Alternative Transportation Technologies: Hydrogen, Biofuels, Advanced Efficiency, and Plug-in Hybrid Electric Vehicles

Results of two Reports from the National Research Council

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DOE Light-Duty Vehicle Workshop
July 26, 2010

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Presentation Outline

- Study Methodology and Scenarios
- Market Penetration Rates
- Oil and CO_2 Savings
- Fuel, Fuel Cell, Battery and Vehicle Costs
- Timing and Transition Costs to Achieve Market Competitiveness for FCVs and PHEVs
- Infrastructure Issues
- Conclusions

Goals of 2 Studies

- Establish as a goal the *maximum practicable number* of vehicles that can be fueled by hydrogen by 2020 and potential fuel and CO_2 savings
- 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 whether *other technologies* could achieve significant CO_2 and oil reductions by 2020
- Completed July 2008

- Determine the *maximum practicable* penetration rate for PHEVs and estimate the potential fuel and CO_2 savings, and required funding
- Completed December 2009

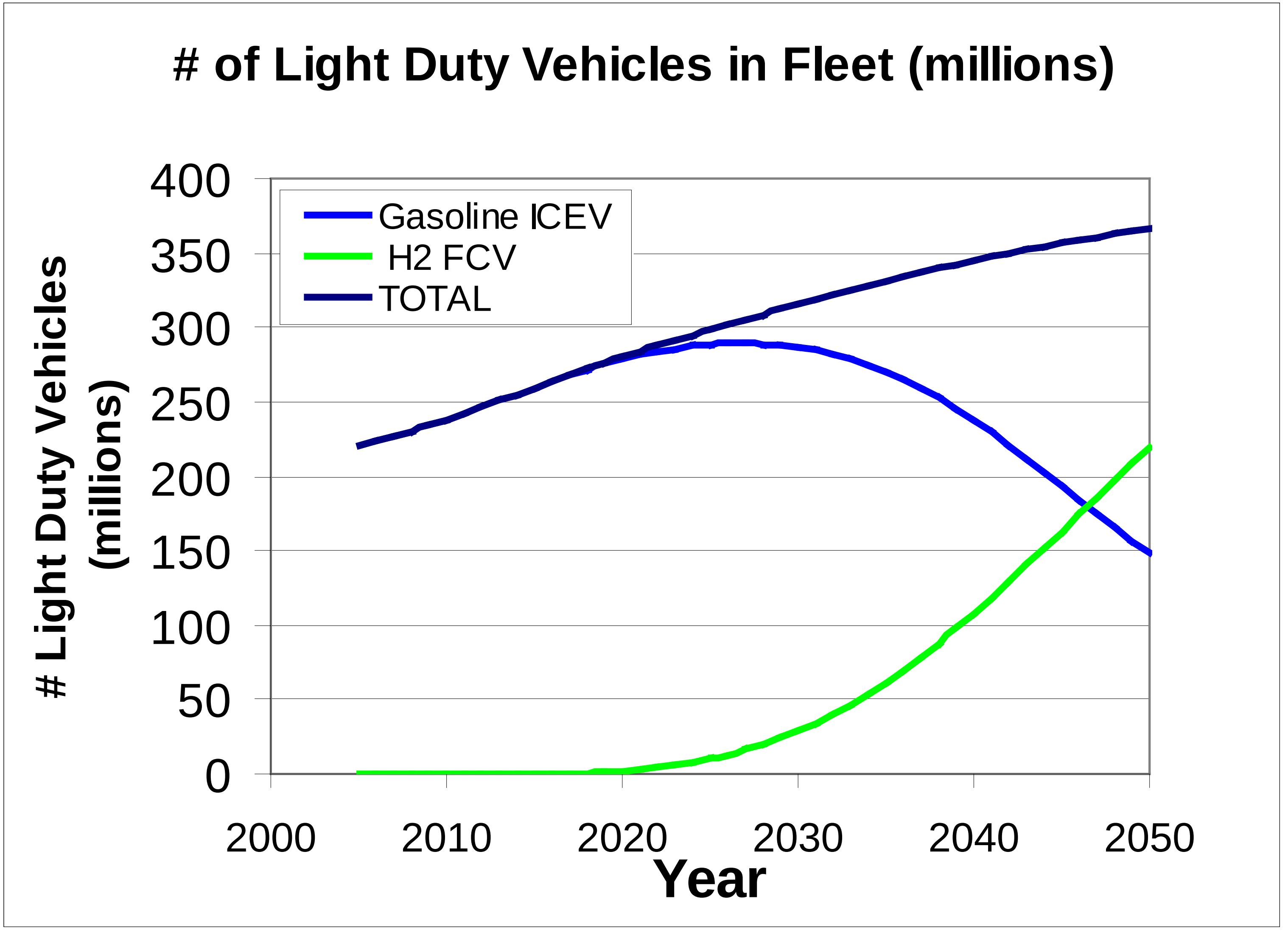
Vehicle Penetration Rates and Potential Fuel and CO_2 Reductions

SCENARIOS

1) **H2 SUCCESS** H2 & fuel cells play a major role beyond 2025
2) **EFFICIENCY** Currently feasible and projected improvements in gasoline internal combustion engine technology are introduced rapidly
3) **BIOFUELS** Large scale use of biofuels, including ethanol and biodiesel
4) **PLUG-IN HYBRID SUCCESS** PHEVs play a major role beyond 2025
5) **PORTFOLIO APPROACH** More efficient ICEVs + biofuels + FCVs or PHEVs introduced

CASE 1: H2 SUCCESS Scenario

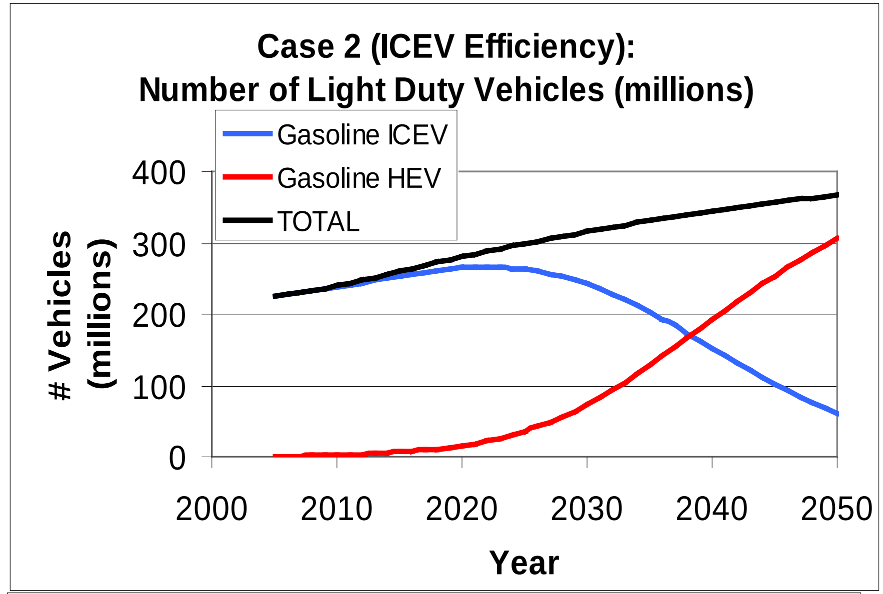
Fuel cell @ $30/kW and H2 storage @ $10/kWh by 2025)

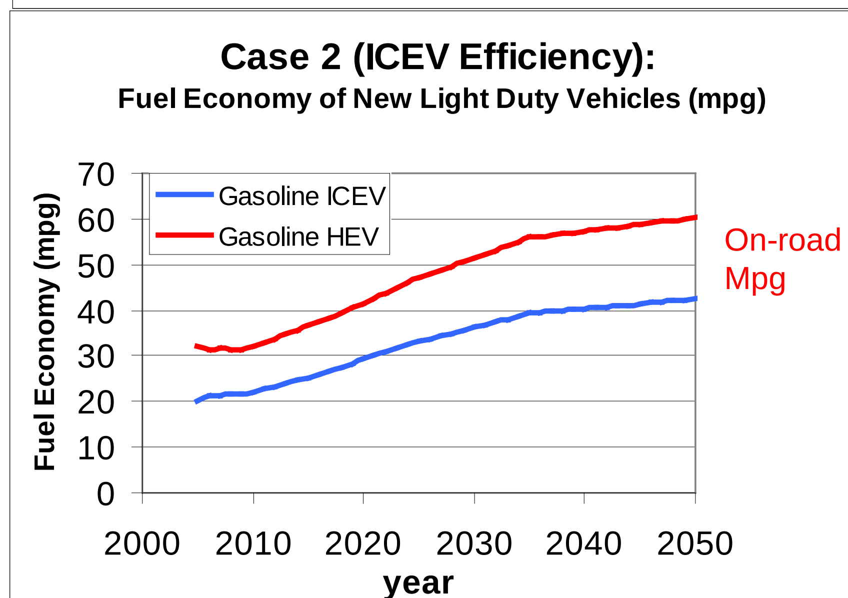


A Partial Success Case was also studied (FC @ $50/kW and H2 storage @ $15/kWh)

CASE 2: ICEV EFFICIENCY

- Currently available and projected improvements in conventional vehicle 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 or PHEVs





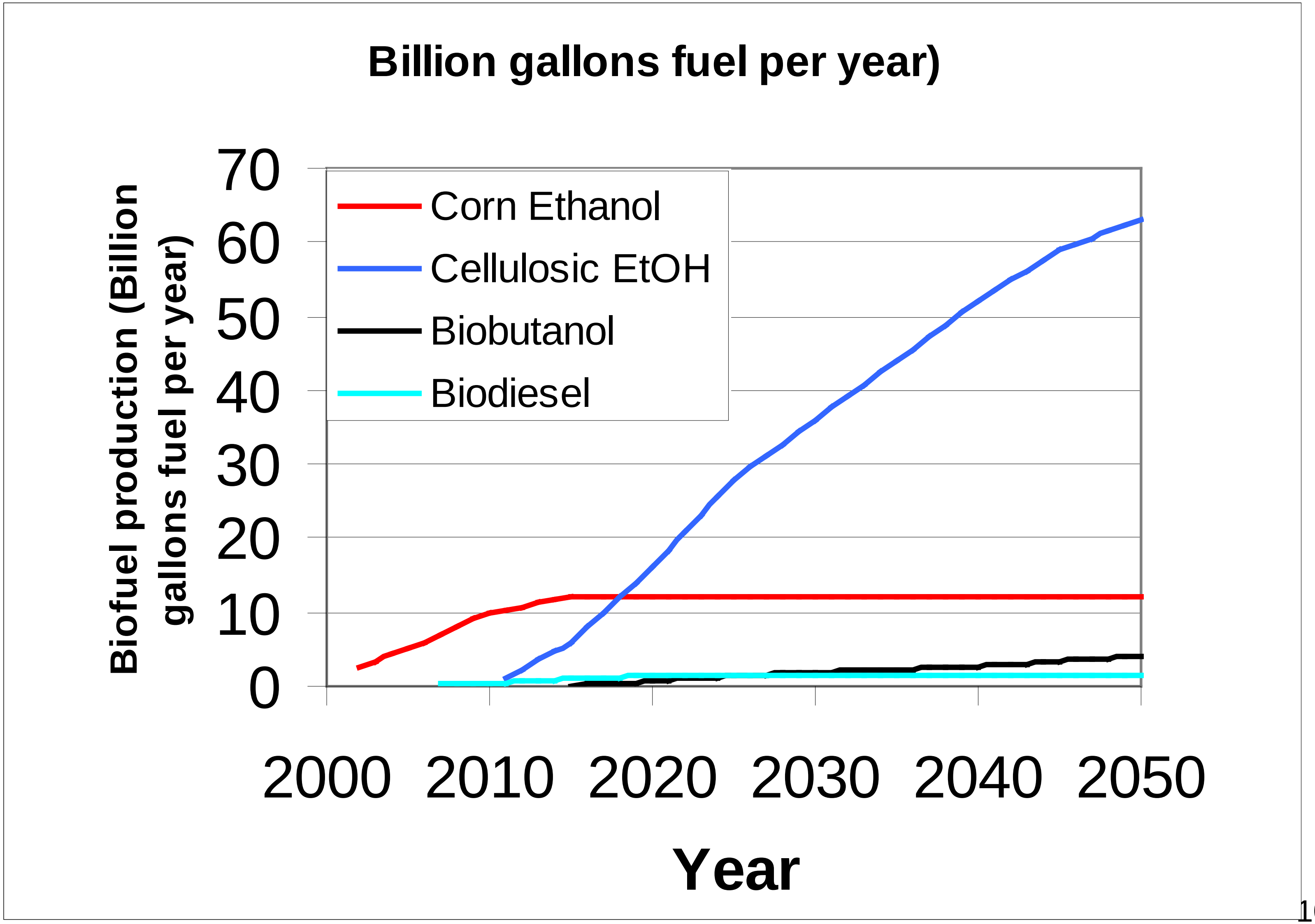
CASE 3: BIOFUEL SUCCESS

- Grain and Sugar based ethanol - maximum potential 12 billion gallons/year
- Sustainable biomass (million dry tons per year)*

  300 mtpy current, 500 mtpy 2030, 700 mtpy 2050
- Cellulosic ethanol has greater potential, 16 billion gallons/year by 2020 and 63 billion by 2050 **
- Potential for a much larger % of biomass to be converted to biobutanol or other advanced biofuels after 2020

*crop residues, energy crops, forest residues   ** maximum practicable case

CASE 3: BIOFUEL SUCCESS

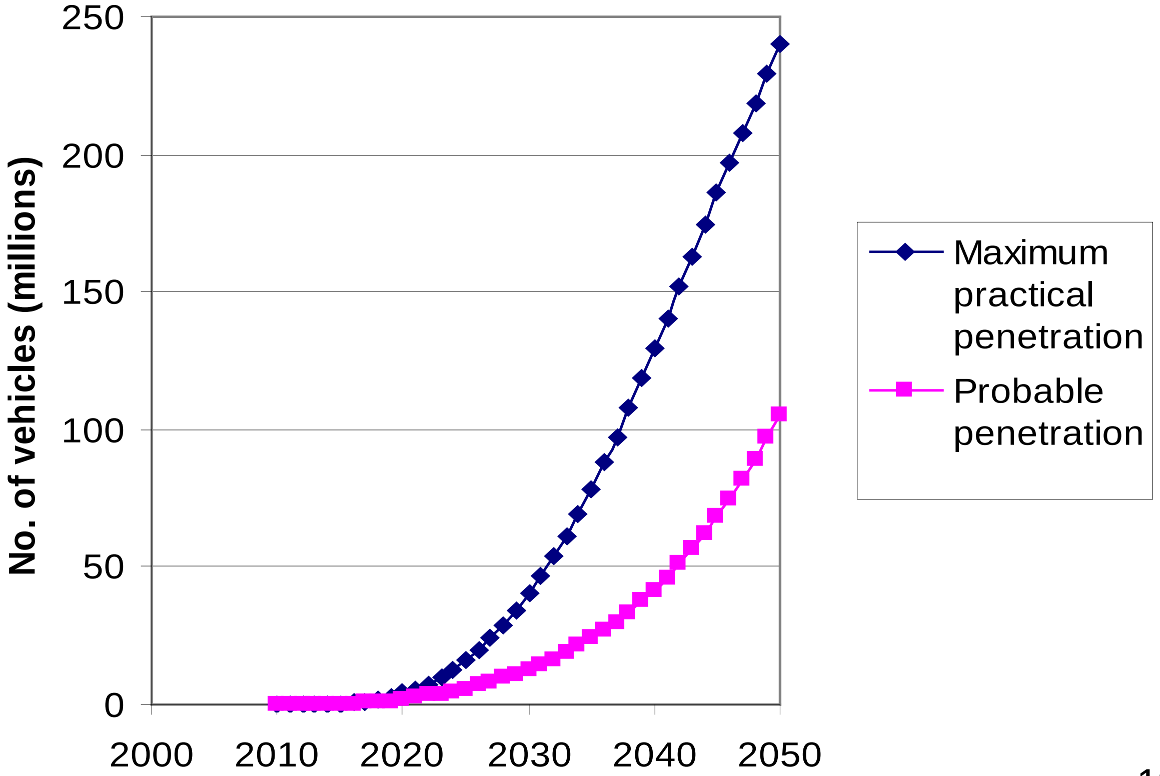


CASE 4: PHEV SUCCESS

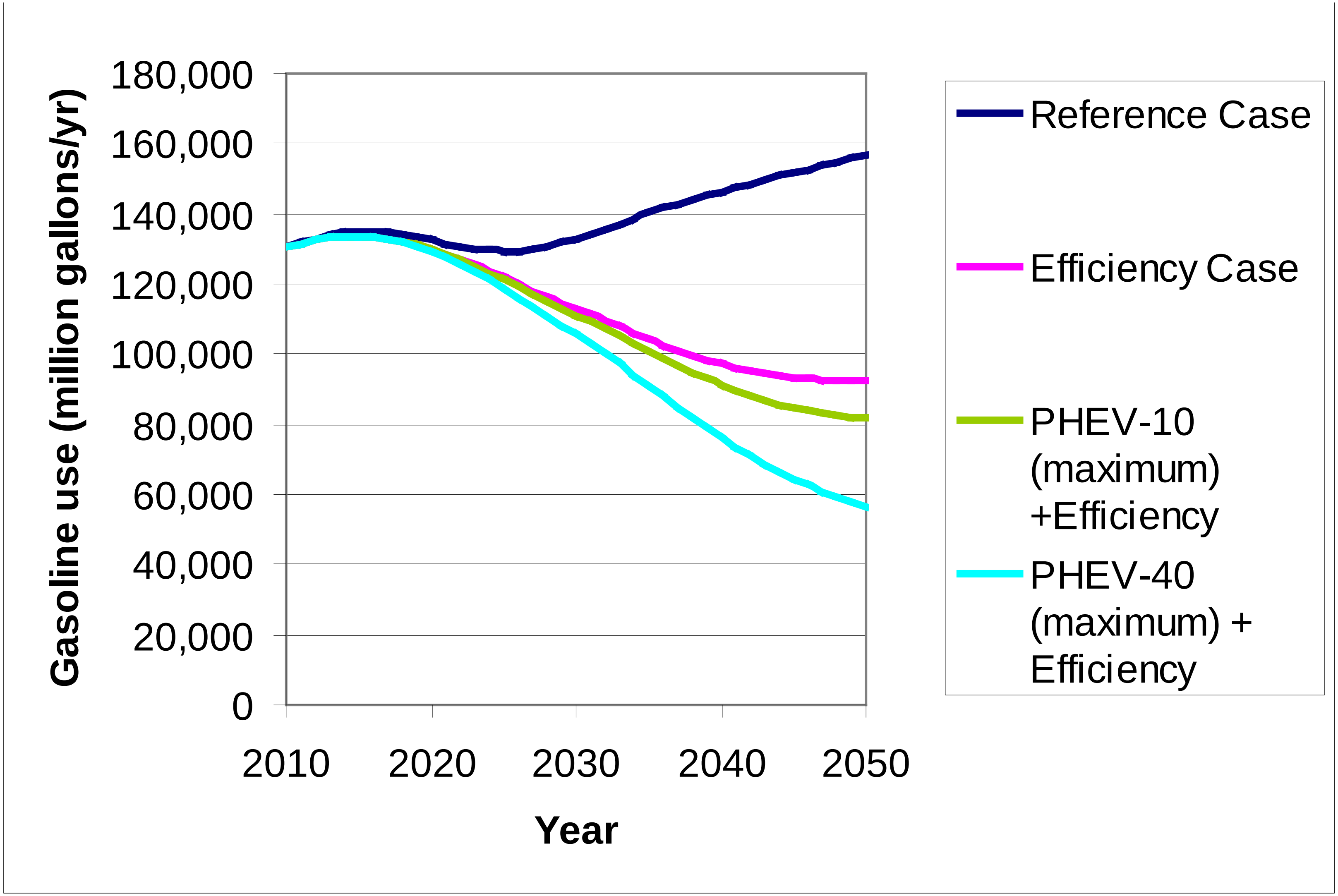
- 2 mid-size vehicle types: PHEV-10s, PHEV-40s
- 2 market penetration rates:
  - Maximum Practical (same as H2 FCVs but start earlier (2010)
  - Probable
- 2 electricity grid mixes (business as usual and EPRI/NRDC scenario for de-carbonized generation in a 2007 study)
- PHEV gasoline and electricity use based on estimates by MIT, NREL, ANL

CASE 4: PHEV Market penetration

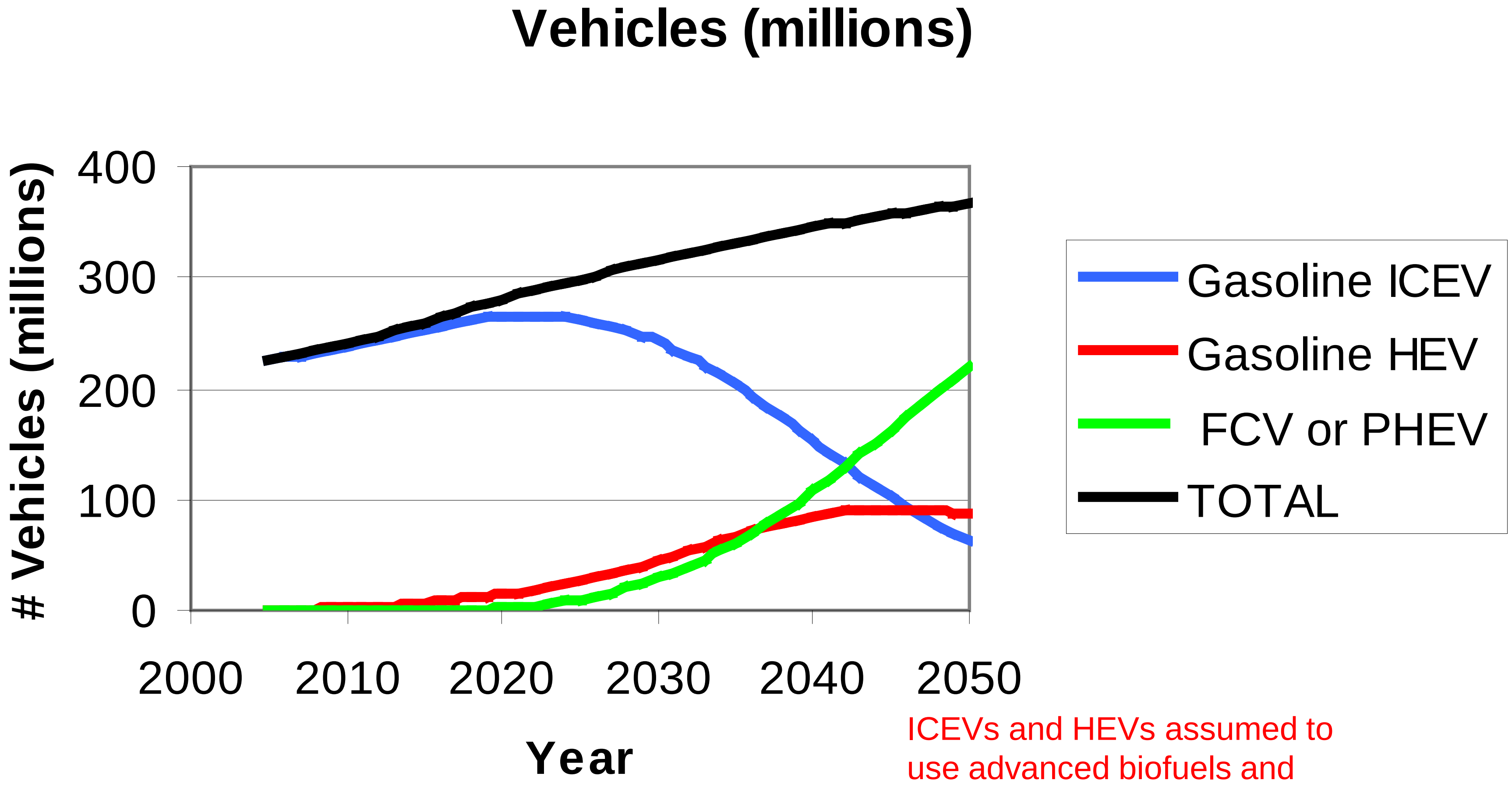
- Maximum Practical (with optimistic tech development estimates): 4 million PHEVs in 2020 and 40 million in 2030
- Probable (with probable technical development): 1.8 million PHEVs in 2020 and 13 million in 2030
- Many uncertainties, especially willingness and ability of drivers to charge batteries almost every day.



CASE 4: PHEV Fuel Savings Relative to Efficiency Case

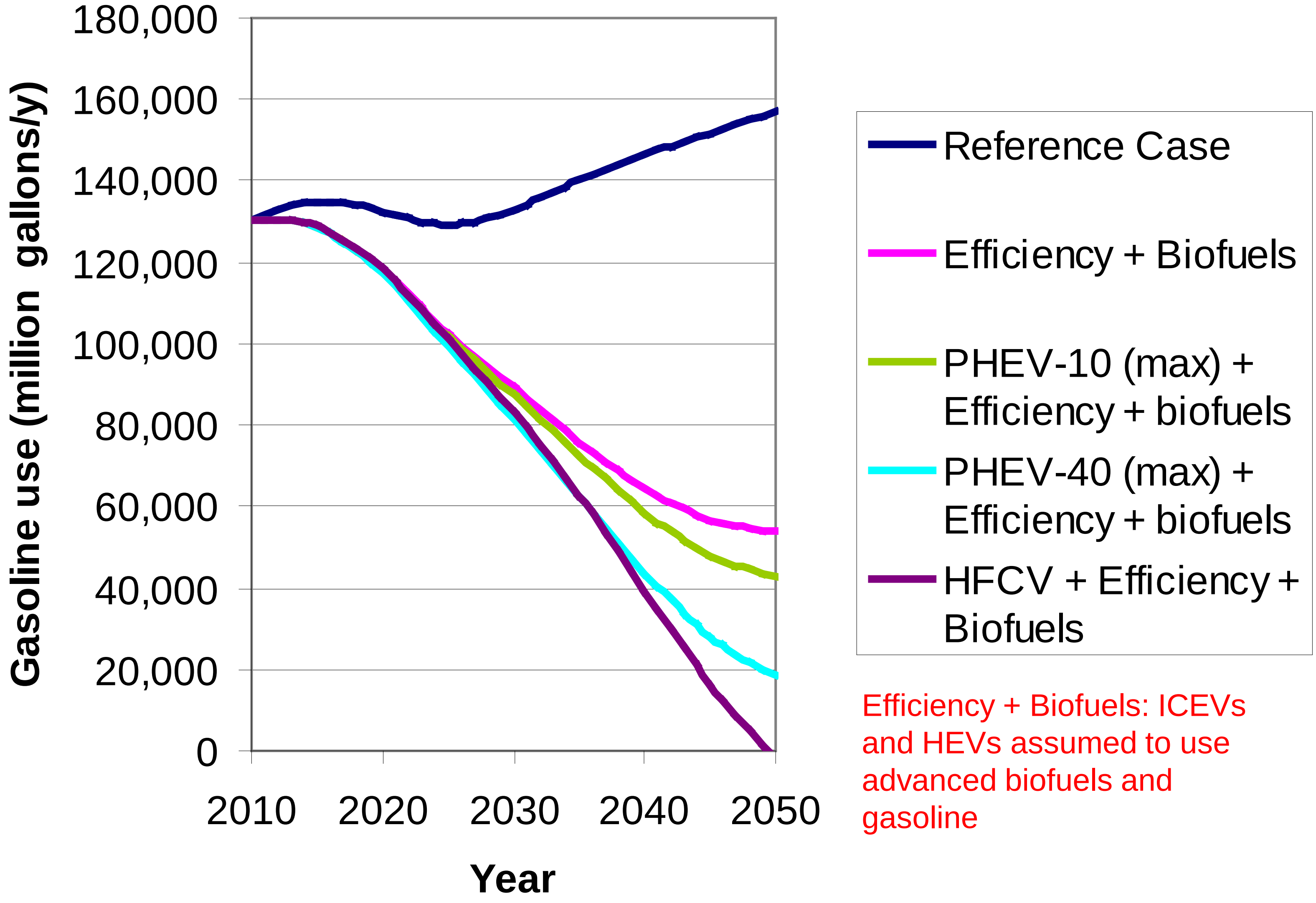


CASE 5: PORTFOLIO APPROACH
Efficient ICEVs + Biofuels + Adv. Veh.



ICEVs and HEVs assumed to use advanced biofuels and gasoline

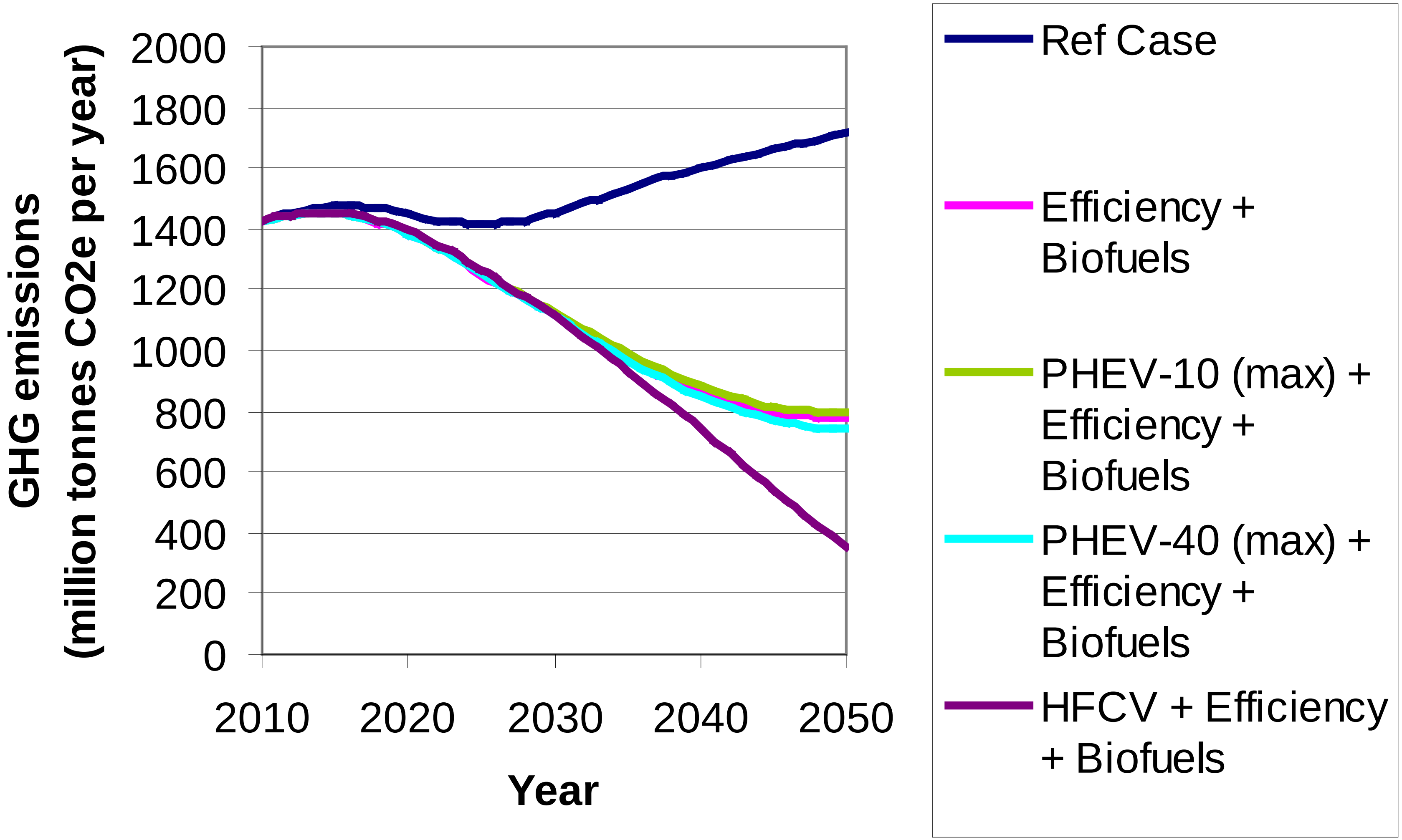
Case 5:Portfolio Fuel Savings



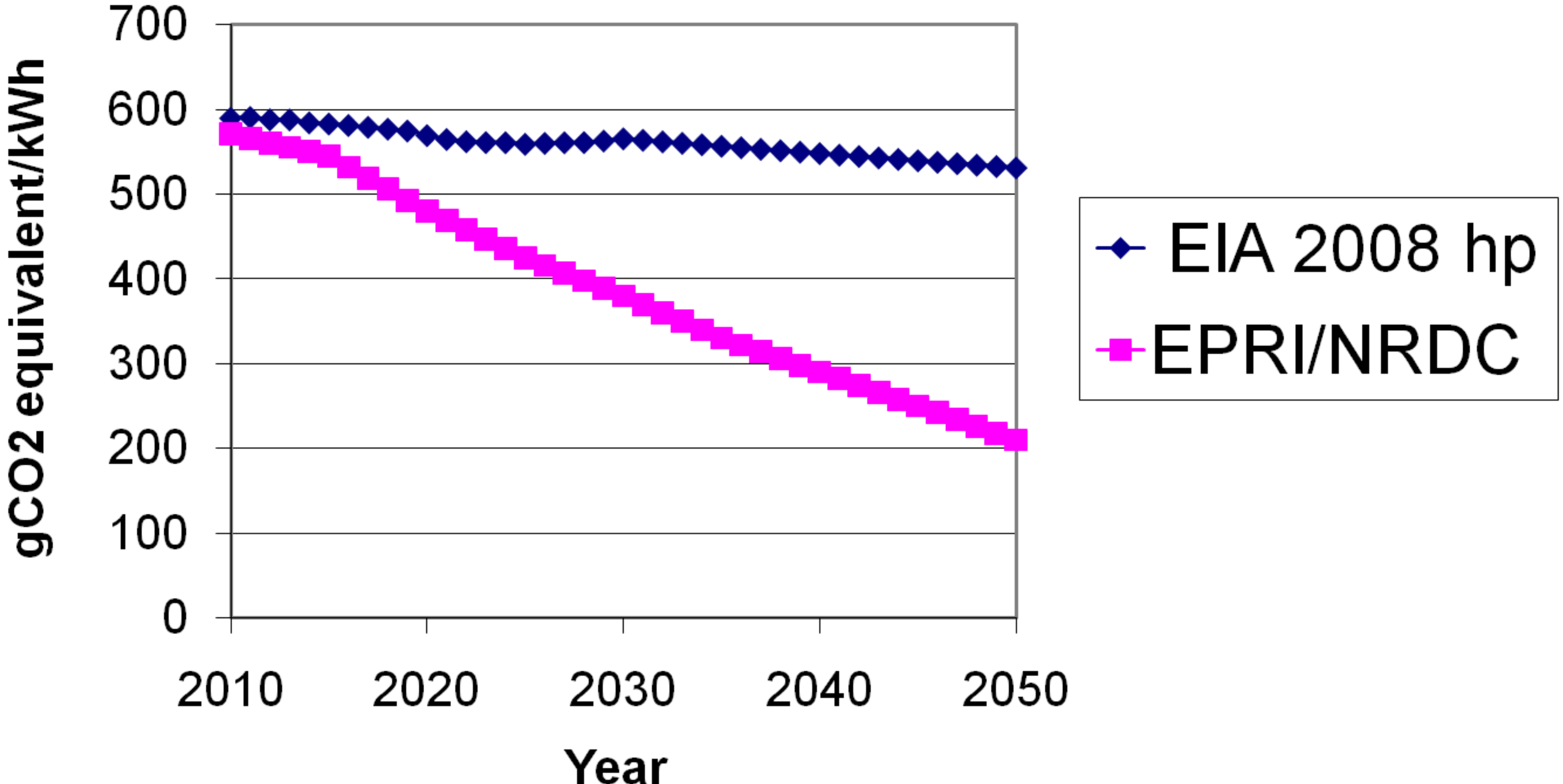
Efficiency + Biofuels: ICEVs and HEVs assumed to use advanced biofuels and gasoline

Case 5:Portfolio GHG Emissions

BAU Electric Grid



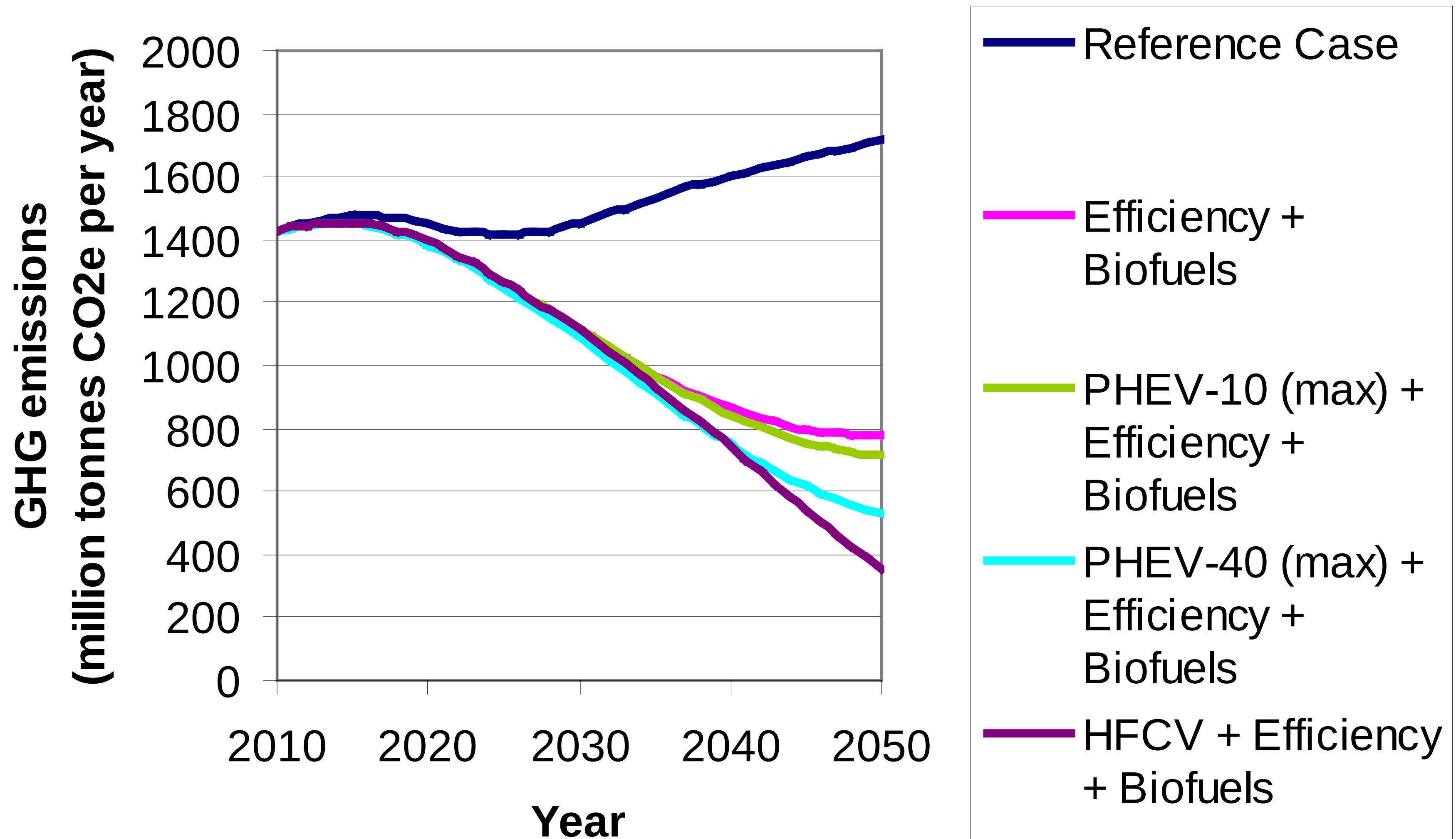
GHG Emissions from Future Electric Grid (gCO2eq/kWh)



AEO 2008 High Oil Prices Case and EPRI/NRDC 2007. Environmental Assessment of Plug-In Hybrid Electric Vehicles. Volume 1: Nationwide Greenhouse Gas Emissions.

Case 5:Portfolio GHG Emissions

De-carbonized Electric Grid



PHEV Cost Analysis: Batteries are Key

Need acceptable cost for reasonable range, durability, and safety

Batteries

- Looked at 10 and 40 mile midsize cars
  - PHEV-10s and PHEV-40s
- Battery packs with 2 and 8 kWh useable or 4 and 16kWh nameplate energy
  - Start of life, not after degradation
  - 200 Wh/mile
  - 50% State of Charge range (increases to compensate for degradation)

Current PHEV Battery Pack Cost* Estimates Compared ($/kWh nameplate)

- $700-1500/kWh (McKinsey Report)
- $1000/kWh (Carnegie Mellon University)
- $800-1000/kWh (Pesaran et al)
- $500-1000/kWh (NRC: America's Energy Future report)
- $875/kWh (probable) NRC PHEV Report
- $625/kWh (optimistic) NRC PHEV Report
- $560/kWh (DOE, adjusted to same basis)
- $500/kWh (ZEV report for California)

*Unsubsidized costs

Future Cost* Estimates Compared
($/kWh nameplate)

- $600/kWh (Anderman)
- $400-560/kWh in 2020 (NRC PHEV)
- $360-500/kWh in 2030 (NRC PHEV)
- $420/kWh in 2015 (McKinsey)
- $350/kWh (Nelson)
- $168-280/kWh by 2014 (DOE goals adj.)
- NRC estimates higher than most but not all
- Assumed packs must meet 10-15 year lifetime
- Dramatic cost reductions unlikely; Li-ion technology well developed and economies of scale limited

*Unsubsidized costs

Vehicle Costs

PHEV-40

- Total Pack cost now $10,000 - $14,000
- Total PHEV cost increment over current conventional (non-hybrid) car: $14,000 - $18,000
- PHEV cost increment in 2030: $8,800 - $11,000

PHEV-10

- Total Pack cost now $2500 - $3,300
- Total PHEV cost increment over current conventional (non-hybrid) car $5,500 - $6,300
- PHEV cost increment in 2030: $3,700 - $4,100

Electric Infrastructure

- No major problems are likely to be encountered for several decades in supplying the power to charge PHEVs, as long as most vehicles are charged at night.
- May need smart meters with TOU billing and other incentives to charge off-peak.
- Charging time could be 12 hours for PHEV-40s at 110-V and 2-3 hours at 220-V. Thus home upgrade might be needed.
- If charged during hours when power demand is high, potential for significant issues with electric supply in some regions.

Potential Transition Costs for HFCV and PHEVs

TRANSITION COSTS: PHEVs and H2 FCVS

	PHEV-10	PHEV-40	PHEV-40 Sensitivity Cases		HFCV	
			High Oil	DOE Goal	Success	Partial Success
Breakeven Year	2024	2040	2025	2024	2023	2033
Cum. Cash flow to breakeven ($billion)	24	408	41	24	22	46
Cum. Vehicle Retail Price Diff to breakeven ($ billion)	82	1639	174	82	40	82
# Vehicles at breakeven (million)	10	132	13	10	5.6	10
Infrastructure Cost at breakeven ($ Billion)	10 (in-home charger @$1000)	132 (in-home charger @$1000)	13 (in-home charger @$1000)	10 (in-home charger @$1000)	8 (H2 stations for first 5.6 million FCVs)	19 (H2 stations for first 10 million FCVs)

1-3 decade transition time; Transition cost $10s-100s Billions; Results very sensitive to oil price and vehicle (battery& fcell) costs

Major Findings

- Significant fuel and CO2 reductions can be achieved over next 20 years with efficient ICE/HEV technologies and biofuels.

- PHEVs and HFCVs have greater long-term potential for fuel savings. HFCVs can greatly reduce CO2 emissions, but savings from PHEVs dependent on grid fuel source.

- A portfolio of technologies has potential to eliminate oil and greatly reduce CO2 from US light duty transportation by 2050

- The U.S. could have tens of millions of H2 FCVs and PHEVs on the road in several decades, but that would require tens or hundreds of billions in subsidies

- Technology breakthroughs are essential for both fuel cells and batteries; cost reductions from manufacturing economies of scale will be much greater for fuel cells than batteries