Analysis of the Hydrogen Production and Delivery Infrastructure as a Complex Adaptive System

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Project ID # AN3

Overview

Timeline

- Project start date: July 2005
- Project end date: Dec 2008
- Percent complete: 15%

Budget

- Total project funding
  $3,616,634
- FY05
  - $401,071 budgeted
  - $70,000 funded
- FY06
  - $1,225,830 budgeted
  - $600,000 funded
- FY07
  - $1,719,500
- FY08
  - $270,233

Barriers

- Barriers addressed
  - Lack of understanding of the transition of a hydrocarbon-based economy to a hydrogen-based economy
  - Lack of consistent data, assumptions and guidelines
  - Lack of prioritized list of analyses for appropriate and timely recommendation

Partners

- RCF, prime
- Argonne National Laboratory
- Air Products and Chemicals
- BP
- Ford Motor Co.
- University of Michigan
- World Resources Institute

Objectives

- Use agent-based modeling (ABM) to provide insights into likely infrastructure investment patterns
- Deal with chicken-or-egg aspect of early transition
- Provide answer to the question, “Will the private sector invest in hydrogen infrastructure?”

Approach

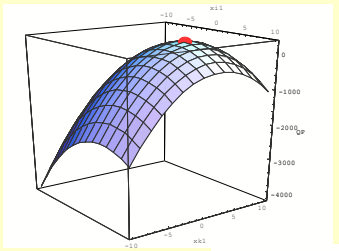
- Focus on investments as business decisions
- Develop basis for preliminary assessment of profitability
- Prepare ABM for detailed simulations

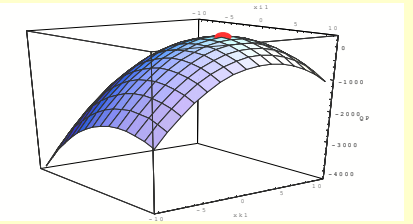
Agent-Based Modeling Is Used to Simulate Business/Investment Decisions

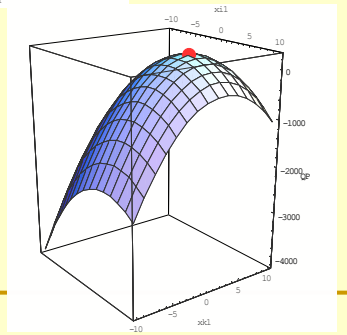
- An agent-based model consists of
  - A set of *agents*
  - A set of agent *relationships*
  - A *framework* for simulating agent behaviors or decision-making and interactions
- **AGENTS** are individuals with characteristics or attributes
  - Set of rules governing agent behavior or decision-making capability, protocols for communication
  - Respond to the environment and interact with other agents in the system
  - Identifiable, discrete units that can learn and adapt
  - Goal-directed, autonomous (self-directed, no central authority or controller exists)
  - Agents are heterogeneous with diverse characteristics
- ABMS simulates the behaviors and interactions of a large number of individuals (agents) and studies the macro-scale consequences of these interactions

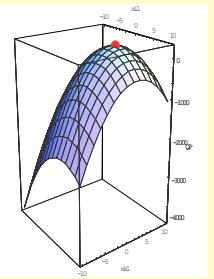
What are the Strengths of the H2-Agent-Based Approach?

- Most traditional H2 transition models assume
  - Single decision-maker with perfect foresight, often with 1 objective (least cost)
  - Energy markets in stable equilibrium
- The H2 agent approach addresses many key features of today's energy markets
  - Multiple stakeholders with *different* strategies, risk preferences, and (multiple) objectives
  - Each stakeholder *maximizes own objectives* and not social welfare
  - Objectives may be *conflicting*
  - Decisions are based on *imperfect* knowledge (uncertainty) and a mix of private and public information
  - Stakeholders *learn* and adapt to real or perceived changes in behavior of others or operating environment









Business Decision Framework

- Business Goals
- Business Profitability
- Expectations
- Decision Algorithm
- Sequential Moves

Technical Accomplishments/ Progress/Results

- Preliminary cost assessment for Los Angeles, California, U.S.
- Expansion path of distributed hydrogen production
- Proof of principle calculations for business decision model
  - risk aversion
  - Infrastructure investors require customers but customers require infrastructure (chicken-or-egg problem)
- Risk exposure of investors
- GIS map platform for ABM modeling of Los Angeles
- Lessons from previous technological innovations

Total 20-Year Business Cost (2018-2038)

	Distributed Production (1500 kg/day SMR)	Centralized Production (380K kg/day SMR)
Los Angeles	$ 8.1 B	$ 9.1 B
California	$24.8 B	$ 27.7 B
United States	$203.9 B	$ 228.0 B

Source: Estimates based on H2A Production and Delivery Models

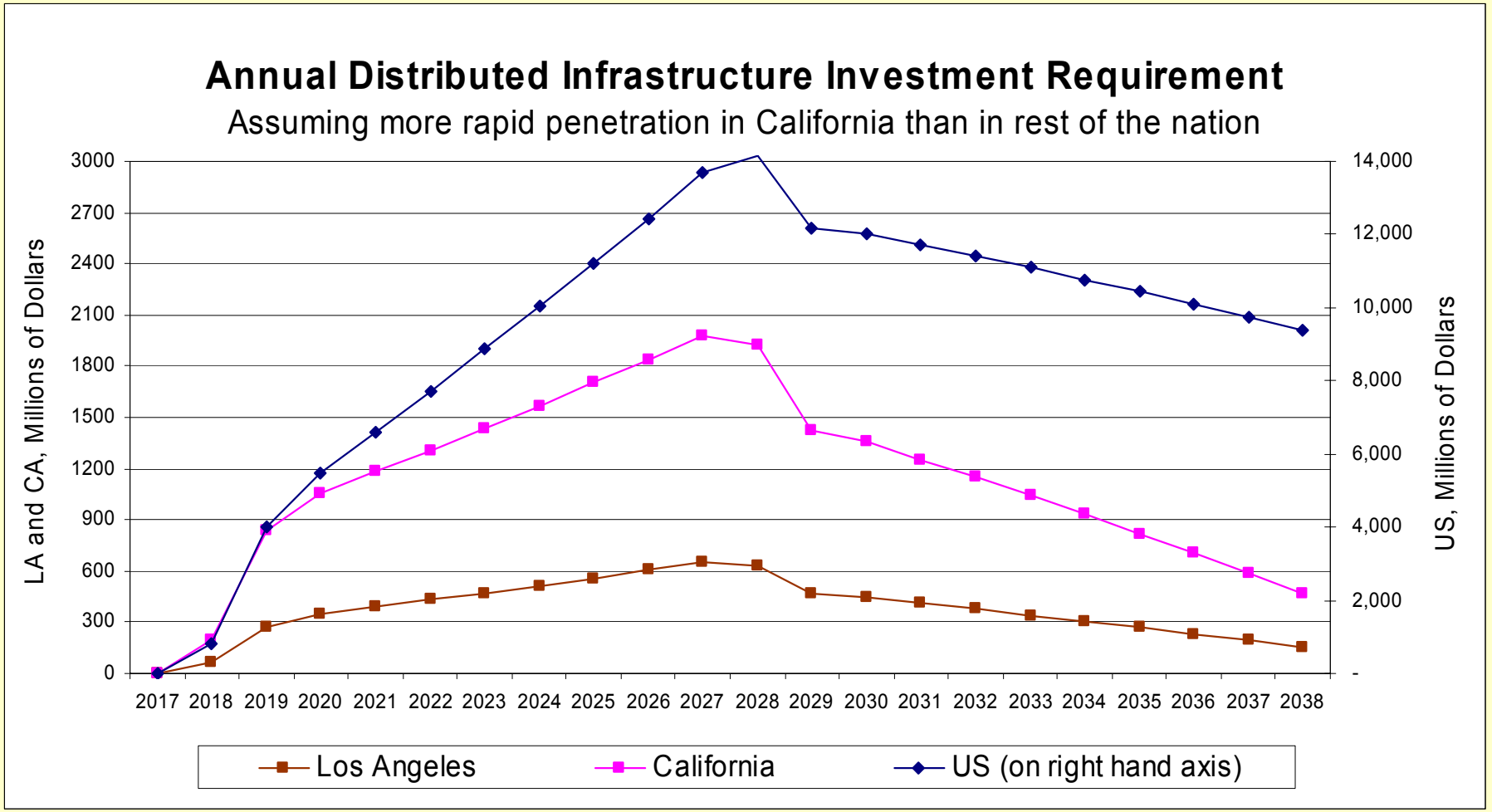
Hydrogen Investment Costs in Perspective

- Infrastructure costs for hydrogen fuel supply over 2018-2038 are significant on an annual basis.

(In Billions of Dollars)	LA	CA	USA
Peak Annual Investment	0.65	2.0	14.1
Average Annual Investment **(over 2018-2038)**	0.39	1.2	9.7

- These investments may be undertaken by major players capable of making large capital investment outlays each year.
- For instance, BP invests about $13 billion each year, and Ford about $7 billion each year.
- Investment requirements for developing a hydrogen fuel supply are small relative to total national investment, but not insignificant relative to investment budgets of major players.

Annual Investment Cost for Infrastructure Supporting Posture Plan's Market Penetration



Scale of Installations

Cost Curve of Hydrogen from Distributed SMR Facilities

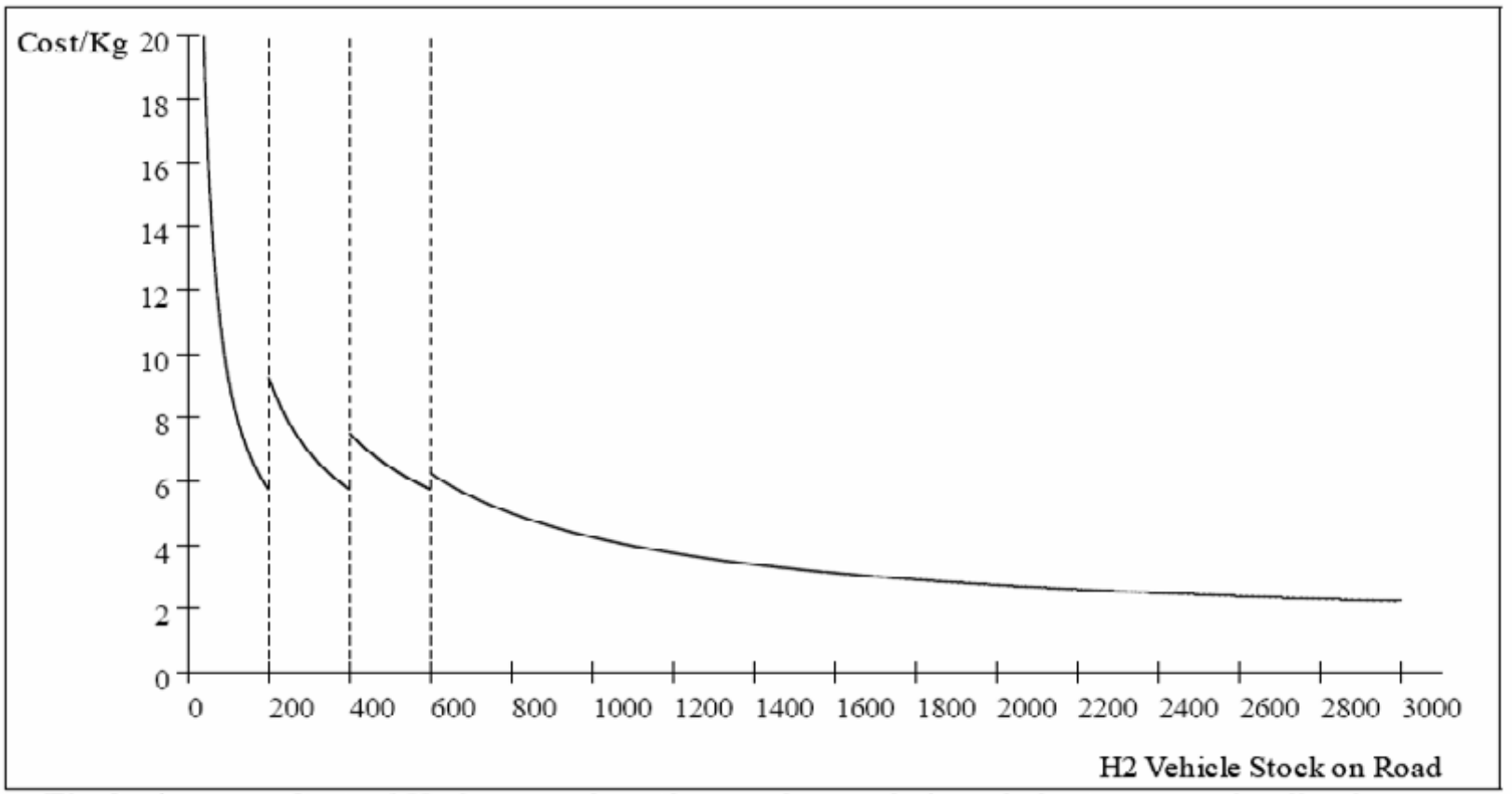
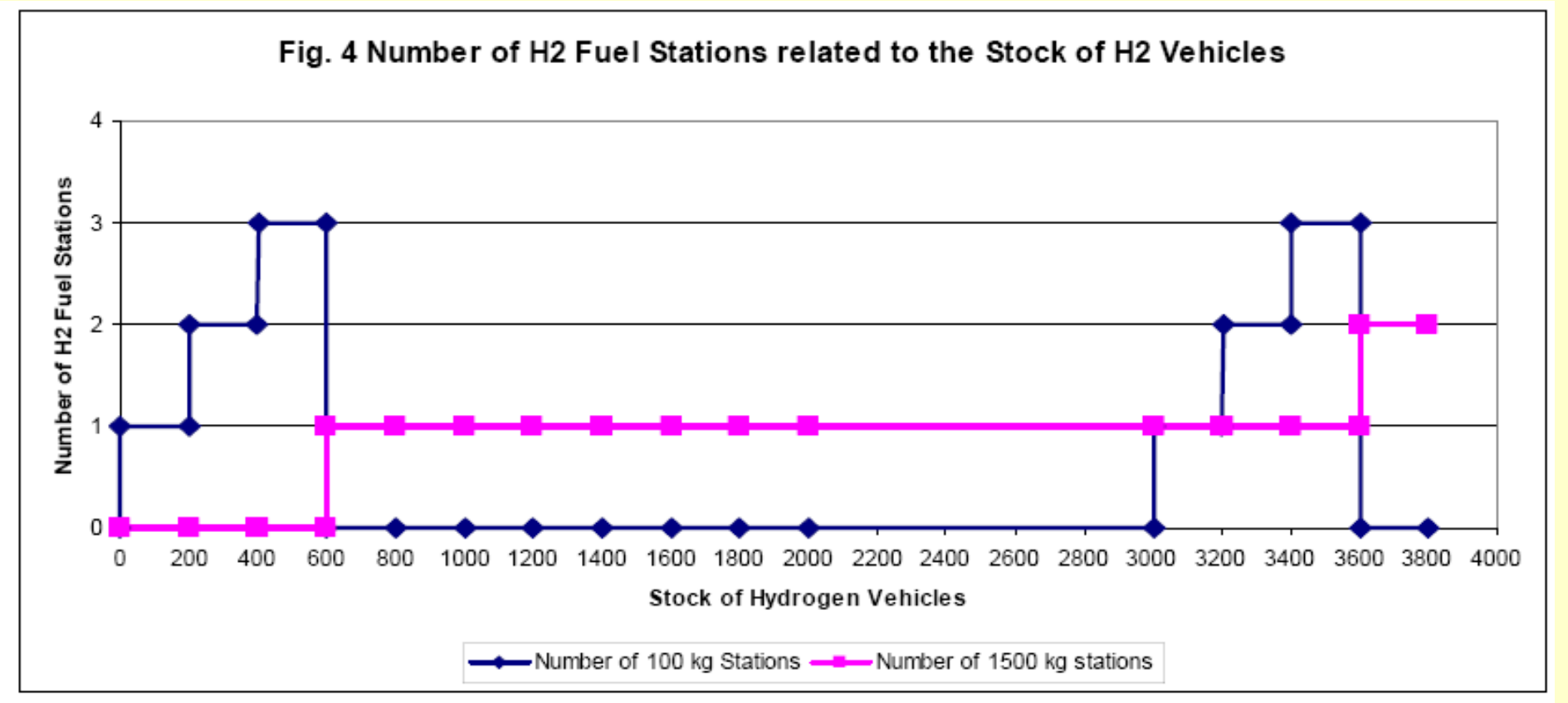


Fig 3. Average Cost of Hydrogen when the number and size of plants are optimally chosen

Scale of Installations

Expansion Path of Distributed Hydrogen Production as Number of Hydrogen Vehicles Increases



Proof of Principle of Decision Model

Example

Assume: simplified quadratic utility function, price and cost parameter values

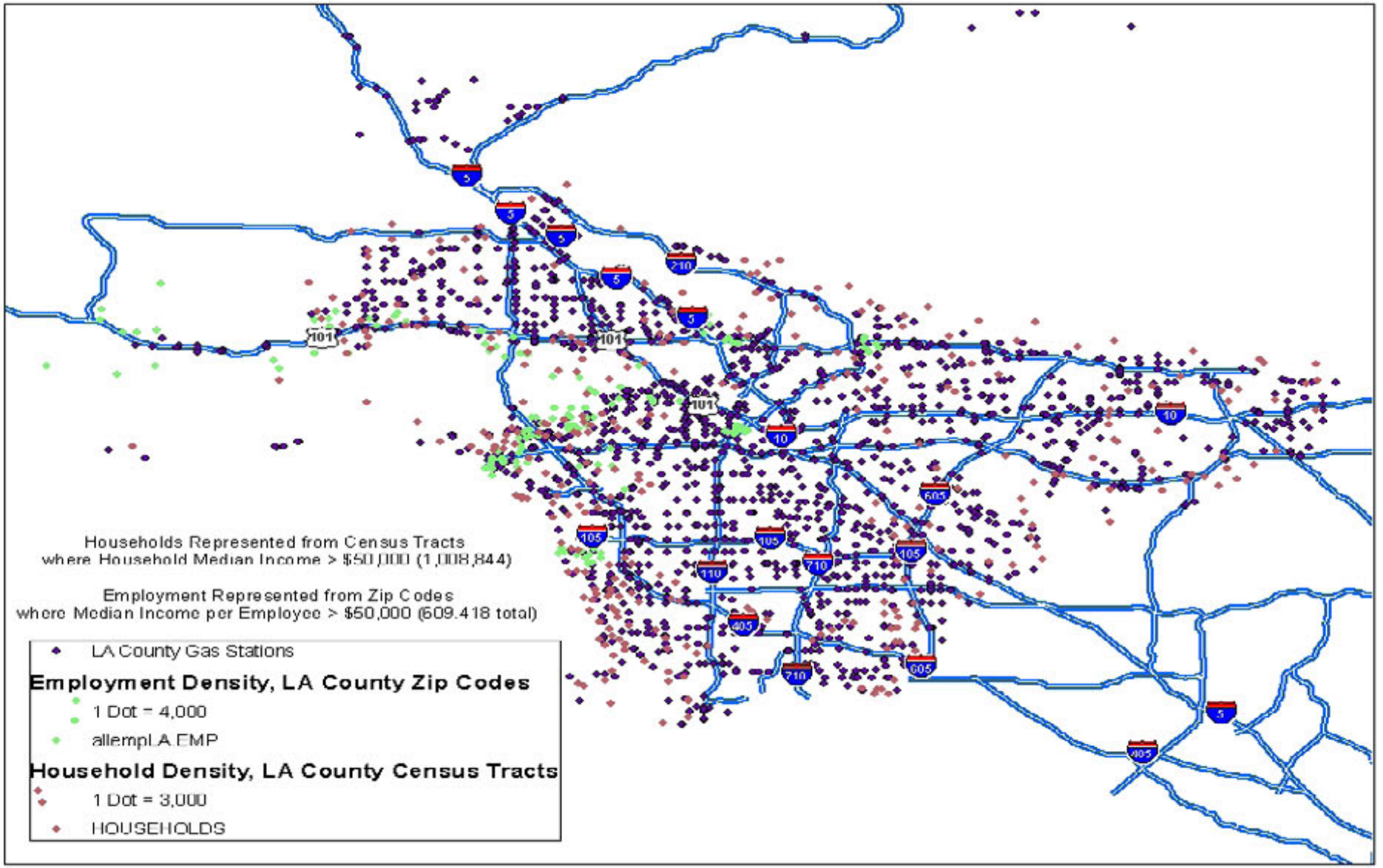
- Magnitude of stylized investment

with risk neutrality	25.0×10^3
with risk aversion	18.1×10^3
with risk aversion and chicken-egg formulation	21.6×10^3

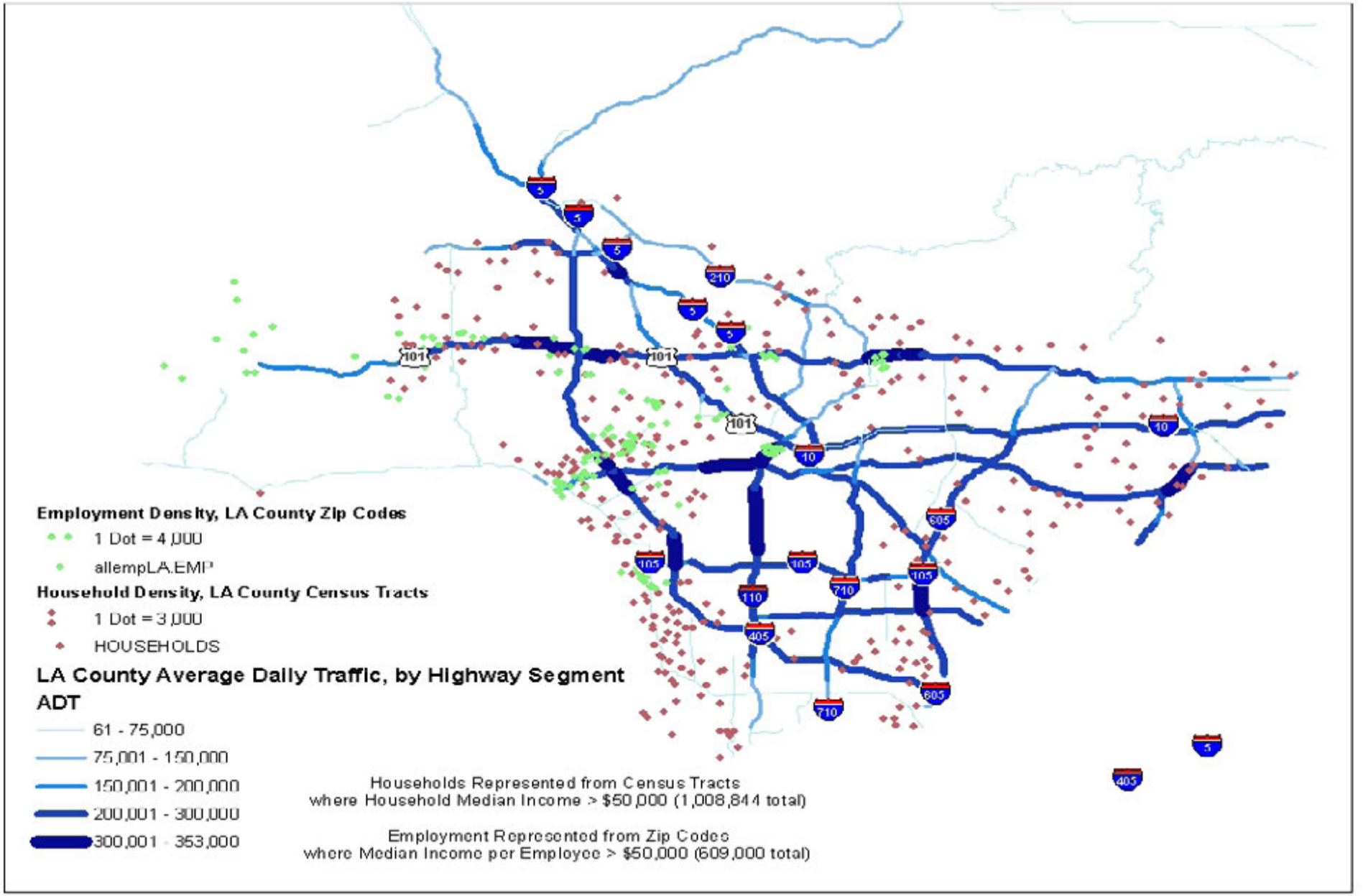
- Analytic solutions not possible for realistic cases
- Excellent candidate for ABM calibration and simulation

ABM Simulations Based on Localized Spatial Relations

Map 8: All Layers of Agents (Employment, Households, Gas Stations)



Map 9: Average Annual Traffic Patterns in Los Angeles County



Lessons Learned from Previous Technological Innovations

Technology	Market Penetration		Substitutes	Initial Users	Size of Investment		Government Intervention or Assistance
	Adoption indicator	Time Required			Cost per Unit	Divisibility	
Telegraph	60% of maximum wire mileage	35 yrs	no electronic communication; horse, river transportation	railroads, finance indsutry	high	high	none of note
Telephone	in 60% of households	73 yrs	telegraph--rough substitute	businesses	moderate	high	none
Radio	in 60% of households	10 yrs	telegraph, telephone, phonograph	govt, amateurs	moderate	high	initial demand
Automobile	in 60% of households: yrs		horse	individuals	high	high	highway construction
Television	in 60% of households	9 yrs	radio, movies	individuals	high	high	delay of commercialization, wartime R&D

- All innovations take time to reach equilibrium
- Chicken-egg problem of initial hydrogen investment is greater than for any 20th century innovation

Future Work

- FY06:
  - Empirically specify goals, profitability & expectations components of business decision algorithms
  - Initial ABM simulations
  - Focus on distributed production
- FY07:
  - Extend analysis to additional pathways
  - Experiment with additional business decision algorithms

Summary

- Hydrogen infrastructure investments are small relative to total national investment but may be big relative to even very large companies—moms & pops won't be distributed station investors
- Risk aversion is a relevant consideration and will have a noticeable dampening effect on infrastructure investment
- If chicken-egg problems can be surmounted, investment would proceed more rapidly than in markets with completely independent supply & demand
- Agent-based modeling necessary to address early transition's chicken-egg problems