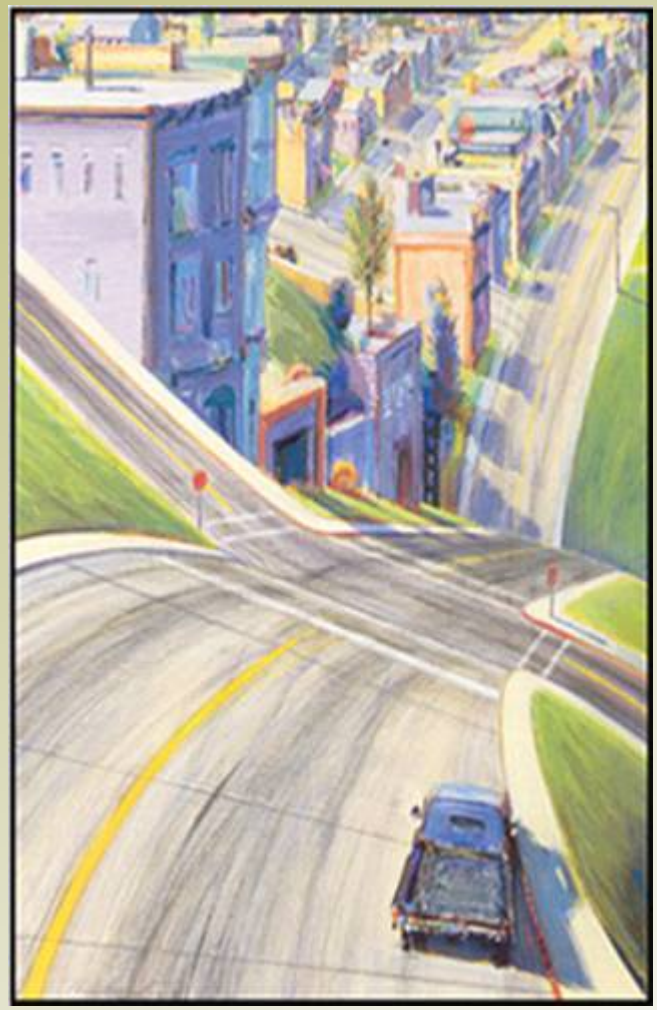
Institute of Transportation Studies
University of California, Davis



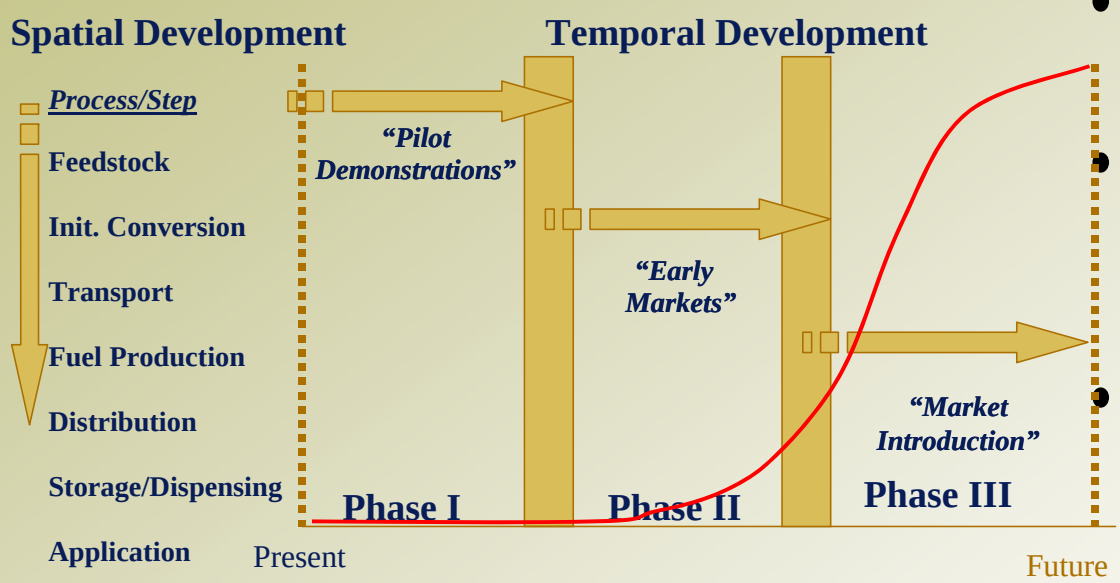
Lessons from the H_2 Pathways Program

Prof. Joan Ogden
University of California, Davis

presented at the
Transportation Research Board Meeting
Washington, DC

January 22, 2007

Hydrogen Pathways



Focus on "Transitions"!

- Multi-year interdisciplinary program (2003-2006)
- Strategies and Pathways for H_2 in transportation
- Consortium, 21 sponsors: automakers, energy firms, government
- Research (15 senior researchers; 15 grad students; >100 publications)
- Public Outreach
- Education

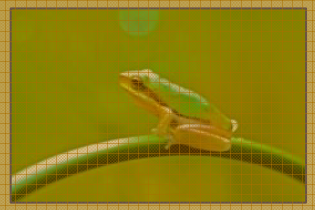
Key Questions for H_2 in Transportation

- Who Will Buy a H_2 Car and Why?
- Where Will the H_2 Come From?
- What Would a H_2 Infrastructure Look Like?
- How Could We Make a Transition to H_2?
- What are the Costs and Benefits of H_2? (Compared to Alternatives)?
- What are Policy and Business Strategies for H_2? (What Should We Do Now?)

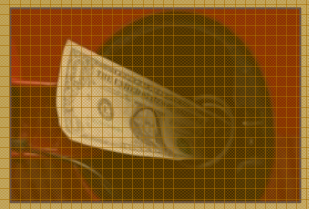
Who Will Buy a H_2 Car and Why?

Lessons from gasoline hybrid buyers for H_2 and Fuel Cell Vehicles

- It's about more than economics and just saving $
- Cars are symbols



Environmental Preservation



Financial Acumen

Independence from Oil

Technology Bravado

FCVs Must Offer Clear Symbolic Meanings to Distinguish Them

FCV (+ Sales, Service, and Refueling) Must Reinforce Meanings and their Personal Significance and Should:

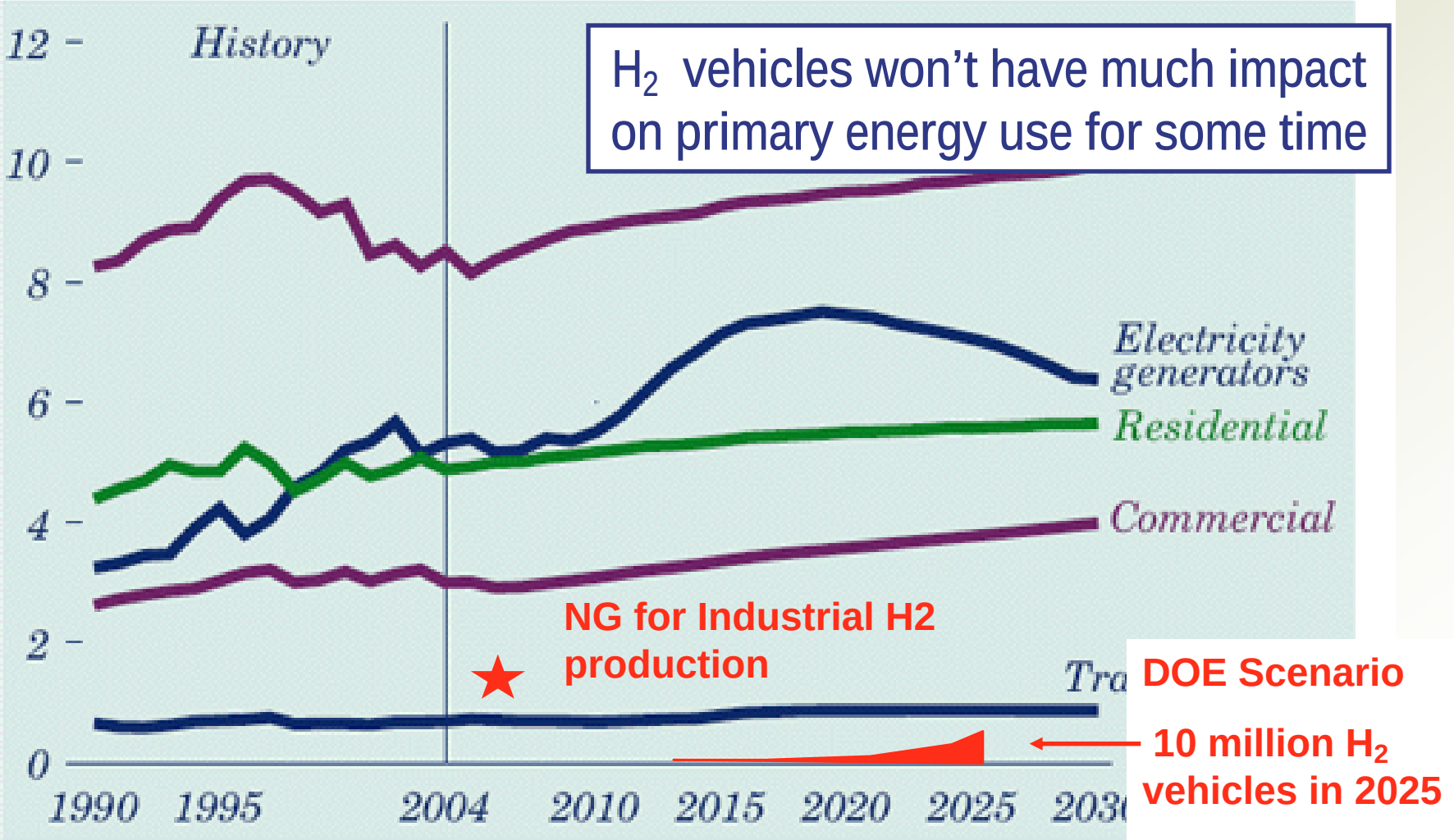
- ***Foster Communication (Car & Owner)***
- ***Be Easily Distinguished from Other Vehicles***
- ***Be Easily Connected to its Owner***

Pro-FCV Voices Important in Discourse (Credibility)

Source: Ken Kurani and Reid Heffner 2006

Where Will H_2 Come From (Next 20 Yr)?

Figure 71. Natural gas consumption by sector, 1990-2030 (trillion cubic feet)

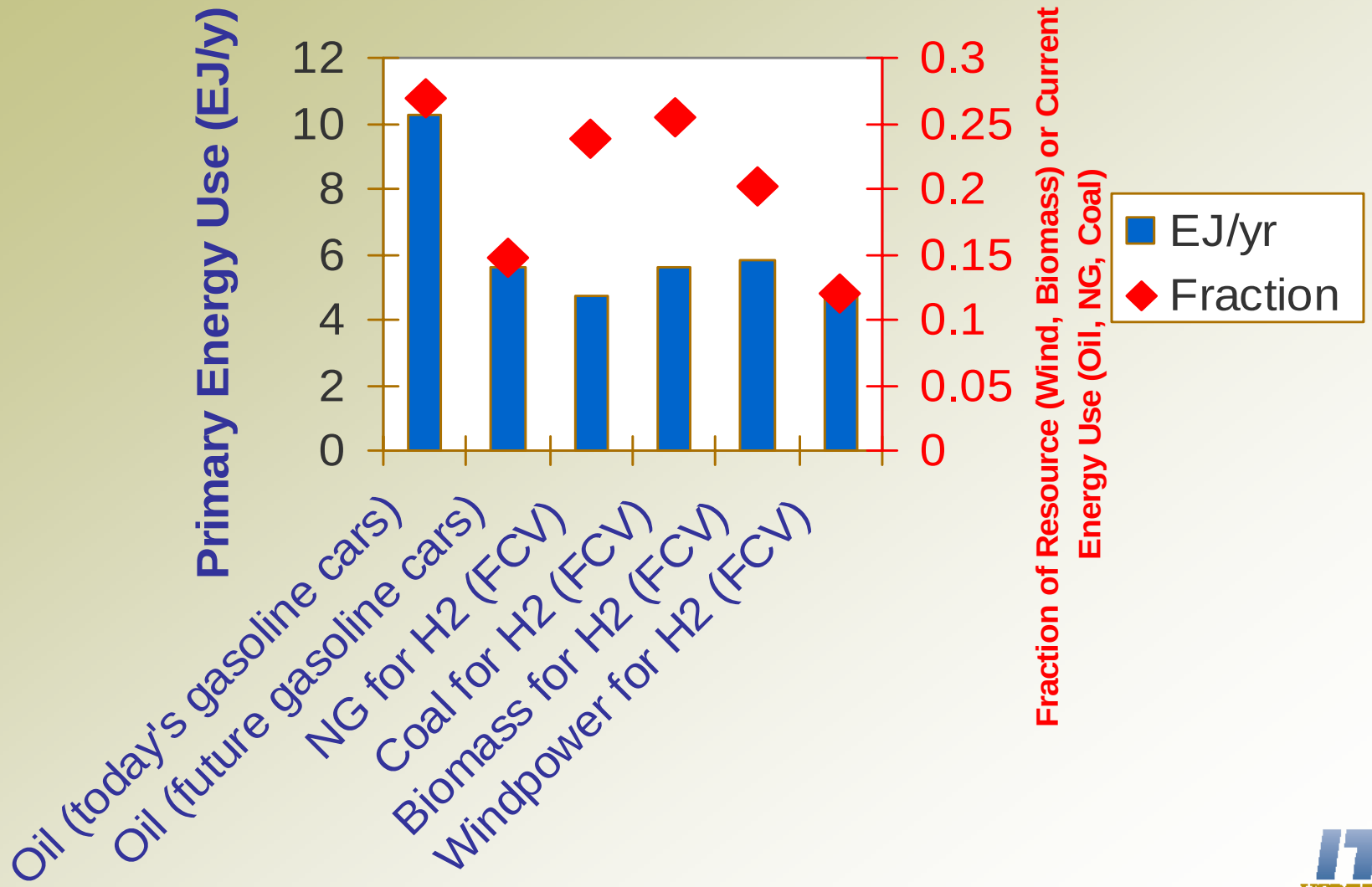


H_2 vehicles won't have much impact on primary energy use for some time

Annual Energy Outlook 2006 with Projections to 2030
http://www.eia.doe.gov/oiaf/aeo/gas.html

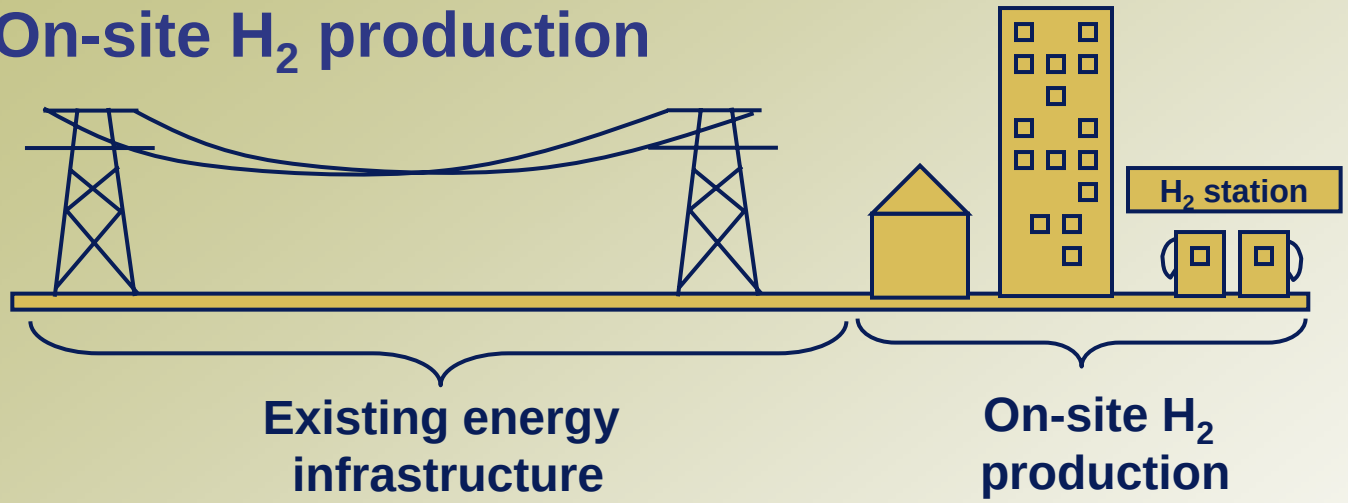
Where Will H_2 Come From (Long Term)?

Resources to fuel 100 million H_2 FCVs

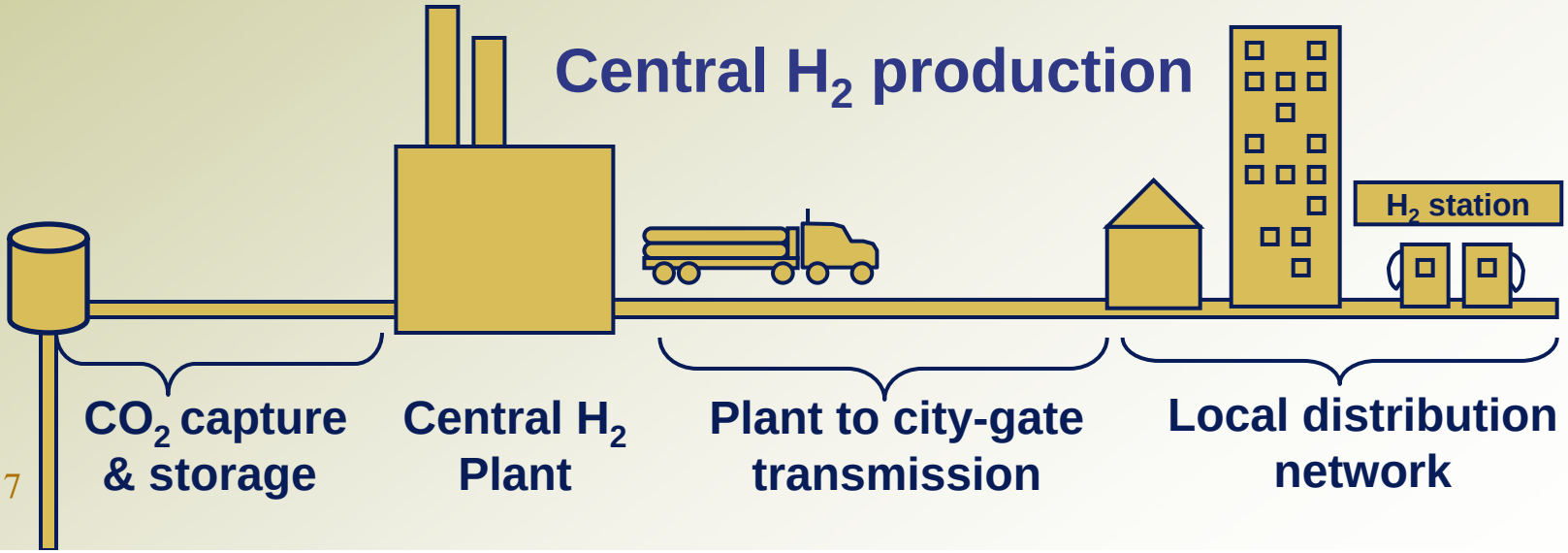


What Would a H_2 Infrastructure Look Like?

On-site H_2 production



Central H_2 production

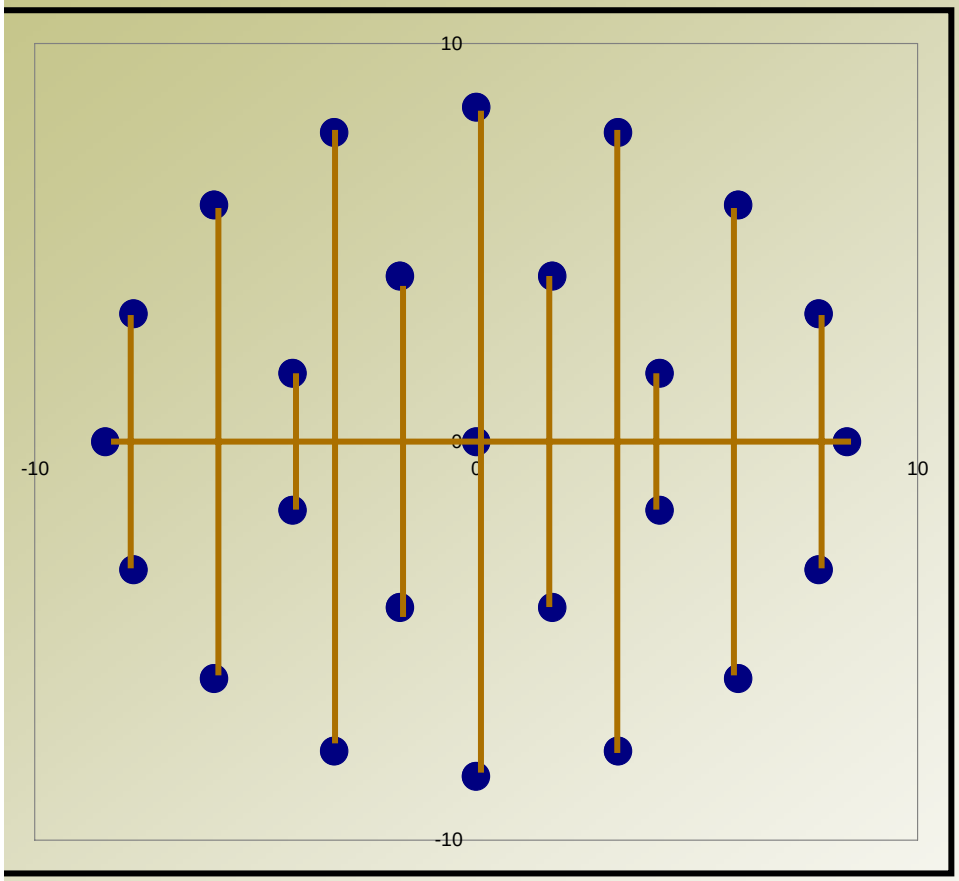


H_2 Infrastructure Design

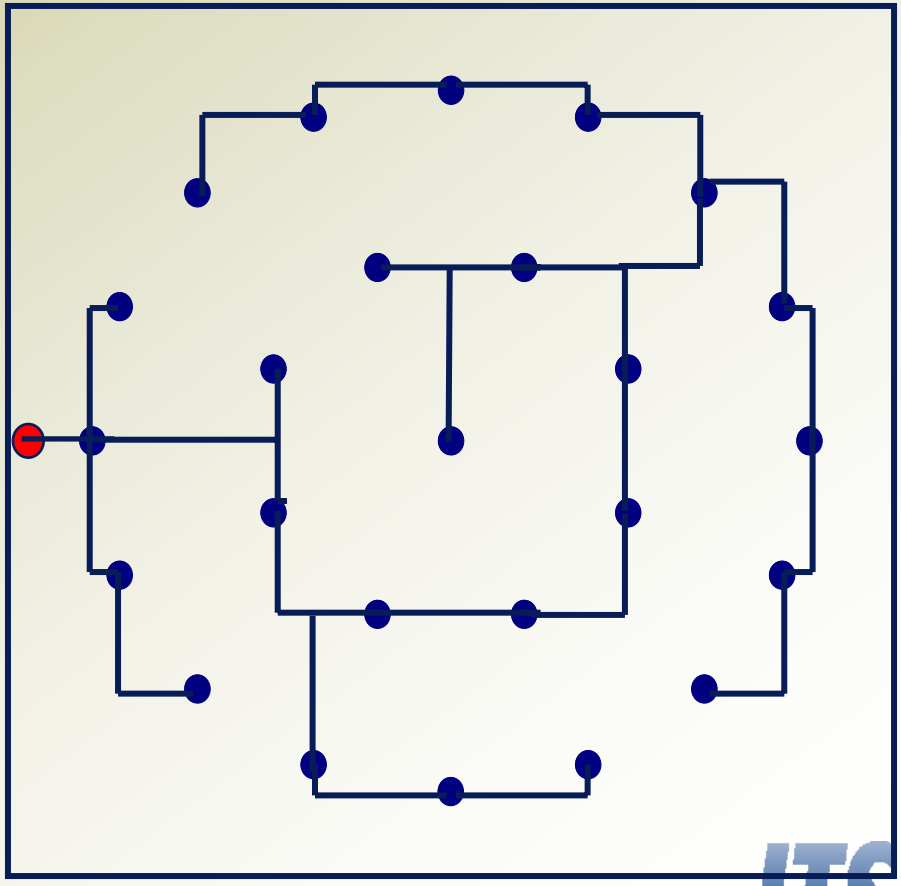
Spatial Layout and Logistics

UCD "Idealized City" Model

Truck delivery

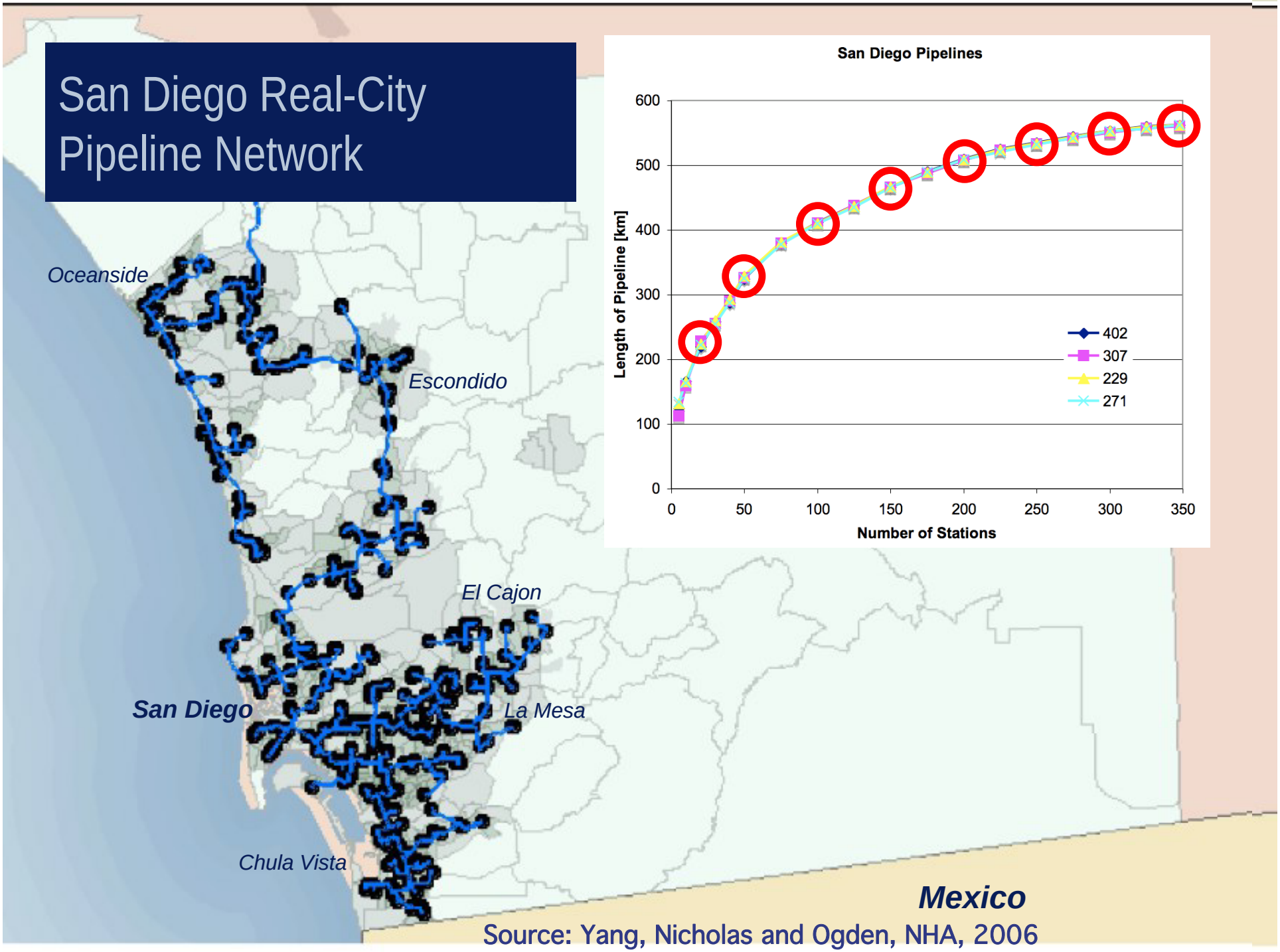


Pipeline



 Source: Yang and Ogden, in press International Journal of Hydrogen Energy, 2006

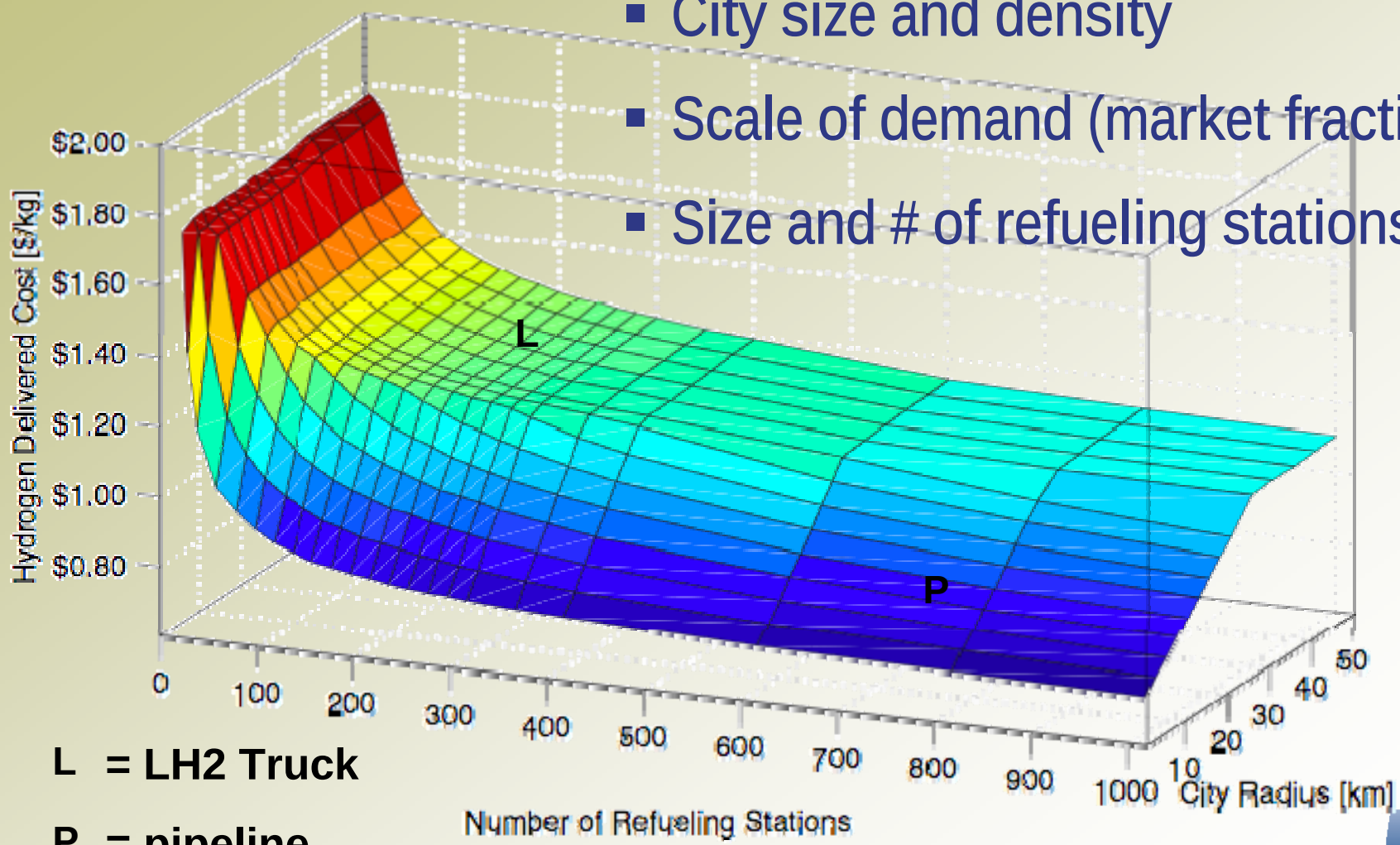
San Diego Real-City Pipeline Network



Source: Yang, Nicholas and Ogden, NHA, 2006

Lowest Cost H_2 Delivery Method Depends on

- City size and density
- Scale of demand (market fraction)
- Size and # of refueling stations



L = LH2 Truck

P = pipeline

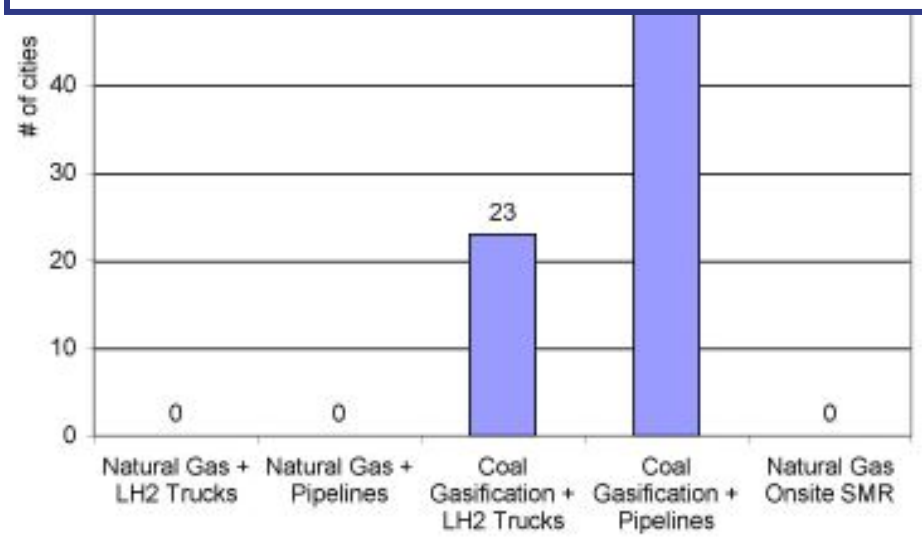
Source: Yang and Ogden, in press IJHE, 2006

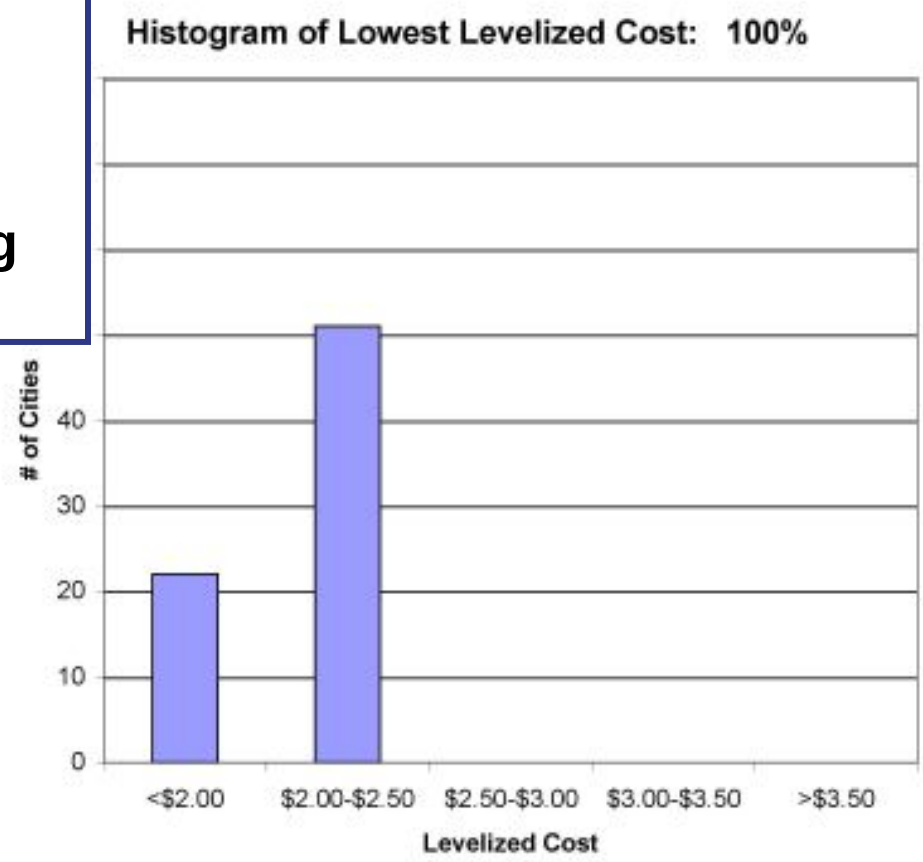
Lowest H2 Cost Pathway:

- **DEPENDS ON GEOGRAPHY**
  - **Less dense cities: LH2 trucks**
  - **High density cities: pipelines**
- **SCALE: AS DEMAND GROWS**
  - **Distributed->central production**
  - **H2 cost decreases w/scale, long term H2 cost/km ≤ gasoline**

5 Pathways Considered

NG-LT	Natural Gas Liquid Truck
NG-P	Natural Gas Pipeline
C-T	Coal Liquid Truck
C-P	Coal Pipeline
NG-Dist	Natural Gas Onsite





 Source: Chris Yang, Joel Bremson 2006

Low Cost H_2 from Waste Biomass

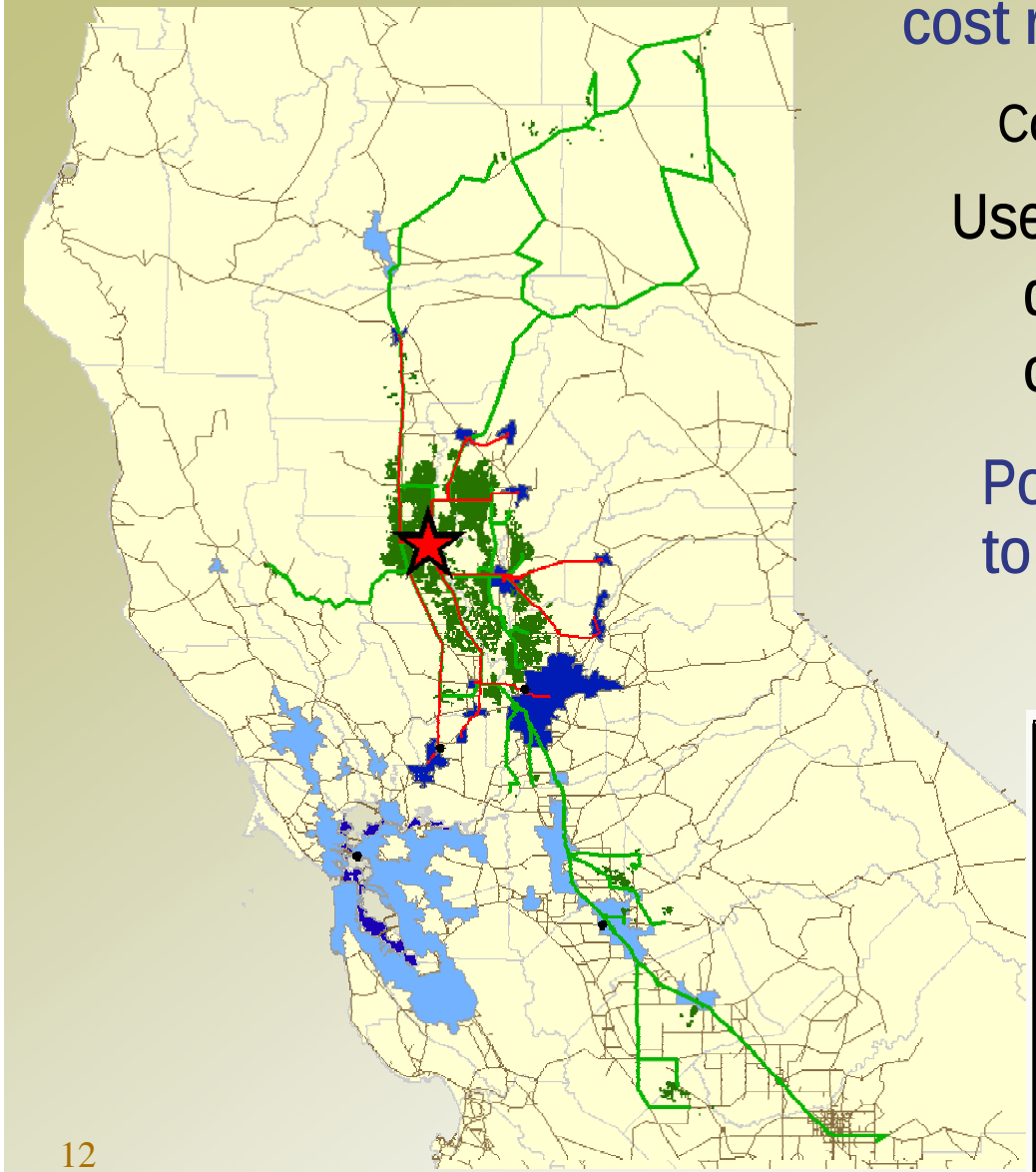
Rice straw is regionally significant low-cost renewable biomass resource.

Could provide H2 for ~ 250,000 FCVs

Use spatial analysis, optimization to design low cost infrastructure for collecting rice straw, supplying H_2.

Potential for competitive near to mid term renewable H2

H2 costs $3.4/kg at pump



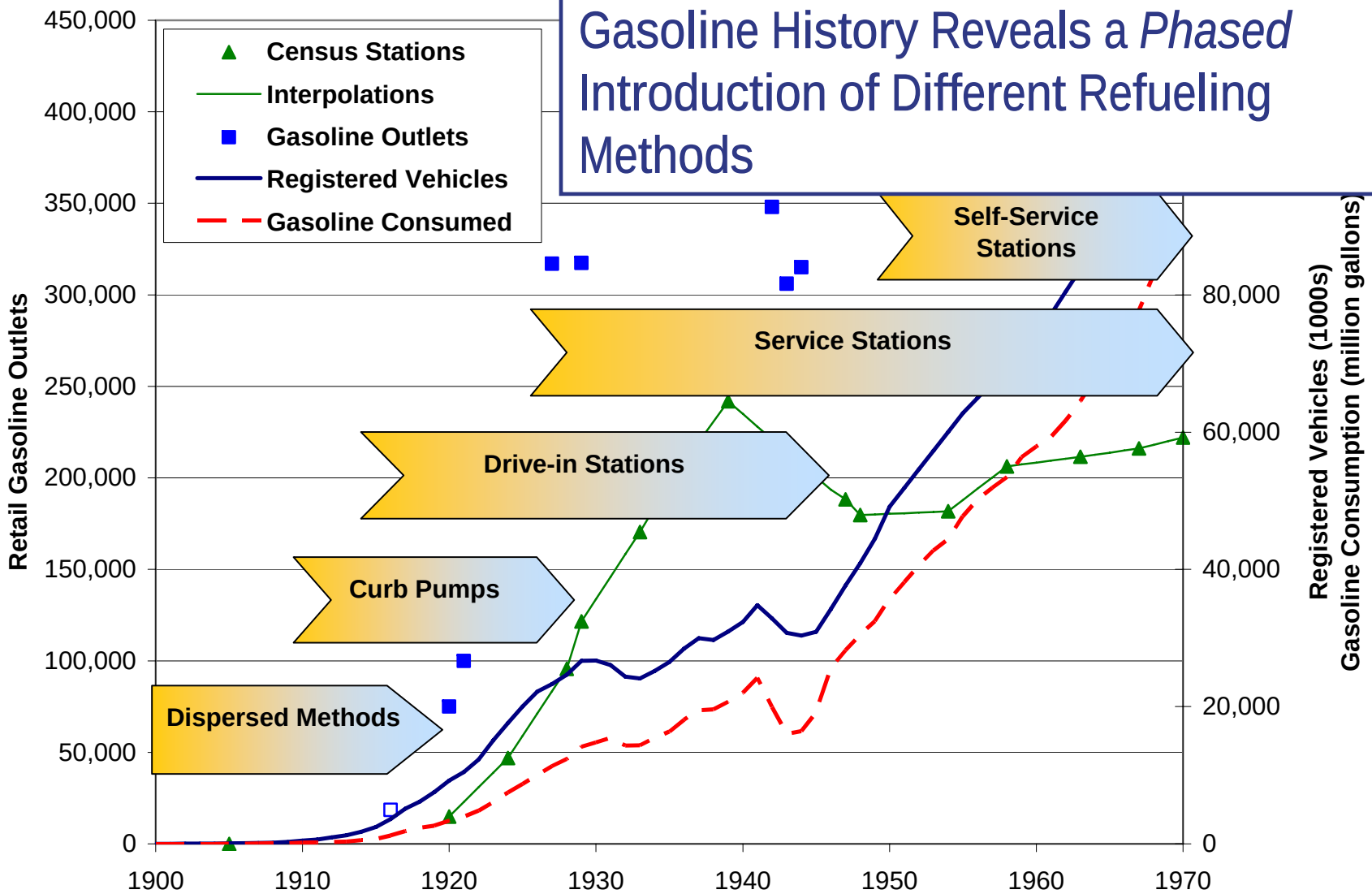
- Optimal Facility Location
- Hydrogen Deliveries
- Rice Straw Deliveries
- Supplying Rice Fields
- Hydrogen Demand Clusters Served
- Other Hydrogen Demand Clusters

Source: Nathan. Parker, Proceedings of the National Hydrogen Association Meeting, 2006.

How Could We Make a Transition to H2?

What Can Gasoline History Teach Us About H_2?

Gasoline History Reveals a *Phased* Introduction of Different Refueling Methods

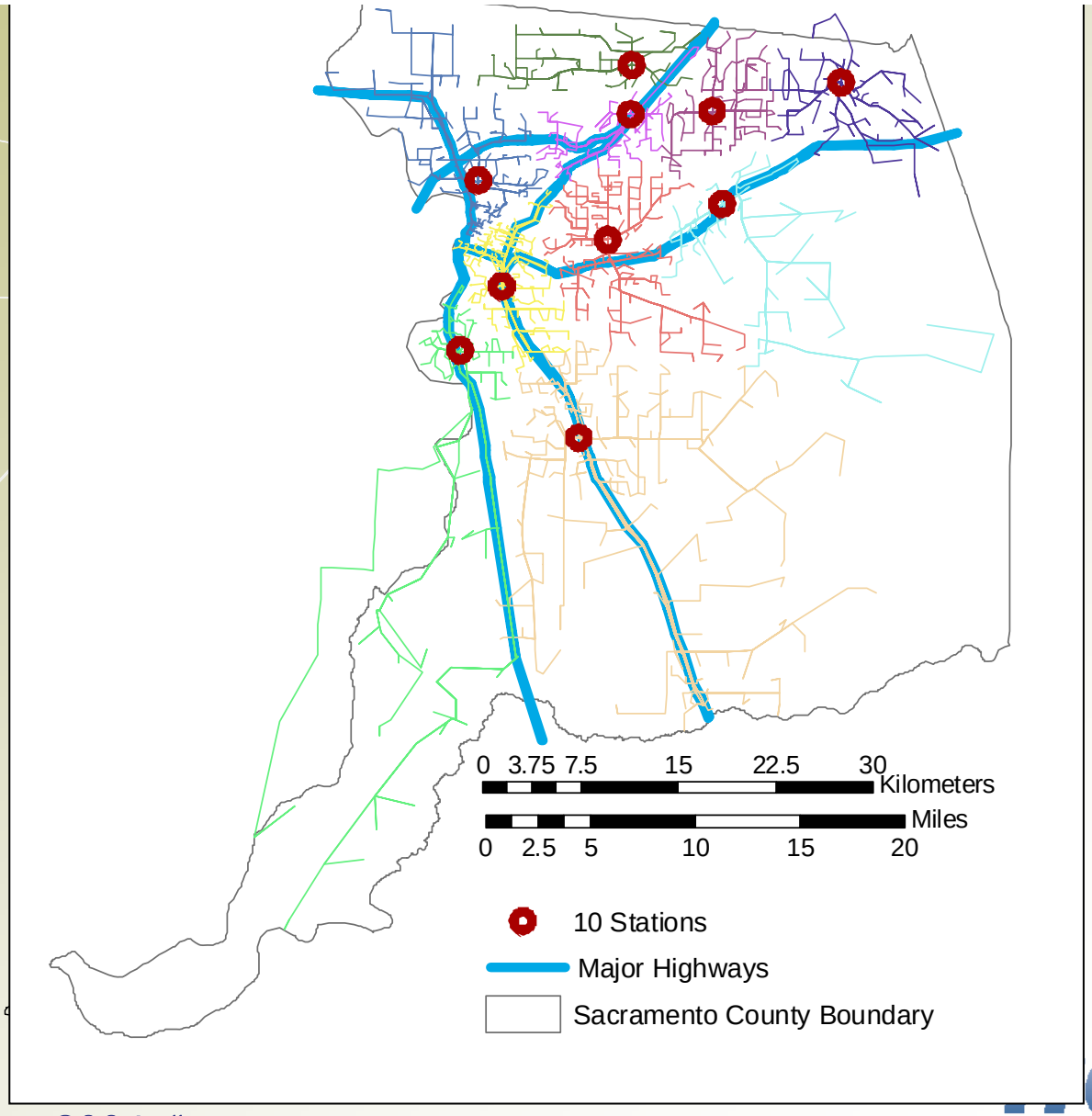


Source: Marc Melaina, Proceedings of the National Hydrogen Association Meeting, 2005.

How Could We Make a Transition to H_2?

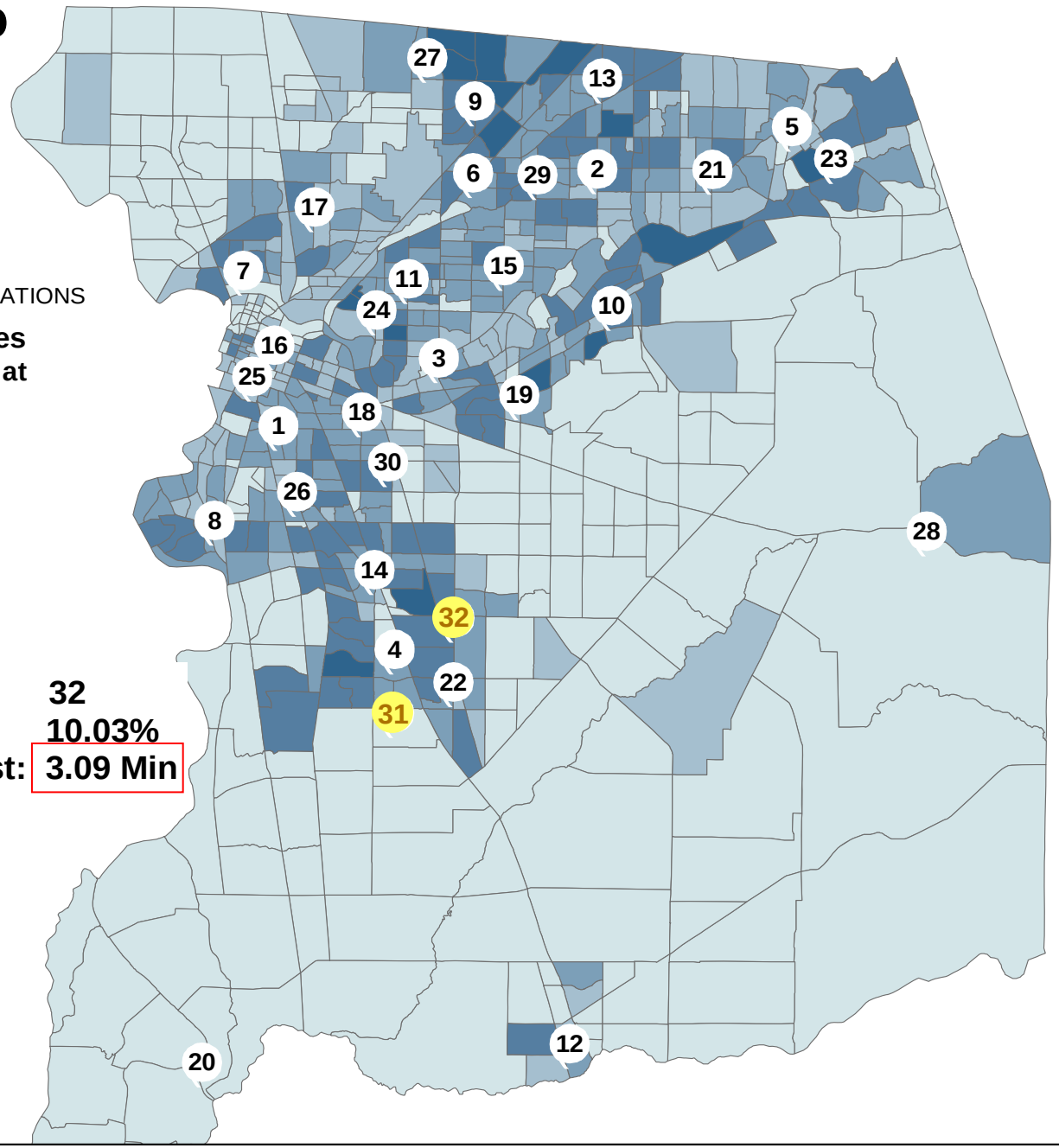
Early infrastructure: How many H_2 stations do we need to get started?

Travel time as a metric for customer convenience



Source: Nicholas, Handy and Sperling, 2004. "Geographic Information System (GIS) Analysis of Refueling Station Siting and sizing"

Sacramento County Analyses



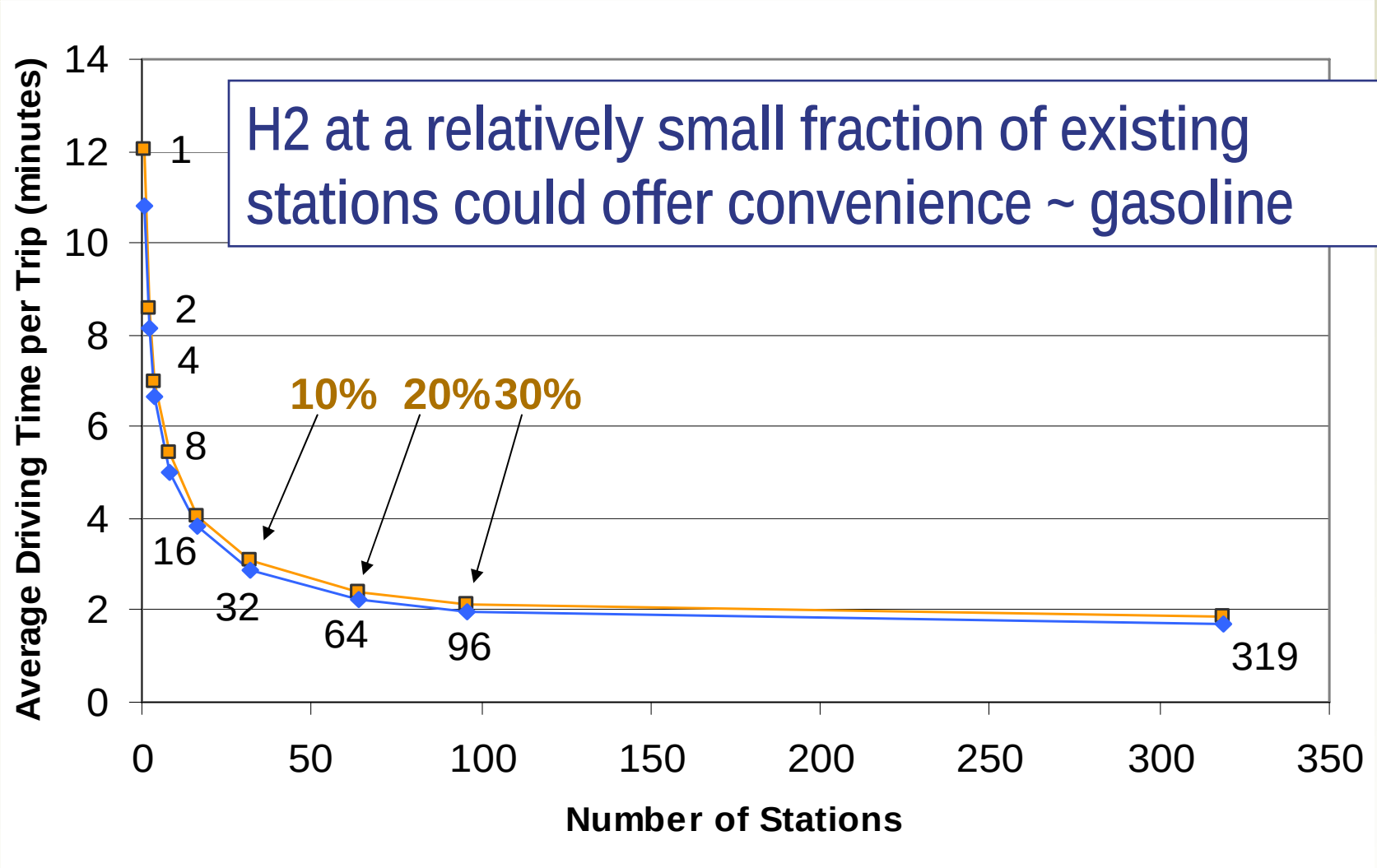
Legend

(HYPOTHETICAL STATIONS

Traffic Analysis Zones
Vehicles leaving zone at
6:30 - 7:30

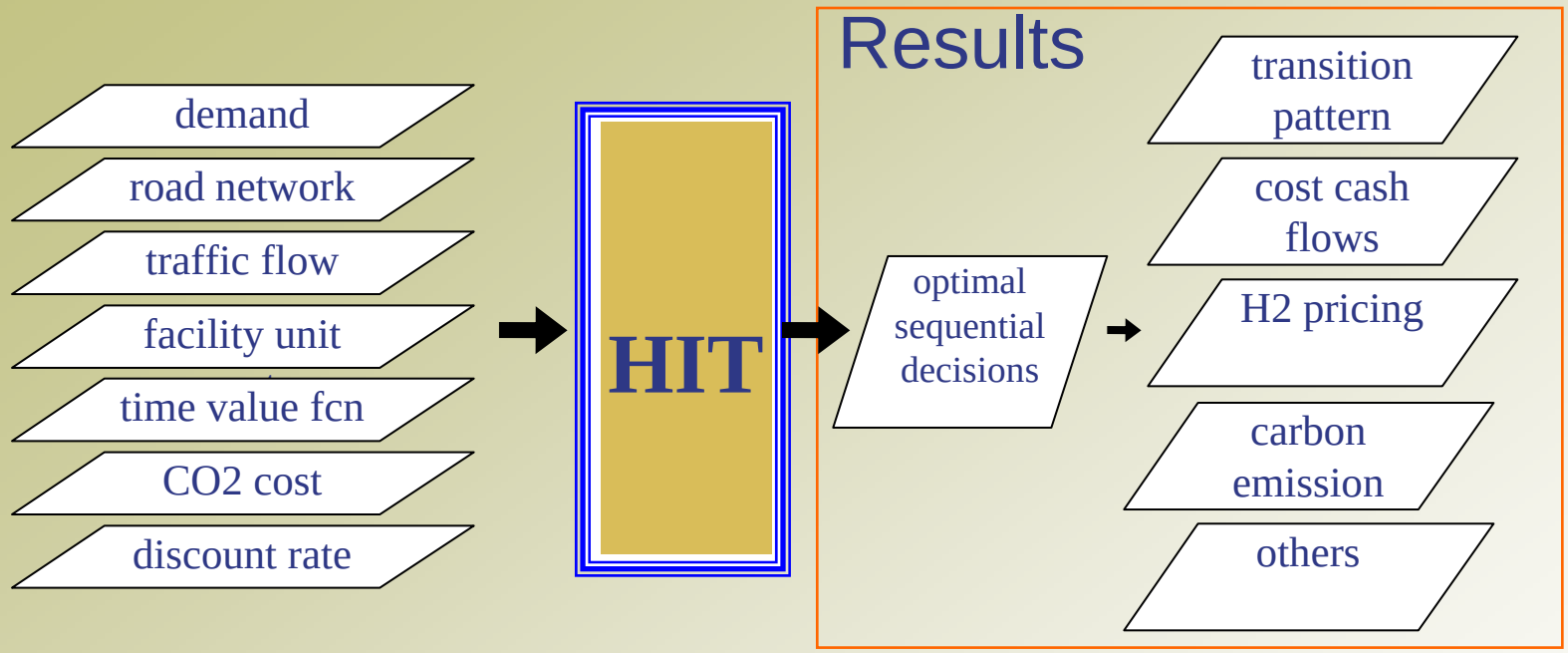
- 0 - 211
- 212 - 491
- 492 - 798
- 799 - 1259
- 1260 - 2125

Number of Stations: 32
Percent of Stations: 10.03%
Avg. Time to Nearest: 3.09 Min



Relationship Between # of Stations and Ave. Travel Time

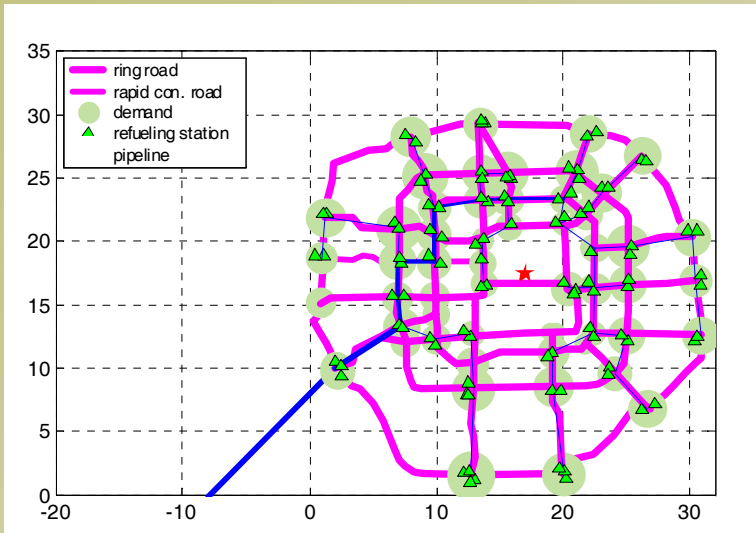
Dynamics of H2 Transition:
Hydrogen Infrastructure Transitions Model (D.Z. Lin)

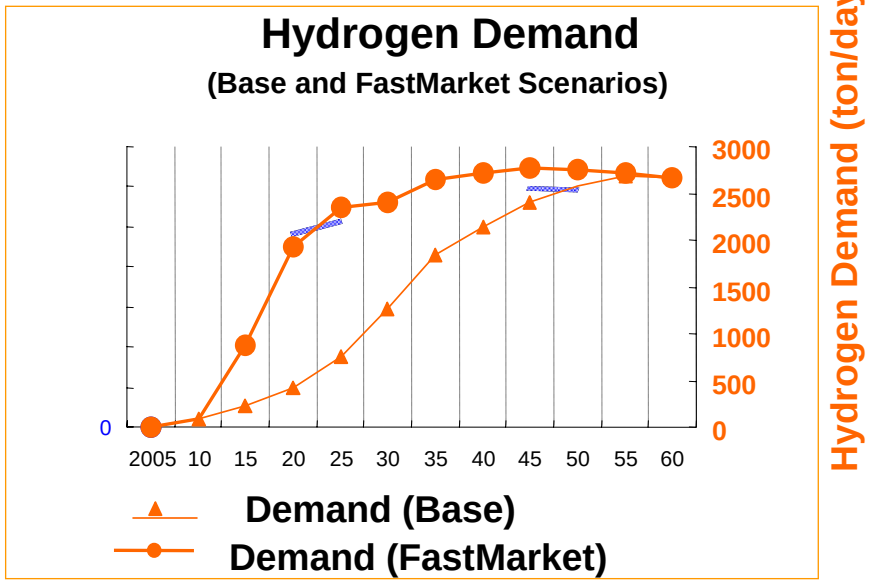


- Metrics: cost, emissions, travel time
- Geographic specific
- Dynamic programming
- Solves for optimal regional build-up over time

Low Cost Transition Strategies

Beijing Case Study



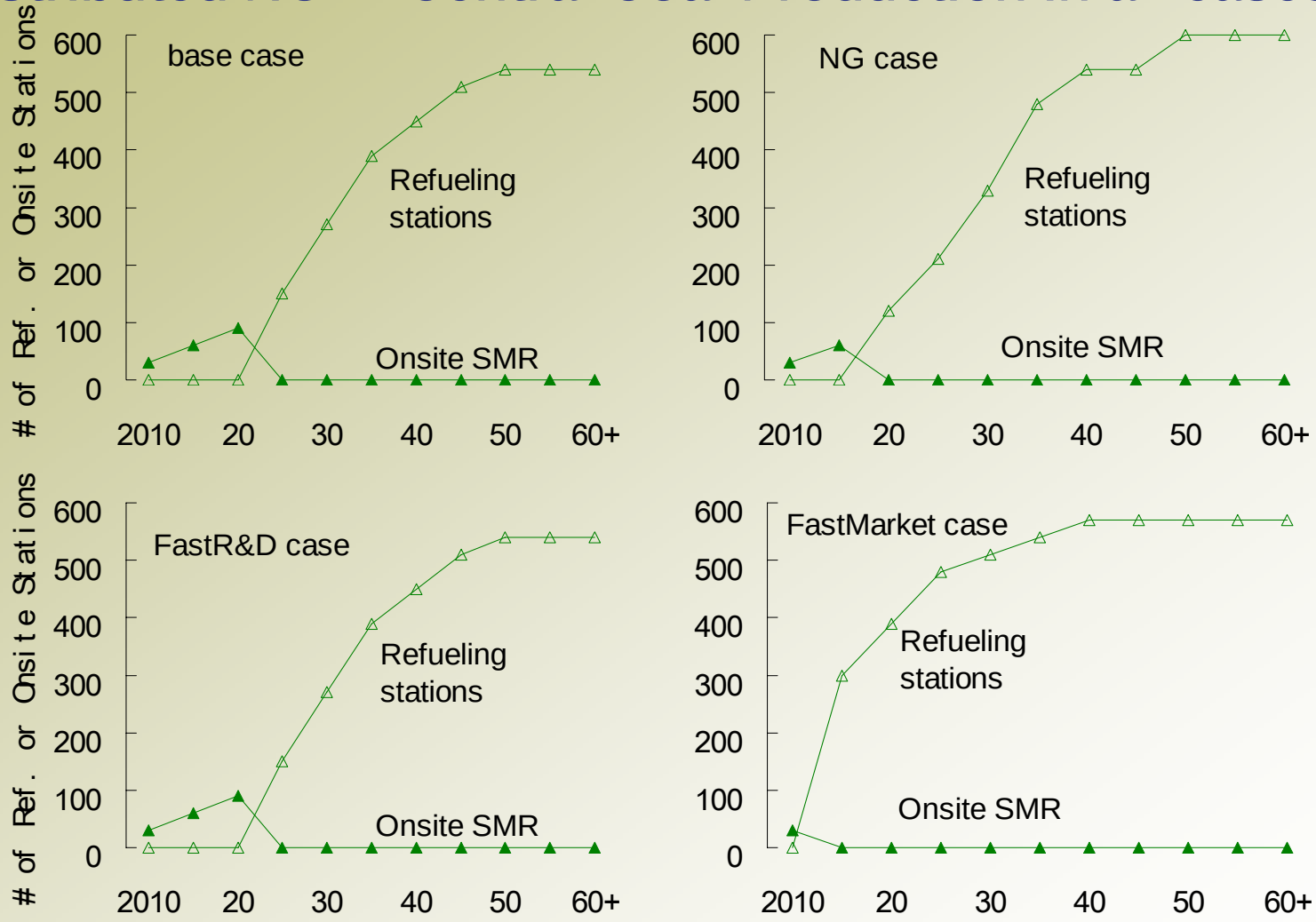


- Fast v. slow market growth
- Fast v. slow tech progress
- Moderate v. aggressive C-policy
- Low v. high NG prices

Source: D.Z. Lin, J.M. Ogden, Y.Y. Fan and D. Sperling, Proceedings of the National Hydrogen Association Meeting, 2006

Optimal Decisions:

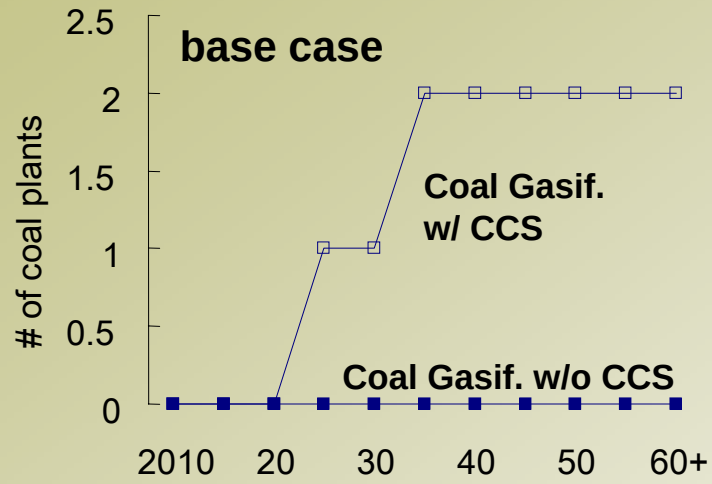
Distributed NG -> Central Coal Production in all cases

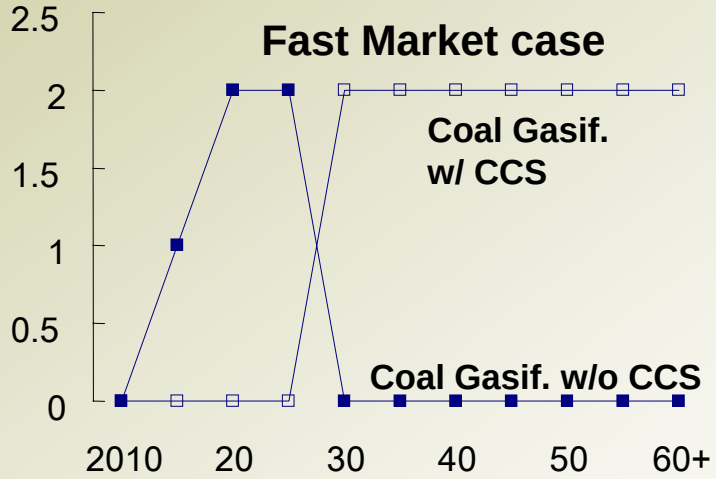


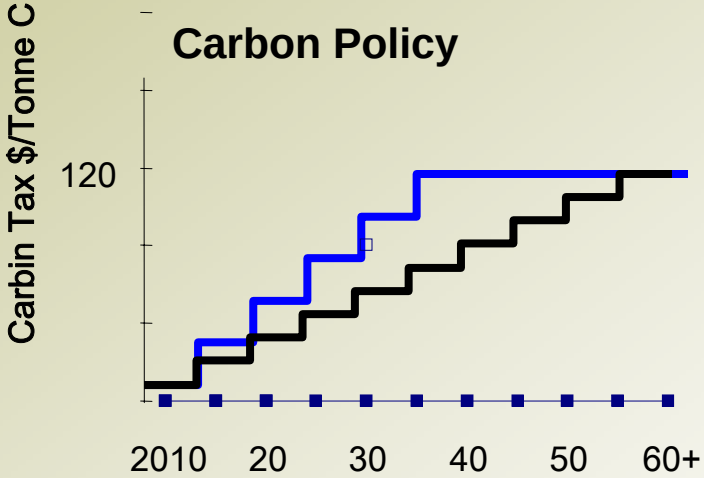
Optimal Decisions:

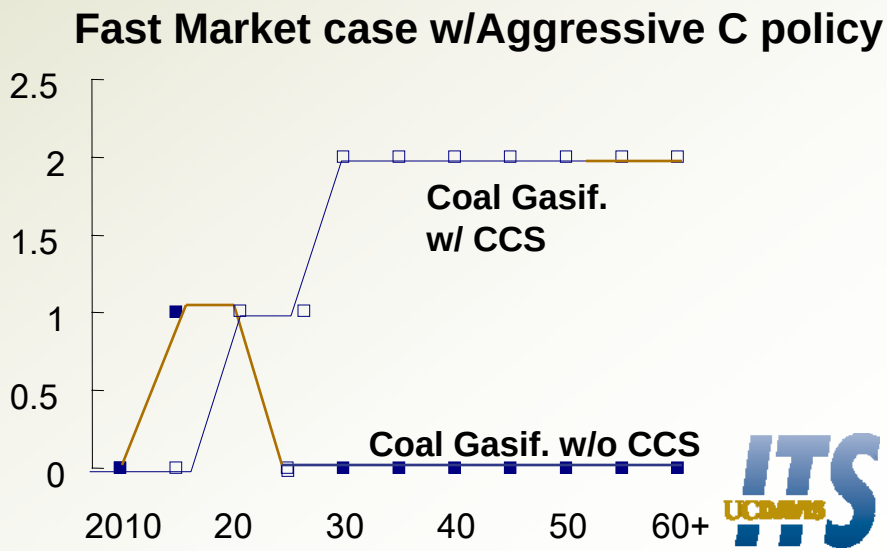
Carbon Policy Leads to Carbon Sequestration,

But Policy needs to "keep up" w/market for low-C transition



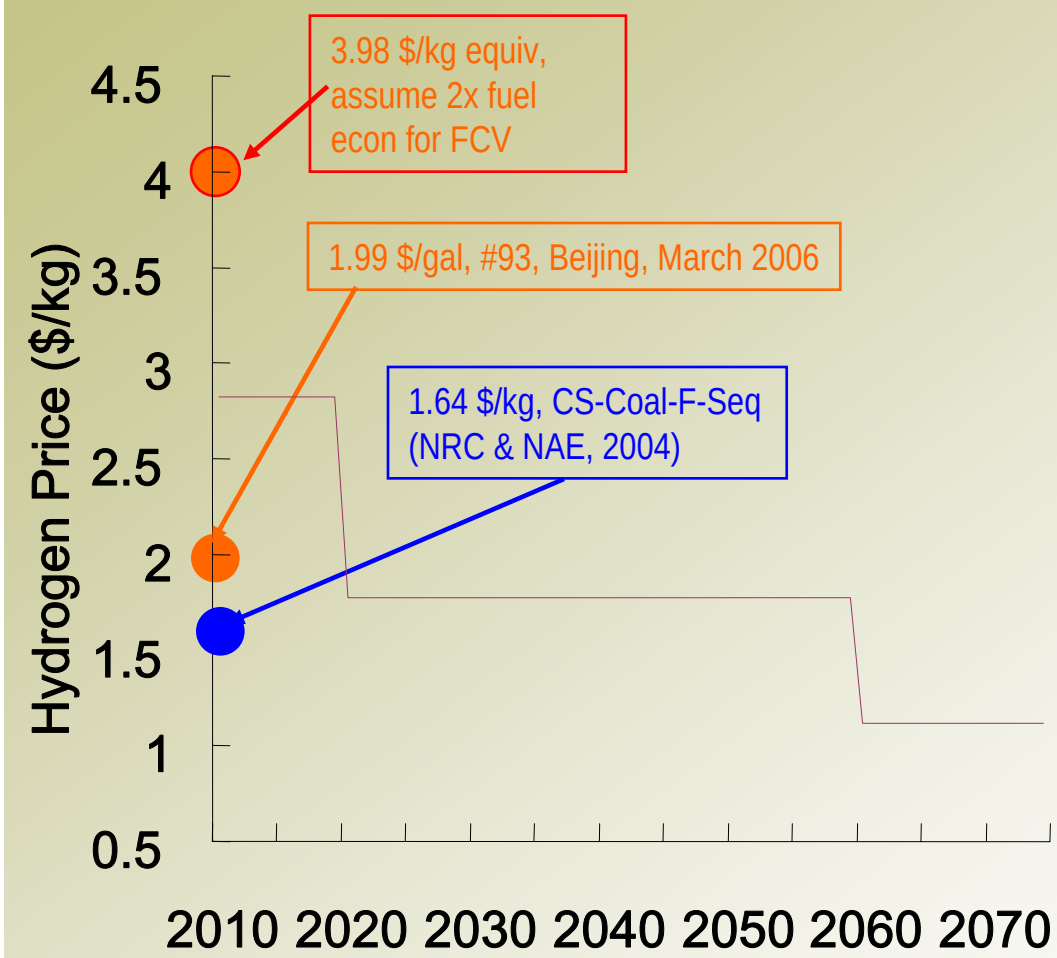






Pricing Strategy for a H_2 Transition?

Phased H_2 Pricing for 12% IRR



- Price H_2 higher initially to pay for more costly early infrastructure
- Lower price over time
- 12% IRR at ~$3/kg for first 10 years;
- $2/kg for next 40 years.
- About $1.2/kg from 2060 on

Cross-cutting issues for H2 Transition

H2 transition impacts entire energy system

H2 transition => Multiple transitions

- Vehicle technology
- Supply infrastructure
- New, low carbon primary supply

Some of these transitions are beginning (though not exclusively tied to H2)

Efficiency is the first step -> sustainable transportation future

H2 part of a larger trend toward decarbonization of energy and more efficient use of resources.

What are Policy & Business Strategies for H_2?

The Dynamic Context for Hydrogen

- In 2003 H_2 widely seen as the "end-game"
  - Better understanding of issues for FCVs, H2 => Projections for 2012 – 2020 for FCV commercialization
  - Many still see H2 as long-term option, seek near term strategy.
- Now several options are widely discussed.
  - Cellulosic ethanol (trees, switch grass, etc)
  - Battery electric vehicles (and plug-in hybrids) with low-carbon grid electricity

KEY DRIVERS FOR H2

MARKET AND BUSINESS DRIVERS FOR H2

- Vehicle suppliers
  - "Better" vehicle?
  - FCVs attractive to consumers?
  - FCVs as "halo" vehicles?
- Energy companies
  - Low Carbon fuel
  - H2 as "halo" fuel?
  - Fuel diversity hedging

POLICY DRIVERS FOR H2

- ZEV mandate
  - 250 FCVs by 2008; 2,500 by 2011, 25,000 by 2014
- California GHG laws
  - AB1493: 30% GHG reduction for new vehicles by 2016
  - AB 32: cap and trade GHG emissions
  - SB 1505: clean H2 (not signed)
- California Low Carbon Fuel Standard
- Station and vehicle funding incentives (local, state, federal); H2 programs in 30 states, 17 countries
- Future CAFE stds?

H2 Transition Strategy

- Need for durable commitments (> 15-20 years)
  - Policy makers: Address Climate change and oil security
  - Consumers: To buy based on green, high-tech values now captured by gasoline hybrids (and in future by H2 and/or FCVs?)
  - Automakers: To mass produce H2 vehicles
  - Energy suppliers: To build H2 infrastructure
- This will time and some real $
- Several actors will probably have to commit together. Who will take the risk?

ACTIONS TO ENABLE A H_2 ECONOMY

- RD&D :
  - Fuel cells
  - H_2 storage for vehicles
  - Small scale H_2 production systems
  - Advanced vehicle systems (ICEs, hybrids. FCVs)
  - Low-cost "zero-C" energy supply (elec, H_2, fuels)
- Demonstrate/enable H_2 infrastructure
  - Demonstrate technology
  - Codes and standards
  - Infrastructure transition cost barrier
  - Strategies for H2 infrastructure
- Policies reflecting external costs of energy (near term->long term)

Questions Going Forward

- **H2 Specific Questions**
  - **What are the best regional strategies toward low-C H2 systems?**
  - **H2 Interactions with rest of energy system**
  - **What are potential impacts of technology advances?**
  - **How are decisions made during transition?**
- **How does the cost and feasibility of H2 transition compare to, interact with other fuels? Compare fuel/vehicle pathways wrt economics, emissions, timing.**

H2 Pathways Research Personnel

H2 Research Track Directors

Dr. C.J. Brodrick, Manager, Heavy Duty Fuel Cell Vehicle Program
Dr. Andy Burke, Director, EV Power Systems
Dr. Mark Delucchi, Research Scientist
Mr. Anthony Eggert, Associate Research Director
Dr. Paul Erickson, Assistant Professor (Mechanical Engineerin
Mr. Nils Johnson, Program Manager, Integrated H2 Infrastruct
Dr. Andy Hargadon, Professor, Graduate School of Manageme
Dr. Ken Kurani, Research Engineer
Dr. Marshall Miller, Manager, Hydrogen Bus Program
Dr. Tim Lipman (Joint Research Faculty, UC Berkeley)
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Yongling Sun, Ph.D. student

H2 Pathways Program Sponsors

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▪Air Products & Chemicals ▪BP* ▪Chevron* ▪ConocoPhillips* ▪ExxonMobil* ▪Indian Oil Company ▪Petrobras ▪PG&E* ▪Shell Hydrogen* ▪Southern California Gas ▪Total*	▪Fuji Heavy Ind./Subaru ▪Honda* ▪General Motors* ▪Nissan* ▪Toyota*

Government	
▪California DOT* ▪Federal Transit Authority* ▪NR-Canada*	▪US DOE* ▪US EPA

* Indicates full program sponsor with Advisory Board position