U.S. Department of Energy Hydrogen Program

Analysis of the Transition to Hydrogen Fuel Cell Vehicles & the Potential Hydrogen Infrastructure Requirements

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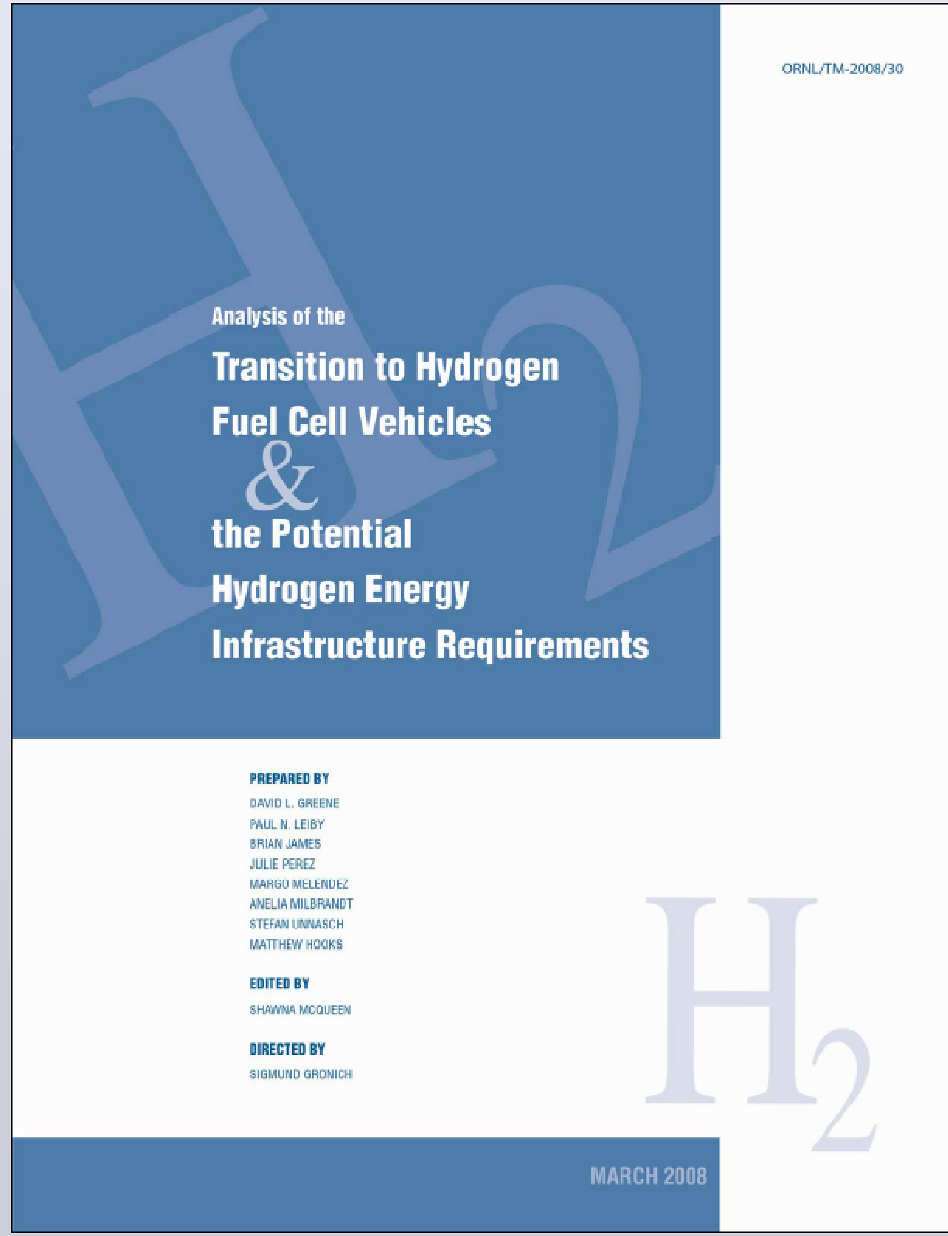
Oakridge National Laboratory

2008 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting

June 9, 2008

The report, published this year, documents the first integrated hydrogen transition analysis.


ORNL/TM-2008/30

Analysis of the
Transition to Hydrogen
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&
the Potential
Hydrogen Energy
Infrastructure Requirements

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MARCH 2008

cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf

The analysis responded to the NAS' call to better understand what a transition to hydrogen powered vehicles would require.

- **NAS 2004 Hydrogen Economy report**

  "…the DOE should map out and evaluate a transition plan consistent with developing the infrastructure and hydrogen resources necessary to support the (NAS) committee's hydrogen penetration scenario (Scenario 3 of the analysis) or another similar demand scenario. The DOE should estimate what levels of investment over time are required…"

- **Engage the stakeholder community about how the market transformation could happen.**
- **Create useful systems analysis tools capable of representing the "chicken or egg?" dilemma.**
- **Test whether DOE's program goals are sufficient to enable the transition.**
- **Evaluated potential scenarios for the purpose of determining infrastructure and policy needs.**

Engaging stakeholders in reviewing scenarios, premises and methods was a key concept.

- ➔ **Select vehicle penetration rates assumptions for 3 scenarios**
- ➔ **Formulate "lighthouse" market development concept**
- ➔ **Review key components**
  - H2A Hydrogen production/delivery technology
  - PSAT vehicle technology simulations
  - DTI analysis of refueling options and costs
  - NREL analysis of refueling network evolution
- ➔ **Over 60 participants from energy and automotive industries, industrial gas companies, fuel cell technology companies, Federal and state governments, national laboratories and academia participated in 4 workshops.**

The three vehicle scenarios were intended to span a range that would encompass an efficient transition.

Scenario 1:

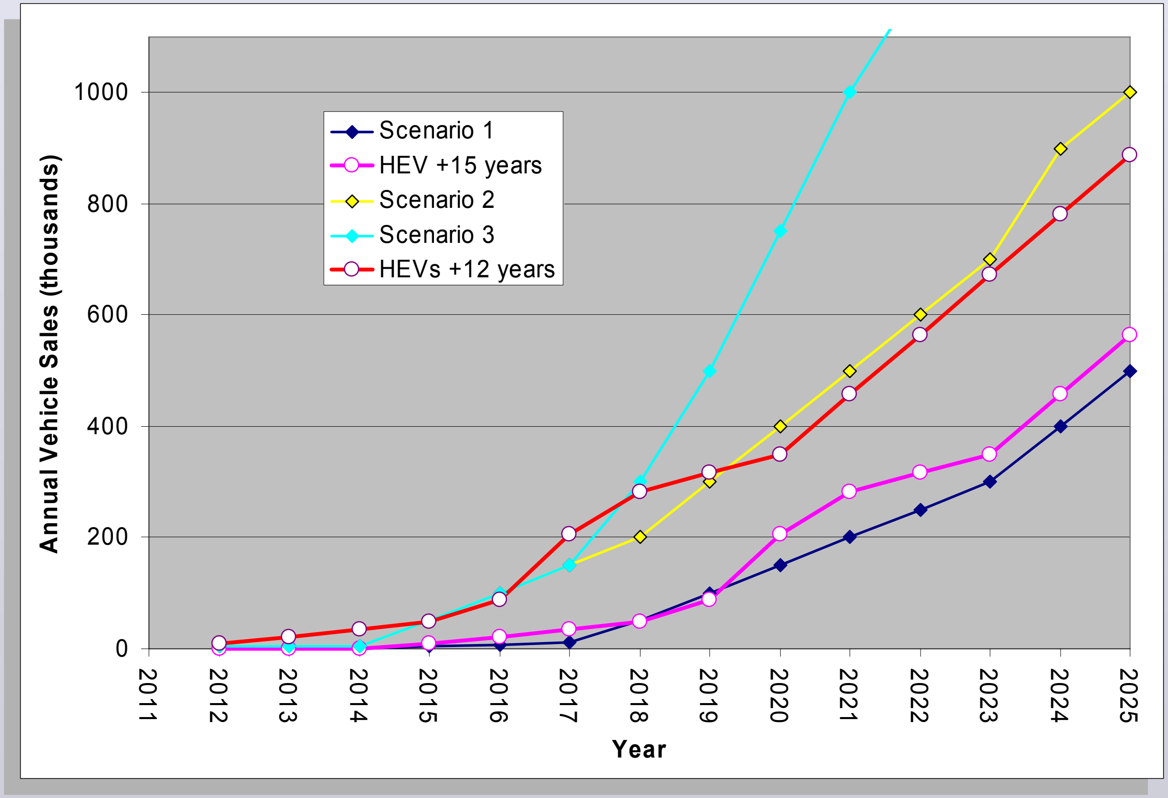
100s per year by 2012, *tens of thousands* of vehicles per year by 2018. On-road fleet of 2.0 million FCVs by 2025.

Scenario 2:

1,000s of FCVs by 2012, *tens of thousands* by 2015 and *hundreds of thousands* by 2018. On-road fleet of 5.0 million FCVs by 2025.

Scenario 3 (NRC scenario):

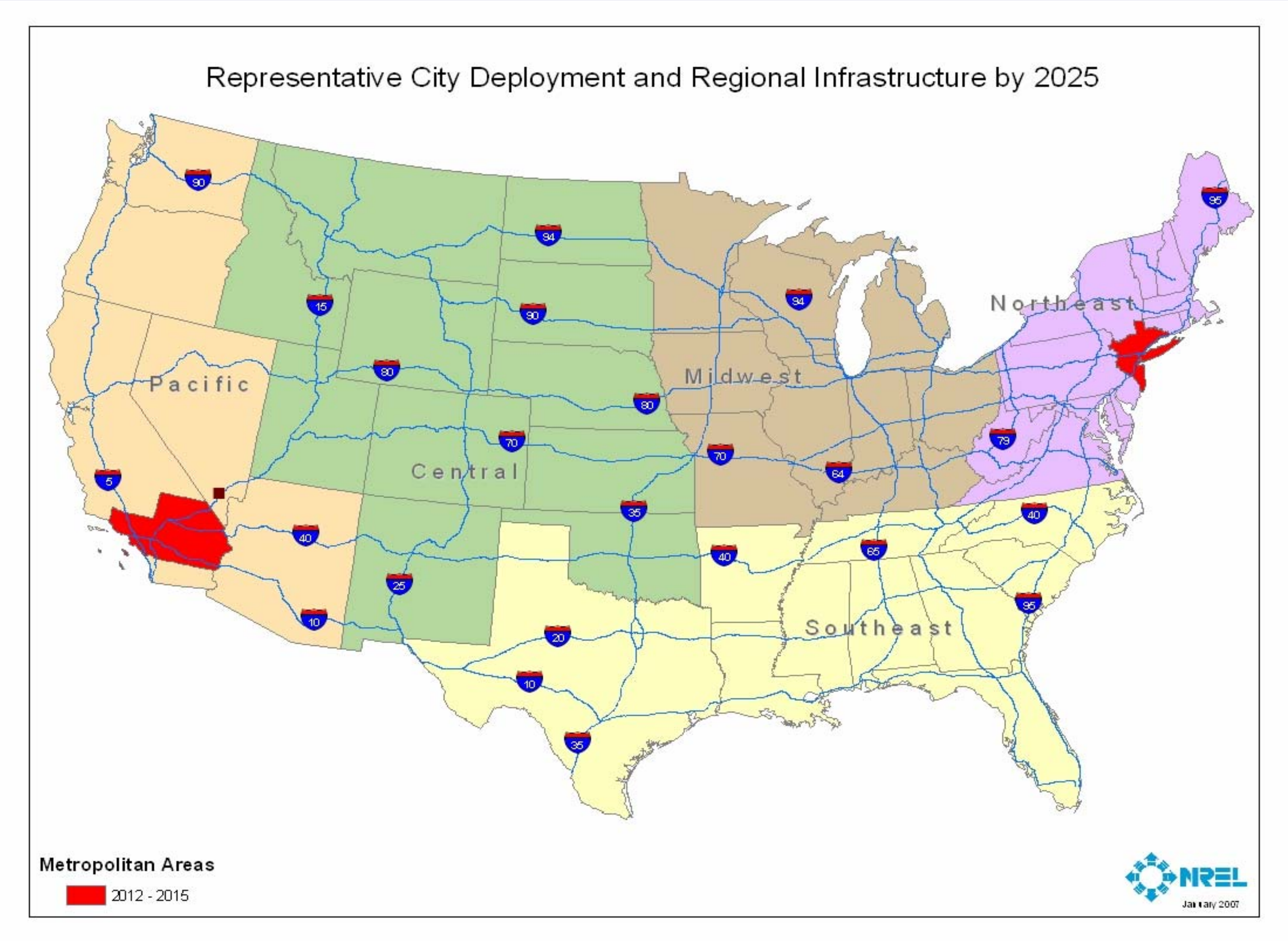
1,000s of FCVs by 2012, and *millions* by 2021, 10 million on the road by 2025.



Scenarios 1 and 2 are consistent with current and projected HEV penetration rates

These scenarios do not represent a plan or policy recommendation.

The Lighthouse concept of infrastructure build-out reflects a trade-off between the need to concentrate infrastructure and the need to maximize hydrogen availability.



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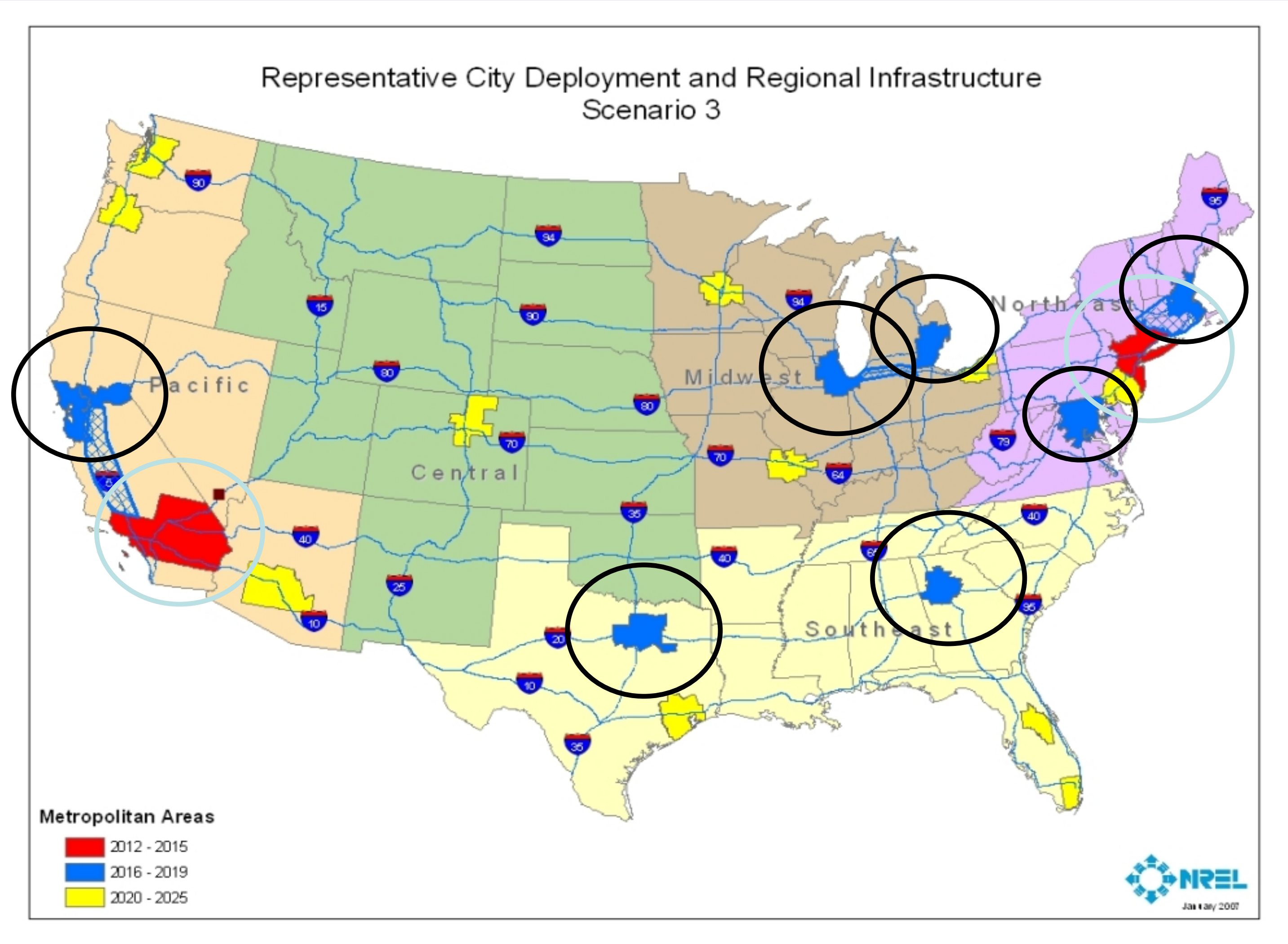

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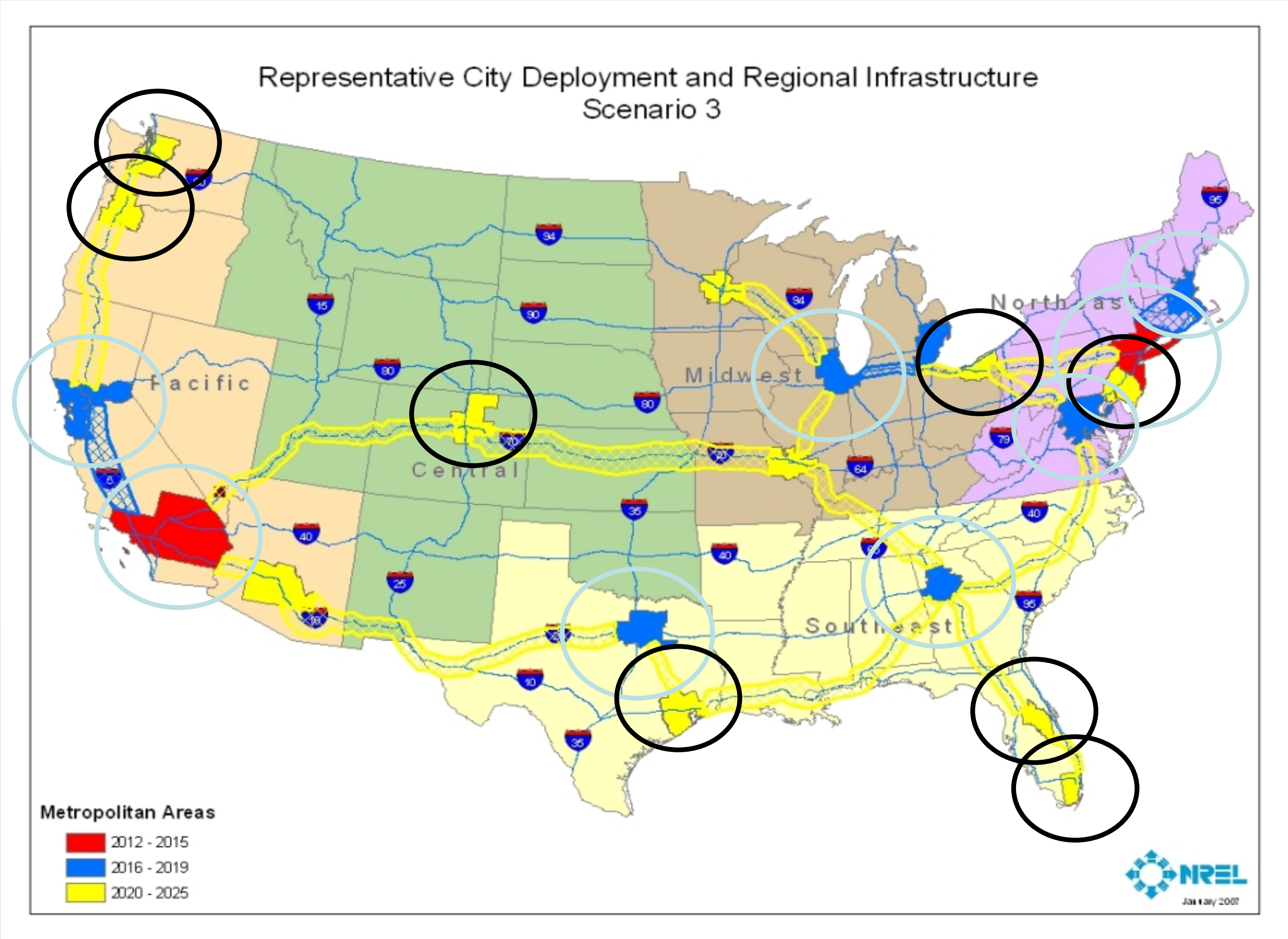


2012-2015: Introduction – LA

NREL analyzed approaches for refueling network evolution

Phase 1 (2012-2015)

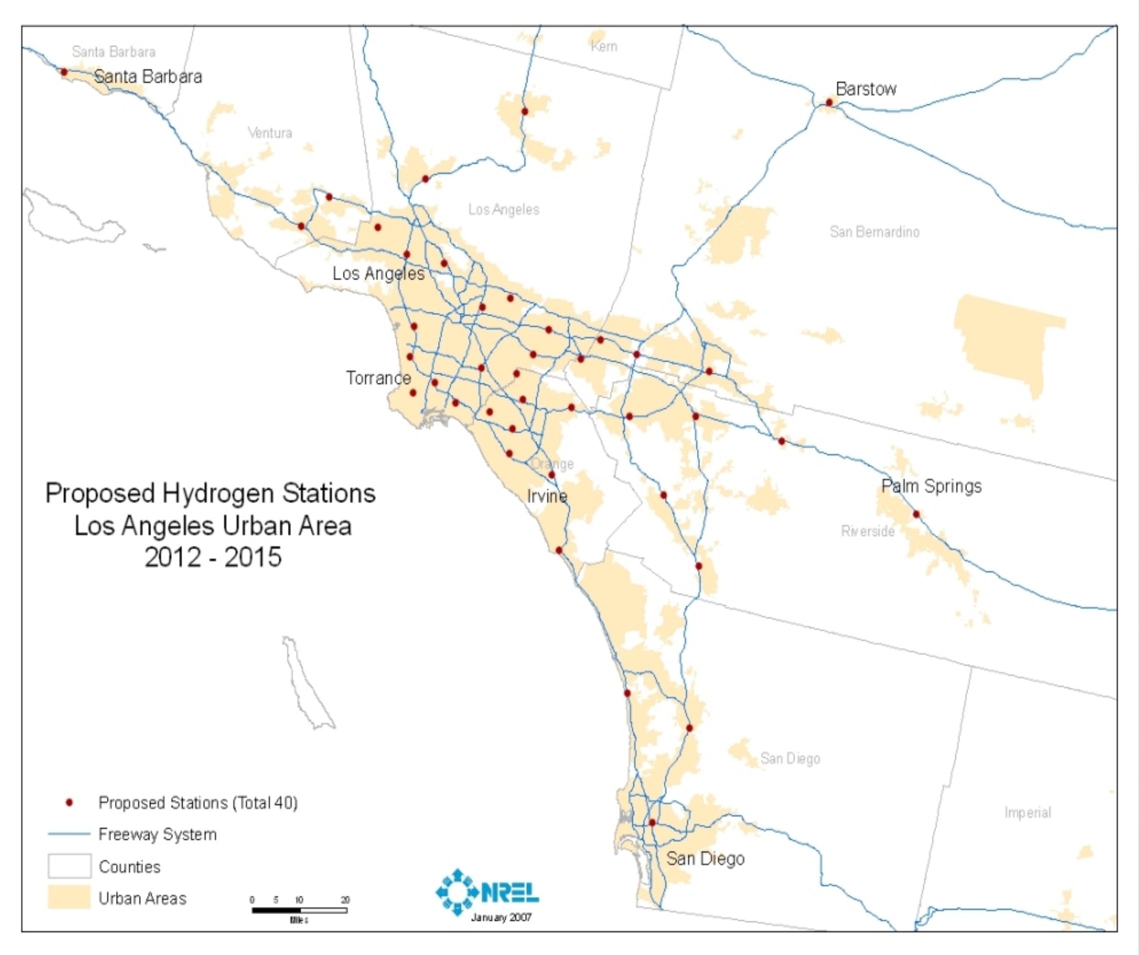
Stations located generally on major arteries

Phase 2 (2016-2019)

Additional stations provided beyond city centers to provide greater driving range

Phase 3 (2020-2025)

High station deployment located outside city limits



Accessibility	Population
3 Miles	23%
5 Miles	51%
10 Miles	88%

2016-2019: Targeted growth– LA

NREL analyzed approaches for refueling network evolution

Phase 1 (2012-2015)

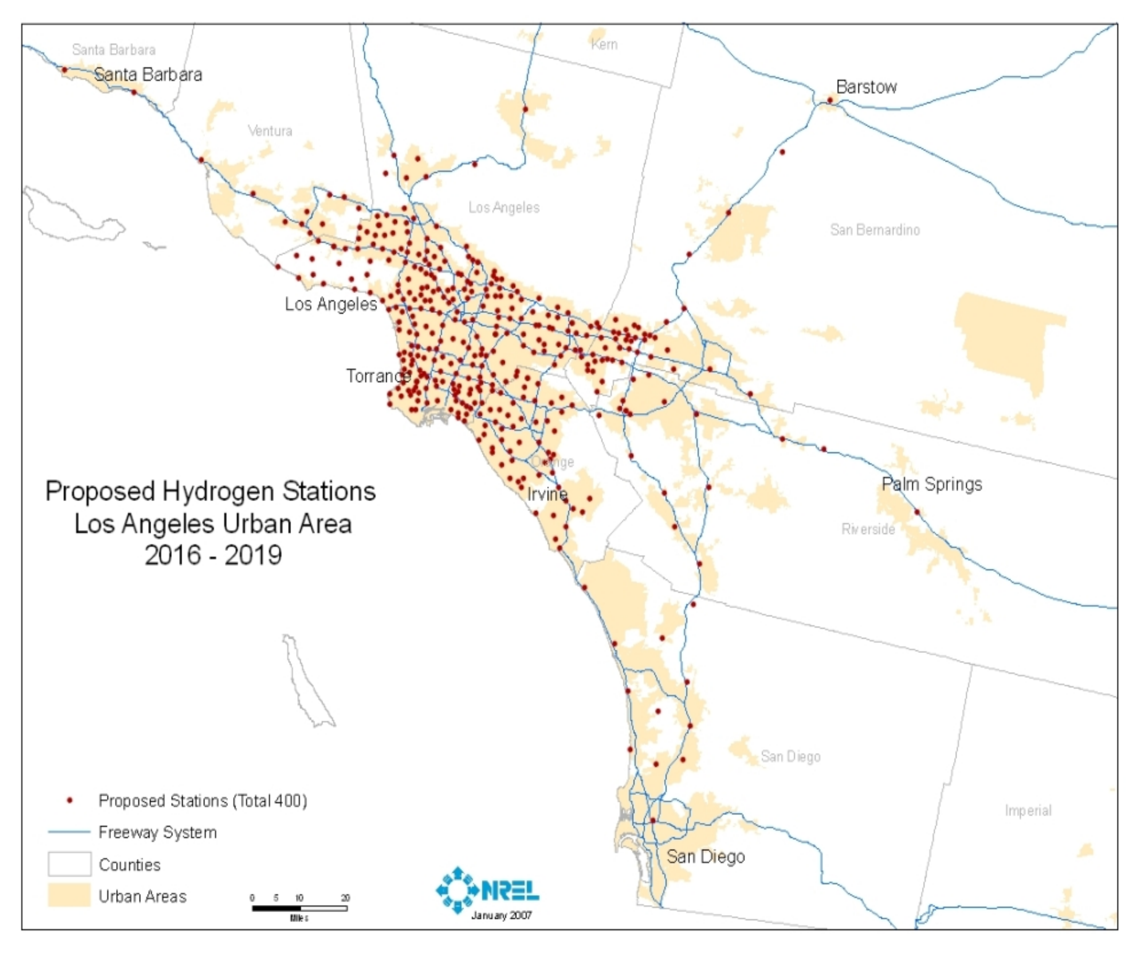
Stations located generally on major arteries

Phase 2 (2016-2019)

Additional stations provided beyond city centers to provide greater driving range

Phase 3 (2020-2025)

High station deployment located outside city limits



Accessibility	Population
3 Miles	73%
5 Miles	83%
10 Miles	94%

2020-2025: Regional Expansion – LA

NREL analyzed approaches for refueling network evolution

Phase 1 (2012-2015)

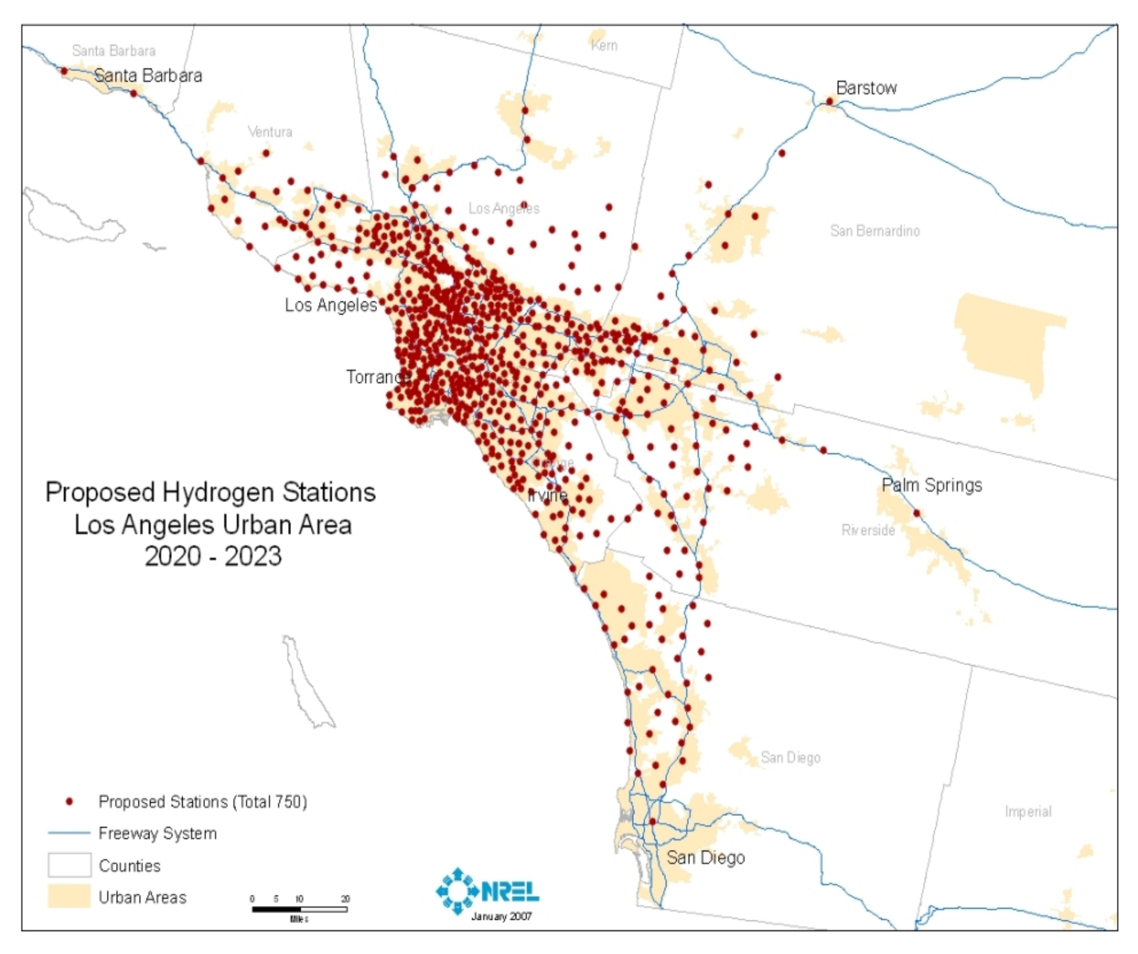
Stations located generally on major arteries

Phase 2 (2016-2019)

Additional stations provided beyond city centers to provide greater driving range

Phase 3 (2020-2025)

High station deployment located outside city limits



Accessibility	Population
3 Miles	83%
5 Miles	89%
10 Miles	95%

Premises matter.

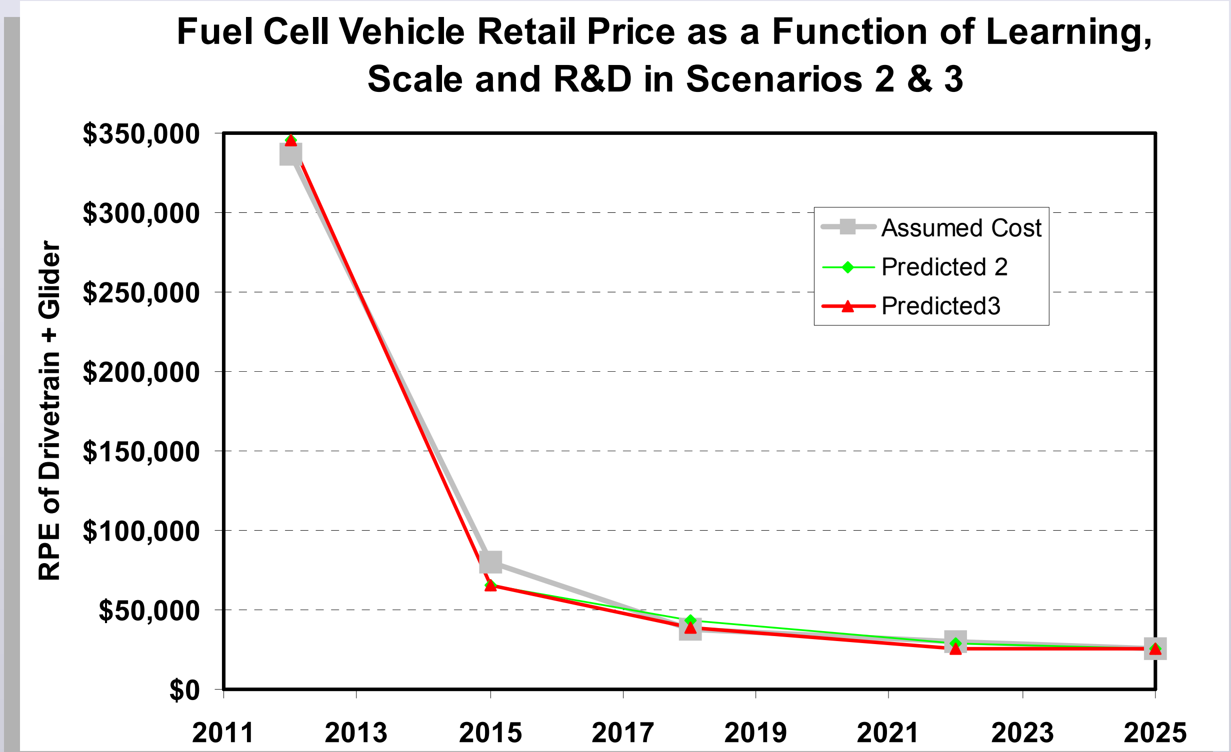
- **All DOE FreedomCar program goals met on schedule.**
  - Vehicle cost and performance estimates based on PSAT/ASCM analysis (Rousseau et al., 2000).
  - Estimates in "DOE Goals" scenario based on meeting program goals in 2010 and 2015, with 5-year lag to the first production vehicles.
- **H2A production and delivery models used for H2 supply costs.**
- **CO2 price impact was investigated in sensitivity cases**
- **2006 AEO oil price scenarios**
  - High Oil Price Case used as base case…$72/bbl in 2015
  - Also Reference Case….$43/bbl in 2015
- **HyTrans constrained to follow scenarios to 2025, then simulate for market solution.**

Excess “transition costs” are incurred in overcoming the natural market barriers to a new transportation fuel.

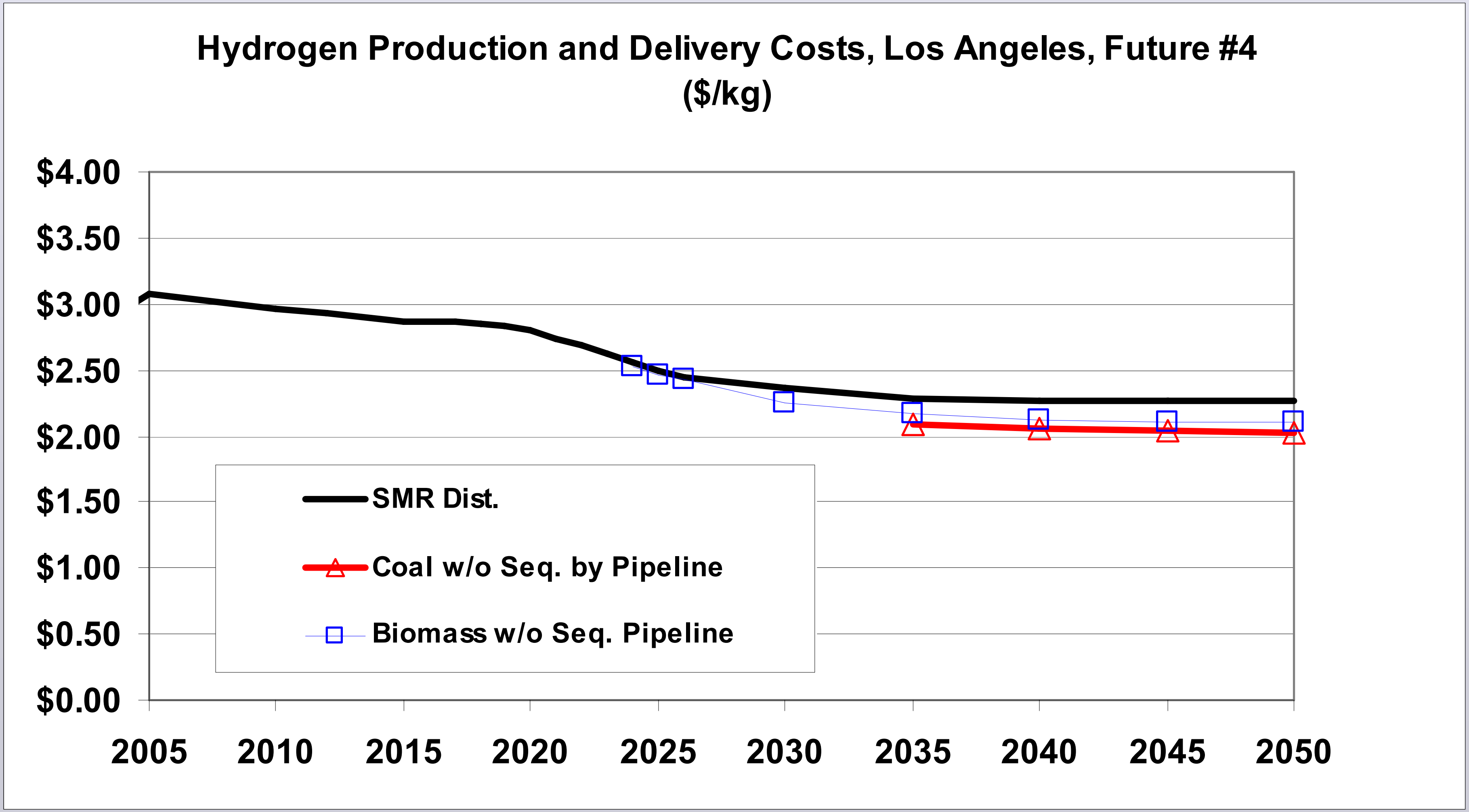
- Limited fuel availability
- Limited make and model availability
- Scale (dis)economies
- Learning-by-doing
- All are represented in HyTrans

In all scenarios FCV costs decline dramatically with reasonable correspondence to the average of the manufacturers' estimates.

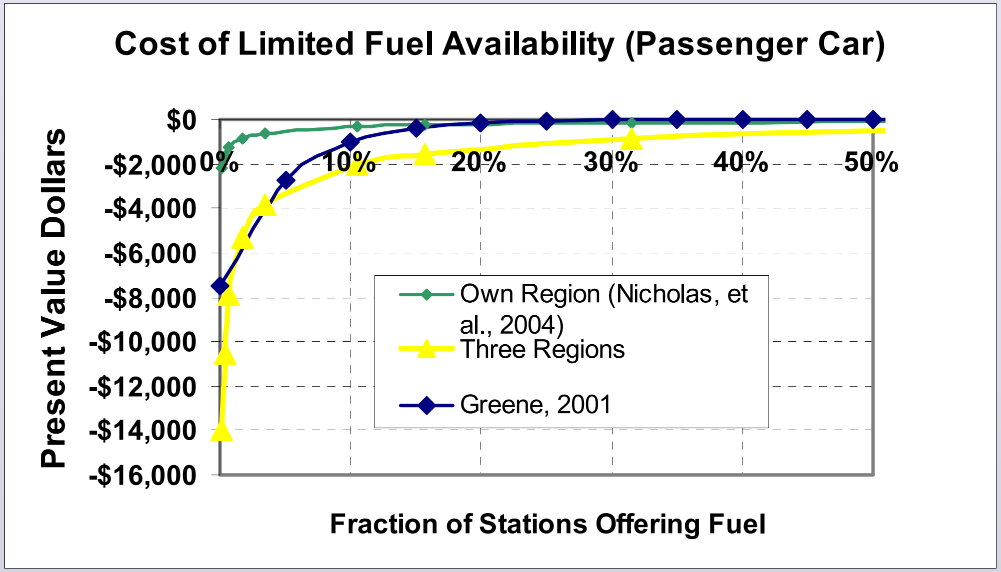
- FCV cost estimates discussed with OEMs – GM, Ford, DC, Toyota, Honda, Nissan, BMW.
- Proprietary cost estimates by year & volume provided by GM, Ford & DC.
- Average used to calibrate HyTrans learning and scale economy functions.
- Results reviewed by GM, Ford, DC and judged reasonable.

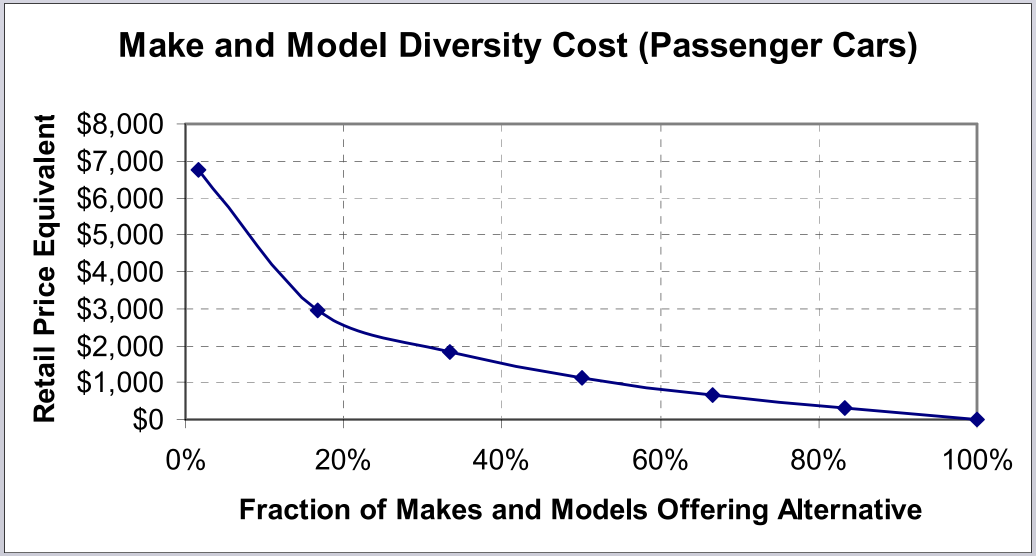


Economies of scale were the chief factor in reducing hydrogen supply costs.



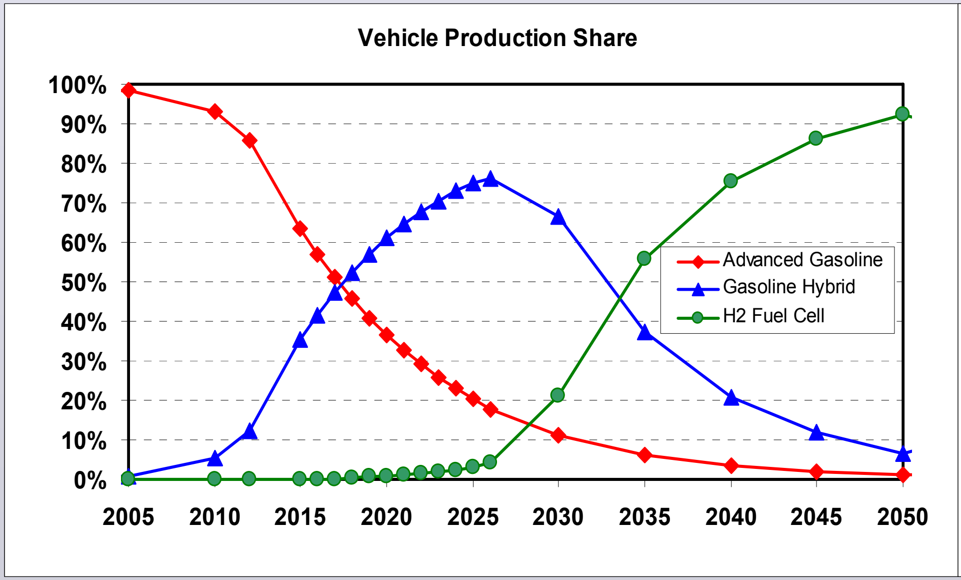
The impacts of limited make and model available and limited fuel availability on consumers' choices were explicitly included in the modeling.



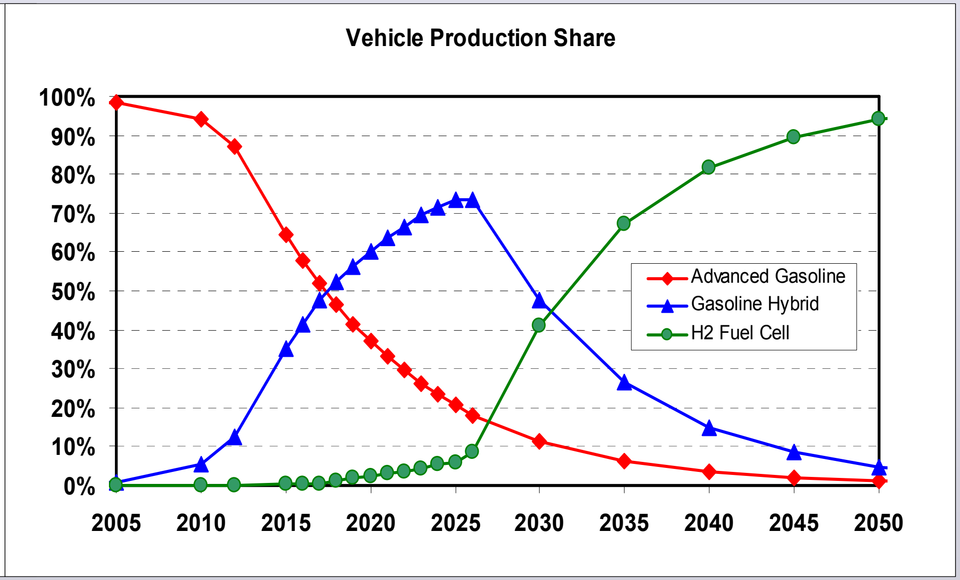


All three scenarios produced a sustainable transition to hydrogen powered light-duty vehicles without any additional policy measures after 2025.

Scenario 1



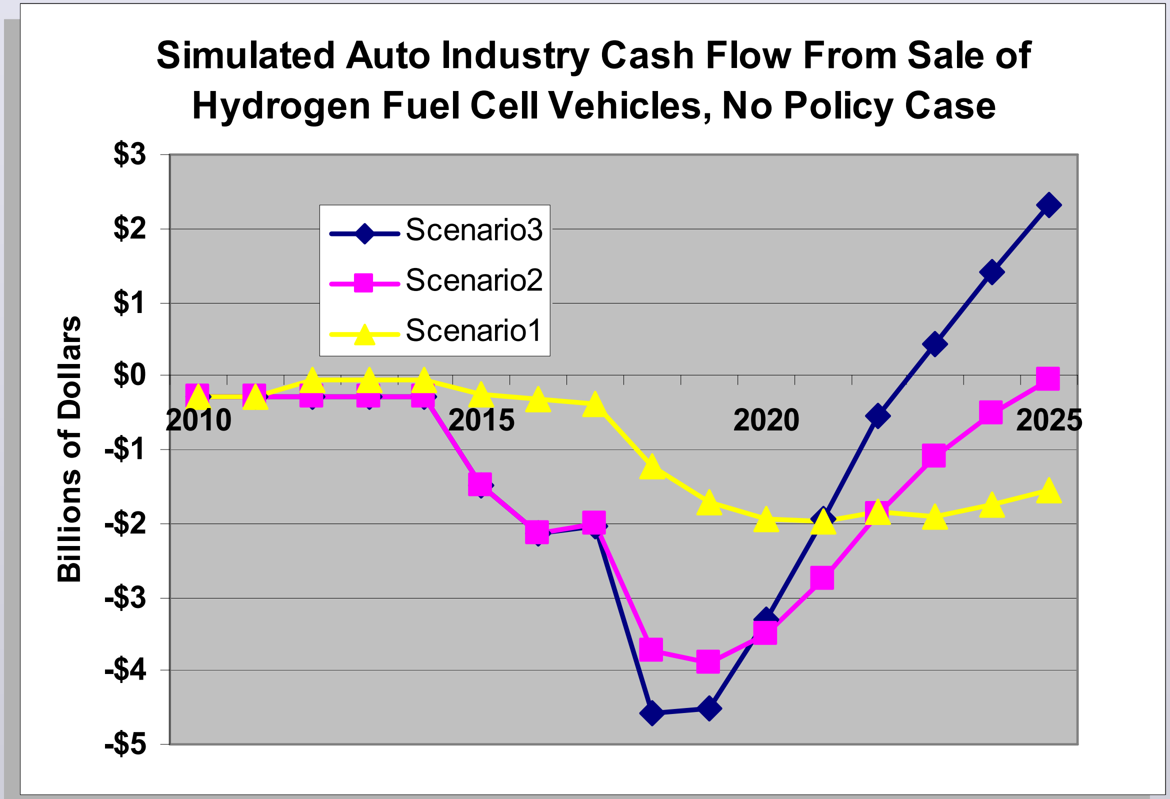
Scenario 3



- Policies will almost certainly be required for early transition period (2012-2025).
- Assumes EIA Hi Oil case and the Hydrogen and FreedomCar Programs achieve full success.
- Does not consider impact of uncertainty on willingness to invest.

The need for transition policies is indicated by the excess costs of the transition scenarios.

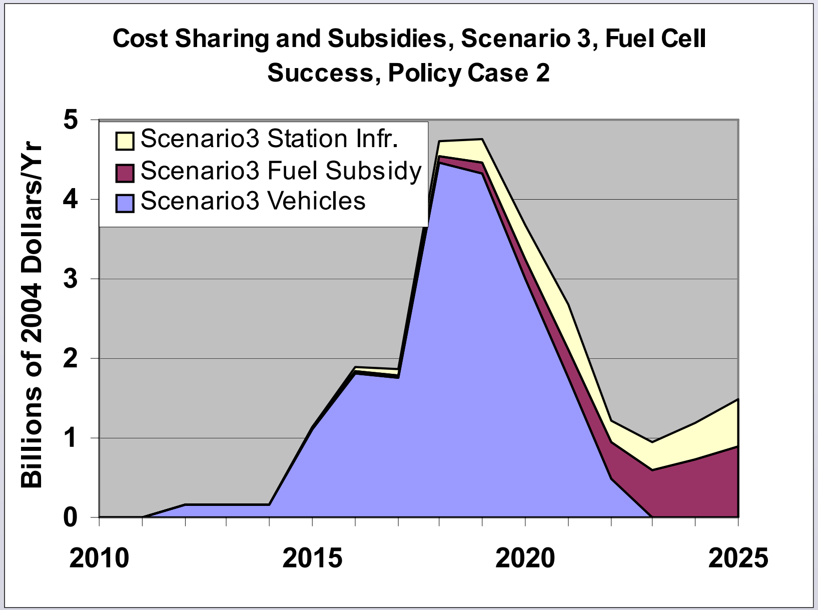
- Without government policies, the entire transition burden would have to be borne by industry.
- Automotive and energy industries faced with years of billion dollar+ losses without government policy.
- Investment unlikely until outer years (2045+)

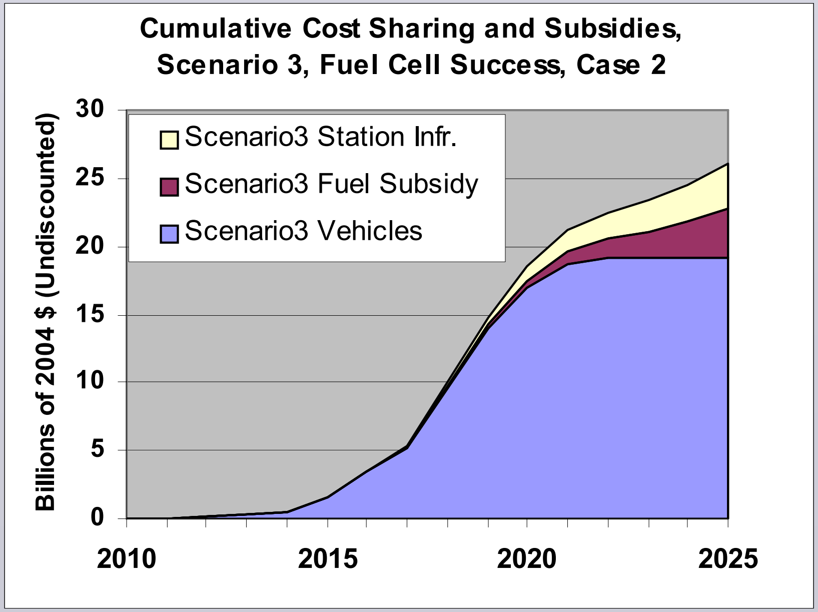


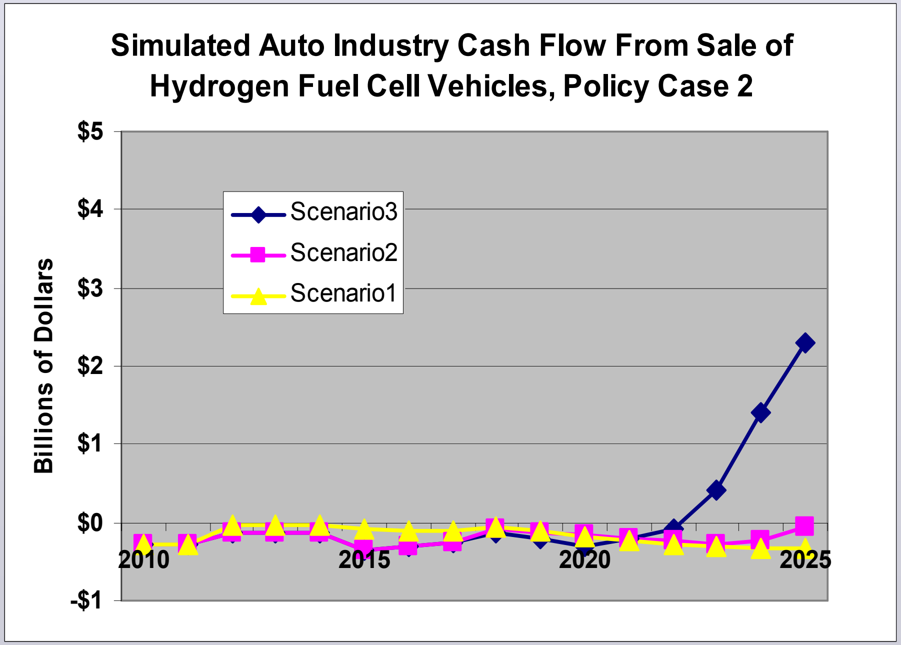
Policy Case 2 provides a reasonable assessment of the costs the government might shoulder to enable a transition to hydrogen.

- **Assumes "Fuel Cell Success"**
- **FCV vehicle production costs (vs advanced HEV) shared**
  - 50% total vehicle cost through and including 2017
  - Tax credit covers 100% of incremental cost 2018 to 2025
- **Station capital cost starts at $3.3 million, declining to $2.0 million**
  - Cost share $1.3 million/station, 2012-2017
  - Cost share $0.7 million/station, 2018-2021
  - Cost share $0.3 or 0.2 million/station, 2022-2025
- **H2 fuel subsidy**
  - $0.50/kg through 2018
  - Declines to $0.30/kg by 2025

In Policy Case 2, scenario 3 annual costs peak near $5B and cumulative costs rise to $26B by 2025.

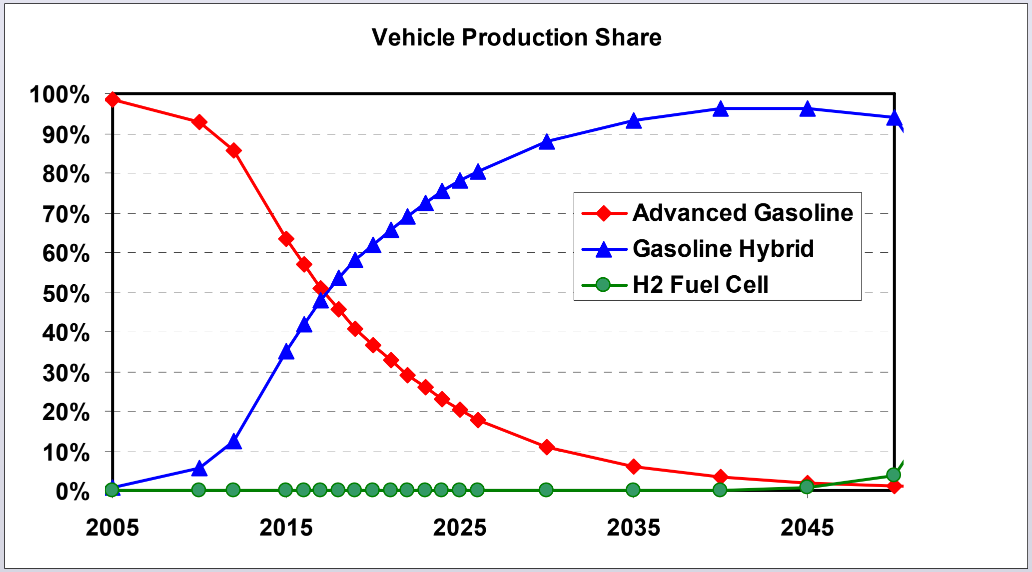






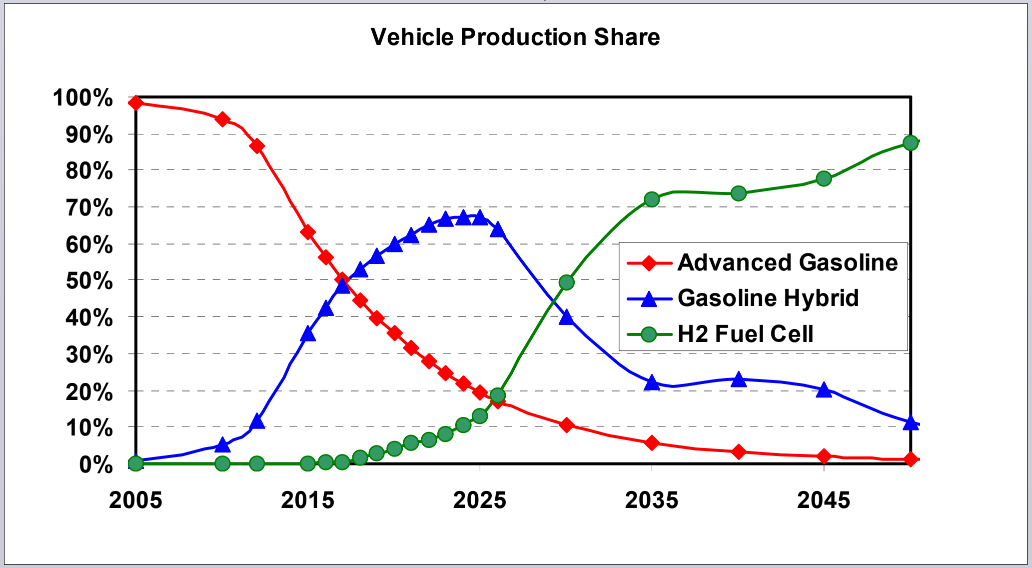
With no early transition scenario, FCVs do not begin to penetrate the market until after 2045.

No Policy Scenario



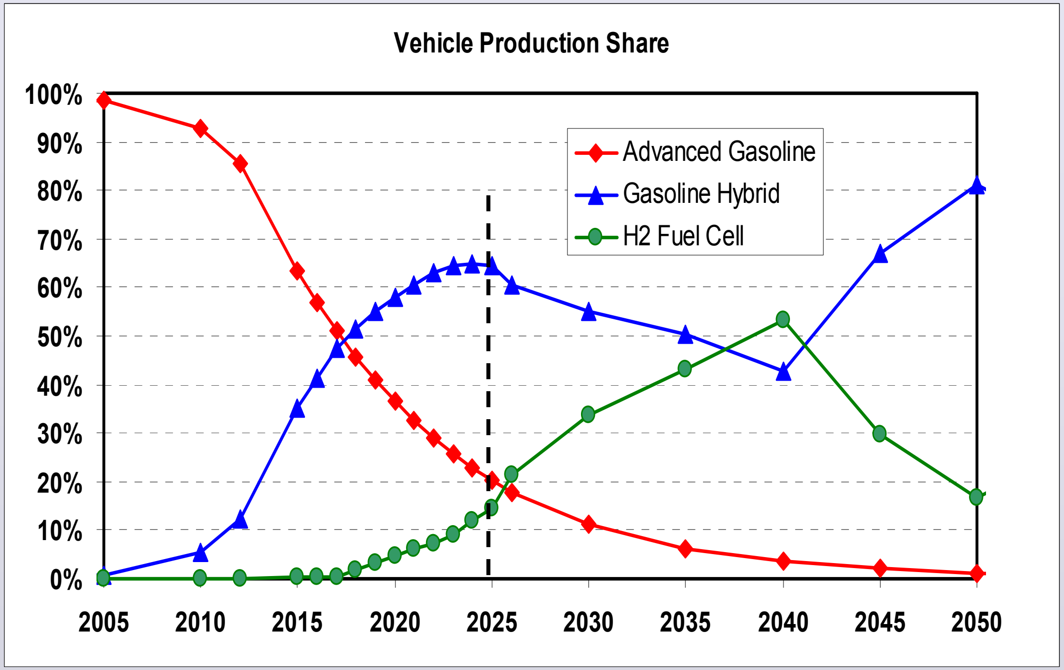
In the absence of an early transition policy, advanced hybrid electric vehicles come to dominate light-duty vehicle propulsion.

AEO Ref., $50/bbl



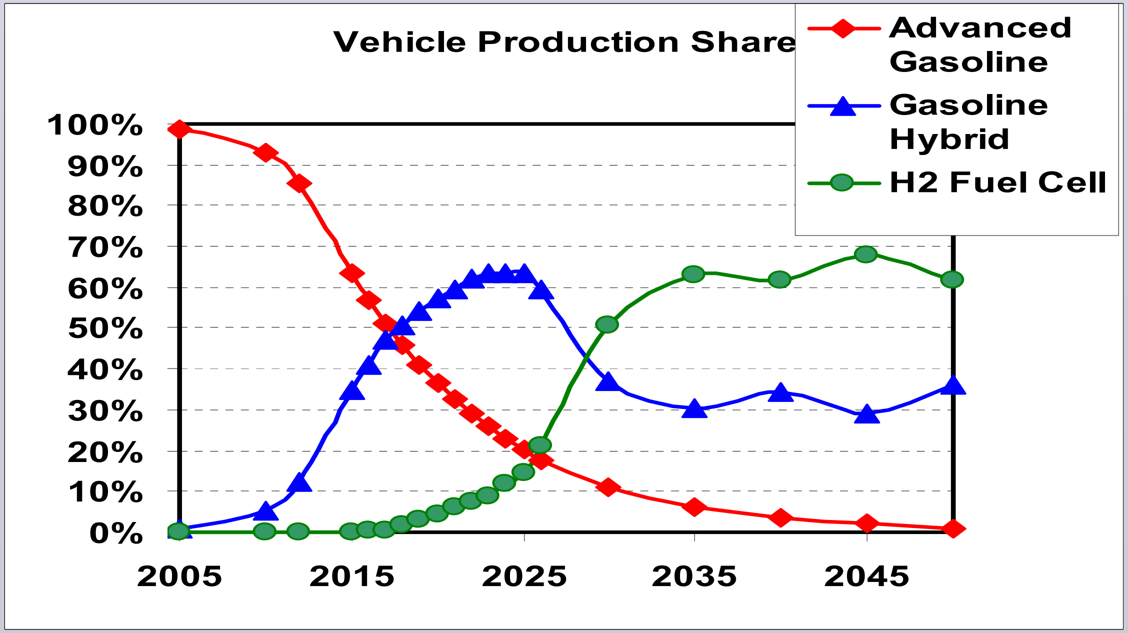
At a lower AEO oil price of $50/bbl in 2030, a sustainable transition to FCVs occurs but there is stronger competition from hybrid electric vehicles.

$60/kW Fuel Cell Cost



If fuel cell and storage technologies fall short of program goals, reaching a sustained market becomes more uncertain.

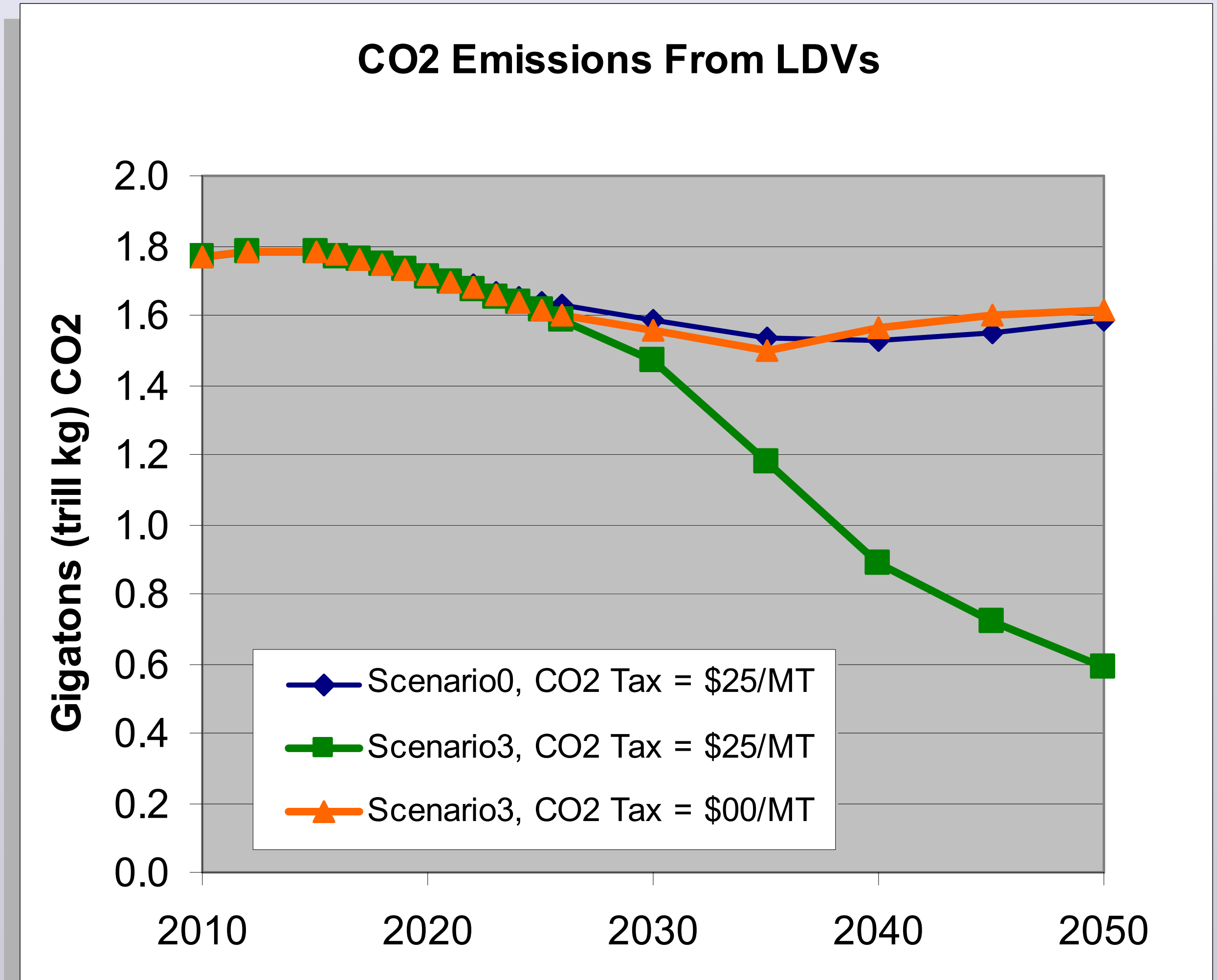
$10/kWh On-board Storage



DOE Fuel Cell Target: $30/kW

DOE Storage Target: $2/kWh

Meaningful carbon mitigation policy is necessary to achieve dramatic reductions in GHG emissions.



Scenario 0: $25/MT

→ no transition policies with a carbon tax

Scenario 3: $00

→ no carbon policy, hydrogen may be produced from carbon-intensive sources such as coal without sequestration

Scenario 3: $25/MT

→ 2/3 reduction by 2050

Carbon emission policy

– $10/ton of CO2 in 2010
– $25/ton of CO2 in 2025

The integrated analysis accomplished many of its objectives.

- **Meeting program goals is important to achieving a sustainable transition to hydrogen vehicles.**
  - Missing storage goal by as much as $6-$8/kWh does not appear to be a show stopper, but significant progress is still needed.
  - Success of competing technologies creates strong competition.
- **The transition analysis provides plausible scenarios of the transition.**
  - “Chicken-or-egg” barriers represented in integrated market model.
  - Involvement of stakeholders + detailed assessments enhance credibility.
- **Costs of early transition policies appear to be feasible: $10B to $50B over 14 yrs.**
- **High oil prices are helpful but may not be essential.**
- **Meaningful GHG mitigation policies enable nearly carbon-free hydrogen powered vehicles.**

The Hydrogen Scenarios Team

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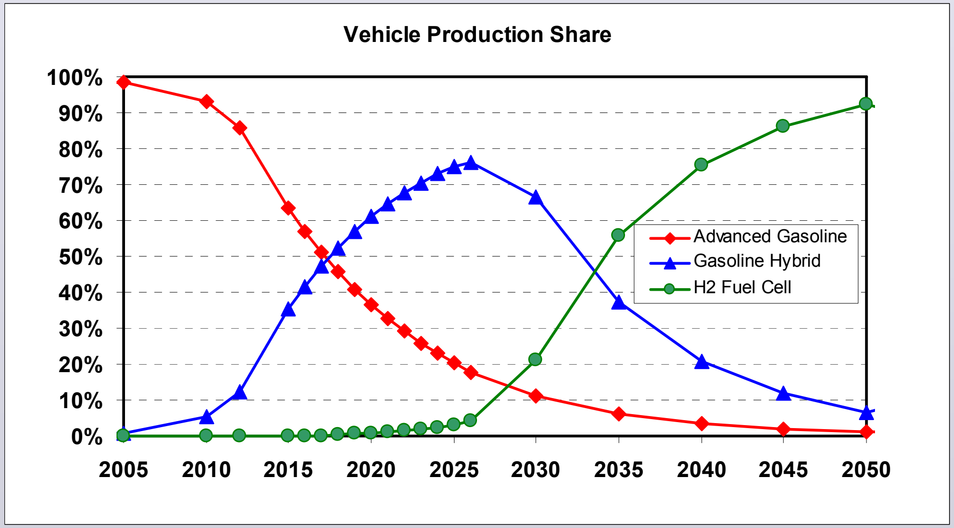
THANK YOU.

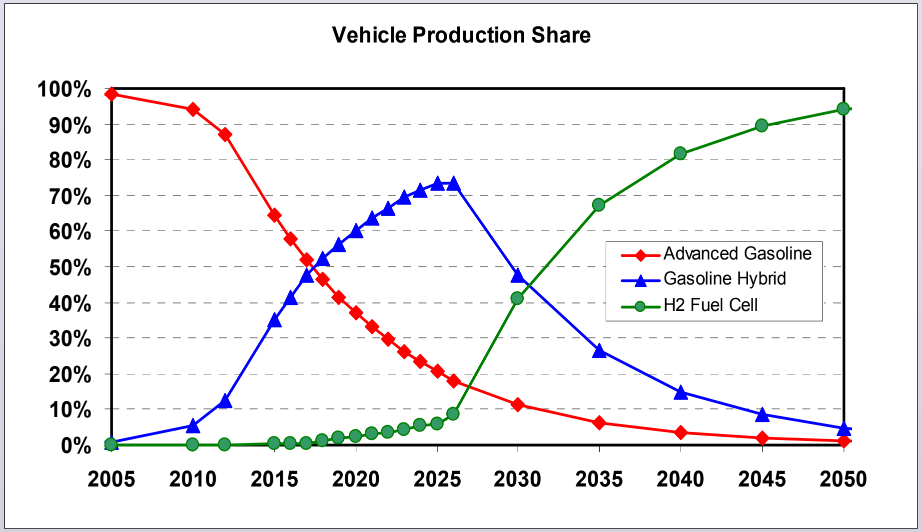
Backup

Sensitivity analyses explored the impacts of different assumptions on the costs and sustainability of the transitions, as well as on their GHG impacts.

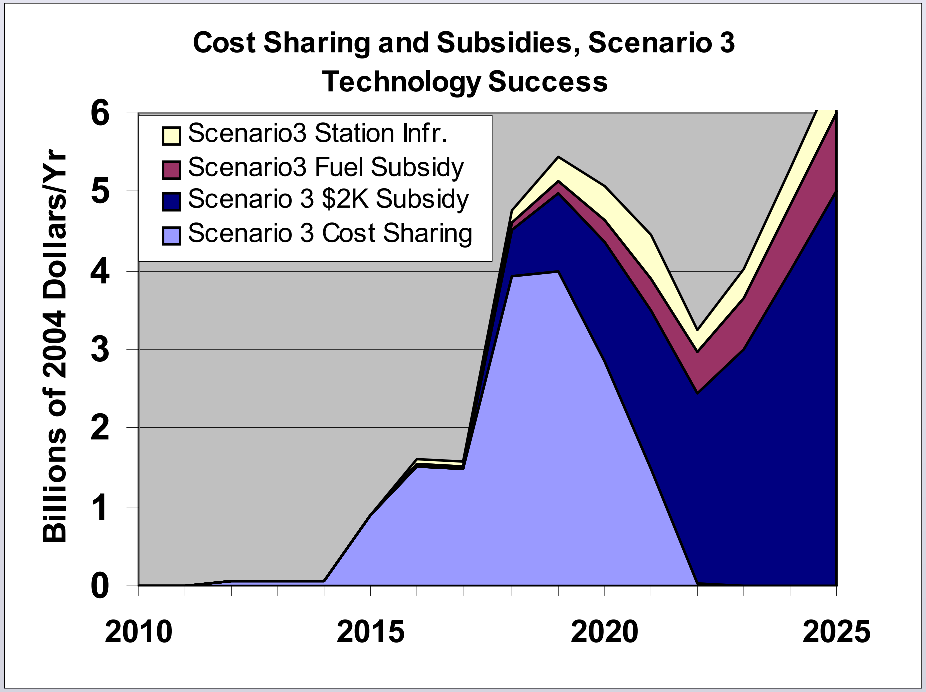
Scenario 1

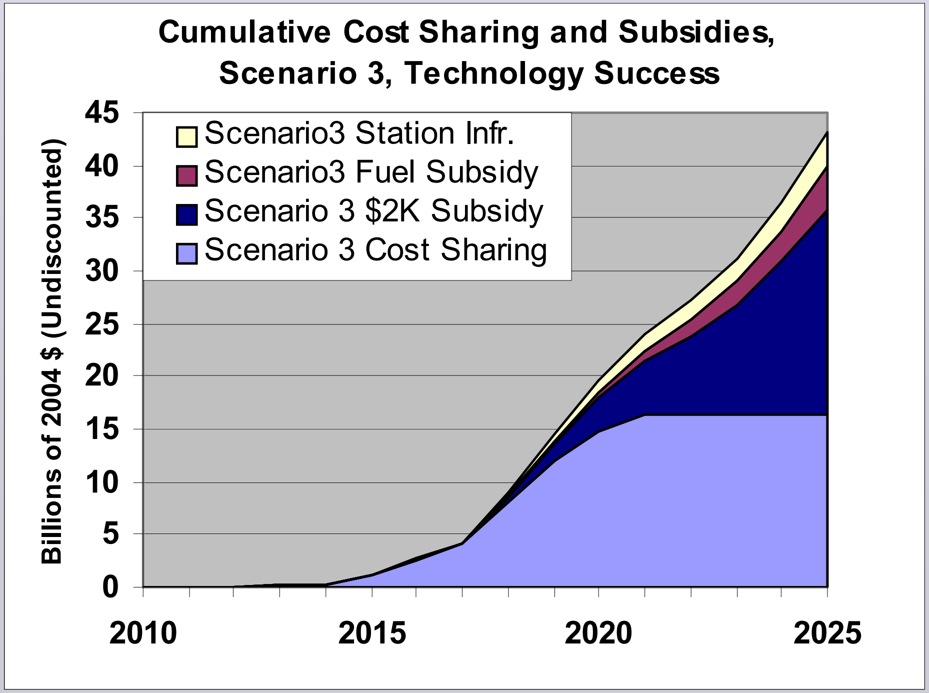


Scenario 3



- Once market transformation occurs, a stable and sustainable FCV market can be achieved beyond 2025.
- Market simulation assumes vehicle penetration achieved through the transition period with policy measures.
- Sensitivity analysis assumes Hi Oil case and the Hydrogen Program achieves fuel cell and storage targets.

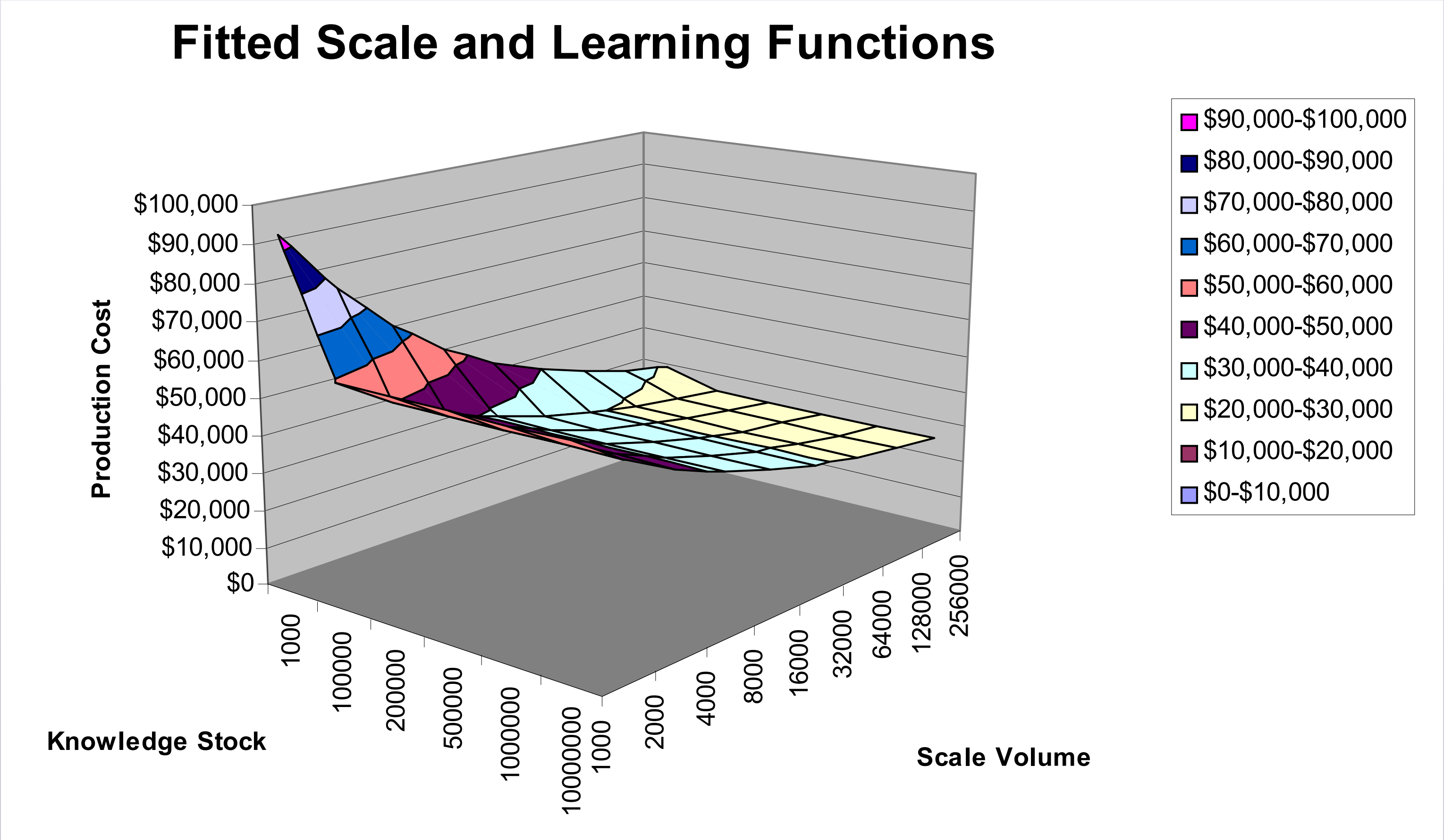




Policy Case 3 adds a $2000/vehicle tax credit which starts at 2018 and ends in 2025, to the policy measures of Case 2.

Learning is exponential and asymptotic to the DOE goals with a calibrated learning rate of approximately 0.9.

The calibration produced a constant elasticity of scale of approximately -0.25.



The vehicle cost model calibrated with data provided by three OEMs is a dynamic function of past and current FCV production volumes.

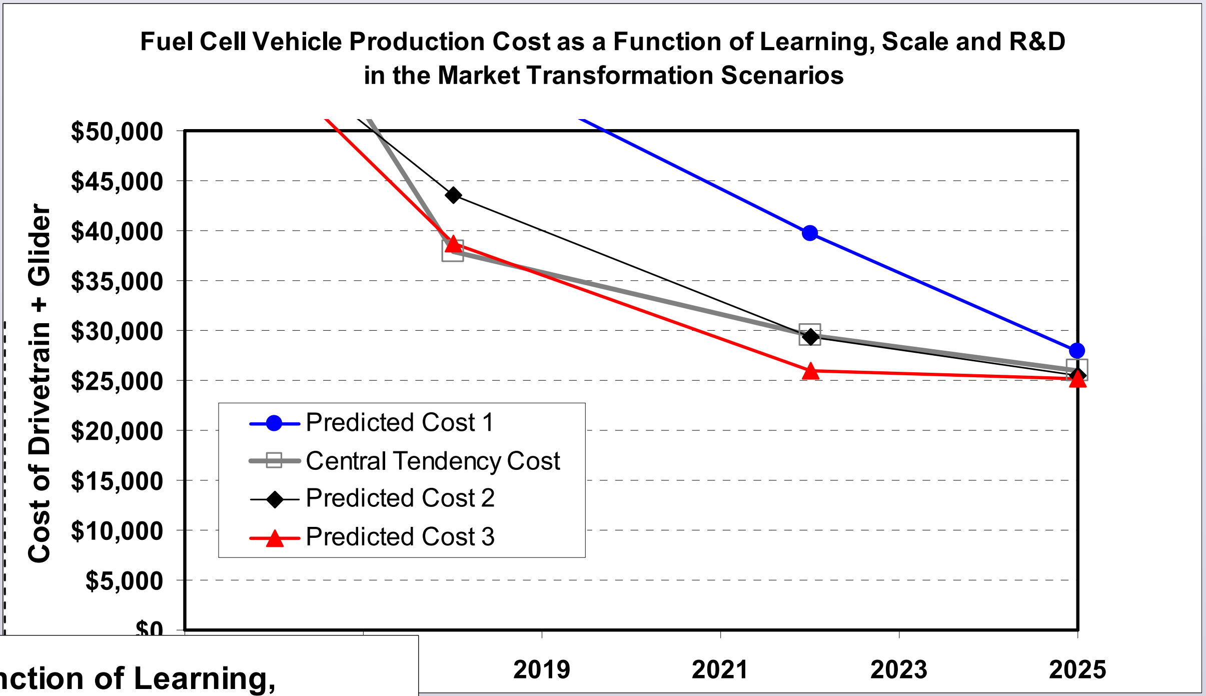
- **Three multiplicative factors:**
  - Independent tech-progress,
  - Learning-by-doing and
  - Scale economies.
- **Vehicle Price =**

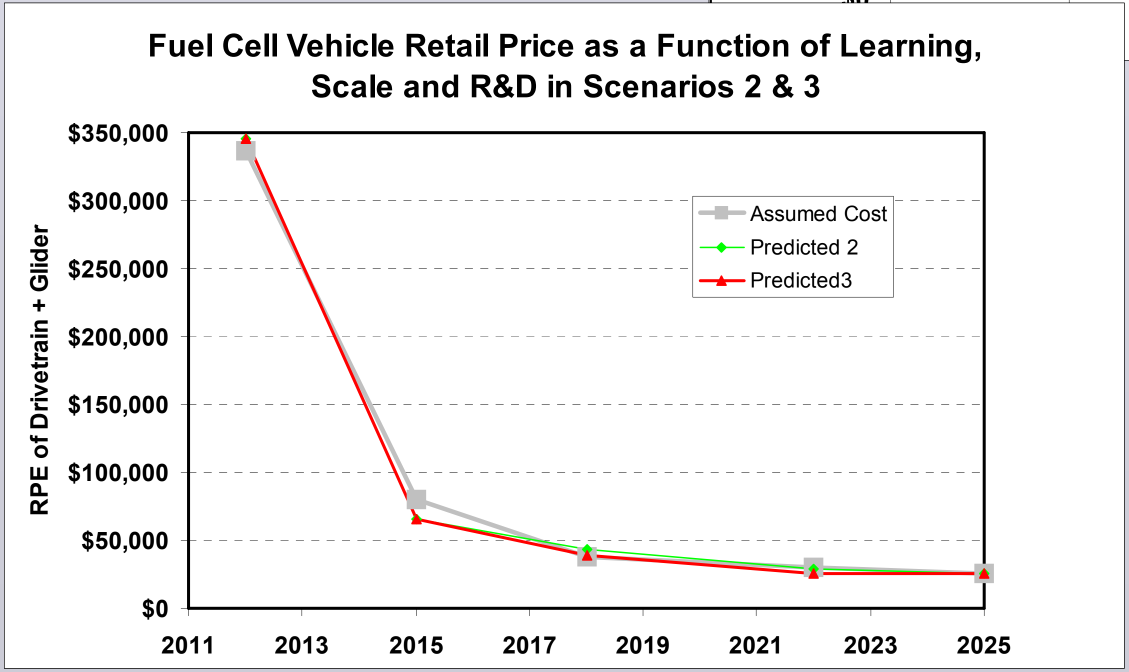
  Glider Cost

  + Long-run Drivetrain Cost x Technology(time)

  x Learning-by-doing(stock) x Scale(volume)
- **Independent Technology progress**
  - calibrated to DOE 2015 goals
  - "in the lab" + available in vehicles in 5 years
- **Learning & Scale**
  - calibrated to central tendency of manufacturers' cost estimates.

Learning Curve Detail for 2018-2025



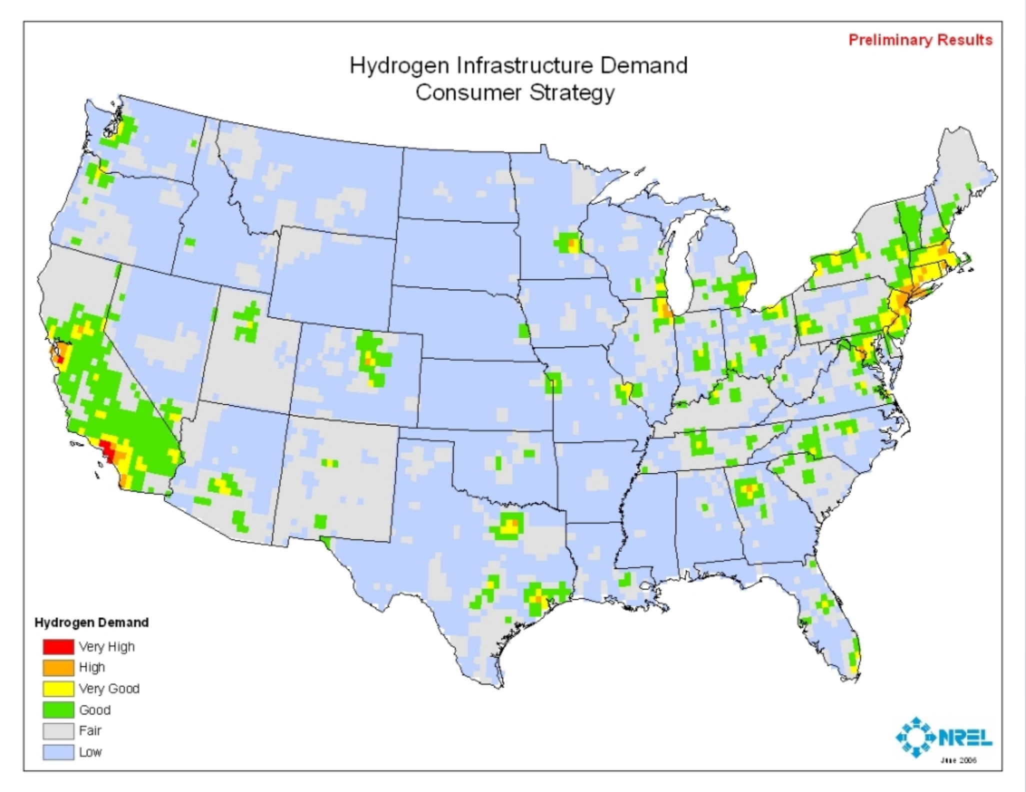


Methodology: Emerging Vehicle Markets

California and the Northeast represent the most attractive initial marketplaces for the introduction of H2 FCVs

Prioritized cities for evaluating vehicle penetration and supporting fuel infrastructure development

- **Criteria for consumer market assessment merits for FCV emergence for geographic regions**
  - Hybrid vehicle registration
  - Education
  - Household income
  - Commute distance
  - State incentives
  - Clean city coalitions
  - Zero emission vehicle (ZEV) mandates
  - Vehicles per household



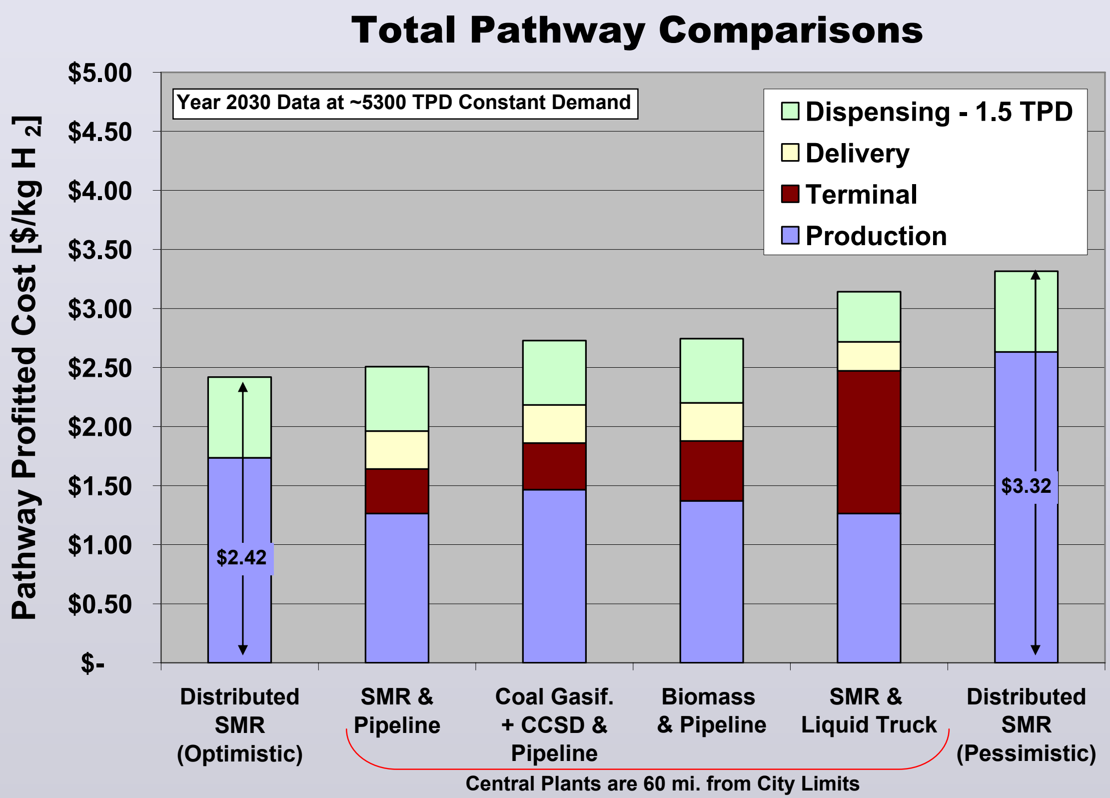
Analysis showed consumers are in the major metropolitan areas

- **Focused rollout scenario**
  - Manage resource requirements
  - Provide adequate station networks

- **Phased urban network approach**
  - Highly populated
  - Gradual addition to other cities

Methodology: Infrastructure Analysis
Production Options for Transition Scenarios

- Infrastructure costs critical factor in making a successful transition to a hydrogen economy
- Ability to deliver low-cost hydrogen is essential in the transition period



Stage 1:

- ❖ Forecourt
- ❖ Cluster or network from mid-size (central) plant
- ❖ Use existing hydrogen production and infrastructure
- ❖ Investigate liquid delivery systems

Stage 2

- ❖ Nascent interconnect system

Future:

- ❖ Hydrogen production from renewables

2021-2025: Widespread utilization in Scenario 3

- **15%+ of existing gasoline stations in key cities**
- **Connecting stations enable inter-regional transport**
- **Focus on pipeline distribution**

4000 stations in scenario 2

8000 stations in scenario 3

~85 interconnect stations

~200 other interstate stations

Infrastructure Feasibility Survey

- **Examined Initial targeted gas stations in LA, NY, Dallas**
  - best demand areas
  - major civic airports
  - traffic above 200,000 veh per day
  - retail center
  - 3,000 + registered vehicles
  - major and secondary roads
  - balanced coverage
- **Identified land area at station compared to required reforming or delivered liquid H2 space**

City	Feasible	Not Feasible	Borderline
LA	5	20	15
NY	4	15	21
Dallas	7	14	19