

# Hydrogen Transition Study

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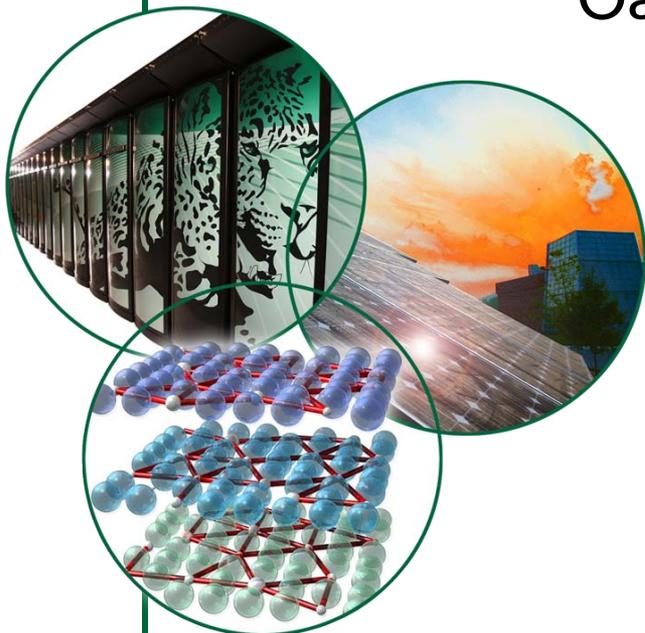
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Washington, DC Workshop

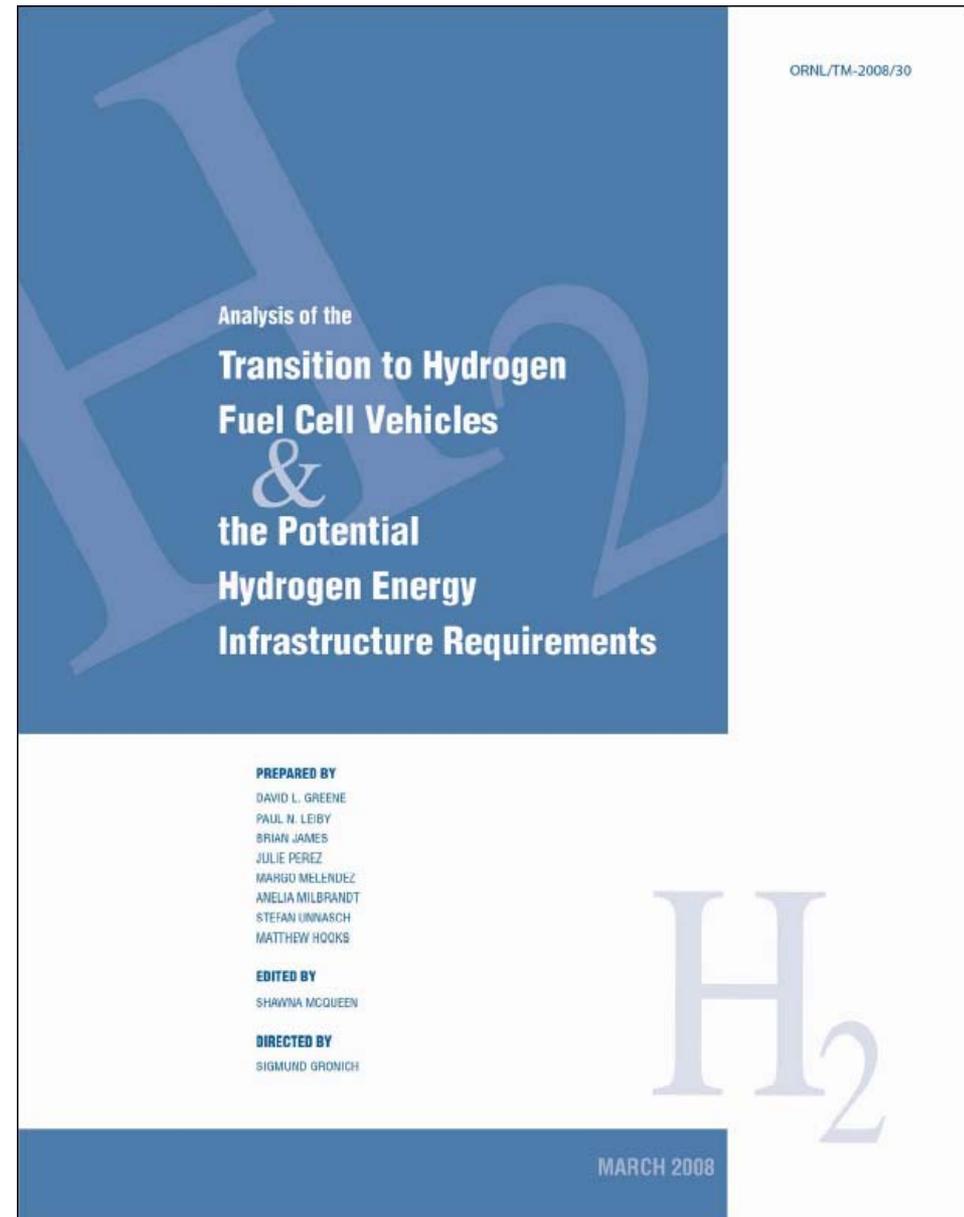


# Overview

- **Some lessons learned from analyzing fuel transitions**
  - Find barriers to transitions significant, but progress being made
  - Review work by DOE-sponsored team, highlighting key factors
    - Note some similar findings by NRC
- **Find important role for policy**
  - in advancing R&D
  - In promoting & shaping infrastructure development and tech choice
- **Policy can help, indeed is necessary**
  - Effectively drive down economy-wide costs of new tech development, achieve scale, and widespread fuel and vehicle availability more quickly
  - Need vehicle and station support to avoid “valley of death” firms face in early years
- **End with results for lower carbon/renewable hydrogen**
  - Policy can prevent early H<sub>2</sub> technology and infrastructure choices from concentrating only on lowest cost, sometimes less beneficial pathways

Sig Gronich's 2008 report described the first integrated national analysis of the transition to hydrogen fuel cell vehicles.

Responded to the NAS' call to better understand what a transition to H<sub>2</sub> powered vehicles would require



# Stakeholder workshops led to Lighthouse strategy. Three Early Vehicle Scenarios intended to span a range that would encompass an efficient transition.

## Scenario 1:

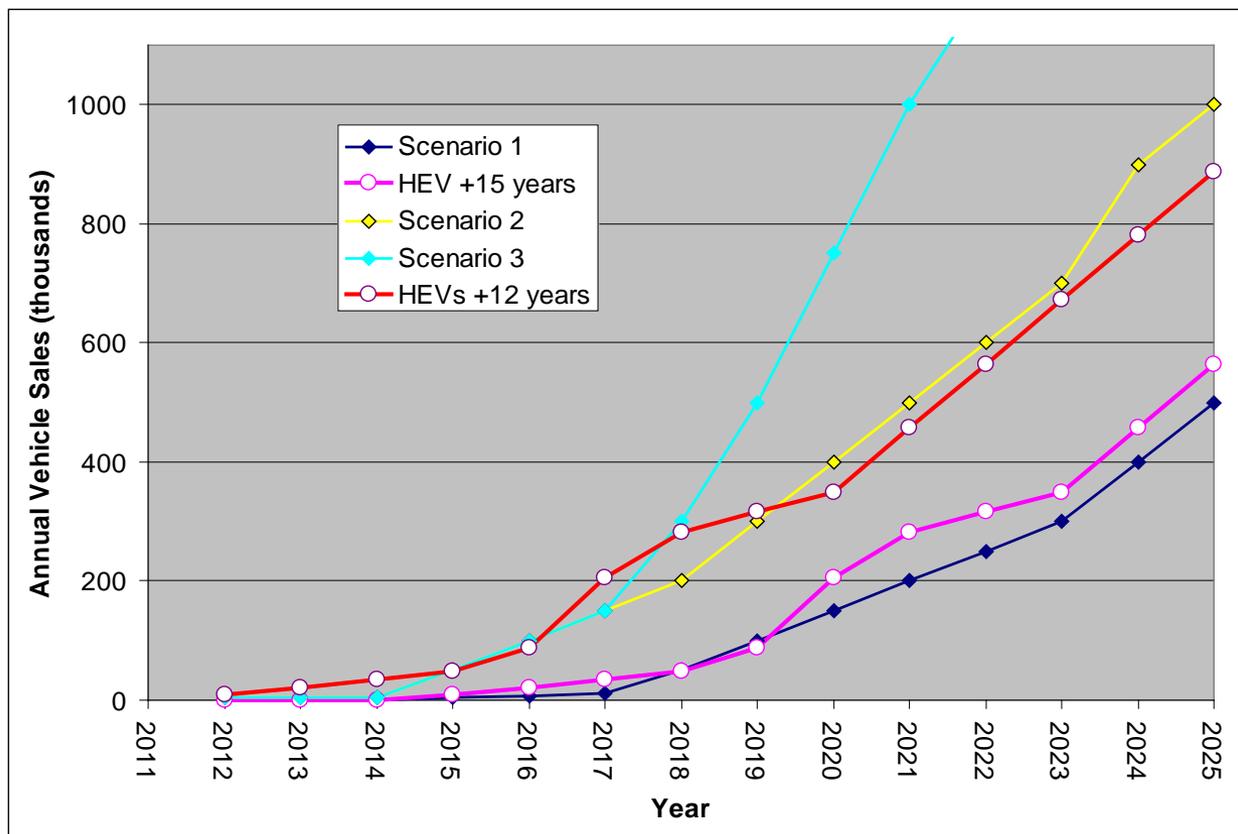
100s per year by 2012, *tens of thousands* of vehicles per year by 2018. On-road fleet of 2.0 million FCVs by 2025.

## 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):

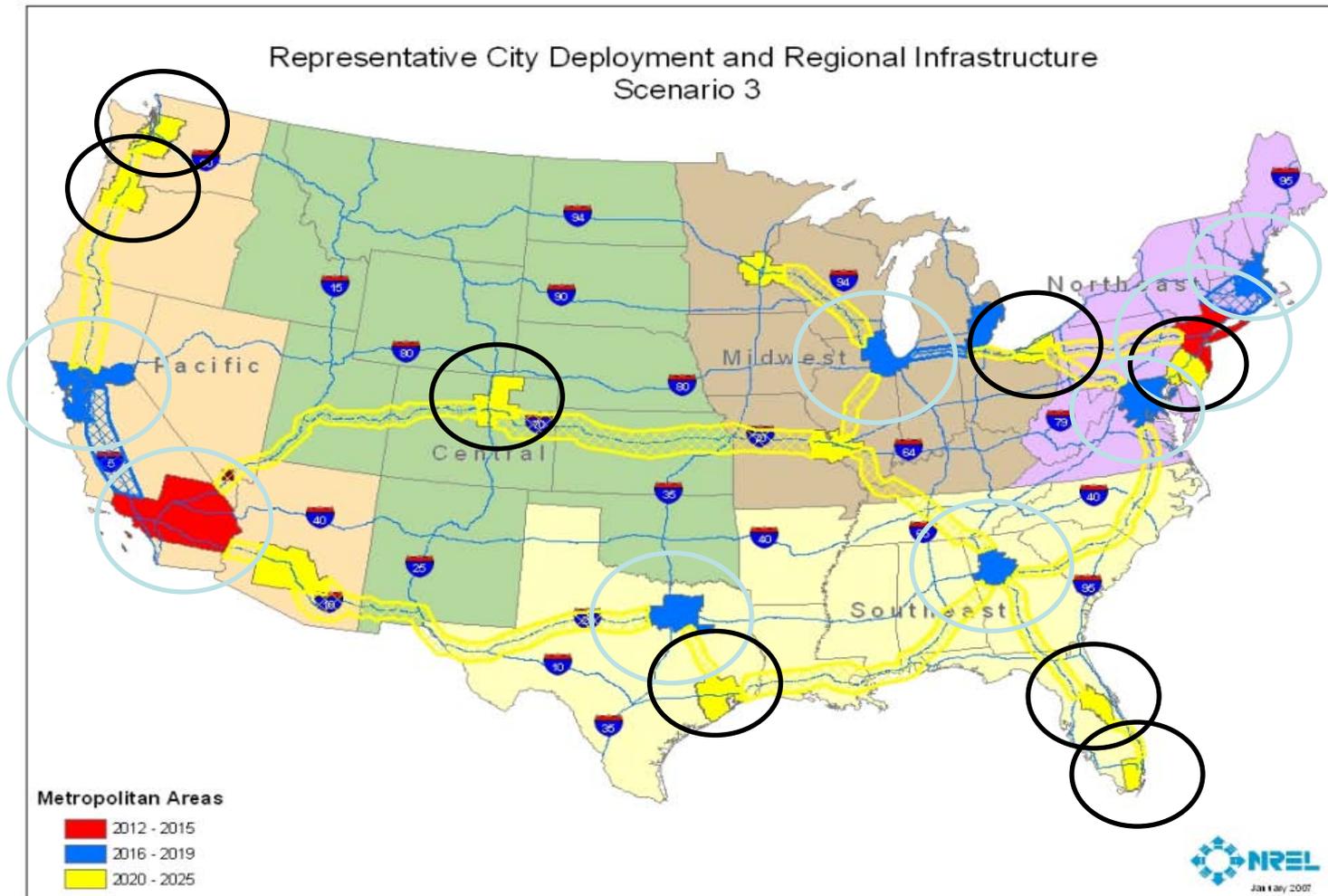
*1,000s* of FCVs by 2012, and *millions* by 2021, 10 million on the road by 2025.



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

**These scenarios do not represent a policy recommendation.**

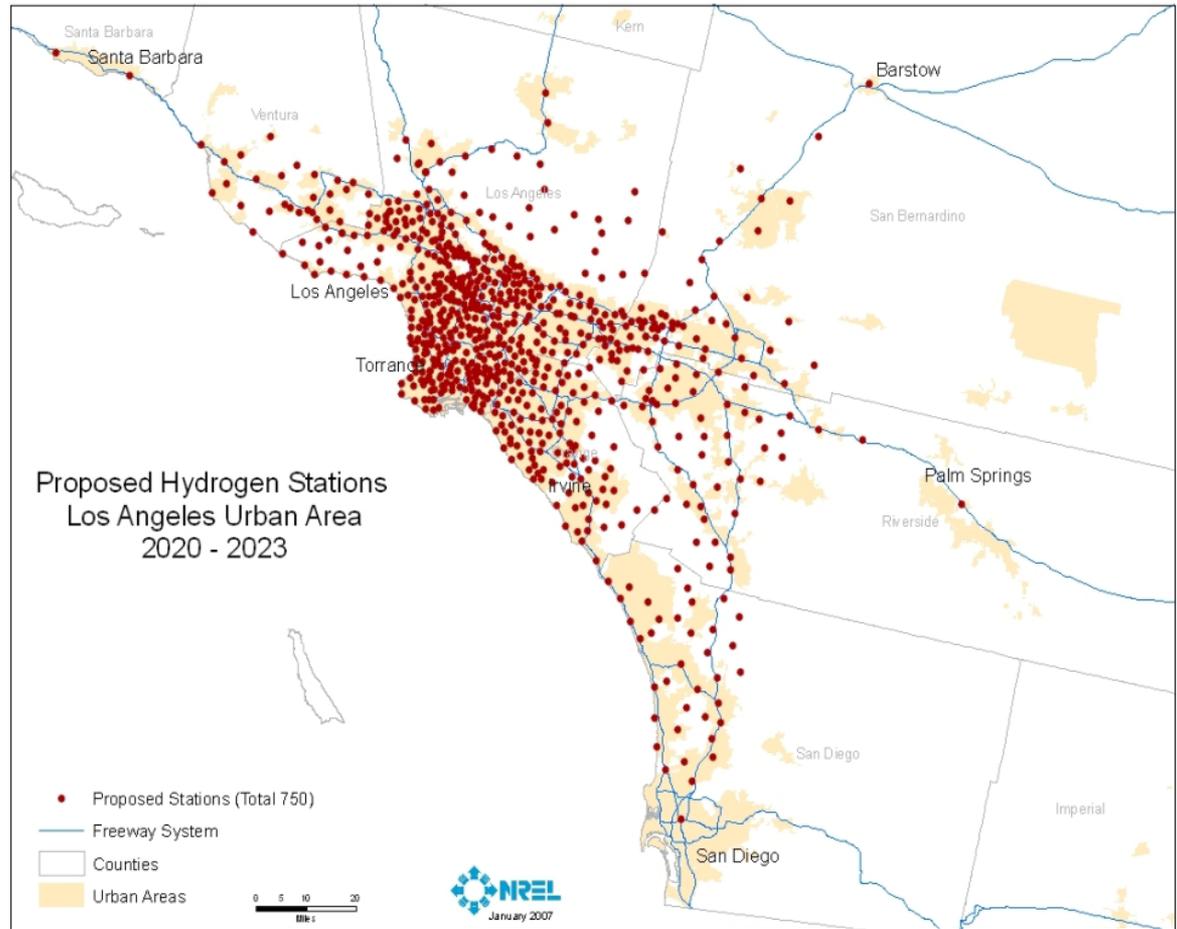
The *Lighthouse* concept of infrastructure build-out reflects a trade-off between the need to concentrate infrastructure and the need to maximize hydrogen availability.



# NREL Analyzed Optimal Strategies 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

## 2020-2025: Regional Expansion LA



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

# Scenarios: 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 H<sub>2</sub> supply costs.
- CO<sub>2</sub> 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 endogenous market solution.

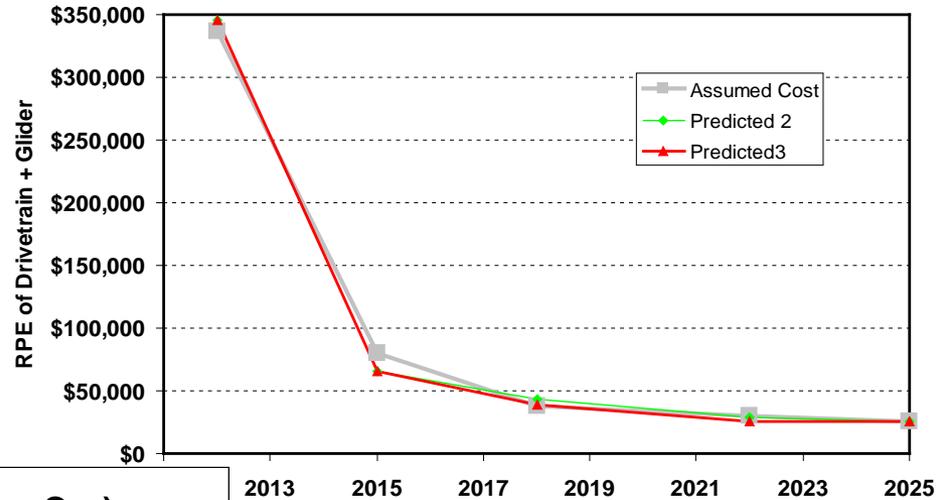
**Finding: Excess “transition costs” are incurred in overcoming the natural market barriers to a new transportation fuel.**

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

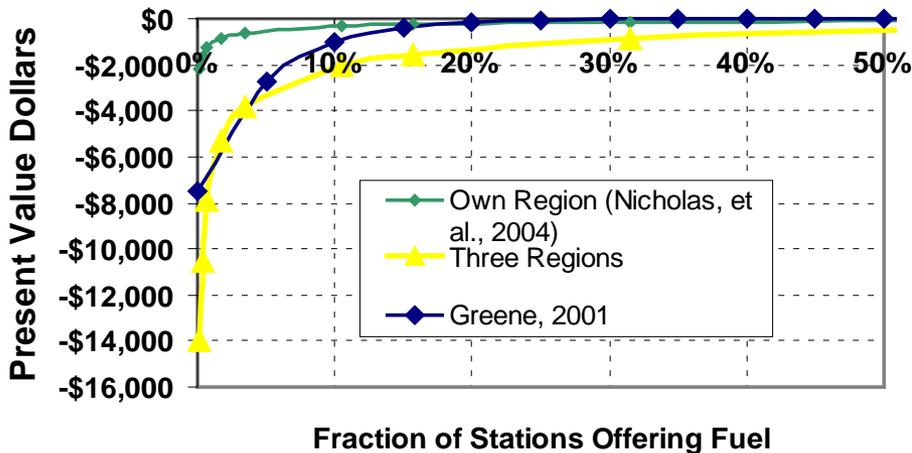
# Early production experience and infrastructure development can drive down costs significantly

Importance of **Learning** through experience and building **Scale**: FCV costs decline dramatically

Fuel Cell Vehicle Retail Price as a Function of Learning, Scale and R&D in Scenarios 2 & 3



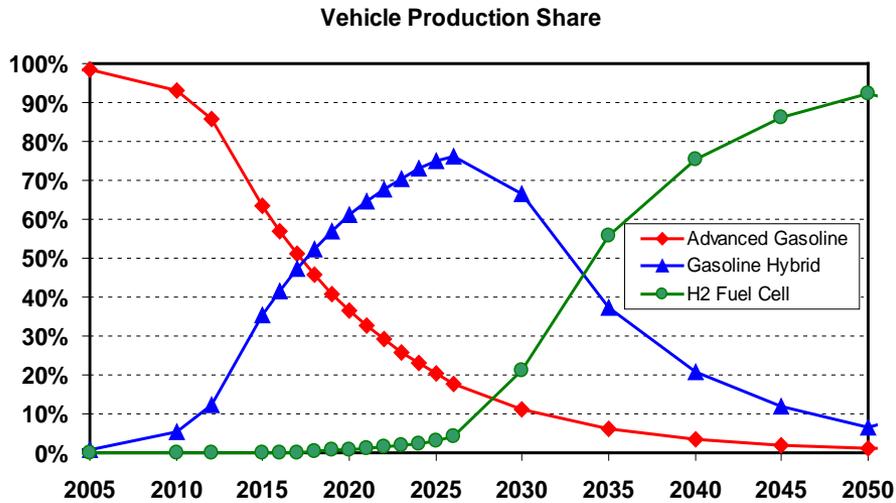
Cost of Limited Fuel Availability (Passenger Car)



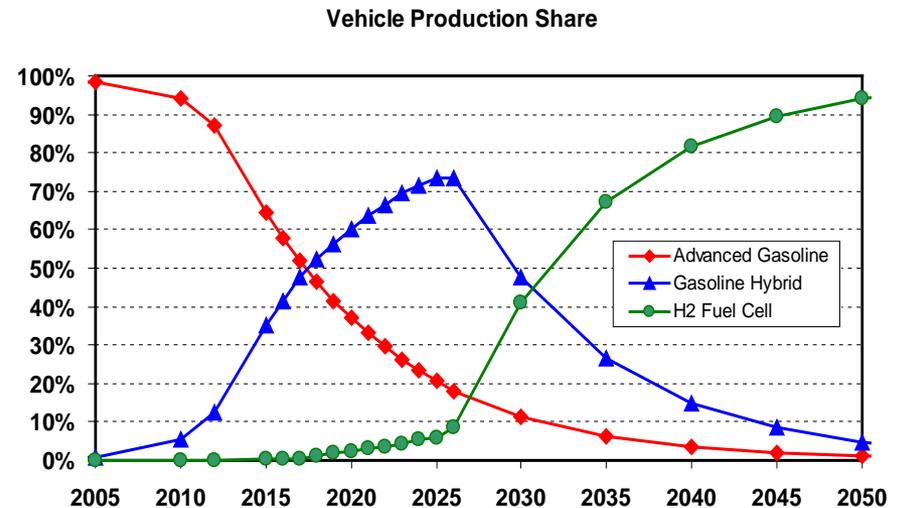
Limited retail **fuel availability** imposes costs on consumers, alters their choices

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

## Scenario 1



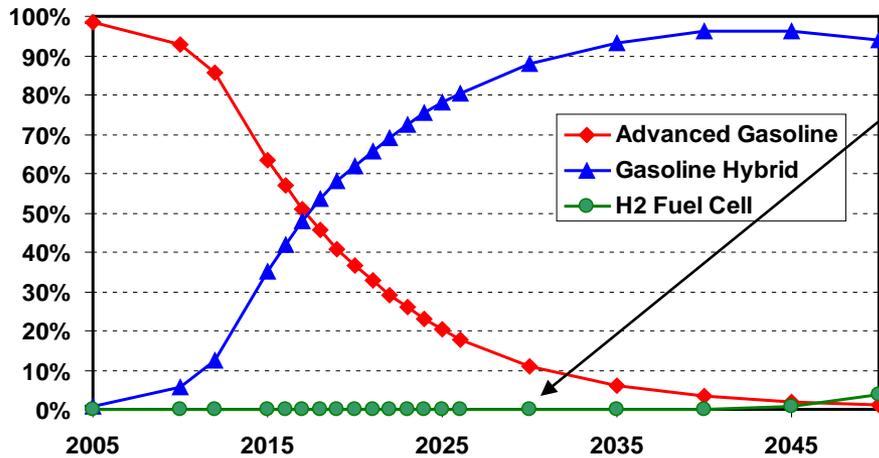
## Scenario 3



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

## No Policy Scenario

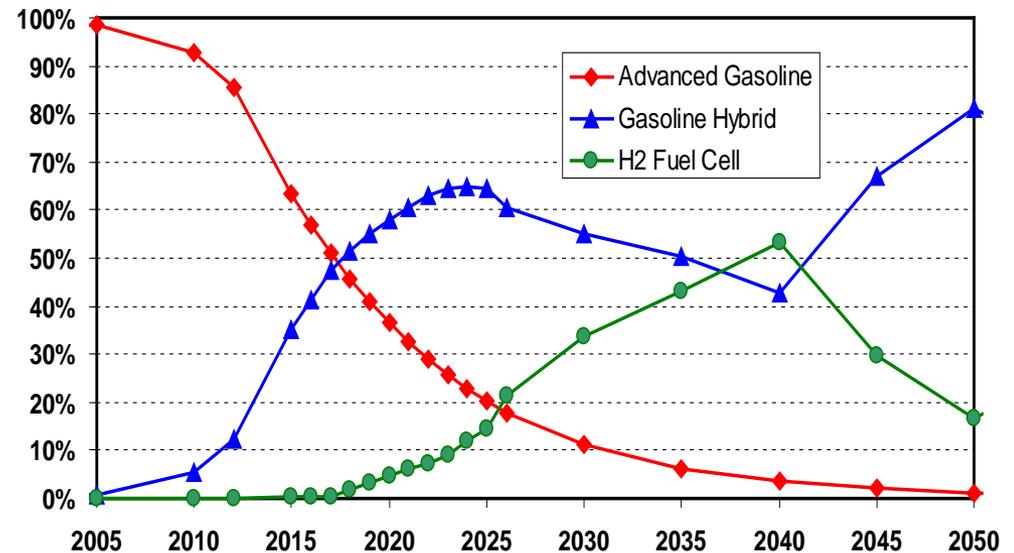
Vehicle Production Share



With no early transition scenario, FCVs do not begin to penetrate the market until after 2045 (still assumes high tech progress, all FC targets met).

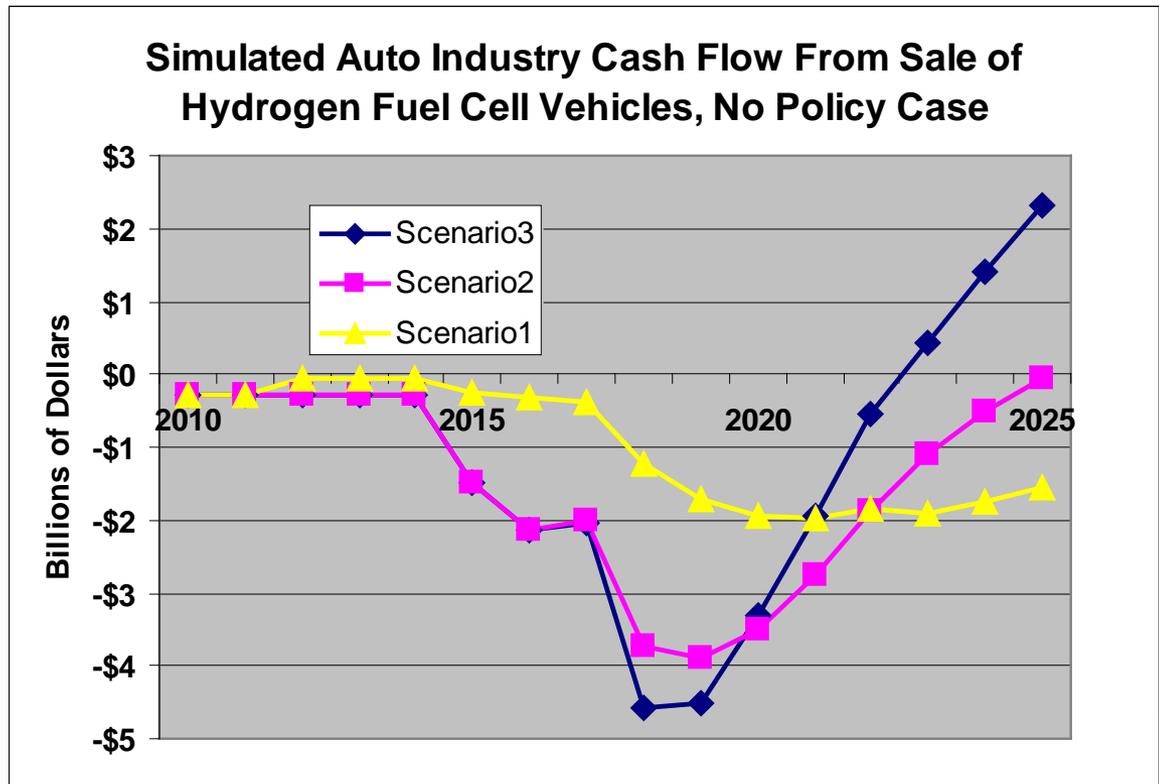
If fuel cell and storage technologies fall short of program goals, reaching a sustained market becomes more uncertain.

## \$60/kW Fuel Cell Cost (short of Program's goal)



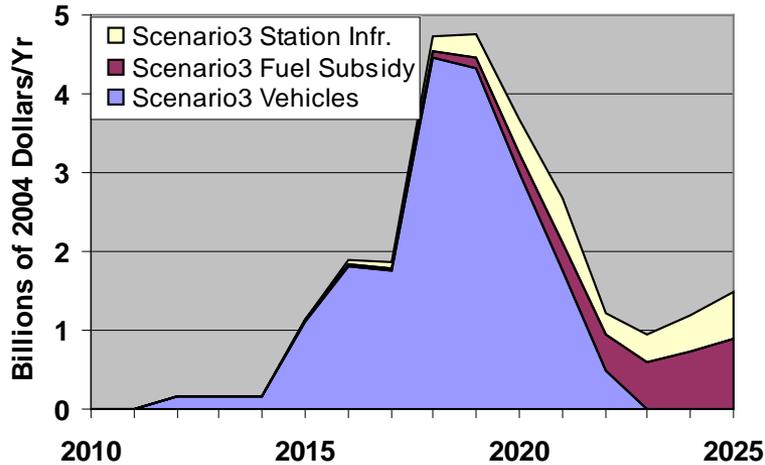
# The need for transition policies is indicated by the excess costs of the transition scenarios.

- 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+)

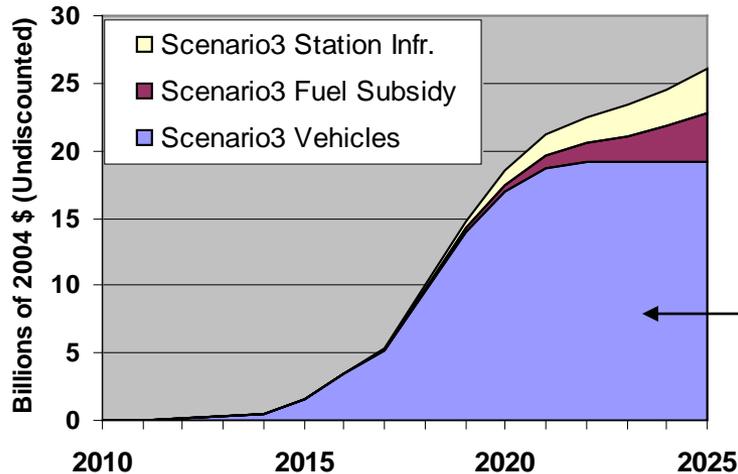


# In Policy Case 2, scenario 3 annual costs peak near \$5B. Cumulative government costs rise to \$26B by 2025.

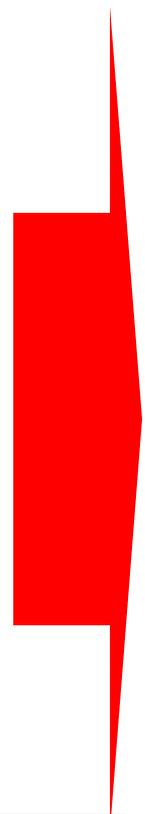
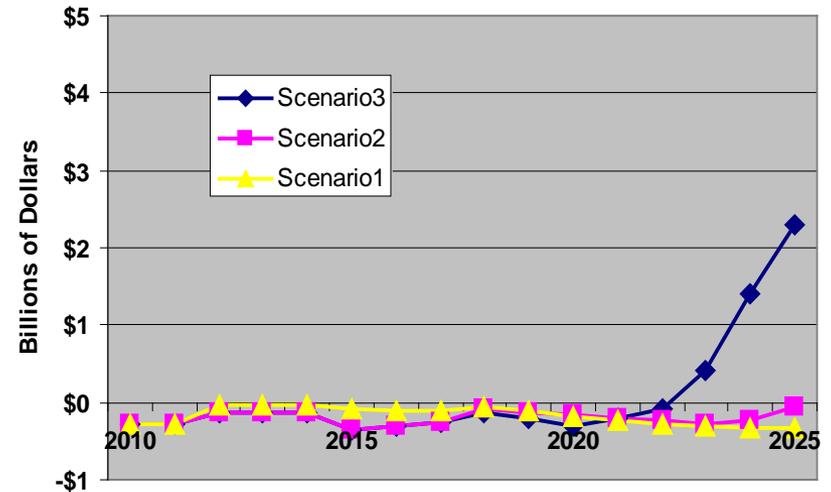
Cost Sharing and Subsidies, Scenario 3, Fuel Cell Success, Policy Case 2



Cumulative Cost Sharing and Subsidies, Scenario 3, Fuel Cell Success, Case 2



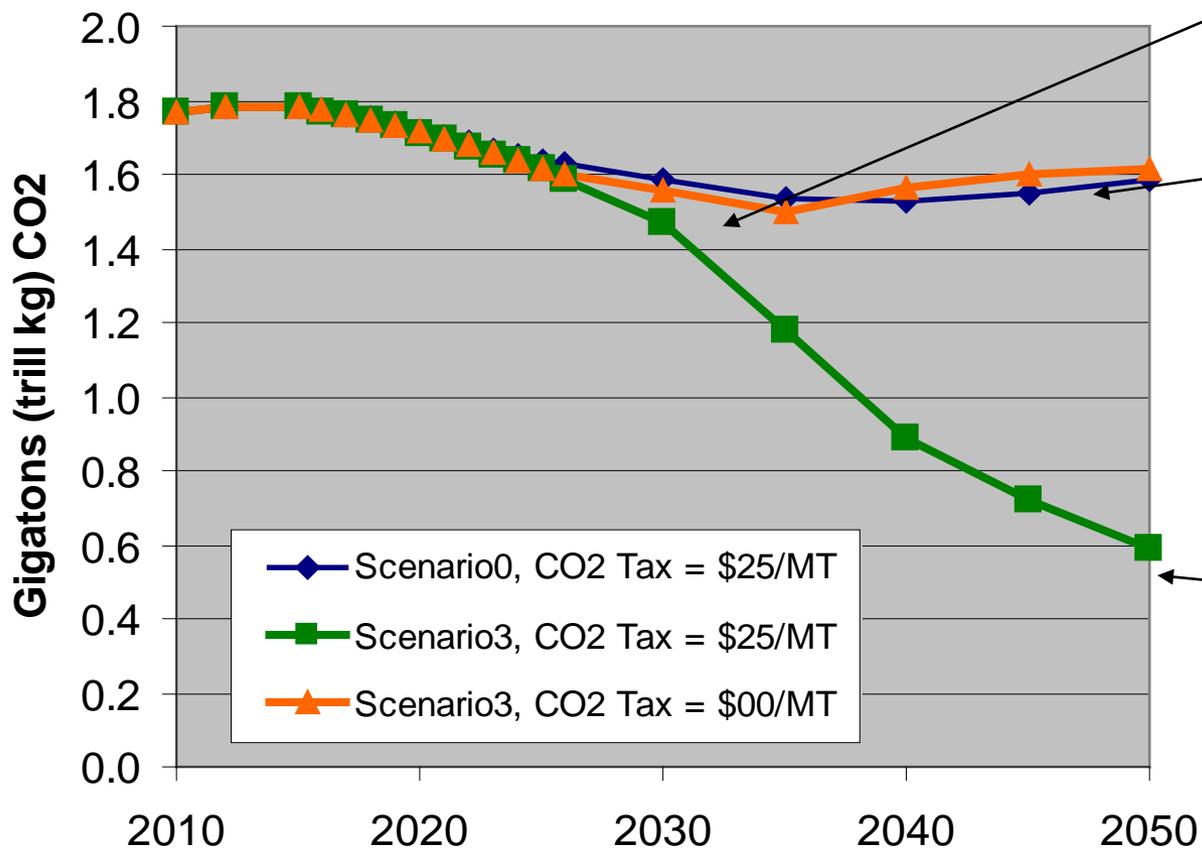
Simulated Auto Industry Cash Flow From Sale of Hydrogen Fuel Cell Vehicles, Policy Case 2



Note that vehicles costs are a much larger part of barrier than fuel/infrastructure costs

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

## CO2 Emissions From LDVs



- Scenario 0 \$25/MT -> no transition policies with a carbon tax.
- Scenario 3 \$00/MT -> no carbon policy, hydrogen may be produced from carbon-intensive sources such as coal without sequestration.
- In Scenario 3 transition policy + \$25/MT (phased in) -> 2/3 C reduction by 2050.

# Integrated analysis provided useful insights.

- **It is possible to model a “chicken or egg” transition.**
  - Measure costs, timing, sustainability.
  - Uncertainty difficult to model, knowledge still incomplete.
- **Meeting technology goals important to achieving a sustainable transition to hydrogen vehicles.**
  - Missing storage goal does not appear to be a show stopper.
  - Success of competing technologies creates strong competition.
- **The transition analysis provides a plausible vision.**
  - Involvement of stakeholders + detailed assessments enhance credibility.
- **Costs of early transition policies appear to be feasible: \$10B to \$50B over 14 yrs (premises!).**
  - NRC 2008 similarly estimated ~\$55 bill
- **High oil prices are helpful, may not be essential.**
- **Meaningful GHG mitigation policies needed for nearly C-free hydrogen powered vehicles.**

# THANK YOU.

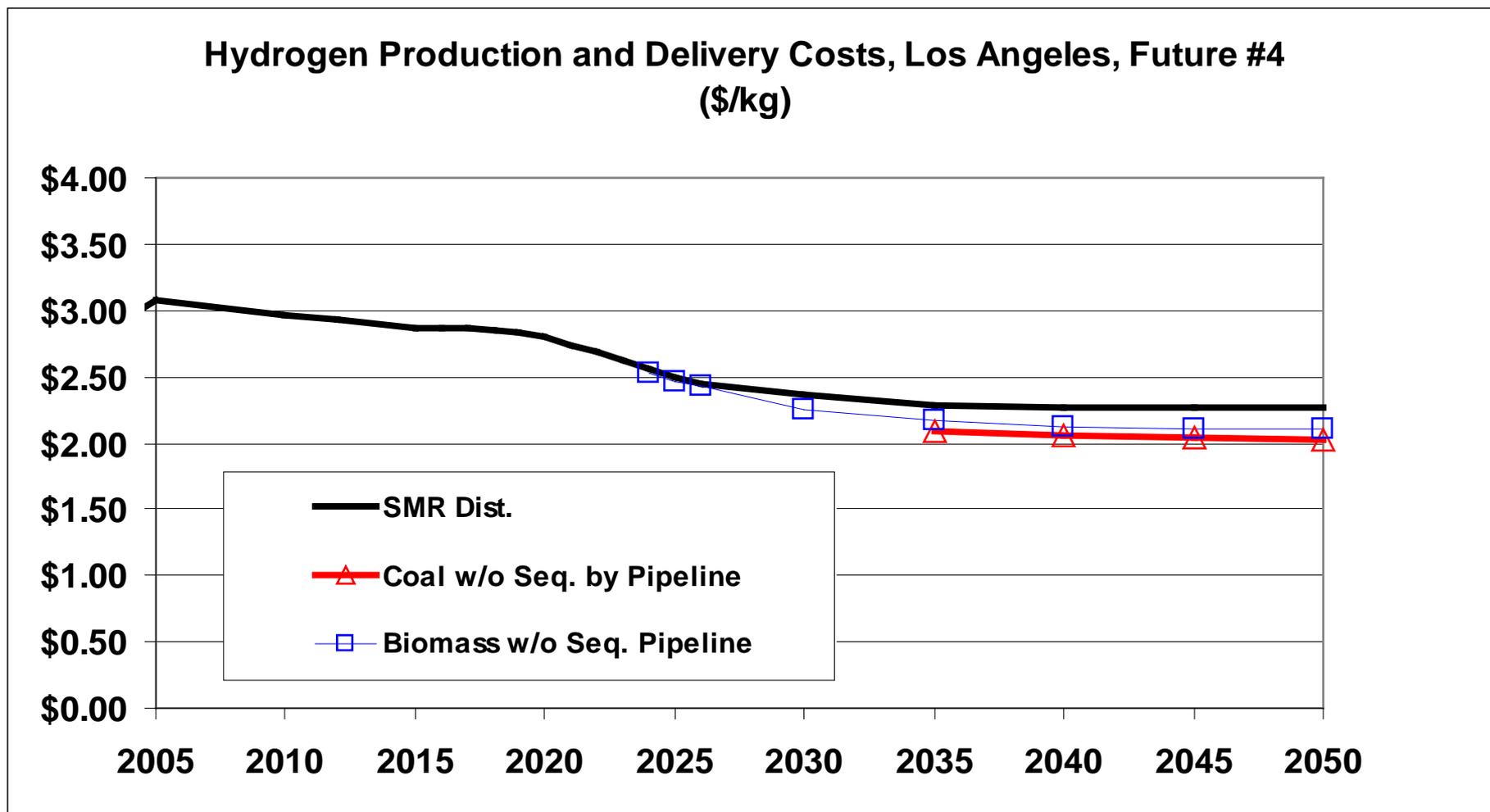
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# Backup

# The Hydrogen Scenarios Team

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- Brian James
- Julie Perez
- Margo Melendez
- Amelia Milbrandt
- Stefan Unnasch
- Matthew Hooks

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

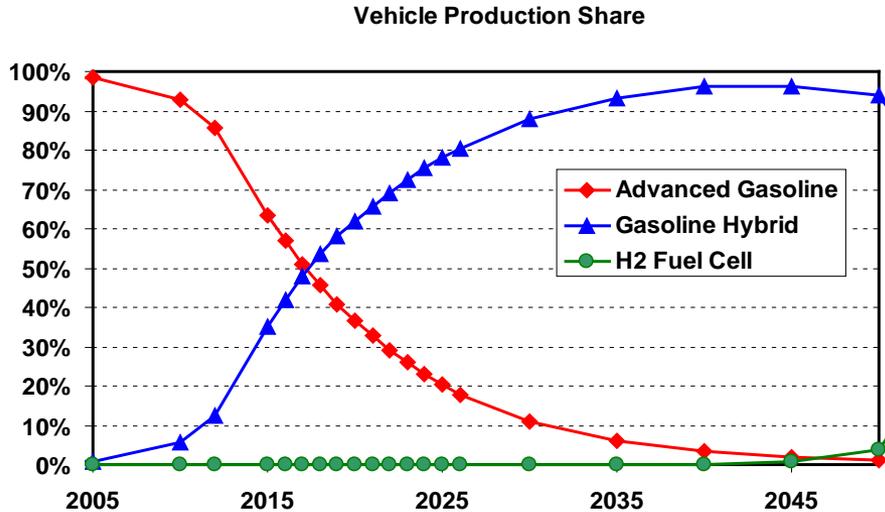


Policy Case 2 provides a reasonable assessment of the costs the government & industry might shoulder to induce a transition to hydrogen.

- **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

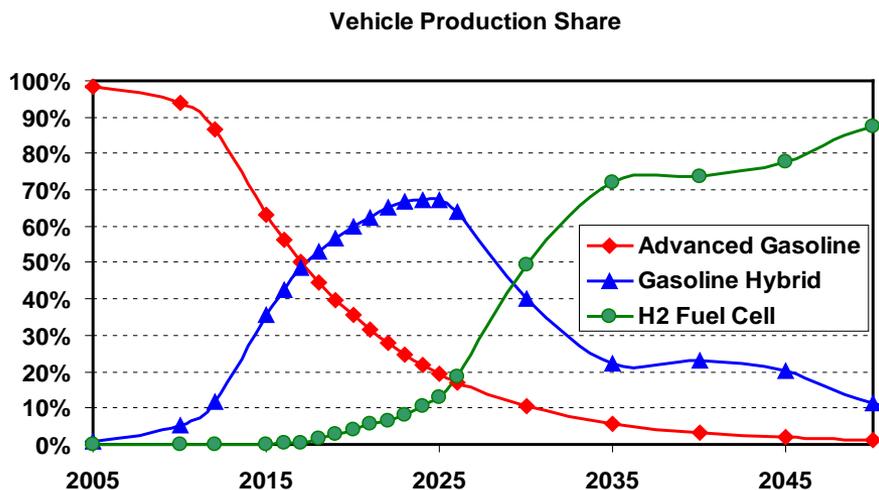
# With no early transition scenario, FCVs do not begin to penetrate the market until after 2045.

No Policy Scenario



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

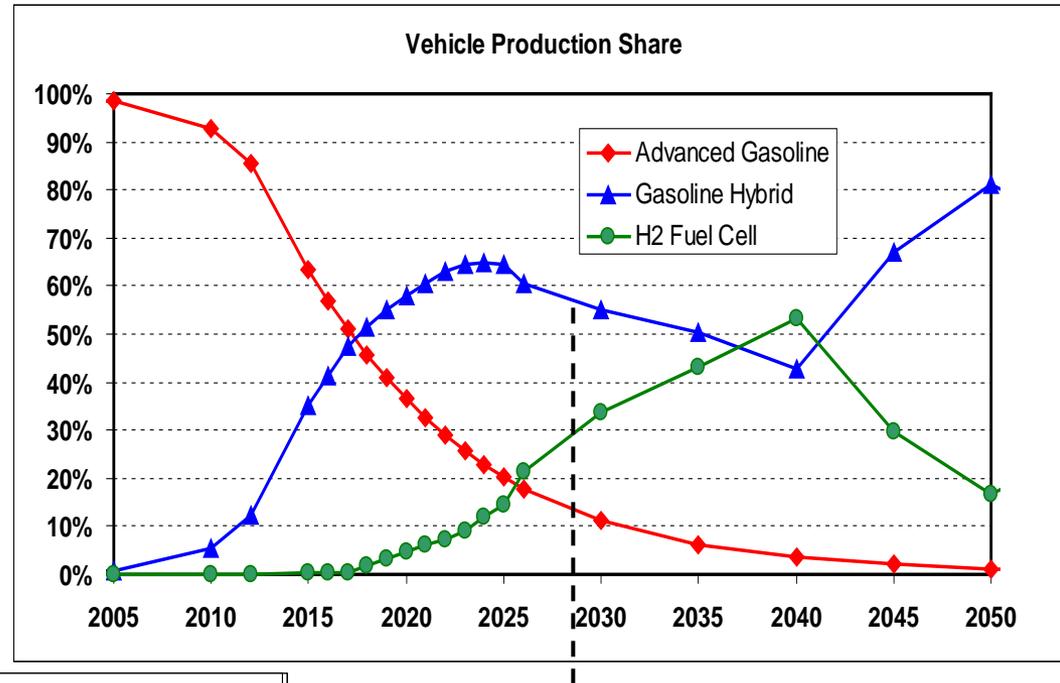
AEO Ref., \$50/bbl



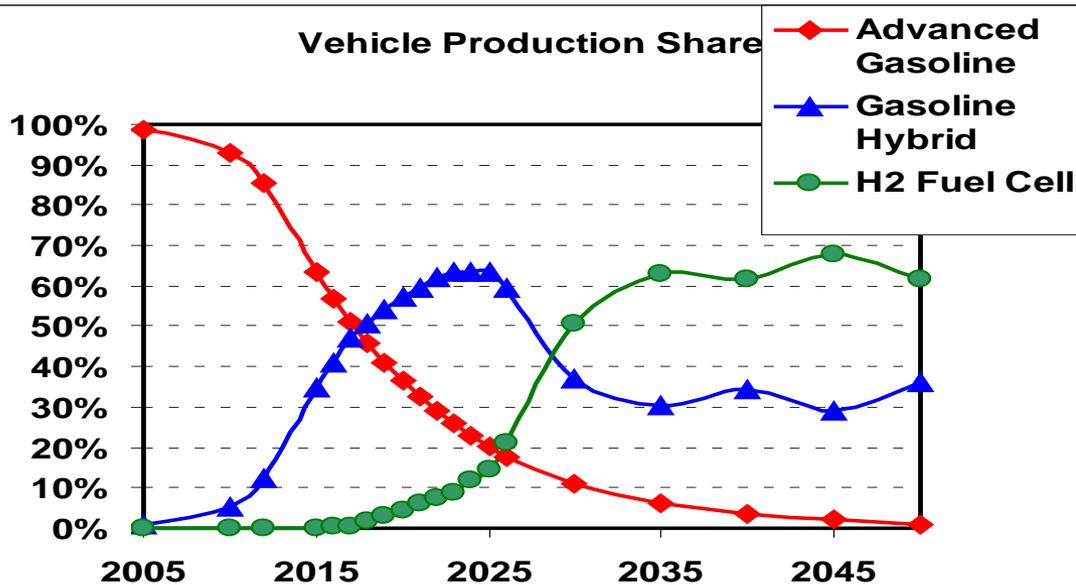
At a lower AEO oil price of \$50/bbl in 2030, a sustainable transition to FCVs occurs but there is stronger competition from hybrid electric vehicles.

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

## \$60/kW Fuel Cell Cost



## \$10/kWh On-board Storage



# Market transformation: Could a government acquisition program for non-automotive PEM fuel cells create a sustainable North American market?

- A rapid study focused on three markets: 1 kW and 5 kW Backup-Power, 5kW Materials Handling Equip.
- Government acquisitions could significantly reduce the cost of fuel cells through learning and economies of scale, and help to support a growing supplier base.

**Impact of Government Acquisitions on Fuel Cell Stack Costs (for non-automotive fuel cells)**



(ORNL study, graphic by DOE)

# Major Technology Goals

## Fuel Cell R&D:

### Improve Durability of Fuel Cells

	2015 Targets
Transportation	5,000 hrs
Stationary Power	40,000 hrs
Auxiliary Power Units ( <i>for trucks</i> )	15,000 hrs

### Reduce Cost of Fuel Cells

	2015 Targets
Transportation	\$30/kW
Stationary Power	\$750/kW
Auxiliary Power Units ( <i>for trucks</i> )	\$600/kW

## Hydrogen Fuel R&D

### Reduce Cost of Producing Hydrogen

	2015 Target	2020 Target
Total Cost of H <sub>2</sub> ( <i>delivered &amp; dispensed</i> )	\$2 – \$3/gge*	
Total Cost of H <sub>2</sub> from <b>Multiple Renewable Pathways</b> ( <i>delivered &amp; dispensed</i> )		\$2 – 3/gge

\* This target has been met for distributed production of H<sub>2</sub> from natural gas.

### Reduce Cost of Delivering H<sub>2</sub> (*from centralized production sites*)

	2015 Target	2020 Target
Cost of Delivering H <sub>2</sub> ( <i>includes off-board storage &amp; dispensing</i> )	\$1.70/gge	<\$1/gge

### Improve Capacity & Reduce Cost of H<sub>2</sub> Storage Systems

	2015 Target
Volumetric Capacity ( <i>reduce size</i> )	40g/L
Gravimetric Capacity ( <i>reduce weight</i> )	5.5 wt %

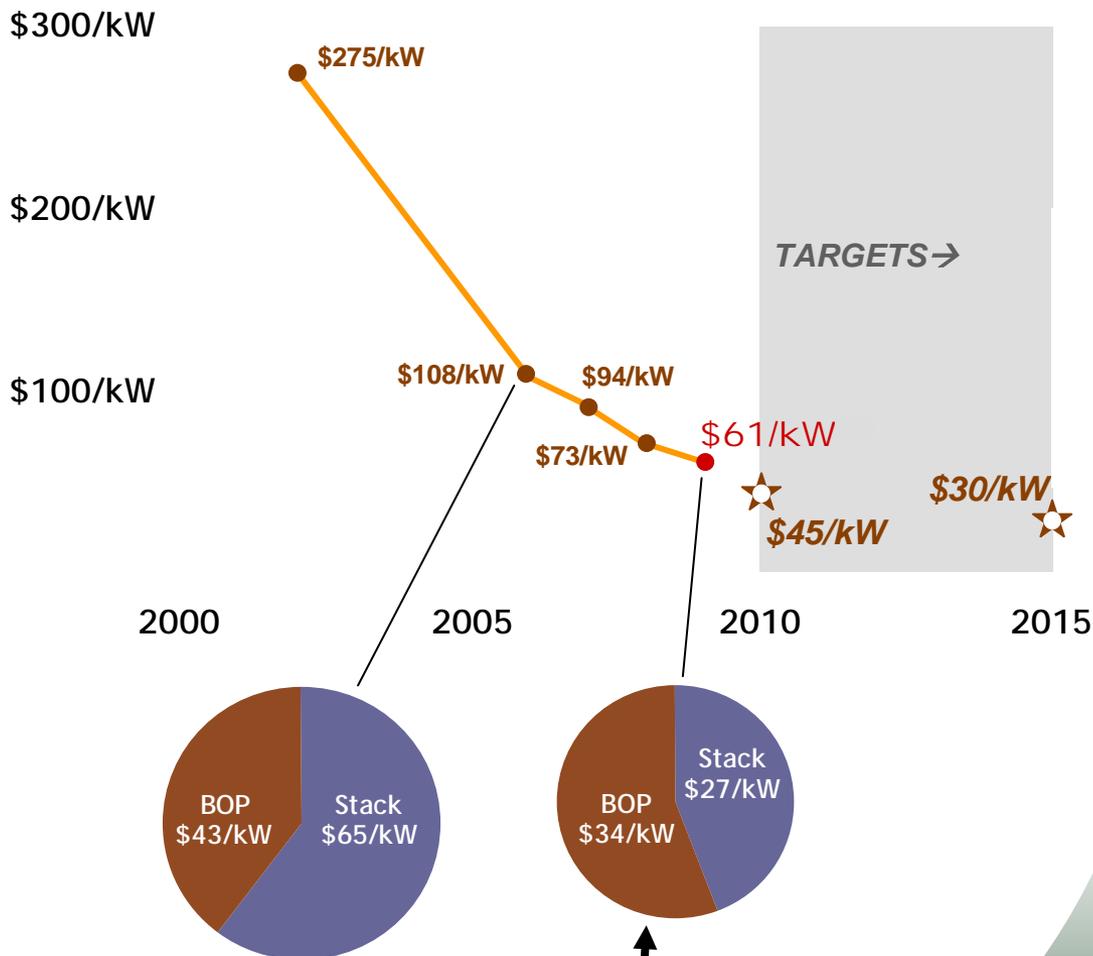
**NOTE:** Hydrogen storage systems also have to meet targets for other critical factors, such as: cost, durability, charge/discharge rates, efficiency, and safety.

We've reduced the cost of fuel cells to \$61/kW\*

- **More than 35% reduction in the last two years**
- **More than 75% reduction since 2002**
- **2008 cost projection was validated by independent panel\*\***

## Projected Transportation Fuel Cell System Cost

- projected to high volume (500,000 units per year) -



\*Based on projection to high-volume manufacturing (500,000 units/year).

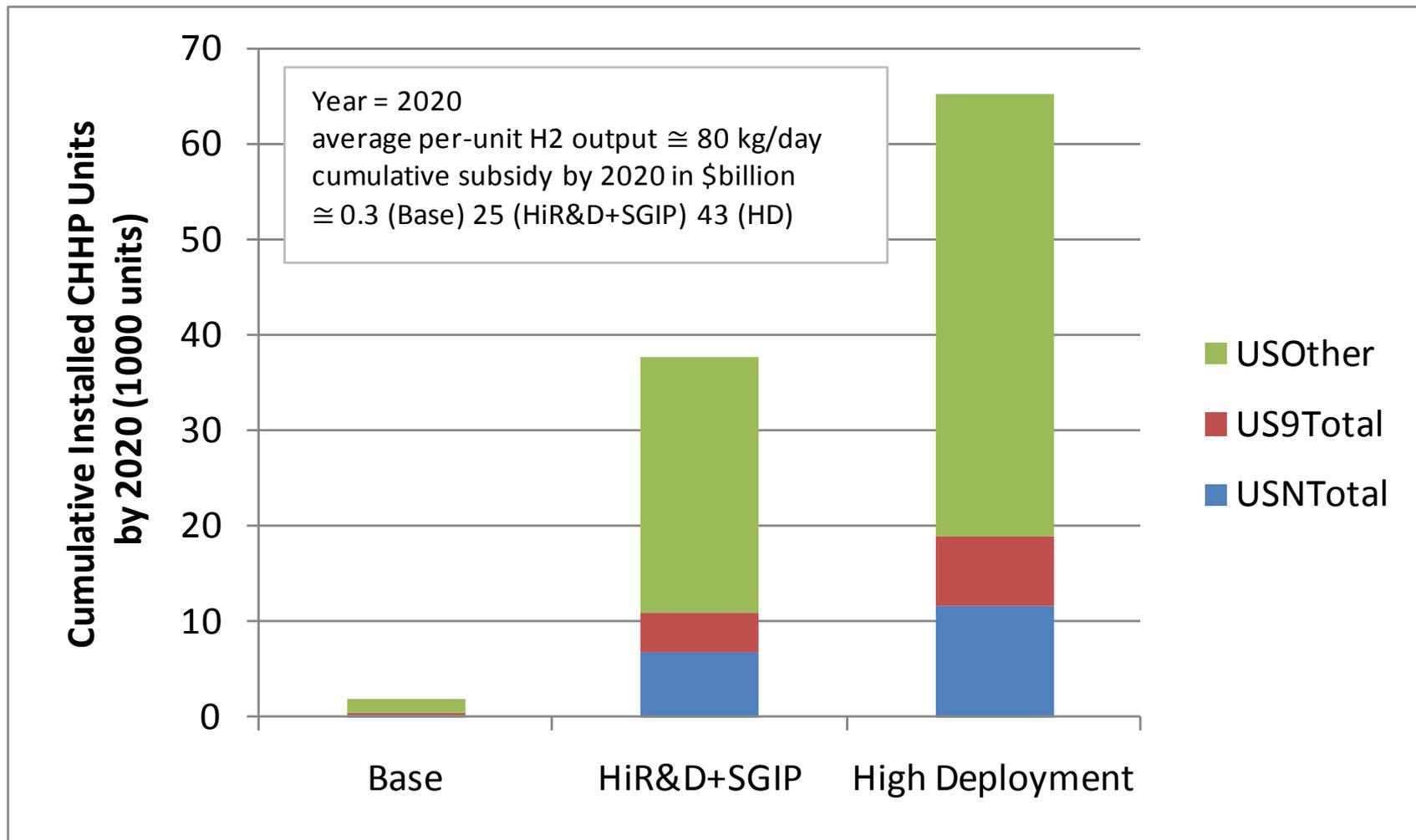
\*\*Panel found \$60 – \$80/kW to be a “valid estimate”:  
[http://hydrogenodev.nrel.gov/peer\\_reviews.html](http://hydrogenodev.nrel.gov/peer_reviews.html)

As stack costs are reduced, balance-of-plant components are responsible for a larger % of costs (BOP costs shown here include system assembly & testing).

## Three national CHHP deployment scenarios were developed based on scenarios created for California by the California Energy Commission and EPRI.

- The CEC-EPRI report projects the FC CHP installed capacity in California under several scenarios. CHHP capacity by census division is projected based on residential and commercial electricity demand relative to California.
- High-R&D + Incentives Case extends the California Self-Generation Incentive Program (SGIP) nationwide + 3-year faster progress in FC technology than the Base Case. High Deployment Case accelerates R&D 2 more years and assumes a more favorable market.
- Three representative CHHP sizes: 150kW, 250kW, 1MW
  - 150 kW producing 56 kg H<sub>2</sub> per day.
  - 250 kW producing 93 kg/d
  - 1 MW producing 340 kg/d
- Two methods of delivery are represented:
  - H2A Power: short pipeline to nearby refueling station
  - HDSAM v 2.0 & NRC (2004): tube trailer to retail site within 5 miles

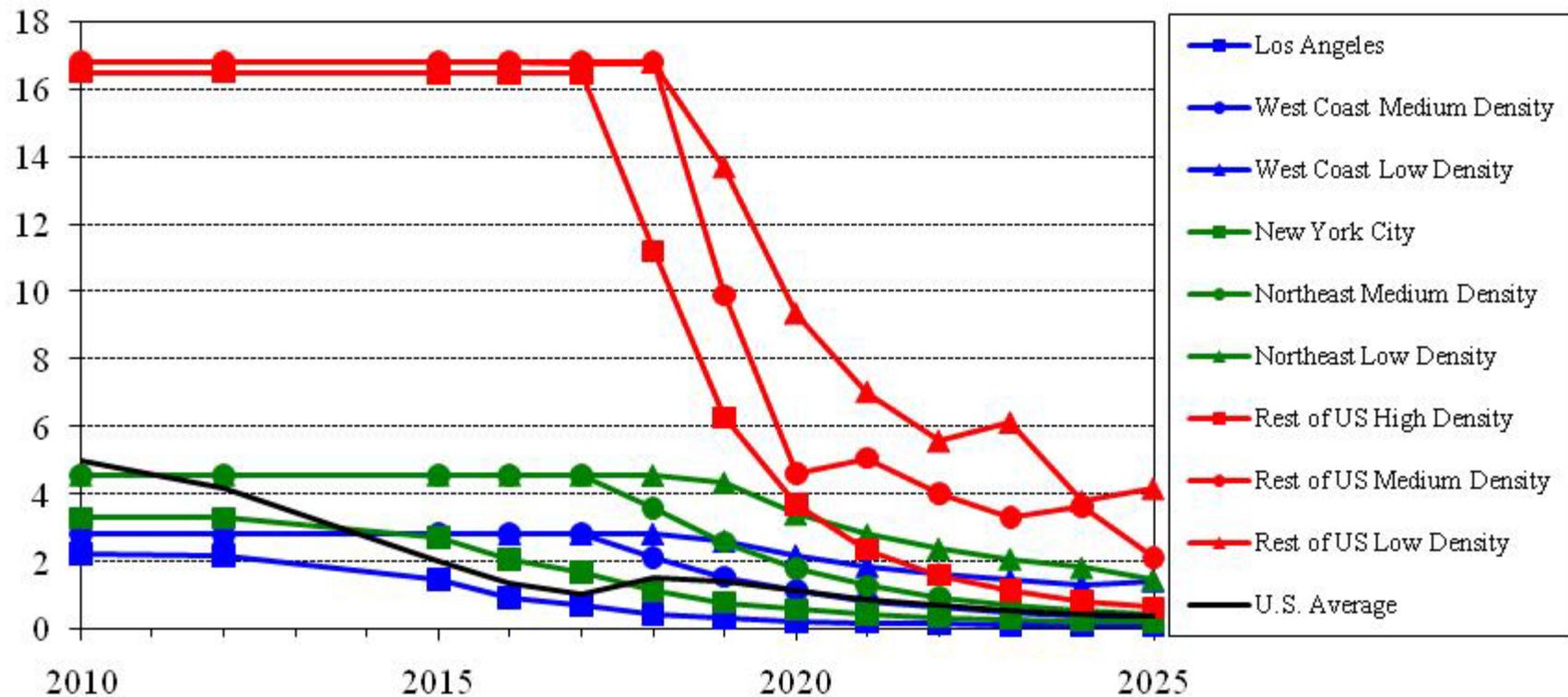
With the kind of strong incentives for CHHP offered by national and California policies, up to 60,000 CHHP sites are potentially active by 2020.



Lack of fuel availability can be a major additional perceived cost for hydrogen fuel cell vehicles during the early transition, especially outside the lighthouse regions.

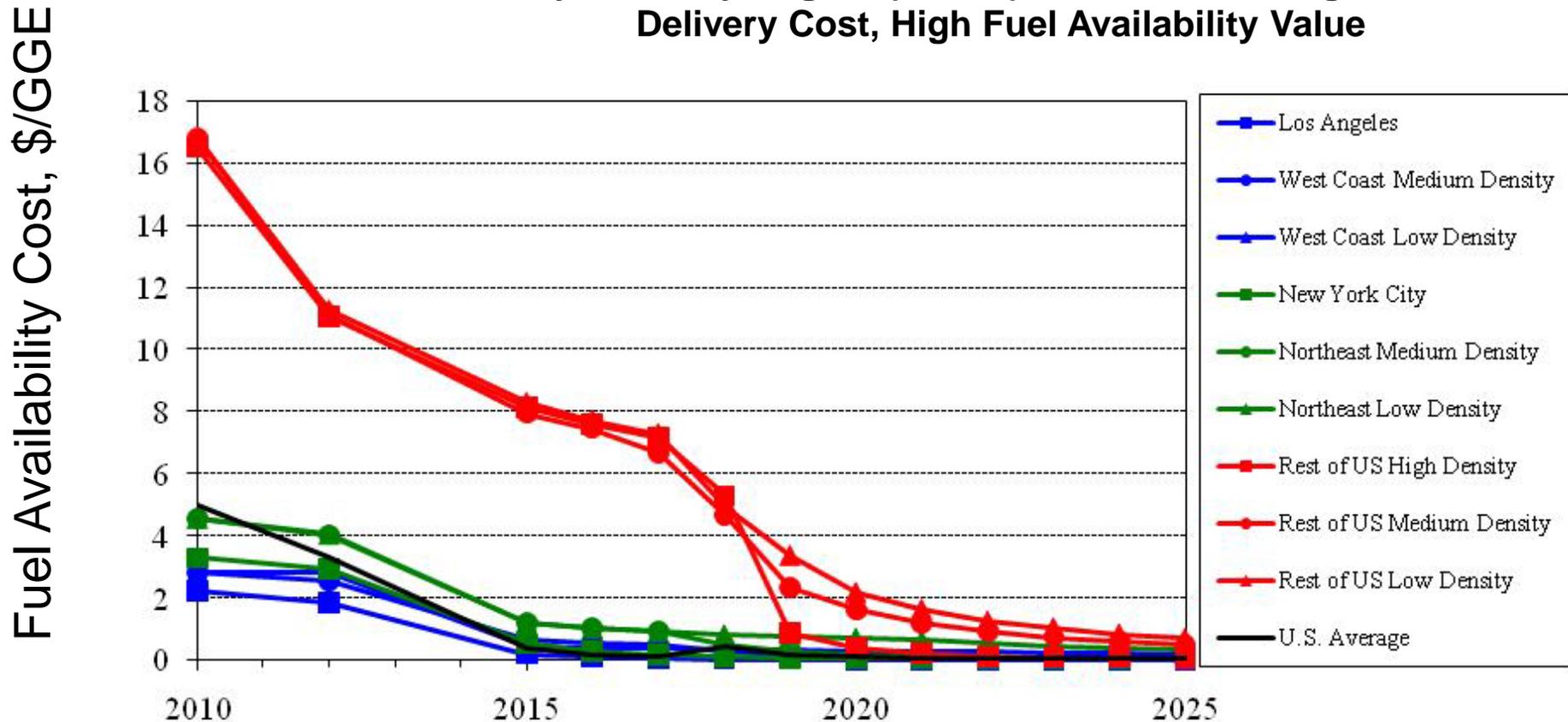
**H2 Retail Fuel Availability Costs (\$/GGE): Scenario 2, No CHHP Deployment, High Value of Fuel Availability**

Fuel Availability Cost, \$/GGE



With better incentives and better technology for CHHP, more CHHPs become sources of H2 supply. This significantly improves fuel availability when coupled with hydrogen retail outlets.

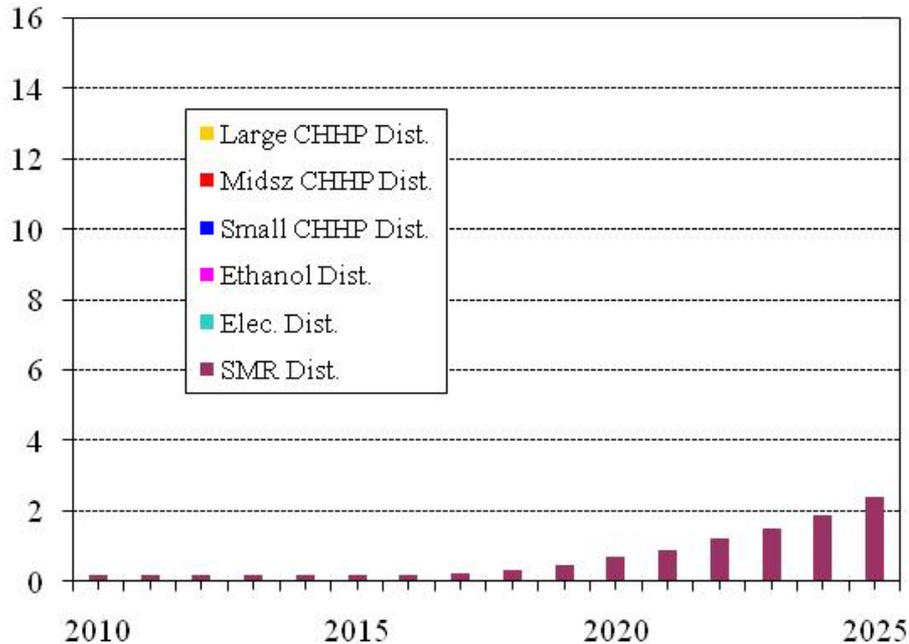
**Retail Fuel Availability Costs by Region (\$/GGE), HiR&D+SGIP, High Delivery Cost, High Fuel Availability Value**



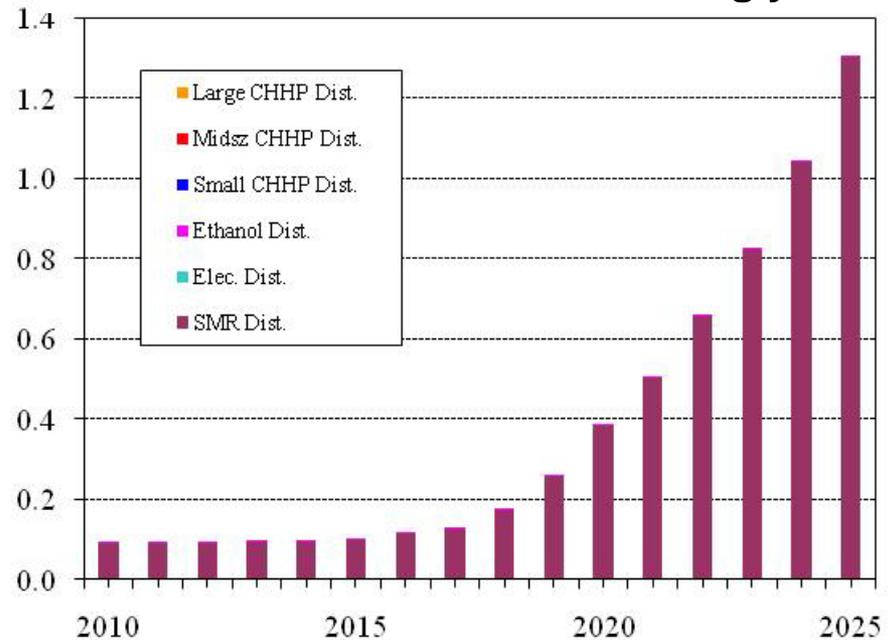
Without CHHP, almost 100% of H<sub>2</sub> supply for vehicles and 100% of retail outlets in the early transition period are 1500 kg/day SMR installations.

### Scenario 2, No CHHP Deployment, High Value of Fuel Availability

#### Thousands of Distributed Retail Stations



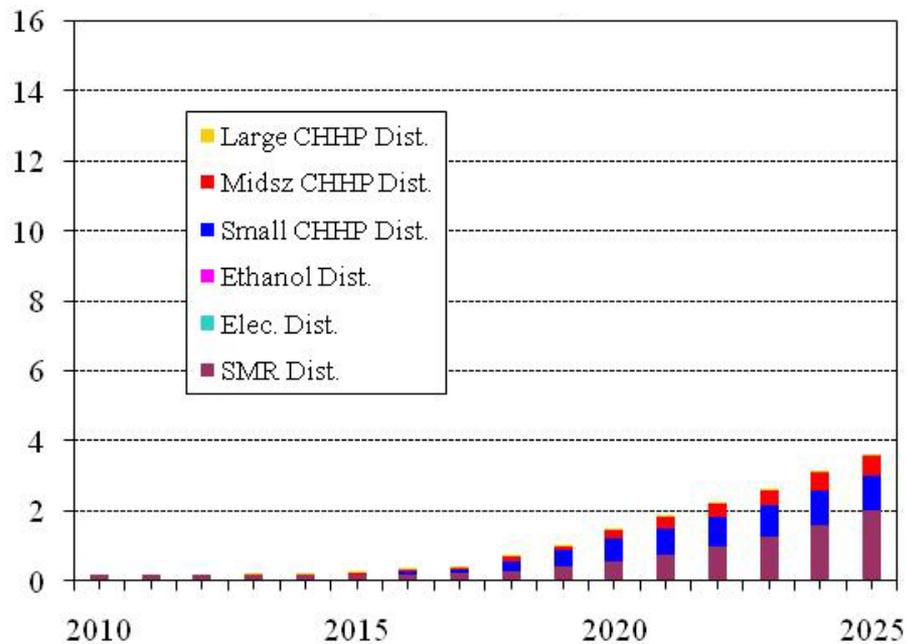
#### Hydrogen Production in Billion kg/year



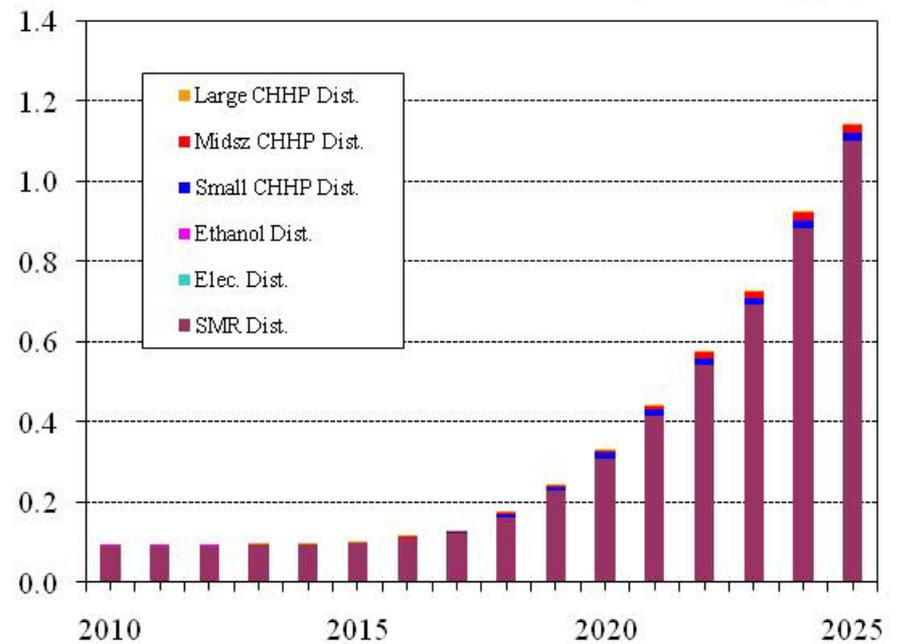
With CHHP, some SMR stations would be replaced by CHHP stations, resulting in more hydrogen stations, smaller average station size and better fuel availability

**Scenario 2, Base CHHP Deployment, High Value of Fuel Availability**

**Thousands of Distributed Retail Stations**



**Hydrogen Production in Billion kg/year**



With better technology progress and CA incentives available to all states, by 2025, hydrogen is mostly provided by SMR while fuel availability is mostly provided by CHHP

**Scenario 2. HiR&D+SGIP Scenario, High Delivery Cost, High Value of Fuel Availability**

**Thousands of Distributed Retail Stations**

**Hydrogen Production in Billion kg/year**

