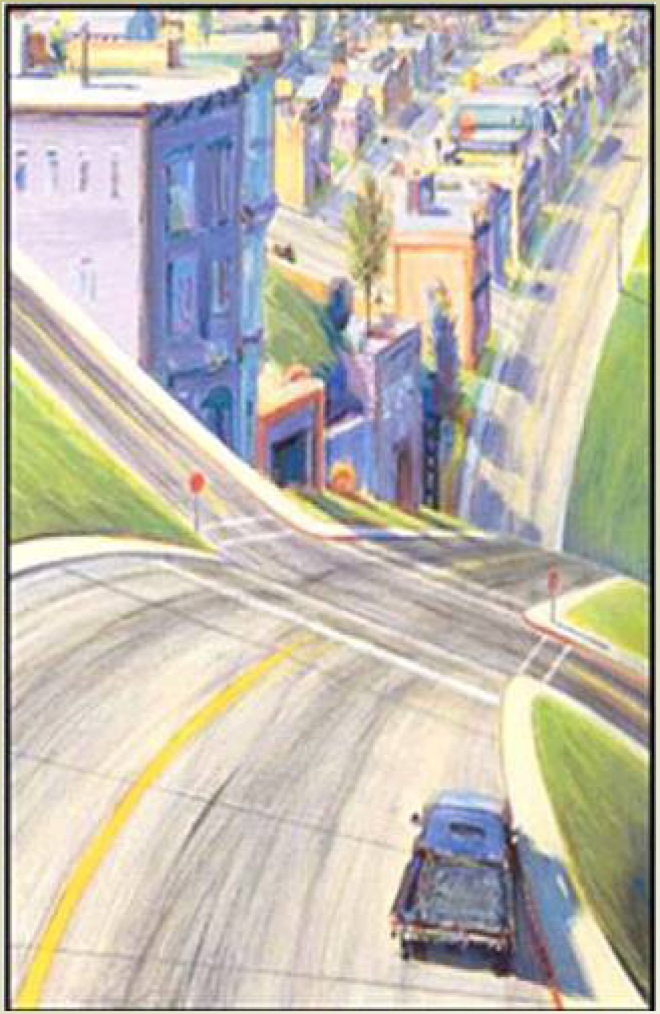
GIS modeling of future energy systems: Research at the UC Davis H2 Pathways Program

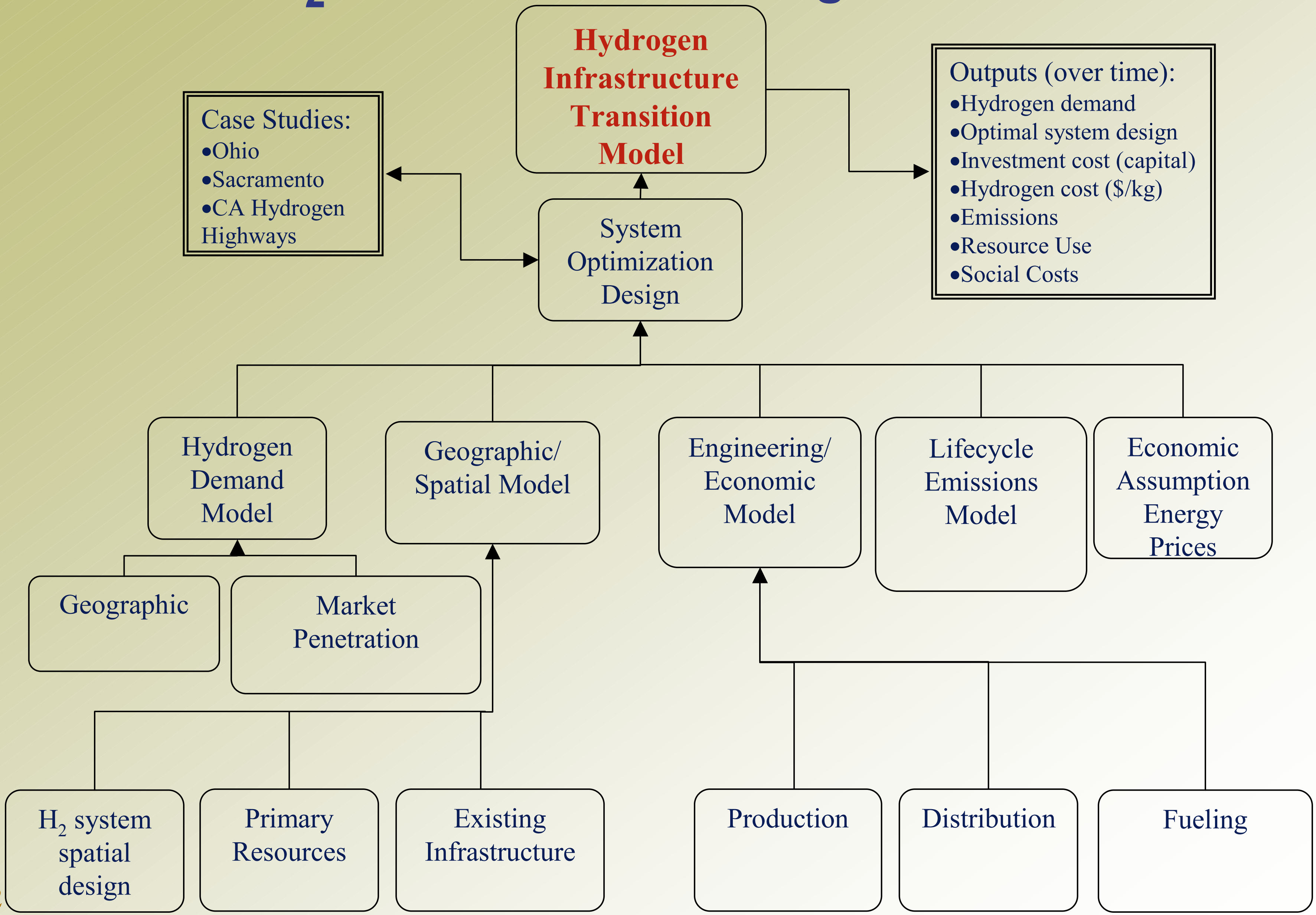


Nils Johnson

Hydrogen Pathways Program
Institute of Transportation Studies
UC Davis

Prepared for:
Geospatial Statistics and Issues in Energy Modeling Workshop
May 10, 2005

ITS-Davis H_2 Infrastructure Integrated Models



GIS modeling applied at multiple spatial scales

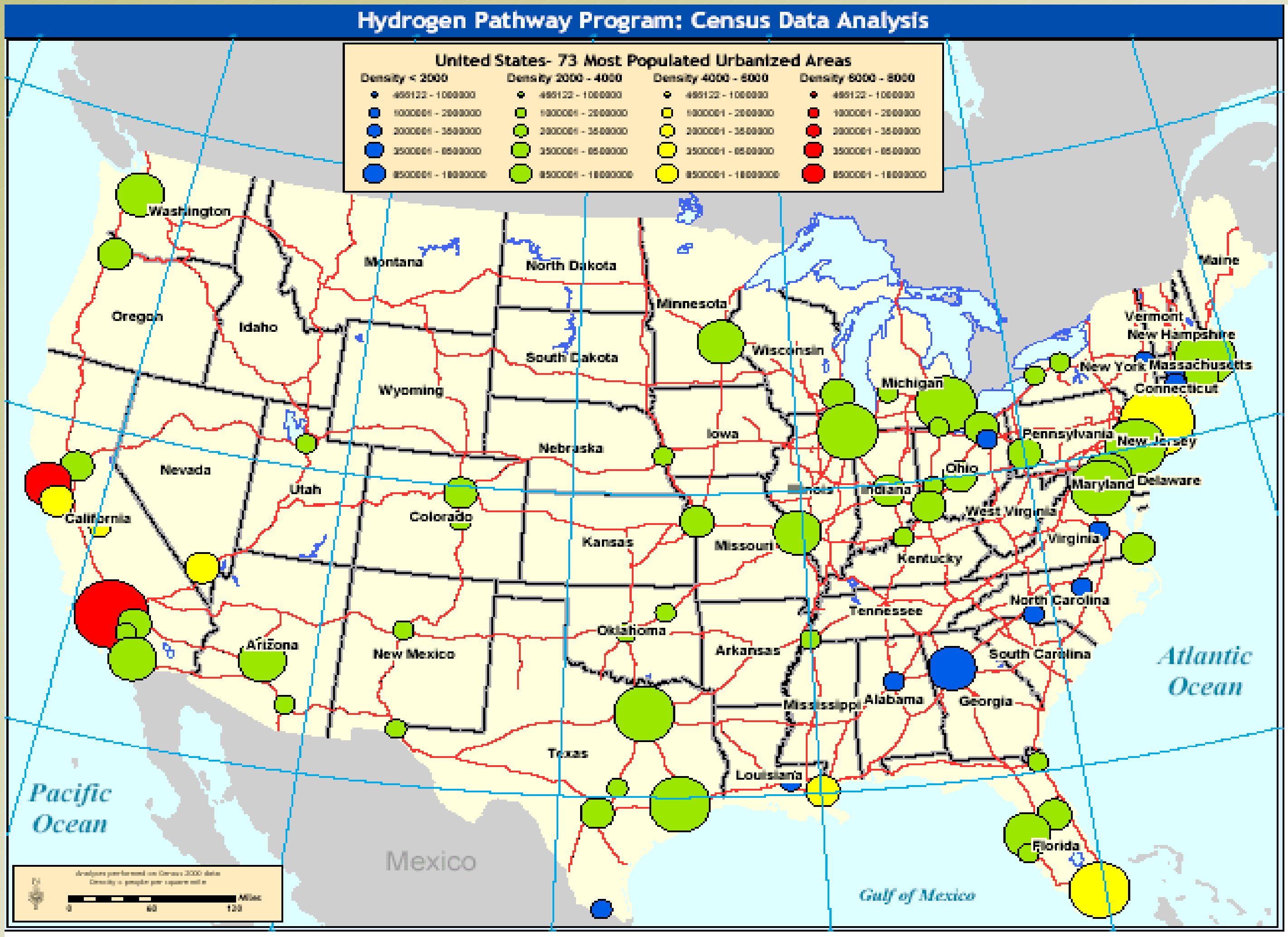
1) National study of variability in regional H2 costs

2) Regional study examining optimization of hydrogen infrastructure for Ohio

3) Regional study examining station siting for CA Hydrogen Highway Network

4) City-level study to optimize station siting based on consumer travel time (Sacramento and Los Angeles)

Assessing Variability in Regional H_2 Costs



Part II: GIS Regional Case Study: Coal-Based H_2 Infrastructure for Ohio w/ CO_2 Capture and Sequestration

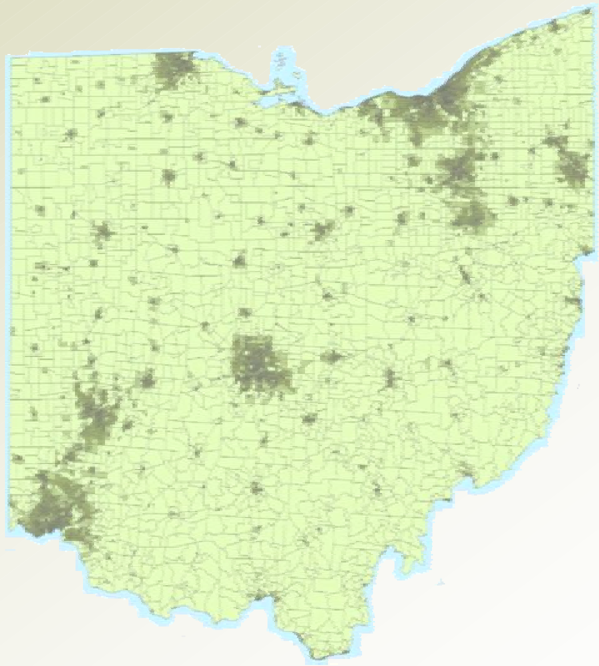
1) Conduct a regional case study of a potential coal-based hydrogen economy in Ohio with CO_2 sequestration

2) Develop GIS-based tools to optimize H_2 infrastructure based on regional characteristics and demand

3) Combine spatial tools and geographic data with engineering and economic models from Transitional Hydrogen Infrastructure Modeling (THIM) project at UC Davis

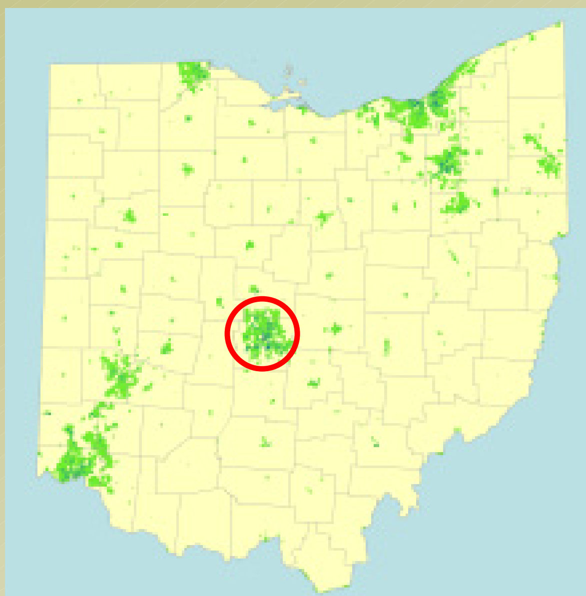
4) Develop methods that can be used anywhere in U.S.

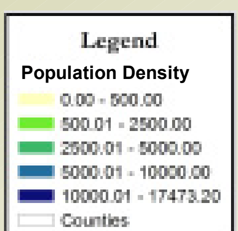
5) Increase understanding of economics and design issues under real-world constraints



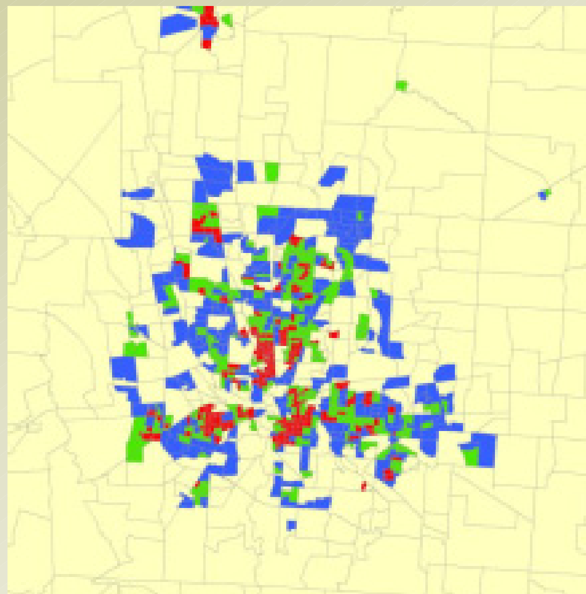
Hydrogen Demand Modeling
(10% Market Penetration)

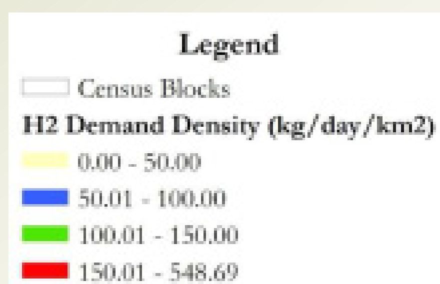
Population Density – US Census (people/km^2)



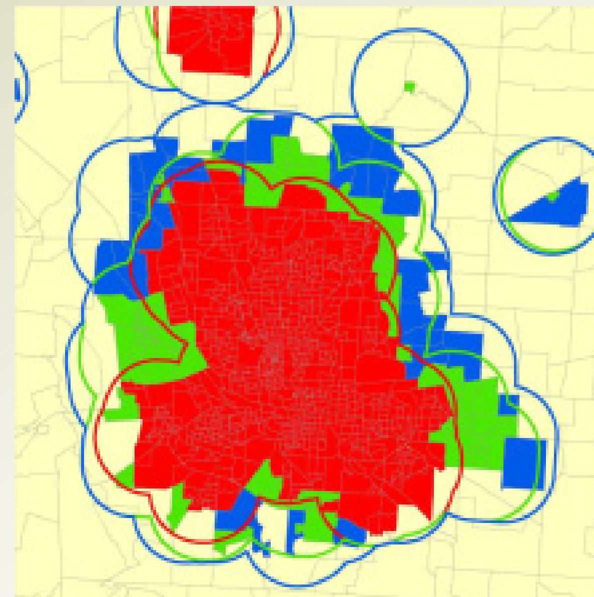


Estimate H_2 Demand Density





Identify Demand Clusters



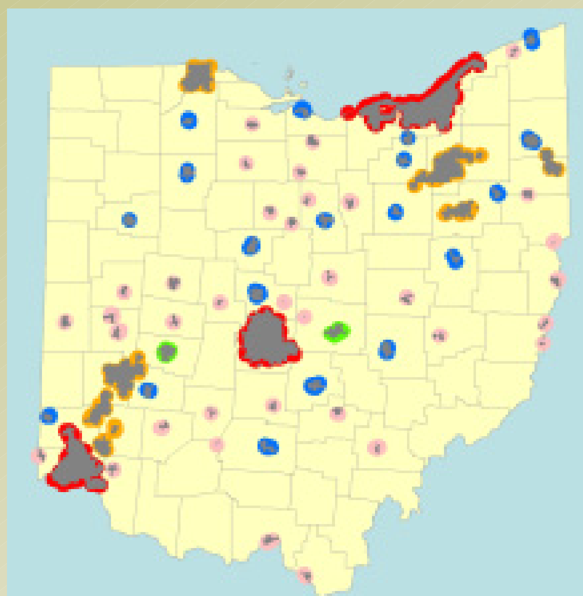
Assumptions:

- Per Capita Vehicle Ownership: 0.7 vehicles/person
- Daily H2 Use/Vehicle: 0.6 kg/day

Hydrogen Demand Modeling (Cont.)

(10% Market Penetration)

Aggregate H_2 Demand



Legend

Counties

Demand Clusters

Aggregate H_2 Demand (kg/day)

85.2500 - 1000.0000

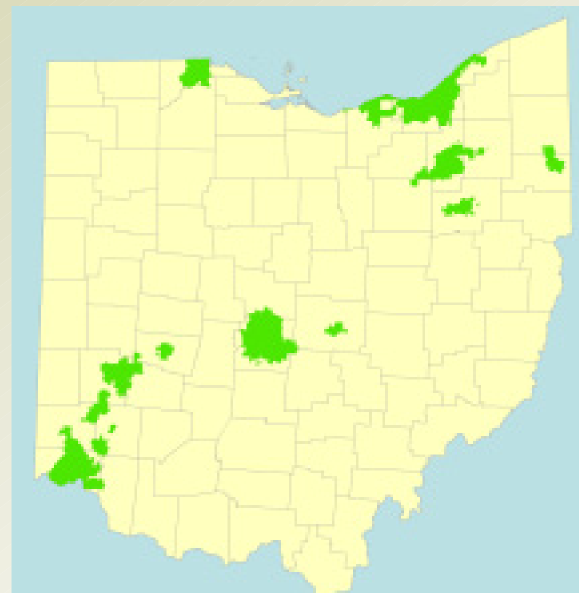
1000.0001 - 3000.0000

3000.0001 - 5000.0000

5000.0001 - 30000.0000

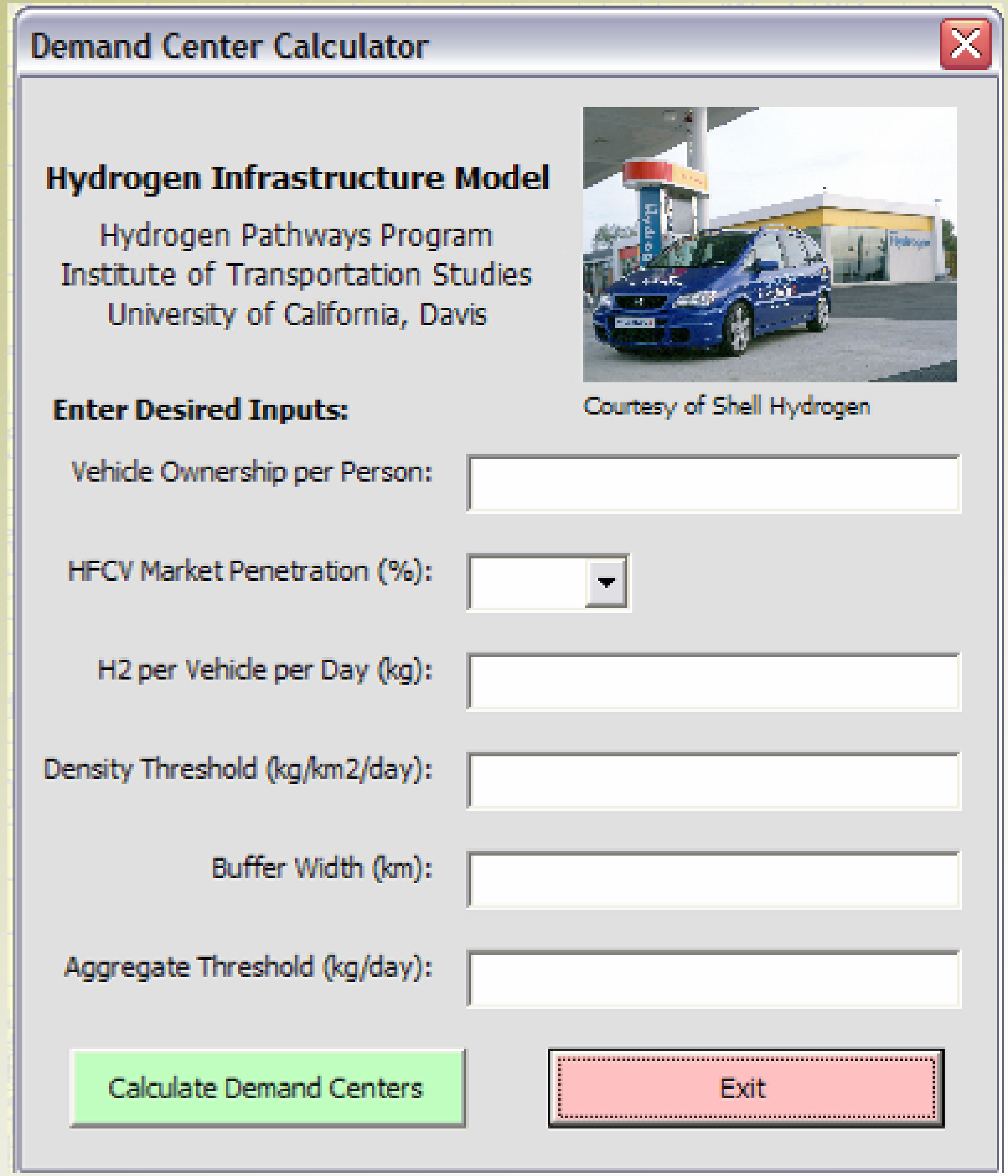
30000.0001 - 63235.4300

Select Demand Centers

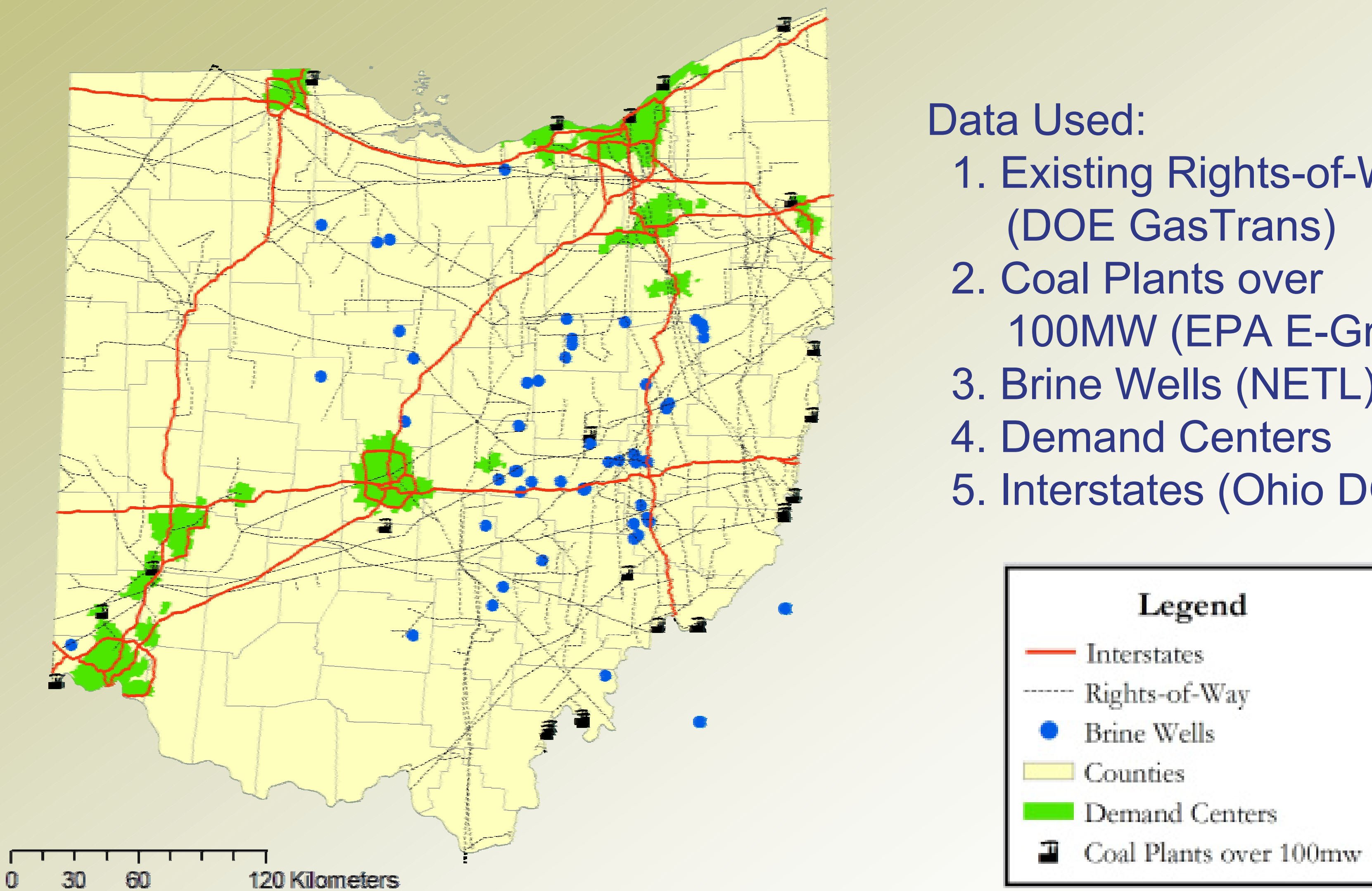


- Demand captured in demand centers ~ 250 t H_2/day
- 48% in 12 demand clusters (5% of land area)

H_2 demand model can be applied to <u>ANY</u> region with GIS census data



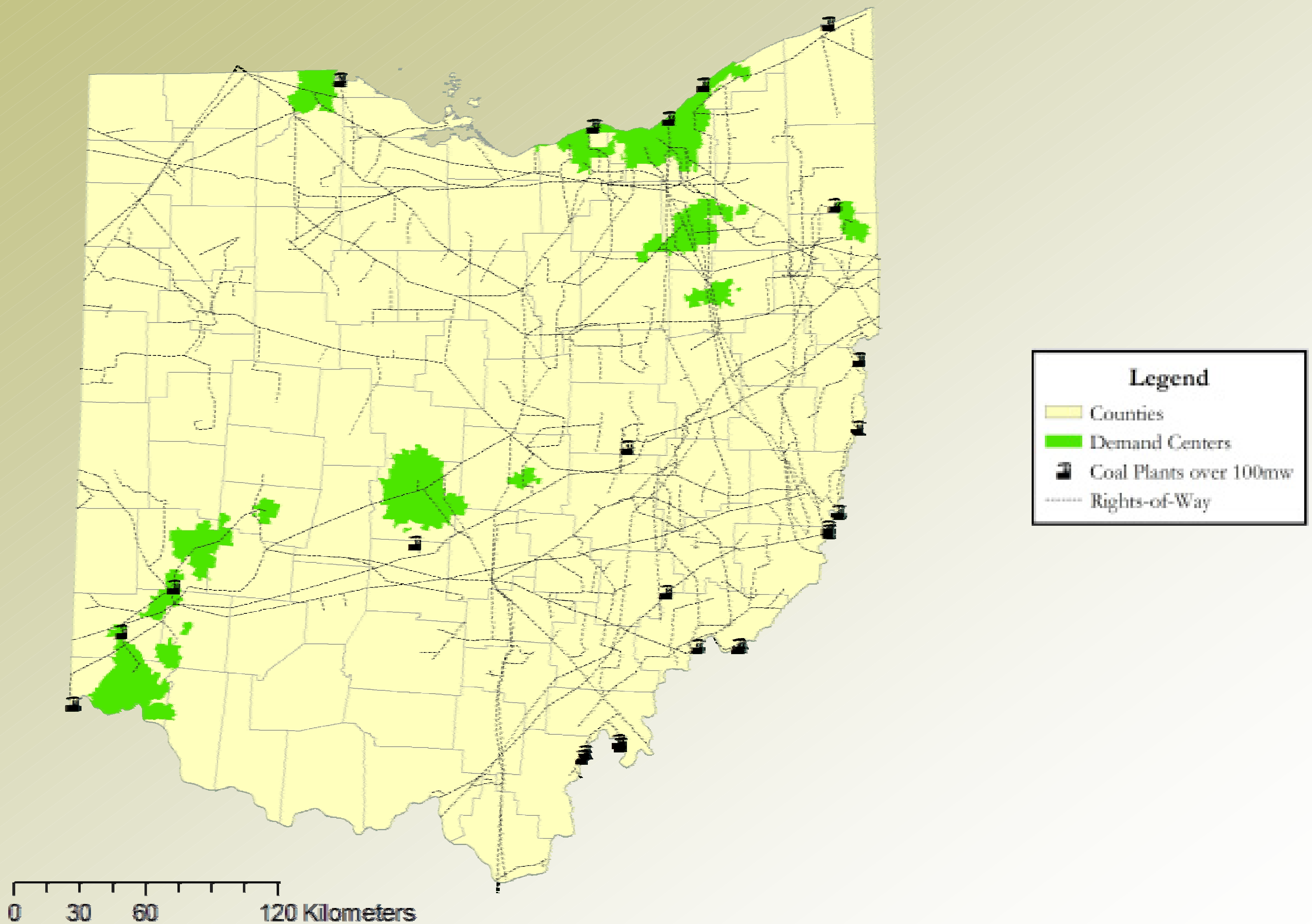
GIS Database



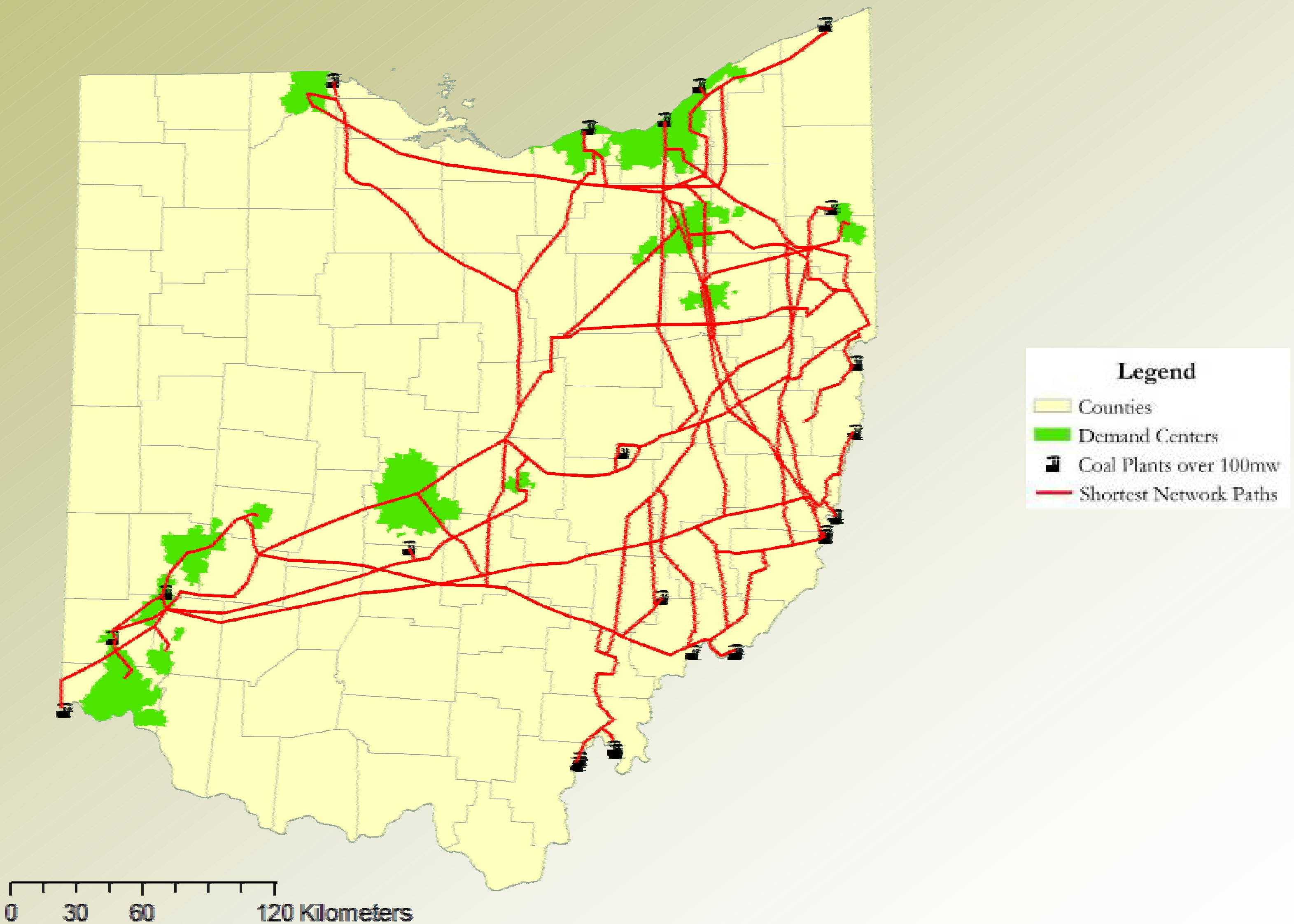
Data Used:

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)

Potential Distribution and Production Infrastructure
(all coal plants and demand centers)

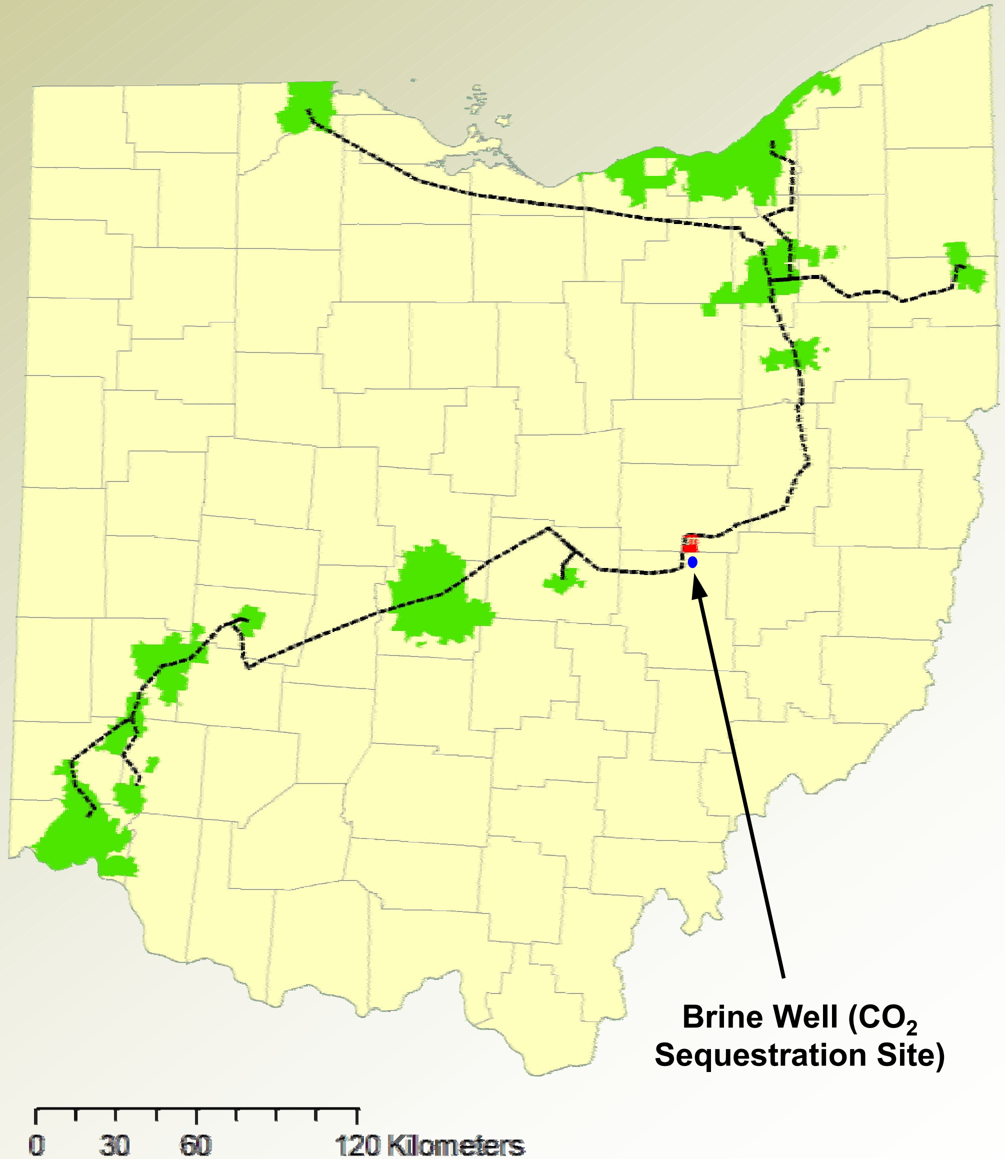


Potential Production & Distribution Network
(coal plants, demand centers, and shortest path ROWs)



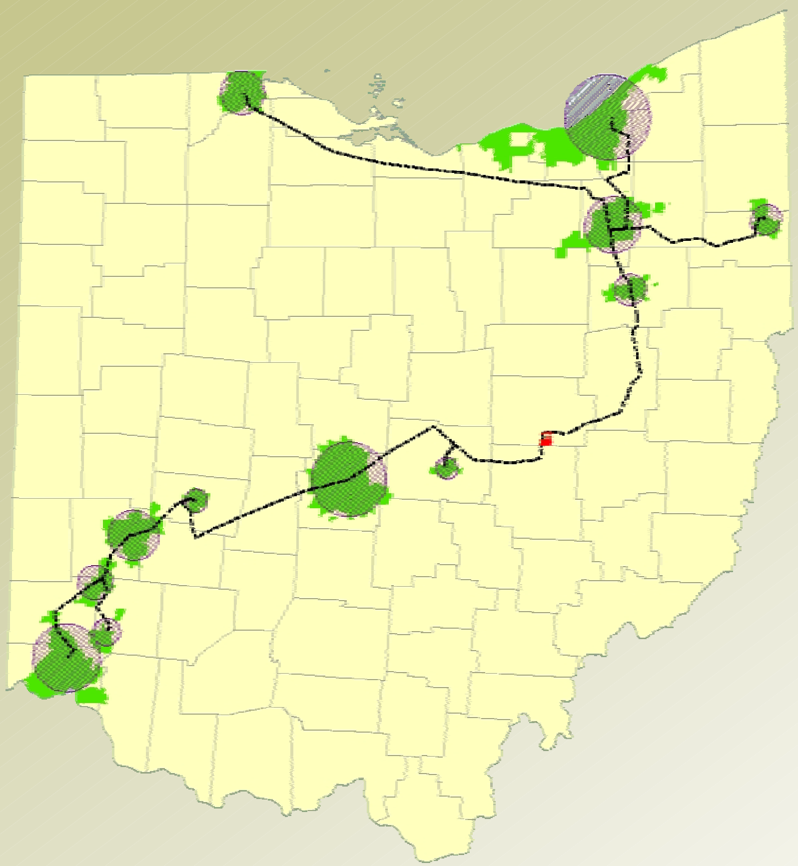
Optimal network – 10% market penetration

- 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

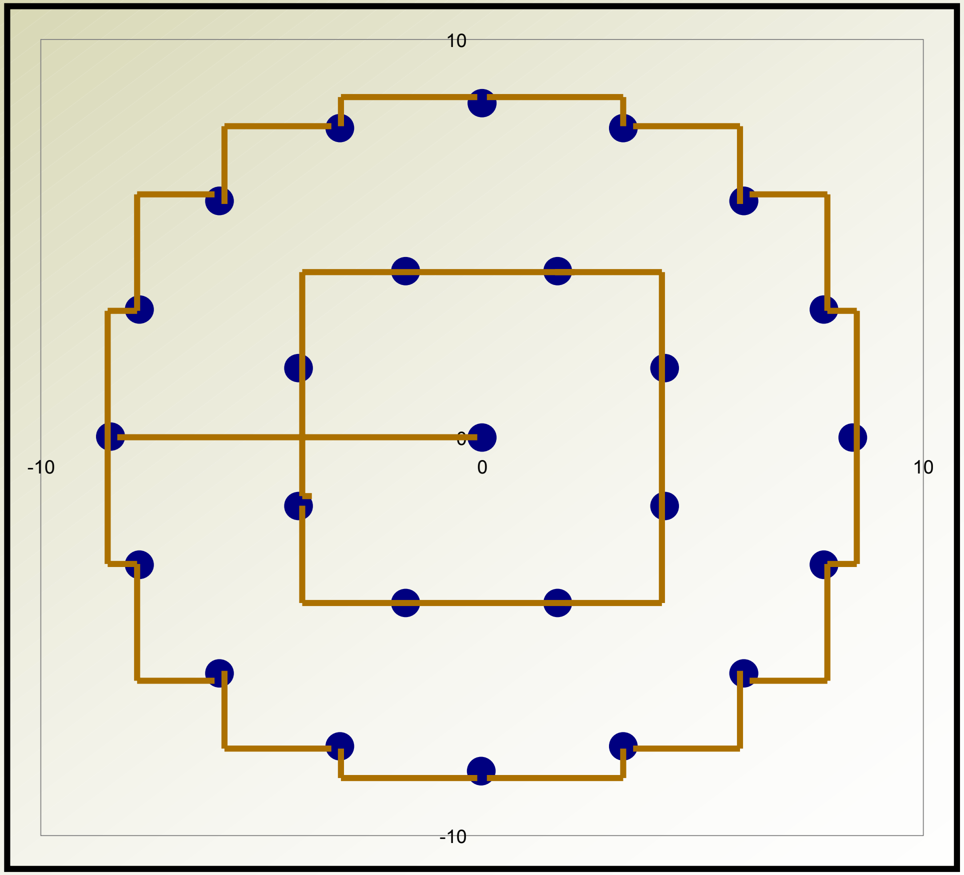


Intracity Distribution and Station Siting
"Idealized City" Model

Equivalent Circles



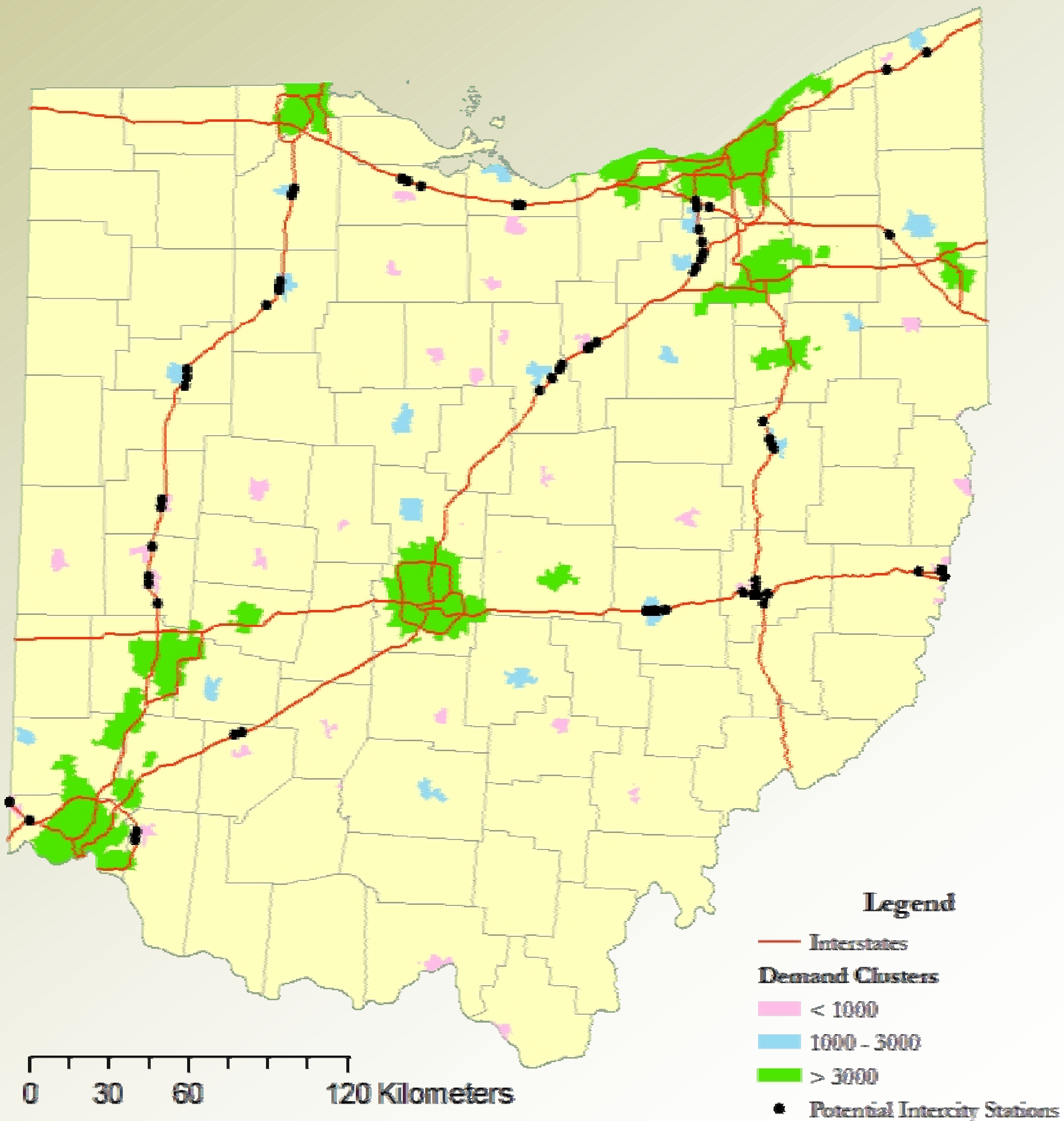
Pipeline Design



Intercity Station Siting

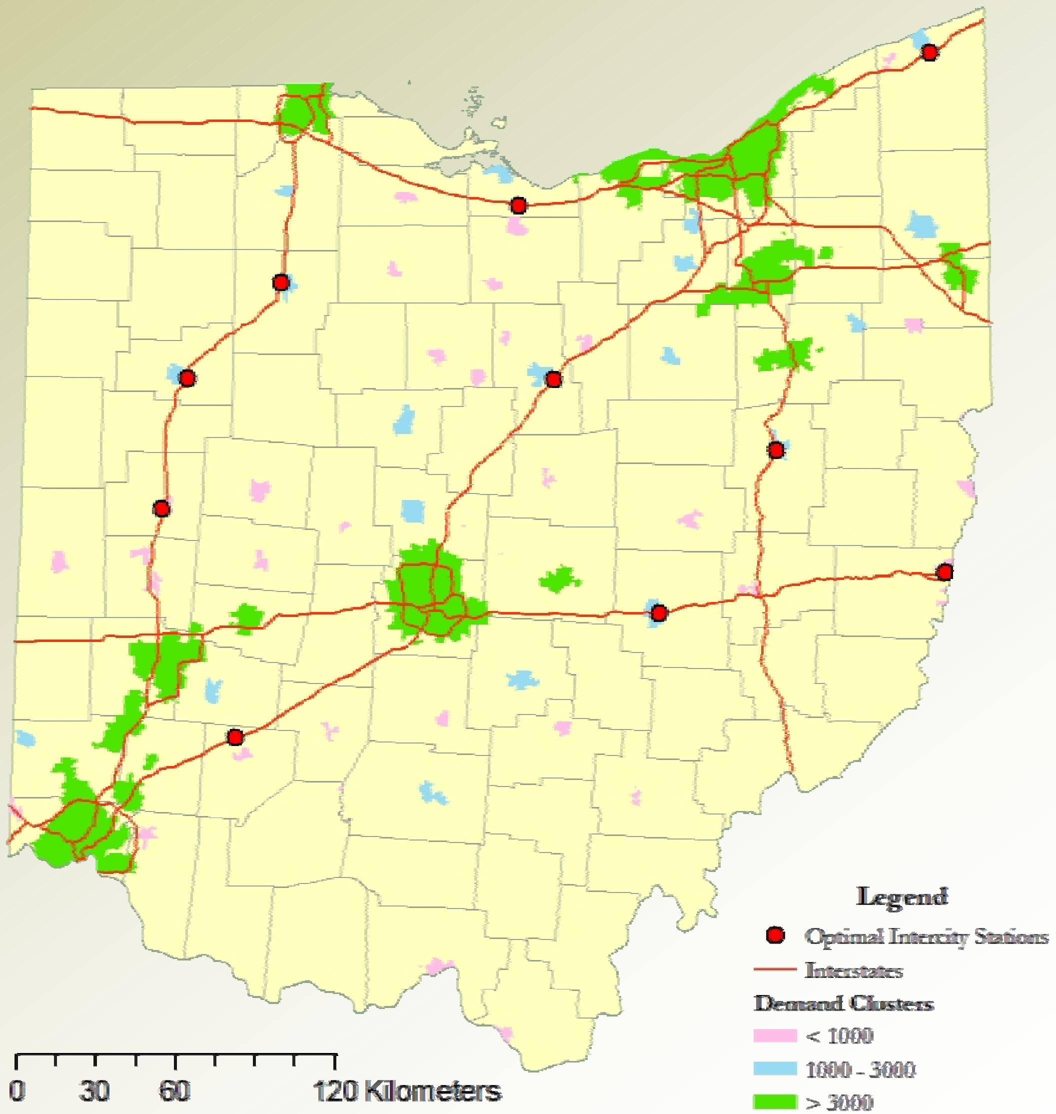
Intended to allow travel between demand centers

- **Potential stations**
  - Intersections along interstates
  - Within 5 km of intercity demand clusters
- **Calculated for each station**
  - Average daily traffic flow
  - Distance to nearest demand cluster
  - Distance from both corridor endpoints
  - Hydrogen demand at nearest demand cluster



Optimal Intercity Stations

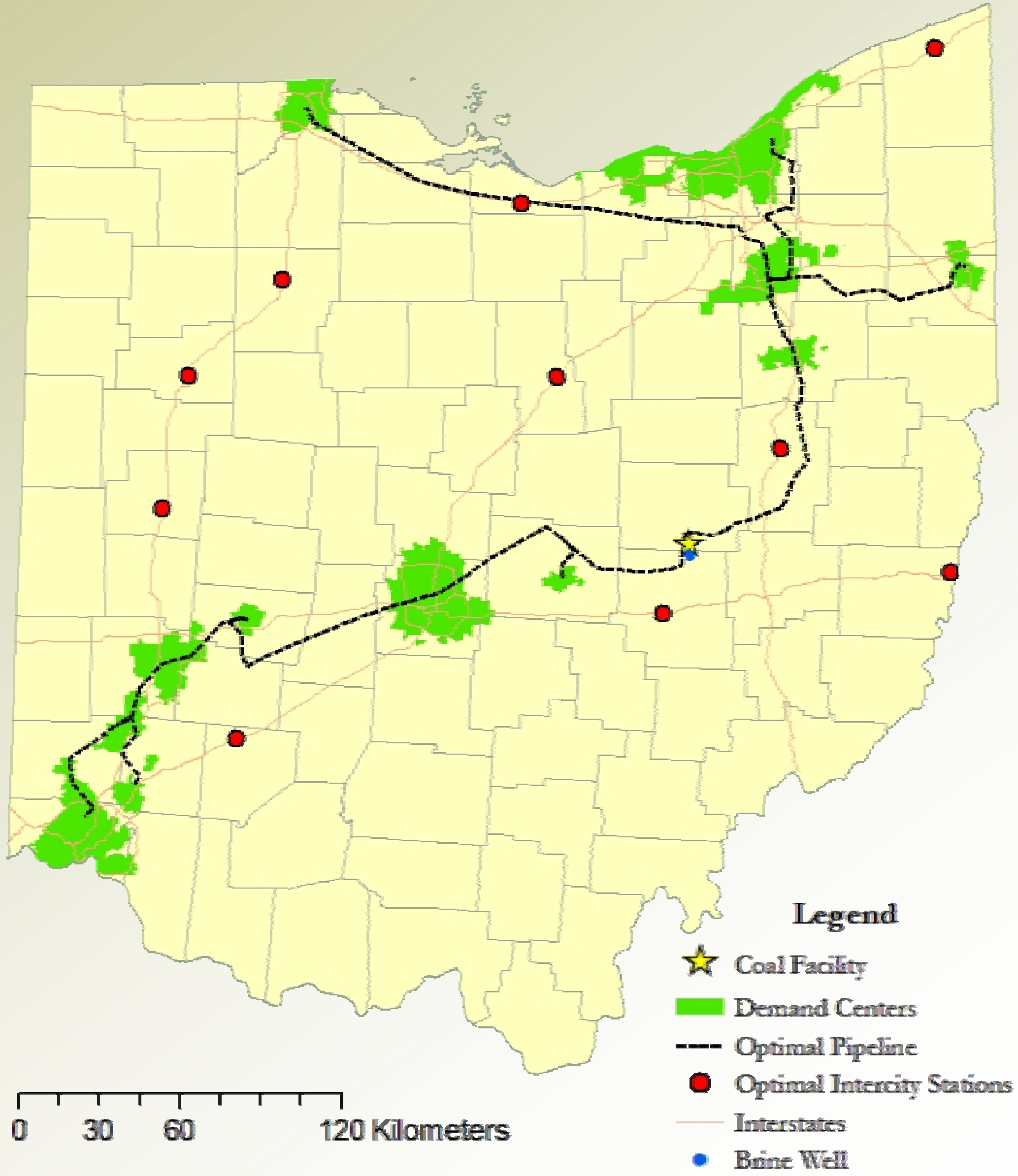
- **Selection criteria**
  - Maximize average daily traffic flow at station sites
  - Locate close to large demand clusters
  - Place greater than 30 km from corridor endpoints (large cities)
- **Results**
  - 10 Stations (onsite H_2 production)
  - Max stretch without a H_2 station: ~60 miles
  - Additional demand of ~ 20 tons H_2/day



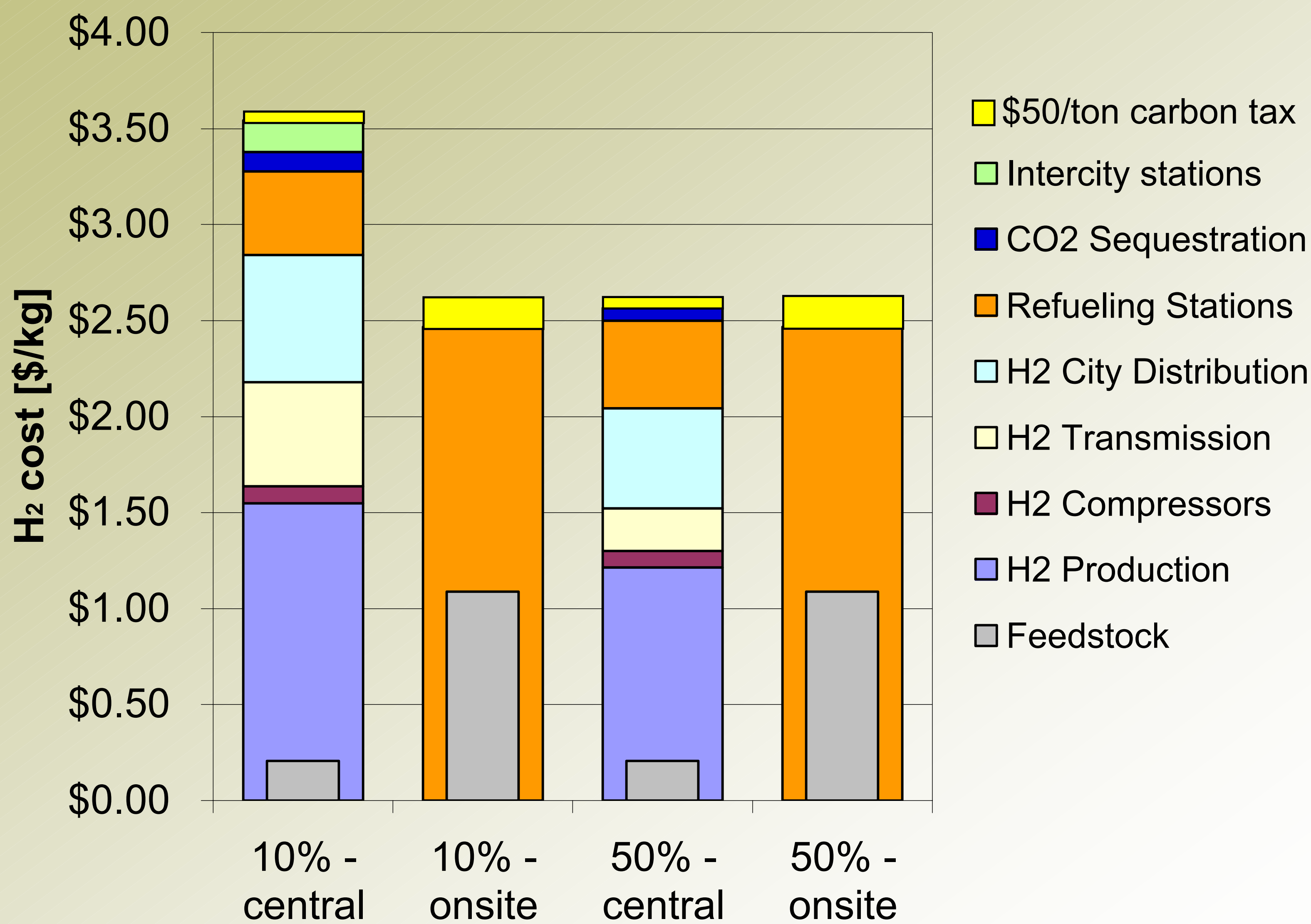
Results – 10% market penetration

Capital Cost ($ Millions)

- 1 coal plant producing 253 tons H_2/day ($381)
- 936 km of intercity pipeline ($358)
- 12 demand centers serving 48% of the population (~420,000 vehicles)
  - 1,344 km of local distribution pipelines ($439)
  - 147 refueling stations, each dispensing ~1,800 kg/day ($164)
- 10 intercity stations, each dispensing ~ 2,000 kg/day ($37)
- 1 CO_2 sequestration site: 4,500 tons CO_2/day ($55 w/compressor)
- Total capital cost: $1.4B or $3,400/vehicle
- Delivered H_2 cost: ~$3.54/kg



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



Future directions

Alternative Scenarios

- Apply model to other regions
- Examine a mix of feedstocks and multiple production facilities
- Evaluate a mix of centralized and distributed production

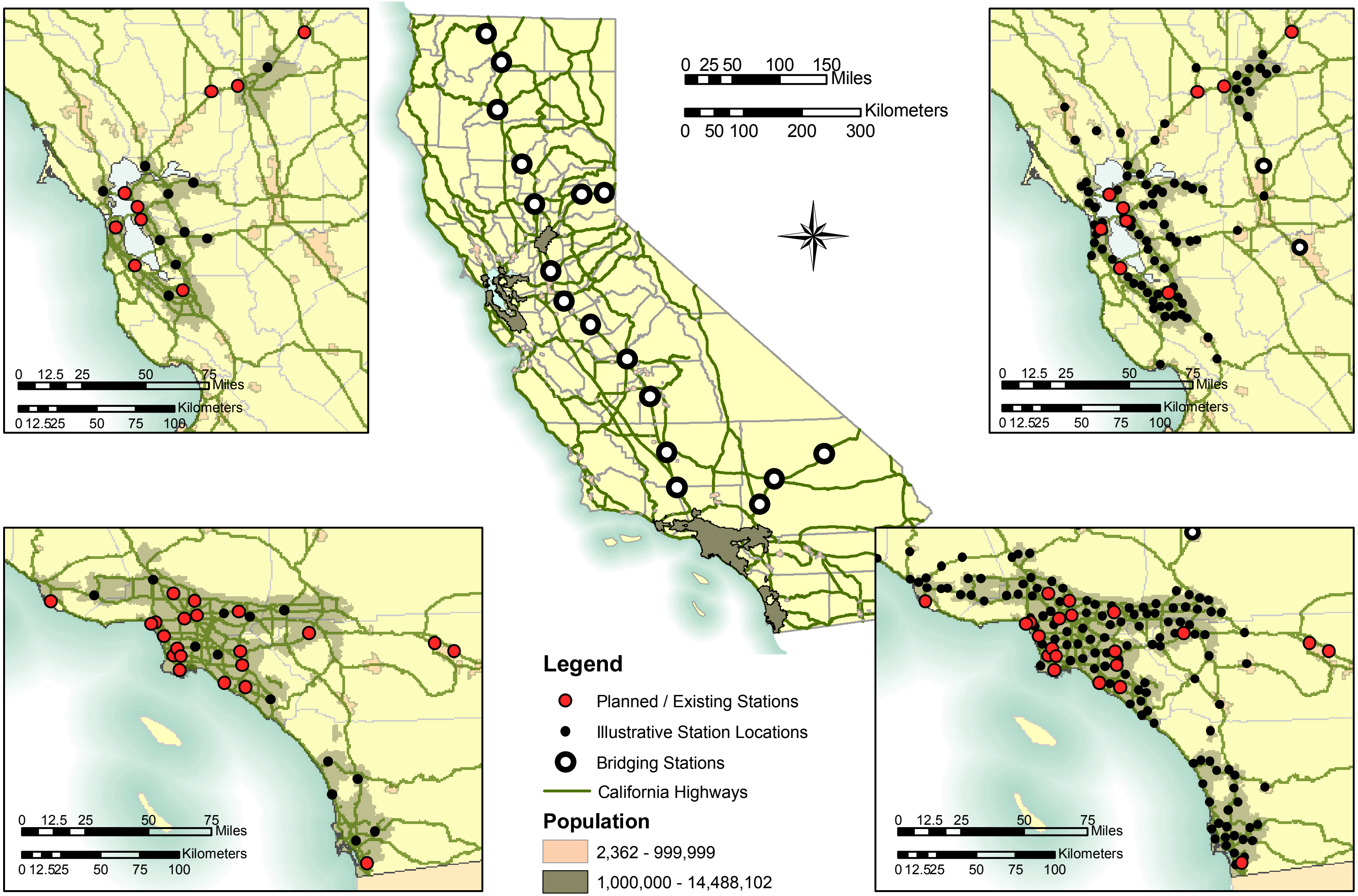
Improve Distribution Models

- Refine pipeline costs based on terrain and land use
- Compare pipeline and truck distribution
- Improve models of intracity distribution and refueling station siting

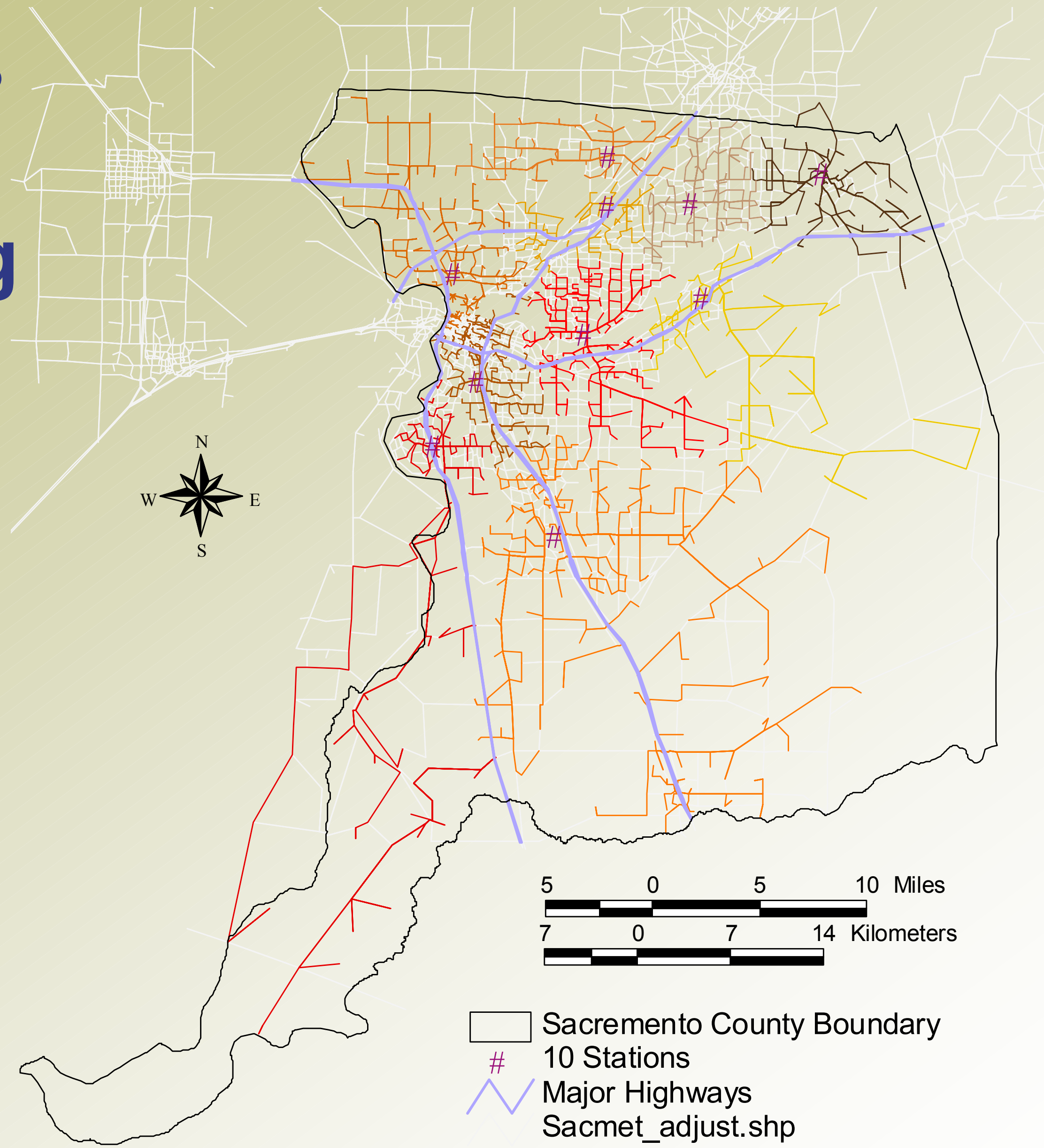
Tool Development

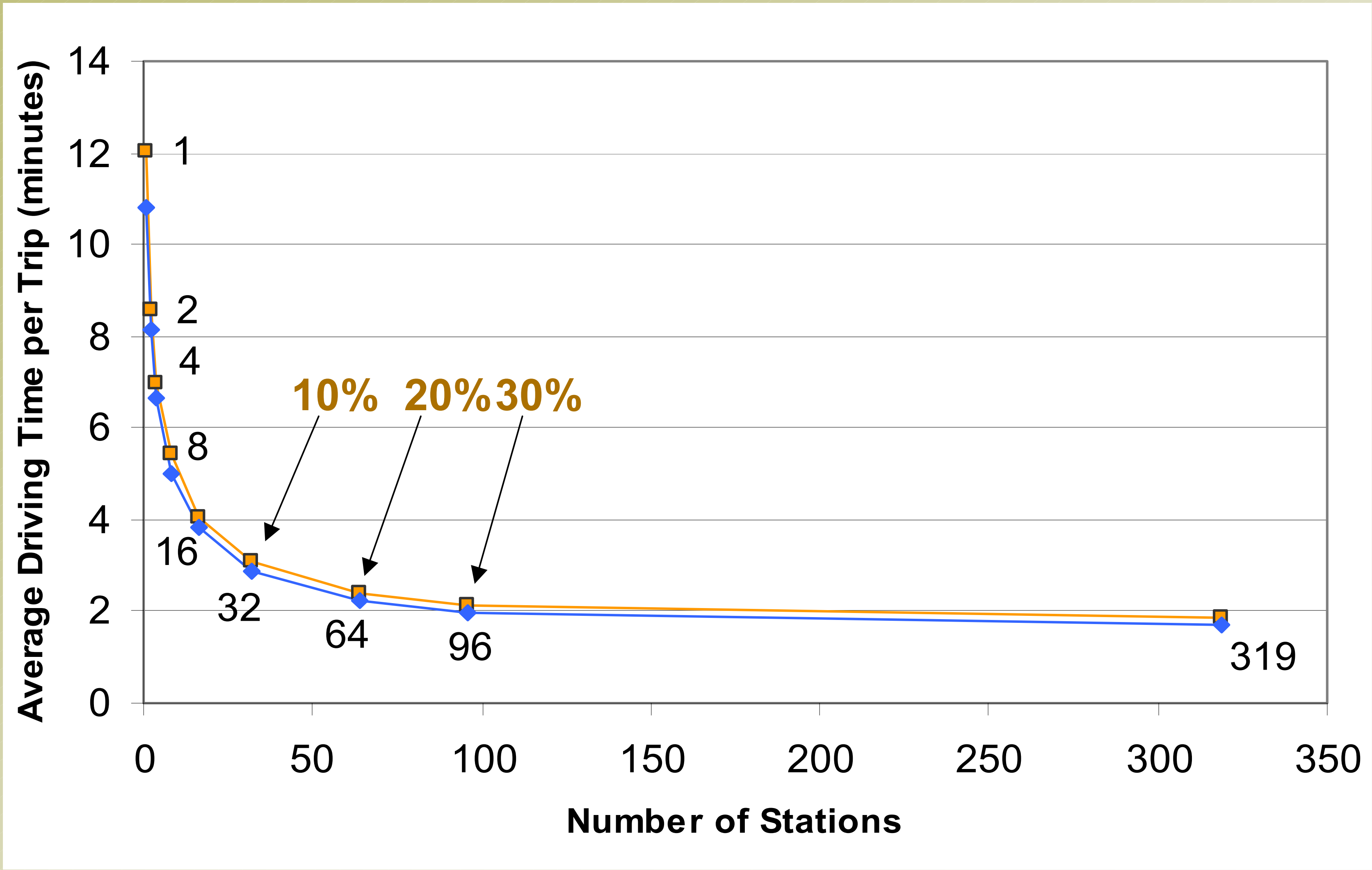
- Refine demand modeling tool based on other demographic data
- Develop more sophisticated and integrated optimization methodology
- Develop flexible computer user interface for model

CA Hydrogen Highway Network



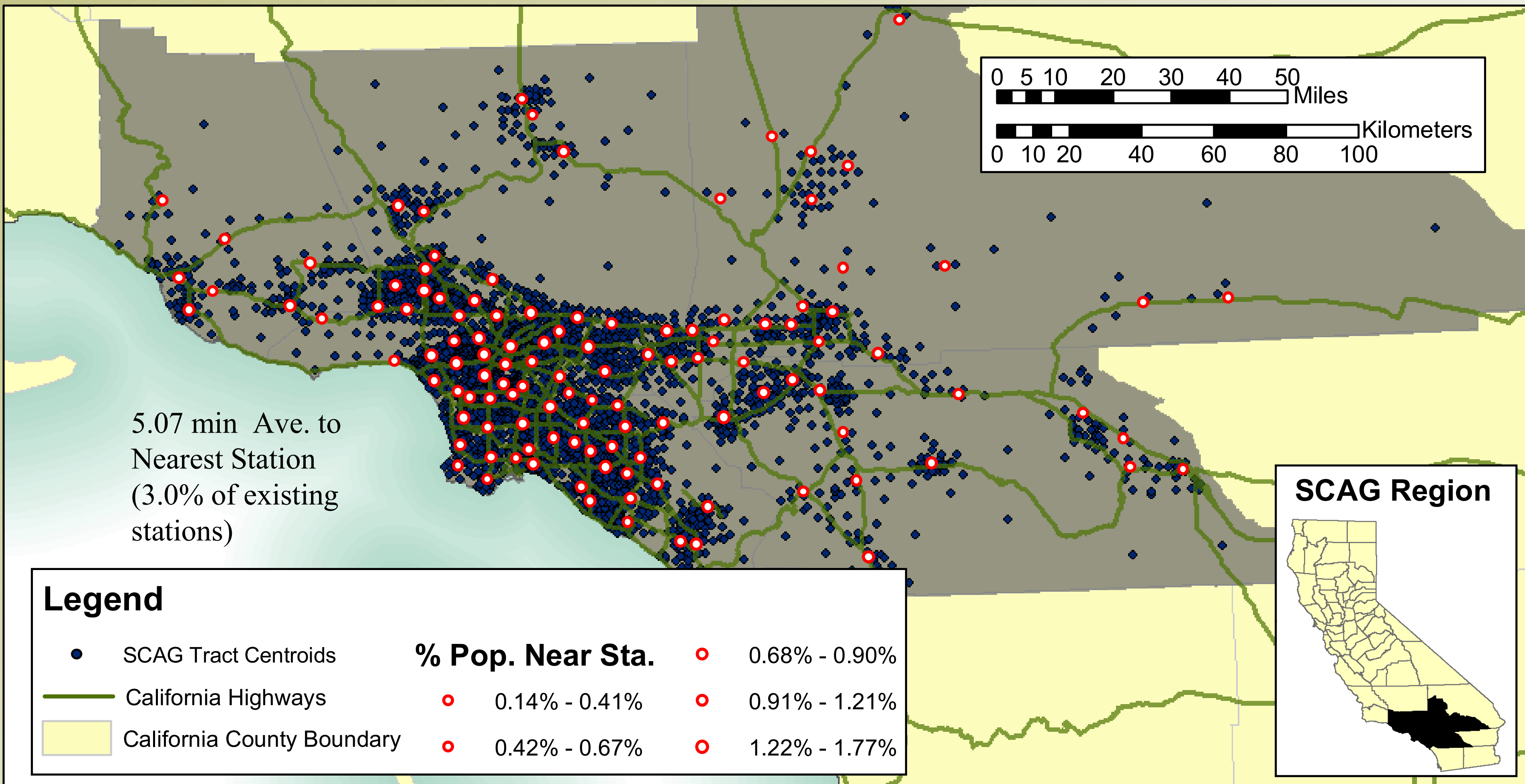
GIS Analysis of Refueling Station Siting and Deployment Strategies



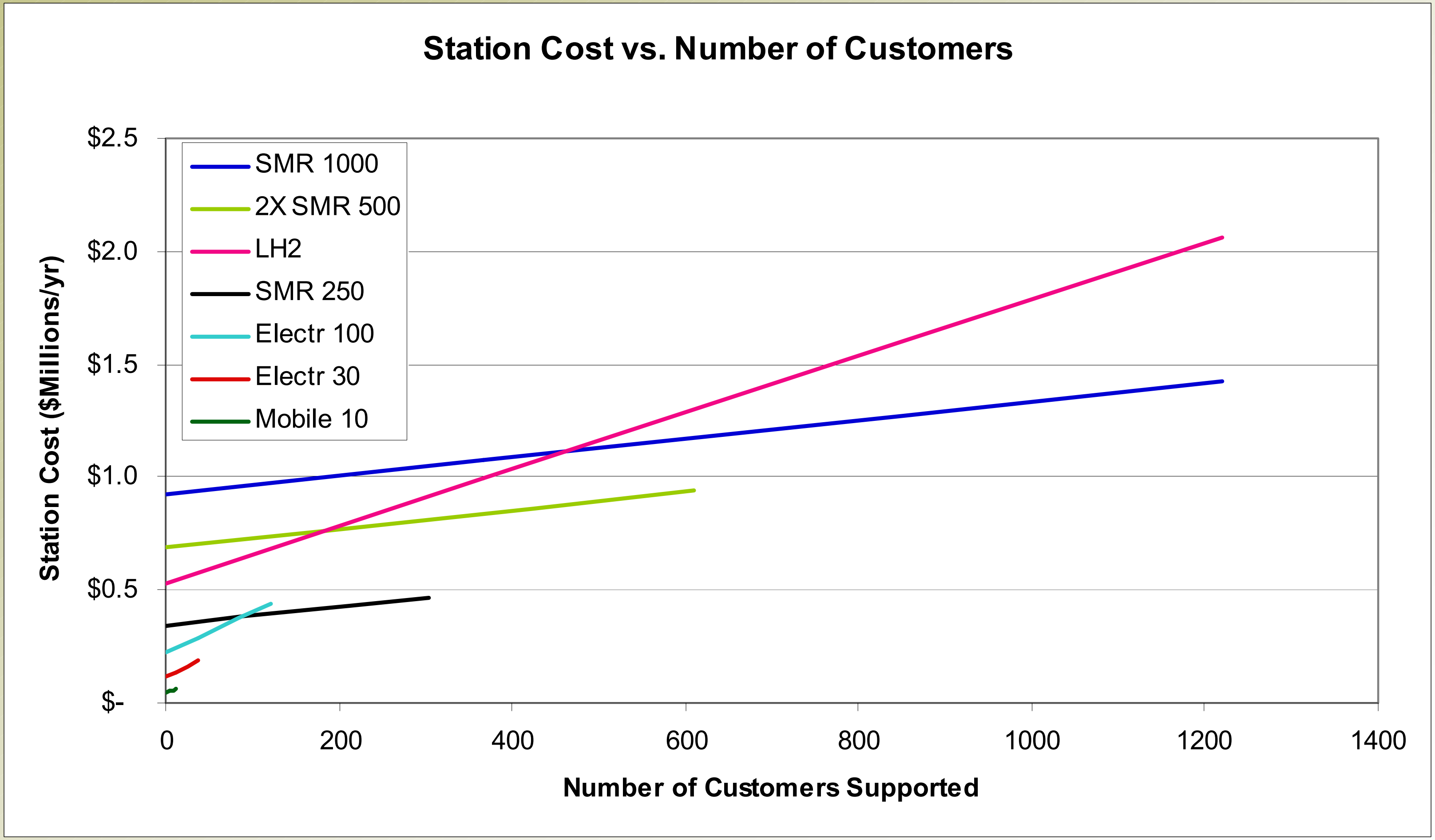


Relationship Between Number of Stations and Average Travel Time – H2 offered at 10-30% of existing gasoline stations might provide adequate convenience

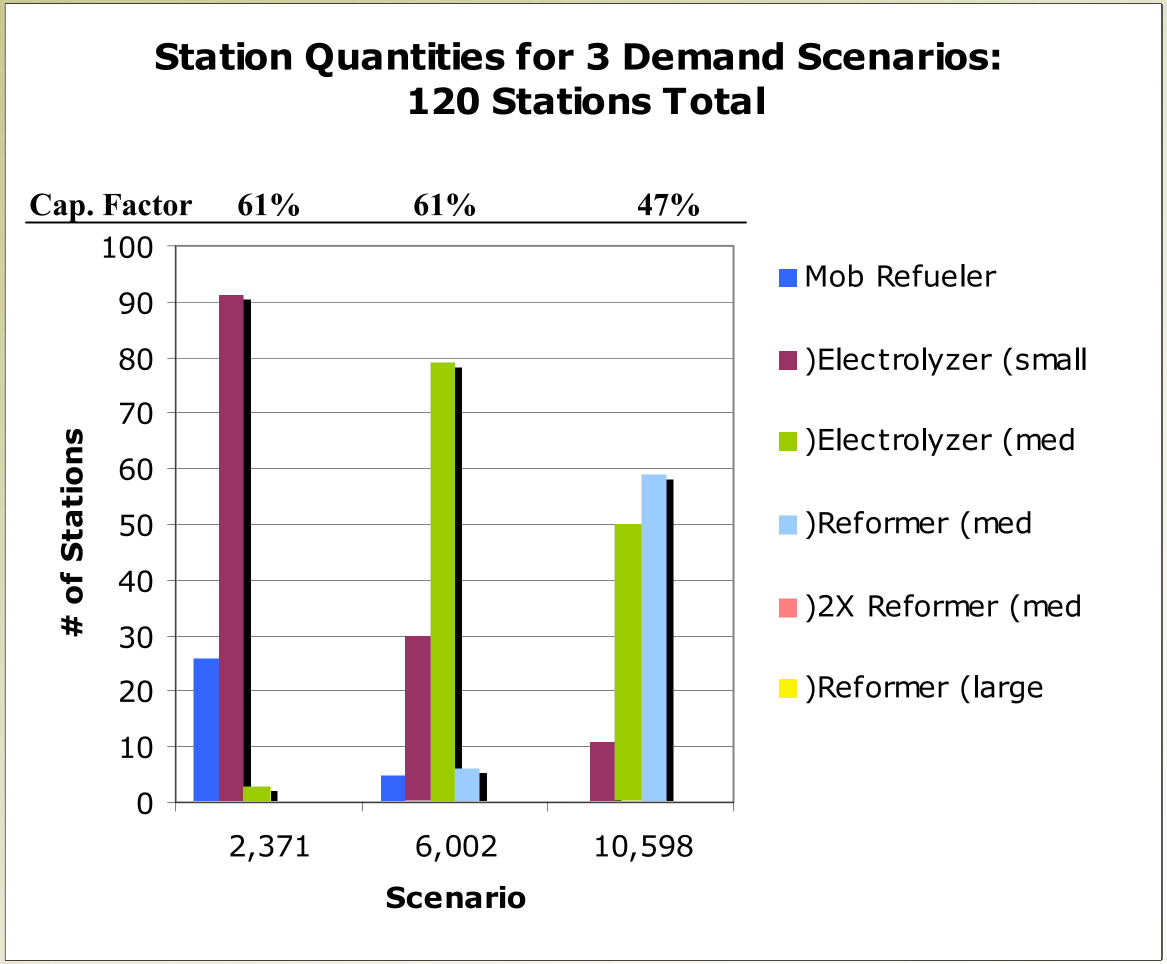
Incorporating Station Size, Type, and Cost into Station Siting Analysis (120 Stations)



Choose Station Size & Type based on Demand



Station Size and Type for 3 Scenarios



Conclusions

- Cost per customer per year:
  - 20 stations: $1800 - $3600
  - 60 stations: $2800 - $6500
  - 120 stations: $4500 - $7500
- Trade-off: Fewer, bigger stations results in a lower cost per kg of hydrogen, but increases average travel time for customers.
- Developed method for linking population distribution to station size and location.

H2 System Modeling: Results and Future Work (1)

- **GIS analysis of hydrogen station siting**
  - Adequate convenience with about 10-30% current gasoline sites
  - A model has been developed that estimates station siting based on data about travel time and city structure
  - Station size, type, and cost has been added to the analysis
  - Future: Comparative analysis of different regions in CA using a constant dataset; examining more station options
- **Developed simplified EXCEL model of entire H2 system including production, storage, distribution and refueling.**
  - Developed method to find H2 costs v. market penetration, city size and population density.
  - Idealized models of cities and hydrogen distribution system
  - Future: Improve performance and cost estimates of H2 components; Sensitivity studies

H2 System Modeling: Results and Future Work (2)

- **GIS methods for studying regional H2 infrastructure development**
  - Developed preliminary GIS data base for state of Ohio
  - Developed methods for estimating H2 demand spatially (method can be readily applied elsewhere)
  - Found lowest cost H2 distribution network for steady-state demand and simple infrastructure scenario
  - Future: Developing methods to include time dependence to model transitions
  - Future: Developing optimization techniques for looking at more complex infrastructure scenarios (e.g., mixed pathways)
- **Studies of Interaction between hydrogen and electricity system**

Thank You

Scenarios Considered

- Four scenarios have been considered at this time

	Feedstock	Market Penetration	Distribution	CO_2 Sequestration
Centralized	Coal	10%	Pipeline	Yes
	Coal	50%	Pipeline	Yes
Onsite	Natural Gas	10%	N/A	No
	Natural Gas	50%	N/A	No