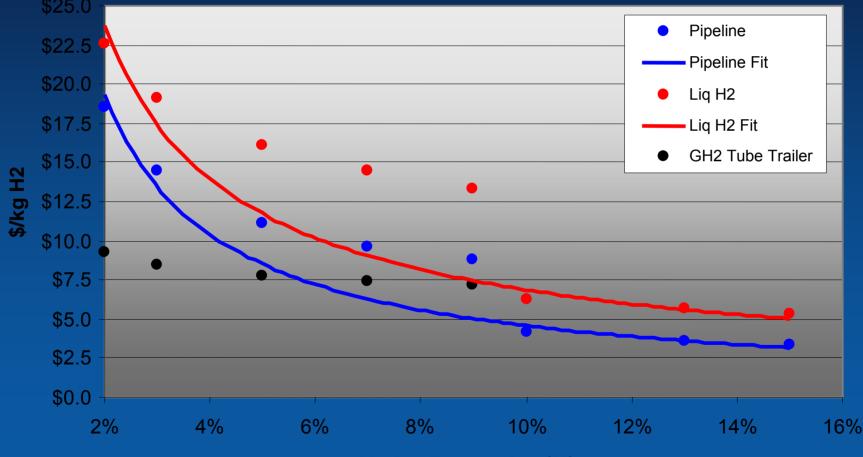
Urban Delivery Cost Declines with Increased Market Penetration and Forecourt Size (250,000 case)



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

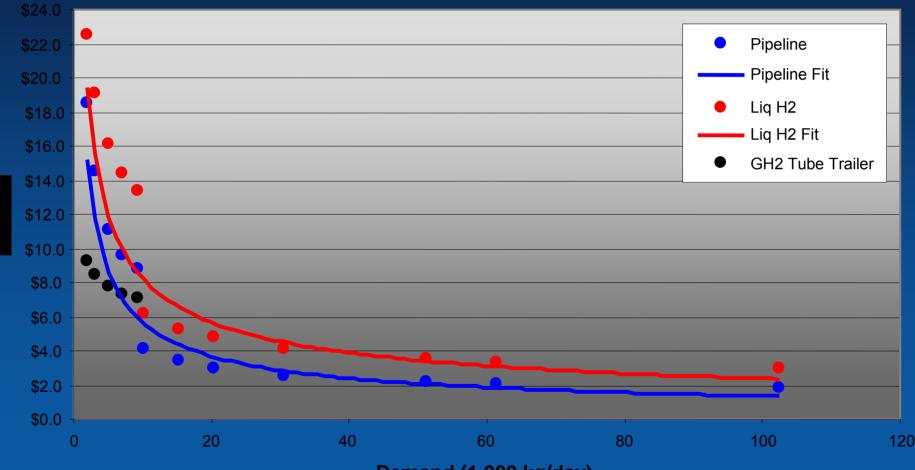


Urban Delivery Cost at Low Market Penetration (250,000 population, 100 & 1500 kg/d forecourts)



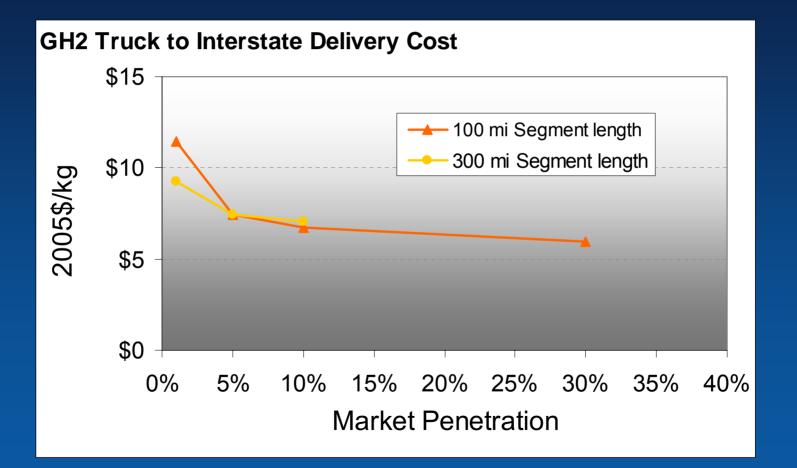
Market Penetration (%)

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

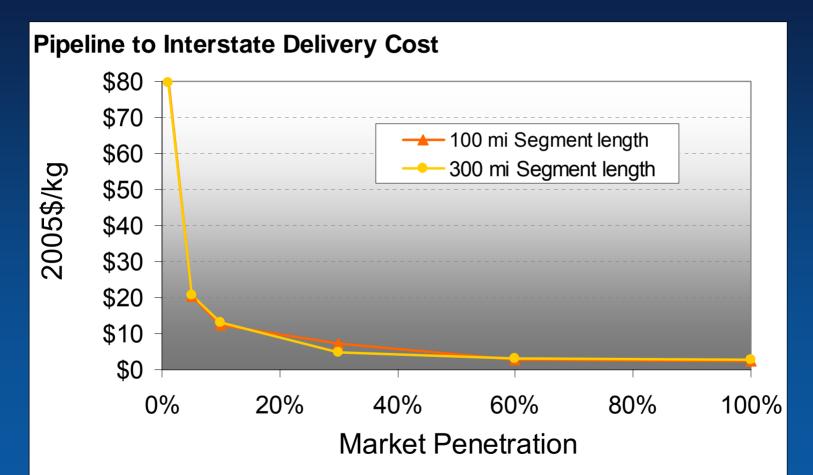


Demand (1,000 kg/day)

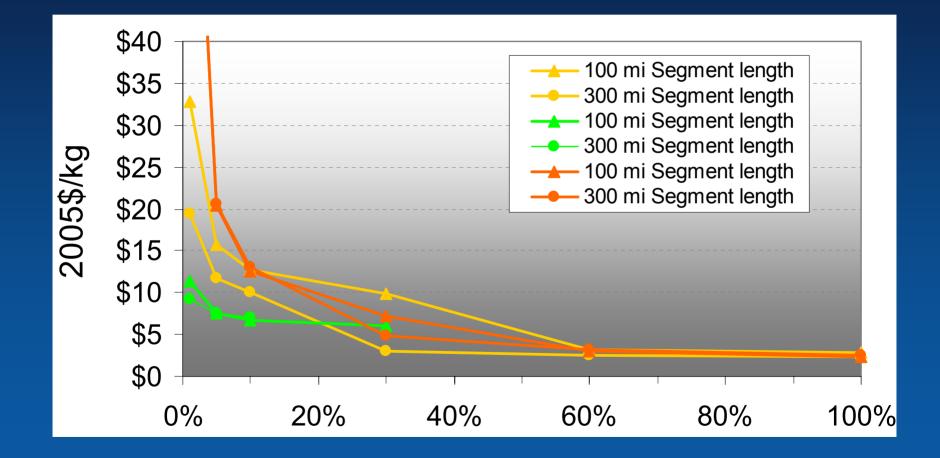
Rural/Interstate Delivery Cost Consistently Exceeds Urban; Scale Effects Limited for Tube Trailers



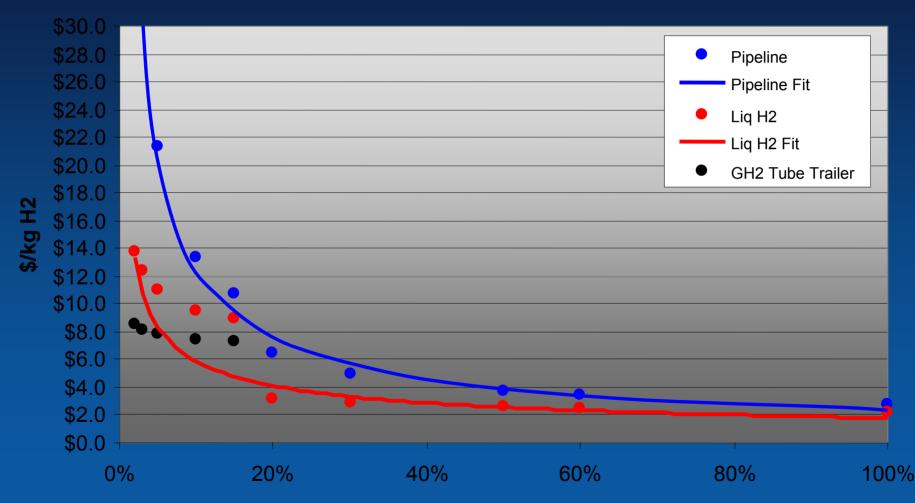
Pipeline Delivery to Interstate Markets Becomes Attractive above 30% Market Penetration



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

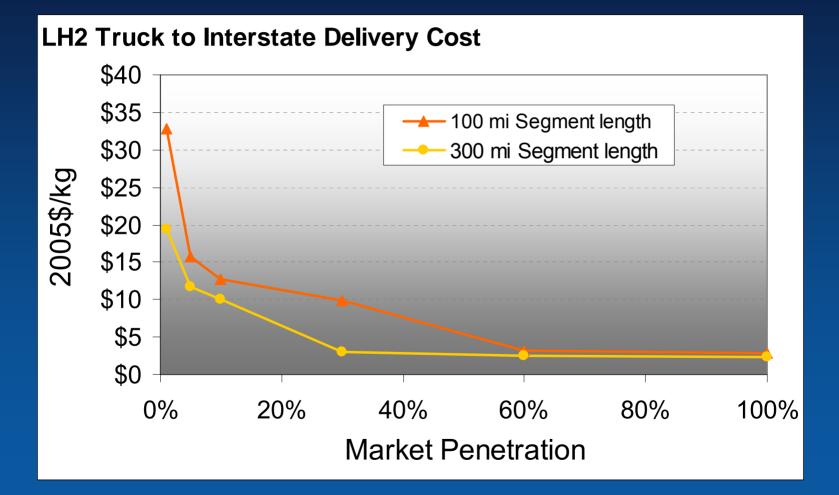


Rural/Interstate Delivery Cost by Mode and Market Penetration (400-mi segment)

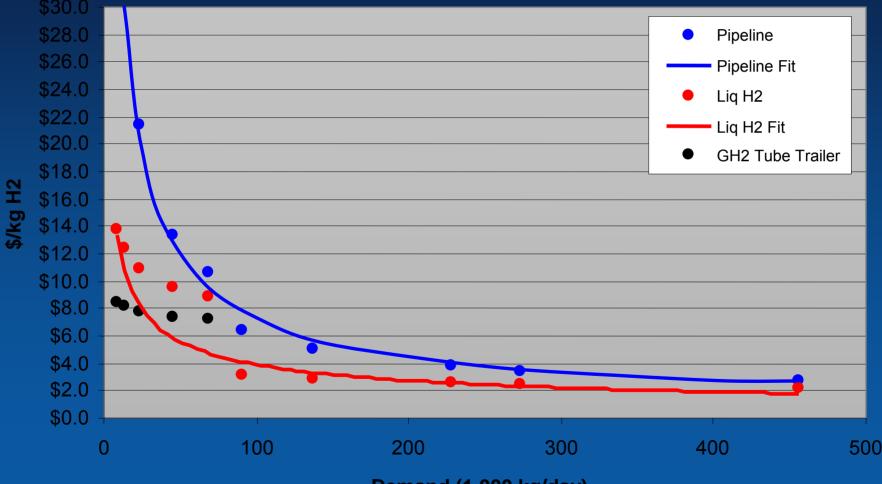


Market Penetration (%)

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

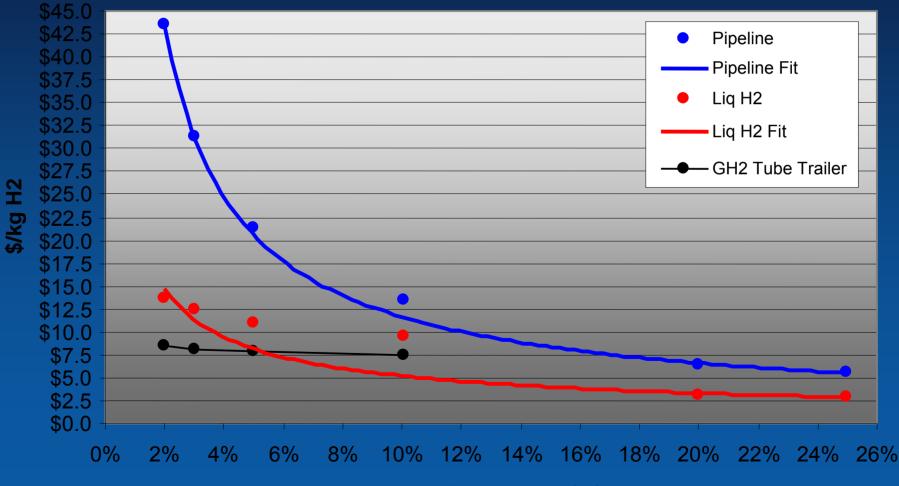


Rural Delivery Cost by Mode and Daily Demand (400-mi segment, 100 & 1500 kg/d forecourts)



Demand (1,000 kg/day)

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

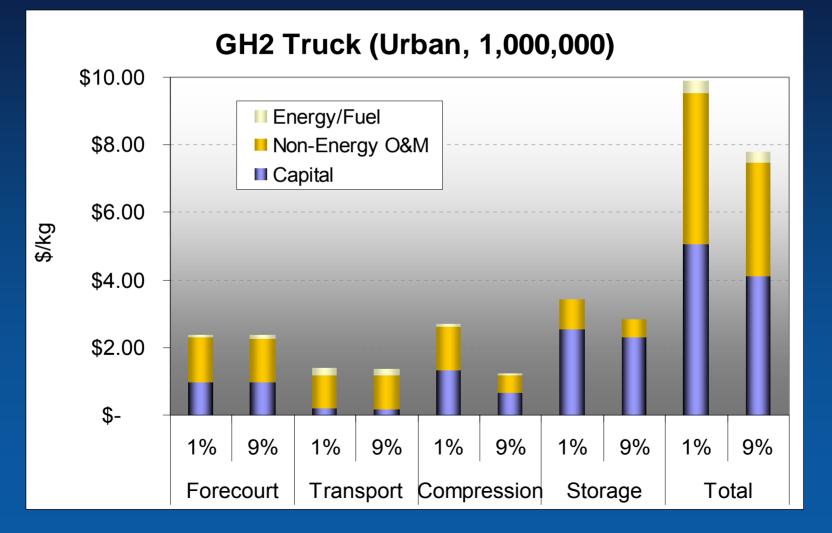


Market Penetration (%)

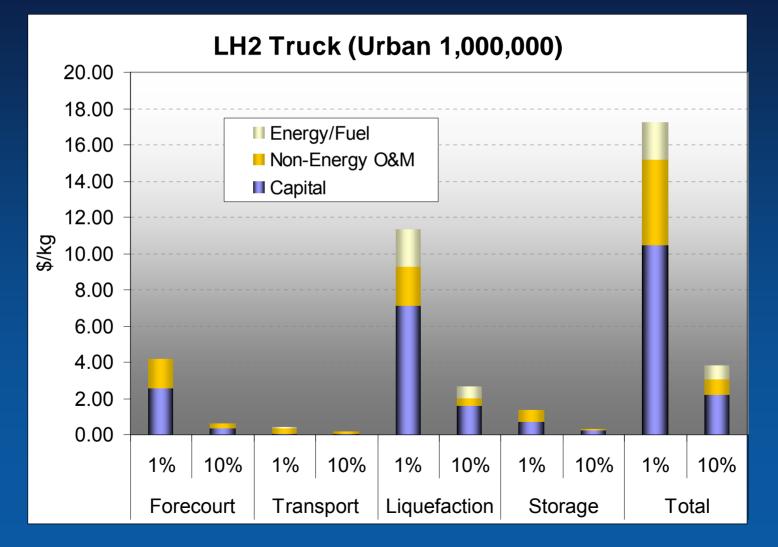


Cost Details

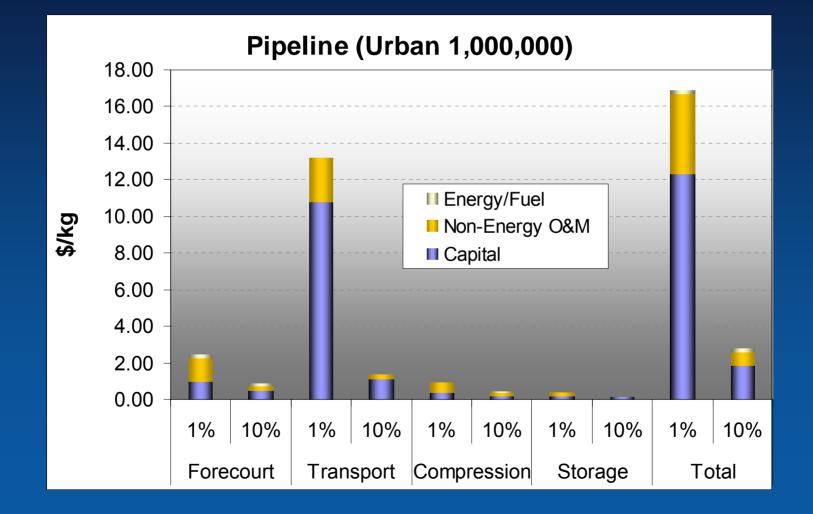
Conventional CH2 Truck Delivery Is Capital & Labor Intensive, Low Scale Economy (100 kg/d forecourt)



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



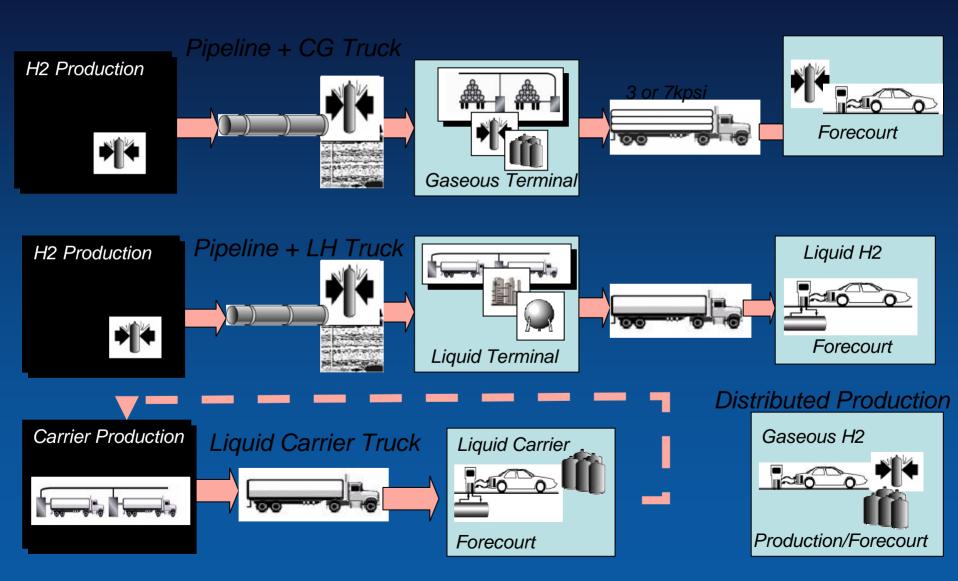
Pipeline Delivery Is Capital Intensive and Has Significant Scale Economies



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 CO₂ emissions
- Sensitivity analyses (service ratio, service lines, storage/compression tradeoffs, etc.)

HDSAM V2.6 Will Characterize 4 Additional Pathways, Estimating Delivery Cost for 7 Potential Options



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



Extra Slides

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

	<u> </u>				
General Economic Assumptions		Liquid H2 Delivery Market Assumptions			
Assumed start-up year	2005	Distance from production to city (mi)	62		
Reference year dollars	2005				
Real After-tax Discount Rate (%)	10.0%	Refueling Station Data			
Analysis period (years) State Taxes (%)	20 6.0%	Ave. Light Duty Vehicles (LDV) per gasoline station (US ave)	2,000		
Federal Taxes (%)	6.0% 35.0%				
Total Tax Rate (%)	38.9%				
	00.070				
Truck-LH2 Assumptions		Liquid H2 Terminal Assumptions Terminal Economic Assumptions		H2 Liquefier Assumptions Liquefier Economic Assumptions	
Tractor MACRS Depreciation Schedule Length (years)	5	MACRS Depreciation Schedule Length (years)	15	MACRS Depreciation Schedule Length (years)	15
Tank Trailer MACRS Depreciation Schedule Length (years)	5 5	Liquid Hydrogen Terminal Lifetime (years)	20	Liquefier Lifetime (years)	20
Tractor Lifetime (years)	5	Inflation Rate (%)	1.9%	Inflation Rate (%)	1.9%
Tank Trailer Lifetime (years)	20	Unit installed cost of piping (\$(2005)/ft)	\$503		
Inflation Rate (%)	1.9%	Cost of plumbing, electrical, and instrumentation at each individual bay (Year 2005 \$)	\$25,000		
				Liquefier Design Assumptions Hydrogen Flowrate into Liquefier (kg/day)	519,799
Truck-LH2 Design Inputs		Terminal Design Assumptions		Use Liquefier Electrical Efficiency Calculation?	yes
Tank Water Volume (ft3)	2295.5	Terminal capacity (kg/day)	506,856	ete Elquenor Electrical Emolency edicalation:	0.0%
Tank Loading Losses (% of Tank Volume)	0.0%	Useable Percent of Liquid Storage Unit (%)	90.0%	Use Default Inlet Hydrogen Temperature?	yes
Tank Unloading Losses (% of Tank Volume)	6.0%	Boil-off (%/day)	0.25%		0
Tank Boil-off Rate (% per day)	0.5%			Use default outlet hydrogen temperature?	yes 0
To all Martines Constants to the					-
Truck-LH2 Delivery Scenario Inputs Tanker Useable Delivery Capacity (%)	90%	Terminal Delivery Assumptions Liquid H2 Terminal Availability	98.6%	Liquefier Scenario Assumptions	
Round-Trip Distance (mi)	195	Time required per fill, connected time (hours)	2.0	Hydrogen Loss During Liquefaction (%)	0.5%
		Time required for parking, connection, disconnection, and removal of	1.0		98%
Average Station Hydrogen Demand (kg/day)	1,049	trailer (hours)		Liquefier Availability (% per year)	98%
Number of Stations per Trip	1	Number of Days of Storage (days)	5.0		
Total Time for Load Truck (hours)	3.0	Width of individual bay (ft)	16.4	Consider Lawrendow and Assessmentic and	
Total Time to Unload Truck at each Station (hours) Average Truck Speed (mph)	3.5 43.5	Distance from storage to pump (ft) Distance from pump to fill header (ft)	100.1	Capital Investment Assumptions Land Cost	
Average Truck Gas Mileage (mpg)	6.0		100.1	Land Cost (\$(2005)/ft2)	\$0.12
Truck Yearly Availability (%)	98%			Other Capital Cost	\$0.12
		Capital Investment Assumptions		Site Preparation (% of Initial Capital Investment)	12.0%
		Land Cost		Engineering & Design (% of Initial Capital Investment)	32.0%
O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$)		Land Cost (\$(2005)/ft2)	\$0.12	Project Contingency (% of Initial Capital Invesment)	25.0%
Labor Cost Labor cost (\$(2005)/man-hour)	\$20.00	Other Capital Cost Site Preparation (% of Initial Capital Investment)	12.0%	One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment)	1.5% 4.0%
Percent of Total Labor Costs Allocated to Tractor (%)	100%	Engineering & Design (% of Initial Capital Investment)	32.0%	Other capital (\$(2005))	\$0
Fuel Cost	10070	Project Contingency (% of Initial Capital Investment)	25.0%		φ υ
Use the H2A Feedstock Cost Projections?	yes	One-time Licensing Fees (% of Initial Capital Investment)	1.5%		
	\$0.00	Up-Front Permitting Costs (% of Initial Capital Investment)	4.0%	O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$)	
Percent of Total Fuel Costs Allocated to Tractor (%) Other Fixed Cost	100%	Other capital (\$(2005))	\$0	Labor Cost Labor required (hrs/year)	15.768
Insurance (\$(2005)/mi)	\$0.097			Labor required (his/year) Labor cost (\$(2005)/man-hr)	\$24.20
Percentage of Insurance Costs Allocated to Tractor (%)	75%	O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$)		Electricity Cost	ψ24.20
Property Taxes (% of total capital investment)	1.5%	Labor Cost		Use the H2A Commercial Electricity Cost Projection?	ves, industrial
	\$0.113		47.500		\$0.05
Licensing and permits (\$(2005)/mi) Percentage of Licensing and Permits Allocated to Tractor (%)	\$0.113 75%	Labor required (hrs/year) Labor cost (\$(2005)/man-hr)	17,520 \$24.20	Electricity Cost (\$(2005)/kWh)	\$0.05
Operating, Maintenance and Repairs (\$(2005)/mi)	\$0.080	Other Fixed Cost	φ24.2U	Other Fixed Cost	\$0.00
Percentage of Operating, Maintenance and Repairs Allocated to			1.00/		4.00%
Tractor (%)	75%	Insurance (% of Total Capital Investment)	1.0%	Insurance (% of Total Capital Investment)	1.0%
Overhead and G&A (% of Total Labor Cost)	50%	Property Taxes (% of Total Capital Investment)	1.5%	Property Taxes (% of Total Capital Investment)	1.5%
Other Fixed Operating Costs (\$(2005)/year)	\$5,000	Licensing and Permits (% of Total Capital Investment)	1.0%	Licensing and Permits (% of Total Capital Investment)	1.0%
Percentage of Other Fixed Operating Costs Allocated to Tractor (%)	50%	Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost)	0.5% 50.0%	Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost)	0.5% 50.0%
		Other Fixed Operating Costs (\$(2005)/year)	\$0.0% \$0	Other Fixed Operating Costs (\$(2005)/year)	\$0
Truck-LH2 Components Financial Assumptions		LH2 Terminal Components Financial Assumptions		LH2 Liquefier Components Financial Assumptions	
Debt Ratio	0%	Debt Ratio	0%	Debt Ratio	0%
Debt Interest	10%	Debt Interest	10%	Debt Interest	10%
Debt Period Construction Period	10 1	Debt Period Construction Period	10 3	Debt Period Construction Period	10 2
Startup Time	1	Startup Time	1	Startup Time	2
Salvage Value	10%	Salvage Value	10%	Salvage Value	10%
Decommission Value	10%	Decommission Value	10%	Decommission Value	10%
% Variable Cost during Startup	75%	% Variable Cost during Startup	75%	% Variable Cost during Startup	75%
% fixed Cost during Startup % Revenue During Startup	100%	% fixed Cost during Startup % Revenue During Startup	100%	% fixed Cost during Startup % Revenue During Startup	100%

50%

% Revenue During Startup

50%

% Revenue During Startup

50%

% Revenue During Startup

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

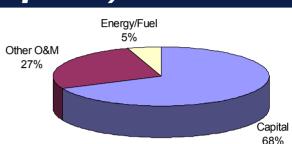
H2 Market	H2 Vehicle 50 %		
City Selection	•		
Indianapolis, IN		•	
	1,218,919)	

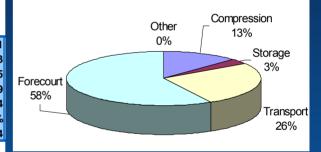
Delivery Mode Compressed H2 Liquid H2 Truck Pipeline	Calculate	
Delivery Costs		
Total Cost [\$/kg]		1.82

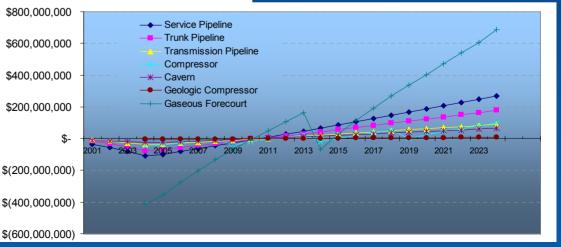
Key Delivery Inputs and Assumptions	
City population	1,218,919
City area (mi2)	553
Population density (people/mi2)	2,205
Vehicles/person	0.85
Miles driven per year/ vehicle	13,748
Distance from production to city (km)	100
Actual refueling station capacity factor	0.7
H2 refueling station ave. H2 dispensed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

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

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







Inputs Tab: (50%, Pipe, Indianapolis)

62

2.000

	/	
General Economic Assumptions		Discling Delivery Merket Assumptions
Assumed start-up year	2005	Pipeline Delivery Market Assumptions Distance from production to city (mi)
Reference year dollars	2005	
Real After-tax Discount Rate (%)	10.0%	Refueling Station Data
Analysis period (years)	20	Ave. Light Duty Vehicles (LDV) per gasoline station (US ave)
State Taxes (%)	6.0%	
Federal Taxes (%) Total Tax Rate (%)	35.0% 38.9%	
H2 Pipeline Assumptions H2 Pipeline Economic Assumptions		GH2 Geologic Storage Assumptions Geologic Storage Economic Assumptions
ACRS Depreciation Schedule Length (vears)	15	Geologic Storage Economic Assumptions Compressor MACRS Depreciation Schedule Length (years)
2 Pipeline Lifetime (years)	20	Cavern MACRS Depreciation Schedule Length (years)
nflation Rate (%)	1.9%	Compressor Lifetime (years)
		Cavern Lifetime (years) Inflation Rate (%)
		Cost of Hydrogen Cushion Gas (\$(2005)/kg)
12 Pipeline Design Inputs		Geologic Storage Design Assumptions
lydrogen Flowrate to System (kg/day)	479,865	Enter Demand Hydrogen Flowrate for the System that the Geo Storage Cavern Provides Surge Capacity for (kg/day)
Ise H2A calculations, using the Panhandle B Pipeline Equation, to		
alculate pipeline diameter?	yes	Cavern Maximum Pressure (psi)
ransmission Pipeline Inlet Pressure (psi) esired Transmission Pipeline Outlet Pressure (psi)	999	Cavern Minimum Pressure (psi)
esired Transmission Pipeline Outlet Pressure (psi) ransmission Pipeline Temperature (degrees F)	705	Cavern Temperature (degrees F)
ransmission Pipeline Temperature (degrees F) ransmission Pipeline Length (mi)	77 62.1	Pipeline pressure in feeder to cavern (psi) Inlet Hydrogen Temperature to Compressor (F)
	0.00	Cp/Cv ratio
runk (ring1) Pipeline Inlet Pressure (psi)	588	Design Compressor Based on Compression Ratio?
Desired Trunk (ring1) Pipeline Outlet Pressure (psi)	441	Enter Compression Ratio Per Stage
Frunk (ring1) Pipeline Temperature (degrees F)	68	
Number of Trunk Pipelines	2	Isentropic Compressor Efficiency Available?
Length of Trunk (ring1) Pipeline (mi)	38.5	Isentropic Compressor Efficiency (%)
	0.00	
lydrogen Flowrate to Trunk (ring2) (kg/day)	253,087	
	514	Use Isentropic Compressor Efficiency to Calculate Power
Frunk (ring2) Pipeline Inlet Pressure (psi)		Requirement?
Desired Trunk (ring2) Pipeline Outlet Pressure (psi)	441	
Frunk (ring2) Pipeline Temperature (degrees F)	68 77.3	Compressor Yearly Availability (%)
_ength of Trunk (ring2) Pipeline (mi)	0.00	
Service Pipeline Inlet Pressure (psi)	397	Geologic Storage Delivery Assumptions
esired Service Pipeline Outlet Pressure (psi)	294	% Above Peak System Demand Required for Surges
ervice Pipeline Temperature (degrees F)	77	Maximum Number of Days for Surges
vice Pipeline Temperature (degrees P)	0.00	Number of Surges per Year Maximum allowable daily hydrogen withdrawal rate (% of total
		capacity) Maximum allowable injection Rate (as Percentage of Withdraw
H2 Pipeline Delivery Scenario Inputs Hydrogen Lost During Pipeline Delivery (%)	0.50%	Cavern Availability (%/year)
Pipeline Availability (%/year)	99%	Capital Investment Assumptions
Capital Investment Assumptions		Land Cost Use H2A correlation for land cost to calculate total land co
Land Cost		
Use H2A right of way/land costs, based on data for natural gas pipelines from the Oil and Gas Journal	yes	
	\$0	Other Capital Cost
	\$0	Site Preparation (% of Initial Capital Investment)
	\$0	Engineering & Design (% of Initial Capital Investment)
		Project Contingency (% of Initial Capital Invesment) One-time Licensing Fees (% of Initial Capital Investment)
O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$)		Up-Front Permitting Costs (% of Initial Capital Investment)
_abor Cost		Other capital (\$(2005))
abor required (hrs/year)	8,320	
_abor cost (\$(2005)/man-hr)	\$15.05	
Other Fixed Cost nsurance (% of Total Capital Investment)	1.0%	O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost
Property Taxes (% of Total Capital Investment)	1.5%	Labor Cost Labor required (hrs/year)
icensing and Permits (% of Total Capital Investment)	1.0%	Labor cost (\$(2005)/man-hr)
Operating, Maintenance and Repairs (% of Total Capital Investment)	0.5%	Percentage Allocated to Compressor (%)
Overhead and G&A (% of Total Labor Cost)	50.0%	Electricity Cost
Other Fixed Operating Costs (\$(2005)/year)	\$0	Use the H2A Commercial Electricity Cost Projection?
		Electricity Cost (\$(2005)/kWh)
H2 Pipeline Components Financial Assumptions		Percent Allocated to Compressor (%)
Debt Ratio	0%	Other Fixed Cost
Debt Interest	10%	Insurance (% of Total Capital Investment)
Debt Period	10	Property Taxes (% of Total Capital Investment)
Construction Period	4	Licensing and Permits (% of Total Capital Investment)
Startup Time	1	Operating, Maintenance and Repairs (% of Total Capital Inves
Salvage Value	10%	Overhead and G&A (% of Total Labor Cost)
Decommission Value	10%	Other Fixed Operating Costs (\$(2005)/year)
% Variable Cost during Startup	75%	Percent Allocated to Compressor (%)
% fixed Cost during Startup	100%	
6 Revenue During Startup	50%	Geologic Storage Compressor Components Financial
		Assumptions
		Debt Ratio
		Debt Interest
		Debt Period
		Construction Period

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) Inflation Rate (%)	20 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) Inlet Hydrogen Temperature to Compressor (F)	999 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
Use Isentropic Compressor Efficiency to Calculate Power	0.0
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	
Land Cost Use H2A correlation for land cost to calculate total land cost?	yes 0
Land Cost Use H2A correlation for land cost to calculate total land cost?	0
Use H2A correlation for land cost to calculate total land cost?	yes O O
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost	0
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment)	0 0 12.0% 32.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment)	0 0 12.0% 32.0% 25.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5% 1.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005))	0 0 12.0% 32.0% 25.0% 1.5% 1.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0 8,760
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0 8,760
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) Other capital (\$(2005)) Abor Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost (\$(2005)/man-hr)	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0 8,760 \$24.20
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost Labor cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%)	0 0 12.0% 32.0% 1.5% 1.0% \$0 8.760 \$24.20 50%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost (§(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection?	0 0 12.0% 32.0% 25.0% 1.5% 1.0% 80 8,760 \$24.20 50% yes, industrial
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (\$(2005)/kWh)	0 0 12.0% 32.0% 1.5% 1.0% 50 8.760 \$24.20 50% yes, industrial \$0.06
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost (§(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection?	0 0 12.0% 32.0% 25.0% 1.5% 1.0% 80 8,760 \$24.20 50% yes, industrial
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (§(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Other Cost Othe	0 0 12.0% 32.0% 25.0% 1.5% 50% 8.760 \$24.20 50% yes, industrial \$0.06 \$0.00 100.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Elabor cost Labor cost Labor cost Labor cost (\$2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$2005)/Wh) Percent Allocated to Compressor (%) Other France (% of Total Capital Investment) Property Taxes (% of Total Capital Investment) Propert	0 0 12.0% 32.0% 25.0% 1.5% \$0 8,760 \$24.20 50% yes, industrial \$0.06 \$0.00 100.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Labor cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated (% of Total Capital Investment) Property Taxes (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5% 50% 8,760 \$24.20 50% 929, industrial \$0.00 100.0% 1.5% 1.5% 1.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Faces (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Property Taxes (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5% 8.760 \$24.20 50% yes, industrial \$0% 10.0% 1.8% 1.0% 0.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) Obertine Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Labor Cost Labor Cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated (S(2005)/kWh) Percent Allocated Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Up-Front Fixed (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Capital Investment)	0 0 12.0% 32.0% 25.0% 1.5% 50% 8,760 \$24.20 50% 929, industrial \$0.00 100.0% 1.5% 1.5% 1.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Faces (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Property Taxes (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment)	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8,760 \$24.20 50% 90.06 \$0.00 1.0% 1.8% 1.8% 1.8% 1.8%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost (\$(2005)) D&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost (\$(2005)/ma-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Userstent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Licensing and Permits (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Other Fixed Cost Other Fixed Cost Insurance (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%)	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8.760 \$24.20 50% yes, industrial \$0.06 \$0.06 \$0.00 1.0% 1.5% 1.0% 0.5% 50.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Ucersing and Permits (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Doresting, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%)	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8.760 \$24.20 50% 90% 90% 100.0% 1.0% 1.0% 1.5% 1.0% 0.5% 50.0% \$0.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor Cost (§2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (§2005)/kWh) Percentage Allocated to Compressor (%) Destination of the Capital Investment) Ucensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Capital Investment) Overhead and G&A (% of Total Capital Investment) Overhead and G&A (% of Total Capital Investment) Other Fixed Operating Costs (§2005)/year) Percent Allocated to Compressor (%) Electricity Cost Use (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Desting Electricity Cost Investment) Other Fixed Operating Costs (§2005)/year) Percent Allocated to Compressor (%) Electricity Cost Use Compressor (%) Electricity Cost Electricity	0 0 0 12.0% 32.0% 25.0% 1.5% 50% \$0 50% \$24.20 50% \$0.06 10.0% 1.5% 1.5% 1.5% 1.5% 1.5% 50.0% \$0.05% 50.0% \$0.05% 50.0% \$0.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Labor cost (\$(2005)/man-hr) Percent Allocated to Compressor (%) Electricity Cost (\$(2005)/kWh) Percent Allocated Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Other Sixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Detre Rised Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Detre Rised Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Detre Rised Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Detre Rised Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Detre Rised Operating Costs (\$(2005)/year) Percent Allocated to Compressor Components Financial Dest Ratio est	0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0 8,760 \$24.20 50% \$24.20 50% yes, industrial \$0.06 \$0.00 1.0% 1.5% 1.0% 50.5% 50.0% \$0 90
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Labor cost Labor cost Labor cost Electricity Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (% (2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Licensing and Permits (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Lapital Investment) Overhead and G&A (% of Total Lapital Investment) Deter Ratio Cost Geologic Storage Compressor Components Financial Assumptions Debt Ratio Debt Interes Debt Ratio Debt Constructio Debt C	0 0 0 12.0% 32.0% 25.0% 1.5% 50% \$0.06 \$0.00 100.0% 1.0% 1.0% 50.06 \$0.00 100.0% 1.0% 50.0%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Faces (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Property Taxes (% of Total Capital Investment) Other Fixed Cost Insurance (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Dether Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Dether Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Dether Fixed Poperating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Dether Fixed Poperating Costs (\$(2005)/year) Percent Allocated to Compressor Cost) Other Fixed Poperating Costs (\$(2005)/year) Percent Allocated to Compressor Components Financial Assumptions Debt Interest Dot Period Deth Ratio Deth	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8.760 \$24.20 50% yes, industrial \$0.06 \$0.06 \$0.00 1.0% 1.5% 1.0% 1.5% 50.5% 50.5%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Engineering & Design (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§2005)) OAM Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost (§2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (§2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost (§2005)/man-hr) Percentage Allocated to Compressor (%) Dent Fixed Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (§2005)/Wh/h) Percent Allocated to Compressor (%) Other Fixed Cost Use of H2A Commercial Electricity Cost Projection? Electricity Cost (% of Total Capital Investment) Horoperty Taxes (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Capital Investment) Other Fixed Operating Costs (\$2005)/year) Percent Allocated to Compressor Components Financial Assumptions Debt Reto Debt Interest Debt Patio Percent Allocated Negative Sign Sign Sign Sign Sign Sign Sign Sign	0 0 0 12.0% 32.0% 25.0% 1.5% 1.0% \$0 8,760 \$24.20 50% \$0.06 \$0.00 100.0% 100.0% 1.5% 1.5% 1.0% 50.0% \$0.0% 100.0% 10% 10%
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Sile Preparation (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of Initial Capital Investment) Other capital (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost (§(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor capital (§(2005)) D&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor capital (\$(2005)) D&M Costs (\$(2005)/ma-hr) Percentage Allocated to Compressor (%) Electricity Cost Use the H2A Commercial Electricity Cost Projection? Electricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Integrater (% of Total Capital Investment) Integrater (% of Total Capital Investment) Deternet Allocated to Compressor (%) Other Fixed Cost Operating, Maintenance and Repairs (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Dept Percent Allocated to Compressor Components Financial Assumptions Debt Period Construction Period Startup Time Satvage Value (% Variable Cost during Startup)	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8.760 \$24.20 50% 90% 100.0% 1.0% 5000 1.0% 5000 1.0% 50.0
Use H2A correlation for land cost to calculate total land cost? Other Capital Cost Site Preparation (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) Project Contingency (% of Initial Capital Investment) One-time Licensing Fees (% of Initial Capital Investment) Up-Front Permitting Costs (% of initial Capital Investment) Other capital (\$(2005)) O&M Costs (Monetary Inputs REQUIRED in Year 2005 \$) Labor Cost Labor cost (\$(2005)/man-hr) Percentage Allocated to Compressor (%) Electricity Cost Lectricity Cost (\$(2005)/kWh) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Uoperating Maintenance and Repairs (% of Total Capital Investment) Operating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Other Fixed Cost Insurance (% of Total Capital Investment) Uoperating, Maintenance and Repairs (% of Total Capital Investment) Overhead and G&A (% of Total Labor Cost) Other Fixed Operating Costs (\$(2005)/year) Percent Allocated to Compressor (%) Geologic Storage Compressor Components Financial Assumptions Debt Interest Debt Interest Debt Period Construction Period Salvage Value Decommission Value	0 0 0 12.0% 32.0% 25.0% 1.5% 50% 8,760 \$24.20 50% 90% 100.0% 100.0% 100.0% 100.0% 50.06 \$0.00 1.5% 50.0% 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 Inlet Hydrogen Temperature (degrees F) Cp/Cv ratio	999 77 1 4
Design Compressor Based on Compression Ratio per Stage? Enter Compression Ratio Per Stage	yes 1.7
Isentropic Compressor Efficiency Available? Isentropic Compressor Efficiency (%)	0 yes 70.0%
Use Isentropic Compressor Efficiency to Calculate Power	0.0% 0.0%
Requirement?	yes 0.0
Hydrogen Lost During Compression (% of Feed H2)	0.50%
Compressor Yearly Availability (%)	100%

Capital Investment Assumptions

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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%

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

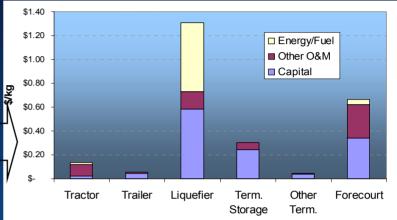
Labor Cost					
Labor required (hrs/year)	1,740				
Labor cost (\$(2005)/man-hr)	\$24.20				
Electricity Cost					
Use the H2A Electricity Cost Projection?	yes, industrial				
Electricity Cost (\$(2005)/kWh)	\$0.06				
	\$0.00				
Other Fixed Cost					
Labor required (hrs/year) 1,740 Labor cost (§2005)/man-hr) \$24.20 Electricity Cost version Use the H2A Electricity Cost Projection? yes, industrial Electricity Cost (\$2005)/kWh) \$0.06 Other Fixed Cost \$0.00 Other Fixed Cost \$0.00 Other Fixed Cost \$0.00 Operating, Maintenance and Repairs (% of Total Capital Investment) 1.5% Operating, Maintenance and Repairs (% of Total Capital Investment) 0.5% Overhead and G&A (% of Total Labor Cost) \$0.0%					
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				
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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%

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	

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	\Box
Land (\$/acre)	5000	5000	ROW	Rented	
Site prep	12%	12%	In pipe \$	6.5%	
E&D	32%	32%	In pipe \$	3%	\$/kd
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	



LH2 Truck Delivery

