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

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RCF Economic and Financial Consulting, Inc.

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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

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# 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?”

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# Approach

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

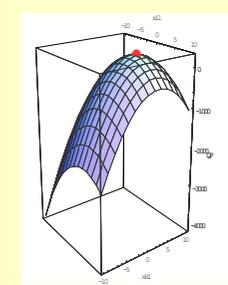
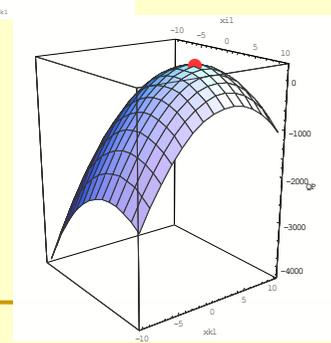
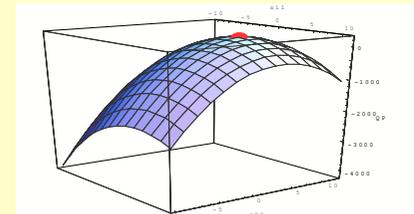
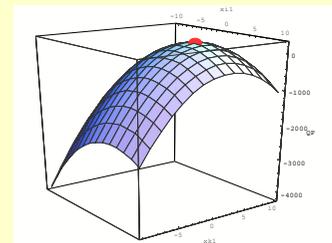
# Agent-Based Modeling Is Used to Simulate Business/Investment Decisions

- 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



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# Business Decision Framework

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

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# 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

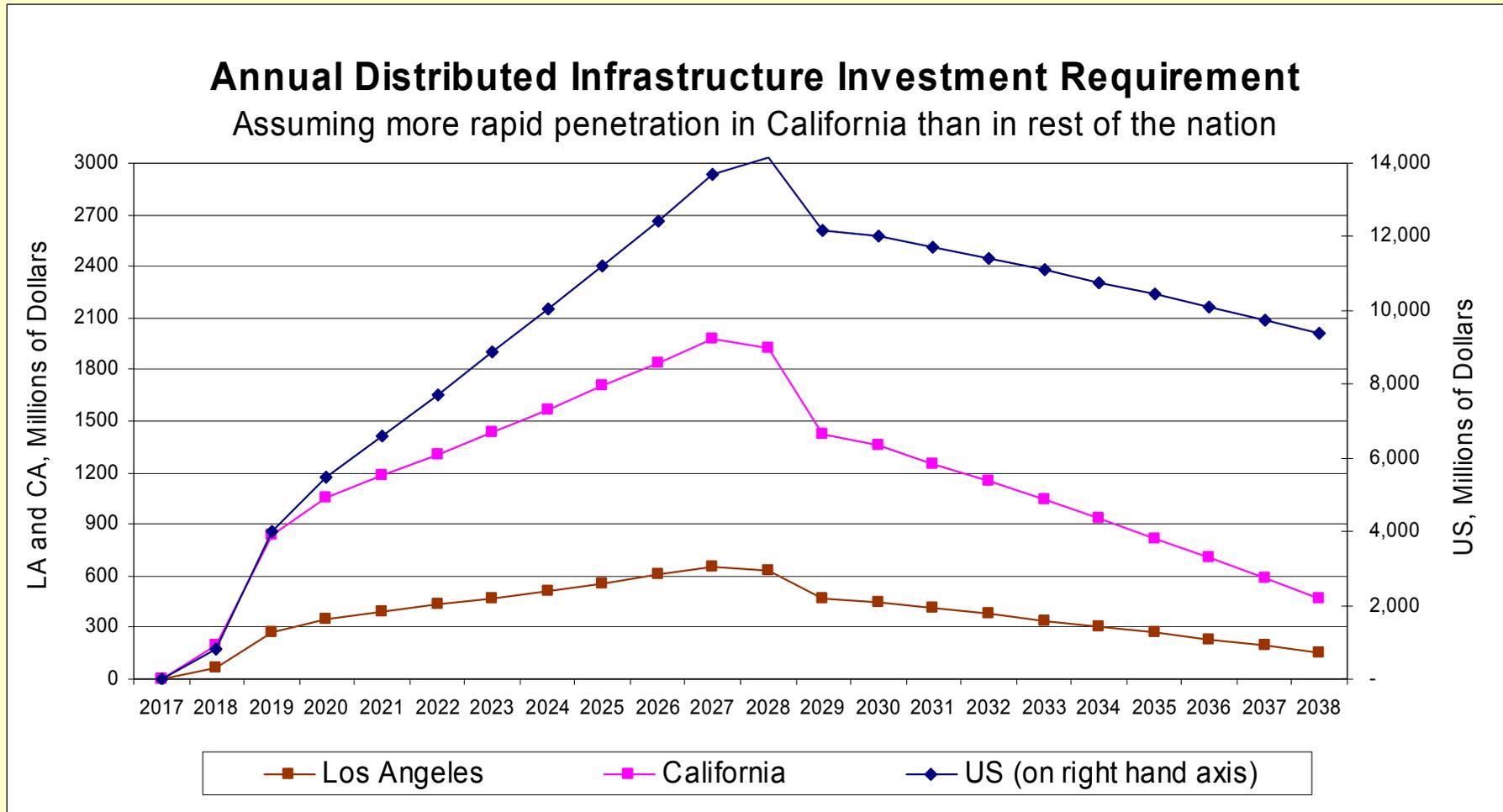
# Hydrogen Investment Costs in Perspective

- 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

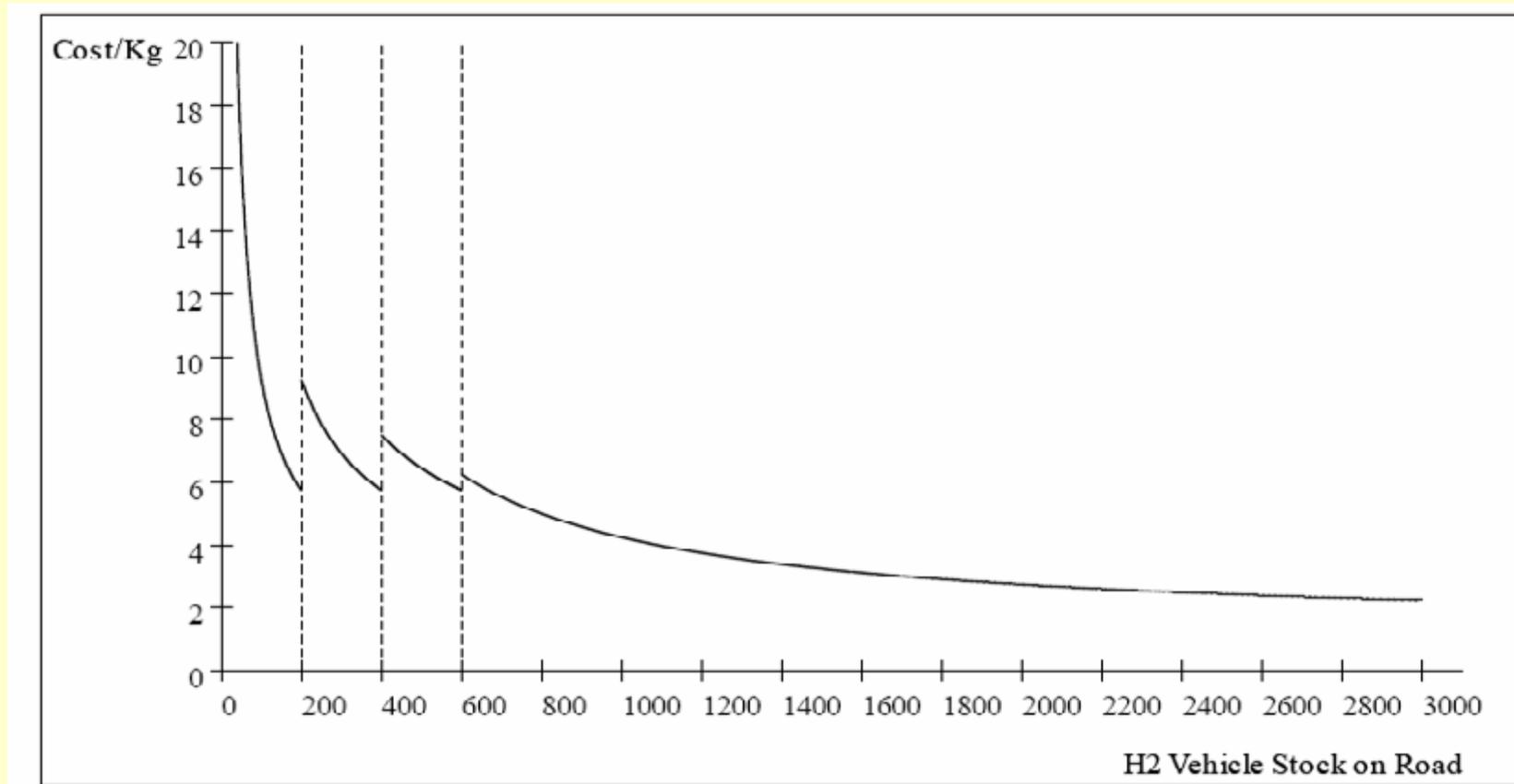
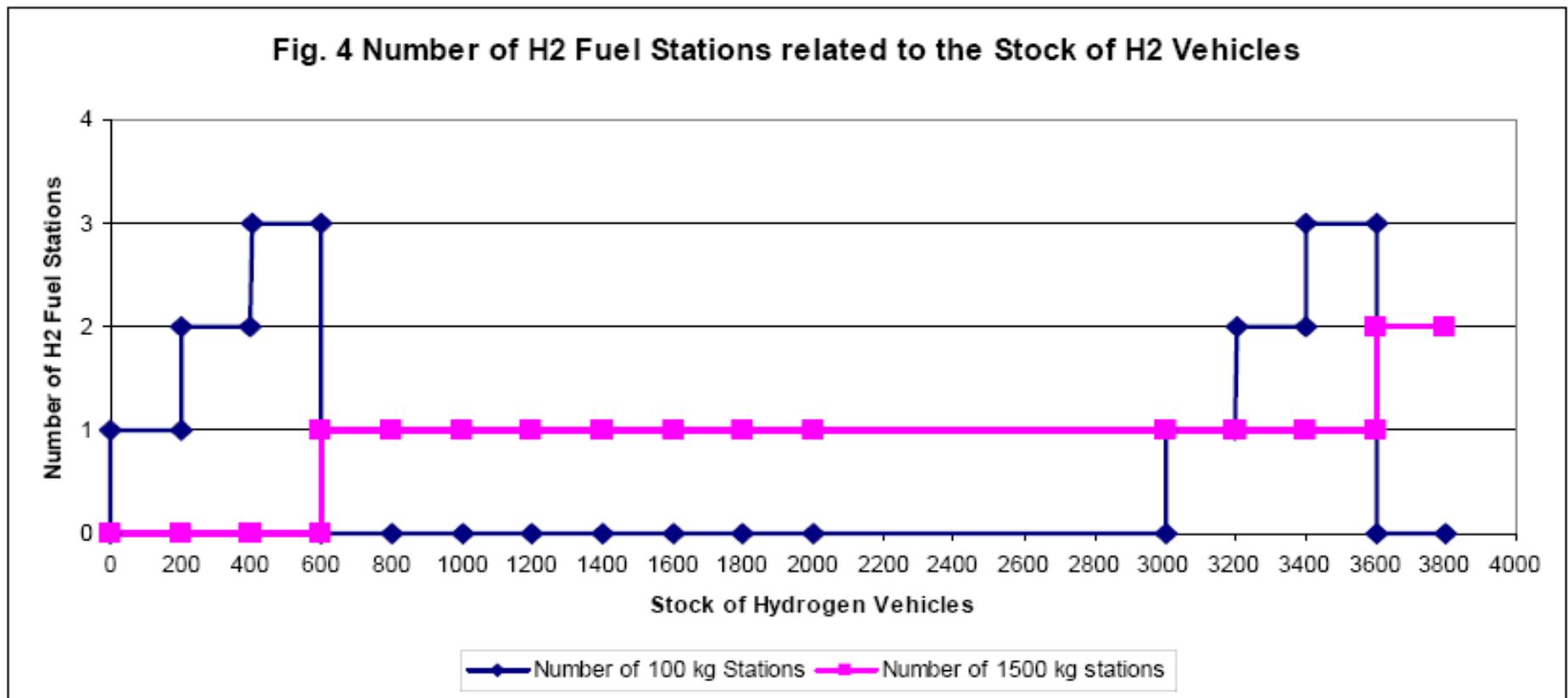


Fig 3. Average Cost of Hydrogen when the number and size of plants are optimally chosen

# 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	$25.0 \times 10^3$
with risk aversion	$18.1 \times 10^3$
with risk aversion and chicken-egg formulation	$21.6 \times 10^3$

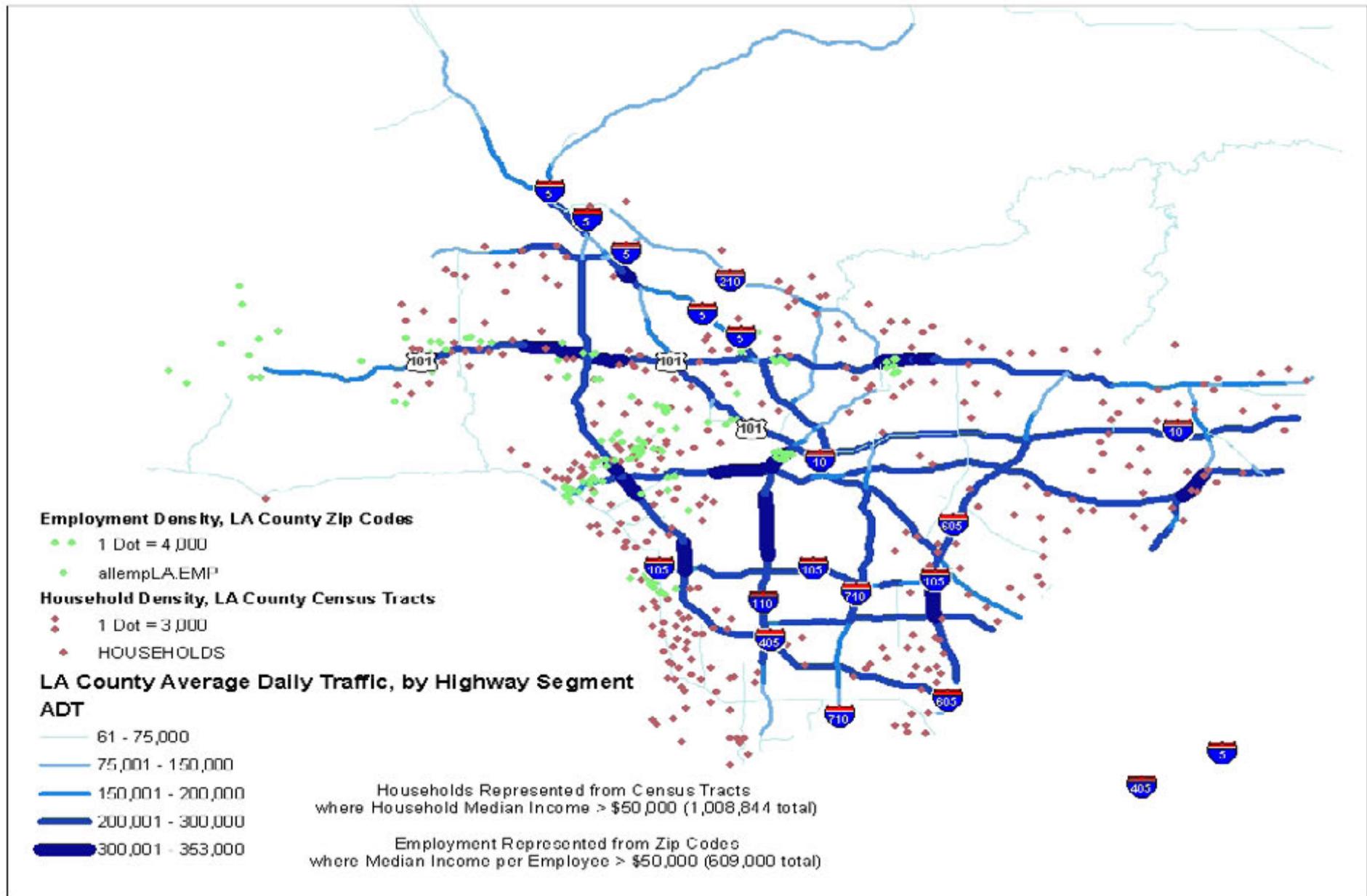
- Analytic solutions not possible for realistic cases
- Excellent candidate for ABM calibration and simulation

# ABM Simulations Based on Localized Spatial Relations





## 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 industry	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 20<sup>th</sup> century innovation

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# 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