Hydrogen Delivery Options and Issues

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DOE

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Hydrogen Delivery

Scope

- From the end point of central or distributed production (300 psi H2) to and including the dispenser at a refueling station or stationary power site
  - GH2 Pipelines and Trucks, LH2 Trucks, Carriers

<$1.00/kg of Hydrogen by 2017

H2 Delivery Current Status

- Technology
  - GH2 Tube Trailers: ~340 kg, ~2600 psi
  - LH2 Trucks: ~3900 kg
  - Pipelines: up to 1500 psi (~630 miles in the U.S.)
  - Refueling Site Operations (compression, storage dispensing): Demonstration projects

- Cost (Does NOT include refueling Site Operations)
  - Trucks: $4-$12/kg
  - Pipeline: <$2/kg

H2A Analysis

- Consistent, comparable, transparent approach to hydrogen production and delivery cost analysis
- Excel spreadsheet tools with common economic parameters, feedstock and utility costs, and approach
- Project Team
  - Production: DTI, TIAX, Technology Insights, PNNL, NREL, ANL
  - Delivery: U.C. Davis, ANL, PNNL, NREL
- Key Industrial Collaborators

Eastman Chemical	Ferco
AEP	Thermochem
Entergy	GE
Framatome	Stuart Energy
APCi	Chevron
Praxair	Exxonmobil
BOC	BP

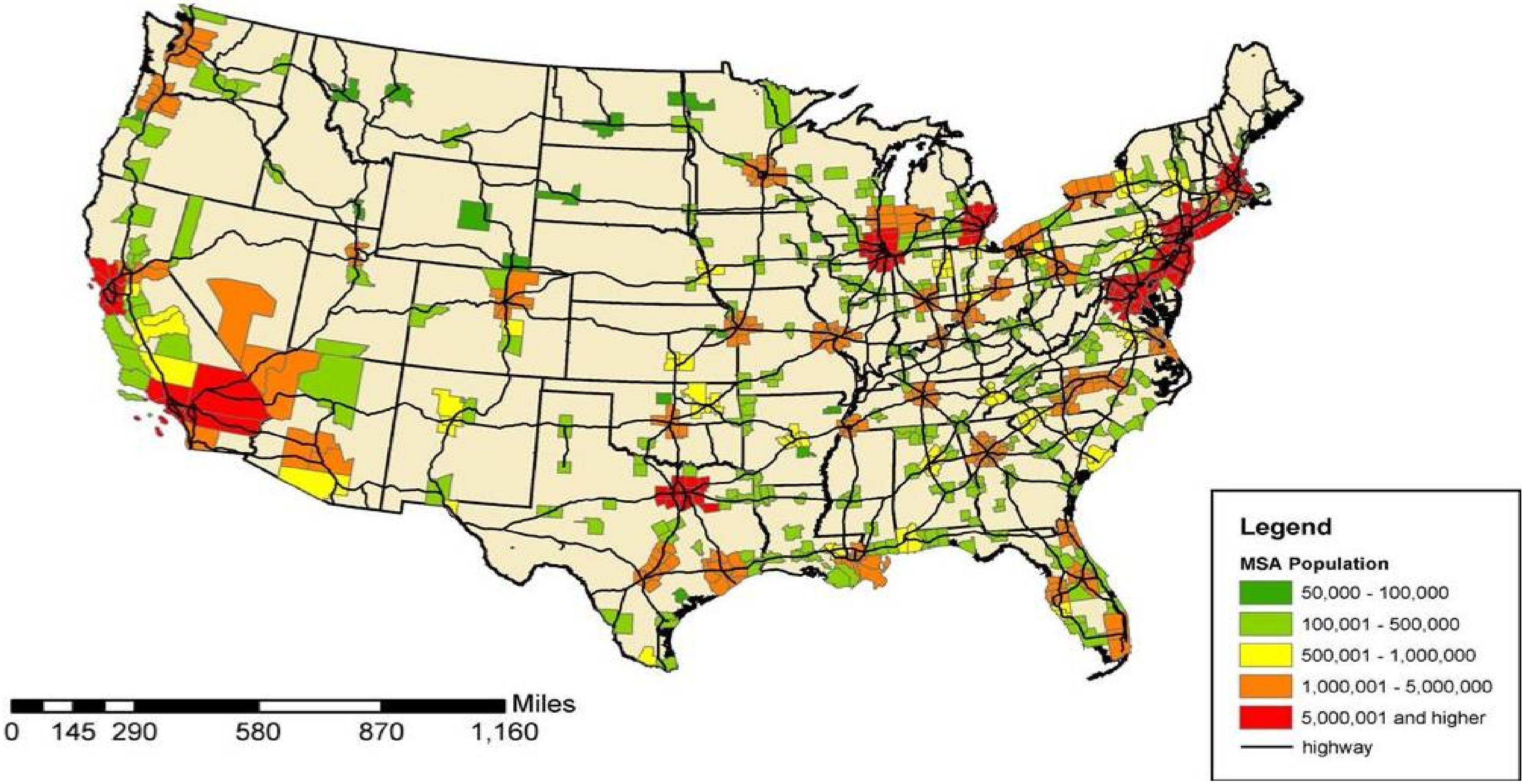
H2A Delivery Goals

- Develop spreadsheet database on delivery system component costs and performance: Component Model
- Develop delivery scenarios for set of well defined "base cases" that span major markets and demand levels. Scenario Model (HDSAM)
- Estimate the cost of H_2 delivery for base cases with current (2005 costs) and at Research Targets

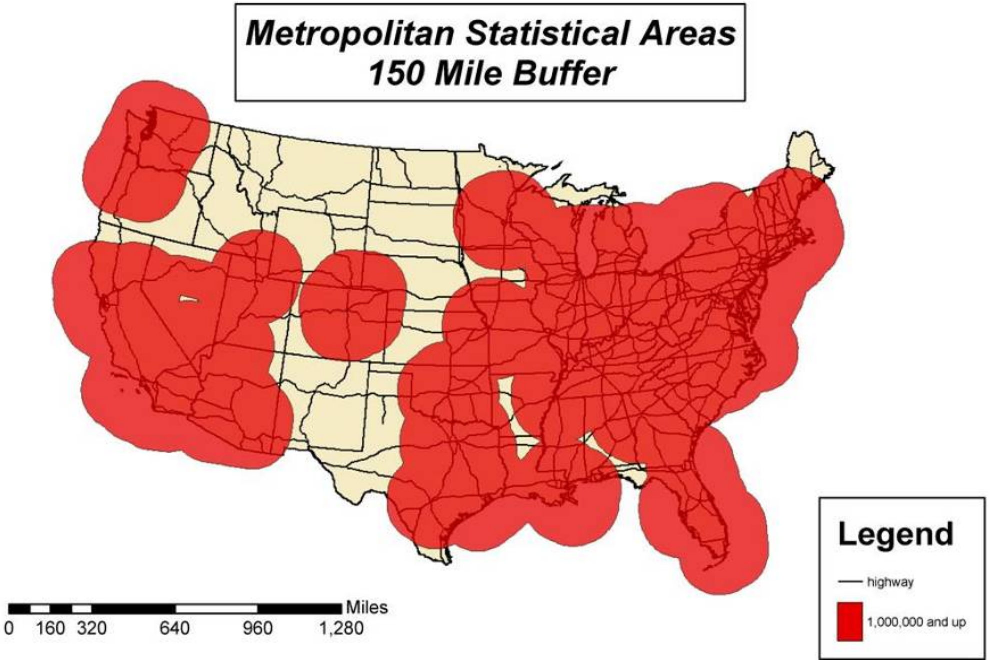
List of Delivery Components

- Compressed Hydrogen Gas Truck (Tube trailer)
- Compressed Hydrogen Gas Truck Terminal
- Liquid Hydrogen 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
- Dispenser
- Forecourt: GH2
- Forecourt: LH2

Three-Quarters of the US Population Reside in Urbanized Areas



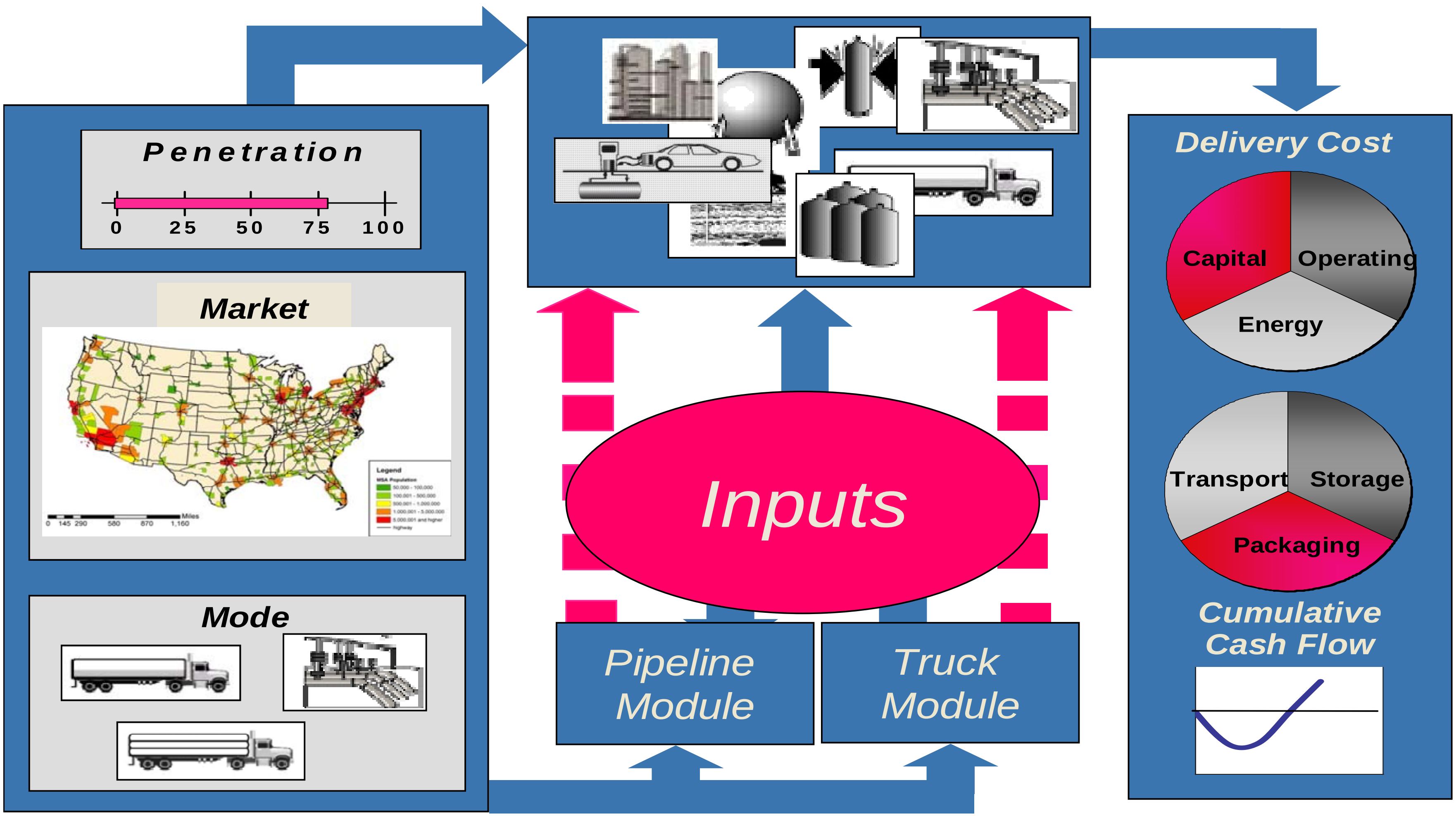
Hydrogen Plants can be Located Relatively Near the Market demand



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

Overview of the H2A Delivery Scenario Model

Scenario Definition | **Components and Other Sub-Models** | **Results**



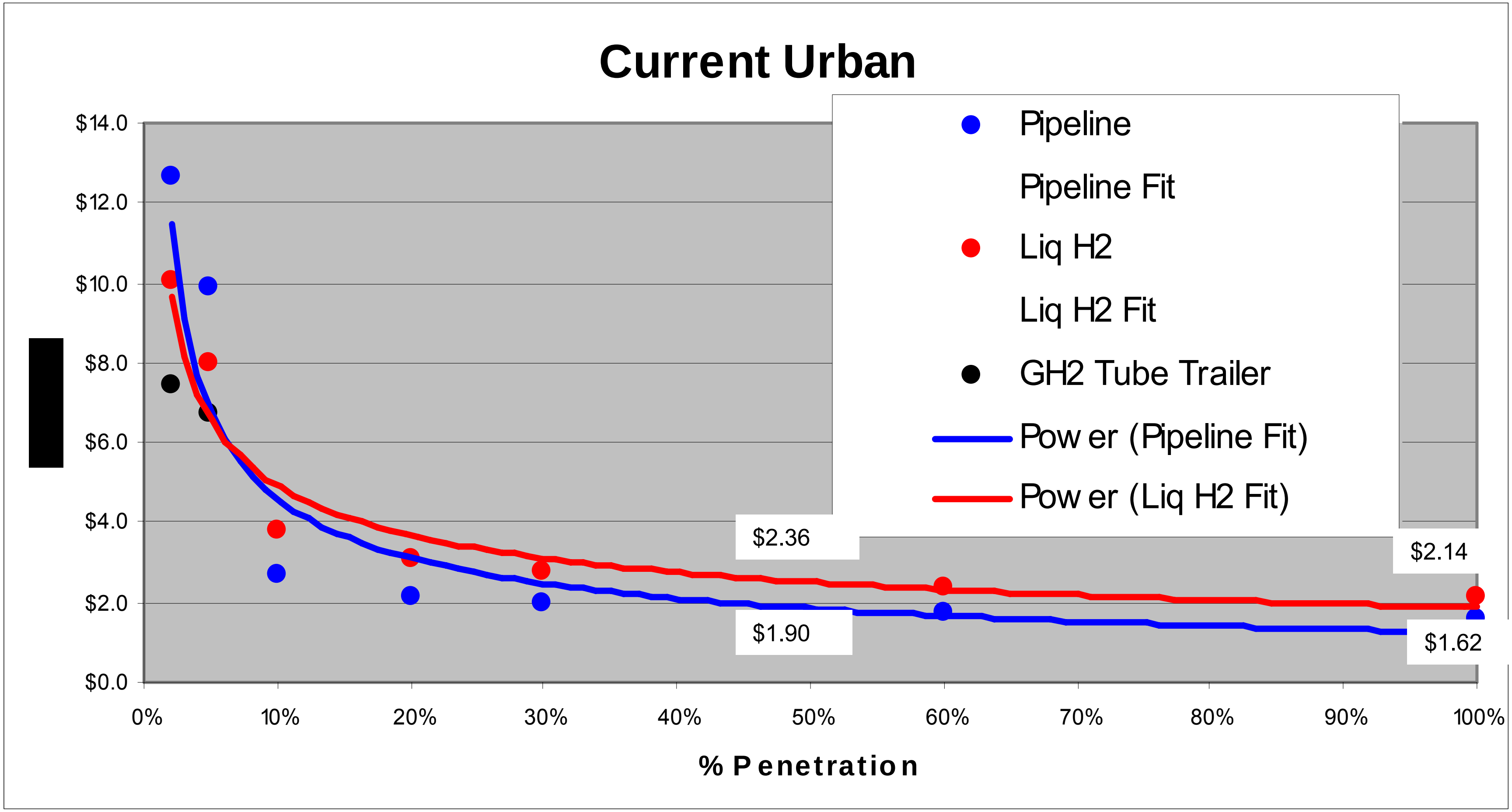
Current Scenario Model

- Predefined demand based on:
  - Market (urban or interstate/rural)
  - Penetration of hydrogen-fueled LDVs (%)
  - Single delivery mode
  - 100 kg/day or 1500 kg/day Forecourts
- Delivery mode defined by user
  - Pipeline with geologic storage
  - Liquid hydrogen (LH2) via terminal and truck
  - Compressed hydrogen (CH2) truck via terminal and truck (18 MPa and 50 MPa)

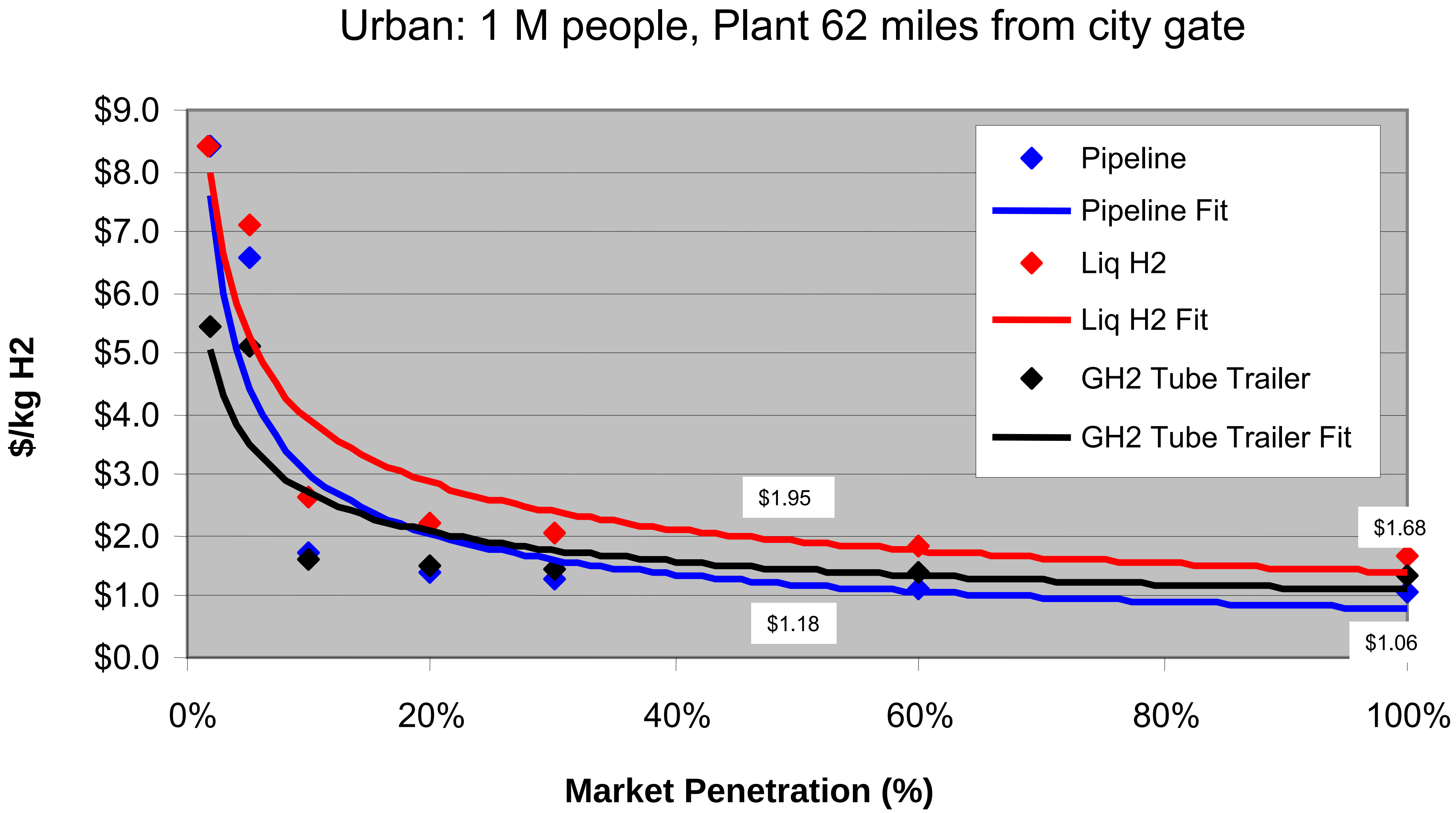
Components tabs linked so pathway capacities reflect losses and availabilities

Current Urban Hydrogen Delivery Costs

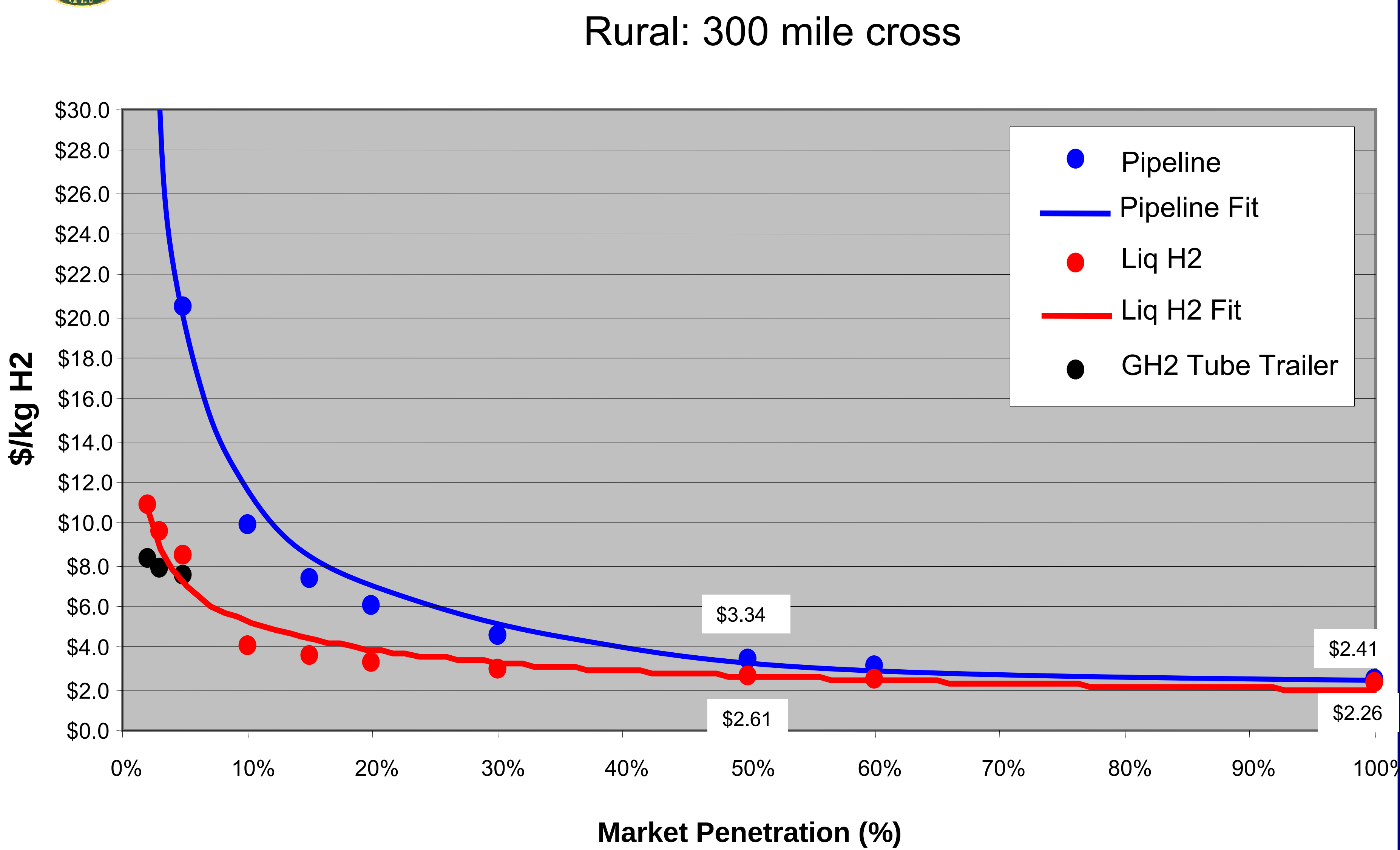
Urban: 1 M people, Plant 62 miles from city gate



Urban Hydrogen Delivery Costs at Research Targets

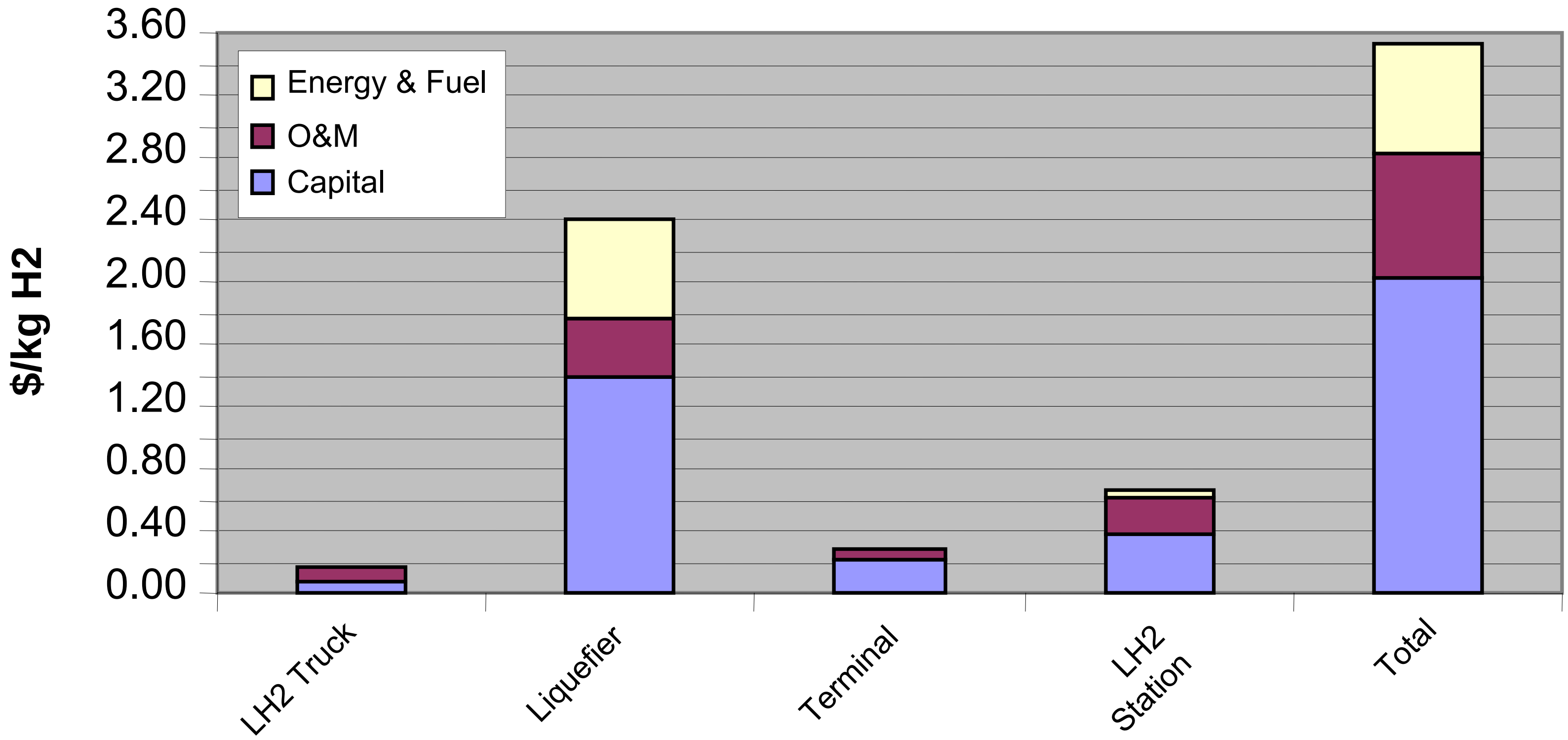


Current Rural Hydrogen Delivery Costs



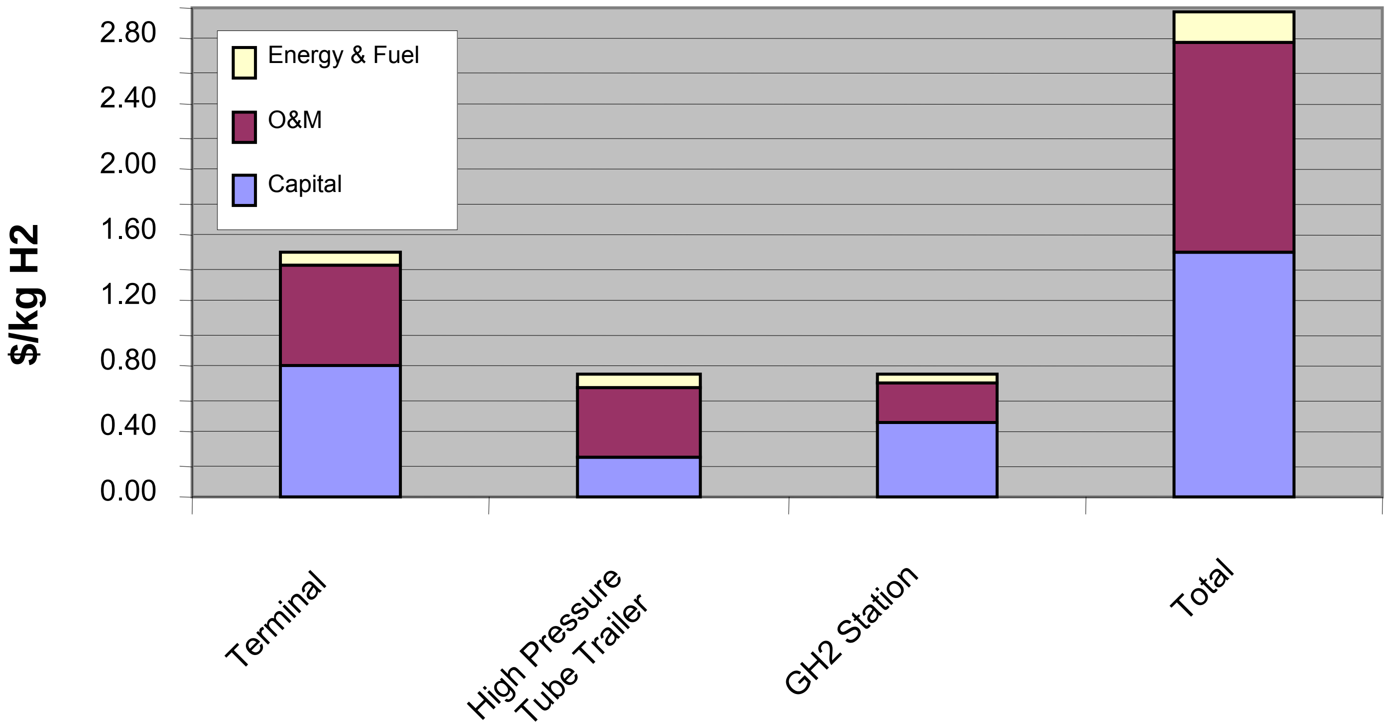
Current Liquid H2: 50% Market Penetration

City: 250k people, Plant 62 miles from city gate

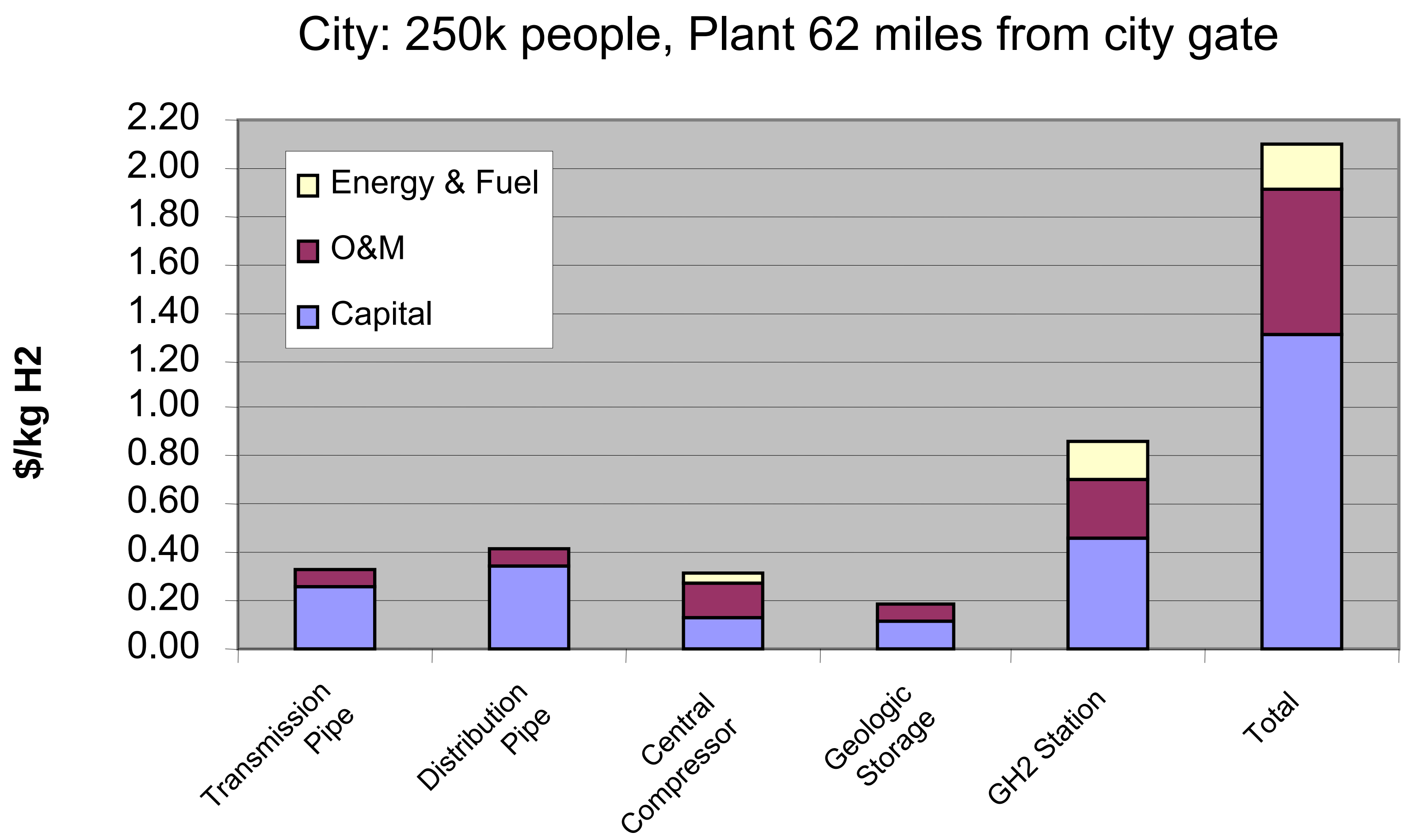


Current* Tube Trailer: 50% Market Penetration

City: 250k people, Plant 62 miles from city gate



Current Pipeline: 50% Market Penetration

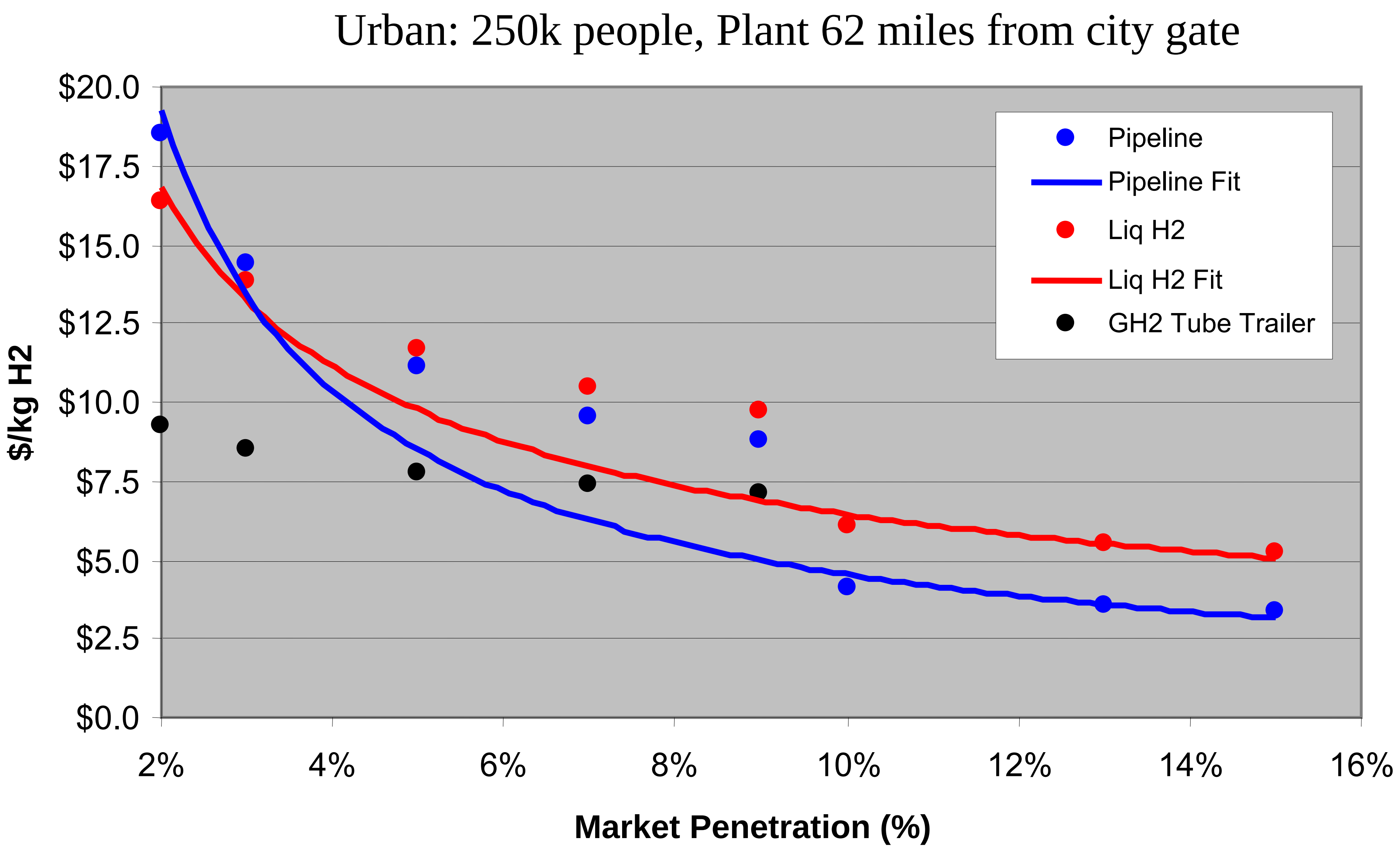


Current Refueling Site Costs

		1500 kg/day Station		
	Compressor	Other (Storage)	Dispenser	Total
Total Cost ($/kg of H2)	**$0.50**	**$0.30**	**$0.05**	**$0.85**
Capital Cost Contribution	$0.26	$0.13	$0.05	$0.44
Energy Cost Contribution	$0.18	$0.00	$0.00	$0.18
Other Costs Contribution	$0.06	$0.17	$0.00	$0.23
Installed Capital Cost ($k)	$460	$293	$81	
Total Capital cost ($k)				$1,014

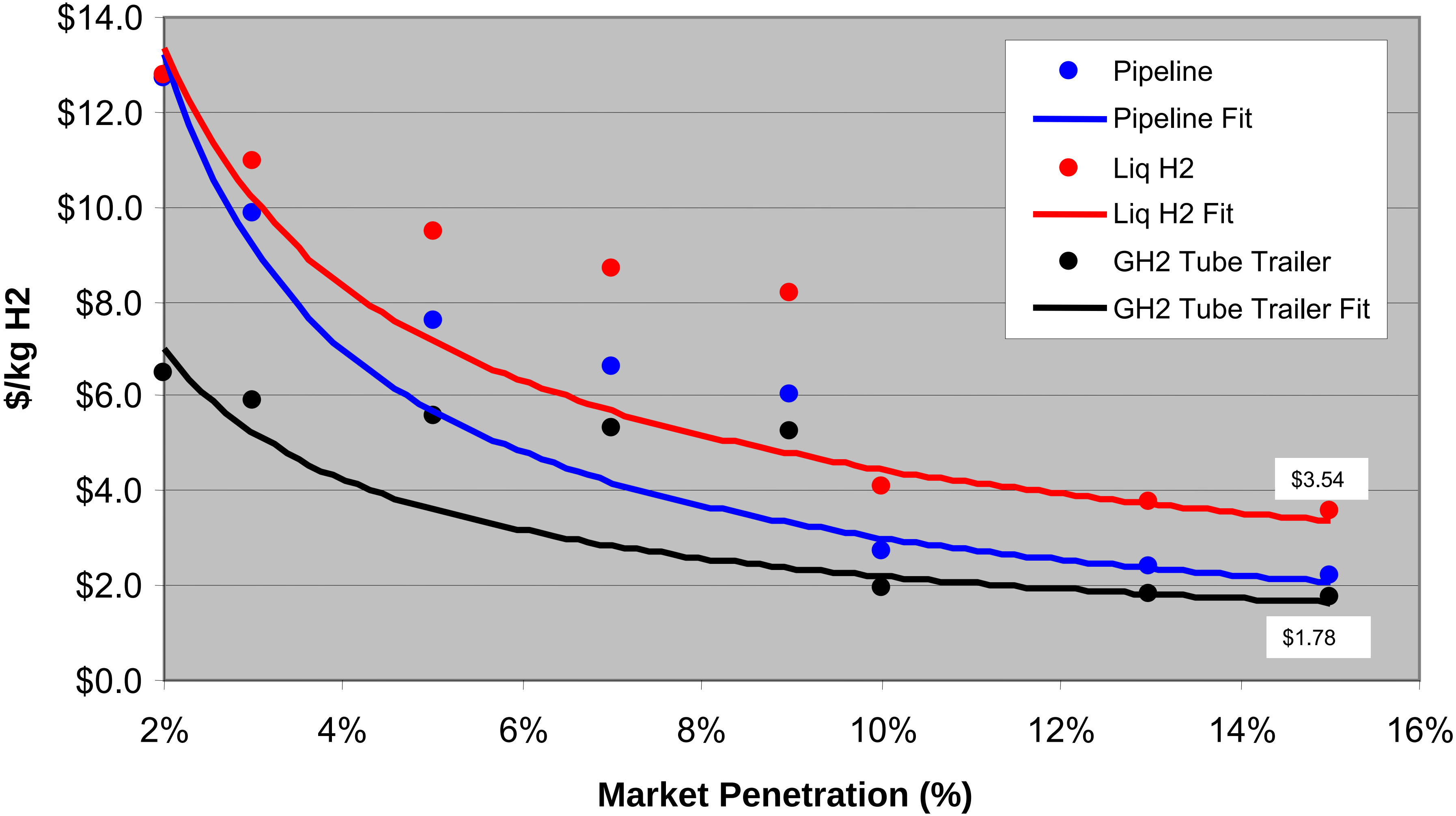
		100 kg/day Station		
	Compressor	Other (Storage)	Dispenser	Total
Total Cost ($/kg of H2)	**$0.71**	**$1.39**	**$0.24**	**$2.34**
Capital Cost Contribution	$0.36	$0.34	$0.24	$0.94
Energy Cost Contribution	$0.18	$0.00	$0.00	$0.18
Other Costs Contribution	$0.17	$1.05	$0.00	$1.22
Purchased Capital Cost ($k)	$42	$31	$26	
Total Capital cost ($k)				$150

Current Urban Hydrogen Delivery Costs



Urban Hydrogen Delivery Costs at Research Targets

Urban: 250k people, Plant 62 miles from city gate



Low Mkt Penetration
Current Costs: Tube Trailer Pathway

City: 1M People, Plant 62 Miles from the City

Refueling Station Size (kg/day)	100	100		1500	1500
LDV Market Penetration (%)	2%	4%		2%	4%
City H2 Demand (kg/day)	8,200	16,400		8,200	16,400
# of Stations	118	236		8	16
% of Existing Stations	32%	64%		2%	4%
Distance between Station (miles)	1.6	1.1		6.2	4.4
Total Delivery Cost ($/kg)	$7.40	$6.90		$4.90	$4.40
Cost Contibitions ($/kg)					
Terminal	$2.40	$1.90		$2.40	$1.90
Tube Trailer	$2.60	$2.60		$1.70	$1.70
Station	$2.40	$2.40		$0.80	$0.80

Improvements to Scenario Model

- Mixed delivery pathway (e.g., pipeline to GH2 terminal to HP Tube Trailer)
- Variable sized Forecourts (50-6,000 kg/day)
- Carriers
- Energy efficiencies and CO_2 emissions
- Mixed demands/markets
  - combining urban areas
  - combining urban areas with interstate demand
- Initial overbuilding of delivery infrastructure

Key Learnings/Challenges

- 70 MPa Refueling
  - Higher compression and storage costs/greater challenge to meet targets
  - May require cooling at the refueling station
- Other potential needs for cooling at refueling stations
  - Metal hydride on-board storage
  - Cryo-gas on board storage
- H2 Quality Requirements
  - Will polishing purification be needed?
  - Geologic storage contamination issues?

➢ **All these issues can increase cost**

- Can Carriers change the Delivery Paradigm?

Key Learnings/Challenges

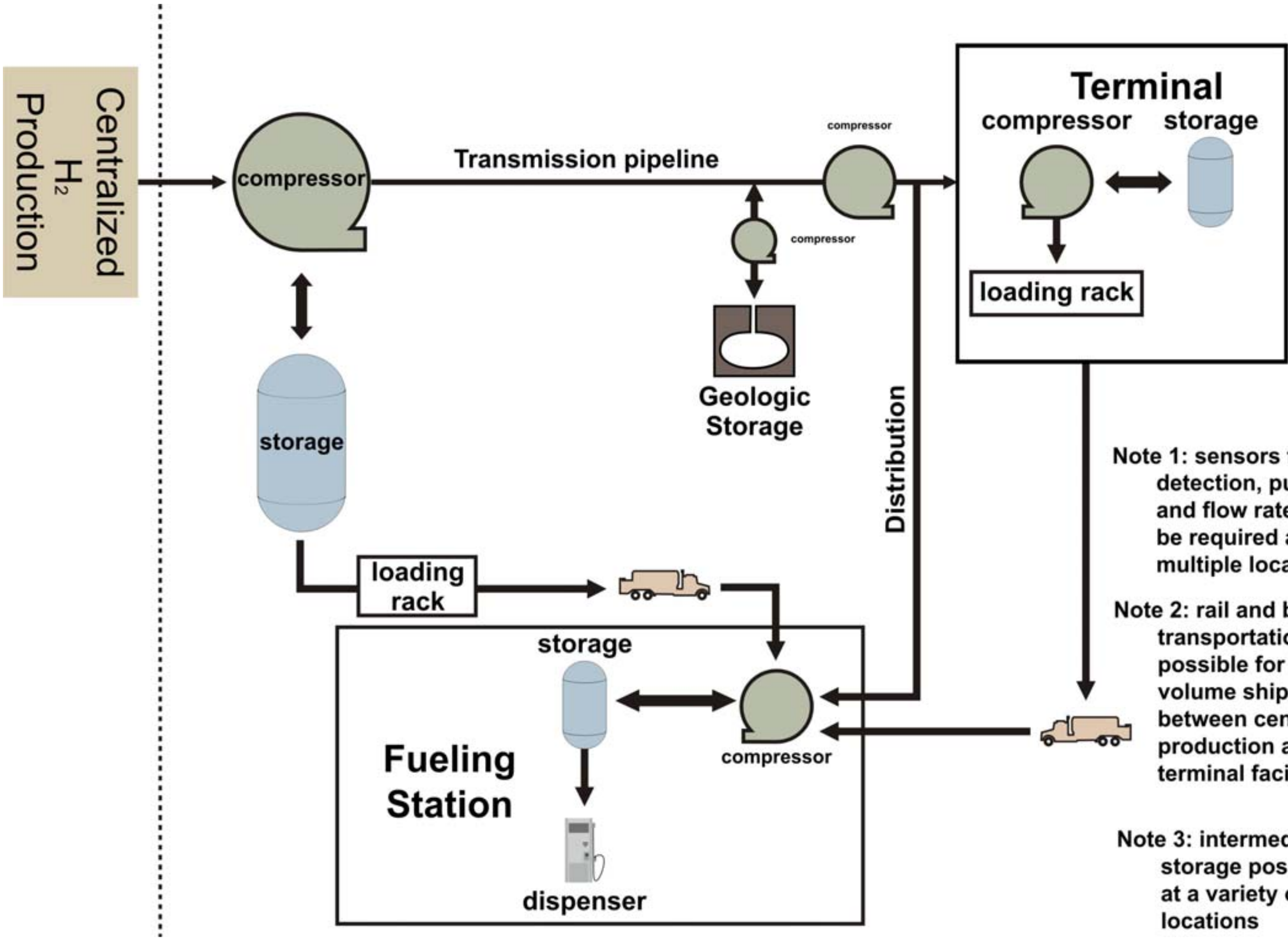
- Low Mkt Pentration
  - Low volumes means much higher delivery costs
  - Distributed/City-Gate production could reduce costs significantly
  - Potential breakthroughs: higher H2 content tube trailers, liquefaction, carrier approach?
- Forecourt costs are significant and need to be reduced
  - Larger and fewer forecourts is very beneficial
  - Compression: reliability needs to be improved, capital cost needs to be reduced
  - Storage: Need a breakthrough
- Pipelines are the current low cost pathway for the long term, but:
  - Hydrogen embrittlement concerns
  - How to move to pipelines (at least transmission) earlier?
  - H2 distribution lines in cities ? And at what pressure? At what cost? Odorants/Sensors?
  - High H2 content tube trailers could be cost effective for distribution
- System storage needs drive costs up
  - Need to better understand storage needs and demand cycles
  - Geologic storage feasibility is critical
- Compression Costs need to be reduced

Additional Information

- FreedomCAR and Fuels Partnership Delivery Tech Team
  - Comprehensive Delivery Roadmap
- Websites
  - www.hydrogen.energy.gov
  - www.eere.energy.gov/hydrogenandfuelcells/

Back-Up slides

Gaseous Hydrogen Delivery Pathway

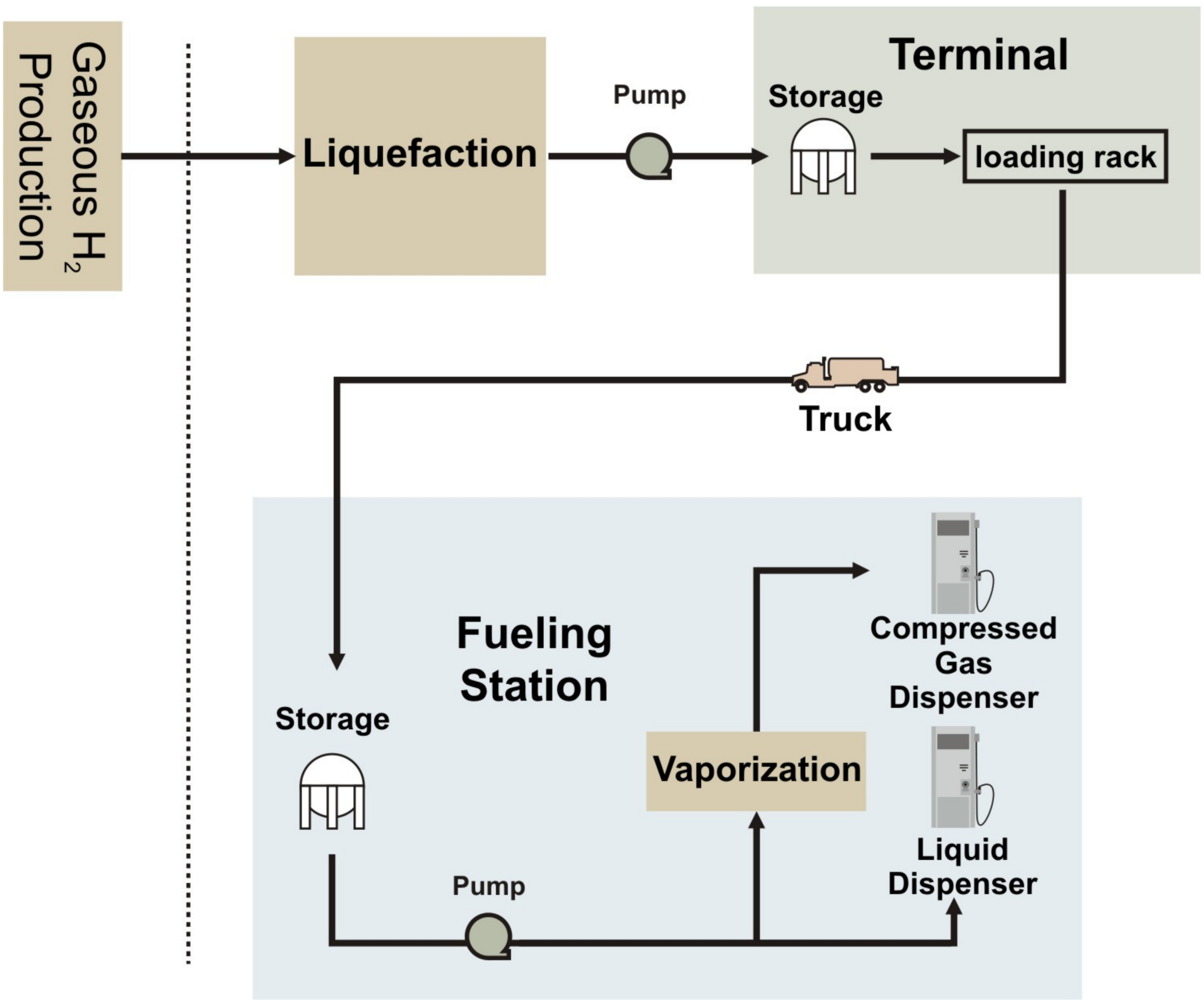


Note 1: sensors for leak detection, purity, and flow rate will be required at multiple locations

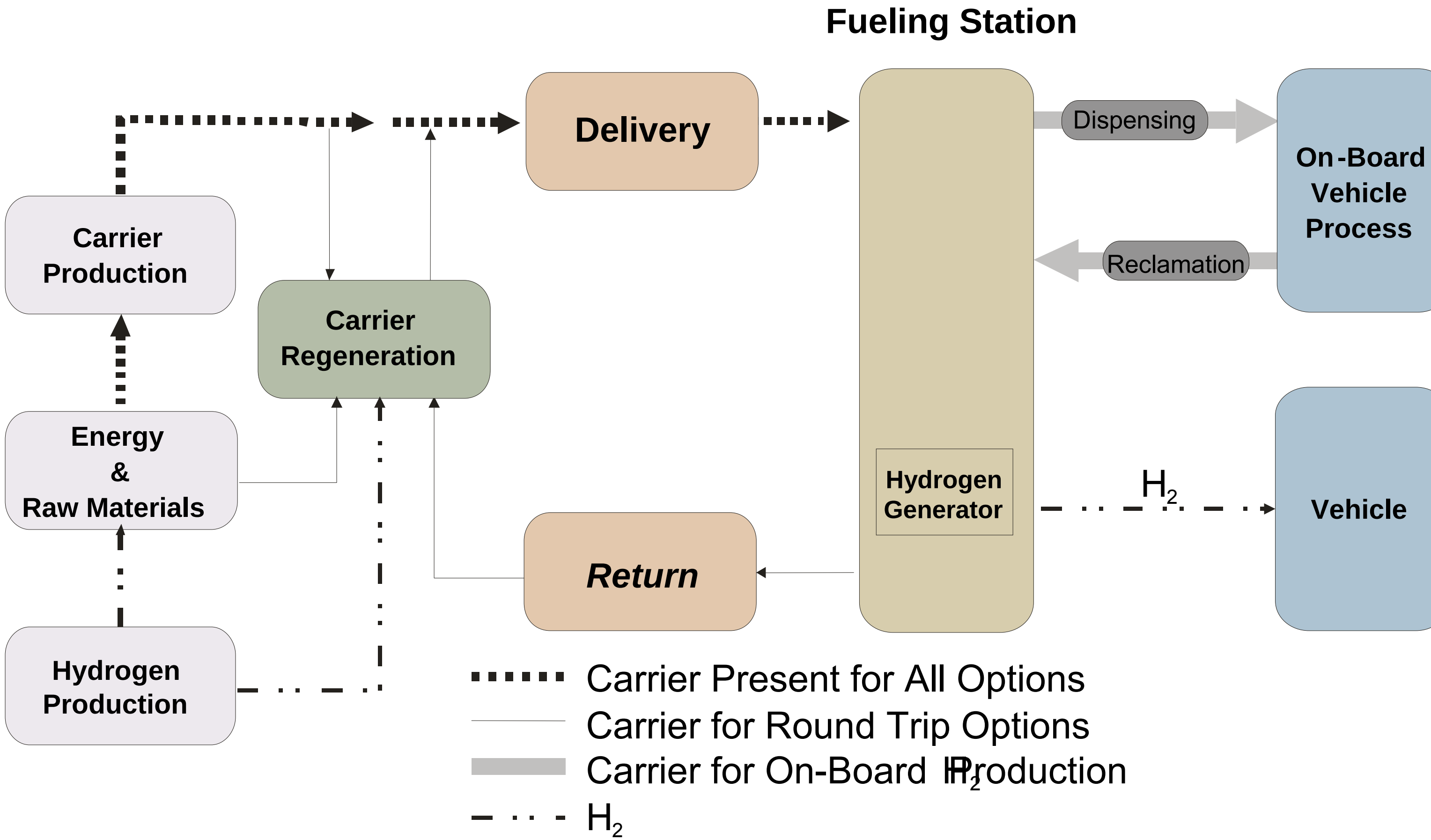
Note 2: rail and barge transportation is possible for large volume shipments between central production and a terminal facility

Note 3: intermediate storage possible at a variety of locations

Liquefaction Distribution Pathway

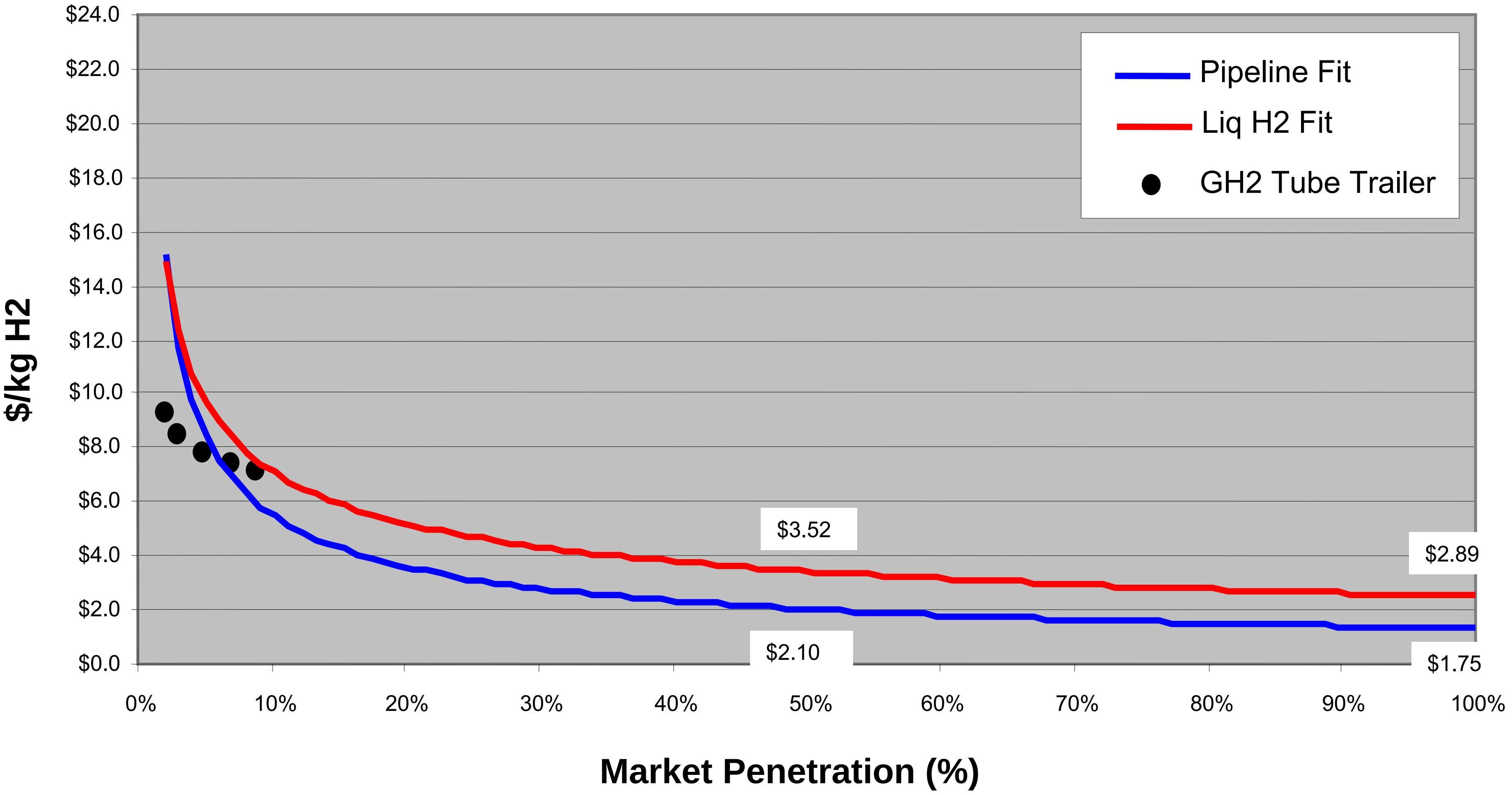


Hydrogen Carrier Delivery Pathway



Current Urban Hydrogen Delivery Costs

City: 250k people, Plant 100 km (62 miles) from city gate



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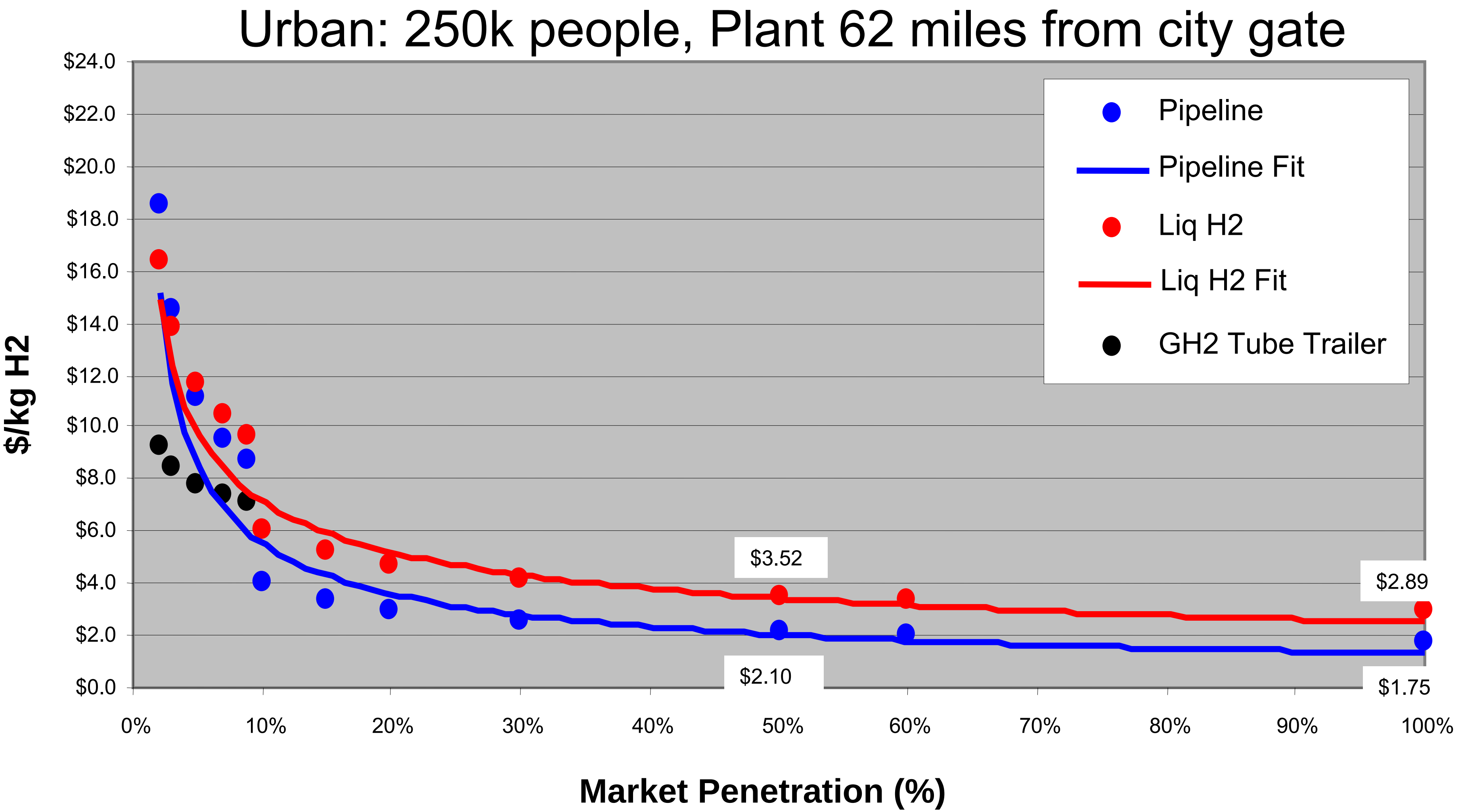

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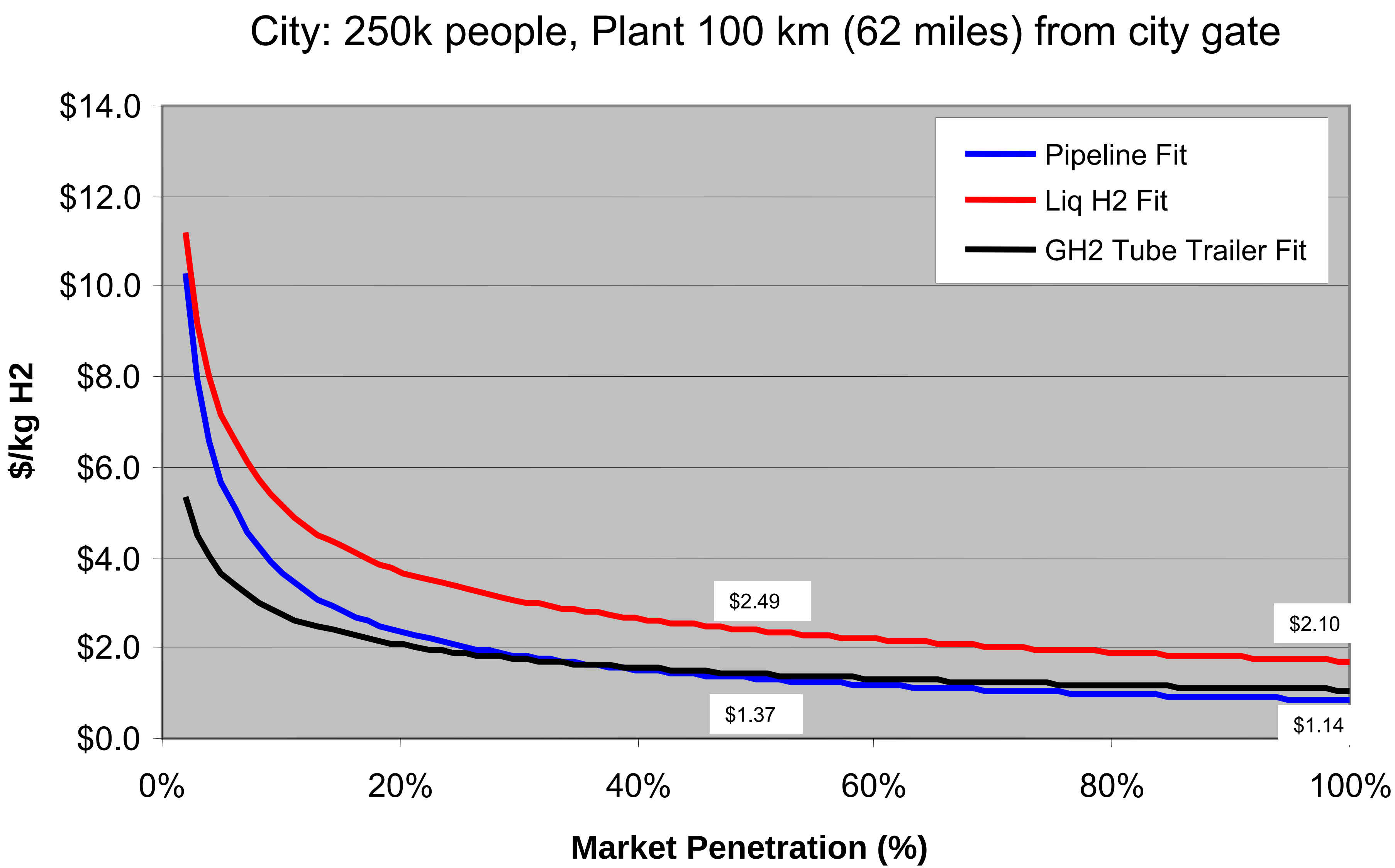
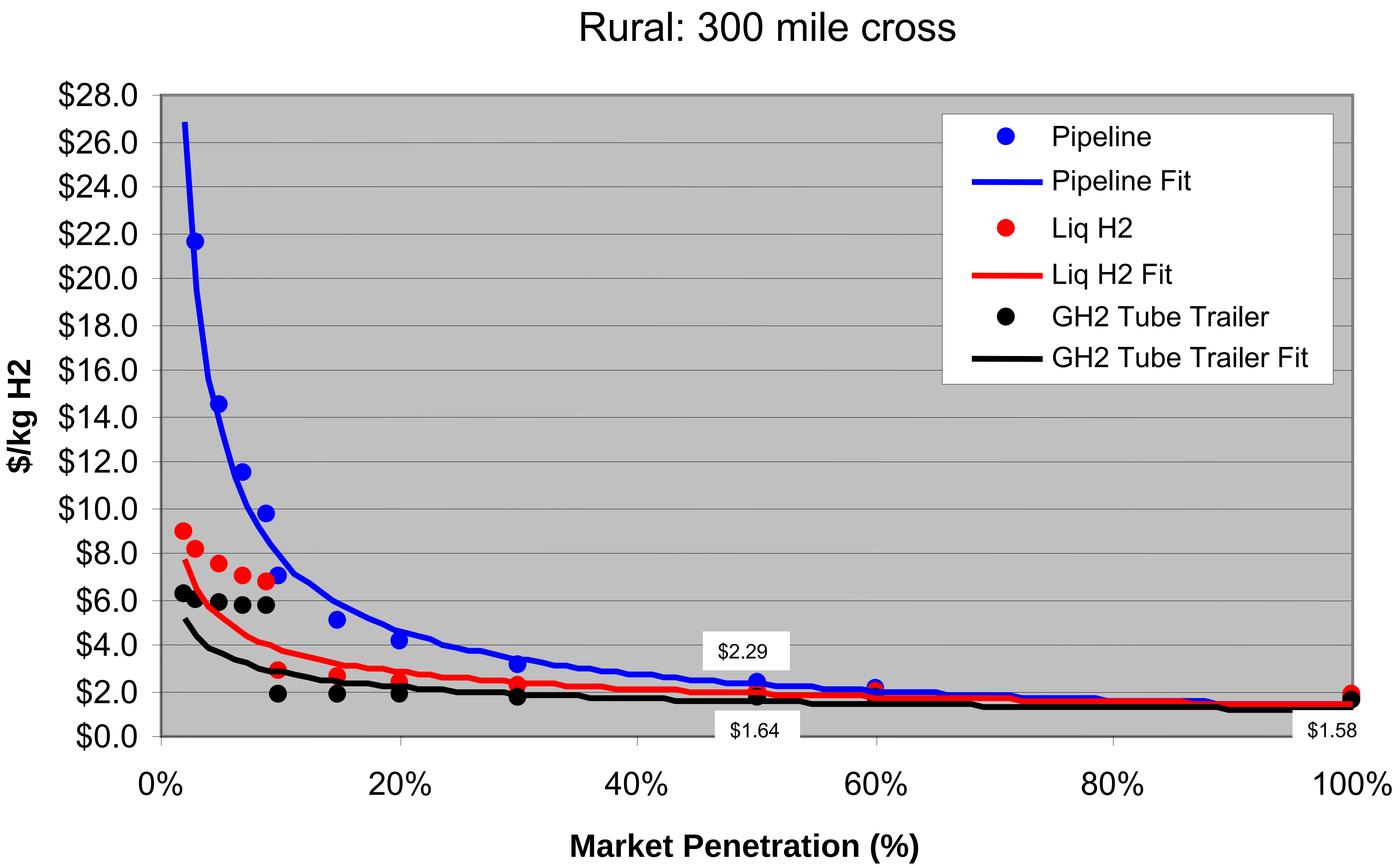
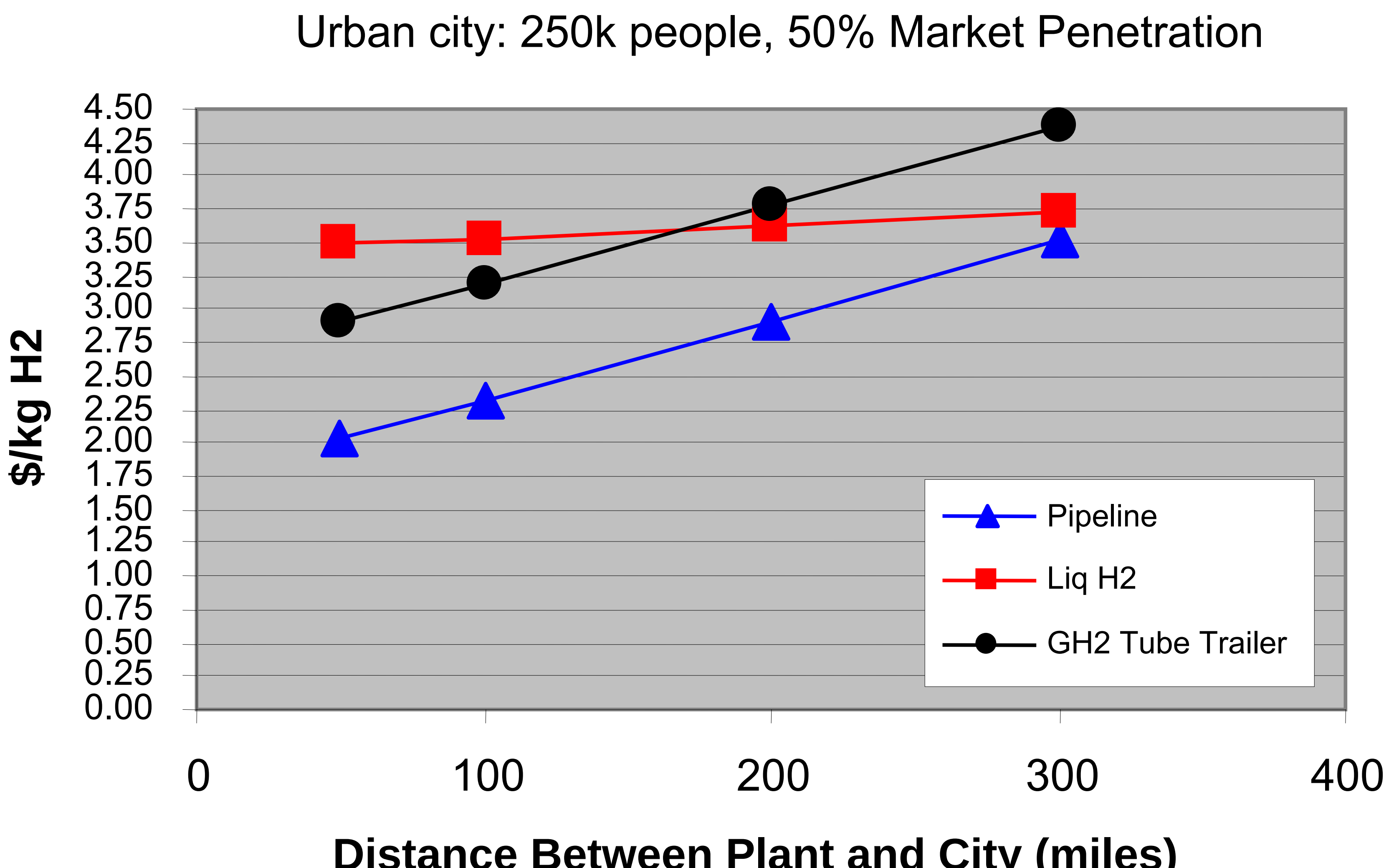


Rural Hydrogen Delivery Costs at Research Targets



Current* Hydrogen Delivery Costs vs. Distance Between Plant and City



Delivery Targets

Category	Units	2005 Status	2015	2017
Pipelines				
Tranmission Capital	$k/mile	$700		$490
Distribution Capital	$k/mile	$320		$190
Reliability (Embrittlement)		Acceptable for current service		Acceptable for H2 as a major energy carrier
Compression				
Large: Reliability		Low		High
Large: Capital Cost	$M (200k kg/day)	$15		$9
Forecourt: Reliability		Medium	High	
Forecourt: Capital Cost	$k/(kg/hr)	$4.60	$3	
Forecourt Fill Pressure	psi	5,000	10,000	
Tube Trailer				
Delivery Capacity	kg of H2	280		1,100
Capital cost	$	$165,000		<$300,000
Storage Tanks				
Capital Cost	$/kg of H2	$820	$300	
Liquefaction				
Small: Capital Cost	$M (30,000 kg/d)	$60		$35
Small: Energy Efficiency	%	73%		84%
Large: Capital Cost	$M (300,000 kg/d)	$200		$120
Large: Energy Efficiency	%	80%		88%
Carriers				
Carrier H2 Content	% by weight	3%		13%
Carrier H2 Content	kg H2/liter			0.027
Energy Efficiency	%	Undefined		85%
System Cost Contribution	$/kg H2	Undefined		<$1

Carriers

Liquid Carriers

- ***Ethanol, Methanol, Bio-oils, Ammonia, etc.***

- ***Liquid Hydrocarbons:*** A liquid hydrocarbon is catalytically dehydrogenated at a station or on a vehicle and “dehydrided” is then returned to a central plant or terminal for rehydriding:

$$C_nH_2n \leftrightarrow C_nH_n + n/2\ H_2$$

Carriers

Solid Carriers

- ***Metal Hydrides***
- ***Nanostructures:*** Single-wall carbon nanotubes (SWNTs). Other Nonostructures

Flowable Powders, Slurries, "Bricks", : Stable solid carriers might be delivered in many different ways. Slurries have been mentioned, but novel systems such as flowable powders or solid "bricks" might also be potential delivery mechanisms.