The Future of Hydrogen

Findings from the National Academies' New Report

An NHA Webinar Series

September 17, 2008 - 12:00 - 1:00 pm, ET

THE NATIONAL HYDROGEN ASSOCIATION

The audio and question & answer session were recorded live – go to www.hydrogenassociation.org/webinar to access the full presentation

Presentations
By

Gene Nemanich
Vice President of Hydrogen Systems (retired), Chevron
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UC Davis

Transitions to Alternative Transportation Technologies; a Focus on Hydrogen

Presentation of Results

Gene Nemanich
Joan Ogden
Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies

September 17, 2008

COMMITTEE ON ASSESSMENT OF RESOURCE NEEDS FOR FUEL CELL AND HYDROGEN TECHNOLOGIES

- **MICHAEL P. RAMAGE**, NAE[1], ExxonMobil Research and Engineering Company (retired), *Chair*
- **RAKESH AGRAWAL**, NAE, Purdue University
- **DAVID L. BODDE**, Clemson University
- **DAVID FRIEDMAN**, Union of Concerned Scientists
- **SUSAN FUHS**, Conundrum Consulting
- **JUDI GREENWALD**, Pew Center on Global Climate Change
- **ROBERT L. HIRSCH**, Management Information Services, Inc.
- **JAMES R. KATZER**, NAE, Massachusetts Institute of Technology
- **GENE NEMANICH**, ChevronTexaco Technology Ventures (retired)
- **JOAN OGDEN**, University of California, Davis
- **LAWRENCE T. PAPAY**, NAE, Science Applications International Corporation (retired)
- **IAN W.H. PARRY**, Resources for the Future
- **WILLIAM F. POWERS**, NAE, Ford Motor Company (retired)
- **EDWARD S. RUBIN**, Carnegie Mellon University
- **ROBERT W. SHAW, JR**., Aretê Corporation
- **ARNOLD F. STANCELL**, NAE, Georgia Institute of Technology
- **TONY WU**, Southern Company

[1] NAE, National Academy of Engineering.

Goals of the Statement of Task

- Establish as a goal the *maximum practicable number* of vehicles that can be fueled by hydrogen by 2020
- Determine the *funding***,** public and private, to reach that goal
- Establish a *budget roadmap* to achieve the goal
- Determine the *government actions* required to achieve the goal
- Consider the role that hydrogen's use in *stationary electric power* applications will play in stimulating the transition to hydrogen-fueled hybrid electric vehicles
- Consider whether *other technologies* could achieve significant CO2 and oil reductions by 2020

Committee's Analytical Approach

Estimate HFCV ***maximum practical penetration rate***, assuming

- Technical goals are met
    - HFCV goals substantially met by 2015
    - Hydrogen production goals when needed
- Consumers accept HFCVs
- Oil prices remain high (EIA high oil price scenario used as reference case)
- Policies are in effect to support HFCVs and hydrogen production

Analytical Approach, continued

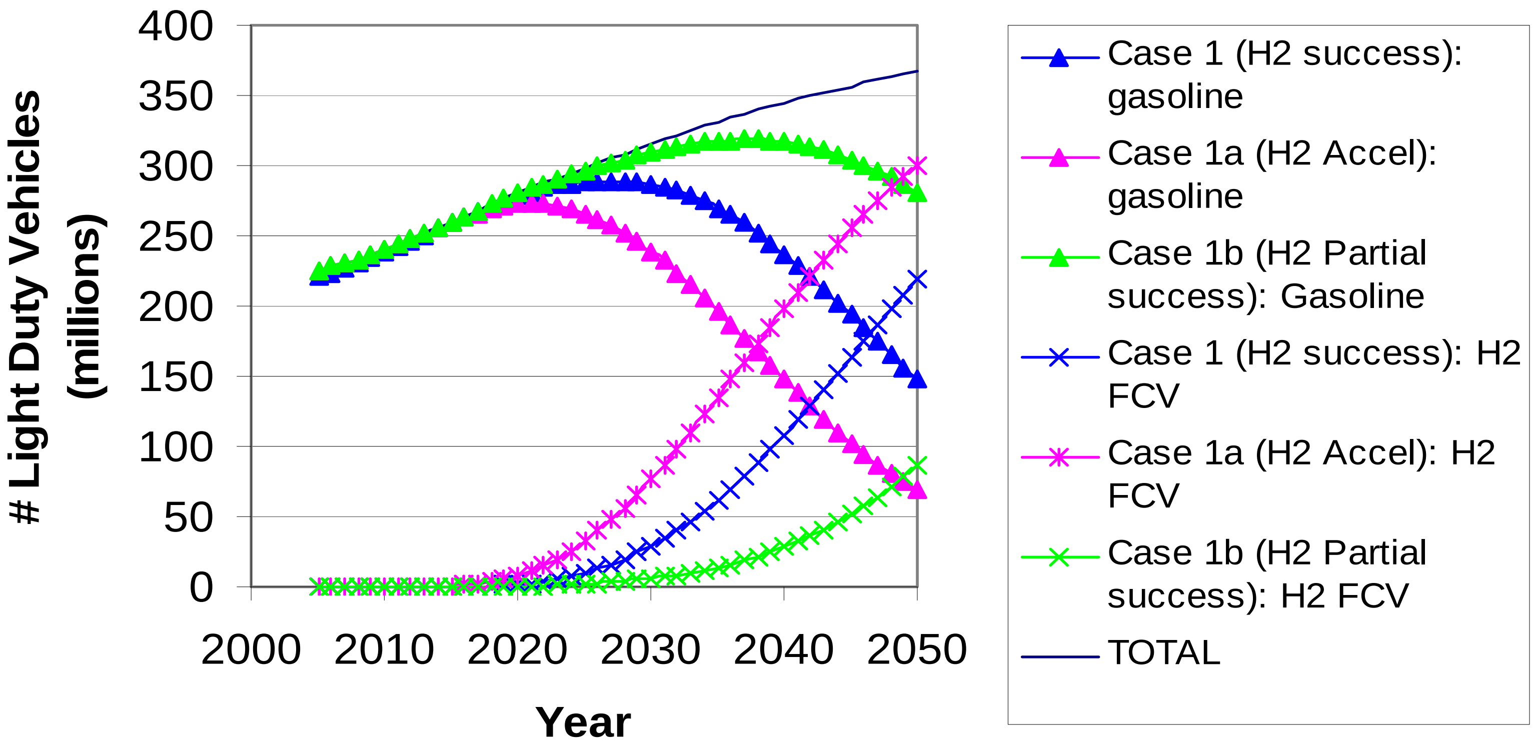
Evaluated three HFCV scenarios

- Hydrogen Success, possible if above assumptions are met, based on DOE scenario and extended to 2050 by committee
- Hydrogen Accelerated, possible if goals are exceeded or stronger policies enacted
- Hydrogen Partial Success, possible if goals not completely met

Committee adopted Hydrogen Success as most plausible **maximum practicable penetration rate.**

Please note this is not a projection.

Hydrogen Cases: Number of Light Duty Vehicles in the Fleet (millions)



Analytical Approach, continued

Reviewed Alternative Technologies

- Continued improvement of ICEV efficiency past 2020
  - Currently available technologies used totally for improved efficiency
- Rapid development of Biofuels
  - Continued aggressive production increases through 2050
- Also considered these two plus HFCVs together
- Some promising alternatives were not included
  - Diesel, battery electric and plug-in hybrid

Needed Government Actions

- Policies designed to accelerate the penetration of HFCVs into the U.S. vehicle market.
    - To ensure continued development of HFCV's
    - To deal with high initial cost of HFCV's
    - To lower the cost of, and to develop the initial H2 infrastructure
- Must be durable over the transition time frame.
- Should be structured so that they are tied to technology and market progress, with any subsidies phased out over time
    - To promote high end use efficiency of transportation fuels
    - Policies to limit greenhouse gas emissions from transportation fuels

HFCV Technology Conclusions

- Lower-cost, durable fuel cell systems are likely to be increasingly available over the next 5-10 years
  - Costs are being reduced and durability is increasing but do not yet meet commercial targets

- Commercialization and growth of HFCVs could get underway by 2015,
  - Even though all DOE targets for HFCVs may not be fully realized.
  - If supported by strong government policies,

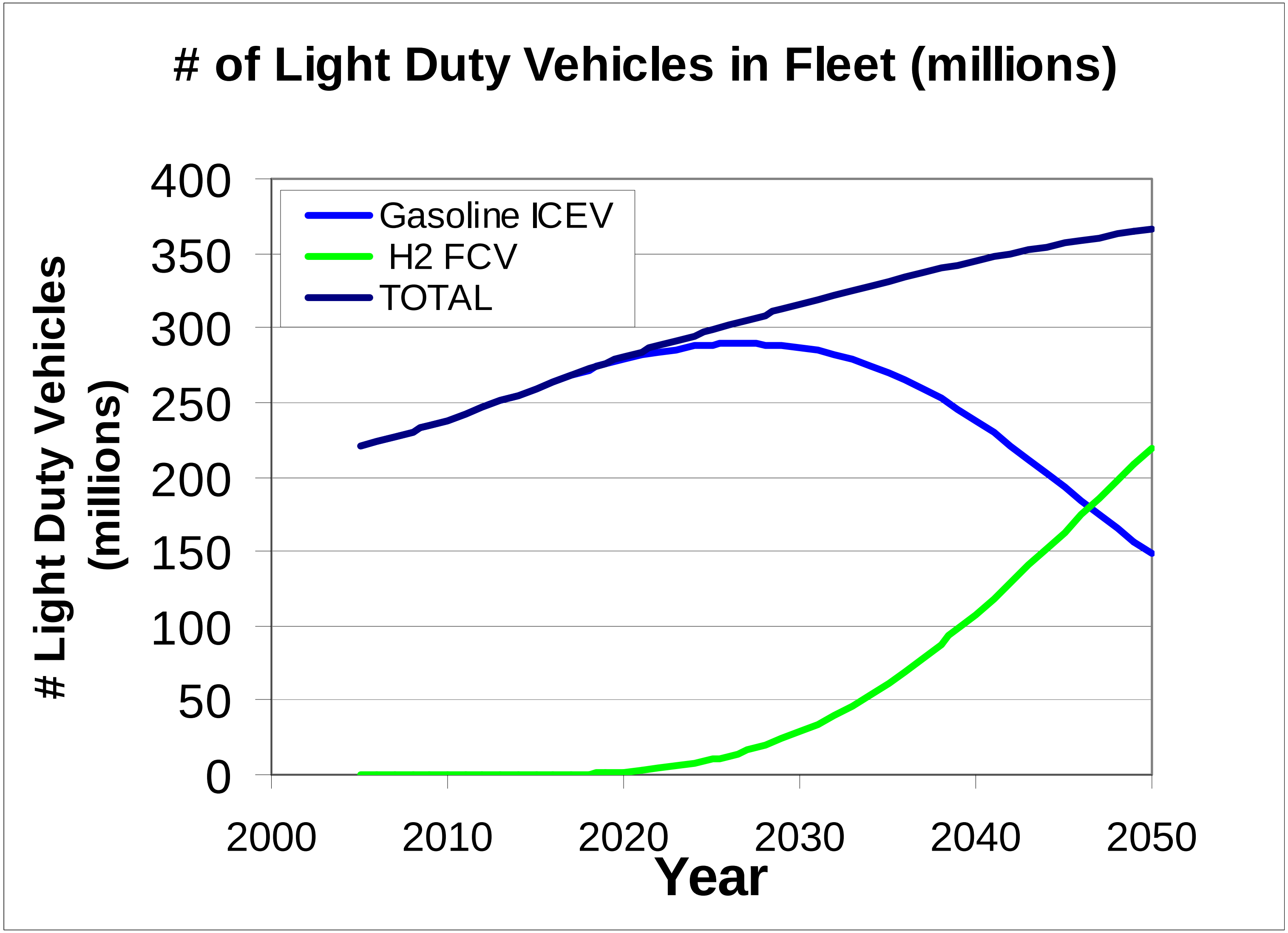
Hydrogen Production Technology Conclusions

- Hydrogen from distributed technologies can be provided at reasonable cost for the beginning of the transition.
- Lower cost hydrogen from central techniques should be available when hydrogen demand is large, if remaining technical targets are met,
  - Hydrogen from coal is cost competitive now, but large scale CO2 sequestration needs to be demonstrated.
  - Hydrogen from biomass gasification technology is at a much earlier stage but is developing rapidly.
- Other technologies could also prove technical and economic readiness during the transition

Alternative Technology Conclusions

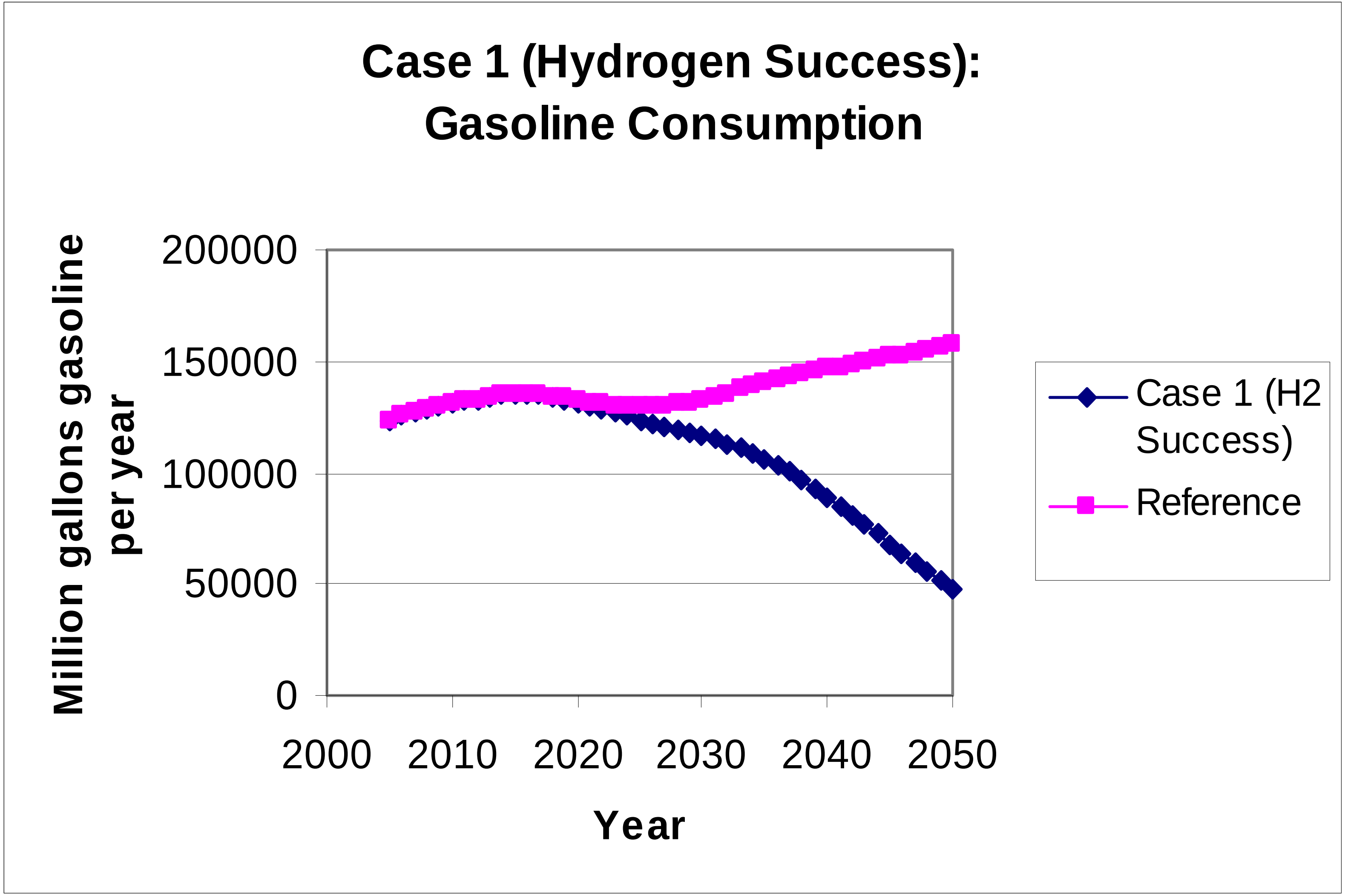
- Both continued ICEV development and aggressive biofuel use have the potential for significant reductions in oil use and CO2 emissions.
  - The rate of growth of the benefits slows after 2 or 3 decades.
- The deepest cuts in oil use and CO2 emissions come from hydrogen.
- A portfolio of all technologies including HFCVs has the potential to nearly eliminate oil use and to reduce CO2 emissions to about 20% of today's by mid century.

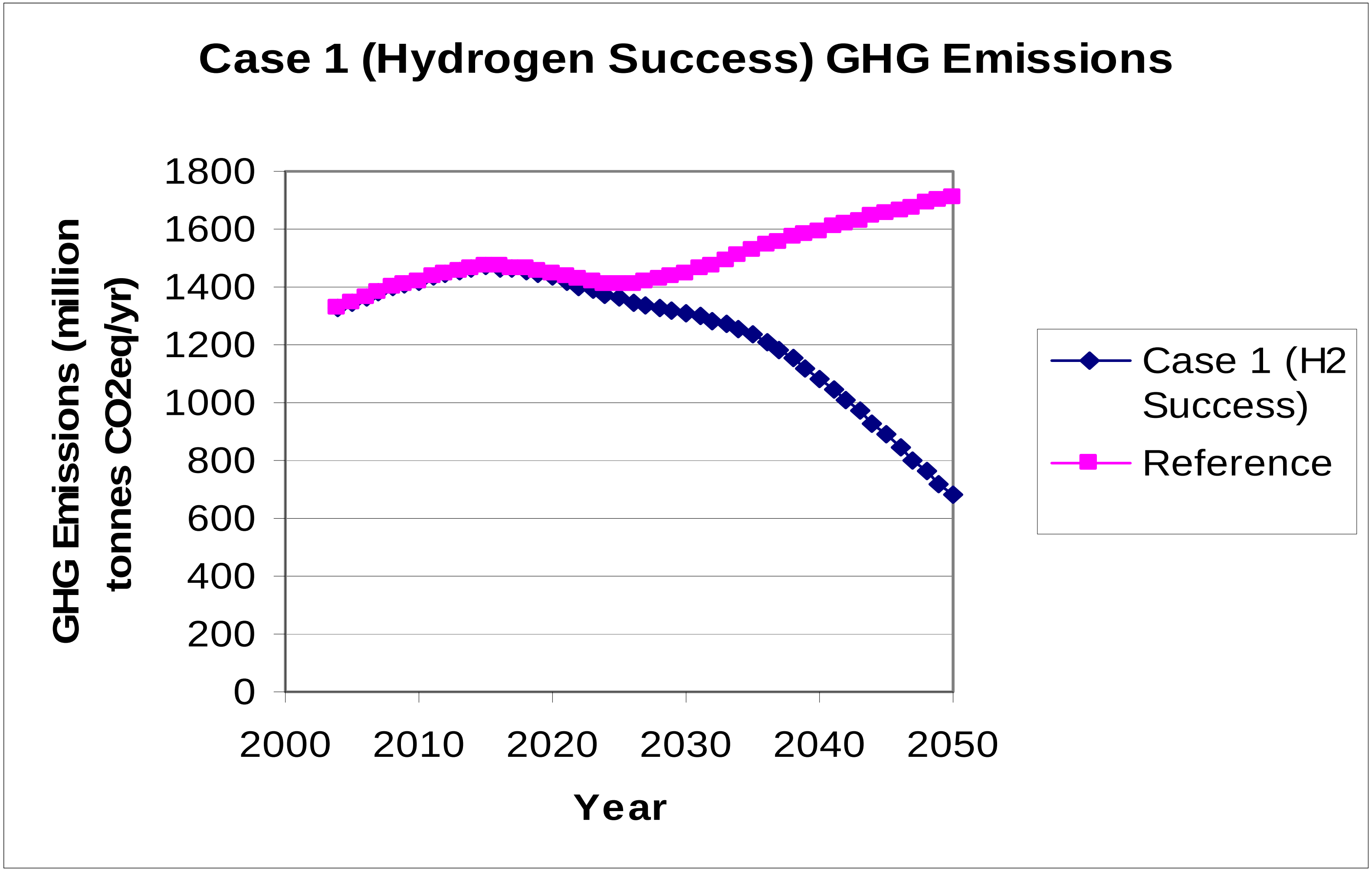
Case 1: H2 Success



Timing for Impact of HFCVs

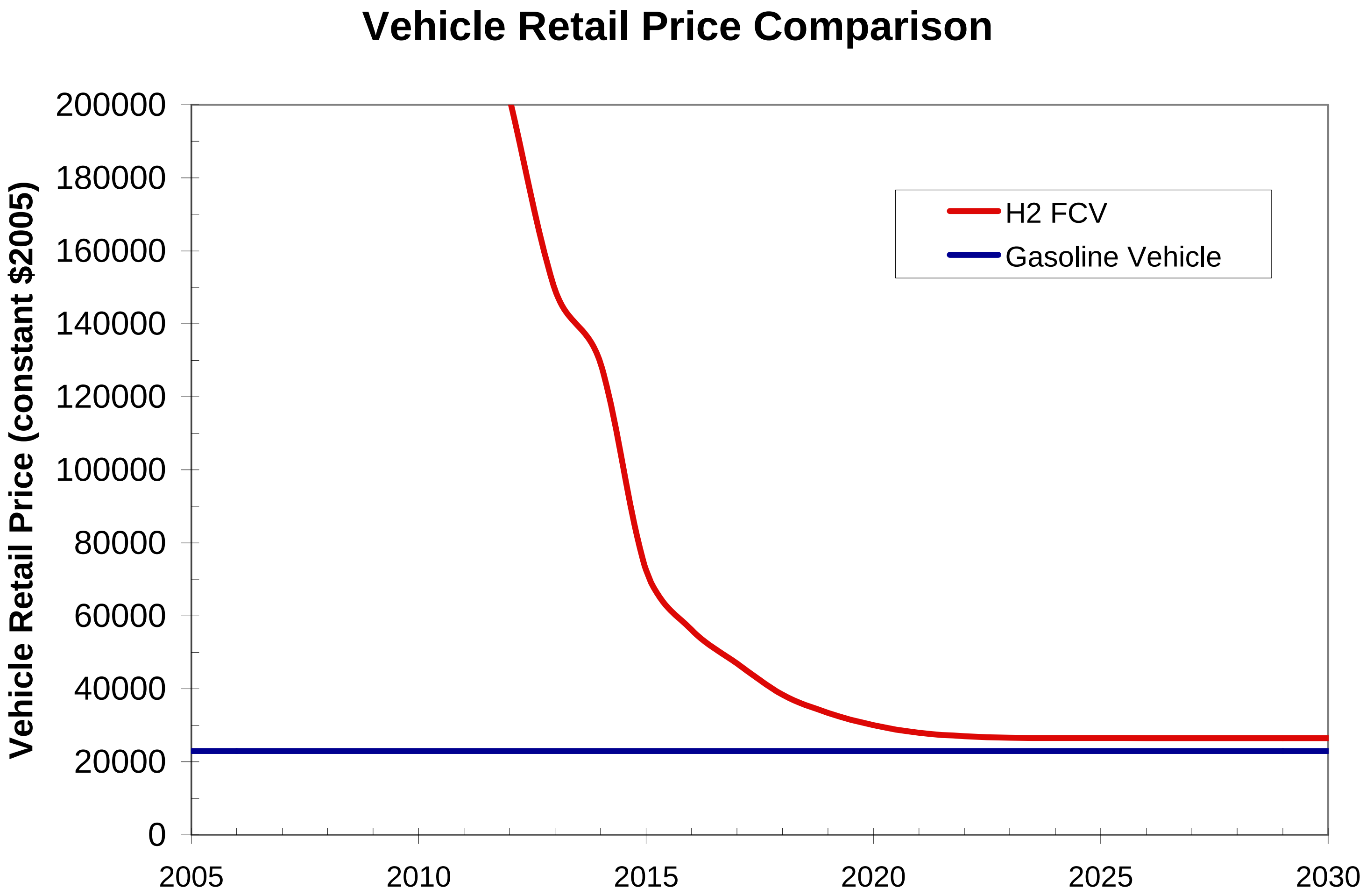
While it will take several decades for HFCVs to have major impact, under the Hydrogen Success scenario, fuel cell vehicles could lead to large reductions in oil consumption. CO2 emissions will also be greatly reduced if strong carbon control policies are implemented.


Case 1 (Hydrogen Success):
Gasoline Consumption
Million gallons gasoline per year
200000
150000
100000
50000
0
2000
2010
2020
2030
2040
2050
Year
Case 1 (H2 Success)
Reference


Case 1 (Hydrogen Success) GHG Emissions
GHG Emissions (million tonnes CO2eq/yr)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2010
2020
2030
2040
2050
Year
Case 1 (H2 Success)
Reference

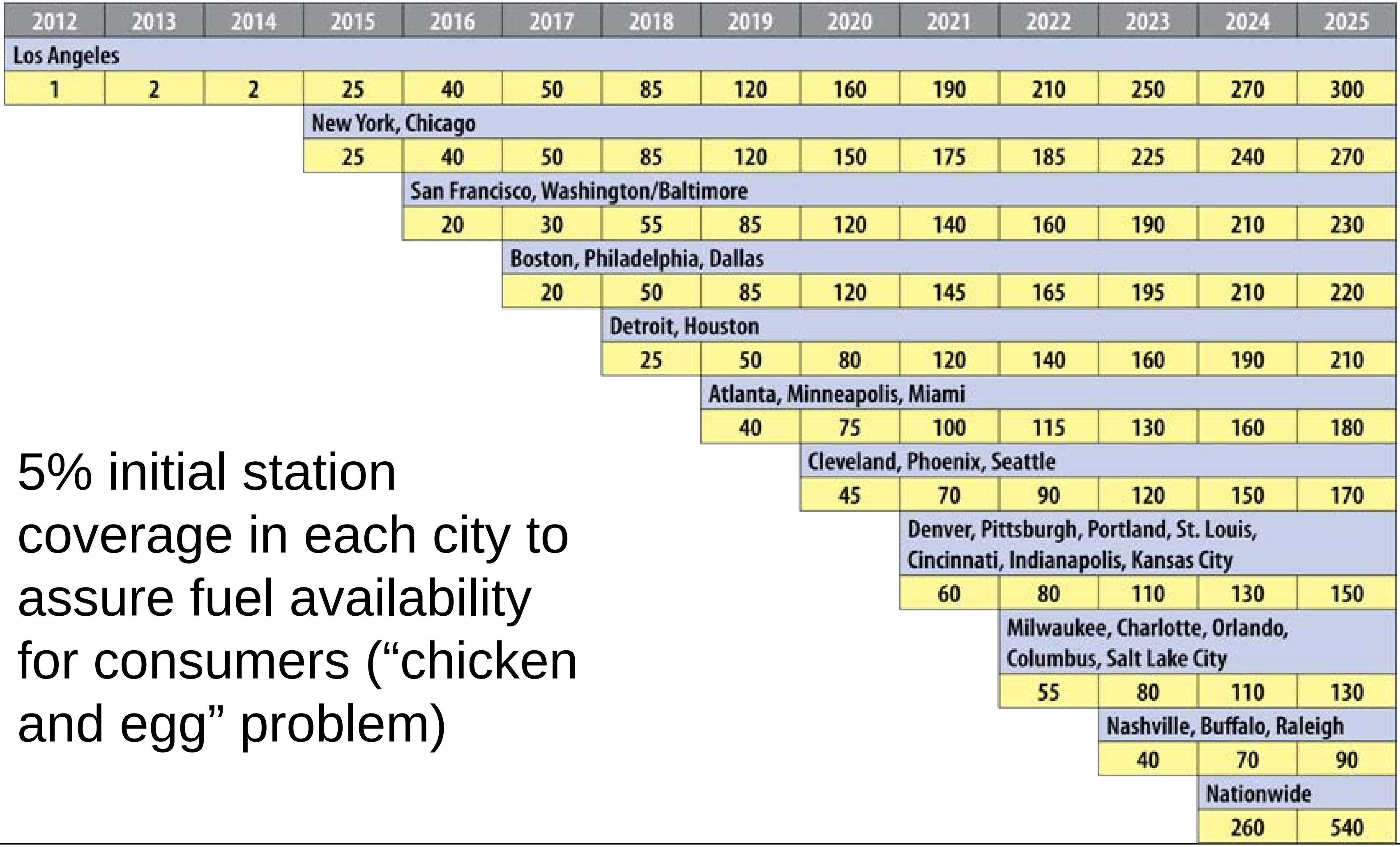
The unit costs of fuel cell vehicles and hydrogen in the Hydrogen Success scenario decline rapidly with increasing vehicle production.

H2 FCV Vehicle Price vs. time



H2 FCV Vehicle Price curve based on model by Greene, Leiby and Bowman (2007).
Price falls due to R&D improvements, cumulative experience and manufacturing scale-up.

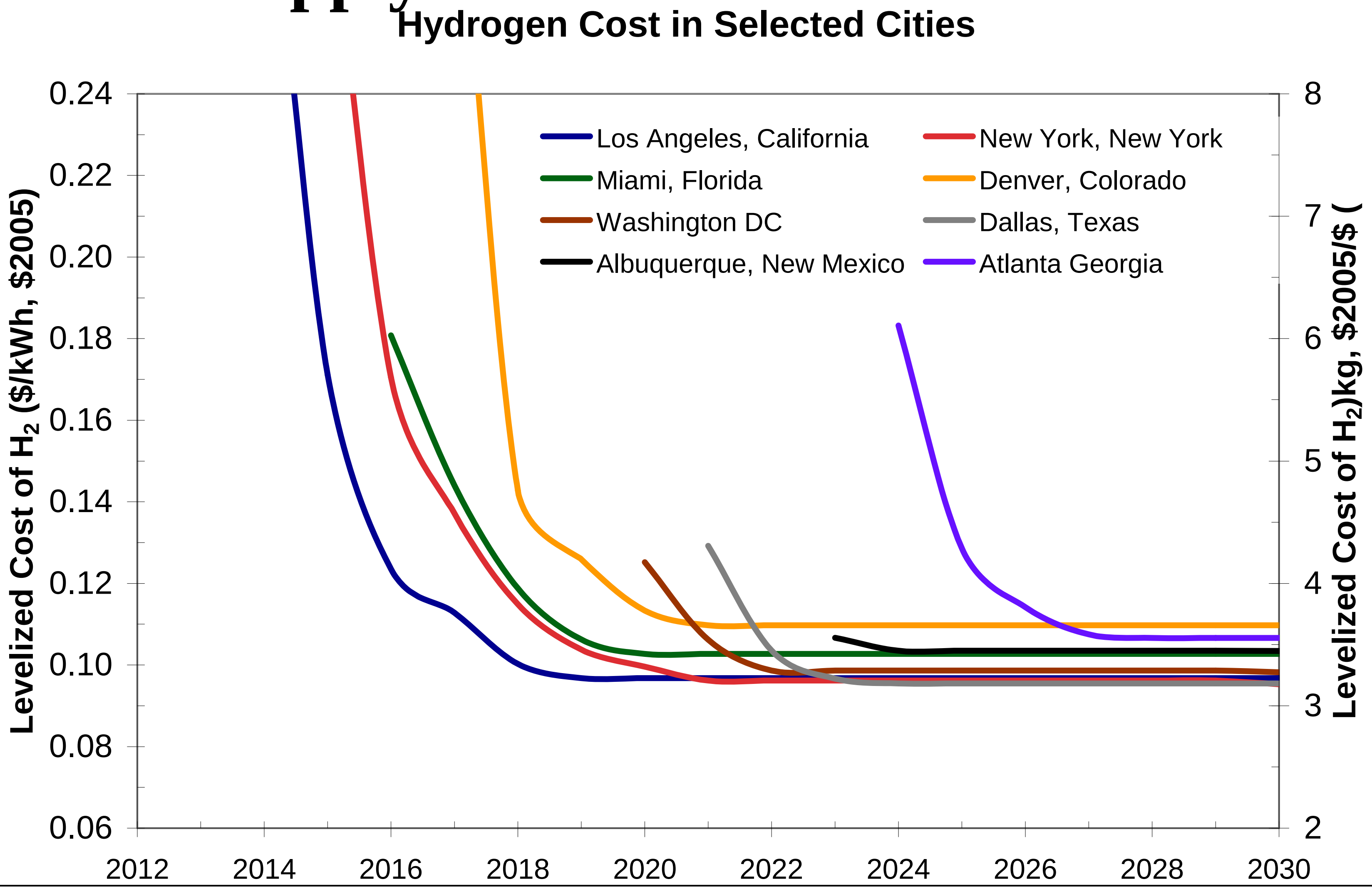
Case 1: Phased Introduction of H2 FCVs in "Lighthouse" Cities [1000s vehicles/yr (USDOE 2007)]



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Los Angeles	1	2	2	25	40	50	85	120	160	190	210	250	270	300
New York, Chicago				25	40	50	85	120	150	175	185	225	240	270
San Francisco, Washington/Baltimore					20	30	55	85	120	140	160	190	210	230
Boston, Philadelphia, Dallas						20	50	85	120	145	165	195	210	220
Detroit, Houston							25	50	80	120	140	160	190	210
Atlanta, Minneapolis, Miami								40	75	100	115	130	160	180
Cleveland, Phoenix, Seattle									45	70	90	120	150	170
Denver, Pittsburgh, Portland, St. Louis, Cincinnati, Indianapolis, Kansas City										60	80	110	130	150
Milwaukee, Charlotte, Orlando, Columbus, Salt Lake City											55	80	110	130
Nashville, Buffalo, Raleigh												40	70	90
Nationwide													260	540

5% initial station coverage in each city to assure fuel availability for consumers ("chicken and egg" problem)

Infrastructure Model Finds Lowest Cost H2 Supply in each of 73 US Cities



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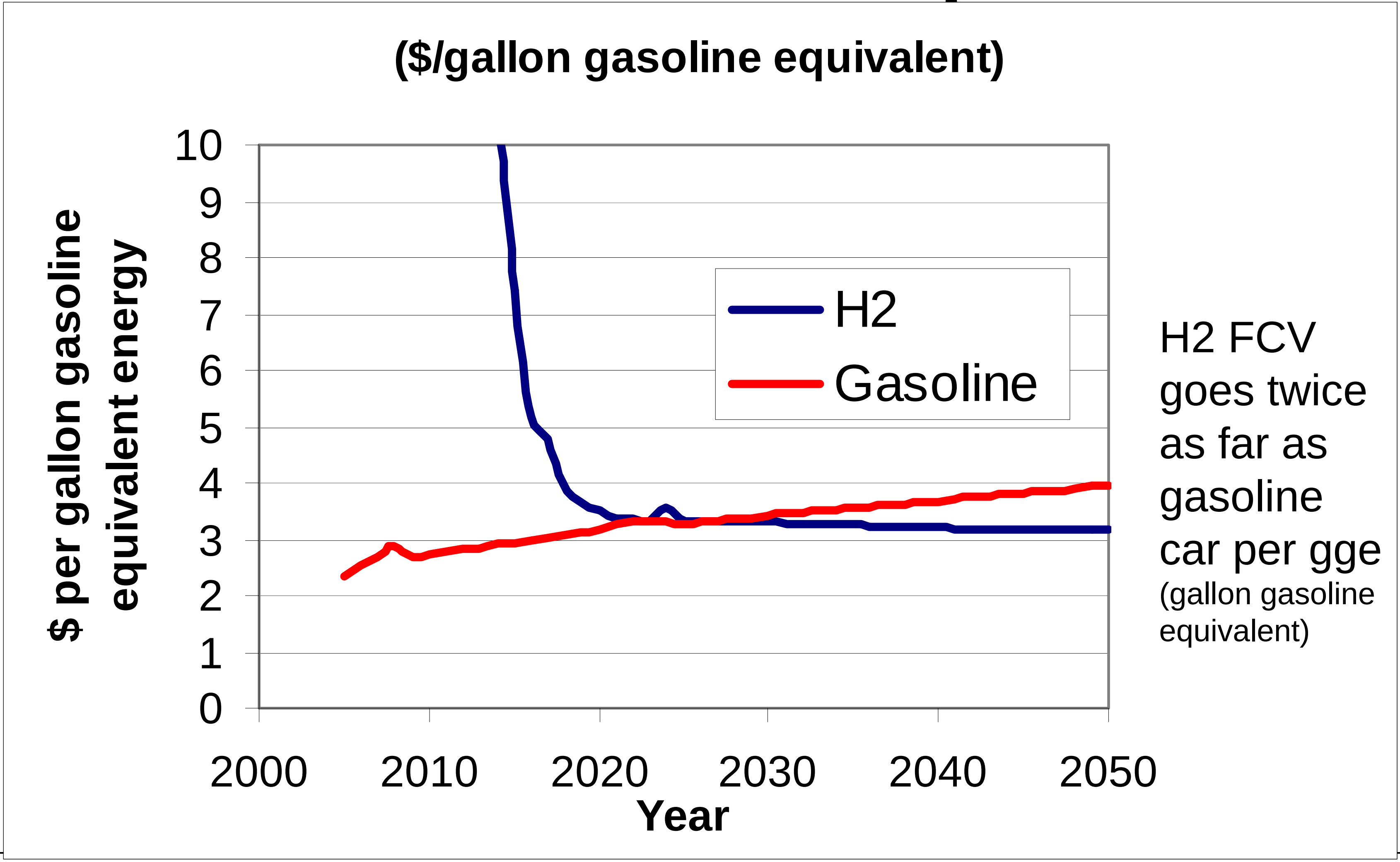
US Average Delivered H2 Cost and Gasoline price



H2 FCV goes twice as far as gasoline car per gge (gallon gasoline equivalent)

Hydrogen Transition Modeling

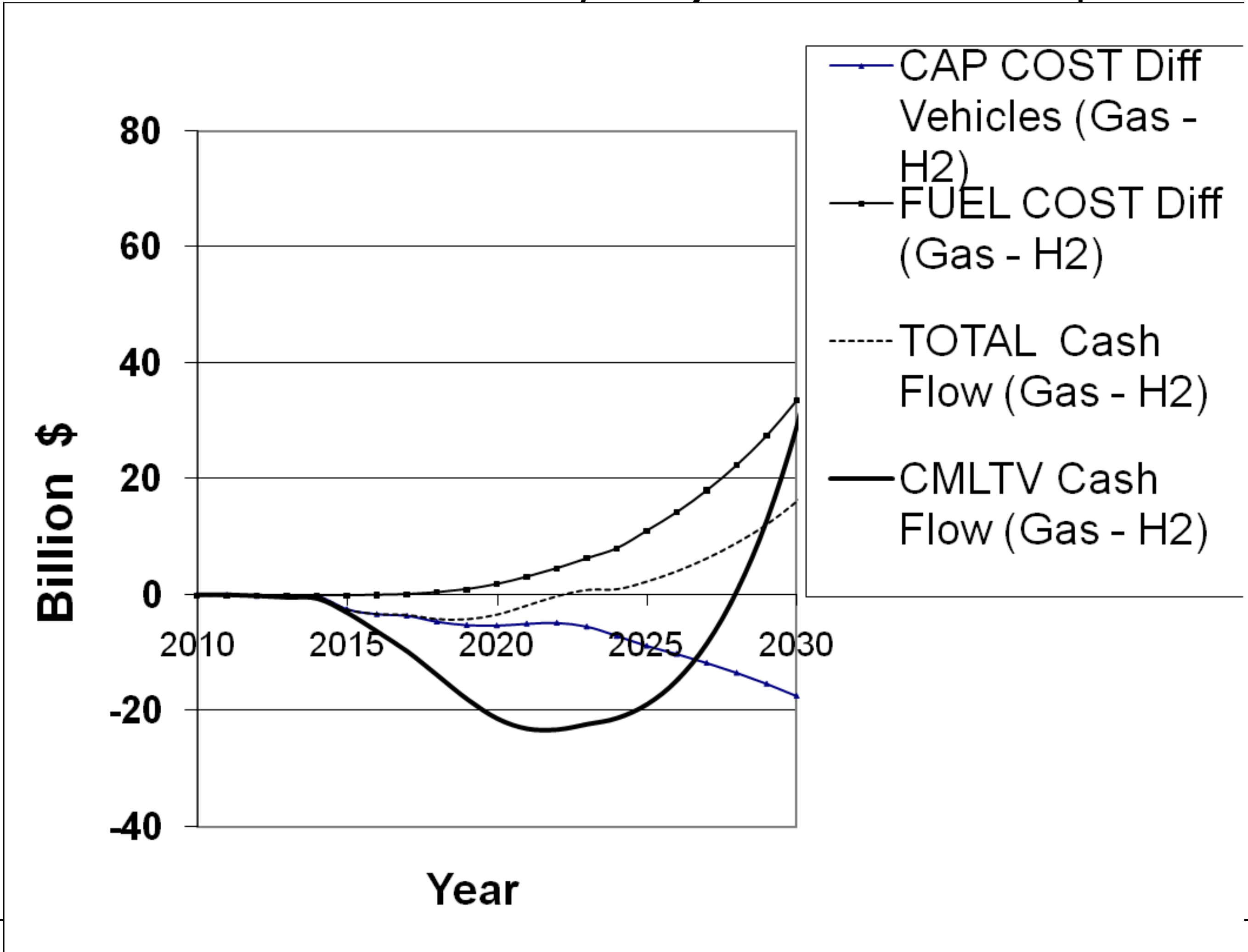
- What are investment costs for H2 fuel cell vehicles to reach cost competitiveness with reference gasoline vehicle?

- Conduct cash flow analysis to see when strategy of introducing H2 FCVs *breaks even* with BAU (staying with gasoline ref vehicle).

- Consider *cost differences* (gasoline-H2) $/y
  - first costs for vehicles
  - fuel costs

H2 Transition Cash Flow Analysis

Breakeven Year = 2023; Buydown Cost = $22 Billion



By 2023 the cost premium for HFCVs relative to conventional gasoline vehicles is projected to be fully offset by the savings in fuel costs.

H2 Transition Timing and Costs

Breakeven Year (Annual Cash flow = 0)	**2023**
Cumulative cash flow difference (H2 FCV - Gasoline ref Car) to breakeven year	$22 Billion
Cumulative vehicle first cost difference (H2 FCVs-Gasoline Ref Car) to breakeven year	$40 Billion
# H2 FCVs cars at breakeven year (millions)	5.6 (1.9% of fleet)
H2 cost at breakeven year	$3.3/kg
H2 demand, # H2 stations at breakeven year	4200 t/d 3600 stations
Total cost to build infrastructure for demand at breakeven year	$8 Billion

RD&D Expenditures

RD&D needed to facilitate the transition to HFCVs totals roughly $16 billion over the 16-year period from 2008 through 2023, of which about $5 billion would come from U.S.(DOE) government sources.

The estimated government cost to support a transition to hydrogen fuel cell vehicles is roughly $55 billion from 2008 to 2023.

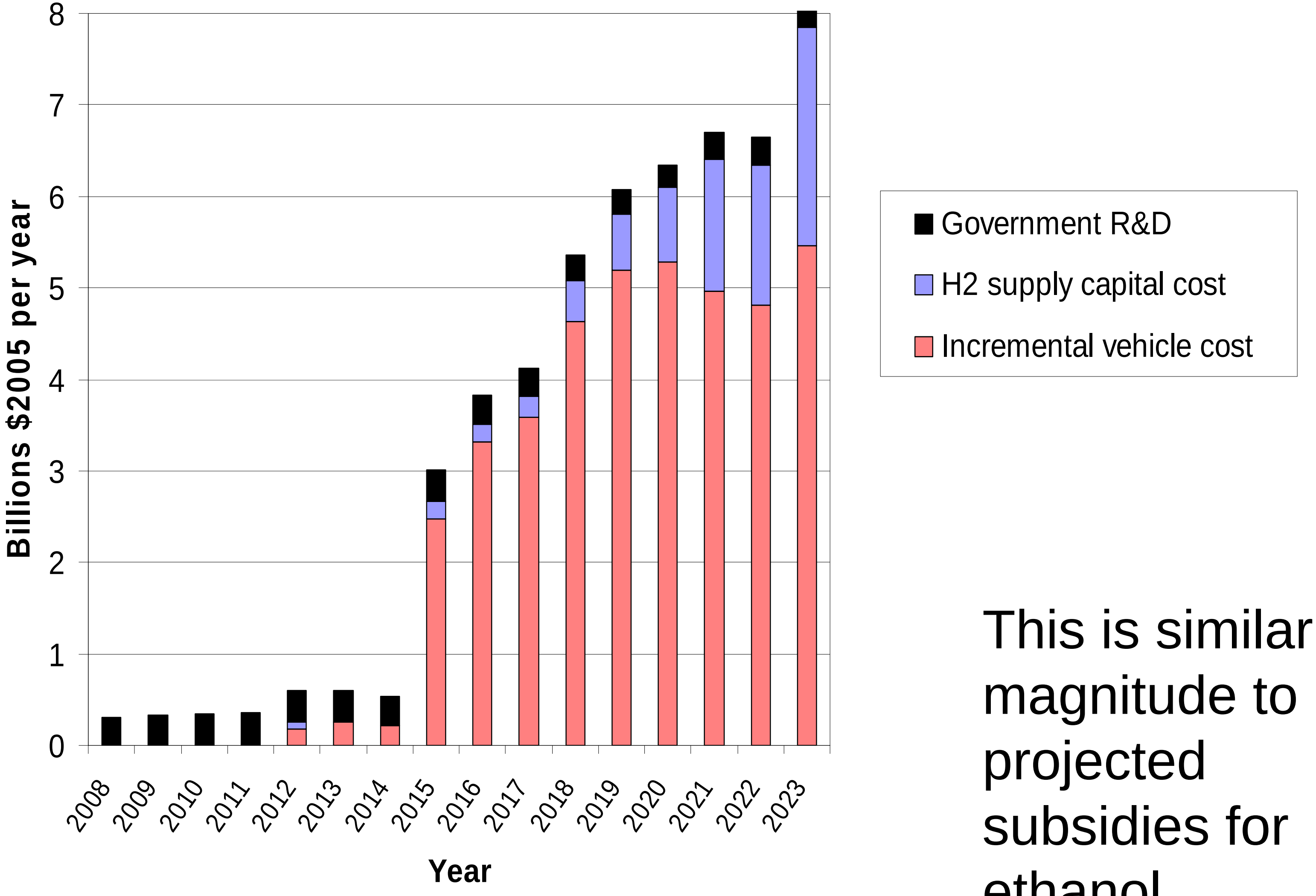
$40 billion for the incremental cost of fuel cell vehicles,

$8 billion for the initial deployment of hydrogen supply infrastructure,

$5 billion for R&D.

The estimated private industry costs is $140 billion from 2008 to 2023

GOVERNMENT COSTS FOR A H2 TRANSITION



This is similar in magnitude to projected subsidies for ethanol

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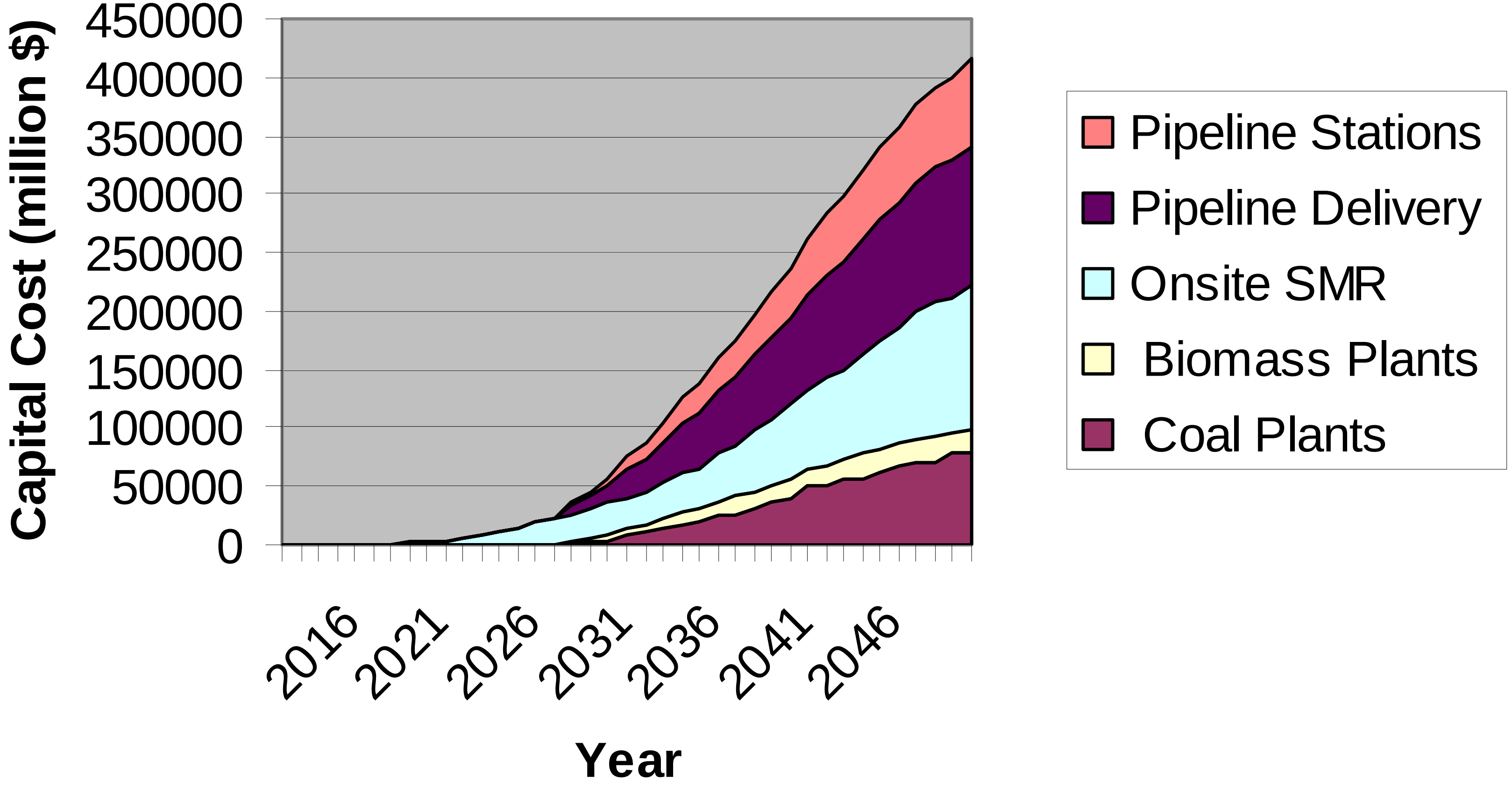
H2 INFRASTRUCTURE COSTS

Industry cost for hydrogen infrastructure would be about $400 billion by 2050 to support 220 million vehicles. This would include 180,000 stations, 210 central plants, and 80,000 miles of pipeline.

Case 1 (Hydrogen Success):
Hydrogen Infrastructure Capital Cost (million $)



HYDROGEN AND ALTERNATIVES

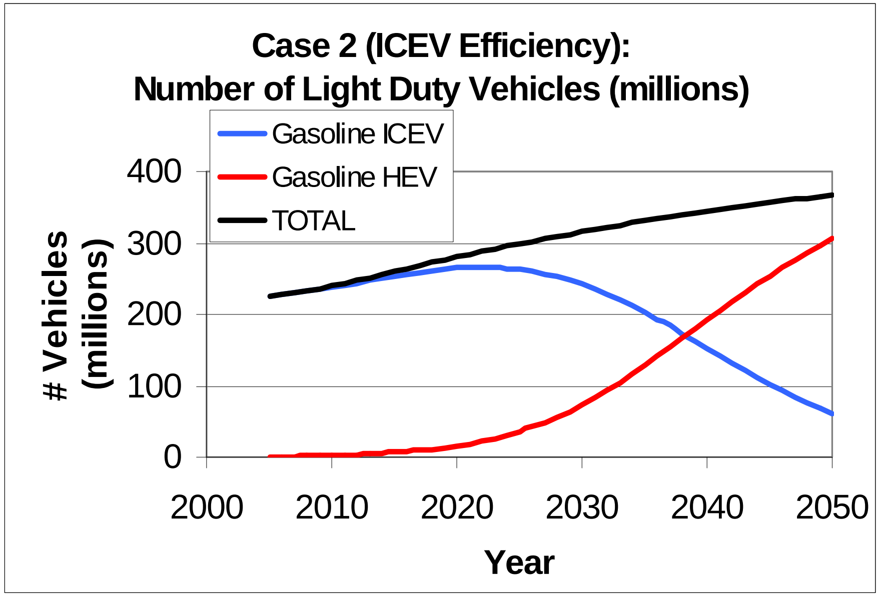
At least two alternatives have the potential to provide significant reductions in projected oil imports and CO2 emissions sooner than HFCVs:

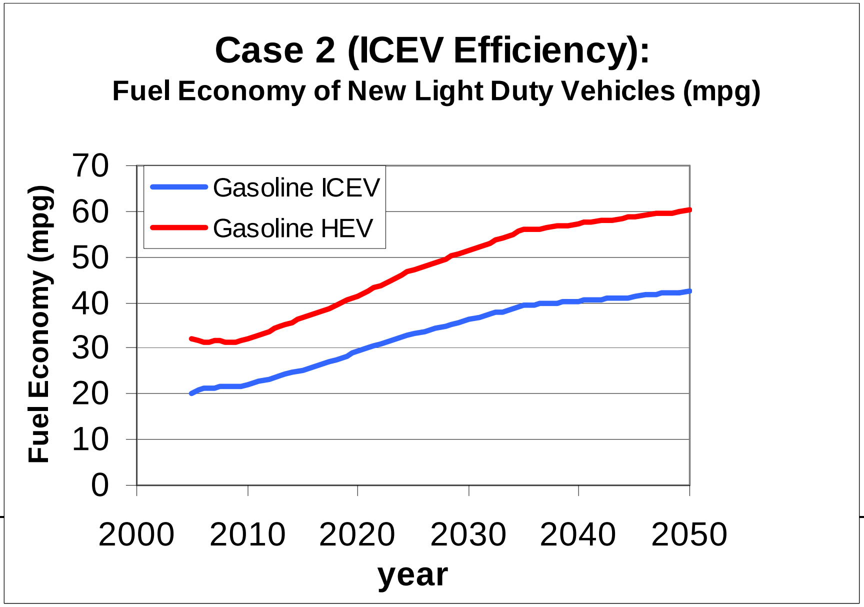
- **Advanced ICE and Hybrid vehicles**
- **Biofuels**

However, their benefits slow after two or three decades, while projected benefits from fuel cell vehicles are still increasing.

Case 2: ICEV Efficiency

- Currently available improvements in gasoline internal combustion engine technology used to increase efficiency
- The fuel economy of gasoline vehicles assumed to improve
    - 2.7 %/year from 2010-2025
    - 1.5 %/year from 2026-2035
    - 0.5%/year from 2036-2050
- Gasoline HEVs dominate; no FCVs

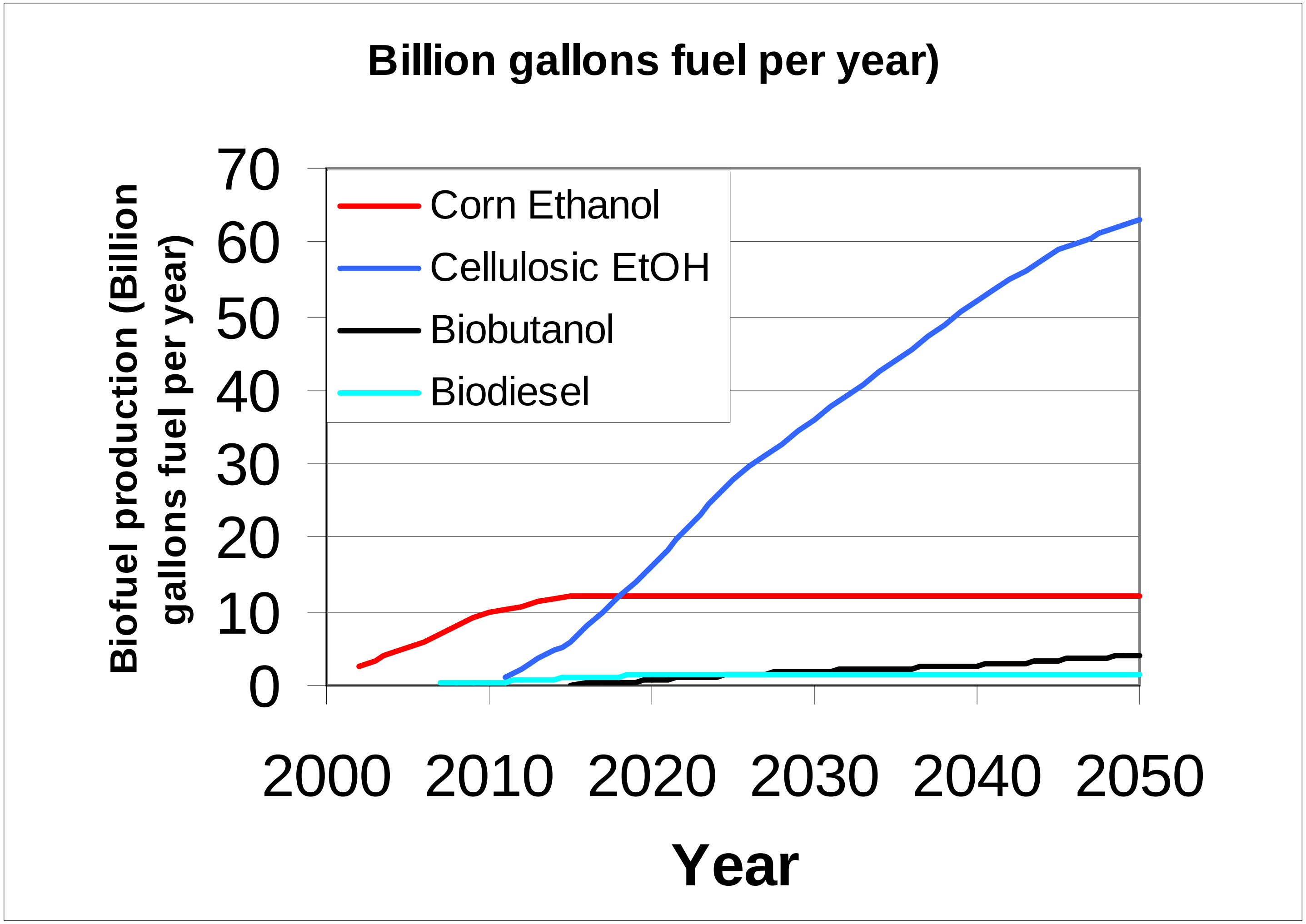




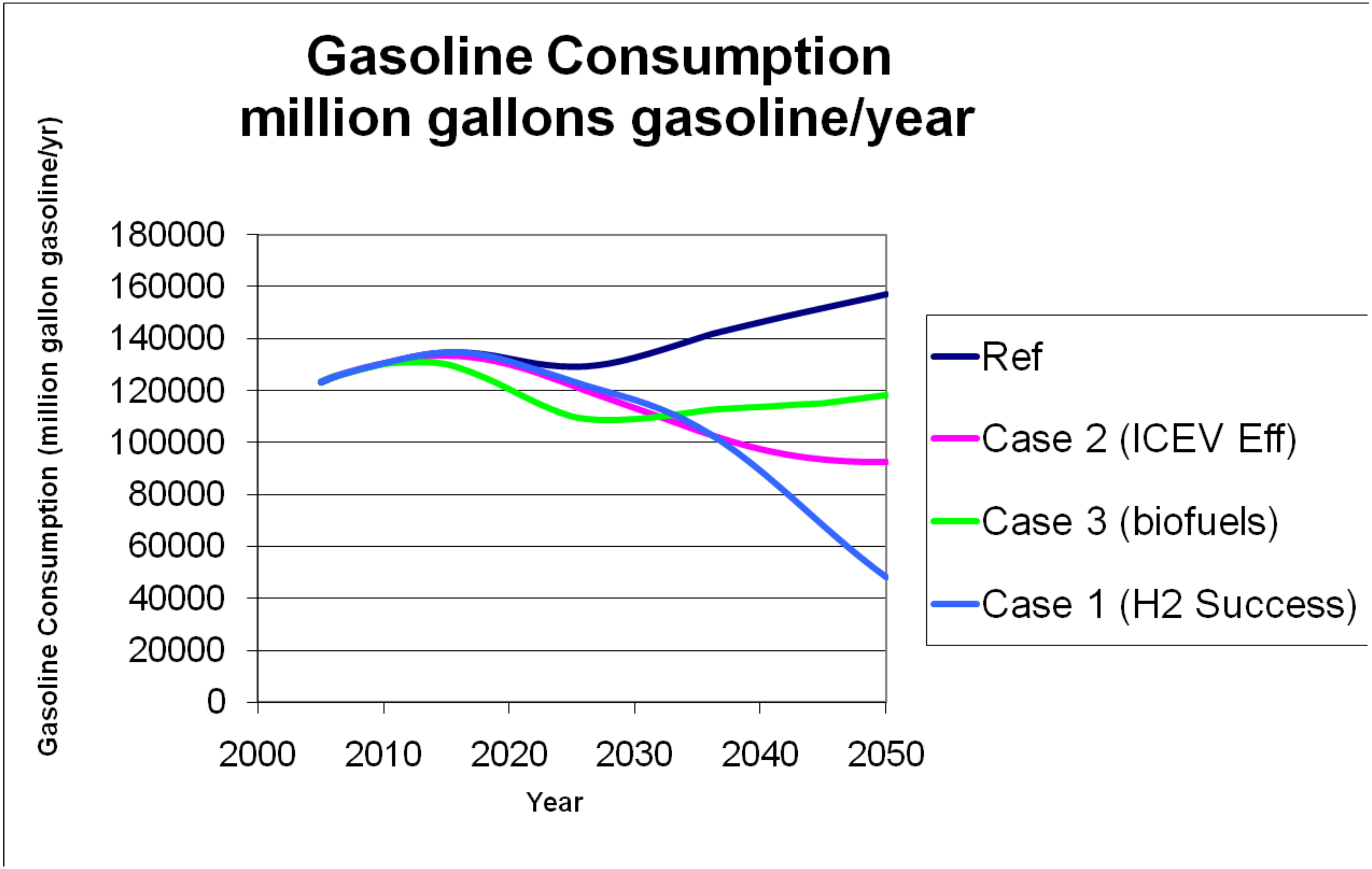
Case 3: Biofuels

- Implement biofuels aggressively
  - Increase corn ethanol to its max feasible level by 2015 (= 30% of expanded corn crop)
  - Increase biodiesel to its max feasible level by 2020 (= 30% of soy crop)
  - Cellulosic ethanol begins in 2010
  - Biobutanol follows cellulosic ethanol after 2015
  - F-T from biomass gasification toward end of analysis period
    - Corn EtOH reduces well to tank GHG 22%; oil use 95%
    - Adv. Biofuel reduces well to tank GHG 85%, oil use 93%

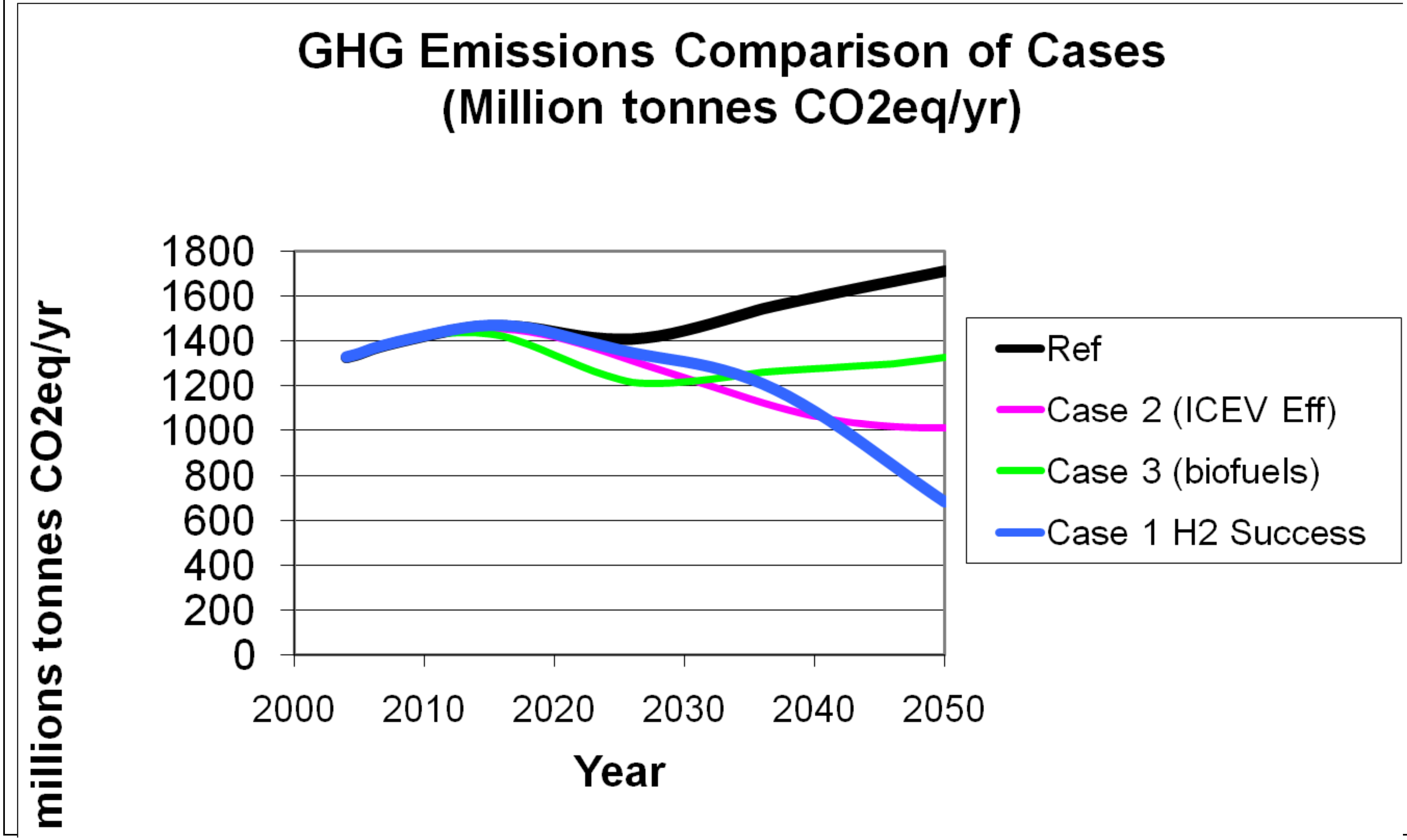
Case 3: Annual Biofuel Production



COMPARISON OF SINGLE PATHWAY STRATEGIES : Oil Use



COMPARISON OF SINGLE PATHWAY STRATEGIES : GHG Emissions

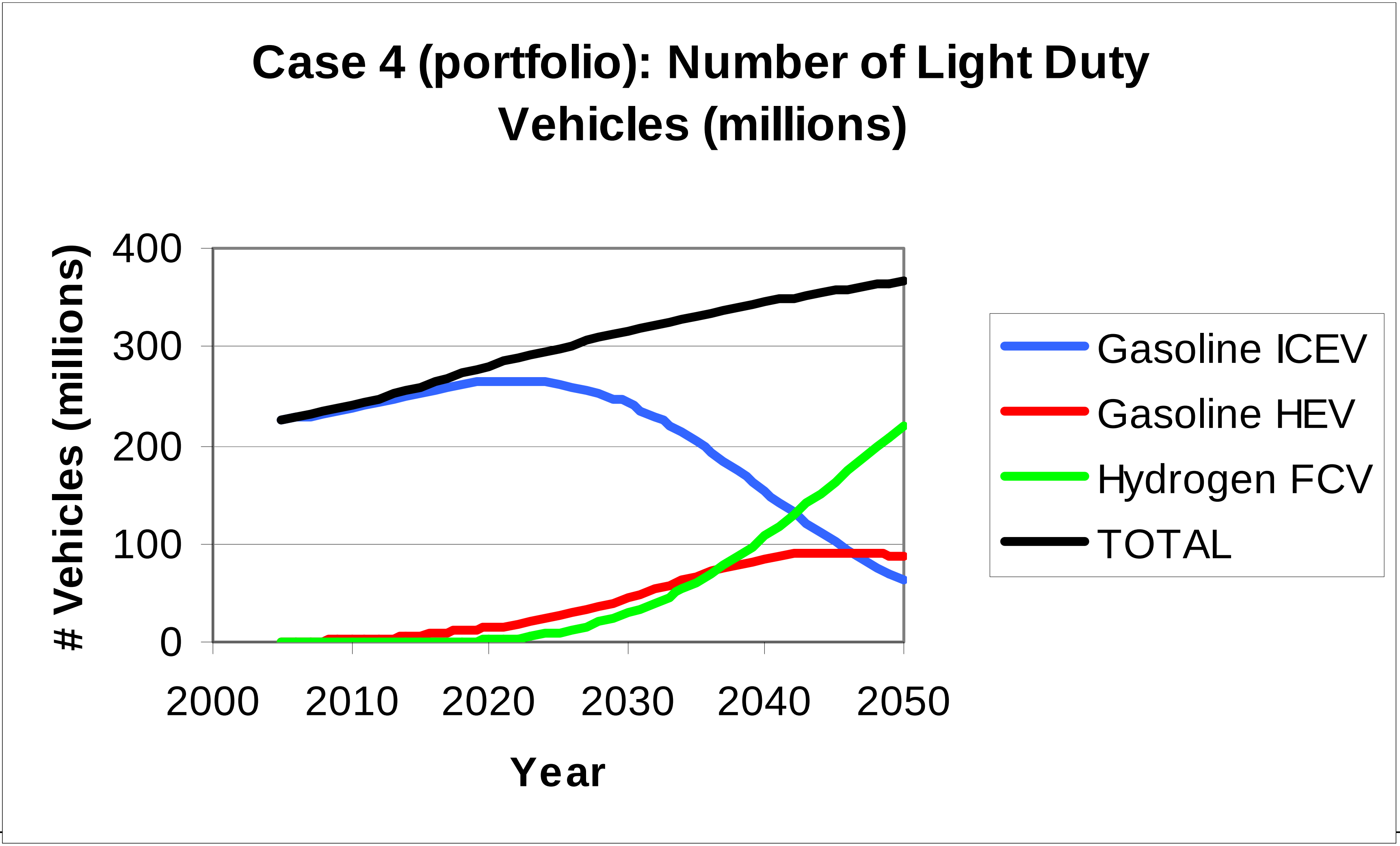


Benefits of a Portfolio Approach

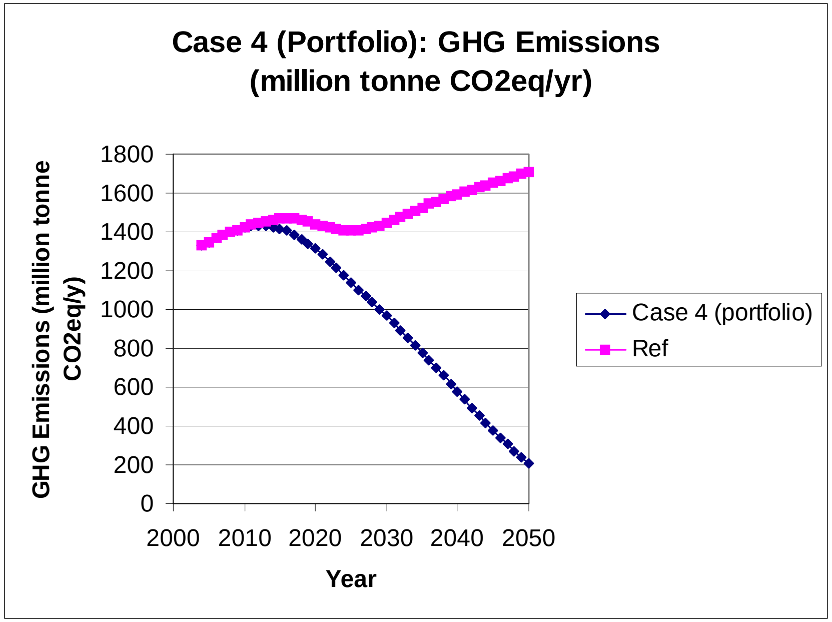
A portfolio of technologies including hydrogen fuel cell vehicles, advanced conventional vehicles, hybrids, and use of biofuels has the potential to nearly eliminate oil demand from light-duty vehicles by the middle of this century, while reducing fleet greenhouse gas emissions to less than 20 percent of current levels.

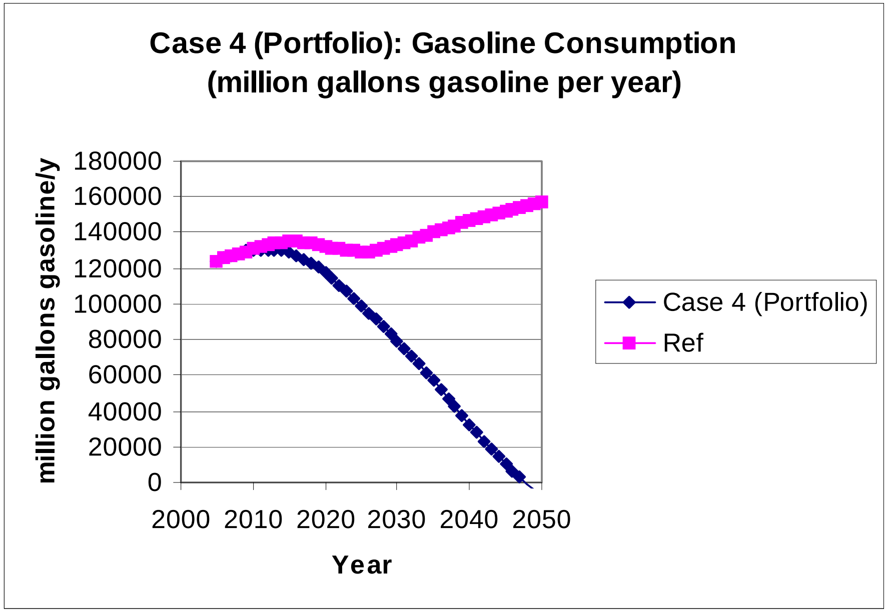
Case 4: Portfolio Approach

Efficient ICEVs + Biofuels + H2 FCVs



Case 4: Portfolio
H2 FCVs +Efficient ICEVs + Biofuels





49% reduction in GHG vs. ref case by 2035

88 % reduction in GHG vs. ref case in 2050

59% reduction in gasoline use vs. ref case by 2035

99% reduction in gasoline use vs. ref case in 2050

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Question & Answer Session is Open

The presenters will now take your questions

Type yours into the 'Questions' Panel for review by the Event Organizers

Thank you for attending the webinar!

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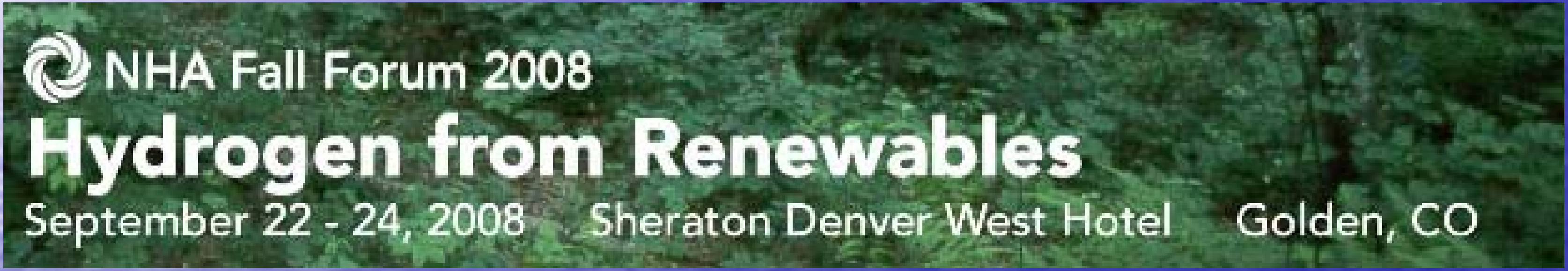

NHA Fall Forum 2008

Hydrogen from Renewables

September 22 - 24, 2008 Sheraton Denver West Hotel Golden, CO