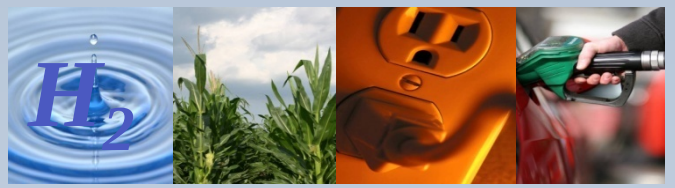
SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
INSTITUTE OF TRANSPORTATION STUDIES



Hydrogen Infrastructure Strategies

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Presented at the NREL Workshop on

Refueling Infrastructure for Alternative Fuel Vehicles: Lessons Learned for Hydrogen

Sacramento, CA

April 3, 2008

H_2 TRANSITION => MULTIPLE TRANSITIONS

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

ALL ALT FUELS/VEHICLES FACE THESE ISSUES TO SOME DEGREE

FIRST STEPS OF THESE TRANSITIONS ARE UNDERWAY (Though Not Exclusively Tied to H_2)

FOCUS OF THIS TALK

THE ROLE OF H_2 INFRASTRUCTURE IN COMMERCIALIZATION OF H_2 VEHICLES

- **Early market/transition issues**
  - **Station deployment strategies**
  - **Transition costs**
- **H2 Infrastructure Design**
  - **Pathway choice**
  - **Cost**

EARLY MARKET/TRANSITION ISSUES

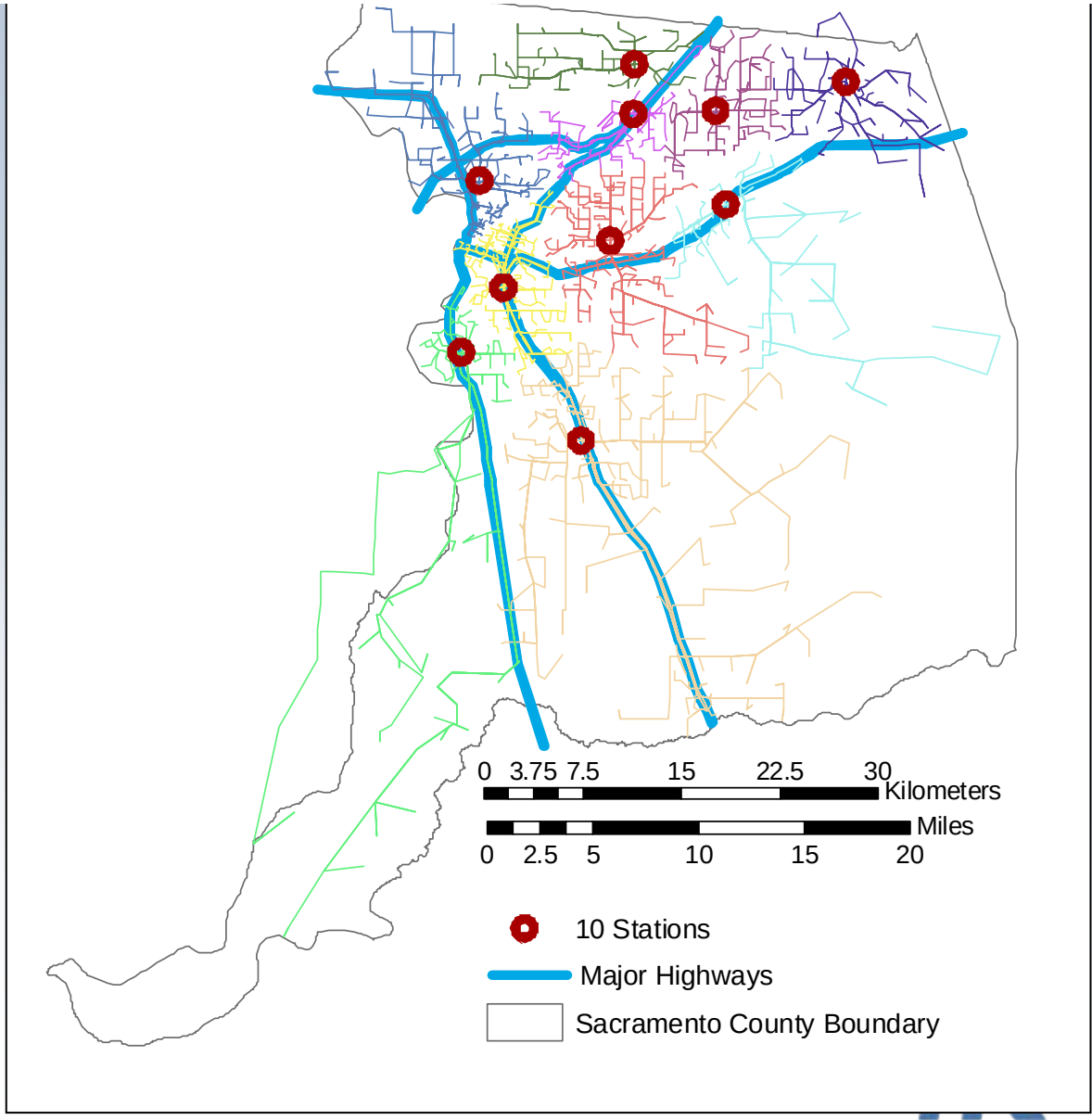
We know how to build individual H_2 stations

Issues:

- Station deployment strategies
  - Coordination: Timing and Co-location H_2 vehicles, users and stations
  - Station siting and permitting
  - # of stations
  - Lighthouse Concepts
- Transition costs (stations and vehicles)

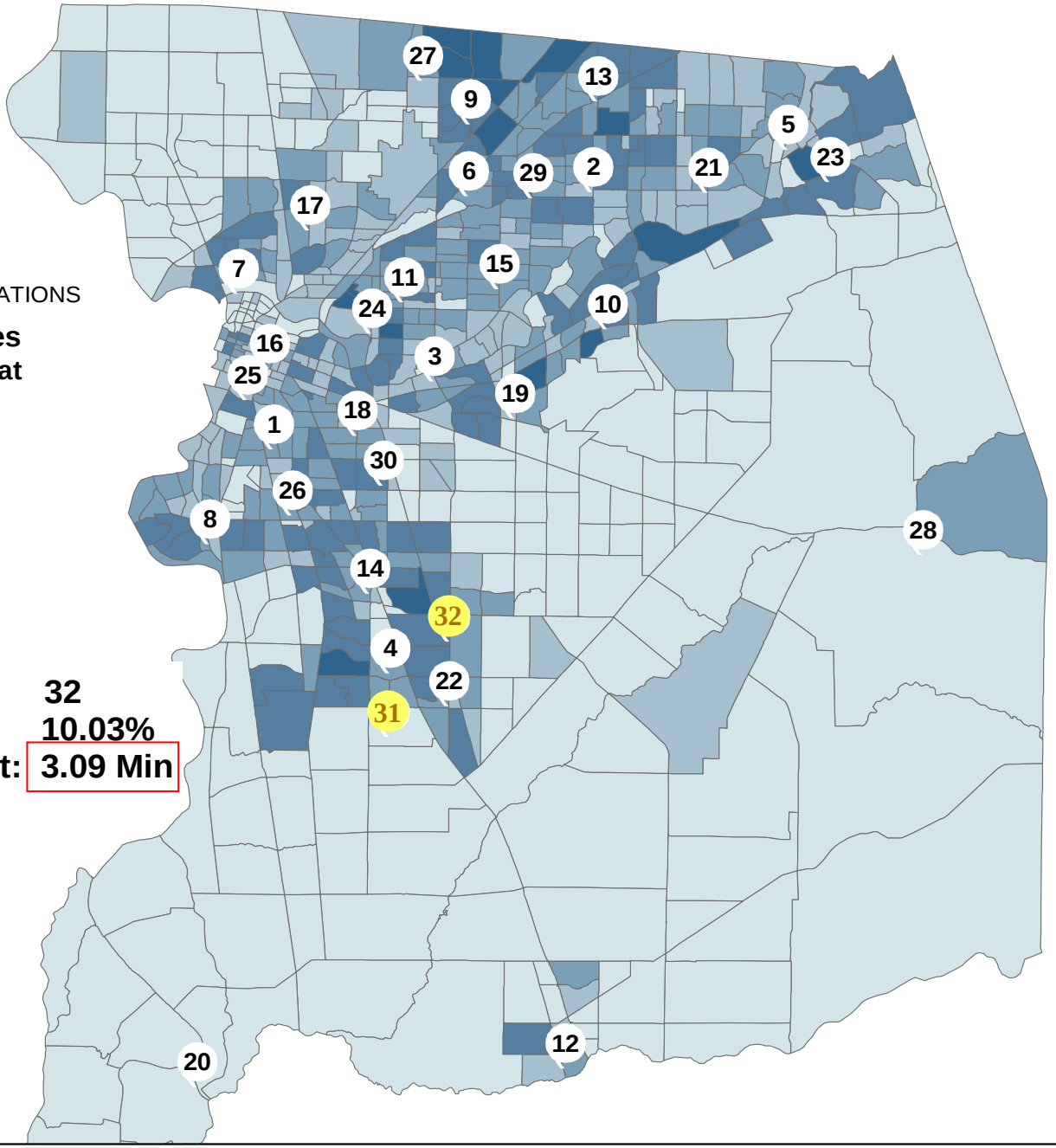
H_2 STATION DEPLOYMENT STRATEGY

- How many H_2 stations are needed for consumer convenience?
- Where should they be located?
- Use 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

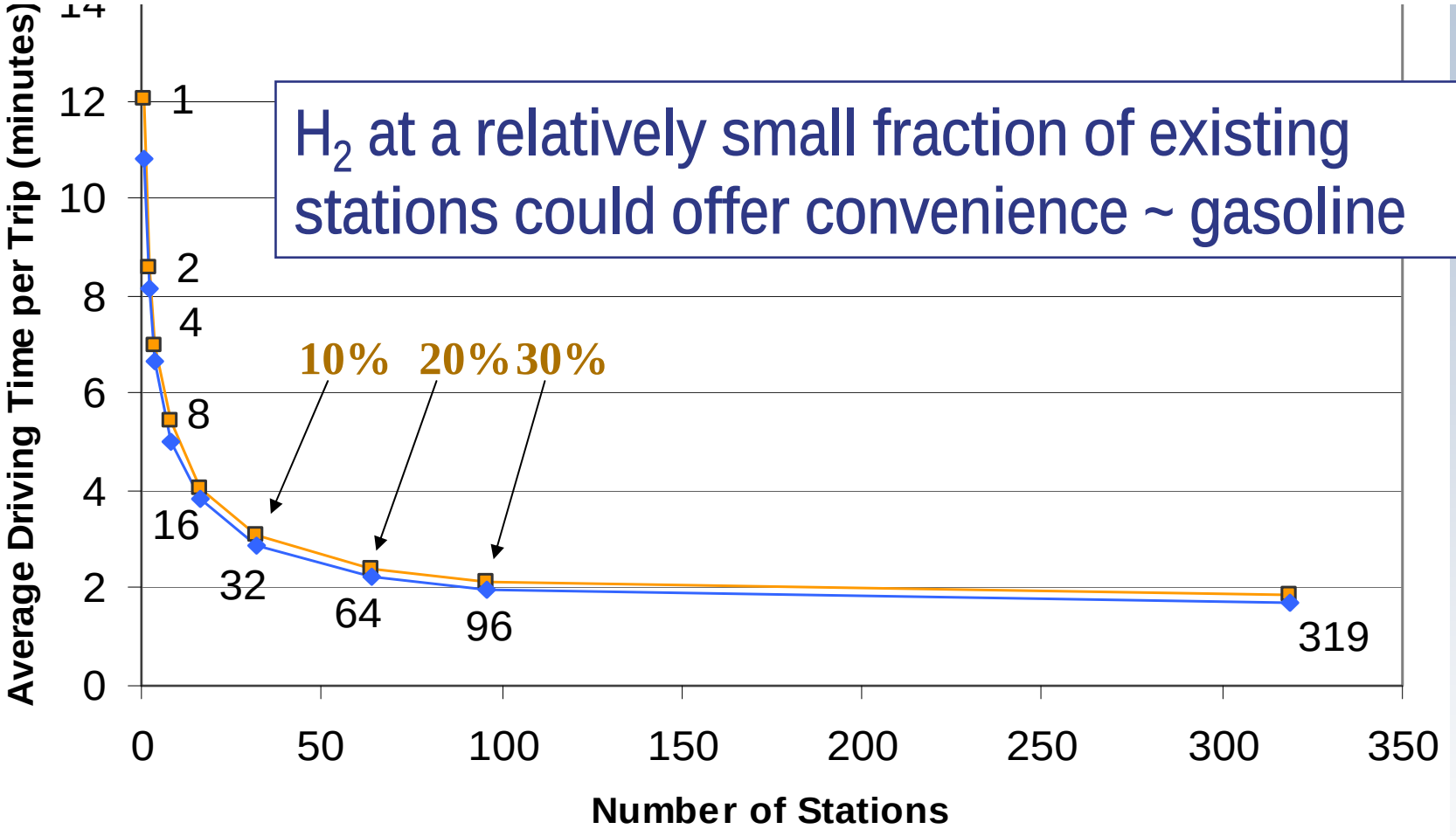
(HYPOTHETICAL STATIONS

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

AVE. TRAVEL TIME VS. # H_2 STATIONS



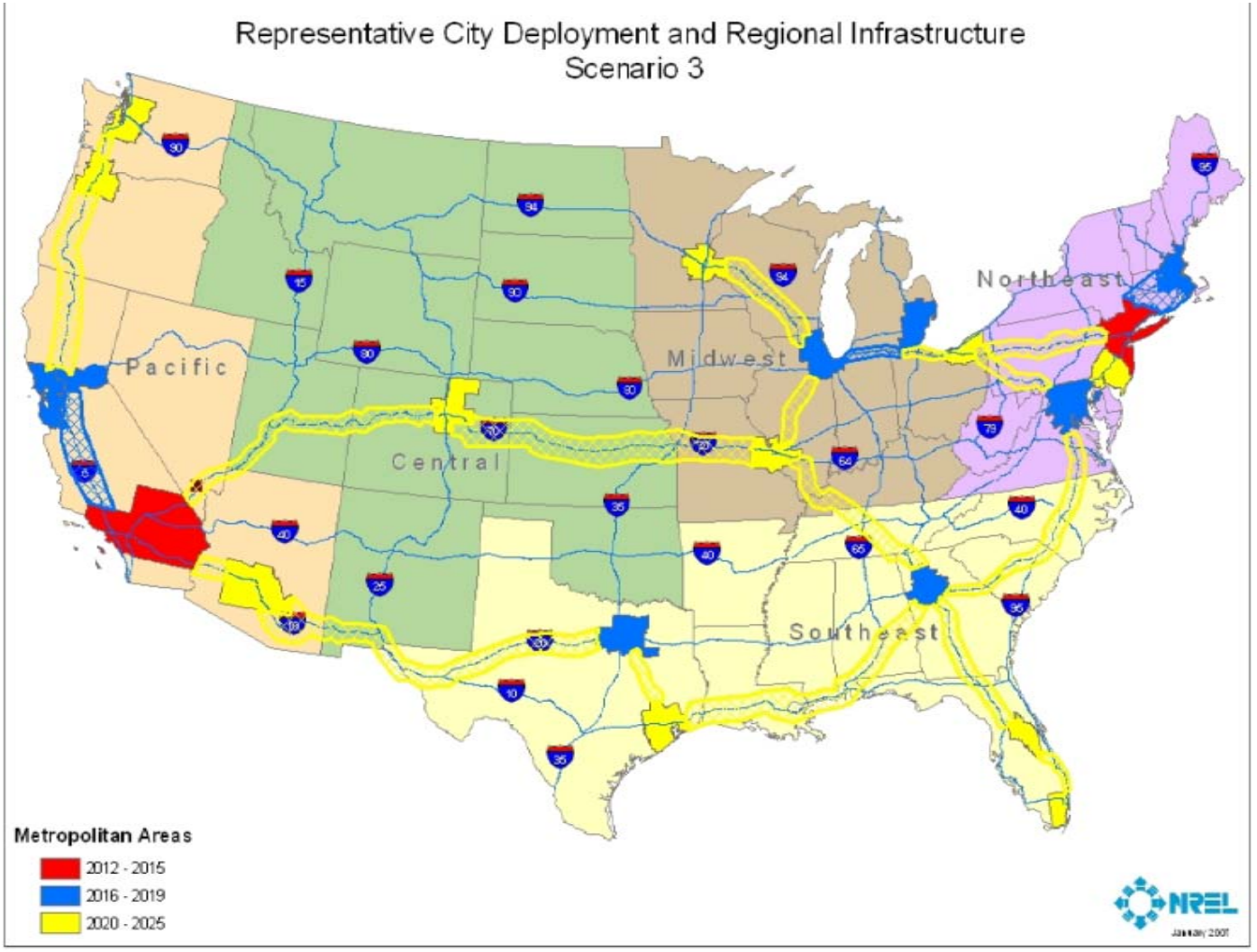
H_2 at a relatively small fraction of existing stations could offer convenience ~ gasoline

We don't need H_2 at every gasoline station to get started. Sparse network is OK initially.

LIGHTHOUSE CONCEPT

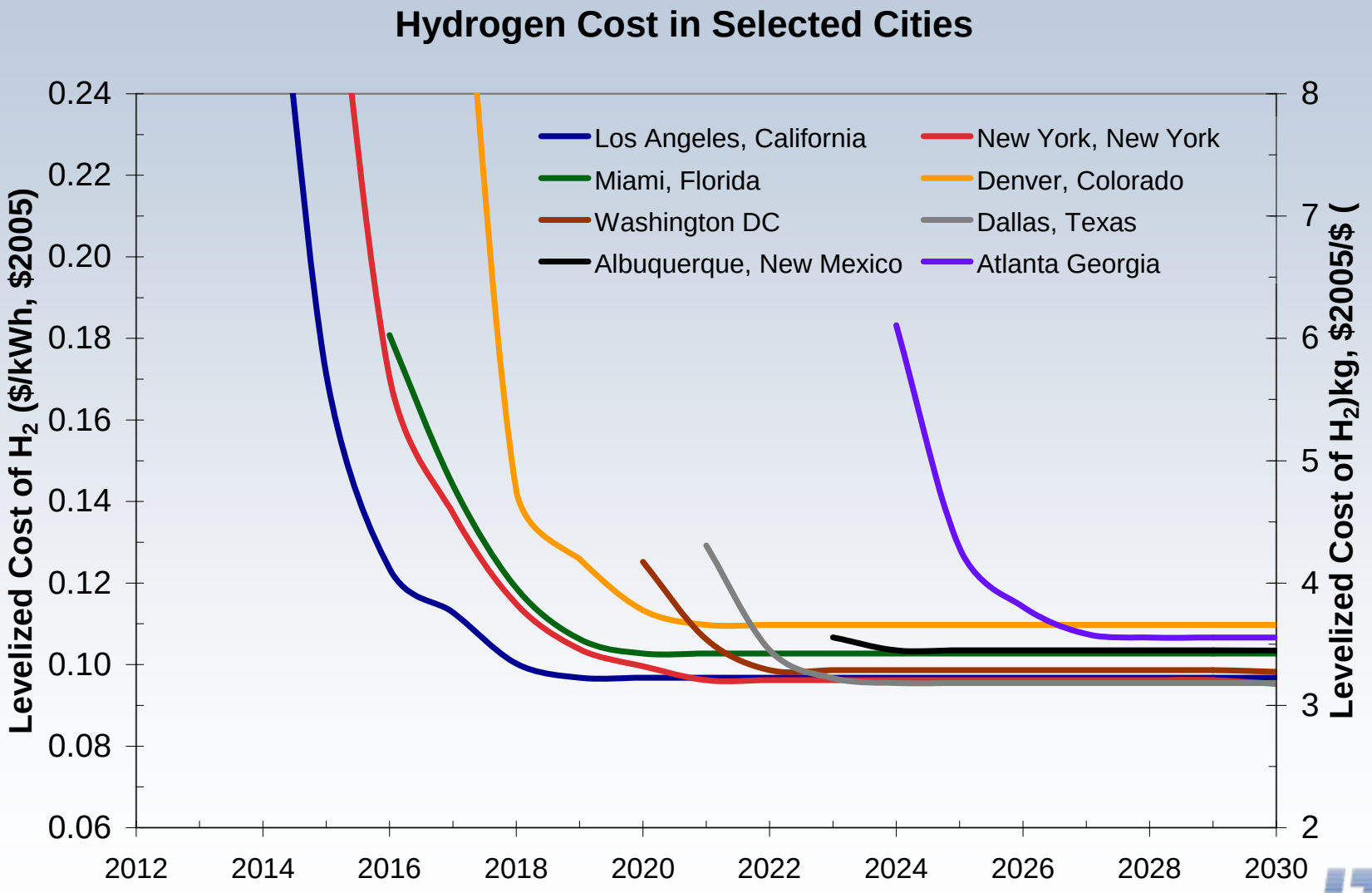
Concentrate early H2 Infrastructure in a few key cities to reach low cost via scale economies

DOE Scenario for Phased Introduction of H2 in Lighthouse Cities.



H_2 COST IN SERIES OF US LIGHTHOUSE CITIES

(UCD Infrastructure Model Results for Lowest Cost Supply Pathways)



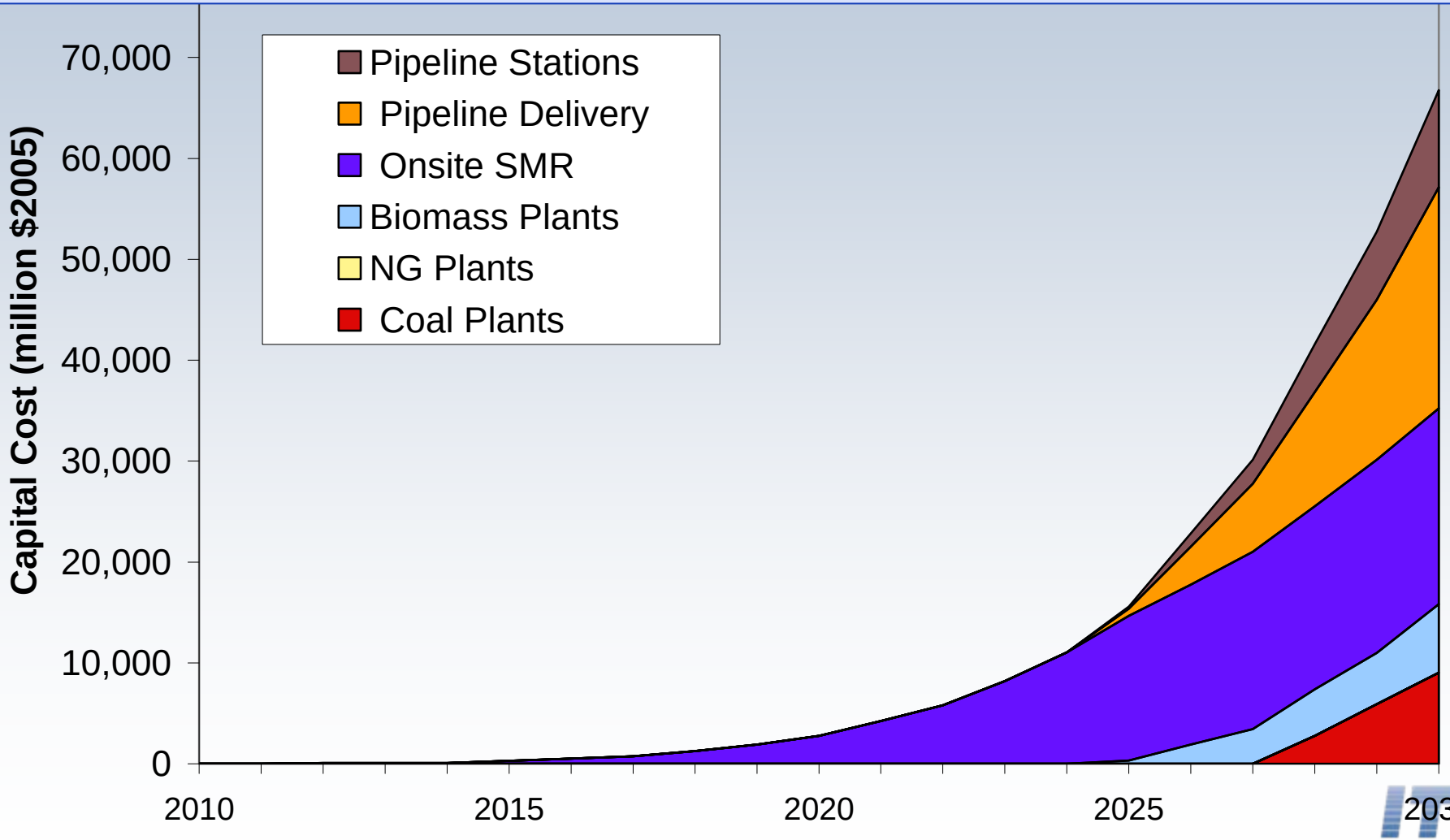
Ogden, Melaina and Yang NHA, 2008.

UCD MODEL RESULTS

LOWEST COST H_2 SUPPLY PATHWAYS

Onsite

SMR + central biomass + central coal w/CCS w/pipelines



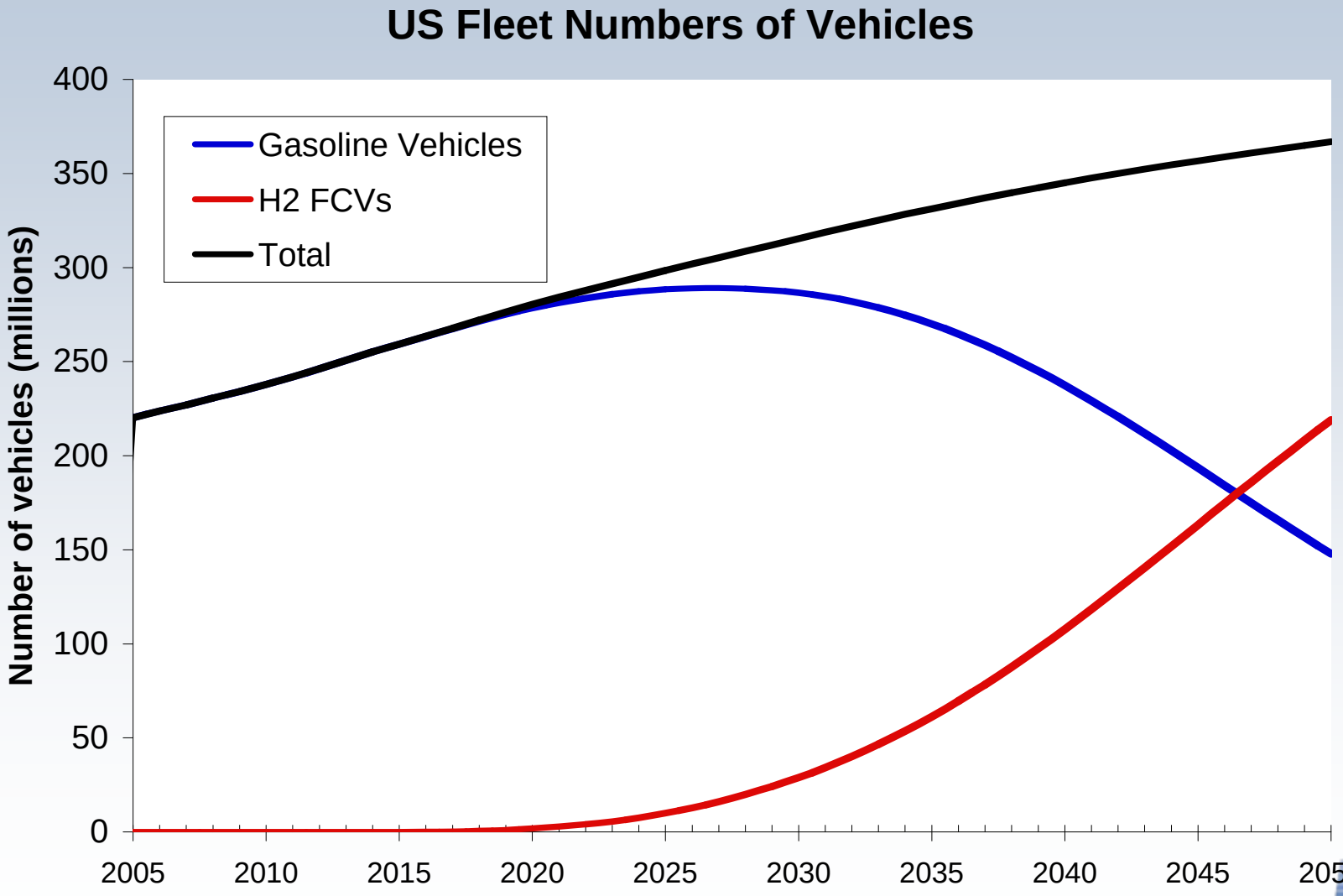
Ogden, Melaina and Yang NHA, 2008.

H_2 TRANSITION COST

What are investment costs required for H_2 fuel cell vehicles to reach lifecycle cost competitiveness with reference gasoline vehicles?

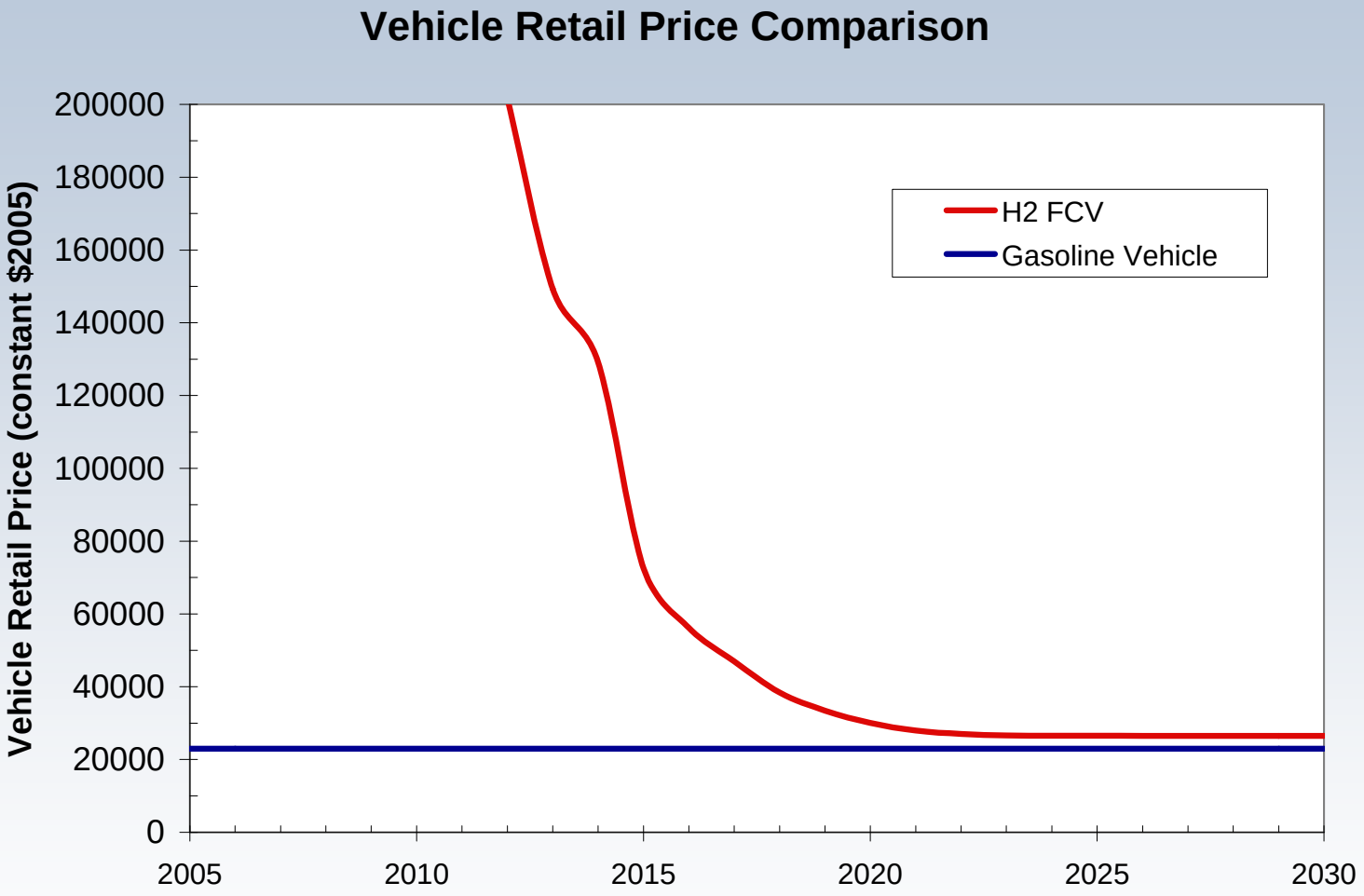
- **H_2 Vehicles**
- **H_2 Infrastructure**

H_2 FCV INTRODUCTION SCENARIO



Ogden, Melaina and Yang NHA, 2008.

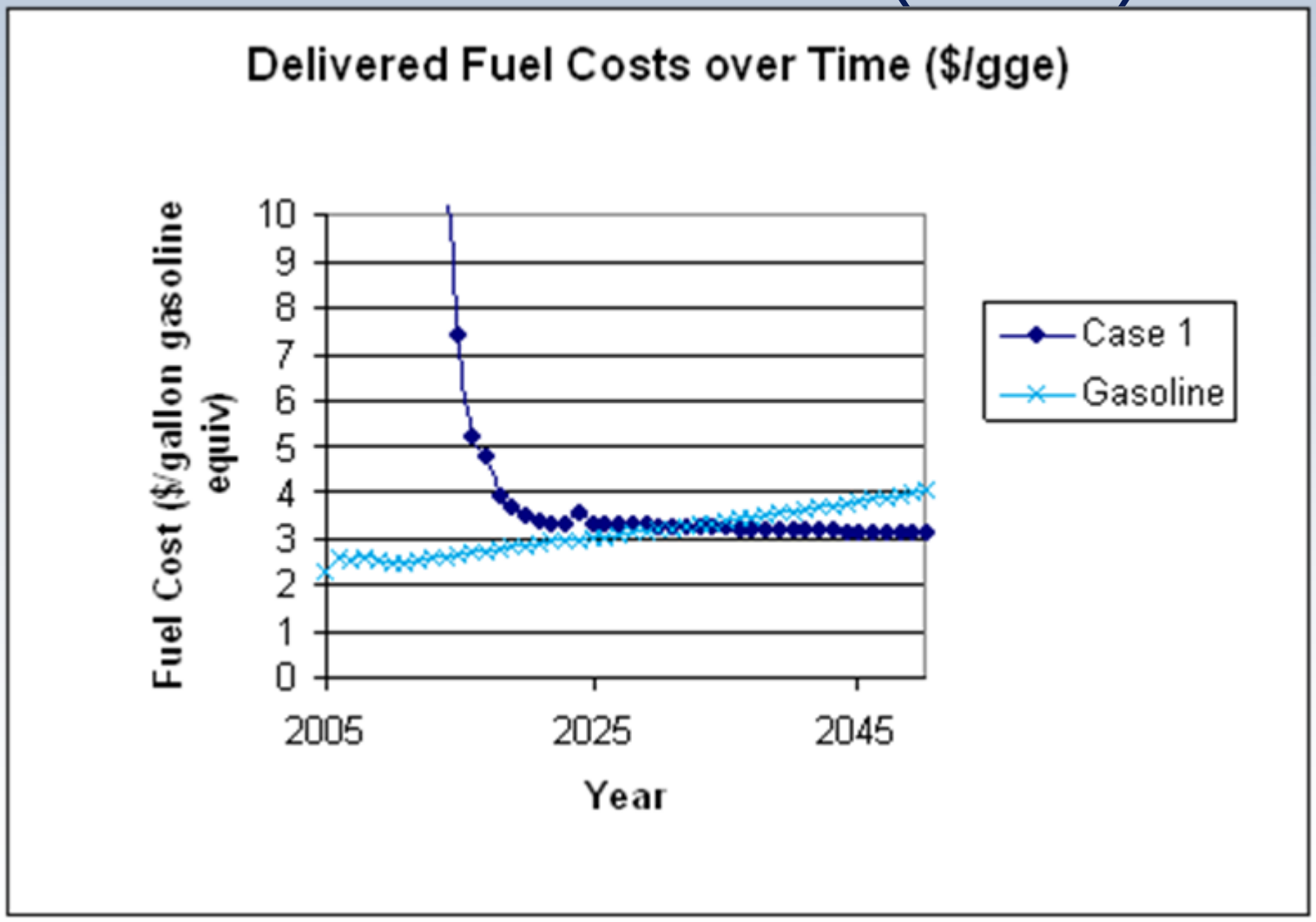
H_2 FCV PRICE VS. TIME



Price falls due to R&D improvements, cumulative experience and manufacturing scale-up.

H2 FCV Vehicle Price from Greene, Leiby, Bowman (2007).

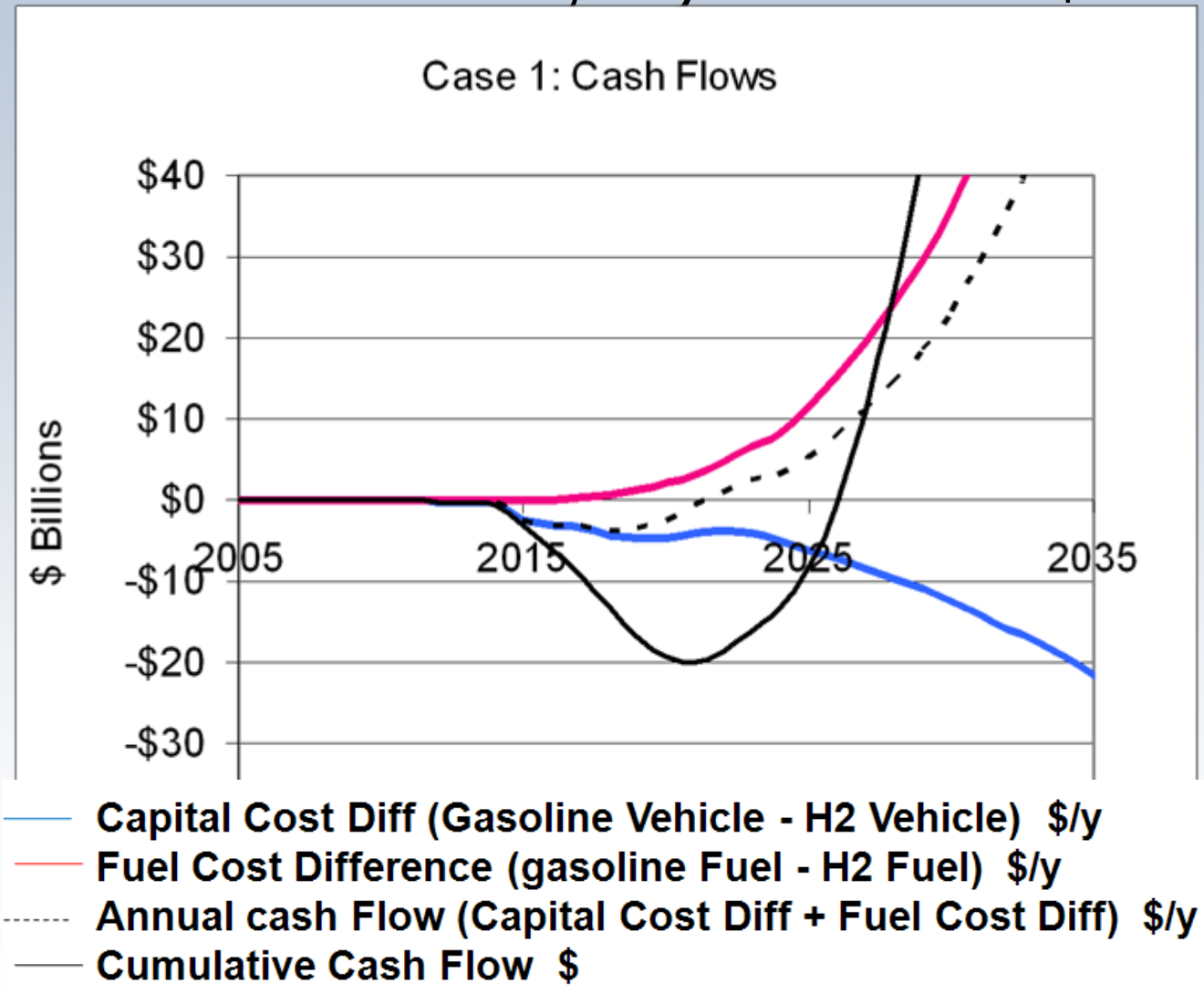
US AVERAGE DELIVERED H_2 COST VS. GASOLINE PRICE ($/GGE)



Ogden, Melaina and Yang NHA, 2008.

CASH FLOW ANALYSIS

Breakeven Year = 2022; Buydown Cost ~ $20 Billion



Ogden, Melaina and Yang NHA, 2008.

H_2 TRANSITION TIMING AND COSTS

Breakeven Year (Annual Cash flow = 0)	2022
Cumulative cash flow difference (H2 FCV - Gasoline ref Car) to breakeven year	$19 Billion
Cumulative vehicles first cost difference (H2 FCVs-Ref Gasoline Car) to breakeven year	$31 Billion
# H2 FCVs cars at breakeven year (millions)	4.1 (1.4% of fleet)
H2 cost at breakeven year	$3.3/kg
H2 demand, # H2 stations at breakeven year	3100 t/d 2900 stations
Total cost to build infrastructure for demand at breakeven year	$5.8 Billion

Breakeven takes ~10 years (~4 million FCVs); Total cost is ~$40B; Vehicle buydown ~80% of cost;

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INSIGHTS ABOUT H_2 INFRASTRUCTURE STRATEGIES AND COMMERCIALIZATION

Infrastructure Modeling Results

- Sparse station networks offer adequate consumer convenience (don't need H_2 at every gasoline station to start)
- Concentrate early infrastructure in lighthouse cities to benefit from scale economies (don't want H_2 in every city to start)
- Best H_2 supply pathway depends on demand level, geography, local energy prices, policy. (Trends: distributed -> central production; NG -> renewables, fossil w/ CCS; long-term larger, fewer stations than gasoline)

Assuming Rapid Implementation of H_2 FCVs (10 Million~2025)

- H_2 FCVs come down learning curve once they make up a few % of LDV fleet (10+ years after introduction)
- H_2 delivered costs come down scale economy curve in lighthouse cities 5-10 years after introduction.
- Overall transition costs $10s Billions over 10+ years (>80% for vehicles; <20% for infrastructure)

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