Technical and Economic Studies of Regional Transition Strategies toward Widespread Use of Hydrogen Energy

Joan M. Ogden

Institute of Transportation Studies

University of California, Davis

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Project ID # AN5

Overview

Timeline

Phase I: 4/04-1/05
Phase II: 5/05-5/06

Phase I complete,
Phase II pending

Budget

- Total project funding: $130K
  (DOE share =100%)
- FY04: $130 K
- FY05: ($100 K pending)

Barriers Addressed:

- Lack of Understanding of transition of Hydrocarbon Based Economy to H2 Based Economy.
- Lack of consistent data, assumptions and guidelines

Technical Targets:

- By 2007, identify and evaluate transition scenarios consistent with developing infrastructure and H2 resources.

Partners/Collaboration

- H2A Delivery Team (NREL, ANL, DOE)
- UC Davis H2 Pathways Program
- NETL (C-sequestration)
- Princeton University

Objectives

- **Assist the DOE in identifying promising paths for developing hydrogen infrastructure.**
  - **Use GIS-based simulation tools to evaluate alternative pathways toward widespread use of hydrogen, under various demand scenarios and regional conditions.**
    - Understand which factors are most important in finding viable transition strategies.
    - Develop "rules of thumb" for future regional hydrogen infrastructure development.
  - **Conduct regional case studies of H2 infrastructure transitions**
- **Work with H2A core group to develop models of hydrogen delivery systems.**

Technical Approach

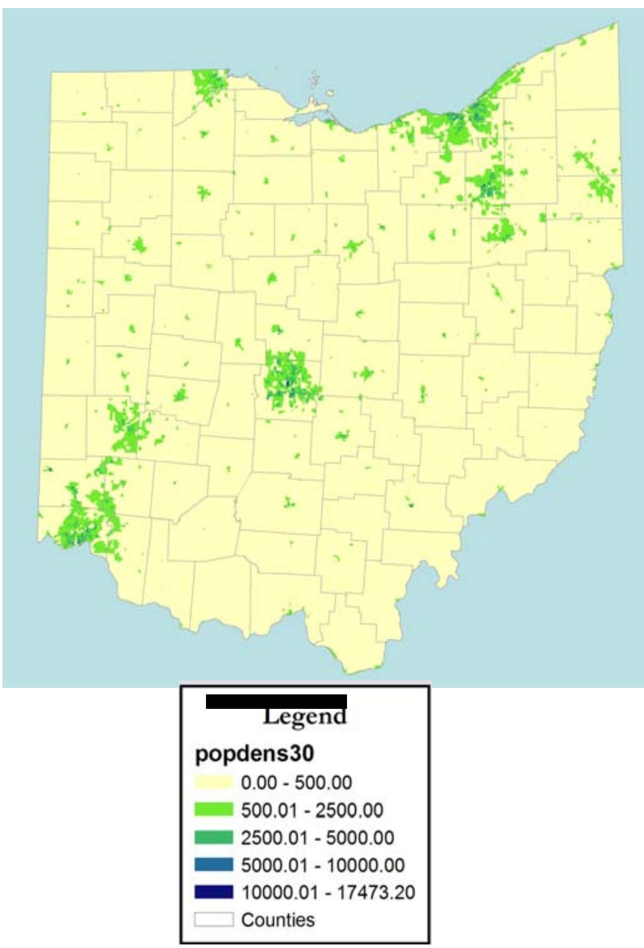
- **TASK 1: Extend UCD's simulation tools for assessing H2 transition strategies under various demand scenarios and regional conditions, to improve:**
  - GIS-based method for estimating regional hydrogen demand
  - Engineering/Economic models of H2 Components (refueling stations, pipelines).
  - Methods for Designing an Hydrogen Infrastructure (idealized models of distribution systems in cities; methods for siting stations)
  - Preliminary Transition studies: Designing infrastructure for growing hydrogen demand
- **TASK 2: Carry out regionally specific case studies of H_2 infrastructure development.**
- **TASK 3: Participate in H2A delivery team**

Technical Accomplishments (1)

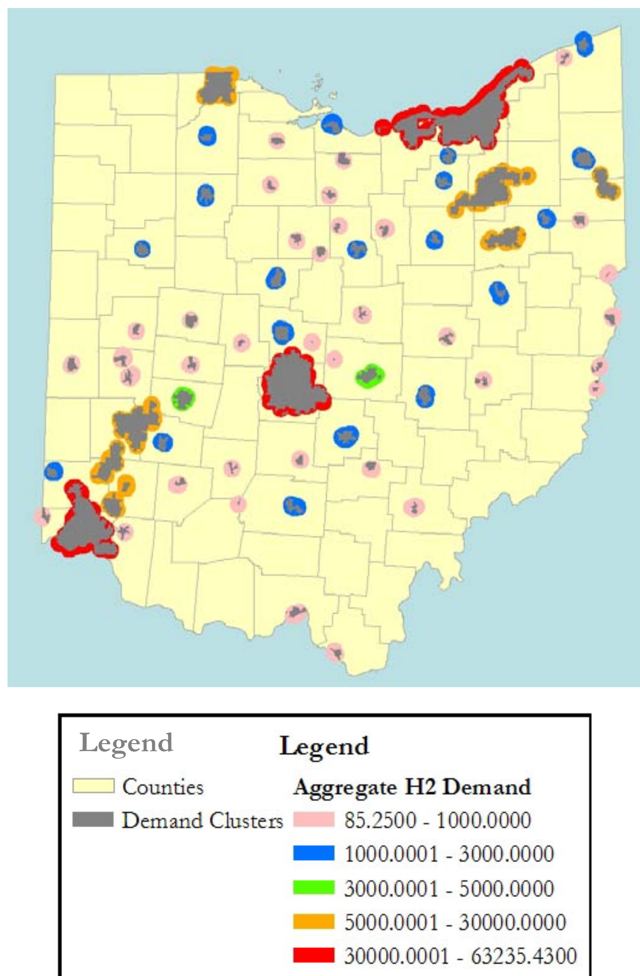
Task 1: Improve simulation tools

GIS-based method for estimating regional hydrogen demand

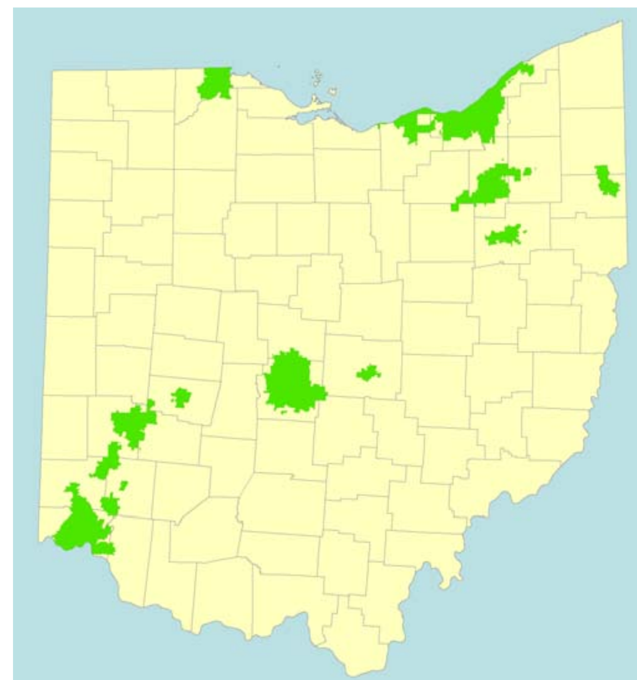
Population Density – US Census (people/km^2)



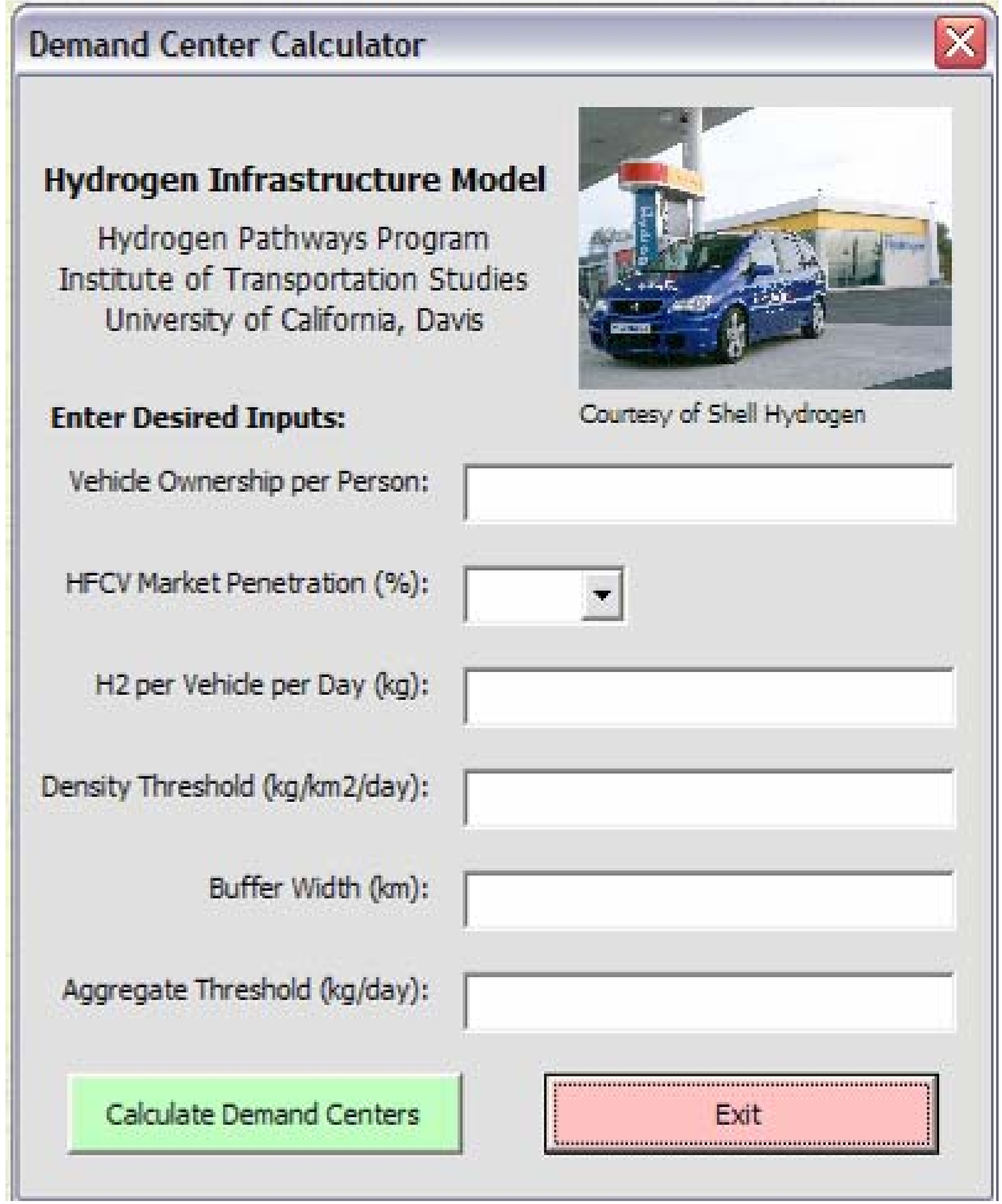
Estimate H_2 Demand and Aggregate



Select Demand Centers



H_2 demand model can be applied to ANY region with GIS census data



Technical Accomplishments (2)

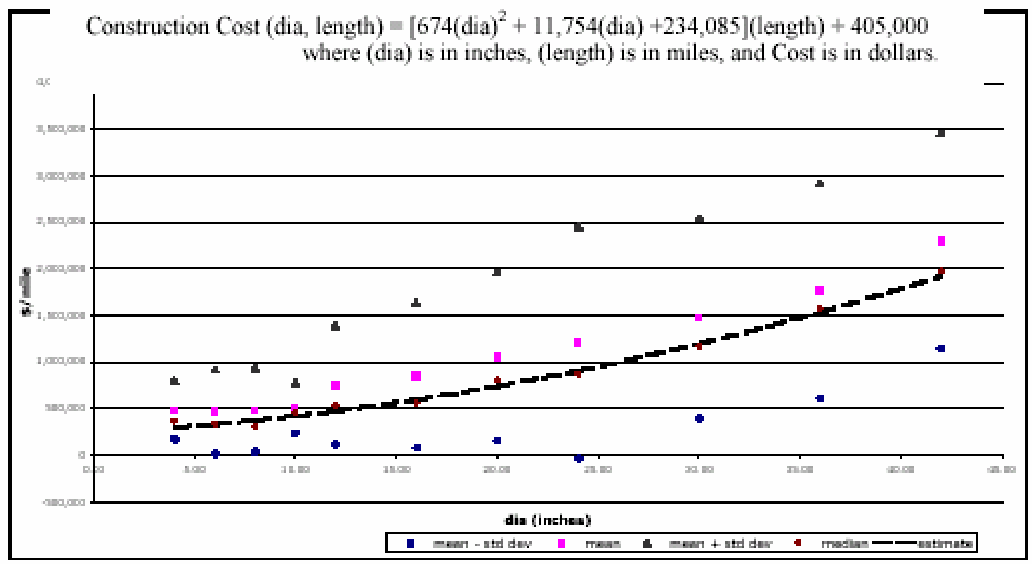
Task 1: Improve simulation tools

Improve Engineering/Economic models of H2 Components

Incorporate Costs from UCD H2 Pathways H2 Refueling Station Model

Refueling station - external production					
Summary					
# of stations			**Discount rate**	**10%**	
Station capacity	**623,258**	**kg/yr**	**CRF (20 years)**	**11.7%**	**20**
Station Capacity	**1,708**	**kg/day**	**CRF (25 years)**	**11.0%**	**25**
% utilization	**100.0%**				
Actual Demand	**1,708**	**kg/day**			
Actual Demand	623,257.5	**kg/yr**			
Delivery	**pipeline**		**O&M Costs**		
			O&M Cost	$ 119,324	10%
Land	**Existing land**				
			Electricity (comp)	$ 71,997	
Total Capital Costs	Per unit	Total	Misc Electricity	$ 438	3
SMR Costs			**Total O&M**	**$ 191,759**	
Compressor		$ 793,242			
Storage		$ 280,000	**Total Costs**		
Dispenser	$30,000	$ 120,000	Total Annual Cost	$ 406,721	
Total		**#######**	**Total Price**	**$ 0.65**	**$/kg**
			Feedstock price	**$ -**	**$/kg**
Installation Costs	30%		**Land Cost**	**$ 0.12**	**$/kg**
Installation Cost		$ 357,973	**Capital cost**	**$ 0.21**	**$/kg**
Land Costs		$400,000	**CO_2**	**1.89**	**$kgCO_2/kgH$**
Total Installation		**$ 757,973**	**Energy Costs**	**13.41%**	**% of LHV**
Annual Costs					
Capital	$ 131,457		**Compressor**		
Installation	$ 83,504		Size (kW)	164.4	
			Electricity usage	3,945	kWh/day
Miscellaneous			**Peak Flowrates**	**200%**	**% of avg**
Fixed Electricity	1	kW	**Average storage**	**20%**	**% Daily flo**
Variable Electricity	0	kW	**Efficiency (PE)**	**13.33%**	**% of LHV**
Total Electricity	8760	kWh	**CO_2 (elec)**	**1.17E+09**	**g/yr**
Efficiency	0.08%				
CO2	7107590	g/yr	**Storage Tanks**		
			Average Storage	**20%**	% daily flow
			Storage Size	**400**	kg
			Cost	$700	/kg
			Tank size	200	kg
			Fuel Dispensers		
			Number of Pumps	**4**	/station
			Cost/pump	$30,000	
			Max pumps	6	

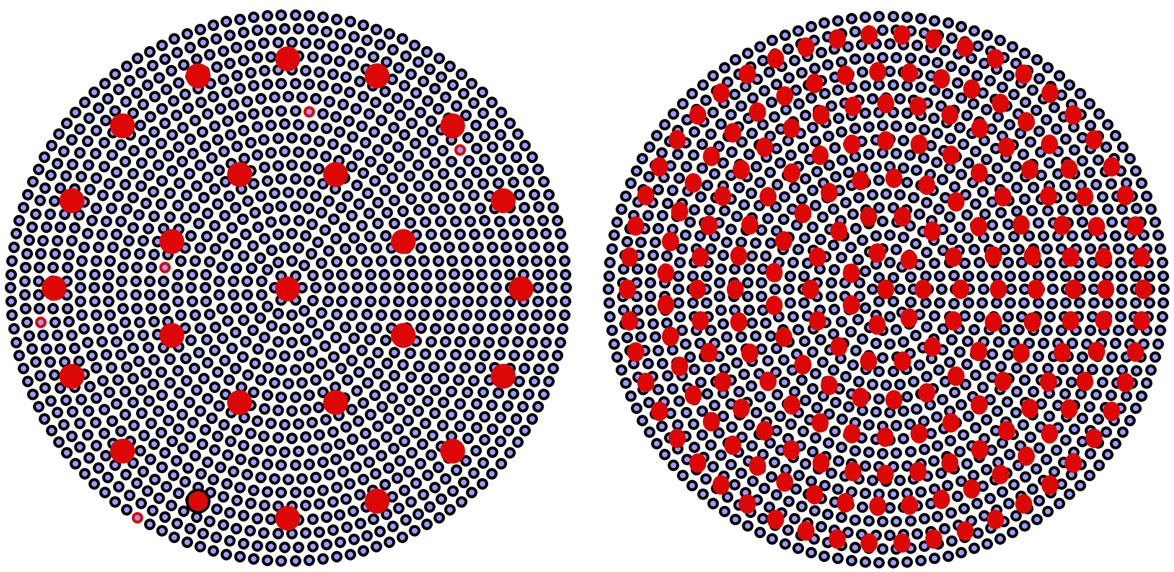
Improve Models for H2 Pipeline Costs via analysis of NG pipeline data



Technical Accomplishments (3)

Task 1: Improve simulation tools

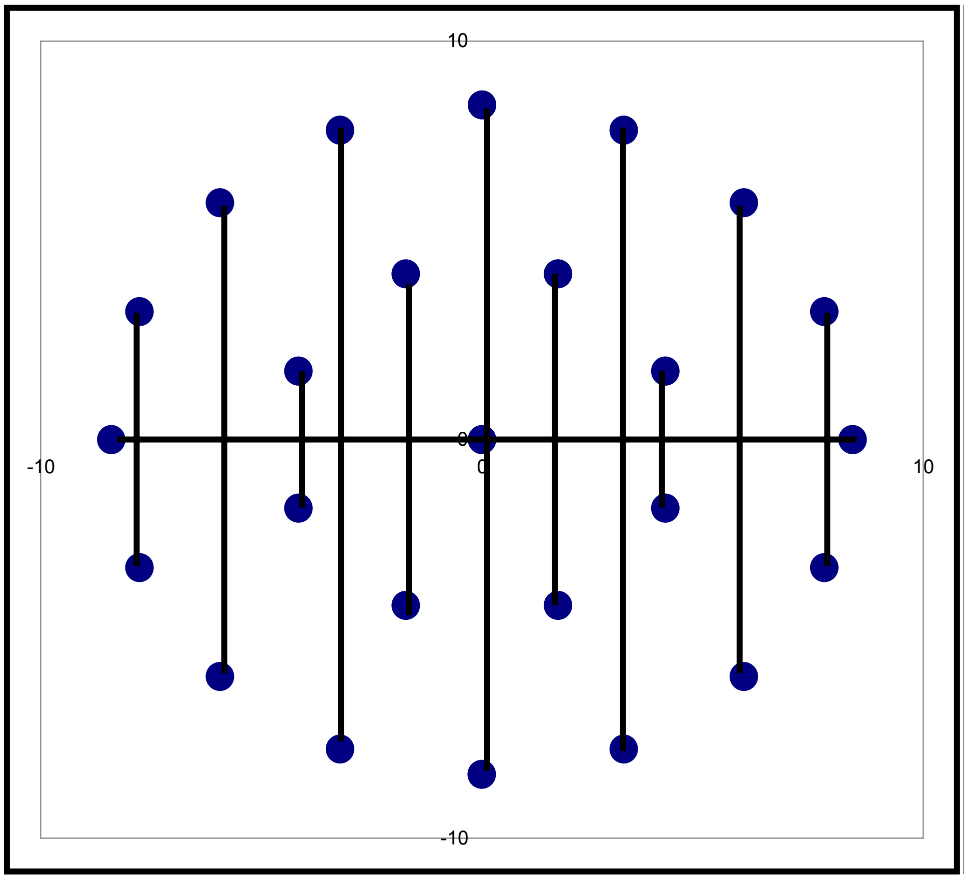
Designing Hydrogen Infrastructure for an Idealized City



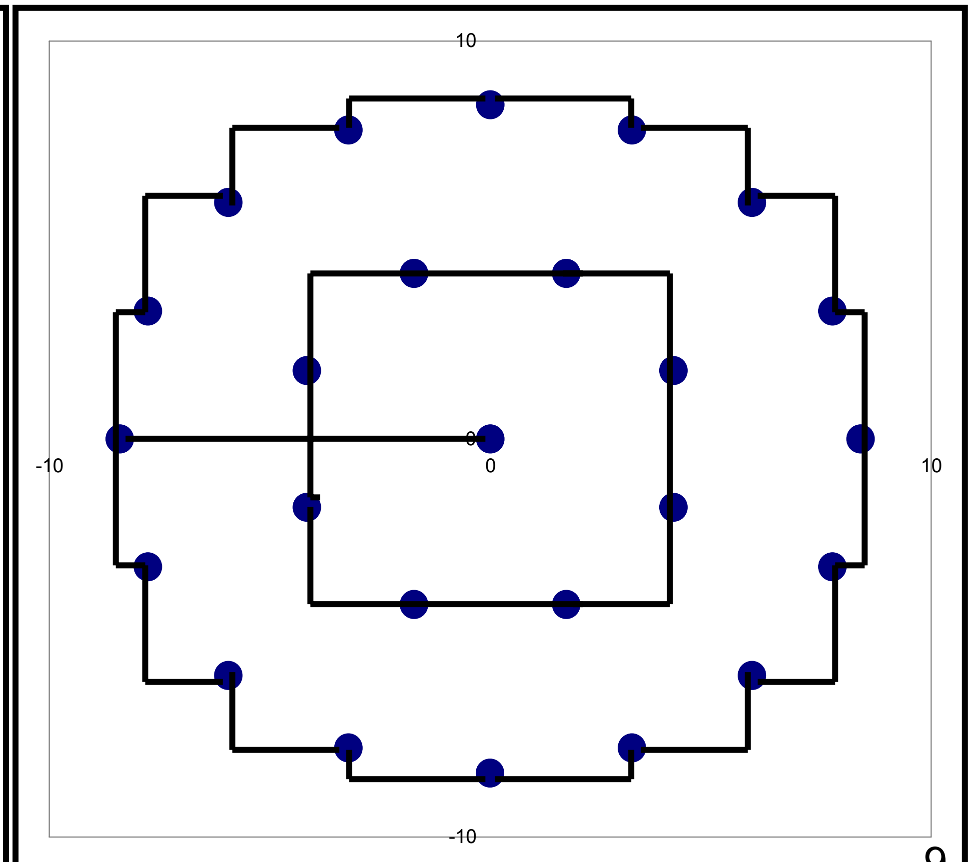
Idealized city model with 25 and 125 hydrogen stations distributed in rings throughout the city.

Distribution System Layout for Idealized City => lengths, costs

Truck delivery



Pipeline



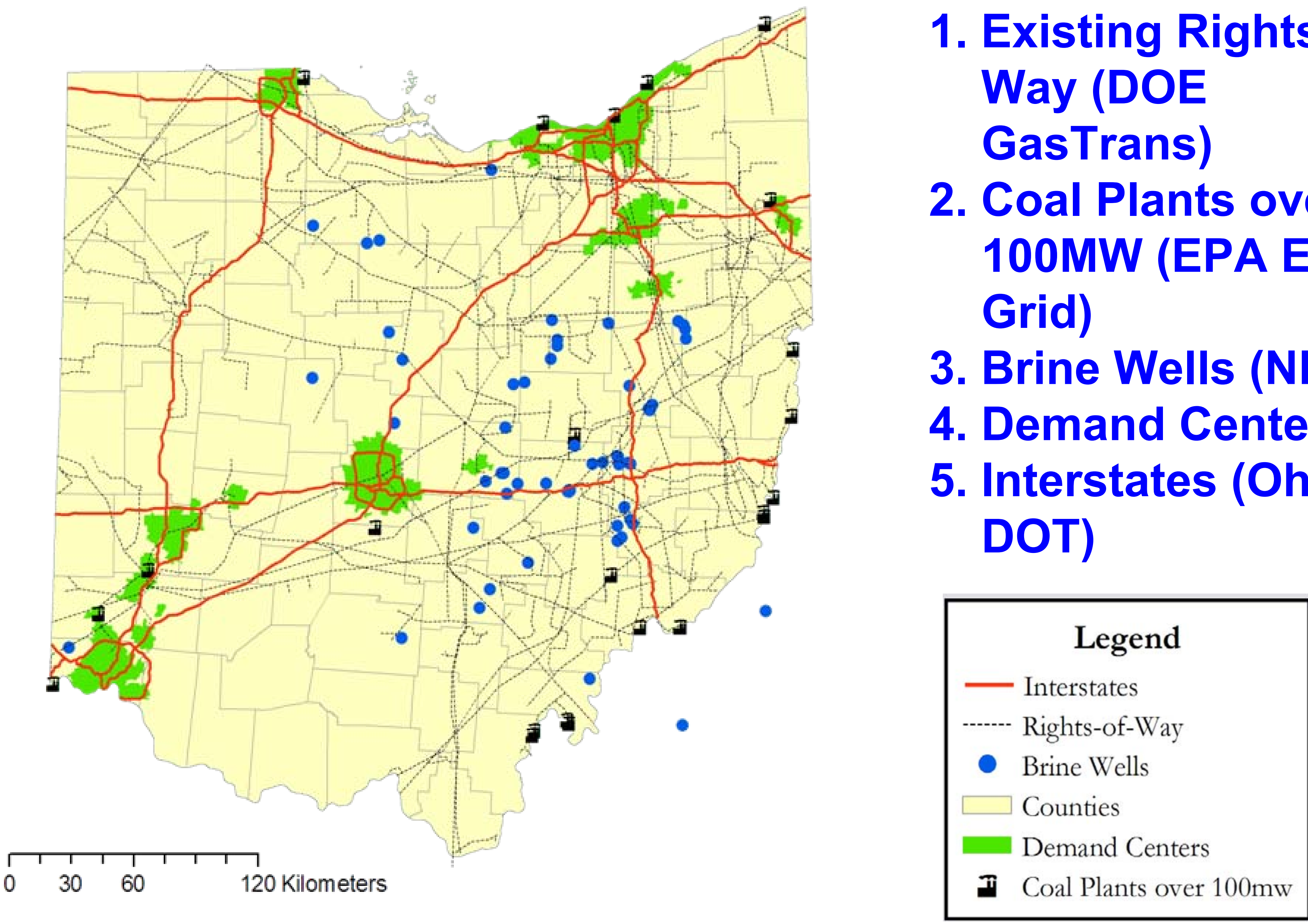
Technical Accomplishments (5)

Task 2: Carry out regionally specific case studies of H_2 infrastructure development

Coal-Based H_2 Infrastructure w/ CO_2 Capture and Sequestration in Ohio

- ***Combine spatial tools and geographic data with engineering and economic models. Develop methods that can be used anywhere in US***
- ***Build GIS data base, incl. H_2 demand, potential H_2 supply, existing infrastructure, CO_2 sequestration sites***
- ***Design H_2 infrastructure, estimate costs, performance, emissions***
- ***Cases analyzed:***
  - ***Central coal w/CO2 Seq. & pipeline delivery***
  - ***Onsite NG reforming***

GIS Database



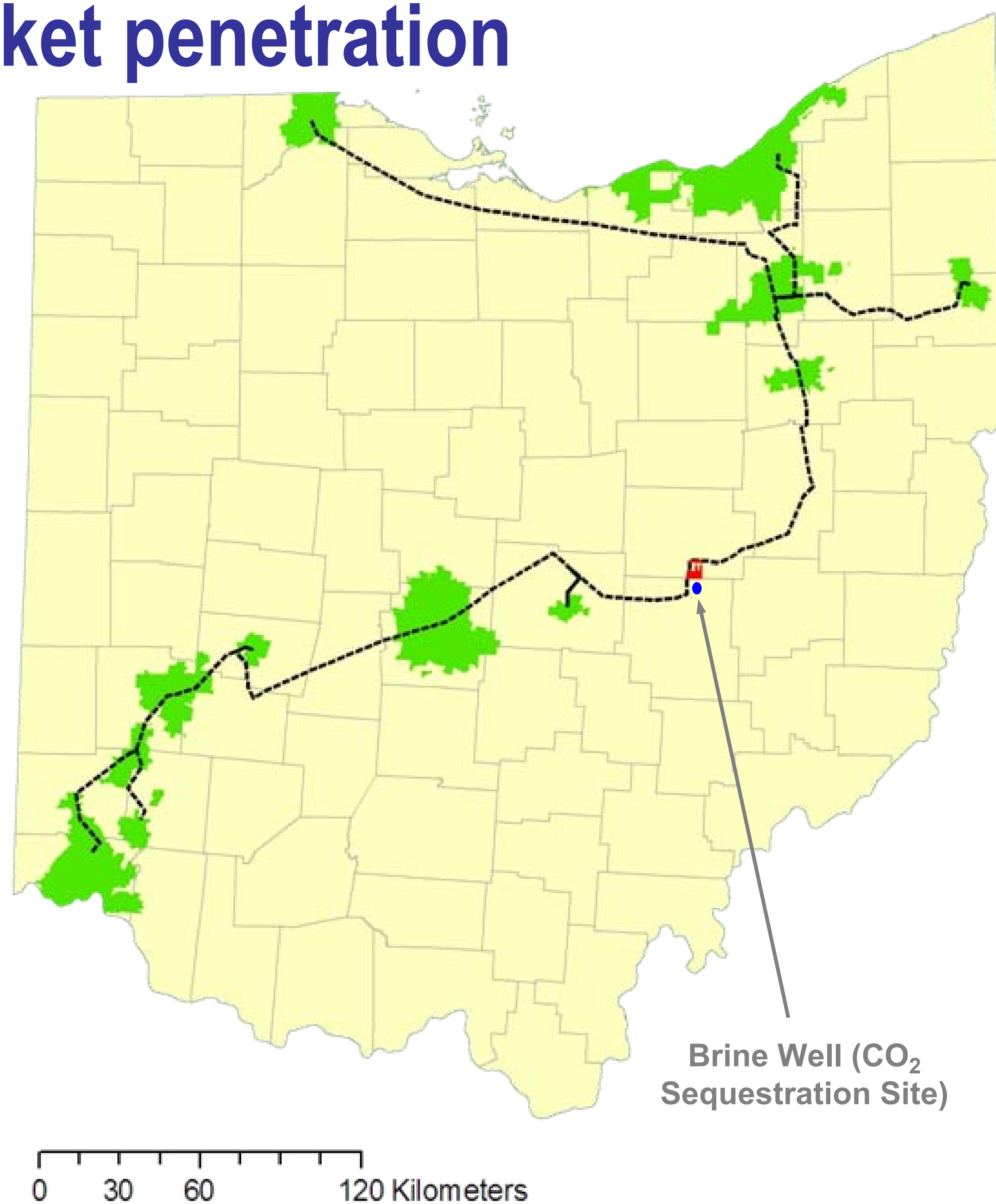
Data Used:

1. Existing Rights-of-Way (DOE GasTrans)
2. Coal Plants over 100MW (EPA E-Grid)
3. Brine Wells (NETL)
4. Demand Centers
5. Interstates (Ohio DOT)

Shortest path intercity network

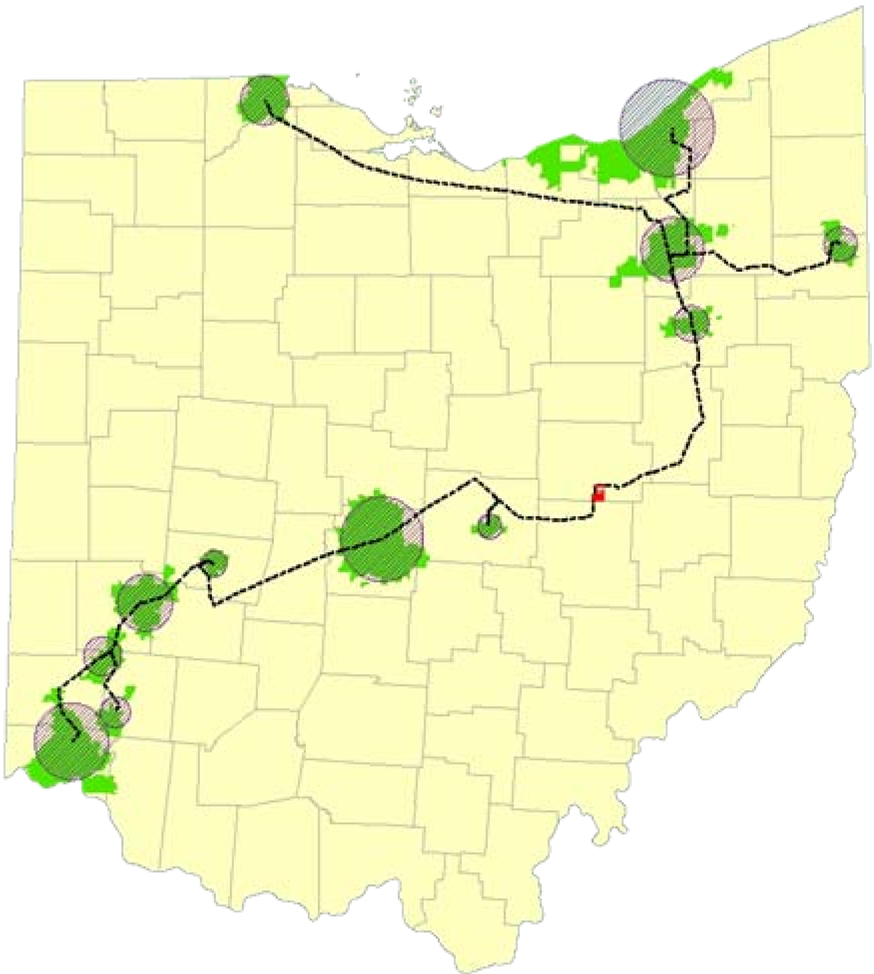
10% market penetration

- One coal plant - 253 tons H_2/day
- 12 demand centers
- 936 km of intercity pipeline
- CO_2 sequestration system: 4,500 tons CO_2/day

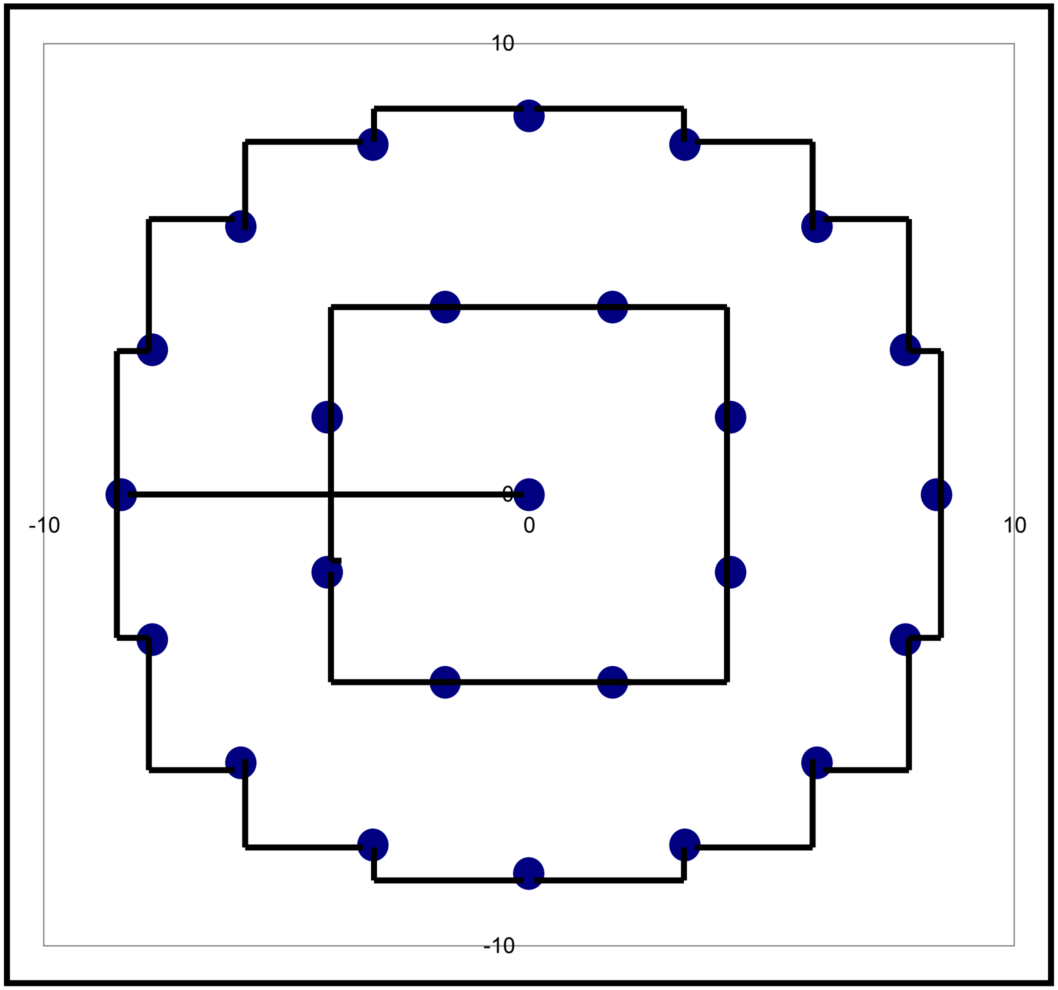


Intracity Distribution and Station Siting
"Idealized City" Model

Equivalent Circles



Pipeline Design



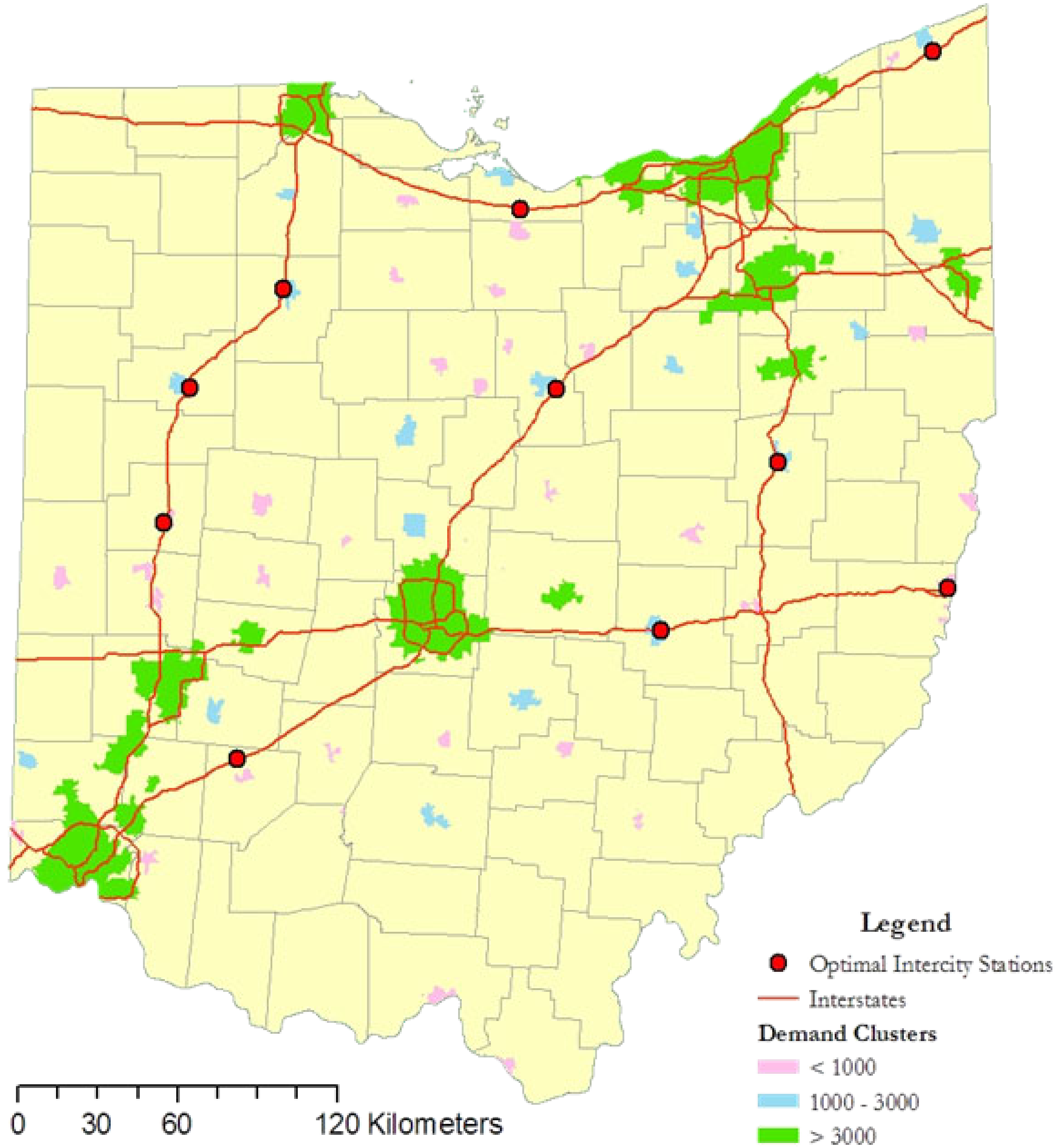
Intercity Stations

Selection criteria

- Maximize average daily traffic flow at station sites
- Locate close to large demand clusters
- Place greater than 30 km from corridor endpoints (large cities)

• **Results**

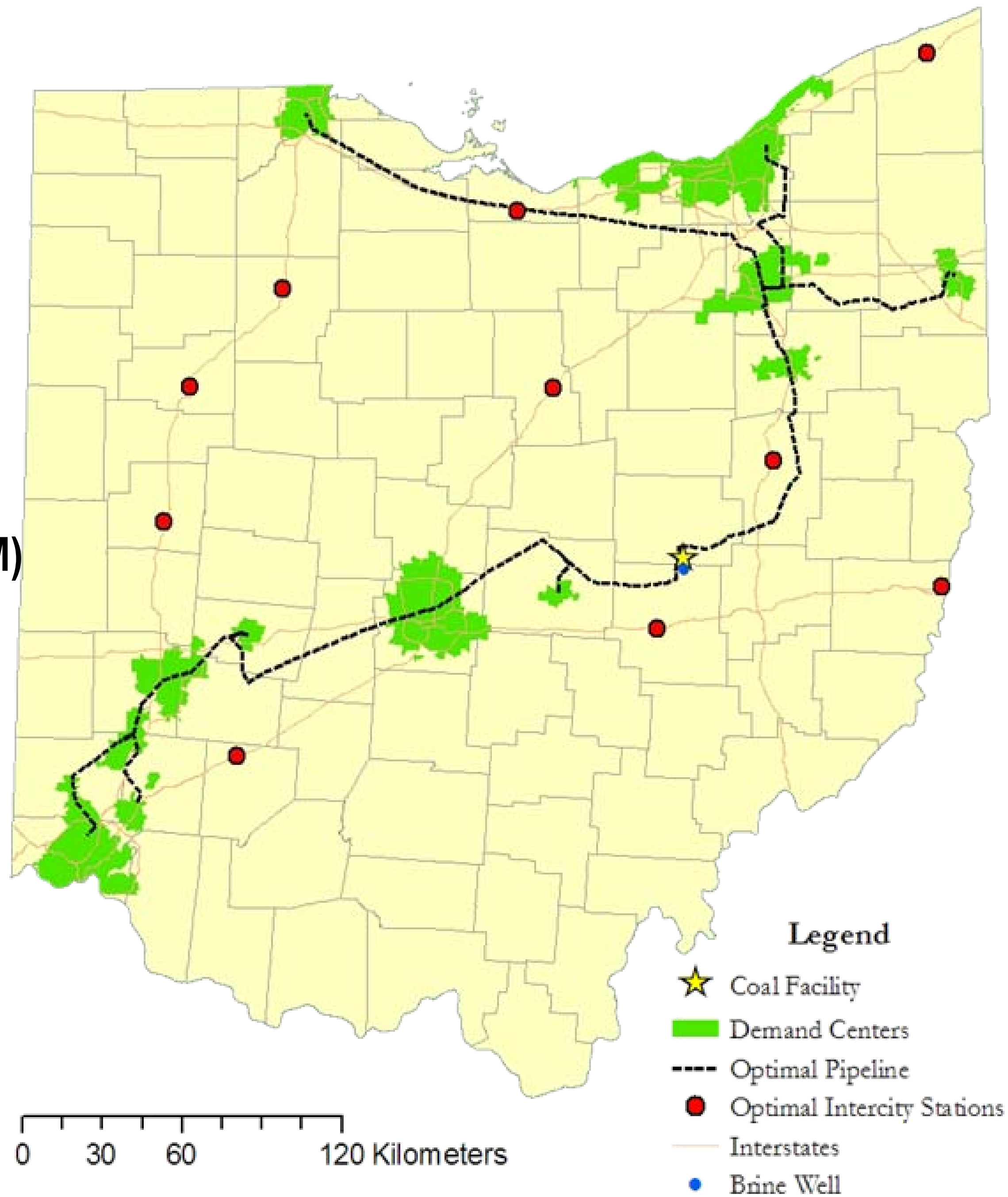
- 10 Stations (onsite H_2 production)
- Max stretch without a H_2 station: ~60 miles
- Total H2 demand ~ 20 tons H_2/day



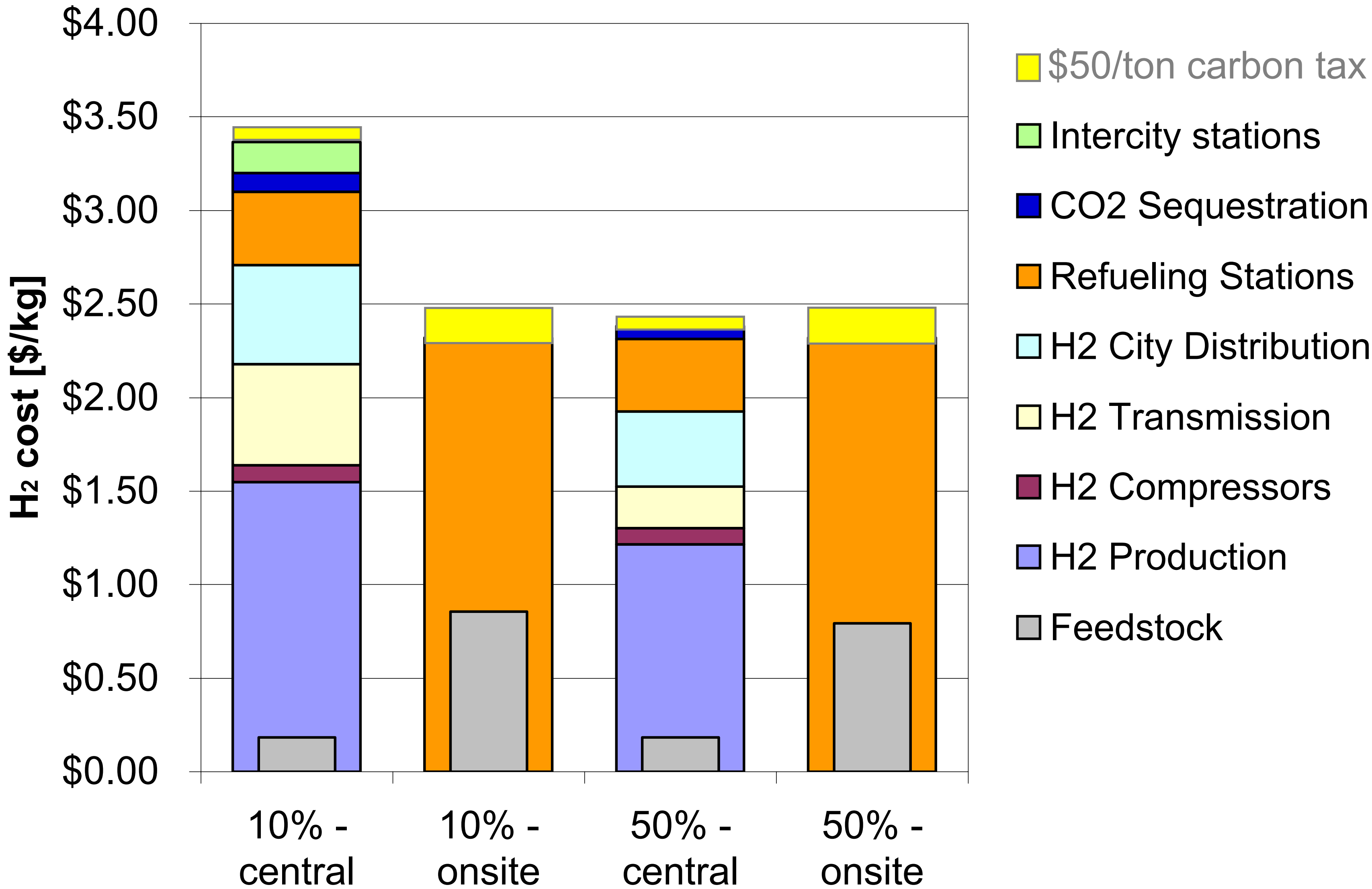
Results – 10% market penetration

Capital Cost

- 1 coal plant producing 253 tons H_2/day ($381 MM)
- 936 km of intercity pipeline ($358 MM)
- 12 demand centers serving 48% of the population (~420,000 vehicles)
  - 1,105 km of local distribution pipelines ($352 MM)
  - 91 refueling stations, each dispensing ~2,800 kg/day ($135 MM)
- 10 intercity stations, each dispensing ~ 2,000 kg/day ($37 MM)
- 1 CO_2 sequestration site: 4,500 tons CO_2/day ($55 MM w/compressor)
- **Total capital cost: $1.3B or $3,100/vehicle**
- **Delivered H_2 cost: ~$3.35/kg**



Delivered H_2 cost
Central coal H_2 w/CCS vs. Onsite SMR



Technical Accomplishments (6)

Participation in H2A Delivery Group

- H2A is a group of analysts convened by DOE to produce a credible, well-documented set of information on H2 production, delivery and forecourt refueling technologies and options.
- FY'05 Accomplishments
  - Member of H2A team analyzing H2 delivery infrastructure. (Close collaboration with researchers at DOE, NREL, Argonne)
  - Developed base case scenarios for hydrogen delivery.
  - Developed EXCEL model for hydrogen delivery system design and cost.
  - Presentation to USDOE FreedomCar Delivery Tech Team on H2A's work
  - Co-author of presentation at 2005 NHA Conference on H2A delivery team's work, March 2005.

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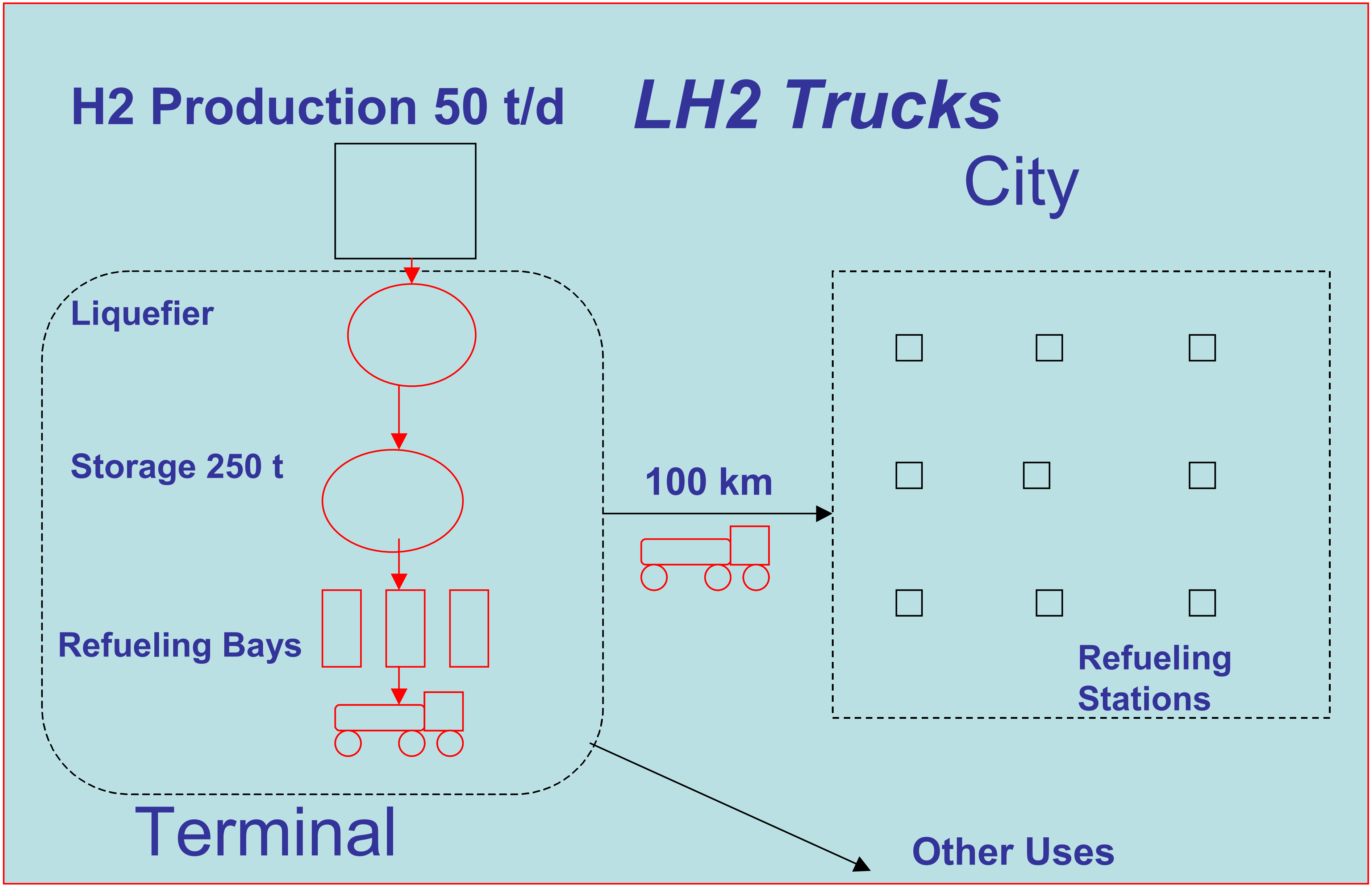
Technical Accomplishments (7)

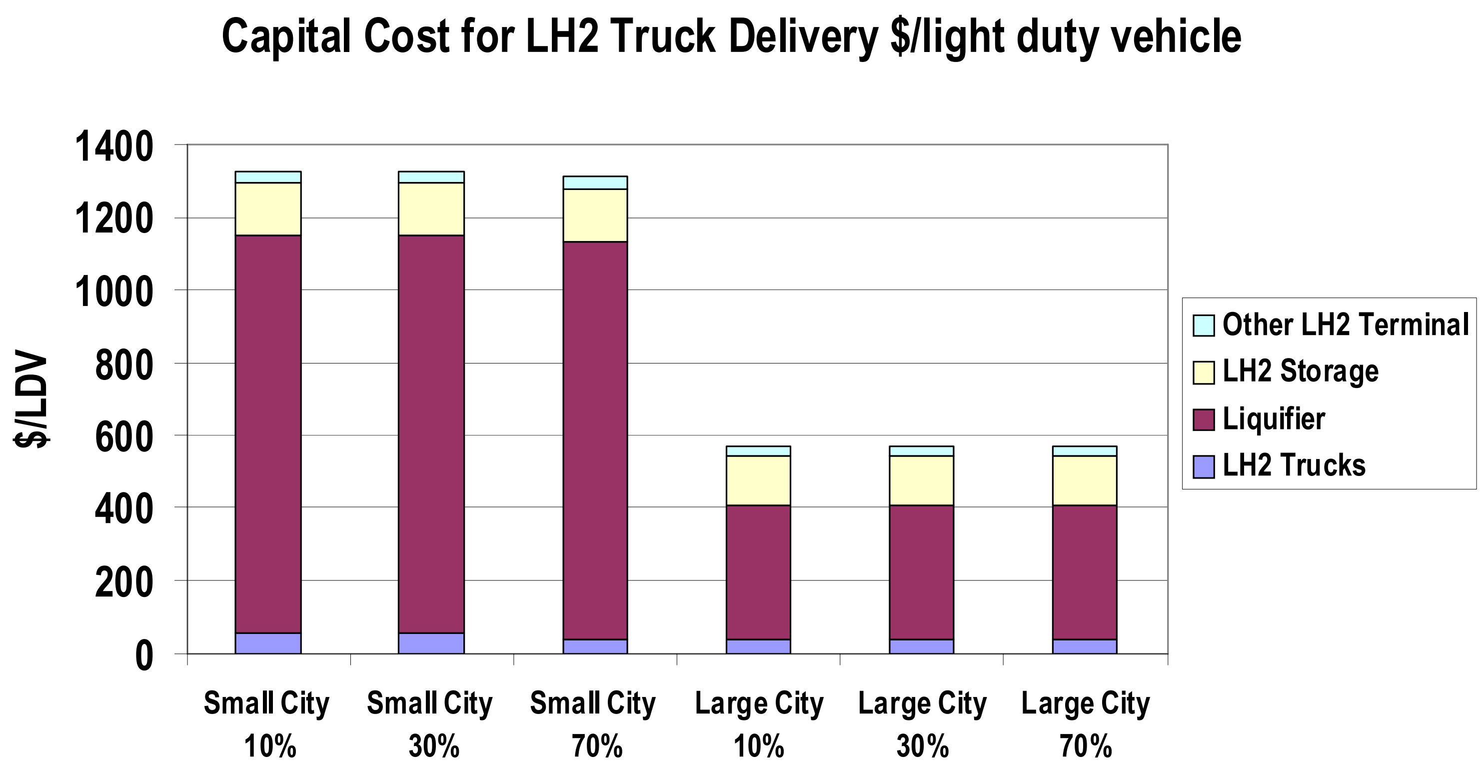
H2A Delivery Results

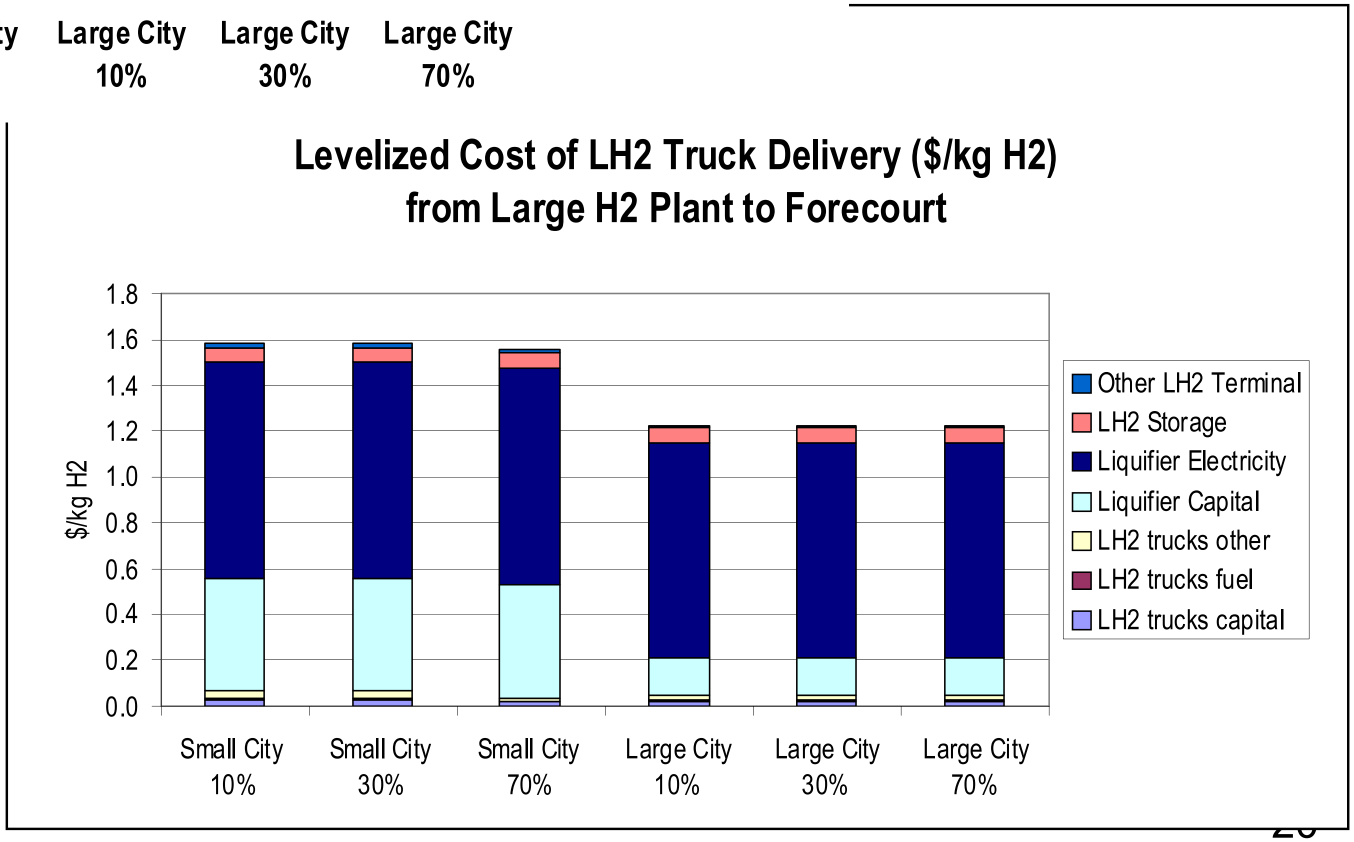
- H2A Delivery Cases Analyzed; large and small cities; rural and interstate regions; delivery by gas truck, LH2 truck, gas pipeline; different market penetration levels.

Market Type	Early Fleet Market (1%)	General Light Duty Vehicles: Market Penetration		
		Small (10%)	Medium (30%)	Large (70%)
Metro	X	X	X	X
Rural			X	
Interstate			X	

We developed an EXCEL program to calculate infrastructure layout, equipment sizes, costs




Capital Cost for LH2 Truck Delivery $/light duty vehicle
$/LDV
1400
1200
1000
800
600
400
200
0
Small City 10%
Small City 30%
Small City 70%
Large City 10%
Large City 30%
Large City 70%
Other LH2 Terminal
LH2 Storage
Liquifier
LH2 Trucks


Levelized Cost of LH2 Truck Delivery ($/kg H2)
from Large H2 Plant to Forecourt
$/kg H2
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Small City 10%
Small City 30%
Small City 70%
Large City 10%
Large City 30%
Large City 70%
Other LH2 Terminal
LH2 Storage
Liquifier Electricity
Liquifier Capital
LH2 trucks other
LH2 trucks fuel
LH2 trucks capital

Response to Previous Year Reviewers' Comments

- **"Need a more robust demand model"**
  - H2 Pathways Demand Conference September 2004. Surveyed current work on this. It's tough to model demand!
  - Developed new GIS-based methods for demand
  - Future plans: estimate market penetration from consumer choice model and couple to infrastructure layout
- **"Optimization leads to ideal case." Maybe misplaced emphasis at this point.**
  - Concentrated on constraining problem to make optimization easier (e.g. assume minimum # of stations needed; only use existing ROWs or refueling sta sites; pipeline cost α length)
- **"Model depends greatly on assumptions"**
  - Sensitivity studies w/ H2A show importance of scale, city size, population density, market fraction, feedstock cost, station size

Future Work

Remainder of FY'05

- Continue to refine simulation tools for modeling hydrogen energy infrastructure development based on geographic information system (GIS) input data and optimization methods.
- Complete a case study of implementing a near-zero emission hydrogen energy system in one or more regions of the US
- Continued participation in the H2A delivery group.

Proposed for FY'06

- Work with NREL and DOE to integrate UC Davis infrastructure models with other H2 models, to answer specific questions related to the development of H2 infrastructure development.
- The goal is to make the best use of existing modeling tools to understand which factors are most important in finding viable transition strategies under different regional conditions.
- Develop "rules of thumb", as a means to more efficiently study infrastructure development in succeeding years.

Publications and Presentations (1)

J. Ogden, "Roles for Hydrogen in a Future Sustainable Transportation System," presented at the Transportation Research Board Integrating Sustainability Meeting, Baltimore, MD, July 12, 2004.

J. Ogden, "Hydrogen Delivery Analysis for the H2A Project," invited talk to the USDOE FreedomCar Technical Team, July 27, 2004.

J. Ogden, Research at UC Davis on Design and Analysis of Hydrogen Distribution Infrastructure," presented to the USDOE FreedomCar Fuel Pathways Technical Team, October 14, 2004.

J. Ogden, "Hydrogen Research at UC Davis," Presentation at Lawrence Livermore National Lab, October 21, 2005

J. Ogden, "The Outlook for Hydrogen as an Energy Carrier," presented at the Annual Meeting og the American Society of Mechanical Engineers, November 15, Anaheim, CA

J. Ogden, "Hydrogen Supply: Pathways and Strategies," presented to the United States Congress, Hydrogen and Fuel Cell Caucus, Washington, DC, January 11, 2005.

. J. Ogden, C. Yang, N. Johnson, J. Ni., Z. Lin, "Technical And Economic Assessment Of Transition Strategies Toward Widespread Use Of Hydrogen As An Energy Carrier," Draft Final Report to the United States Department of Energy Hydrogen, Fuel Cells and Infrastructure Technologies Program For Phase I of NREL contract number XCM-4-44000-01, January 31, 2005

Publications and Presentations (2)

J. Ogden, "Hydrogen as an Energy Carrier," Presented to the Humphrey Scholars Program, University of California, Davis, Feb. 2, 2005.

J. Ogden, "Overview of Hydrogen System Modeling at ITS-Davis", Presentation at Sandia National Laboratory Feb. 18, 2005.

J. J. Ogden, "Infrastructure Development for the Hydrogen Economy," presented at the PowerGen Conference, Las Vegas, NV, March 3, 2005.

J. Ogden,"Pathways to a H2 Economy: Early Results from the Hydrogen Pathways Program," Department of Environmental Science and Policy, Faculty Seminar, University of California, Davis, March 16, 2005.

J. Ogden, "H2 as an Energy Carrier: Pathways and Strategies," presented at the California Biomass Collaborative Forum, Sacramento, CA, March 1, 2005

Christopher Yang and Joan Ogden, "Analyzing Natural Gas Based Hydrogen Infrastructure – Optimizing Transitions From Distributed To Centralized H_2 Production," Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

Jason Ni, Nils Johnson, Joan Ogden, Christopher Yang, and Joshua Johnson, "Estimating Hydrogen Demand Distribution Using Geographic Information Systems (GIS)," Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

N. Johnson, C. Yang J. Ni, J. Johnson, Z. Lin, and J. Ogden, "Design of a Fossil Fuel-Based Hydrogen Infrastructure with Carbon Capture and Sequestration: Case Study in Ohio", Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

M. Mintz, Jerry Gillette, James Burke, John Molburg, and Joan Ogden**, "**Development Of Hydrogen Delivery Scenarios For Transportation Applications, " presented at the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

J. Ogden, "Prospects for Hydrogen in California," presented at the Workshop on Energy and Sustainable Growth in California: New Horizons for Innovation and Adoption sponsored by the Center for Sustainable Resource Development and the Giannini Foundation, April 22, 2005, Berkeley, CA.

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Inadequate attention to safety as an inherent part of H2 system design, when creating computer model descriptions of real systems.

We address this by including only model components and designs that fully incorporate safety, and by "reality checks" from industry reviewers.