Multi-Path Transportation Futures Study: Results from Phase 1

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Notes are provided at the bottom of most slides. These should be read along with the slides.

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Executive Summary

- Description of Pathways
- Pathway Results
- Description of Scenarios
- Scenario Results
- Conclusions
- Accomplishments

Pathway Descriptions

[MPG estimates for a new midsize car in 2030 (low and high)]

Pathways	Start	Max %	MPG Ratio (L/H)
1. FFHEV (Flex Fuel Hybrid)	2015	75	1.54/2.07
2. ACV (Advanced Conventional)	2015	100	1.19/1.38
3. ADV (Advanced Diesel)	2011	75	1.44/1.89
4. GHEV (Gasoline Hybrid)	2011	75	1.53/2.06
5. DHEV (Diesel Hybrid)	2015	56	1.67/2.34
6. FCV (Fuel Cell Vehicle)	2020	76	2.30/3.59
7. GPHEV20 (Gasoline Plug-in 20 mi EV)	2018	70	1.47/1.93
8. GPHEV40 (Gasoline Plug-in 40 mi EV)	2020	70	1.44/1.89
9. DPHEV20 (Diesel Plug-in 20 mi EV)	2018	70	1.62/2.25
10. DPHEV40 (Diesel Plug-in 40 mi EV)	2020	70	1.60/2.19
11. EV (Electric Vehicle)	2020	40	3.61/4.15

Pathway Results (Low and High Cases)

The top 3 pathways are highlighted in red.

Pathways	2030 Oil Savings (mbpd)	2050 Oil Savings (mbpd)	Annual GHG Reduction in 2050 (mmtce)
1. FFHEV	1.1/2.7	6.1/7.2	277/361
2. ACV	0.4/0.6	1.0/1.7	54/103
3. ADV	1.0/2.2	2.4/3.7	127/203
4. GHEV	1.6/3.1	3.2/4.3	167/238
5. DHEV	0.7/1.7	3.0/4.0	158/221
6. FCV	0.9/2.4	9.7/10.1	257/461
7. GPHEV20	0.6/1.7	4.6/5.4	163/255
8. GPHEV40	0.5/1.4	5.1/6.1	148/269
9. DPHEV20	0.7/1.9	4.8/5.8	175/276
10. DPHEV40	0.5/1.5	5.0/6.3	141/282
11. EV	0.5/1.3	5.3/5.6	57/183

Scenario Description

Scenario	2030 Market Penetration (cars)	2050 Market Penetration (cars)	Other Key Factors
1. Mixed	30% ACV, 20% ADV, 30% GHEV, 17% PHEV	10% ACV, 20% ADV, 15% GHEV, 25% PHEV, 30% FCV	ACVs, GHEVs & PHEVS are flex fuel; in 2050, 30 billion gallons ethanol are used
2. H2 Success 9. Regional H2	20% ACV, 10% ADV, 40% GHEV, 10% FCV	24% GHEV, 76% FCV	H2 feedstocks vary between #2 and #9
3. (P)HEV & Ethanol	20% ACV, 40% GHEV, 25% PHEV	45% GHEV, 50% PHEV	ACVs, GHEVs & PHEVS are flex fuel; in 2050, 60 b gals ethanol are used
4. HEV & Ethanol 6. Max Ethanol	25% ACV, 45% GHEV	25% ACV, 75% GHEV	ACVs & GHEVs are flex fuel; in 2050, 60 b gals ethanol are used in #4 & 75 b gals in #6
5. Max Electric	20% ACV, 25% GHEV, 25% PHEV, 5% EV	10% ACV, 20% GHEV, 60% PHEV, 10% EV	
7. ACV Low 8. ACV High Unconventional Oil	50% ACV	95% ACV	2050: 22% of oil resource is from unconventional sources in #7; 42% in #8
10. High Diesel with Biomass	20% ACV, 25% ADV, 8% DHEV, 30% GHEV	50% ADV, 25% DHEV, 20% GHEV	Significant volume of biomass-based diesel

Scenario Results: Oil and GHG Saved

[mbpd (% of base); mmtce (%)]

Scenario	2030	2050
1. Mixed	3.8 (32.3%); 166 (26%)	9.3 (65.9%); 395 (53%)
2. H2 Success/9. Regional H2	3.4 (28.5%); 150 (24%)/152 (24%)	11.7 (83.1%); 521 (70%)/523 (70%)
3. (P)HEV & Ethanol	4.4 (36.9%); 201 (32%)	10.2 (72.6%); 475 (63%)
4. HEV & Ethanol	3.6 (30.1%); 168 (26%)	8.2 (58.4%); 394 (53%)
5. Max Electric	3.5 (29.5%); 145 (23%)	8.6 (60.9%); 367 (49%)
6. Max Ethanol	3.8 (31.5%); 175 (27%)	8.8 (62.7%); 421 (56%)
7. ACV: Low Unconventional Oil	1.2 (9.8%); 29 (5%)	3.9 (27.5%); 120 (16%)
8. ACV: High Unconventional Oil	1.2 (9.8%); 26 (4%)	3.9 (27.5%); 94 (13%)
10. High Diesel with Biomass	4.1 (34.0%); 179 (28%)	8.2 (58.5%); 381 (51%)

Conclusions

1. There are many technologies that EERE is supporting which can have a significant impact on oil use and GHG emissions.
2. The benefits from combining technologies exceeds the benefits of the individual technologies.
3. The 2030 oil savings by pathways range from 0.4 to 3 mbpd
4. Many of the pathways could have oil savings in the range of 4 to 6 mbpd by 2050. The FCV pathway oil savings could be as high as 10 mbpd by 2050.
5. Of the ten scenarios analyzed, (P)HEV Ethanol has the largest 2030 oil and GHG savings (37% and 32%, respectively) and H2 Success and Regional H2 have the largest 2050 oil and GHG savings (83% and 70%, respectively).
6. These results need to be tempered by the costs and risks associated with the technologies. Also, the scenario outcomes depend strongly on assumptions about technology introduction, rates of market penetration, and so forth…which require further parametric analysis to examine the range of plausible assumptions.

Multi-Path Study Accomplishments

- Vigorously reviewed PSAT vehicle assumptions and outputs, yielding benefits to overall PSAT modeling that will help other projects/programs
- Developed a set of alternative (to GPRA) vehicle costs
- Expansion of the VISION model capabilities to include PHEVs and biodiesel use by LVs, and allow wider FFV capability
- Model runs were used to develop oil savings for the President's Advanced Energy Initiative
- Stimulated debate on maximum potentials for different pathways
- Made runs (and can make more runs) that will assist in developing the EERE Transportation and Fuels Plan
- Issues raised in Phase 1 contributed to the development of the Phase 2 plan

Outline

- Background
- Phase 1 Pathways
  - Assumptions
  - Oil savings, GHG reductions
- Phase 1 Scenarios
  - Assumptions
  - Oil savings, GHG reductions
- Other Metrics Examined in Phase 1
  - Costs
  - Infrastructure Issues
  - Criteria Emissions
  - Risk
- Conclusions and Observations
- Next steps

Study Purpose

- Responds to a **EERE Senior Management request for** an integrated analysis of EERE's vehicle-and-fuel-related technologies and how they can leverage each other in the short- and long-term
- Also responds to a **National Academy of Sciences** call for an assessment of pathways other than hydrogen that can yield similar outcomes (low oil use and low GHG emissions)
- Study **compares alternative ways** to achieve significant reductions in oil use and GHG emissions in light vehicles from now to 2050

Overall Goals

- Identify and assess the technology options available to greatly reduce light vehicle oil use and GHG emissions
- Integrate the vehicle pathway analyses being done by DOE programs *and others* while not being bound to the assumption "achieves program goals" in defining technology performance
- Develop and evaluate scenarios that combine several pathways, including an evaluation of positive and negative synergies among different vehicle/fuel pathways

Scope

- Scope of this study is limited to light vehicles (cars and light trucks) in the U.S. and their energy use
  - EERE is spending over half of its R&D budget on light vehicles and their fuels
- Omitted are:
  - Energy used in other transportation modes in the U.S.
  - Oil used elsewhere in the U.S.
  - Other forms of energy used in the U.S.
  - Oil/energy used in the rest of the world
- These “other” oil and energy uses are important and may influence the oil and other fuels used in LVs in the U.S., but we cannot deal with them in the early phase of this study. It remains to be determined the extent to which we deal with them in the latter phase.
- No behavioral changes or attitudes are modeled in Phase 1

The Multi-Path Study: Two Phases

- **Phase 1**:
  - Has two components:
    - Develop pathways and scenarios and estimate their potential benefits
    - Identify key issues and define a robust plan of attack for a full study (Phase 2)
  - Began November 2005, ends December 2006
  - This presentation contains Phase 1 results
- **Phase 2:** The work plan is available and is described in slides at the end of this presentation.

Phase 1 Tasks and Estimated Completion Dates

1. Identify review panel (Jan 06)
2. Select Phase 1 pathways (Feb 06)
3. Develop criteria and measurement methods for Phase 1 (Feb 06)
4. Develop alternative to the Base Case Scenario for Phase 1 (March 06)
5. Develop vehicle market penetration rates and start dates for Phase 1; ditto for fuel production (March 06)
6. Develop vehicle fuel economy estimates for Phase 1 (July 06)
7. Collect other information for pathway analysis for Phase 1 (August 06)
8. Analyze the selected pathways for Phase 1 (October 06)
9. Phase 1 documentation (December 06)
10. Develop Phase 2 Analysis Plan (draft in August, final in December 06)

Phase 1 Analysis Overview

- Uses the **VISION** model to develop quantitative estimates of oil savings, GHG emissions and costs
- Uses the **PSAT** model to estimate vehicle fuel economy to 2050
- Uses the **GREET** model to estimate full fuel cycle GHG emissions for input to the VISION model
- Qualitative evaluation of several other criteria
- Examines pathways and scenarios
  - **Pathways are single vehicle/fuel technologies**
  - **Scenarios are combinations of vehicle/fuel technologies**

Eleven Phase 1 Pathways

1. **ACV**: Advanced Gasoline Vehicle (like today's vehicles, but more efficient than projected by EIA)
2. **ADV**: Advanced Diesel Vehicle (cleaner than today's diesels and more efficient)
3. **GHEV**: Gasoline Hybrid Electric Vehicle
4. **FFHEV**: Flex Fuel Gasoline Hybrid Electric Vehicle
5. **DHEV**: Diesel Hybrid Electric Vehicle
6. **GPHEV20**: Gasoline Plug-in Hybrid Electric Vehicle with 20 miles of driving range on battery
7. **GPHEV40**: …with 40 miles of driving range on battery
8. **DPHEV20**: Diesel Plug-in Hybrid Electric Vehicle with 20 miles of driving range on battery
9. **DPHEV40**: … with 40 miles of driving range on battery
10. **FCV**: Fuel Cell Vehicle
11. **EV**: Electric Vehicle

Pathways

- Each pathway is evaluated against two Base Cases (Low and High) which are variations of the VISION Model Base Case
- The VISION Model Base Case uses EIA's AEO 2006 Reference Case for many assumptions through 2030 and then extends the EIA estimates to 2050 using (generally) EIA's 2025-2030 growth rates
- The Low and High Base Cases contain some assumptions different than those found in EIA's AEO
  - E.g., the ethanol feedstocks are based on DOE program model projections
- See the next slides for a summary of the sources of the assumptions for the two Base Cases and the Single Pathways

Pathways: Base Cases

Source of assumptions by Base Case		
	Low Base Case	High Base Case
New vehicle fuel economies	AEO 2006 Reference Case Extended	AEO 2006 Reference Case Extended
Vehicle technology market penetration	AEO 2006 Reference Case Extended	AEO 2006 Reference Case Extended
Incremental vehicle costs	AEO 2006 Reference Case Extended	AEO 2006 Reference Case Extended
Fuel prices	AEO 2006 Reference Case Extended	AEO 2006 High Oil Price Case Extended
Total ethanol volume used	AEO 2006 Reference Case Extended	Same blend percent as in AEO 2006 Reference Case Extended which results in slightly less ethanol because less gasoline is used

Pathways: Base Cases (cont'd)

Source of assumptions by Base Case		
	Low Base Case	High Base Case
% of ethanol from various feedstocks	BioVISION Model run, modified	BioVISION Model run
% of H2 from various feedstocks	Regional H2 Model run, modified	Regional H2 Model run, modified
% of electricity from various sources (national averages)	AEO 2006 Reference Case Extended	Significant increase in renewables (40% of total by 2050)
% of oil from unconventional sources	"Reference Case" from NETL/ANL study for FE, modified	"Peak Oil Case" from NETL/ANL study for FE

Pathways: Base Cases (cont'd)

% of Fuel from Various Feedstocks

	Low Base Case			High Base Case		
	2010	2030	2050	2010	2030	2050
% ethanol from cellulose	0%	34%	69%	0%	76%	80%
% H2 from low-carbon sources	-	36%	53%	-	65%	94%
% electricity from low carbon sources	29%	25%	25%	29%	37%	55%
% gasoline/diesel from unconventional oil	14%	22%	22%	14%	22%	42%

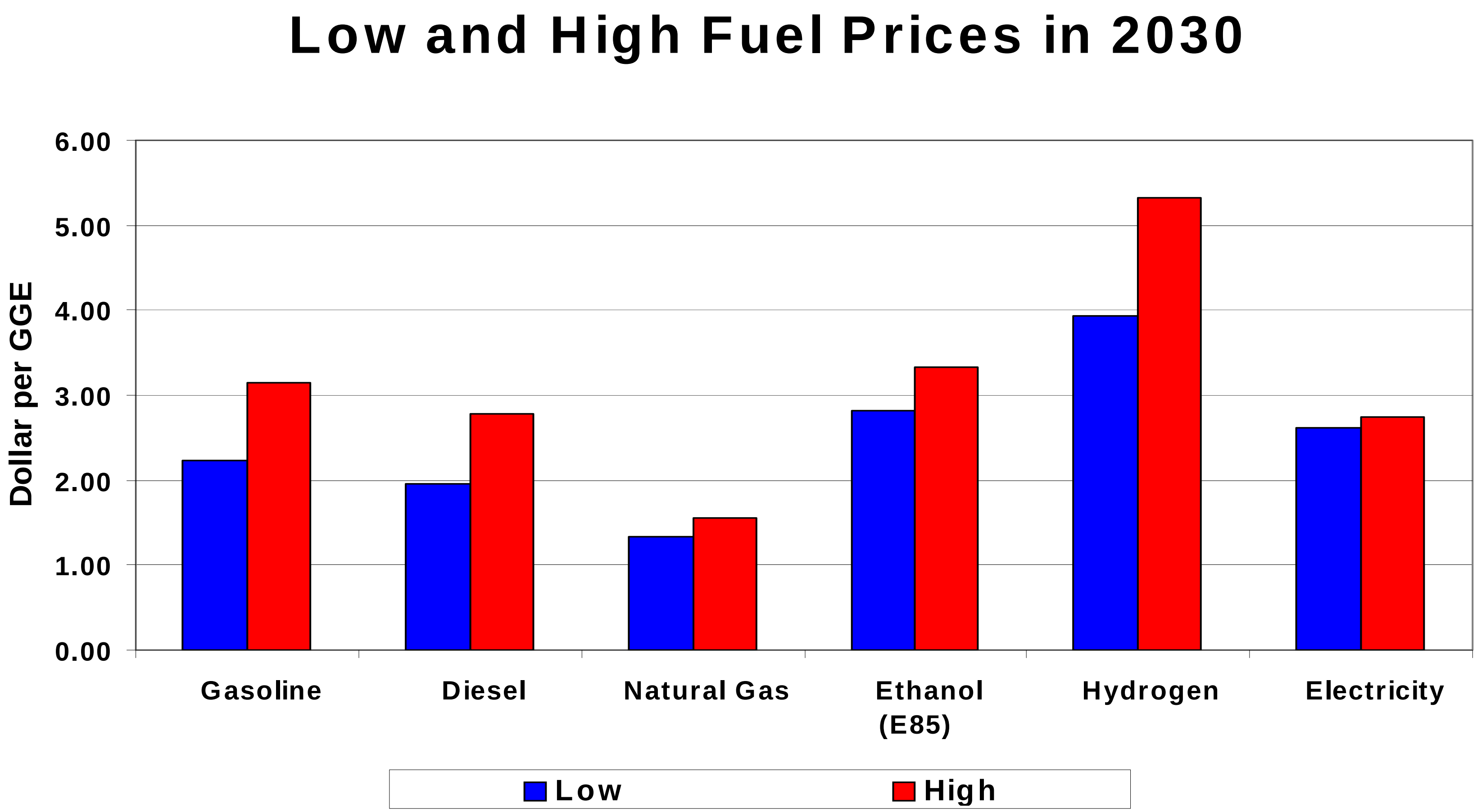
Pathways: Single Pathways

Source of assumptions by Single Pathway Case		
	Low Single Pathway Case	High Single Pathway Case
Base case against which single pathways are evaluated	Low Base Case	High Base Case
New vehicle fuel economies	Assumes that just half of the fuel economy improvement estimated by PSAT for the High Case is achieved	PSAT model runs of June 2006 (see other slide for efficiencies)
Advanced vehicle technology market penetration	Maximum is specific to each pathway and is same in Low and High case	Maximum is specific to each pathway and is same in Low and High case
Rate of market penetration	30 years to achieve maximum penetration	20 years to achieve maximum penetration

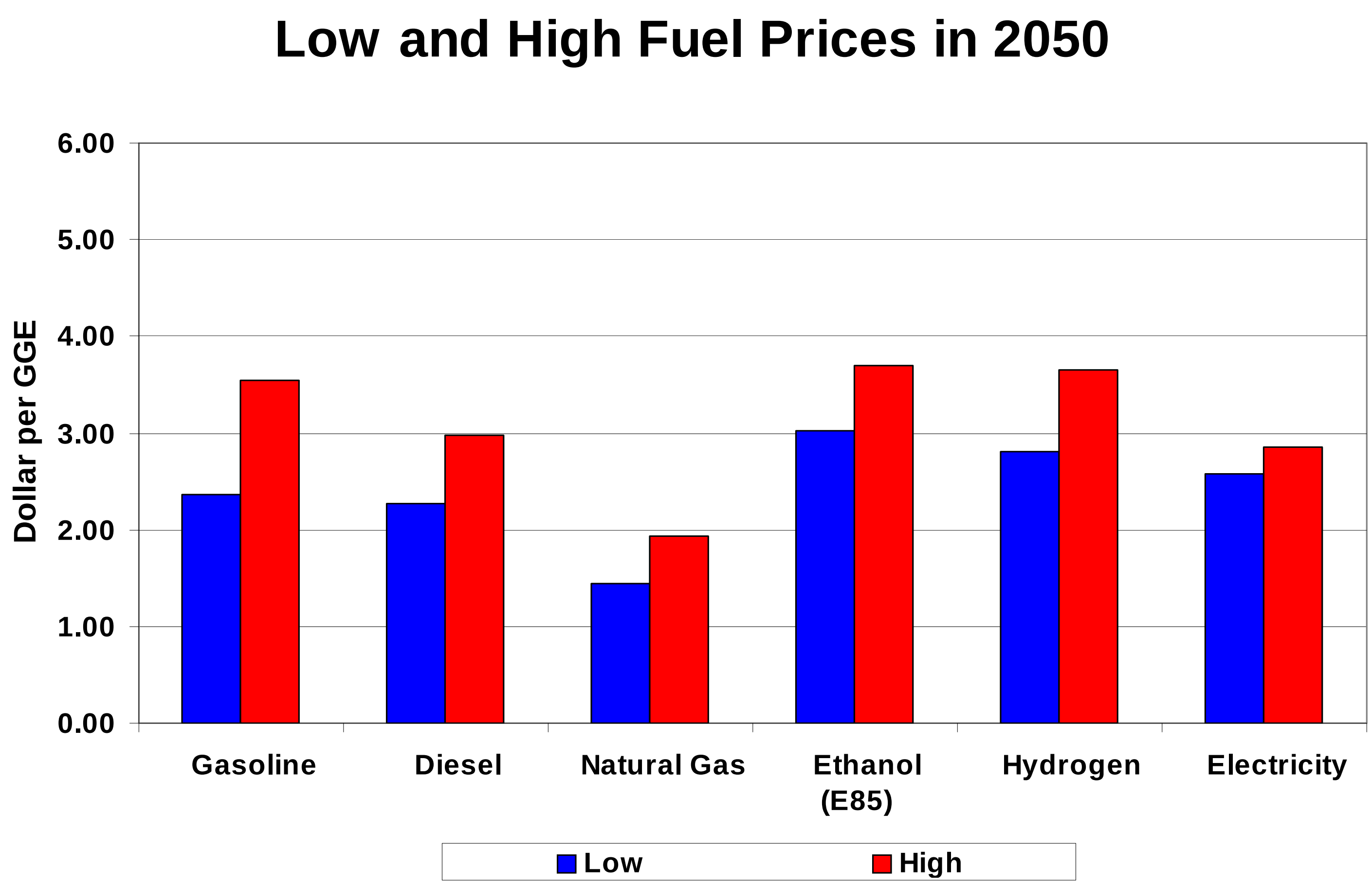
Pathways: Single Pathways (cont'd)

Source of assumptions by Single Pathway Case		
	Low Single Pathway Case	High Single Pathway Case
Incremental vehicle costs	50% higher than the incremental cost for GPRA08	From GPRA08; for technologies not included in GPRA, same cost model is used
Total ethanol volume used in all pathways except FFHEV pathway	Total volume is kept at Base Case levels for as long as possible by increasing blends %, but not beyond 10%	Total volume is kept at Base Case levels for as long as possible by increasing blends %, but not beyond 10%
Total ethanol volume used in FFHEV pathway	Increase % FFHEVs travel on E85 so that 75 billion gallons is used by 2050	Increase % FFHEVs travel on E85 so that 75 billion gallons is used by 2050
Fuel prices; % of ethanol, H2, electricity, H2, and oil from various resources	Same as in Low Base Case	Same as in High Base Case

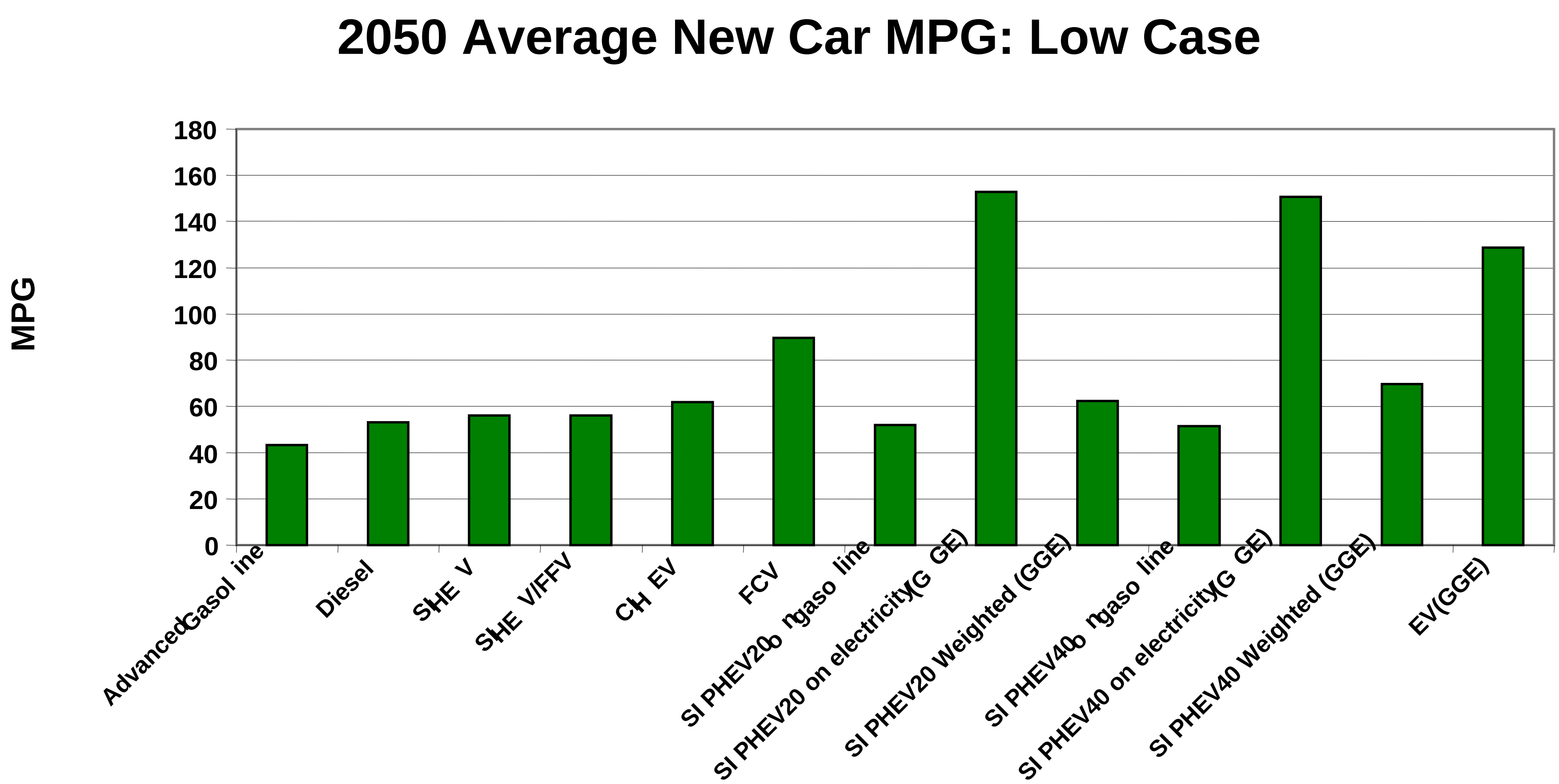
Phase 1: 2030 Low and High Fuel Prices (2004$)



Phase 1: 2050 Low and High Fuel Prices (2004$)



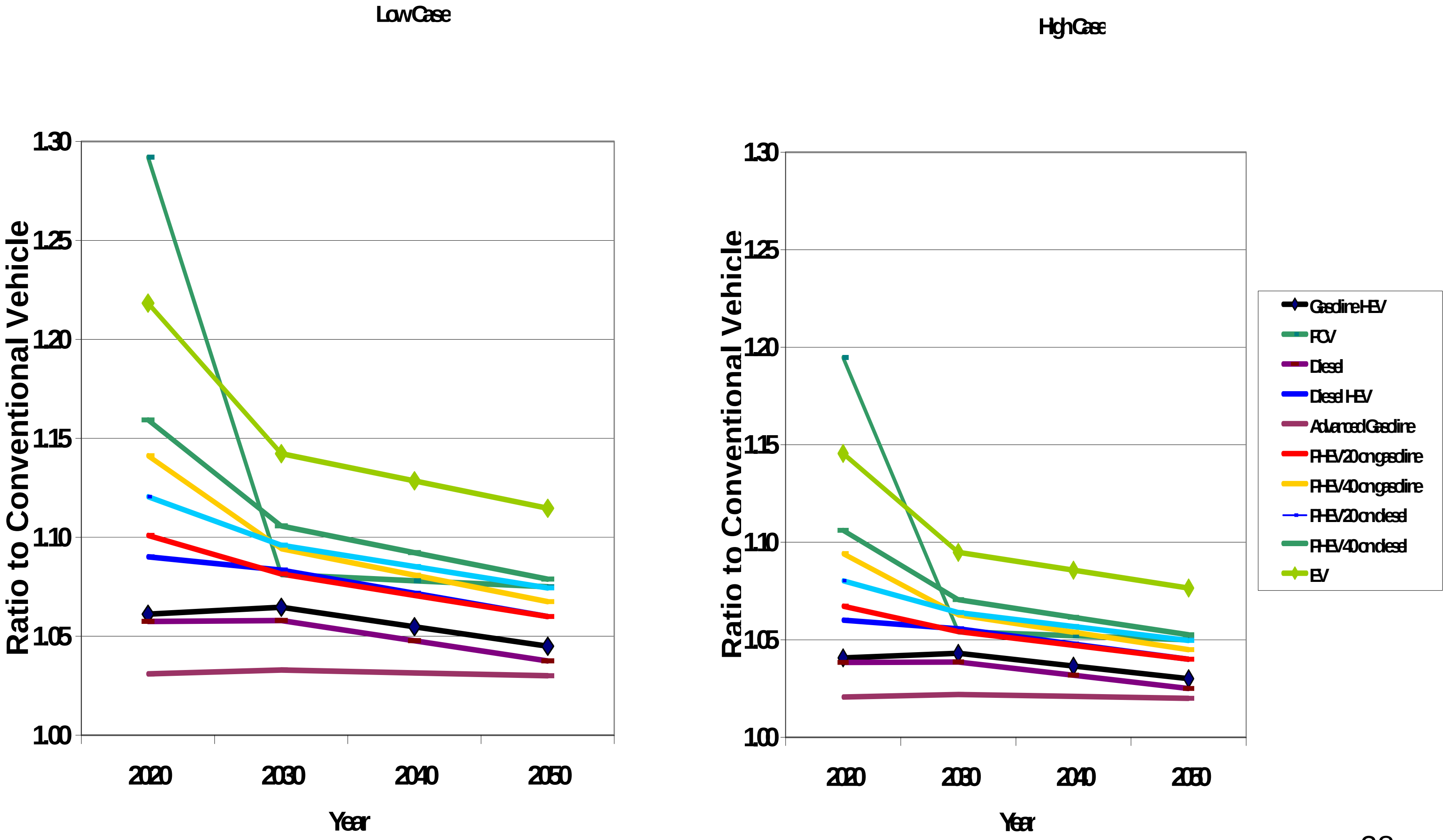
Phase 1: How MPG Varies by Vehicle Technology for Cars in 2050



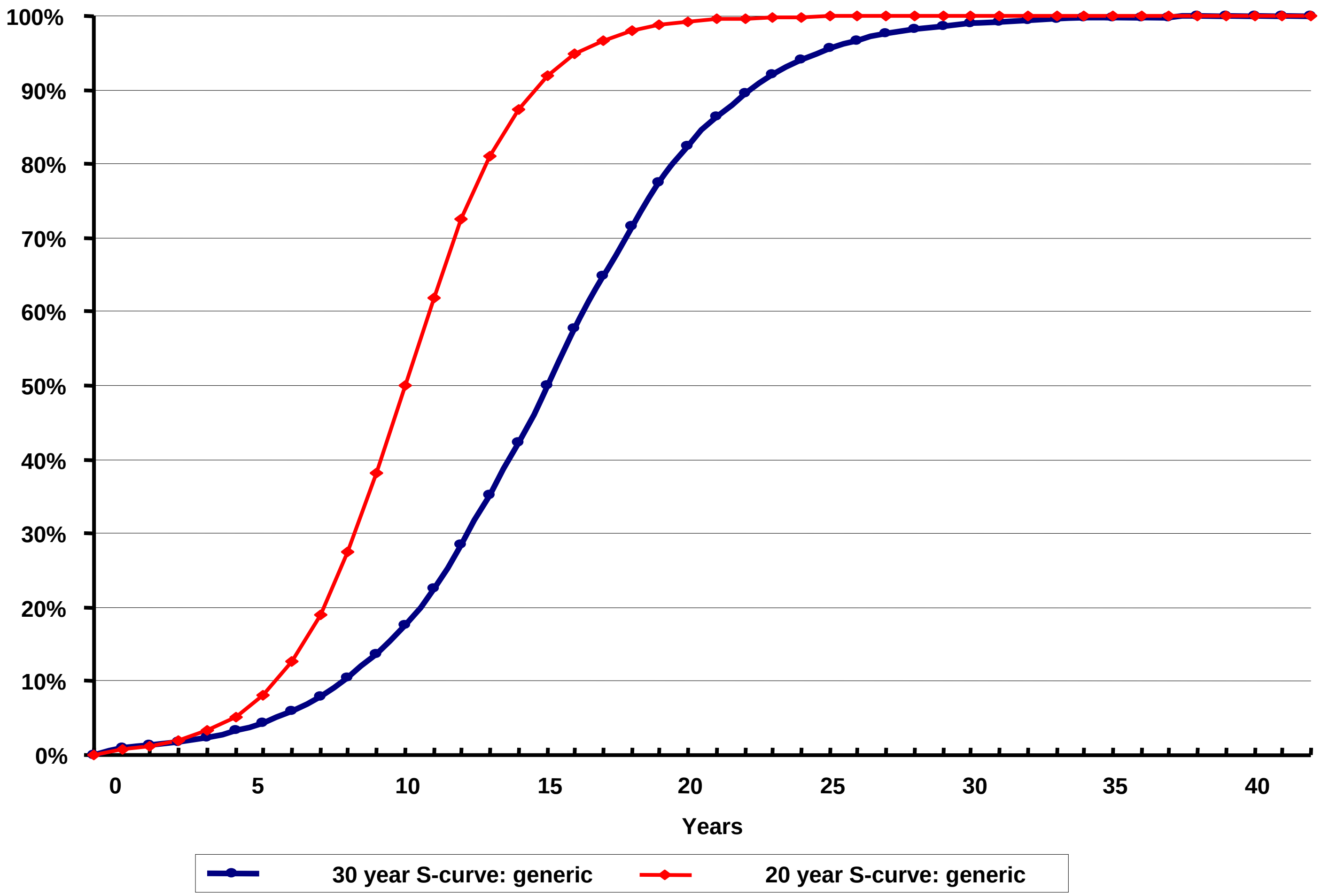
Selected PSAT results: Fuel economy ratios of "leading-edge" cars relative to 2005 conventional car (June 28, 2006 run)

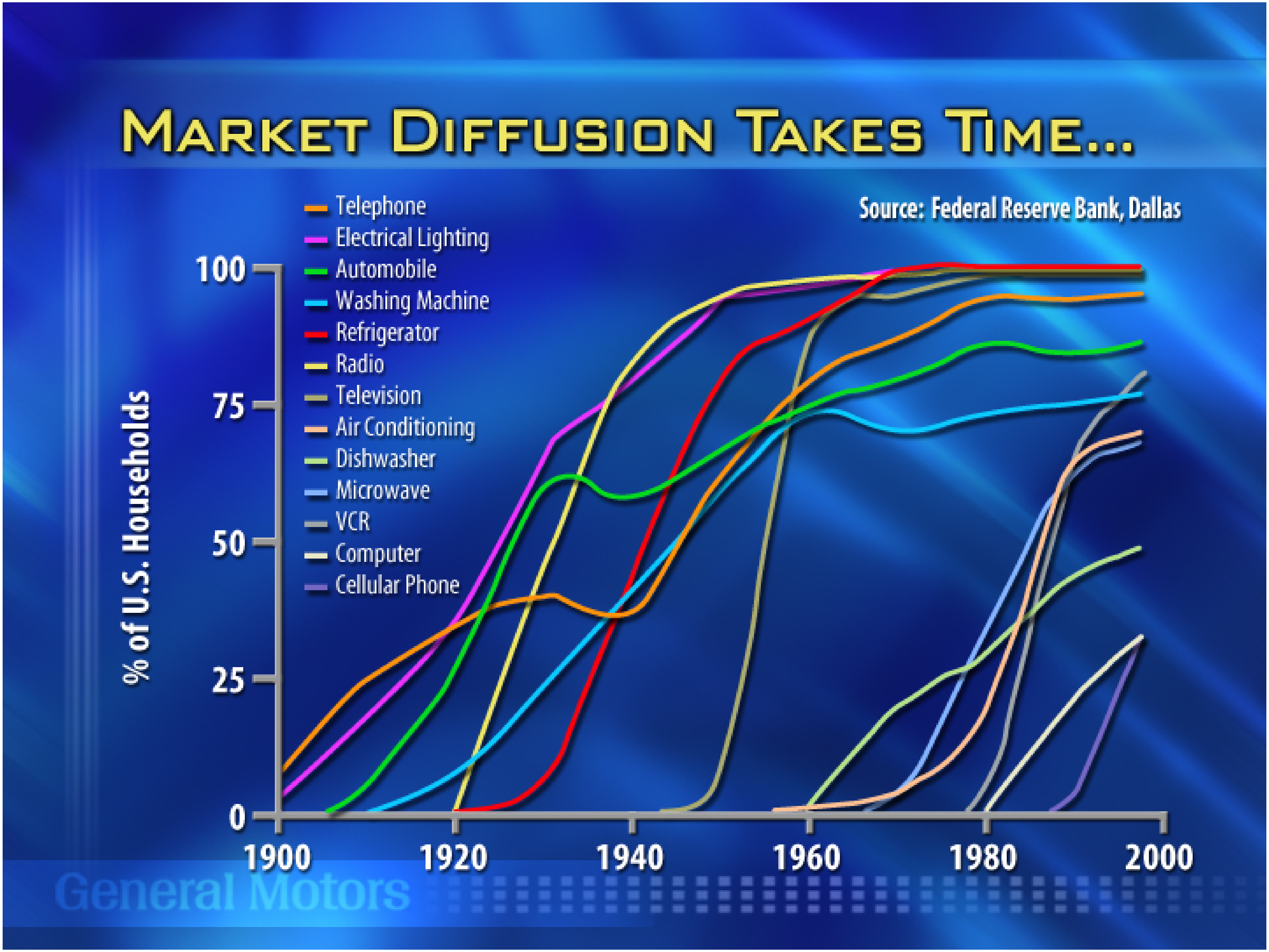
	2015	2030	2045
Advanced gasoline	1.39	1.64	1.85
Diesel	1.97	2.21	2.64
Gasoline HEV	2.20	2.53	2.88
Diesel HEV	2.55	2.90	3.43
FCV	3.43	4.32	5.25
PHEV40 on gasoline	2.14	2.40	2.75
PHEV40 on battery (kWh/mile)	0.262	0.246	0.223

Phase 1: Incremental Vehicle Costs for Advanced Technology Cars



Phase 1: Slow and Fast Market Penetrations





Market Diffusion Takes Time...
Telephone
Electrical Lighting
Automobile
Washing Machine
Refrigerator
Radio
Television
Air Conditioning
Dishwasher
Microwave
VCR
Computer
Cellular Phone
Source: Federal Reserve Bank, Dallas
% of U.S. Households
100
75
50
25
0
1900
1920
1940
1960
1980
2000
General Motors

Data from Dan Santini (ANL) Study

The U.S. Department of Energy Scenario for the Replacement of Oil by Hydrogen Fuel Cell Vehicles in an Historical Context, May 2004

Switch Type	Details	Year Started	Years to go from 5% to 95%
New Powertrain	Car: Multi for Single Point FI	1985	9
New Powertrain	Light Truck: Multi for Single Point FI	1986	4
New Vehicle	Car: Front Wheel Drive	1984	19
New Powertrain/Fuel	France: Diesel Car Share	1995	35
Fleet Fuel	Rail Roads: Wood-to-Coal	1869	31
Fleet Powertrain/Fuel	Transit Buses: Gasoline to Diesel Fuel	1959	33
Fleet Powertrain/Fuel	Automobiles: Leaded-Unleaded	1981	31
Fleet Vehicle/Fuel	Street Rail Road: Horse to Electric	1895	15
Fleet Vehicle/Fuel	Rail Road: Coal Steam to Diesel Locomotive	1955	16

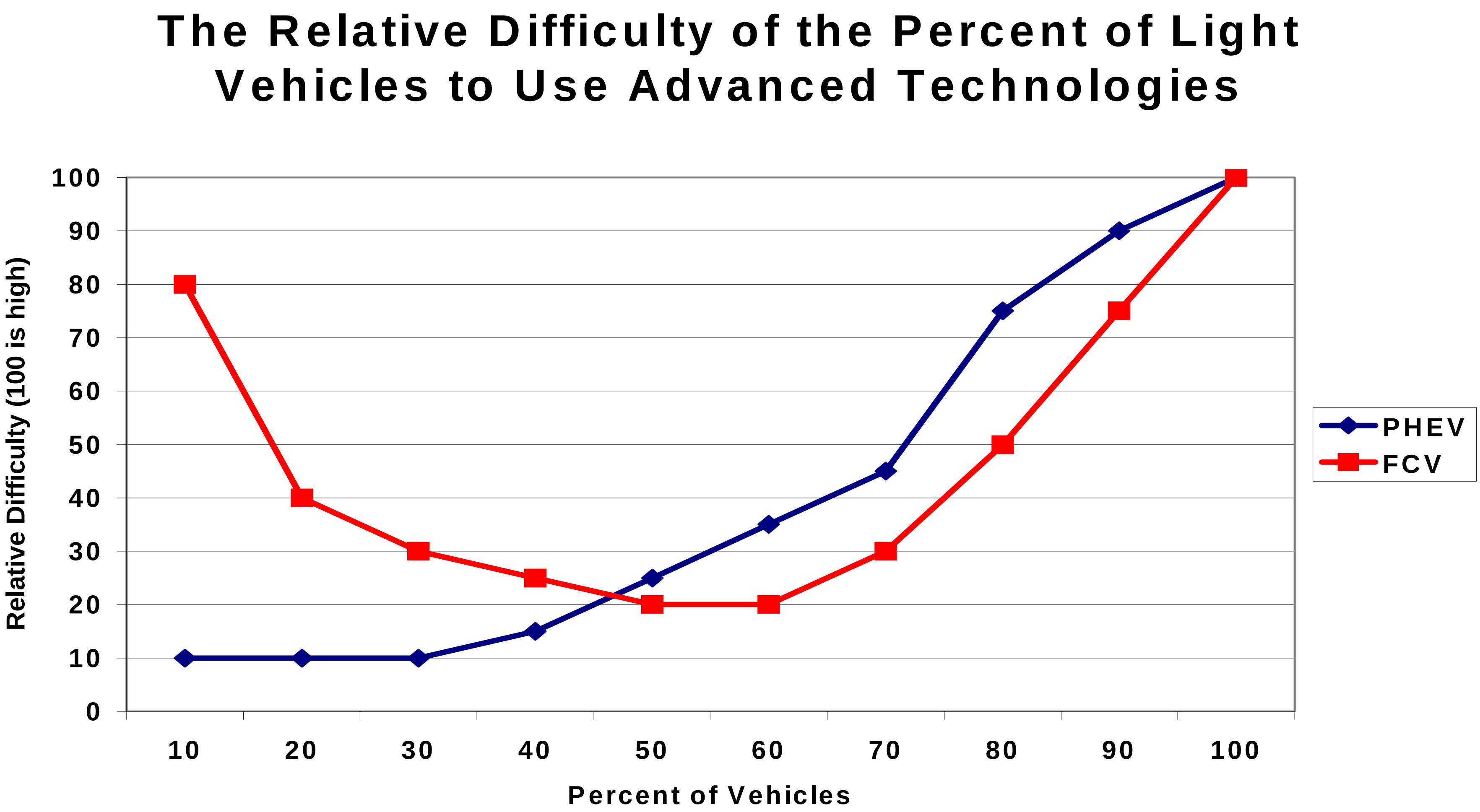
Most Pathways Have Limited Maximum Penetration Levels

- **Gasoline HEVs: 75%** (based on the fact that about 25% of the drivers do most of their driving on a highway cycle that would not benefit from hybridization)
- **PHEVs: 70%** (based on the fact that about 30% of vehicle owners have very little or no opportunity to be able to charge their main vehicle each night)
- **EVs: 40%** (based on most EVs being the second vehicle in multi-vehicle households)
- **FCVs: 76%** (based on 24% of vmt is by non-metro residents
- **Diesels: 75%** (based on concerns about refinery limitations and on European trends)
- **Diesel HEVs: 56%** (result of multiplying 75% GHEV times 75% ADV)

Example of a Vehicle Choice Modeling Difficulty

- The cost and/or attractiveness of some vehicle technologies to people who have not yet purchased the technology will vary according to the percent that technology has of the total vehicle market.
- When FCVs are first introduced, they will be expensive, it will be hard to find convenient fueling stations in the local area, and fueling outside the local area might be scarce or not available.
- As FCVs become a larger share of the market, these impediments will lessen.
- Beyond about 75% of the market, the attractiveness of the FVC will decline sharply because people in rural areas or in less populated regions will find hydrogen too expensive to buy.
- FCVs might also never be practical for the smallest vehicles.
- PHEVs, on the other hand, will be bought first by people who have the ability to charge them without any infrastructure expense.
- As PHEVs become a bigger part of the market, buyers will have to make infrastructure expenditures that make them less attractive. People in high rises and other multi-family residences may never be able to easily recharge a PHEV.

Example of How the Attractiveness of Two Vehicle Technologies Might Differ as a Function of Market Share



U.S. 2005 GHGs in Carbon Equivalents: mmtce (%)

Gas	Total	Transportation	Light Vehicles (full fuel cycle)
CO_2	1639 (84%)	534 (97%)	435 (96.5%)
Methane	167 (9%)	1.4 (0.2%)	12 (2.6%)
Nitrous Oxide	100 (5%)	14 (2.5%)	4 (0.9%)
HFCs, PFCs, and SF	44 (2%)	?	?

Phase 1 Pathways: Summary of Key Results/Observations

- FCVs achieve the greatest oil savings in 2050, but other technologies save more in earlier years
- Flexible fuel gasoline HEVs are second to FCVs in oil savings, but this assumes 60-70% of travel is on E-85
- Depending on feedstock assumptions, flex fuel HEVs can generate greater GHG reductions than FCVs
- Electricity requirements of PHEV40s could be substantial (8% of U.S. total electricity in 2050)
- Total VMT increases in all pathways because of the improved fuel economy of the vehicle stock
  - In the Low Case from 1.9% to 3.9% in 2050 and in the High Case from 5.4% to 10.2% in 2050

Pathway Results (Low and High Cases)

The top 3 pathways are highlighted in red.

Pathways	2030 Oil Savings (mbpd)	2050 Oil Savings (mbpd)	Annual GHG Reduction in 2050 (mmtce)
1. FFHEV	1.1/2.7	6.1/7.2	277/361
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3. ADV	1.0/2.2	2.4/3.7	127/203
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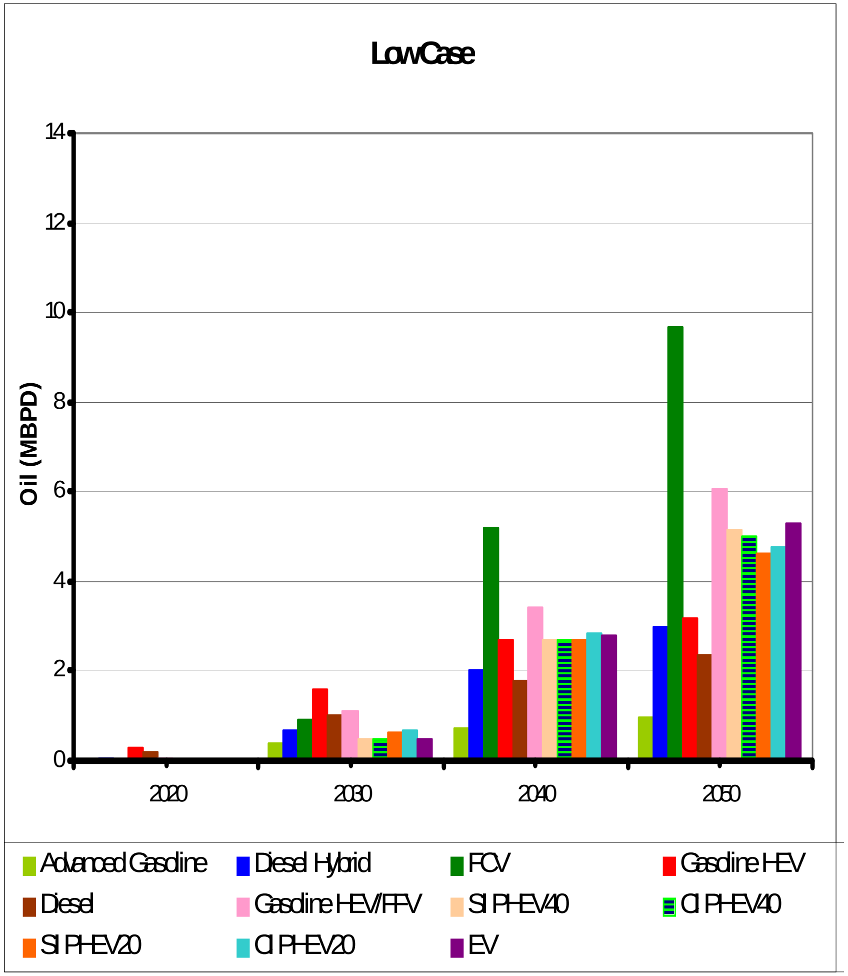
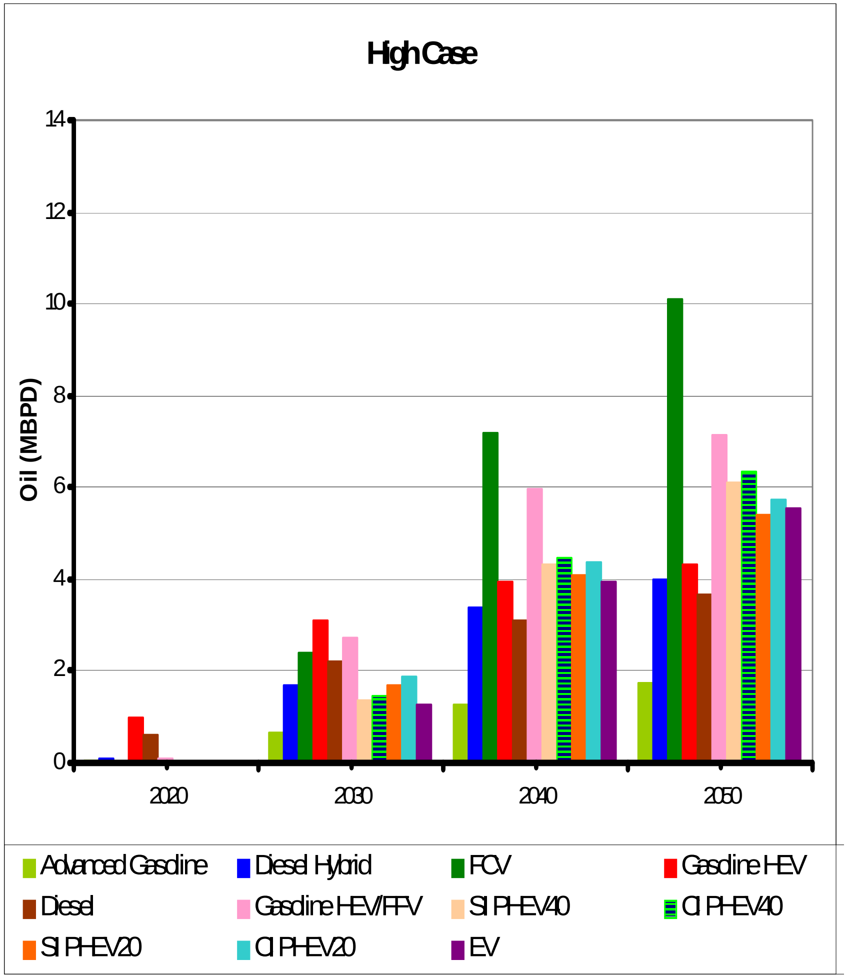
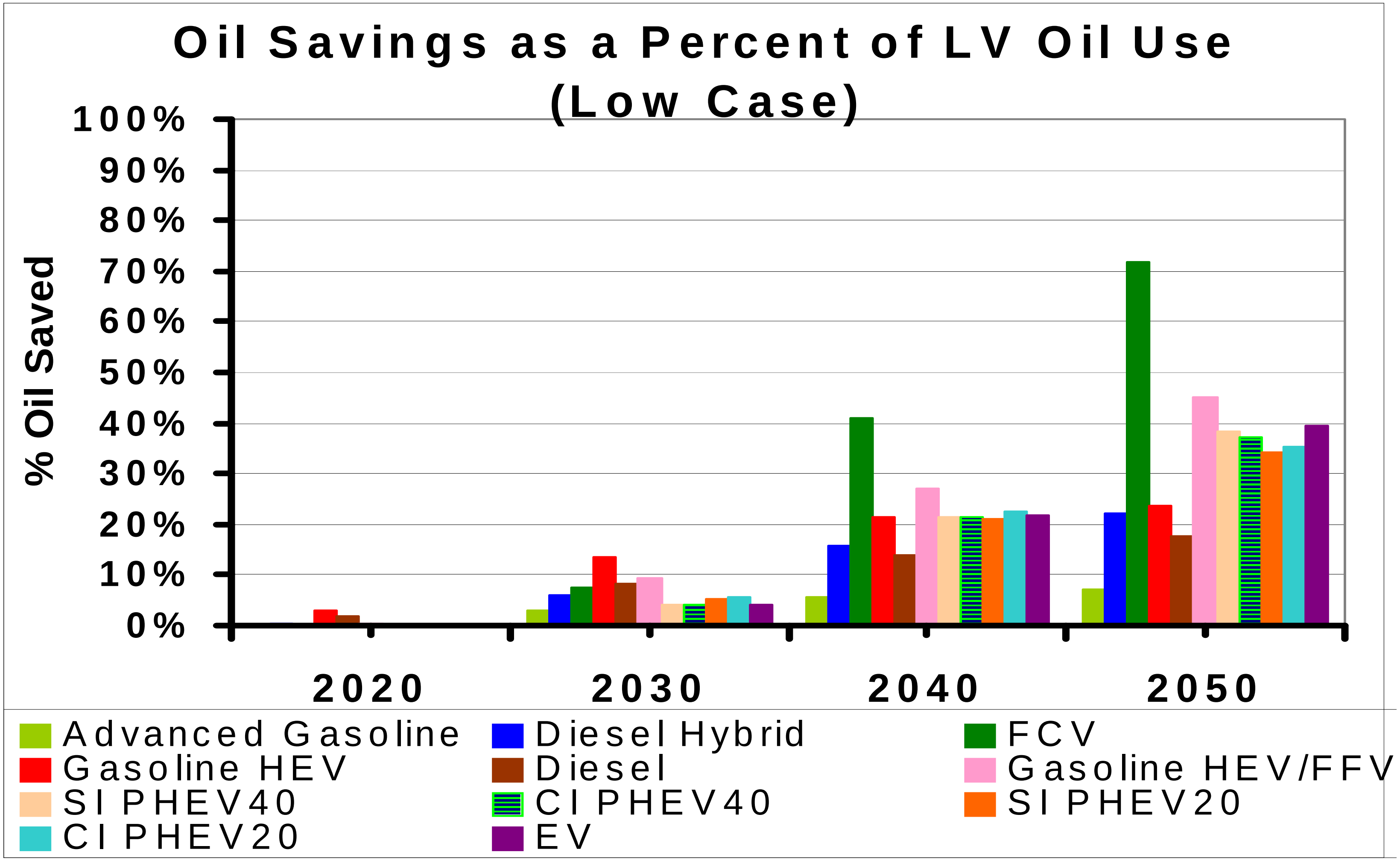
Pathway Impacts: Oil Savings for High and Low Cases

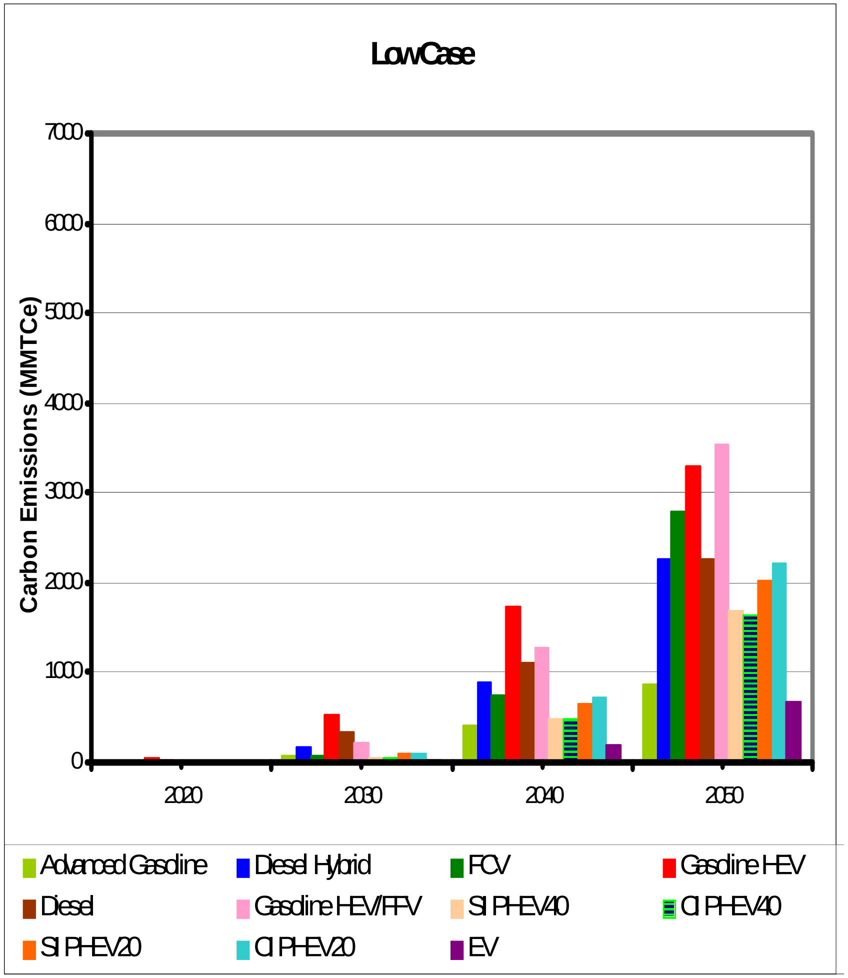


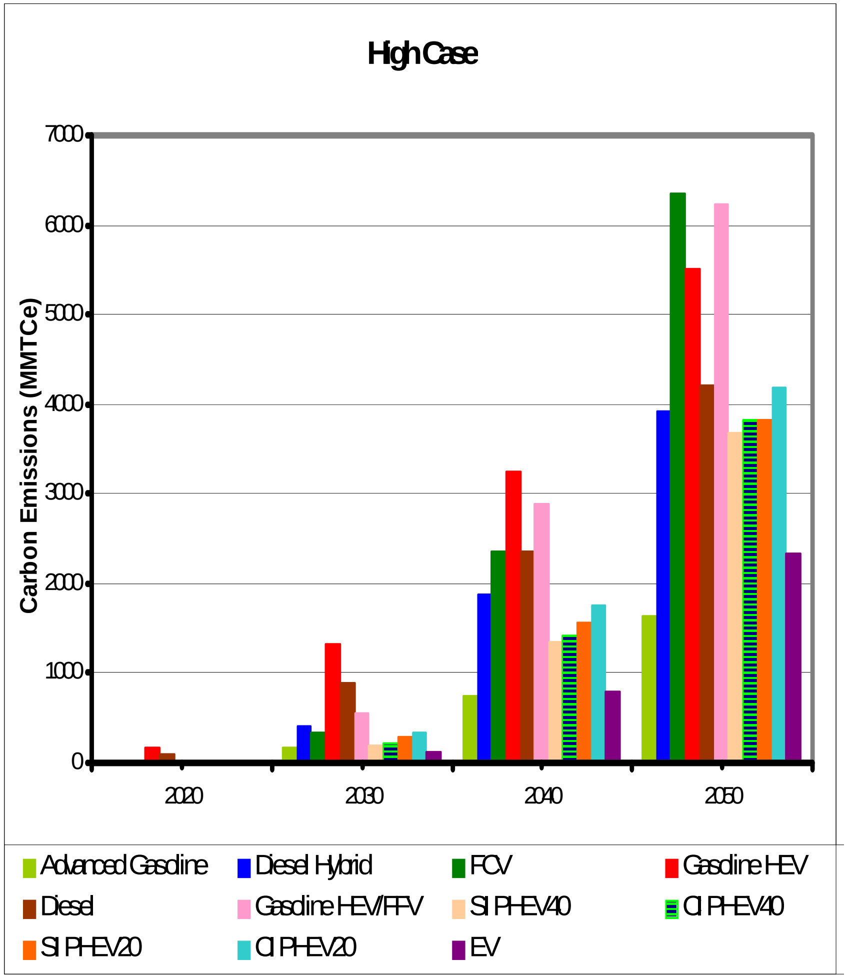


Percent of Light Vehicle Oil Use That Is Saved

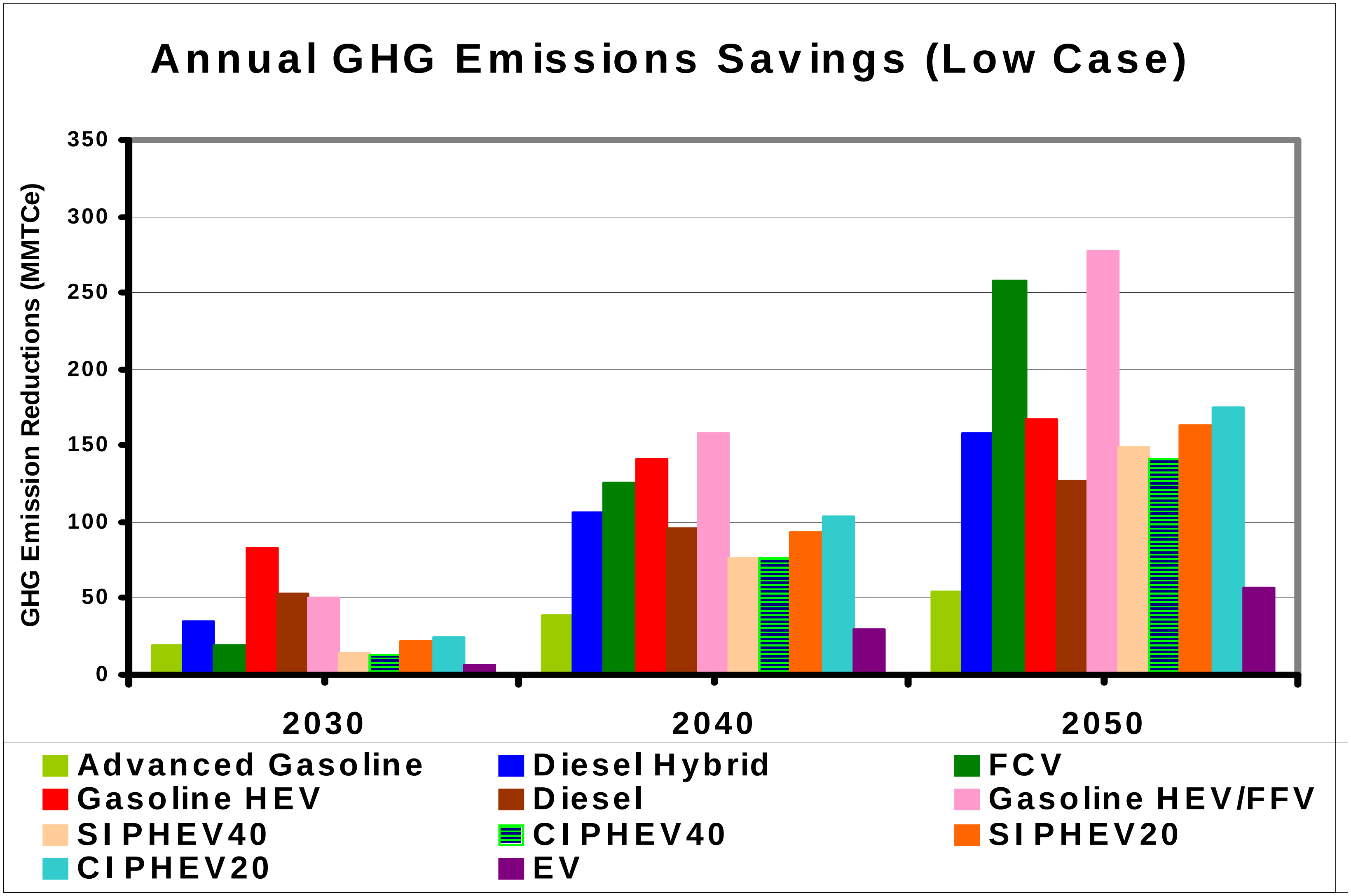


Pathway Impacts: Cumulative GHG Emission Reductions by Case

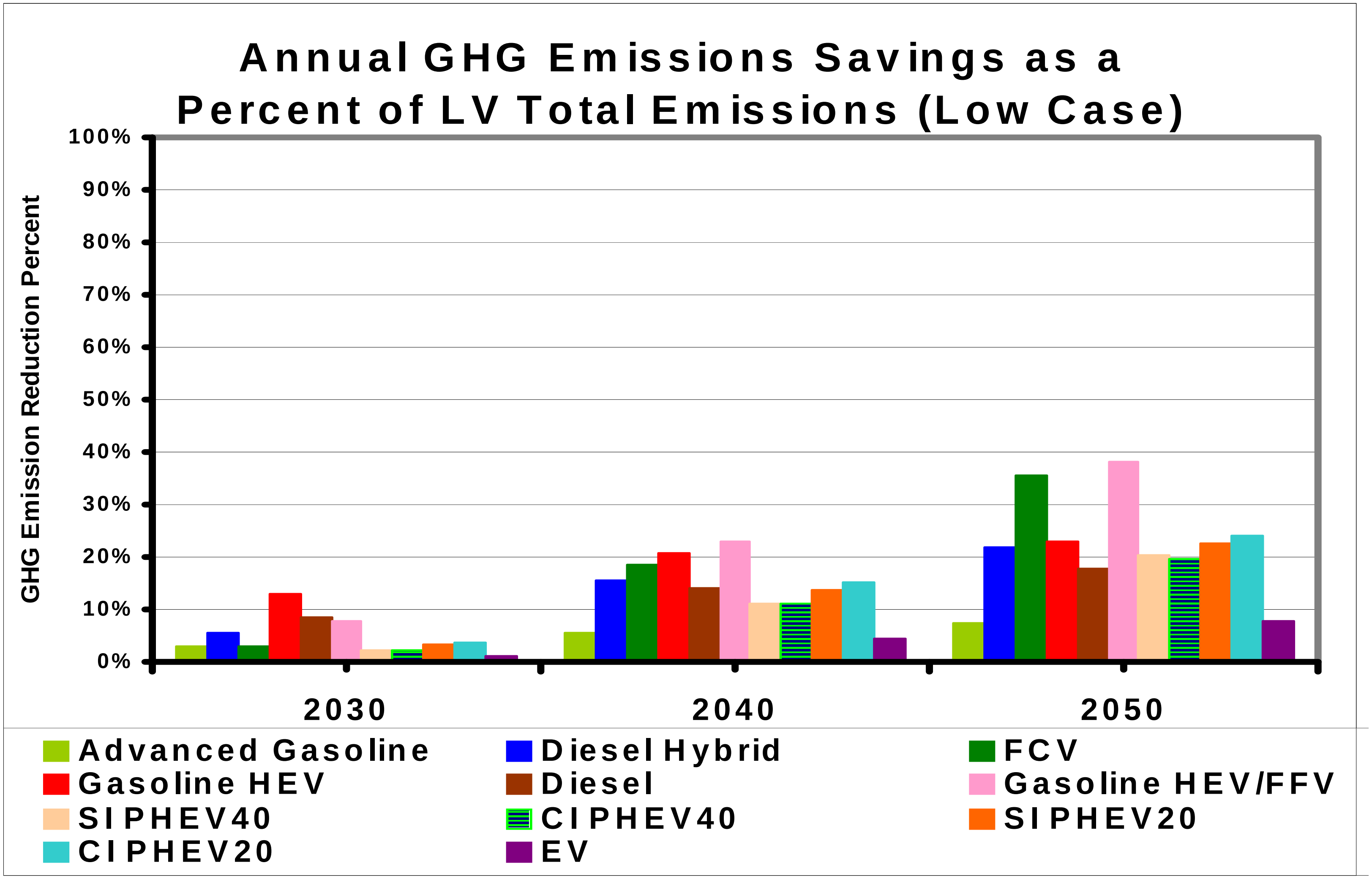




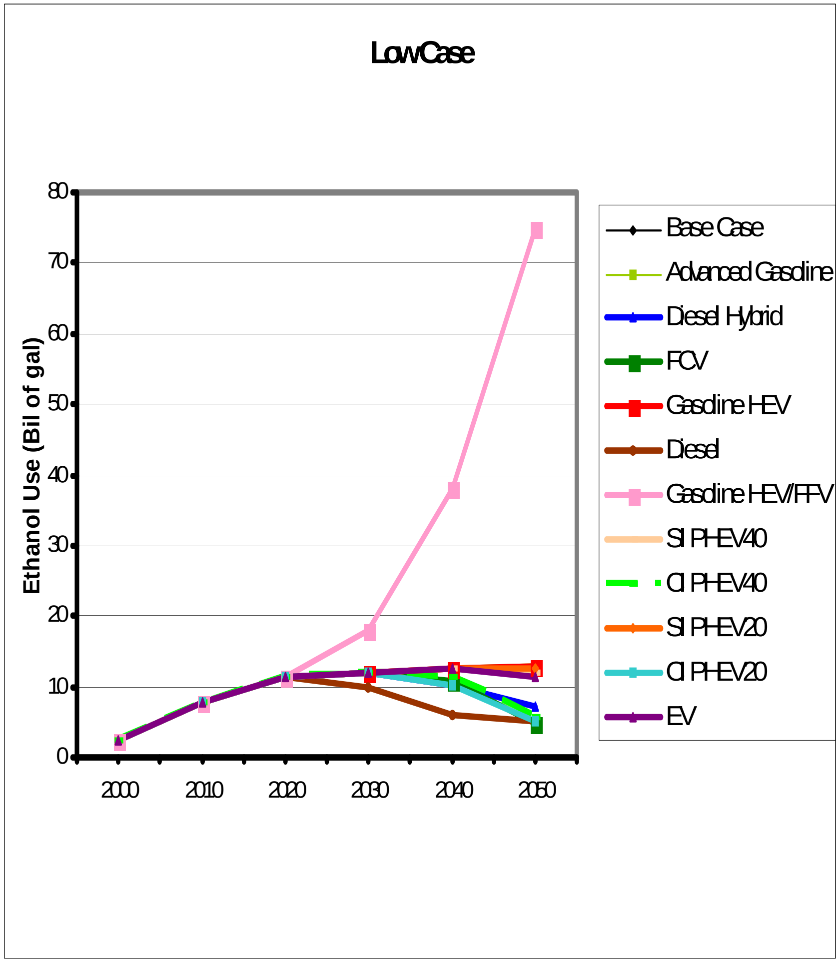
Annual GHG Savings by Pathways

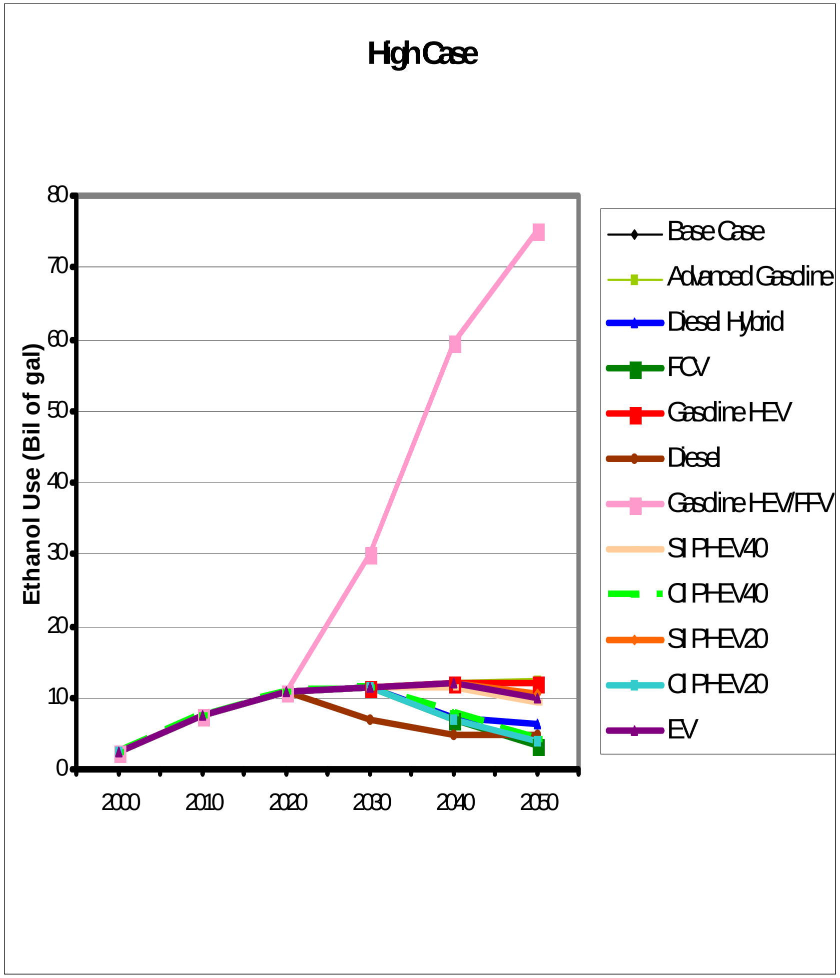


Percent of GHG Emissions That Are Saved by Pathways

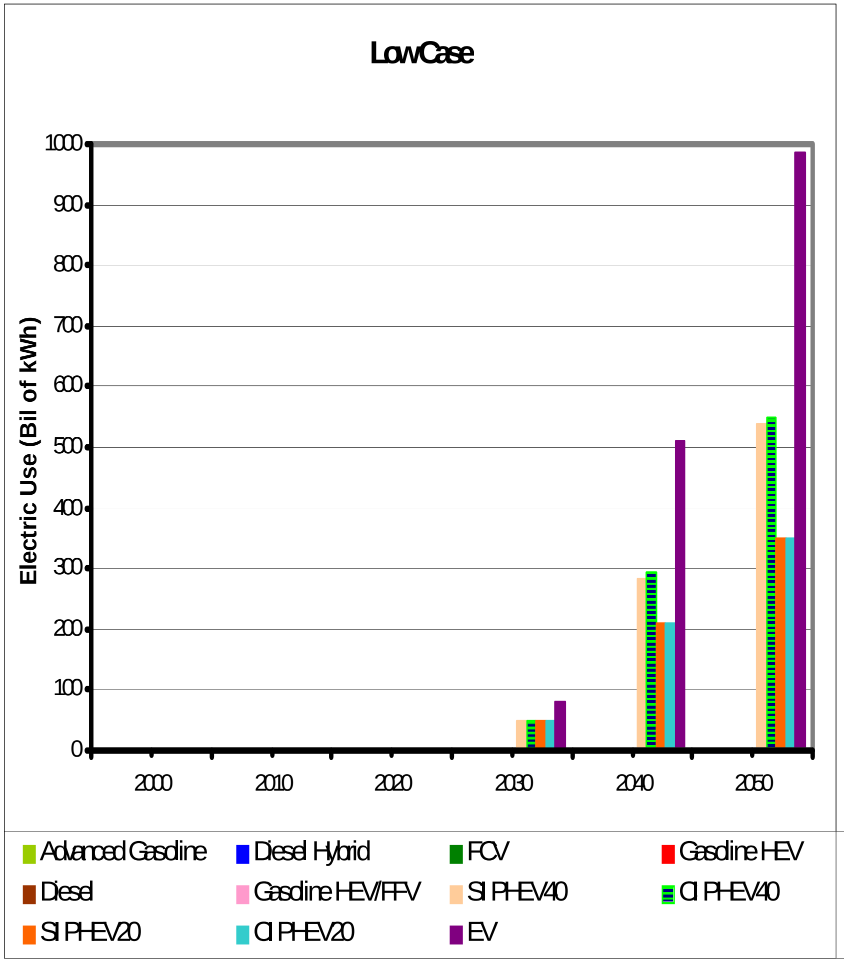


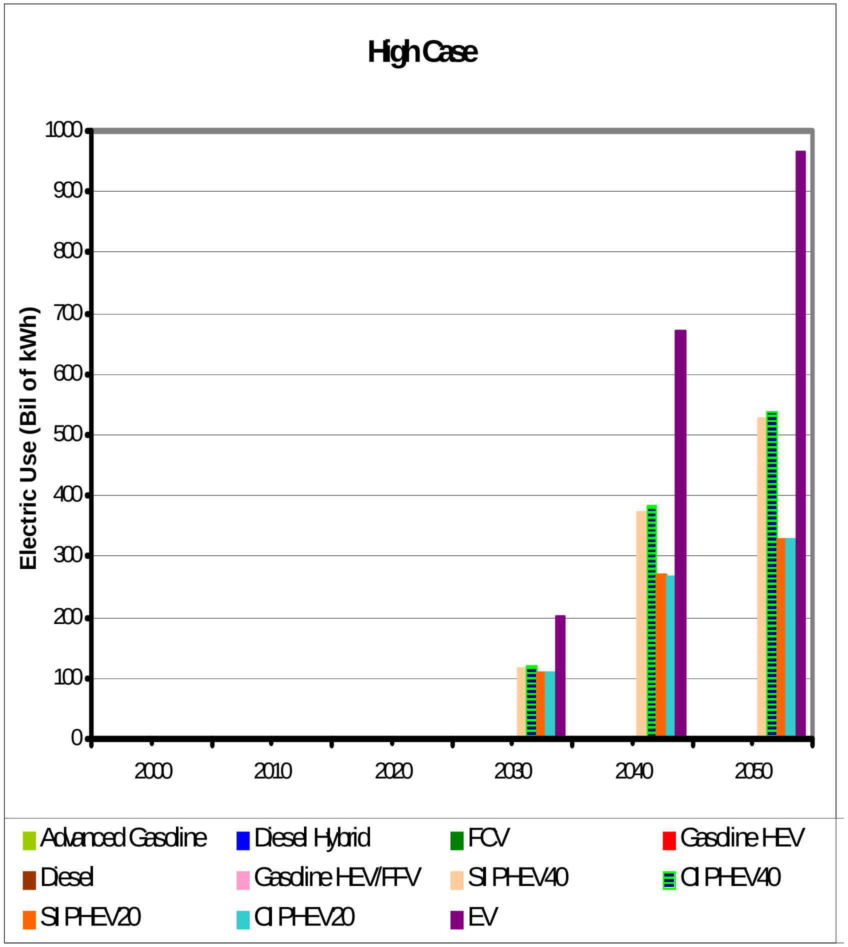
Pathway Results: Ethanol Use by Case





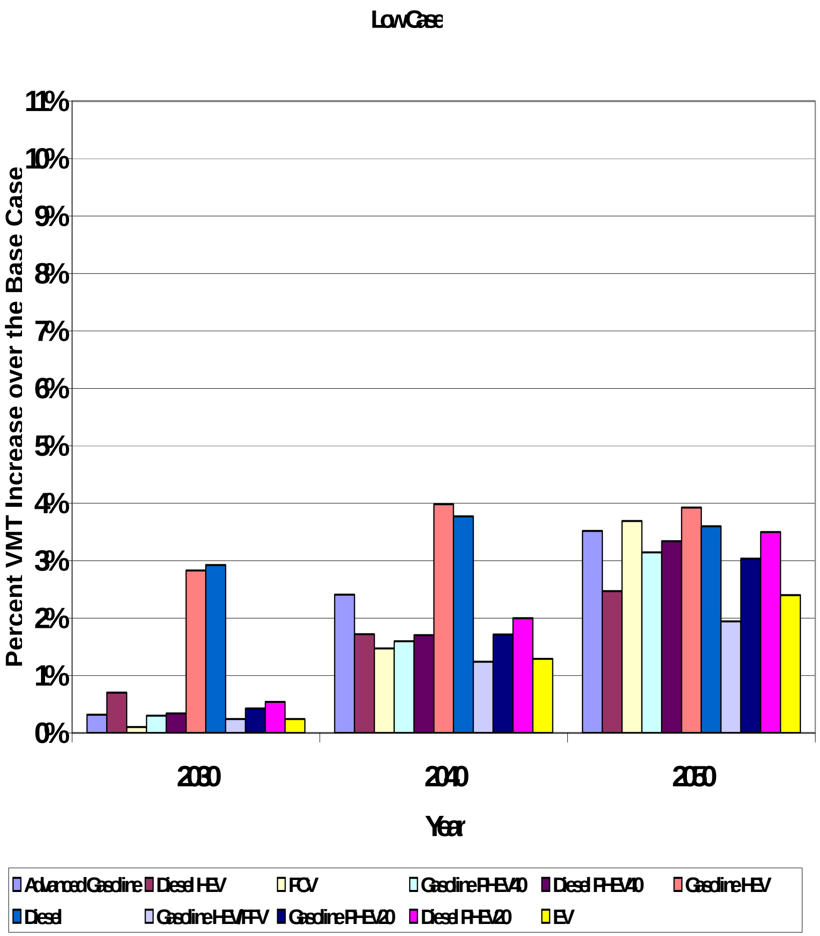
Pathway Impacts: Electricity Use by Case

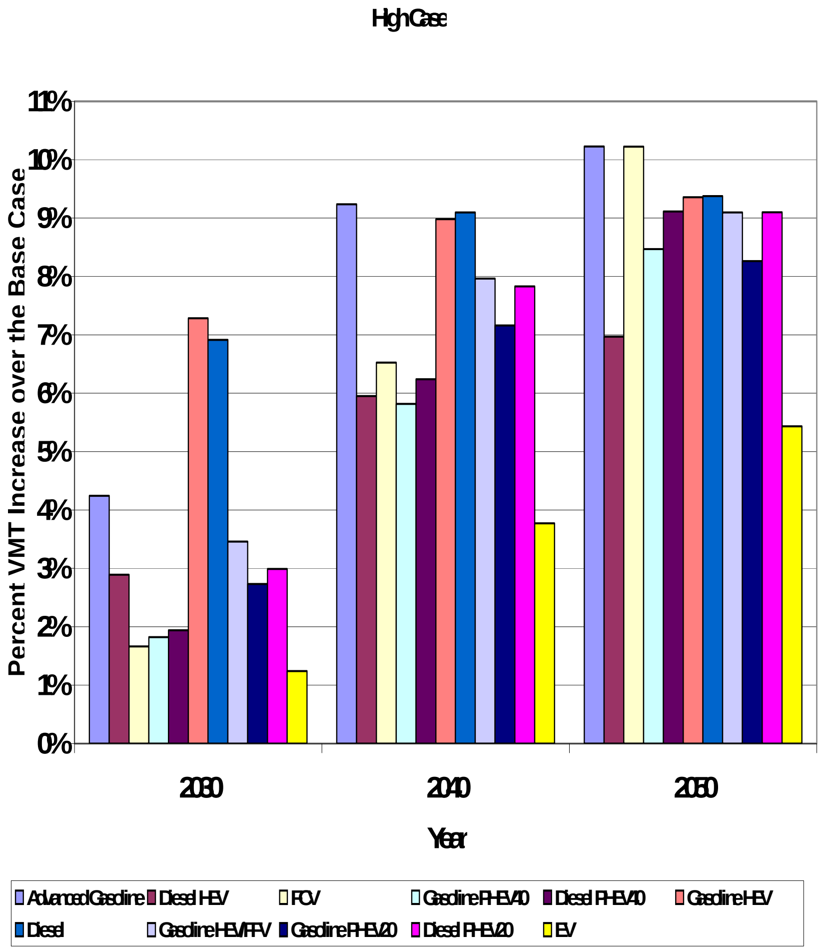




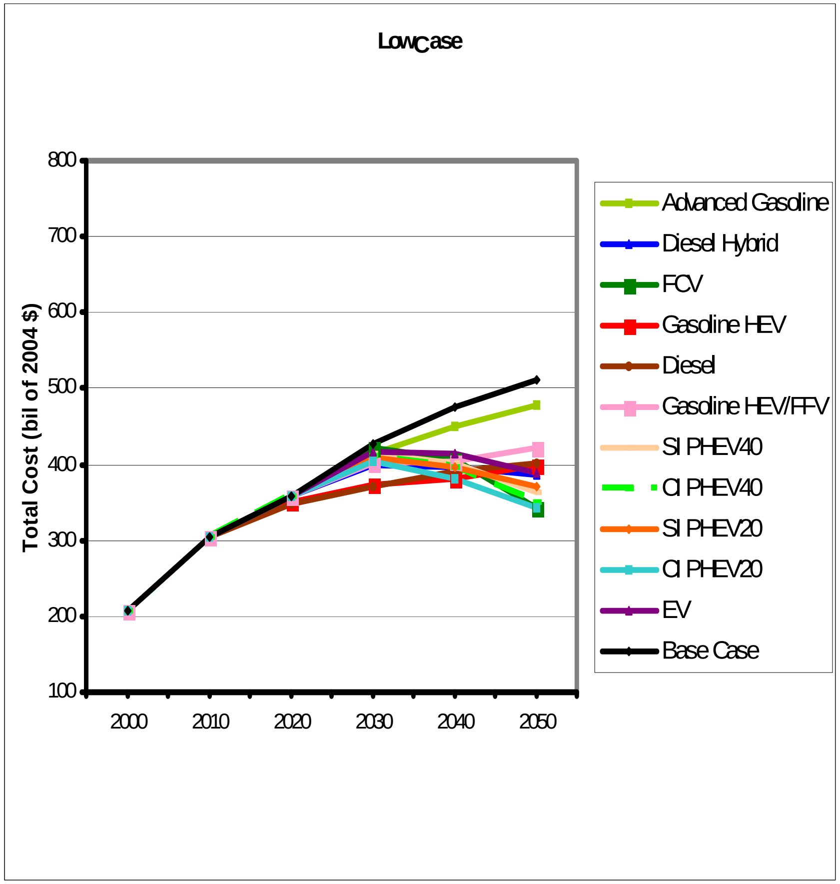
Pathway Impacts: VMT Increases Caused by the Rebound Effect

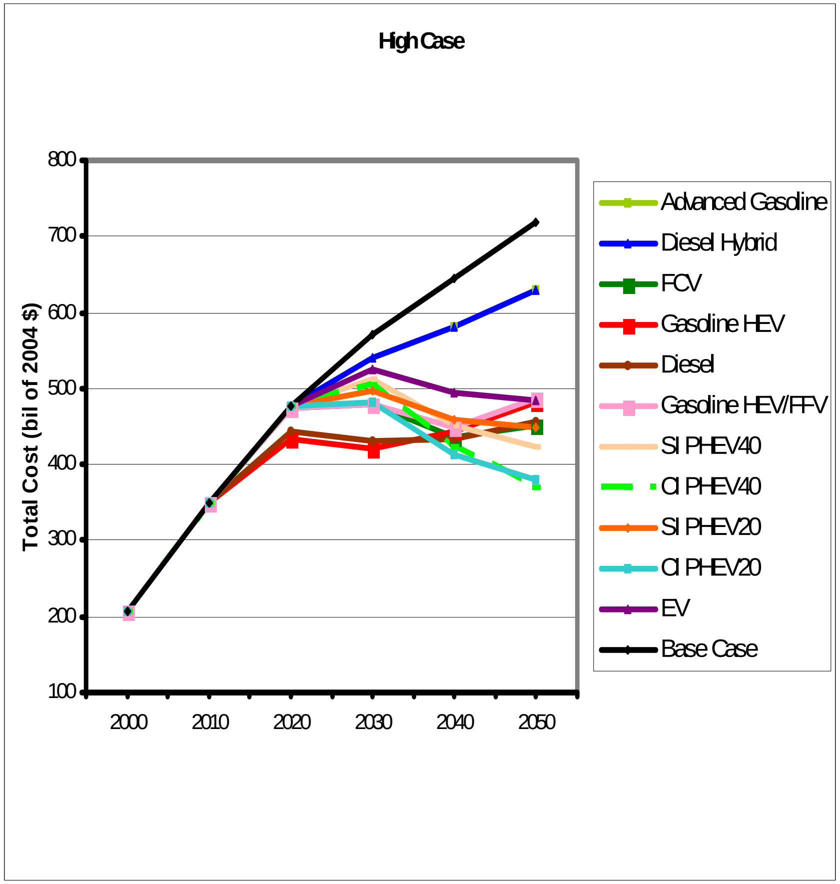
[Assuming a 10% Rebound Effect]





Pathway Results: Total Fuel Costs by Case





Phase 1 Scenarios

- Major Analysis
  - 1. **Mixed** (HEV, PHEV, FCV and Ethanol)
  - 2. **Hydrogen Success** (Some HEV to ~75% FCVs)
  - 3. **(P)HEV and Ethanol** (HEV, PHEV, and E85)
- Minor Analysis
  - 4. **Hybrid and Ethanol** (HEV and Ethanol)
  - 5. **Maximum Electric** (PHEV and EV)
  - 6. **Maximum Ethanol** (Ethanol in efficient vehicles)
  - 7. **Advanced Conventional Vehicles: Low Unconventional Oil**
  - 8. **Advanced Conventional Vehicles: High Unconventional Oil**
  - 9. **Regional H2 Case** (based on the regional introduction of FCVs)
  - 10. **High Diesel with Biomass**

Phase 1 Scenarios: General

- To date, all 10 scenarios have been analyzed
- The Base Case against which they are evaluated is generally the same as the “Low Base Case” used for the single pathways
  - With a few exceptions as noted in the following slides

Scenario Description

Scenario	2030 Market Penetration (cars)	2050 Market Penetration (cars)	Other Key Factors
1. Mixed	30% ACV, 20% ADV, 30% GHEV, 17% PHEV	10% ACV, 20% ADV, 15% GHEV, 25% PHEV, 30% FCV	ACVs, GHEVs & PHEVS are flex fuel; in 2050, 30 billion gallons ethanol are used
2. H2 Success 9. Regional H2	20% ACV, 10% ADV, 40% GHEV, 10% FCV	24% GHEV, 76% FCV	H2 feedstocks vary between #2 and #9
3. (P)HEV & Ethanol	20% ACV, 40% GHEV, 25% PHEV	45% GHEV, 50% PHEV	ACVs, GHEVs & PHEVS are flex fuel; in 2050, 60 b gals ethanol are used
4. HEV & Ethanol 6. Max Ethanol	25% ACV, 45% GHEV	25% ACV, 75% GHEV	ACVs & GHEVs are flex fuel; in 2050, 60 b gals ethanol are used in #4 & 75 b gals in #6
5. Max Electric	20% ACV, 25% GHEV, 25% PHEV, 5% EV	10% ACV, 20% GHEV, 60% PHEV, 10% EV	
7. ACV Low 8. ACV High Unconventional Oil	50% ACV	95% ACV	2050: 22% of oil resource is from unconventional sources in #7; 42% in #8
10. High Diesel with Biomass	20% ACV, 25% ADV, 8% DHEV, 30% GHEV	50% ADV, 25% DHEV, 20% GHEV	Significant volume of biomass-based diesel

Scenario Assumptions

Scenario	Fuel Economy	Fuel Prices	Incremental Vehicle Costs
1. Mixed	From PSAT Model runs of October 2006; see other slide for efficiencies	Except for electricity, same as Low Base Case which used AEO 2006 Reference Case Extended	From literature review
2. H2 Success; 9. Regional H2	Same as above	Same as above	Same as above
3. (P)HEV & Ethanol	Same as above	Same as above	Same as above
4. HEV & Ethanol; 6. Max Ethanol	Same as above	Same as above	Same as above
5. Max Electric	Same as above	Same as above	Same as above
7. ACV Low; 8. ACV High Unconventional Oil	Same as above	Same as above	Same as above
10. High Diesel with Biomass	Same as above	Same as above	Same as above

Scenario Assumptions (cont'd)

Scenario	Fuel Feedstocks	Scenario	Fuel Feedstocks
1. Mixed	Same as in Low Base Case	6. Max Ethanol	Uses High Base Case ethanol assumptions; other assumptions are as in the Low Base Case
2. H2 Success	Uses High Base Case H2 feedstock assumptions; other assumptions are as in the Low Base Case	7. ACV Low Unconventional Oil	Same as in Low Base Case
3. (P)HEV & Ethanol	Uses High Base Case ethanol and electricity assumptions; other assumptions are as in the Low Base Case	8. ACV High Unconventional Oil	Uses High Base Case unconventional oil assumptions; other assumptions are as in the Low Base Case
4. HEV & Ethanol	Uses High Base Case ethanol assumptions; other assumptions are as in the Low Base Case	9. Regional H2	Same as H2 Success except much greater use of low carbon fuels to produce H2 in 2020/2030
5. Max Electric	Uses High Base Case electricity assumptions; other assumptions are as in the Low Base Case	10. High Diesel with Biomass	Biodiesel and FT from biomass used; energy use of both = 60 billion gallons ethanol (2050)

Fuel Economy Ratios Used in Scenarios

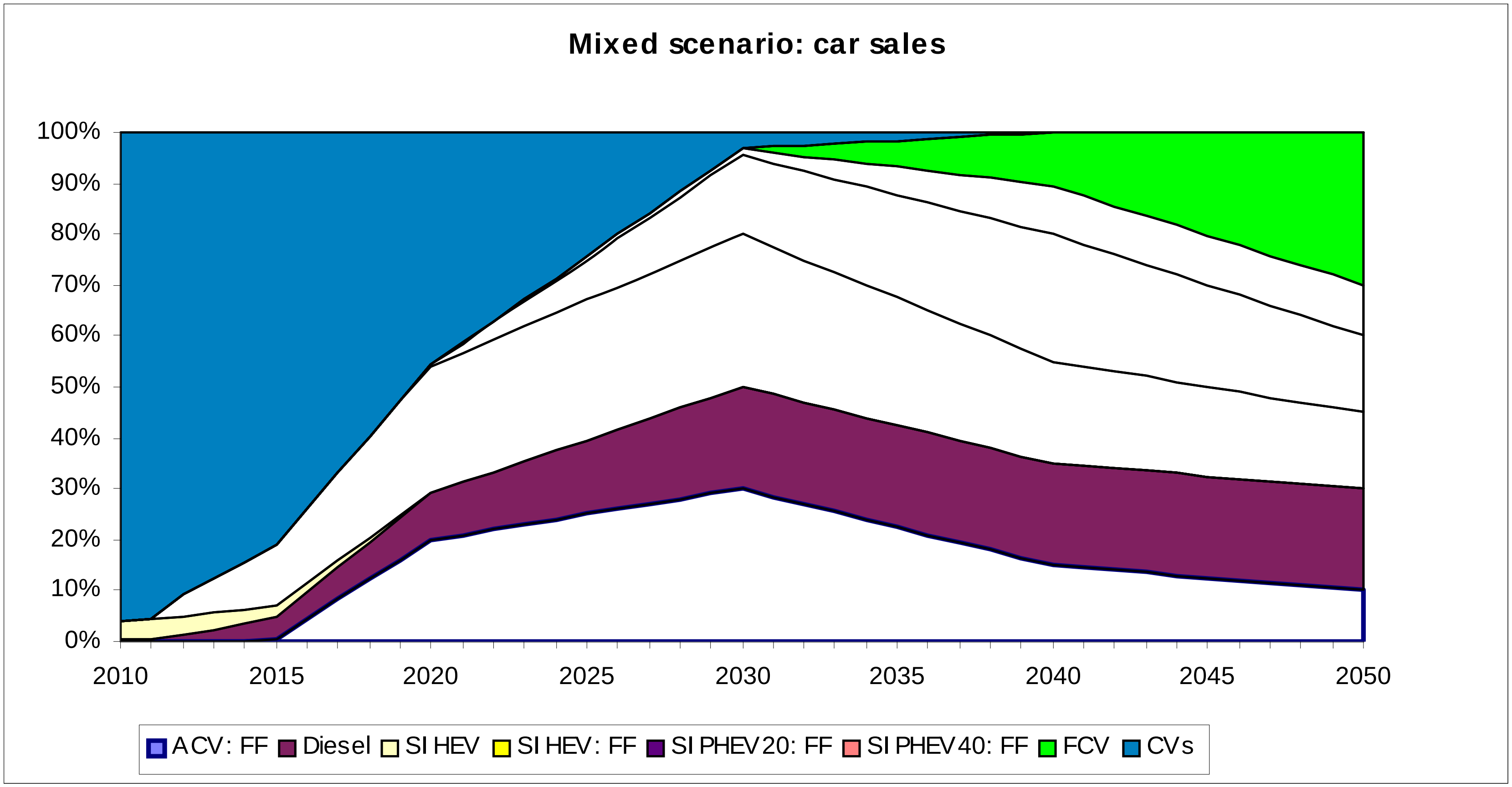
[MPGGE ratios are for 2030 new cars relative to new gasoline car]

	Scenario (Based on October 2006 PSAT results)	
	Ratio on liquid fuel	**Ratio on electricity**
1. ACV	**1.32**	
2. ADV	**1.79**	
3. GHEV	**2.02**	
4. FFHEV	**2.02**	
5. DHEV	**2.21**	
6. FCV	**3.19**	
7. GPHEV20	**1.92**	**4.42**
8. GPHEV40	**1.87**	**4.36**
9. DPHEV20	**2.14**	**4.29**
10. DPHEV40	**2.09**	**4.23**
11. EV		**4.15**

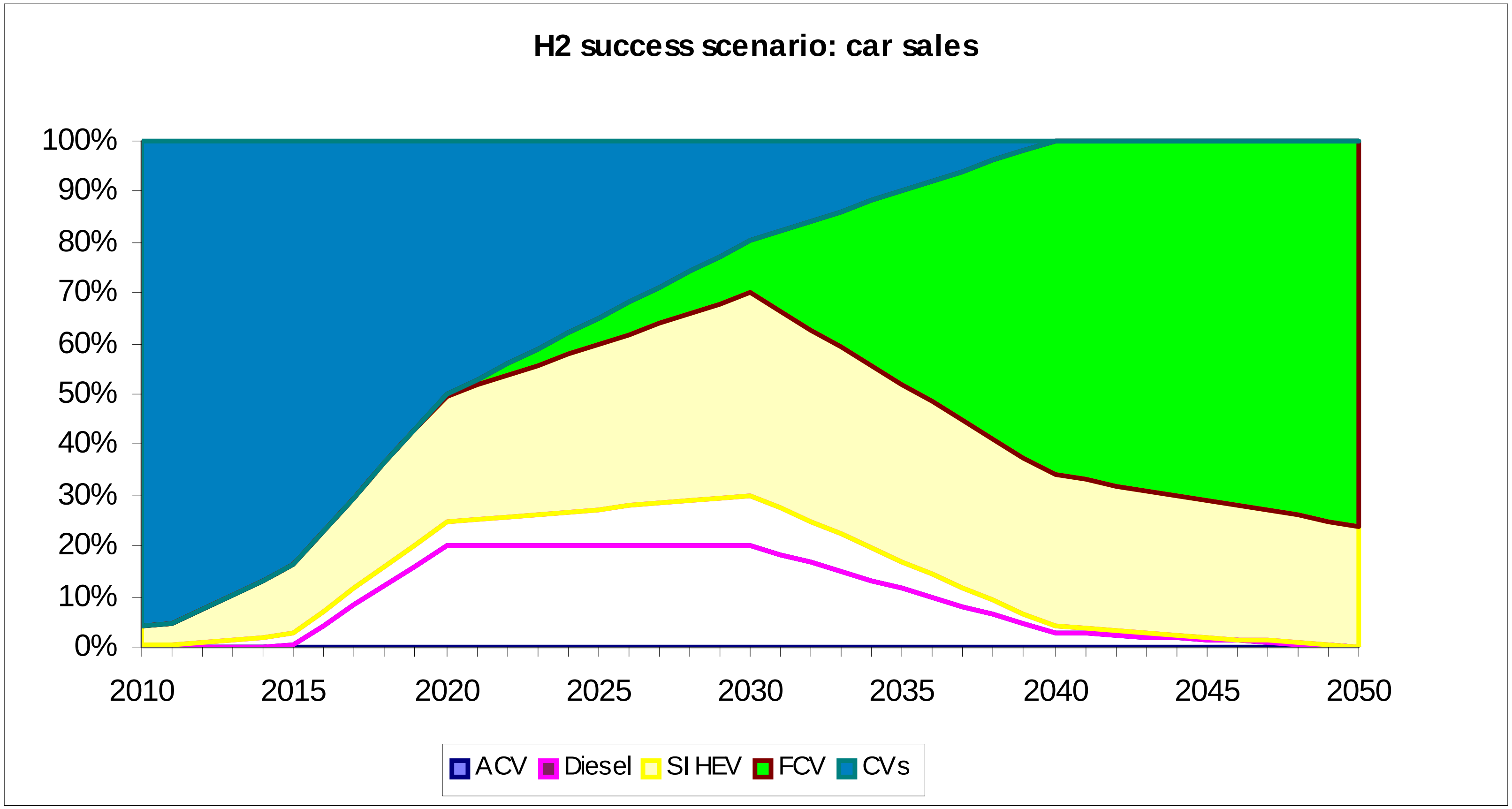
Vehicle Cost Ratios: GPRA08 vs Estimates Based on Literature Review Used in Scenario Analysis (relative to new gasoline car)

	GPRA 08 (or estimated using GPRA model)		From Literature Review	
	2030	2050	2030	2050
1. ACV	1.022	1.020	1.078	1.083
2. ADV	1.039	1.025	1.123	1.124
3. GHEV	1.043	1.030	1.156	1.145
4. FFHEV	1.043	1.030	1.156	1.145
5. DHEV	1.056	1.040	1.196	1.183
6. FCV	1.054	1.050	1.240	1.201
7. GPHEV20	1.054	1.040	1.210	1.183
8. GPHEV40	1.063	1.045	1.267	1.221
9. DPHEV20	1.064	1.050	1.251	1.220
10. DPHEV40	1.071	1.053	1.308	1.259
11. EV	1.095	1.076	1.344	1.288

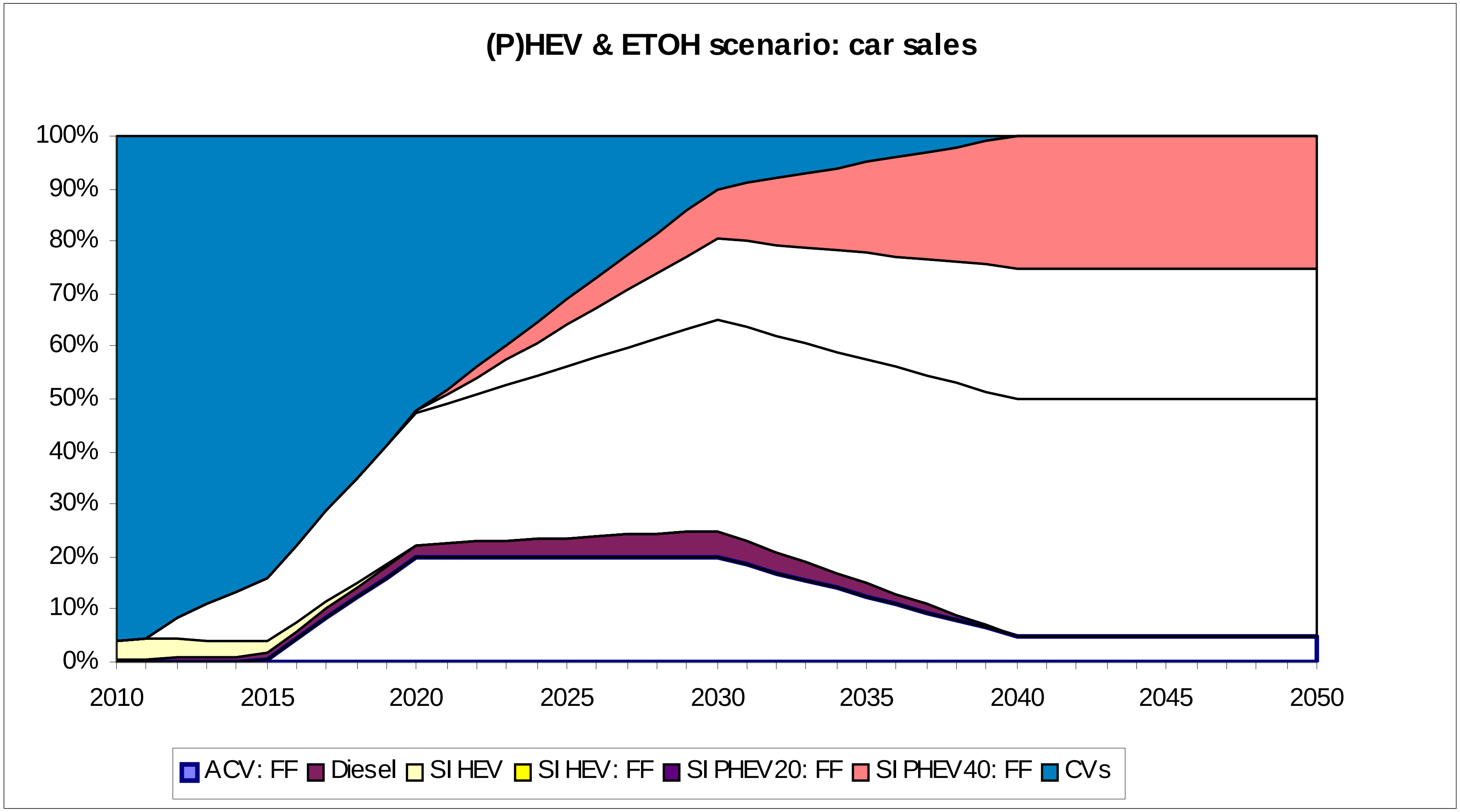
The Mixed Scenario: Market Penetration Assumptions (Cars)



The H2 Success Scenario: Market Penetration Assumptions (Cars)



The HEV, PHEV and Ethanol Scenario: Market Penetration Assumptions (Cars)



Phase 1 Scenarios: Results

- Metrics:
  - Substantial oil and GHG emission savings are achieved in these scenarios
  - The (P)HEV and Ethanol scenario provides the greatest oil savings by 2030, while the H2 Success and Regional H2 scenarios provide the greatest savings by 2050
  - The H2 Success, Regional H2 and Max Electric scenarios can use as much ethanol as EIA projects to 2030, but ethanol use declines in these scenarios post-2030
    - It also declines in the High Diesel scenario, but the biomass is used to produce diesel fuel rather than ethanol
  - The electricity demand of PHEVs can be substantial (4.4% in 2050 for the (P)HEV and Ethanol scenario and about 8.5% in the Maximum Electric scenario)
- All scenarios lead to increases in VMT because of the rebound effect, with the High Diesel with Biomass scenario having the greatest increase (5.9% by 2050)

Phase 1 Scenarios: Results (cont'd)

- Regional introduction of FCVs rather than uniform introduction throughout the US might make little difference in cumulative GHG emissions from FCVs assuming that ultimately (2040/2050) the same total FCV penetration by region will be achieved
  - H2 will be produced from different resources in different regions
  - Thus there should be some differences in total GHG emissions between a scenario of regional FCV introduction (i.e., Regional H2) and one of uniform introduction throughout the US (i.e, H2 Success)
  - However, in the early years (2020 to 2030) , when the differences between the scenarios would be at their greatest, FCV stock is small and H2 demand is low so that the GHG emissions generated by these vehicles won't contribute much to the cumulative GHG emissions of FCVs by 2050

Phase 1 Scenarios: Results (cont’d)

- **The % of travel on E-85 required by flex fuel-capable vehicles to meet specific goals for ethanol use varies not only by the goal, but by vehicle mix.**
  - In all scenarios (except Base), ethanol in gasoline is 10% ethanol in 2050

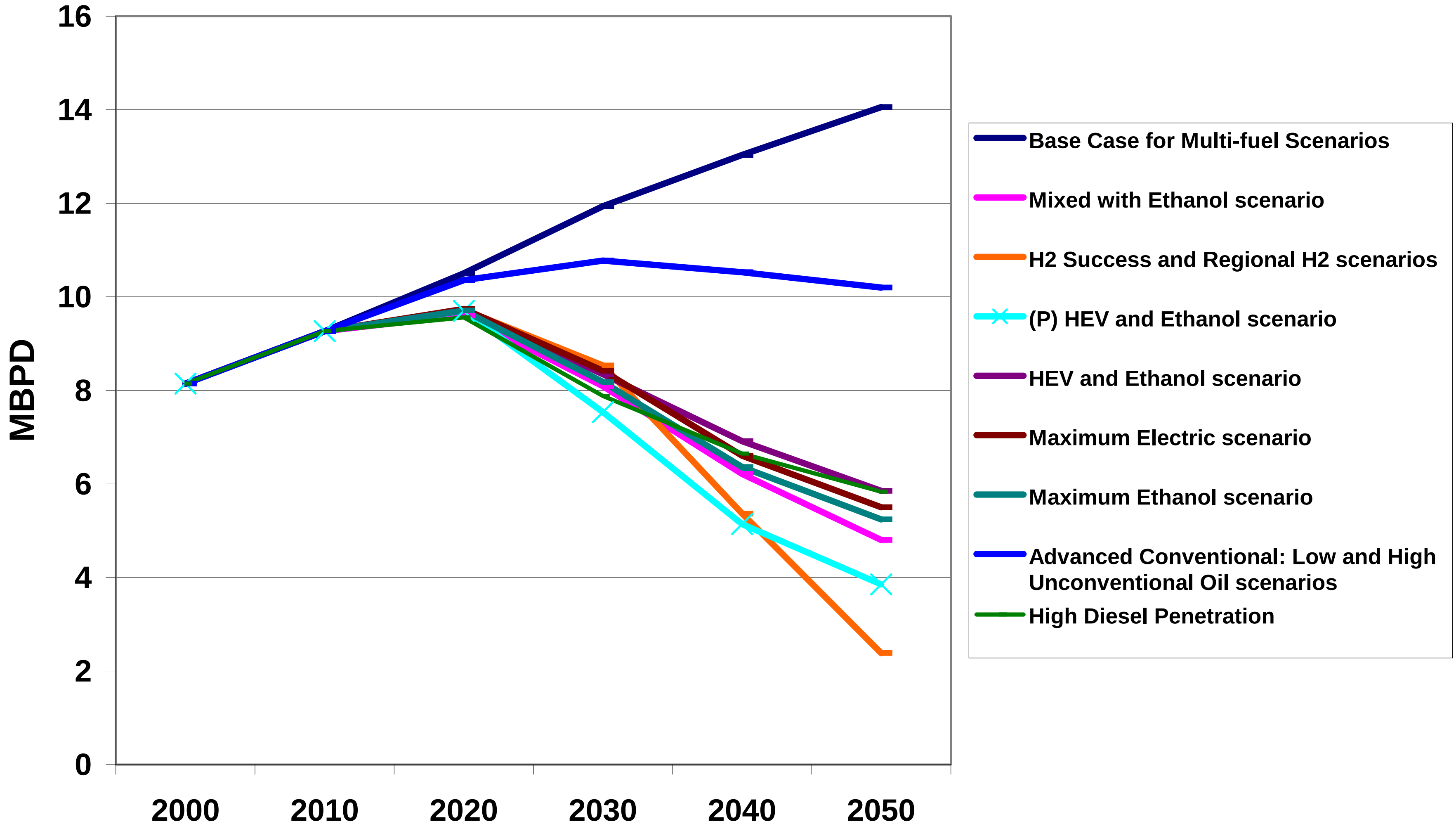
Scenario	2050 Ethanol Use/Goal (billion gallons)	% of VMT on E-85 by flex-fuel vehicles (all technologies)	% of stock (cars) that is flex-fuel
Base	13.5	3.5	5
Mixed	30	34	63
(P)HEV & Ethanol	60	51	98
HEV & Ethanol	60	36	96
Max Ethanol	75	47	96

Scenario Results: Oil and GHG Saved

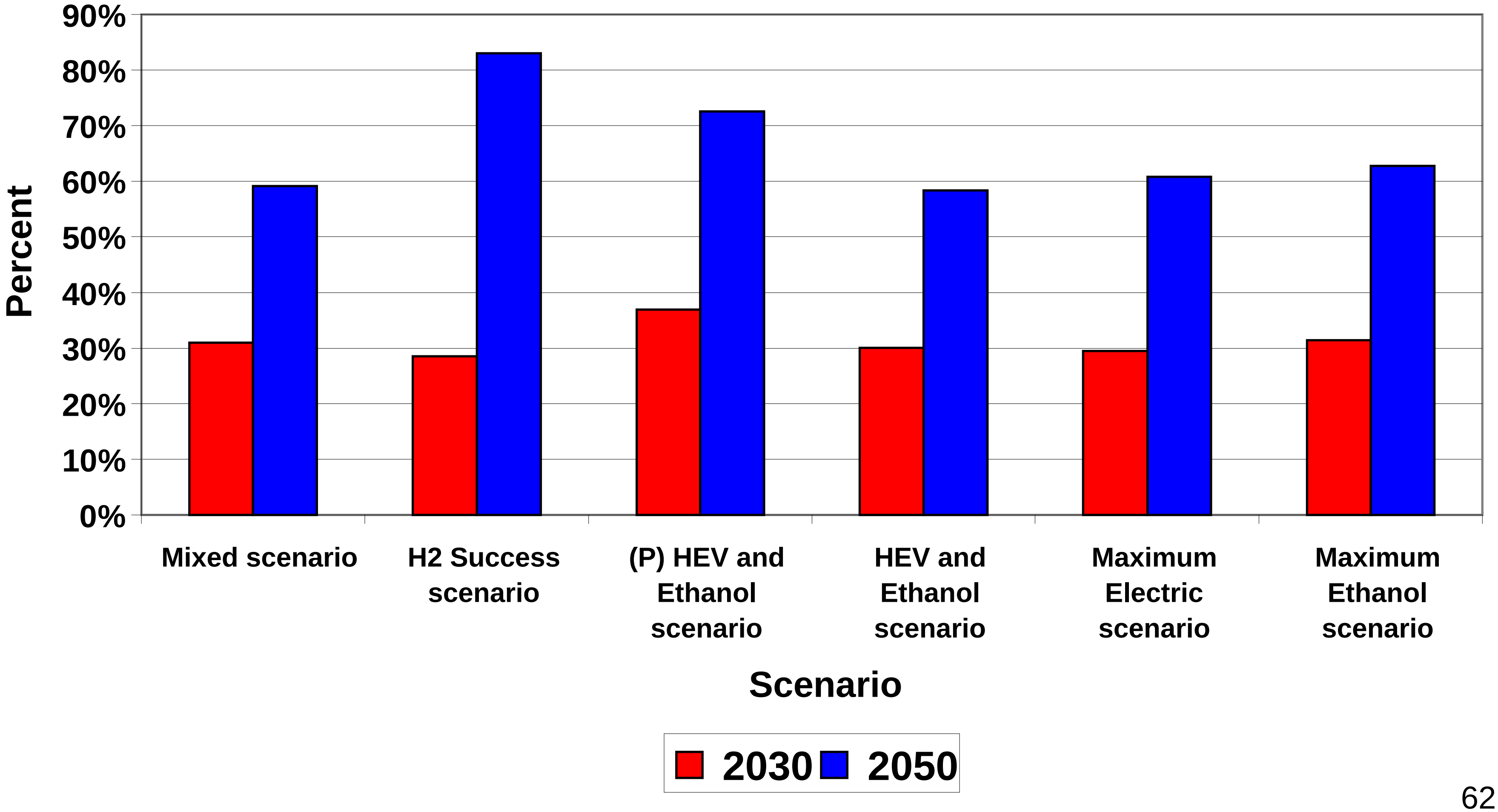
[mbpd (% of base); mmtce (%)]

Scenario	2030	2050
1. Mixed	3.8 (32.3%); 166 (26%)	9.3 (65.9%); 395 (53%)
2. H2 Success/9. Regional H2	3.4 (28.5%); 150 (24%)/152 (24%)	11.7 (83.1%); 521 (70%)/523 (70%)
3. (P)HEV & Ethanol	4.4 (36.9%); 201 (32%)	10.2 (72.6%); 475 (63%)
4. HEV & Ethanol	3.6 (30.1%); 168 (26%)	8.2 (58.4%); 394 (53%)
5. Max Electric	3.5 (29.5%); 145 (23%)	8.6 (60.9%); 367 (49%)
6. Max Ethanol	3.8 (31.5%); 175 (27%)	8.8 (62.7%); 421 (56%)
7. ACV: Low Unconventional Oil	1.2 (9.8%); 29 (5%)	3.9 (27.5%); 120 (16%)
8. ACV: High Unconventional Oil	1.2 (9.8%); 26 (4%)	3.9 (27.5%); 94 (13%)
10. High Diesel with Biomass	4.1 (34.0%); 179 (28%)	8.2 (58.5%); 381 (51%)

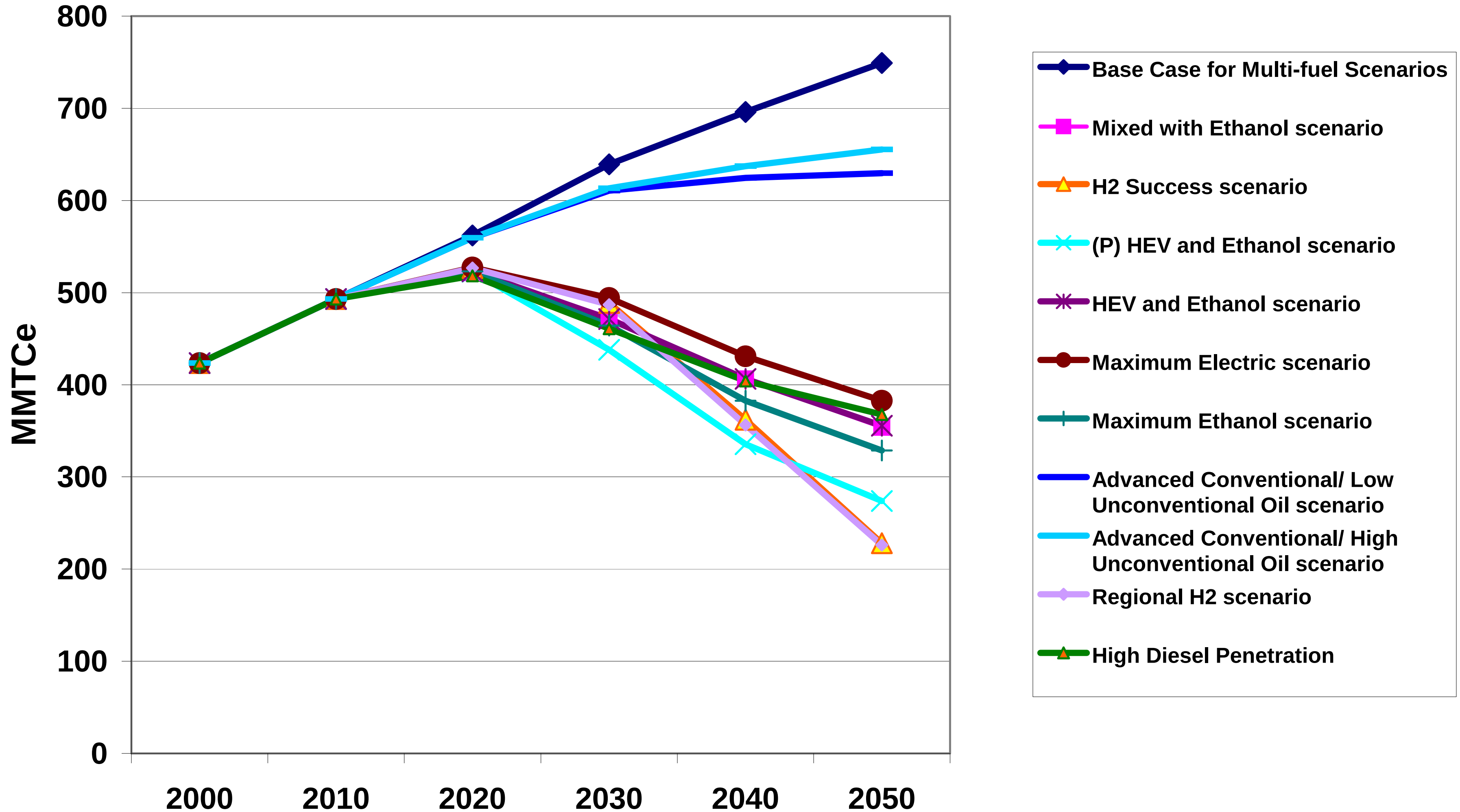
Oil Use in Ten Scenarios



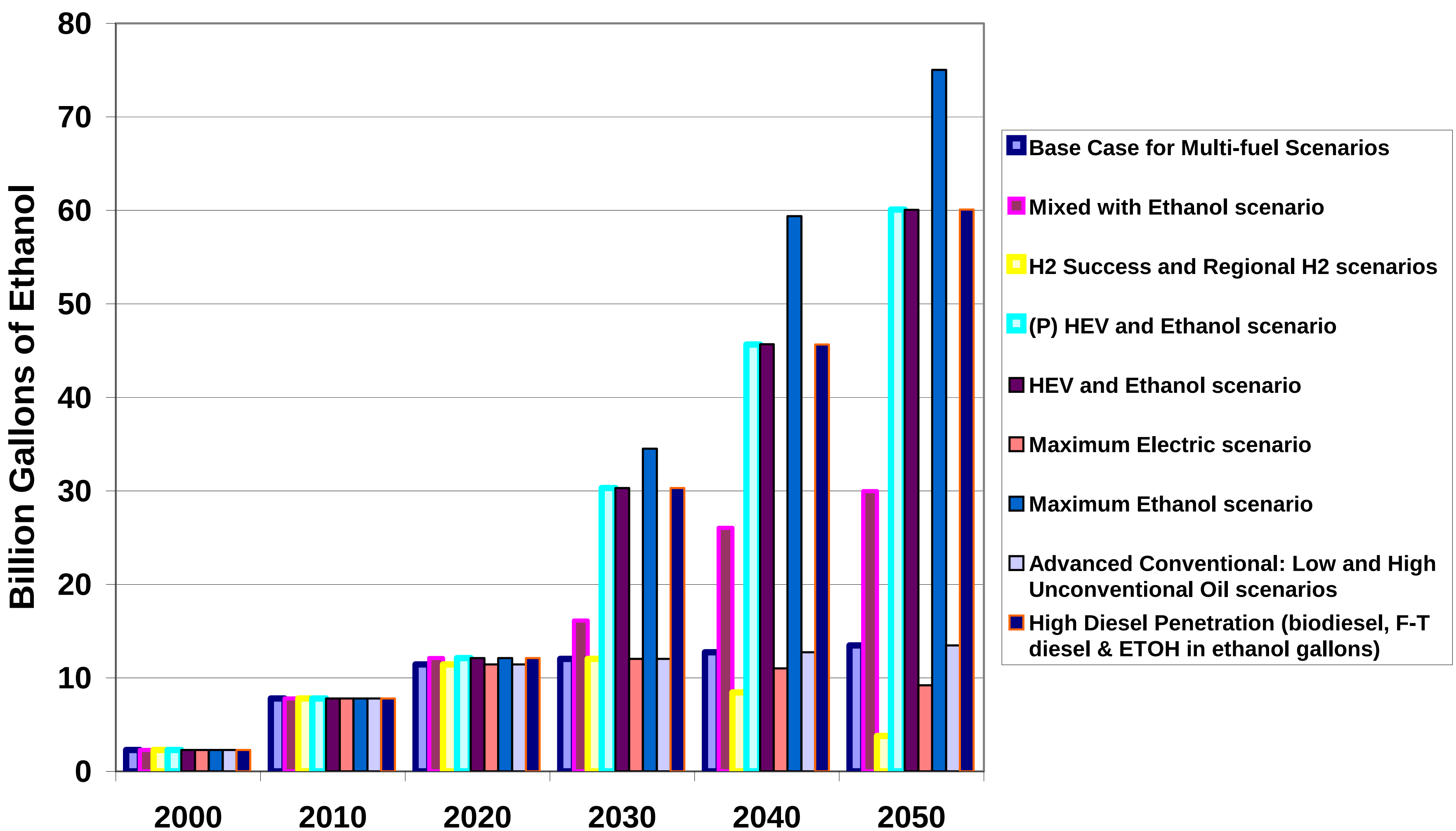
Selected Scenarios: Percent of Light Vehicle Oil Use That Is Saved



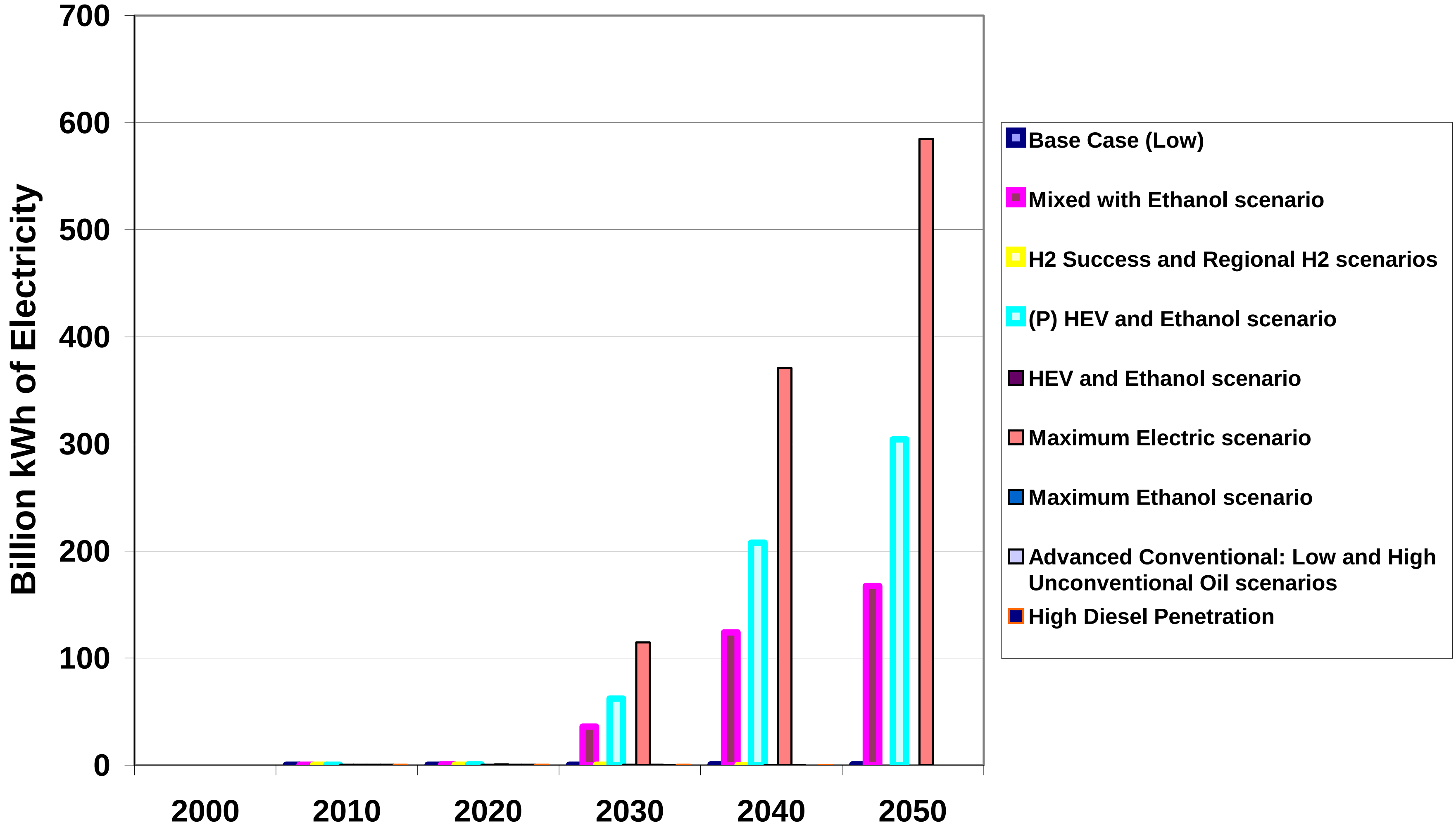
Annual GHG Emissions for the Ten Scenarios

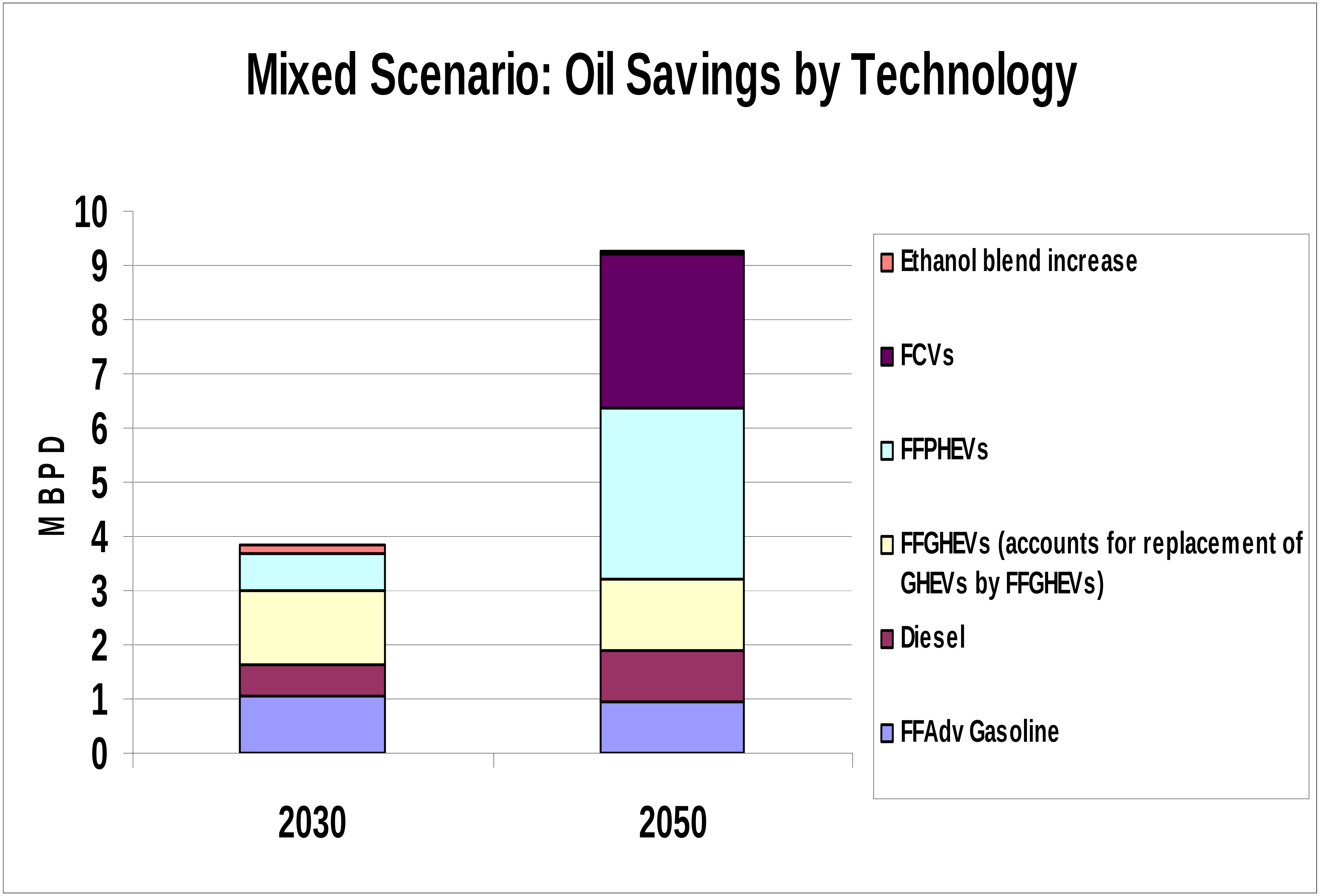


Ten Scenarios: Ethanol Use

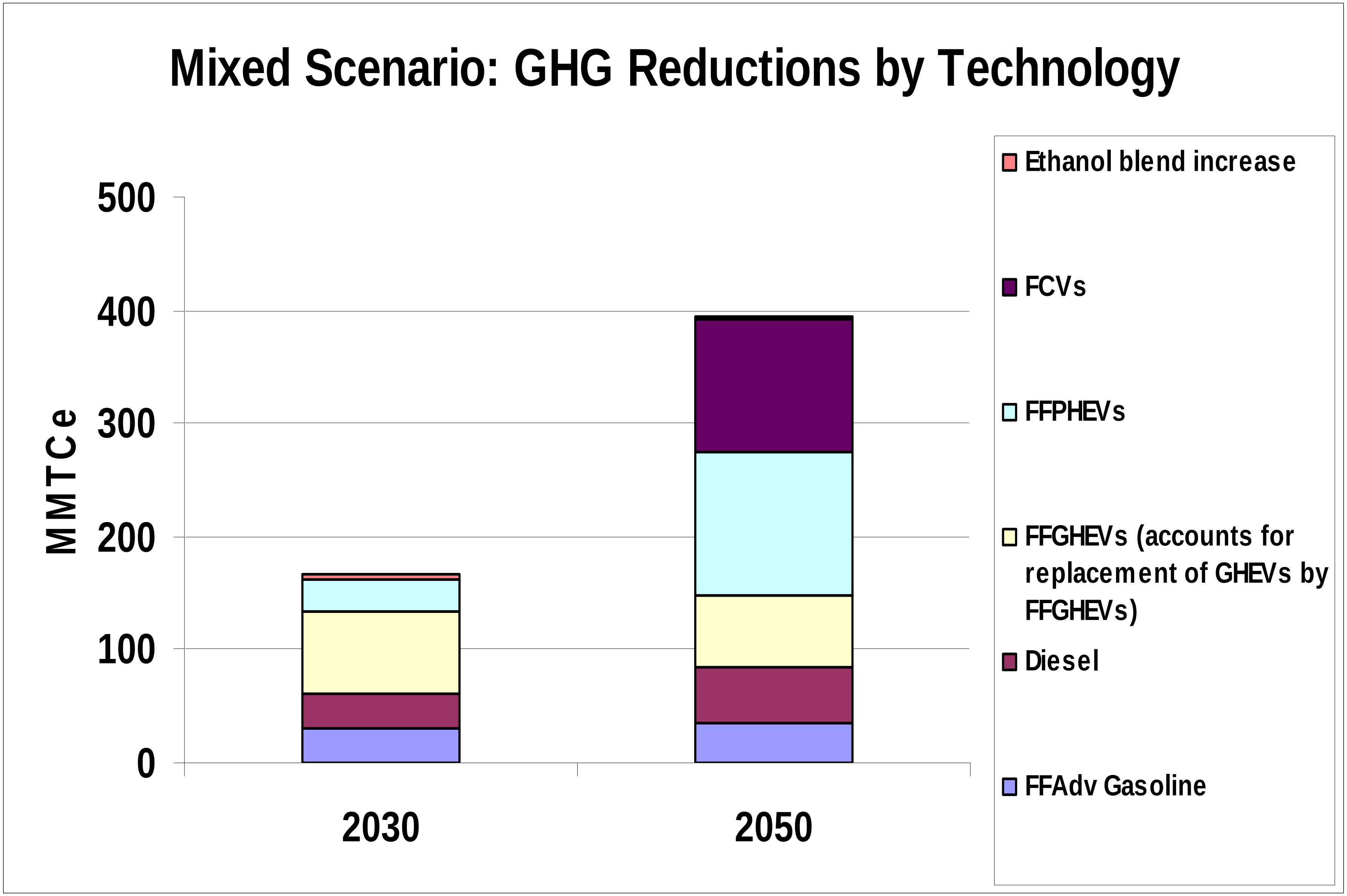


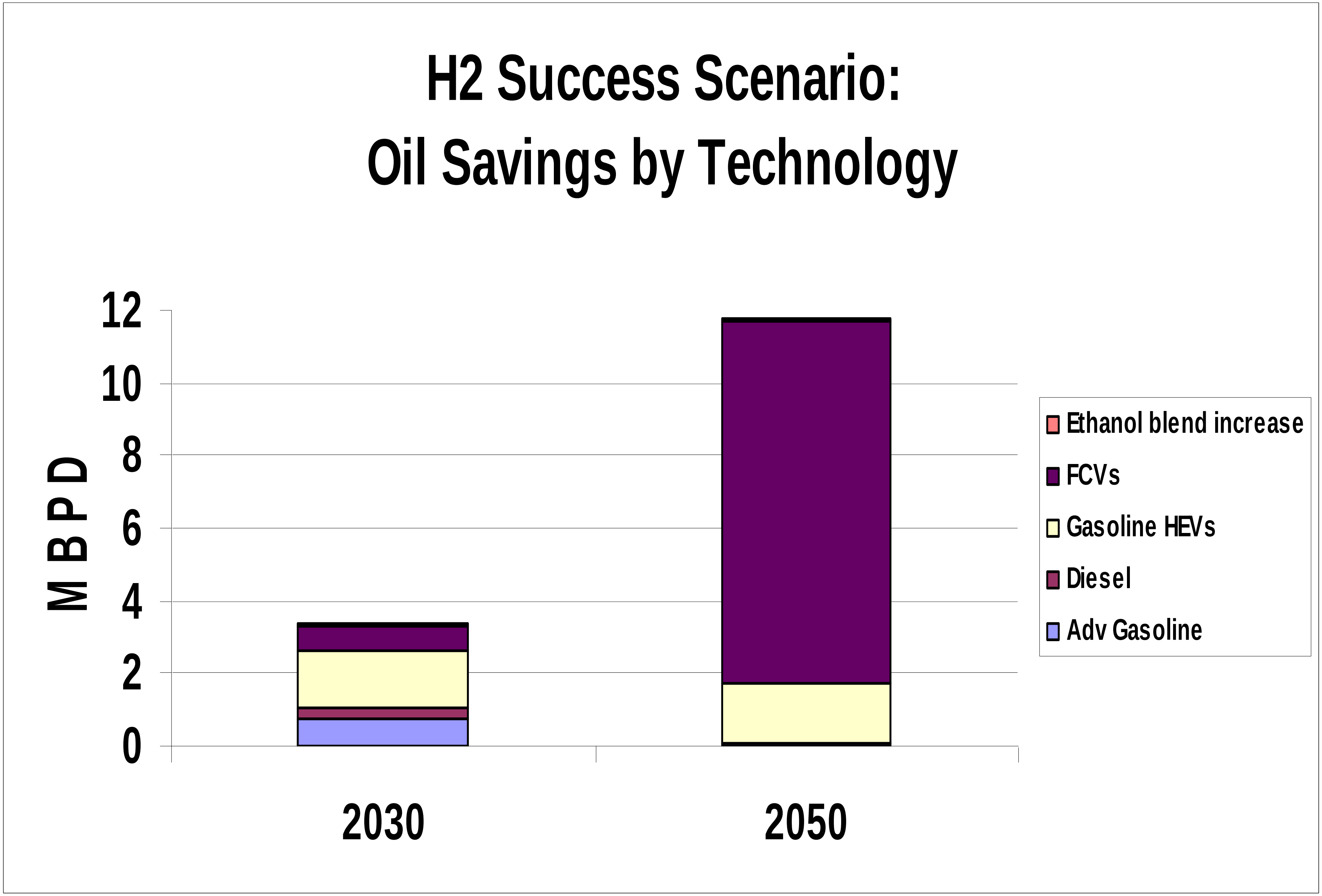
Ten Scenarios: Electricity Use



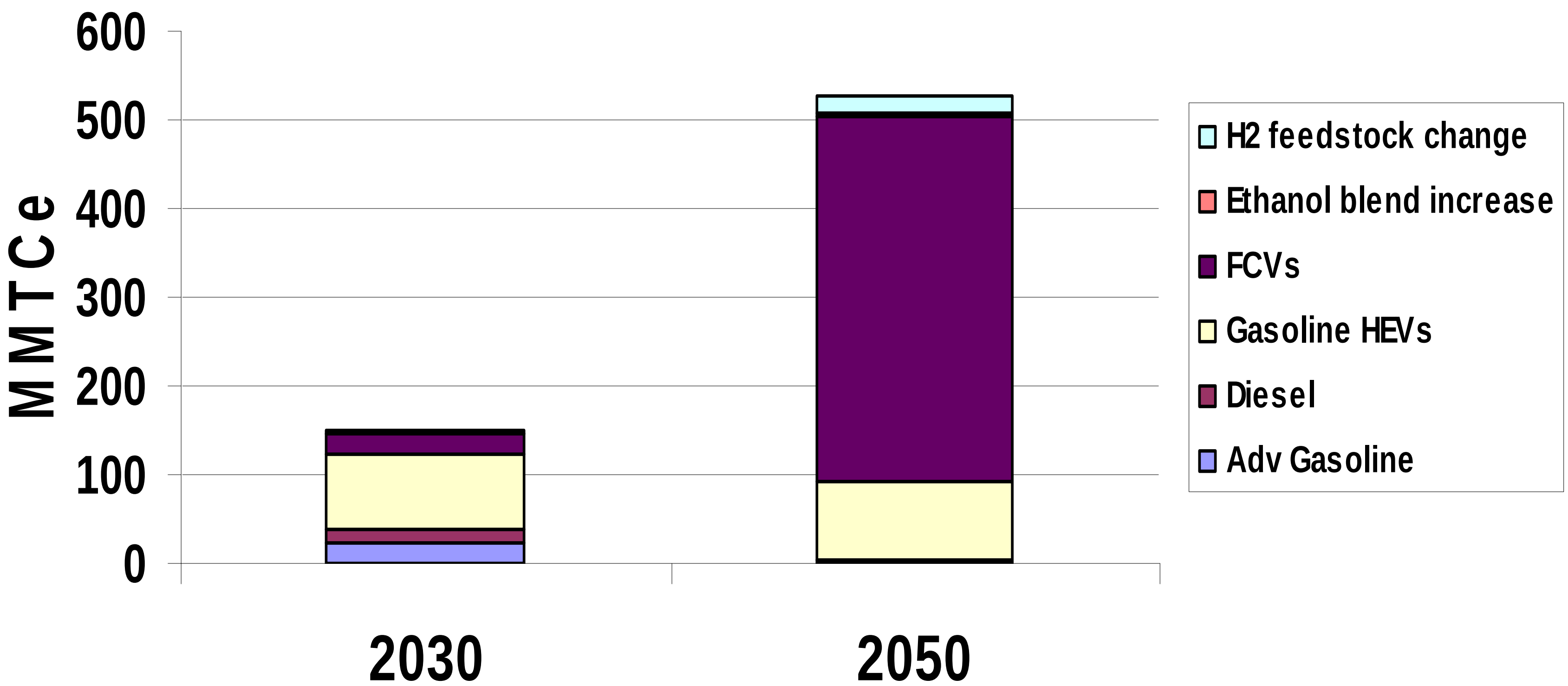


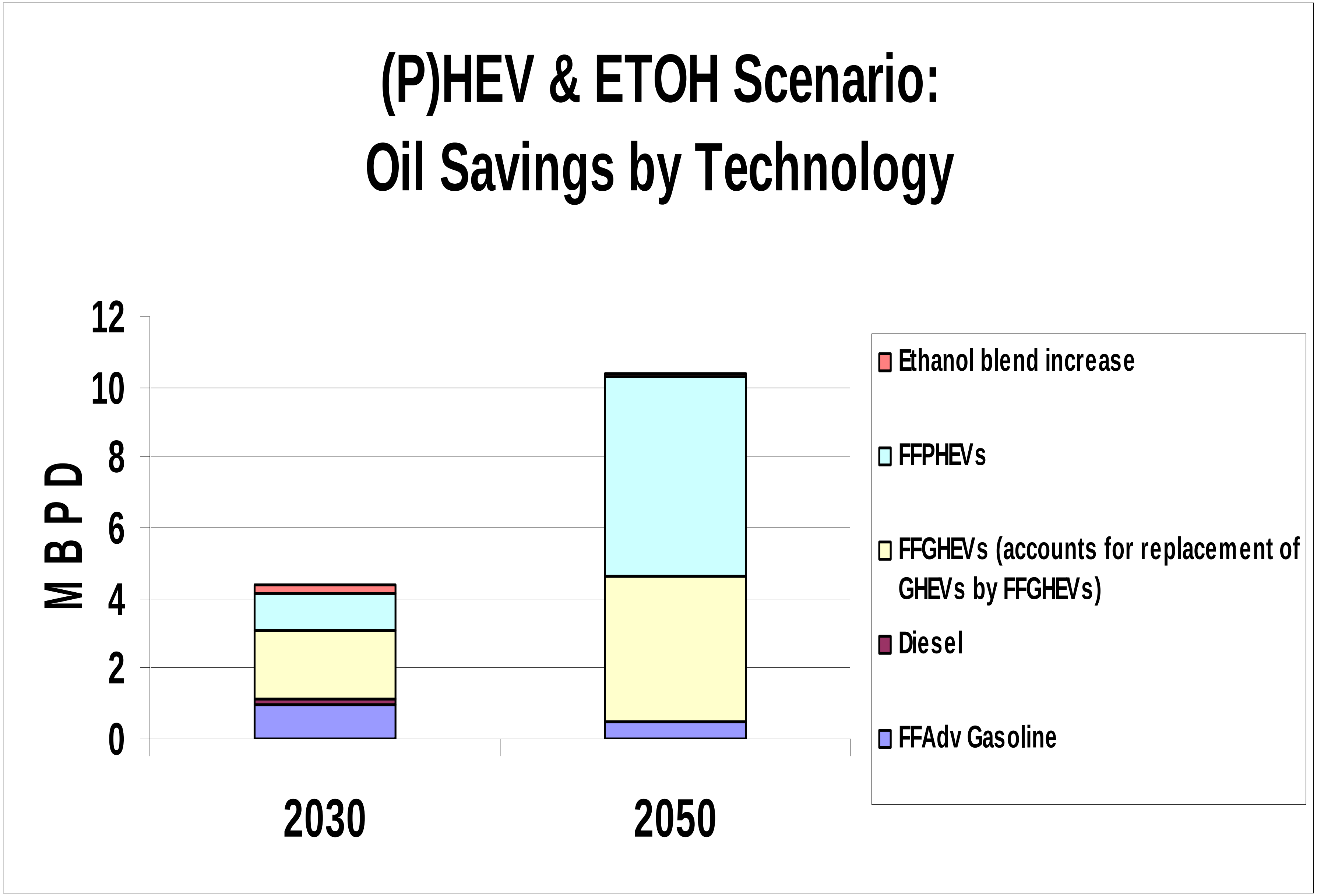
Mixed Scenario: Oil Savings by Technology
10
9
8
7
6
5
4
3
2
1
0
MBPD
2030
2050
Ethanol blend increase
FCVs
FFPHEVs
FFGHEVs (accounts for replacement of GHEVs by FFGHEVs)
Diesel
FFAdv Gasoline


Mixed Scenario: GHG Reductions by Technology
MMTCe
500
400
300
200
100
0
2030
2050
Ethanol blend increase
FCVs
FFPHEVs
FFGHEVs (accounts for replacement of GHEVs by FFGHEVs)
Diesel
FFAdv Gasoline

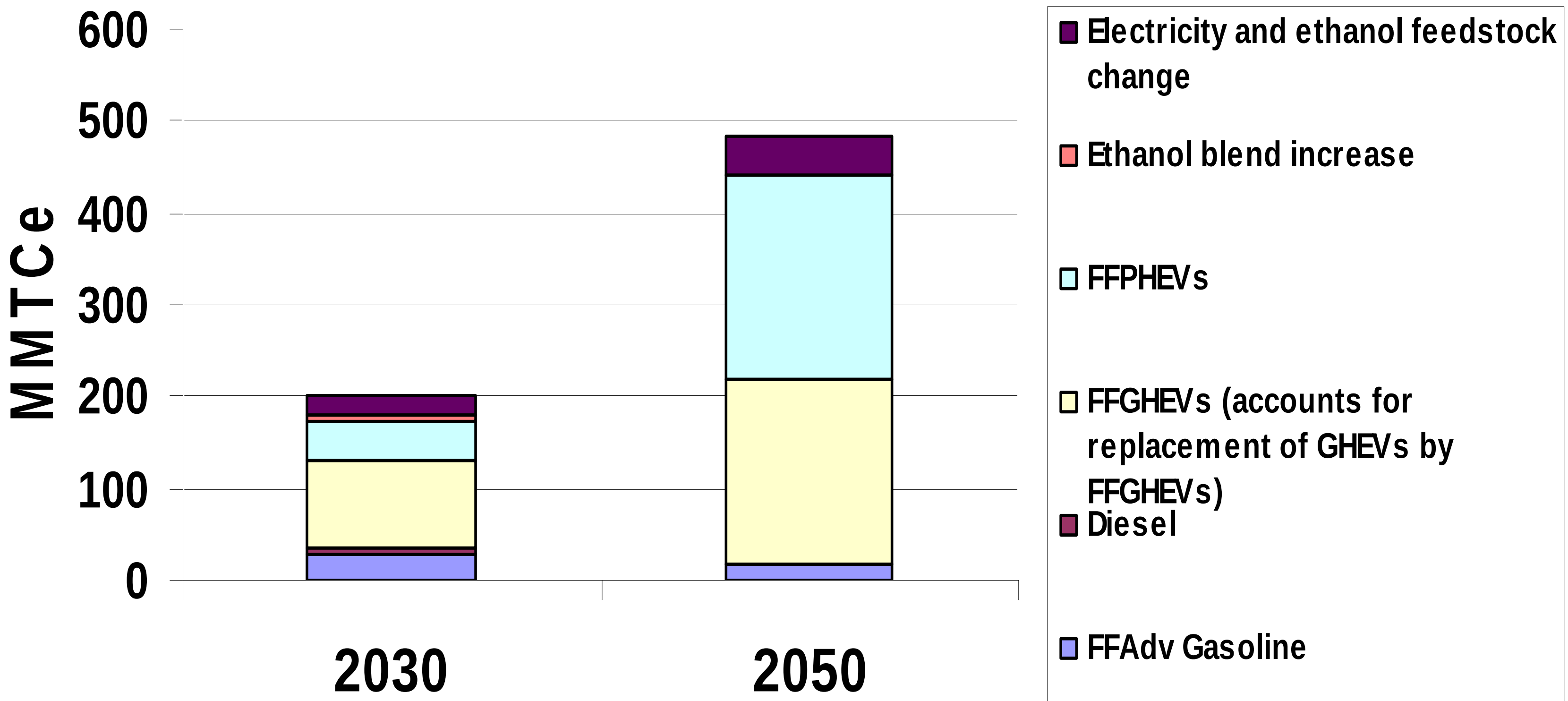

H2 Success Scenario:
Oil Savings by Technology
M B P D
12
10
8
6
4
2
0
2030
2050
Ethanol blend increase
FCVs
Gasoline HEVs
Diesel
Adv Gasoline

H2 Success Scenario: GHG Reductions by Technology




(P)HEV & ETOH Scenario:
Oil Savings by Technology
M B P D
12
10
8
6
4
2
0
2030
2050
Ethanol blend increase
FFPHEVs
FFGHEVs (accounts for replacement of GHEVs by FFGHEVs)
Diesel
FFAdv Gasoline

(P)HEV & ETOH Scenario: GHG Reductions by Technology



Fuel economy analysis

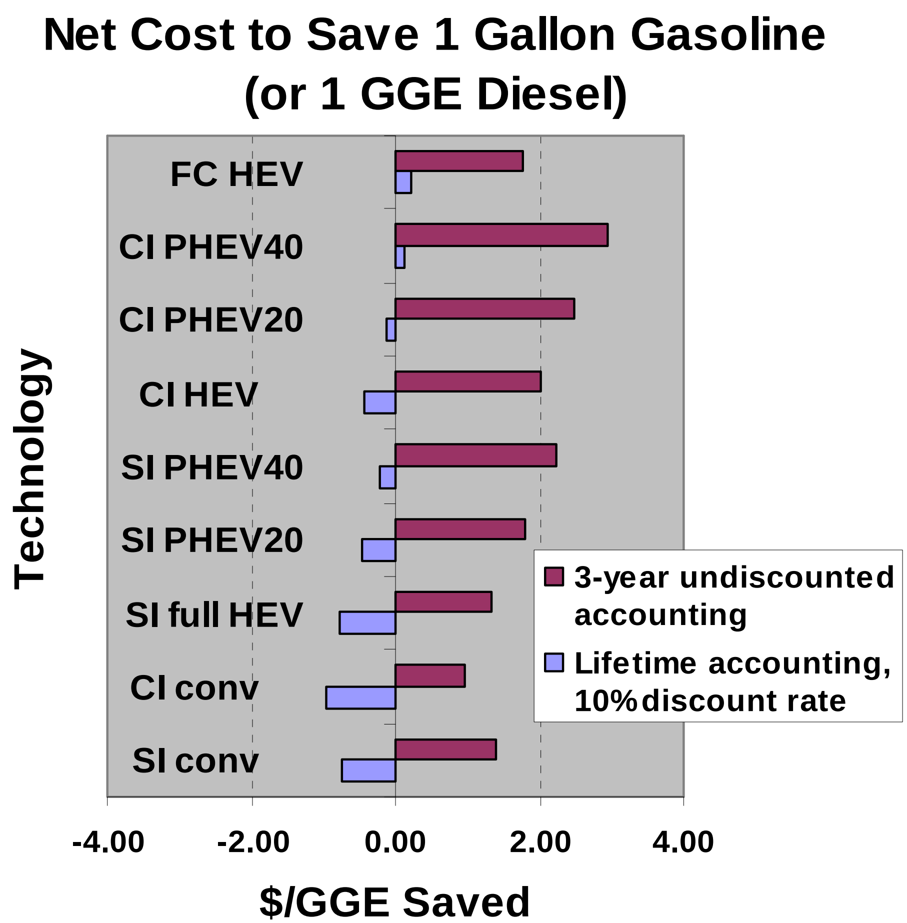
- Two vehicle categories – midsize car, midsize SUV
- Same "glider" for all drivetrain types within each category – lightweight structure, advanced aerodynamics and tires; 2030 examples:
  - Weight reduction of 30%
  - Aerodynamics 0.22 C_D
  - Tire rolling resistance 0.006
- Vehicles have the same minimum performance (0-60 mph acceleration time, grade climbing ability), though some exceed this
- Analyzed with Powertrain Systems Analysis Toolkit (PSAT) model

Cost to Save a Gallon of Gasoline for New Cars in 2030:

Using a 2030 leading edge midsize car, with 3-year and lifetime (15 years and 165,000 miles) accounting , saving gasoline is a net gain with lifetime accounting and a net loss with 3-year accounting.

Assumptions:

- **$2.80/gallon gasoline**
- **$4.75/kg hydrogen**
- **$.067/kWh electricity**
- **Vehicle costs based on MIT On the Road in 2020 (2000)**
- **Vehicle Fuel Economy from Multi-Path PSAT runs**



Other Metrics

- The metrics of infrastructure issues, criteria pollutants, and risk are very tough to quantify and compare to oil savings and GHG reductions.
- The following slides on these three metrics are provided to illustrate the key issues.
- We welcome suggestions on ways to compare these metrics to the oil and GHG metrics.

Infrastructure Issues

- **Ethanol** has few vehicle issues (inexpensive FFVs), but can use only the "distribution terminal to fueling station" part of the petroleum delivery infrastructure; cannot use petroleum pipelines. New production can be used for blending. ***Infrastructure risk: low to moderate***
- **Hydrogen** has minimal existing infrastructure, classic "chicken and egg" problem; at low penetration, distribution by inefficient tube trailers or cryogenic tankers, or hydrogen production at the dispensing station w/natural gas reforming. ***Infrastructure risk: high***
- **Electricity** requires multiple new charging stations but added production can be delayed until high vehicle penetration; with PHEVs, "fuel availability risk" is nonexistent. ***Infrastructure risk: low to moderate***

Infrastructure Requirements: Preliminary Analysis

- Infrastructure requirements vary among the fuel options
- On the next four slides, major subsystems of the ***plant to the point of sale to consumers*** are indicated
- We start by summarizing the transportation and distribution systems for gasoline from petroleum

Principal elements of the Petroleum to Gasoline-Diesel Transportation and Distribution Systems are described in the table below

Stage	Modes	Capacities	Comments
Petroleum Refinery		5,000,000 gal/day	Avg. US Refinery Capacity
Transportation	Pipeline	100-500 Mi	Up to 48 in. diameter
Distribution Terminal	Tank farm	150,000-750,000 gal/day	Representative range
Local Distribution	Trucks	4,000-4,800 gal/unit	Class 8 Tank Truck
Dispensing	Fuel Marketer	2,200-4,400 gal/day	Representative range

Characteristics of the system include:

- Large throughput capacities to support ~20 million BPD consumption
- Highly automated operation
- Significant capital investment

While ethanol cannot be transported in pipelines with gasoline, ethanol can be mixed with gasoline, making it possible to take advantage of the rest of the existing gasoline distribution infrastructure

Stage	Modes	Capacities	Comments
Ethanol Plant		100,000 gal/day	Average of US Plants
Transportation	Rail Truck Barge	30,000 gal 4,000-4,800 gal 450,000 gal	Capacities are ‘per unit’ Batch delivery at this scale
Distribution Terminal	Tank farm	150,000-750,000 gal/day	Blend 85% ETOH with gasoline for delivery
Local Distribution	Truck	4,000-4,800 gal/unit	Class 8 Tank Truck
Dispensing	Fuel Marketer	2,200-4,400 gal/dat	Representative Range

•Ethanol production capacity is growing, but scale of operations is considerably lower than oil refineries

•Options for transportation of ethanol to Distribution Terminal are limited

Hydrogen Transportation Considerations

- Hydrogen can be produced at different capacity levels
- Initial transportation is likely to be by truck, pressurized tube and/or cryogenic
- Some movement by pipeline occurs now and more can be anticipated in the future with market penetration of FCVs

Hydrogen dispensing/fuel marketing infrastructure is much different than petroleum products. Range of capacities in the table below spans *central plant to marketing outlet* and *decentralized fueling station* production

<table>
<tr><th>Stage</th><th>Modes</th><th>Capacities</th><th>Comments</th></tr>
<tr><td>Hydrogen Production Plant</td><td>Gasification</td><td>150,000kg/day</td><td>Via Biomass Gasification ("transitional capacity")</td></tr>
<tr><td>Transportation</td><td rowspan="3">Truck (cryogenic)</td><td rowspan="3">4000kg</td><td rowspan="3">Rail, pipeline options feasible with higher production</td></tr>
<tr><td>Distribution Terminal</td></tr>
<tr><td>Local Distribution</td></tr>
<tr><td>Dispensing</td><td>Fuel Marketer</td><td>120-2400 vehicle/day</td><td>20-70kg/hr (Varies by whether fueling station is also Forecourt Production Plant)</td></tr>
</table>

•The characteristics of hydrogen result in its distribution requirements having the greatest difference compared to gasoline

•Total infrastructure costs are also expected to be the highest of the options considered

• A kg of hydrogen is about equal the energy in a gallon of gasoline.

Electricity infrastructure requirements to support automotive transportation needs are distinct compared to other liquid and gaseous fuel options

•Generation and Transmission—transportation market represents a new market. Load duration and ‘customer demand’ times need to be understood and addressed in future planning

•Local distribution—greater access to power sources for recharging will be required. Locations are places where power demands have historically been minimal: e.g., commercial parking structures, home garages, on-street parking

•PHEV20, PHEV40, and EV charging requirements (energy demand and duration) differ

Criteria emissions results for vehicle technologies
(full fuel cycle)

Initial analysis uses GREET default assumptions for 2015; we need lots of sensitivity analysis, conclusions are useful ***only*** *for raising issues*

- EVs: urban emissions substantially down except for SOx, total PM2.5 and SOx up
- FCV: PM2.5 and SOx up for both total and urban (urban PM2.5 result raises questions), large reductions for other emissions
- SI HEV on gasoline and E85: all emissions down moderately, SOx significantly with E85

A preliminary analysis of criteria emissions effects was initiated

- GREET 1.7 was used to compare six technologies to ICE Conventional Gasoline Vehicle:
  - Electric (option for PHEV not found)
  - Fuel Cell, Gaseous Hydrogen
  - Grid-independent (GI) SI HEV, E85 (Biomass)
  - GI SI HEV, Conventional Gasoline
  - CIDI Conventional Diesel
  - SI, Advanced Gasoline
- Initial results mostly using GREET default assumptions (which are not the same as the Multi-Path study assumptions)
  - Results are presented in order of smallest to largest vehicle operating energy requirement
  - Total Energy results rank differently

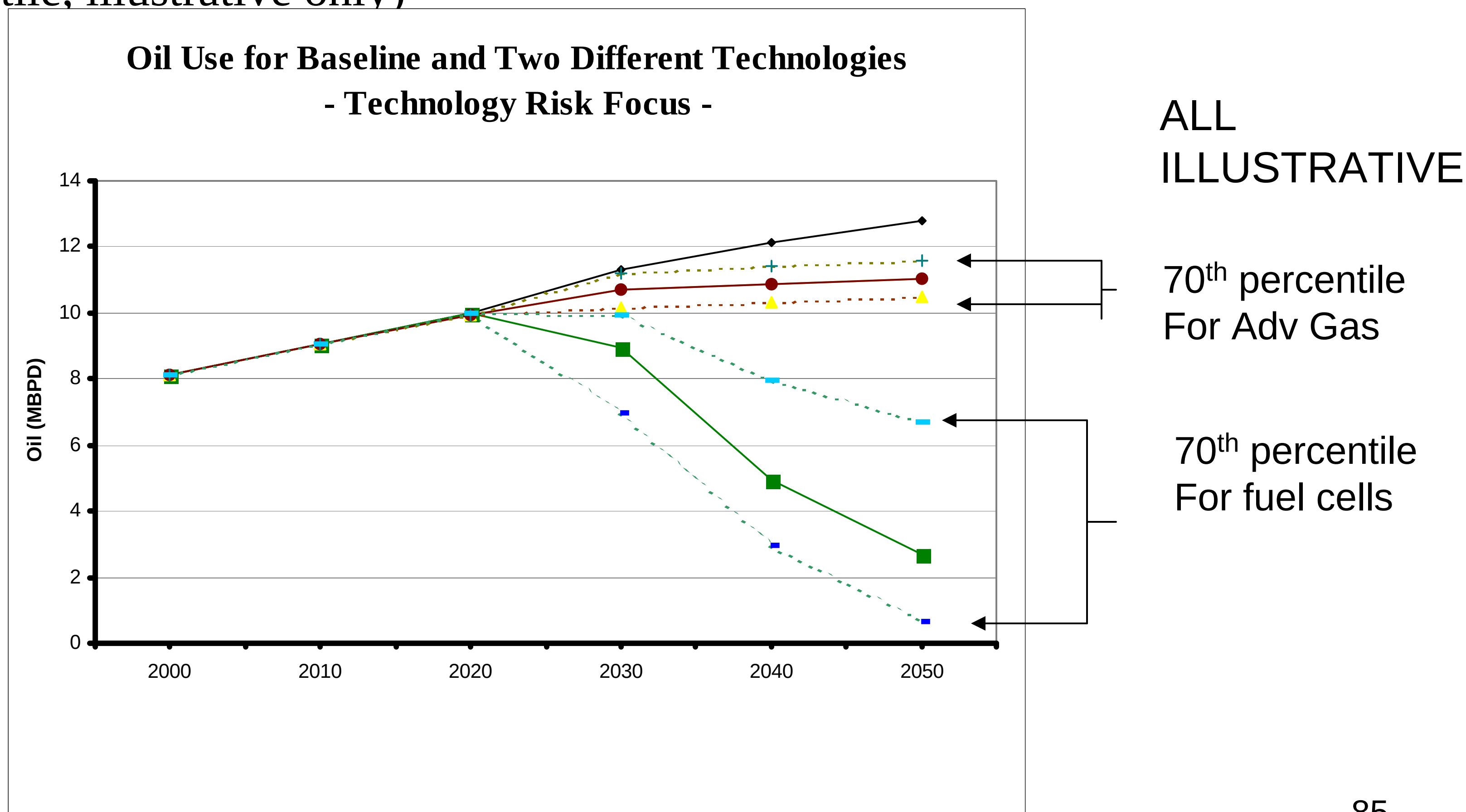
Risk: Technical and market risk are important to consider when estimating potential oil savings and GHG reductions

- Simple risk analysis takes place already (because we deal with alternative fuel prices, technology costs, and efficiency improvements)
  - For each of the scenarios considered
  - And for High and Low cases for particular scenarios

    These represent different "worlds" where the oil and GHG savings are different – likelihood and plausibility are another matter
- At this point simple ideas are shown to see how and why technical risk and uncertainty matter
- Most of the risk analysis will take place in Phase 2
  - In part this is because Risk is being considered as part of a broader ESE-wide initiative – and will be folded into this study where appropriate and vice-versa
  - In addition the "likelihood" or plausibility of particular fuel-vehicle scenarios needs further consideration of competition issues
  - This work should also tie to analysis being done by other Programs e.g. Biomass, Hydrogen, Vehicles and so on

The potential for different technologies to save oil varies substantially

- However, while the benefits of FCVs are higher than those of advanced CVs, the range of uncertainty is greater for hydrogen as is shown below (70% percentile, illustrative only)



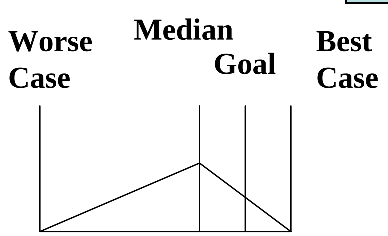
Note: Not shown but could is 95% case in which case low improvement for FC could be baseline

In the longer term understanding risk is important in interpreting results of the Multi-Path Study

- The risk framework needs to operate at a number of levels e.g.,
  - **Risk of Scenarios:**
    - **Technological risk** for different technologies (both vehicles and fuels)
    - **Market risk** of technologies being competitive if they meet their technological goals I.e. under what circumstances is a scenario viable
    - **Other Risks**
  - **Goal risk:** Risk related to the likelihood – and uncertainty - of *at least* meeting particular oil savings or emissions goals
  - **Risk diversification:** Benefits of pursuing multiple ways of achieving the same goal and how it increases the likelihood that that goal will be achieved for a given scenario, and for an uncertain world more generally (e.g. multiple scenarios)
- Many of these types of risk are interrelated and refining them and understanding their relationships may be an important part of the next Phase

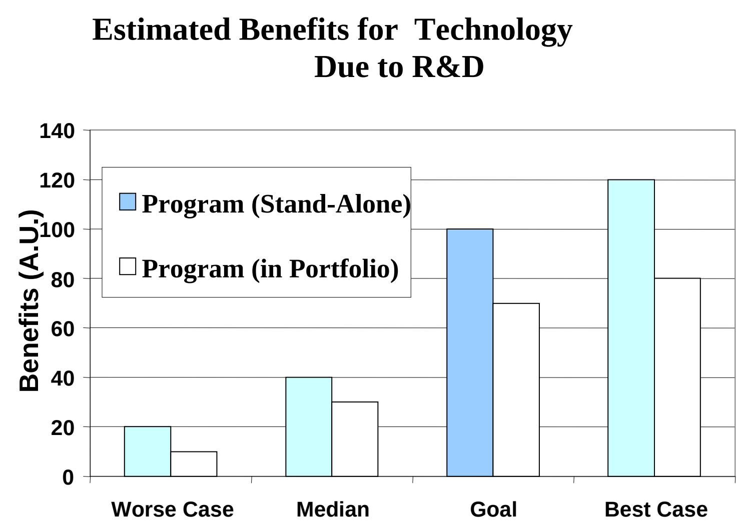
The technical risk distribution allows benefits to be compared on a comparable risk basis - and a sense of uncertainty of benefits to be developed.

R&D
Output Distribution
(e.g. mpg)



NEMS or MARKAL (later Stochastic Model)

Energy System Output
(e.g. oil saved)

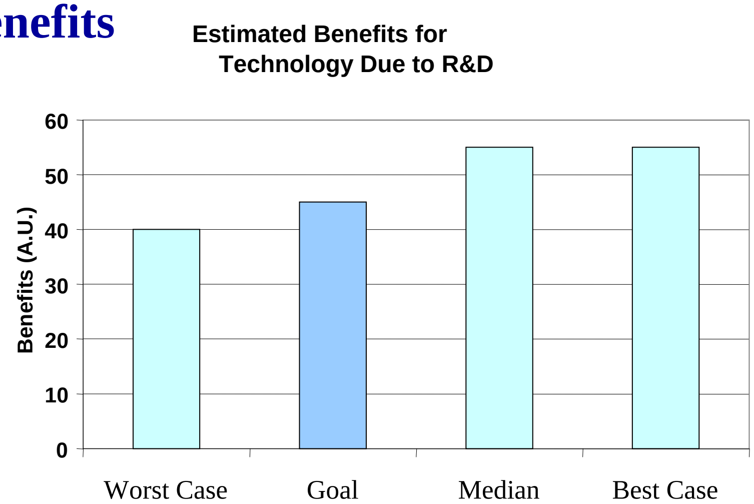


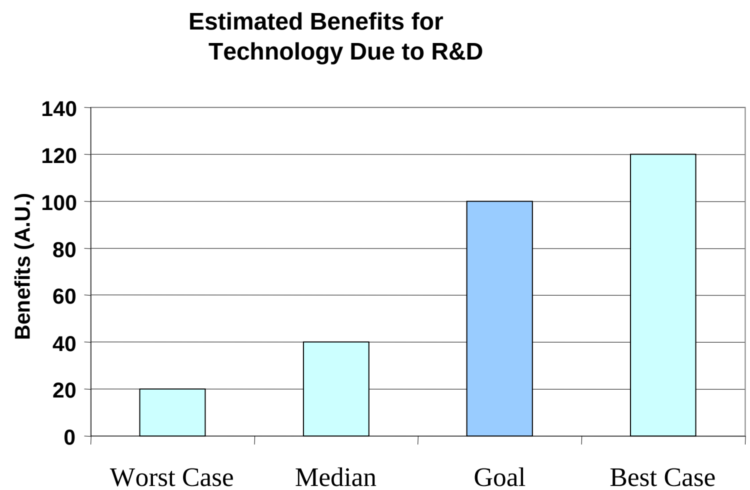
← Risk & Uncertainty →

This approach allows for fair comparison and allows management to see impact of uncertainty, i.e. does it matter?

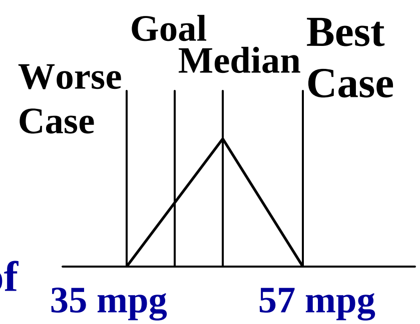
(Technology A in 2020) **(Technology B in 2020)**

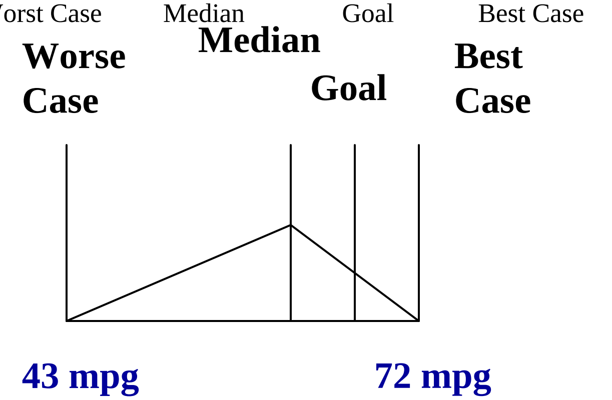
Benefits





Technical Risk (uncertainty of R&D output in a given year)





Next Steps

- Phase 1 is final
  - Have received many comments
  - Some, not all, have been addressed in this document
  - Remainder will be addressed in Phase 2

Phase 2 will substantially expand the analysis:

- Full range of pathways, multiple scenarios
- Improve pathway characterization
- Examine interactive effects of multiple pathways, and interactions with the rest of the economy
- Improve vehicle fuel economy estimates
- Far more focus on costs
- More metrics for scenario analysis
- Oil security impacts

Pathway characterization will be expanded

- Phase 1 relies on DOE Program Documents (e.g., goals/targets) and GREET
- Phase 2 will broaden the sources for key assumptions – identify key uncertainties, provide ranges where appropriate, explain differences among sources
- Feedstock assumptions – develop analytical basis
- Cost analysis will be based on identified references and disaggregated component costs rather than generalized DOE targets
- Scenario characterizations will be more fully fleshed out

Fuel economy analysis will be revised and expanded

- Phase 1 analysis was robust but limited
- Phase 2 will focus on key improvements:
  - Revisited assumptions
  - Electric Vehicles require revised analysis with multi-speed transmission, new battery characterization
  - Examination of on-road fuel economy performance (Phase 1 used only EPA city and highway cycles)

Phase 2 will examine interactive effects

- Pathway and scenario outcomes will affect oil prices, feedstock availability, and other factors – that will in turn have interactive effects with the pathways/scenarios
- Phase 2 will examine these effects based on available integrated energy models and analyses of such effects
- Extent of model use will depend on examination of need, model characteristics, etc. – first task is to define a methodology

New scenarios, possibly some new pathways will be examined in detail

- Phase 1 fully examines 3 scenarios; Phase 2 will examine several more
- Some new pathways may be added, e.g. Fischer-Tropsch conversion of biomass or coal to liquid fuels or hydrogen

New criteria for scenario analysis will be added; examples include:

- Change in type of fuel imported and geographic location of source
- Potential for large stranded capital assets
- Potential competition for feedstocks
- Potential to open worldwide markets for U.S. companies

Phase 2 Tasks and Effort

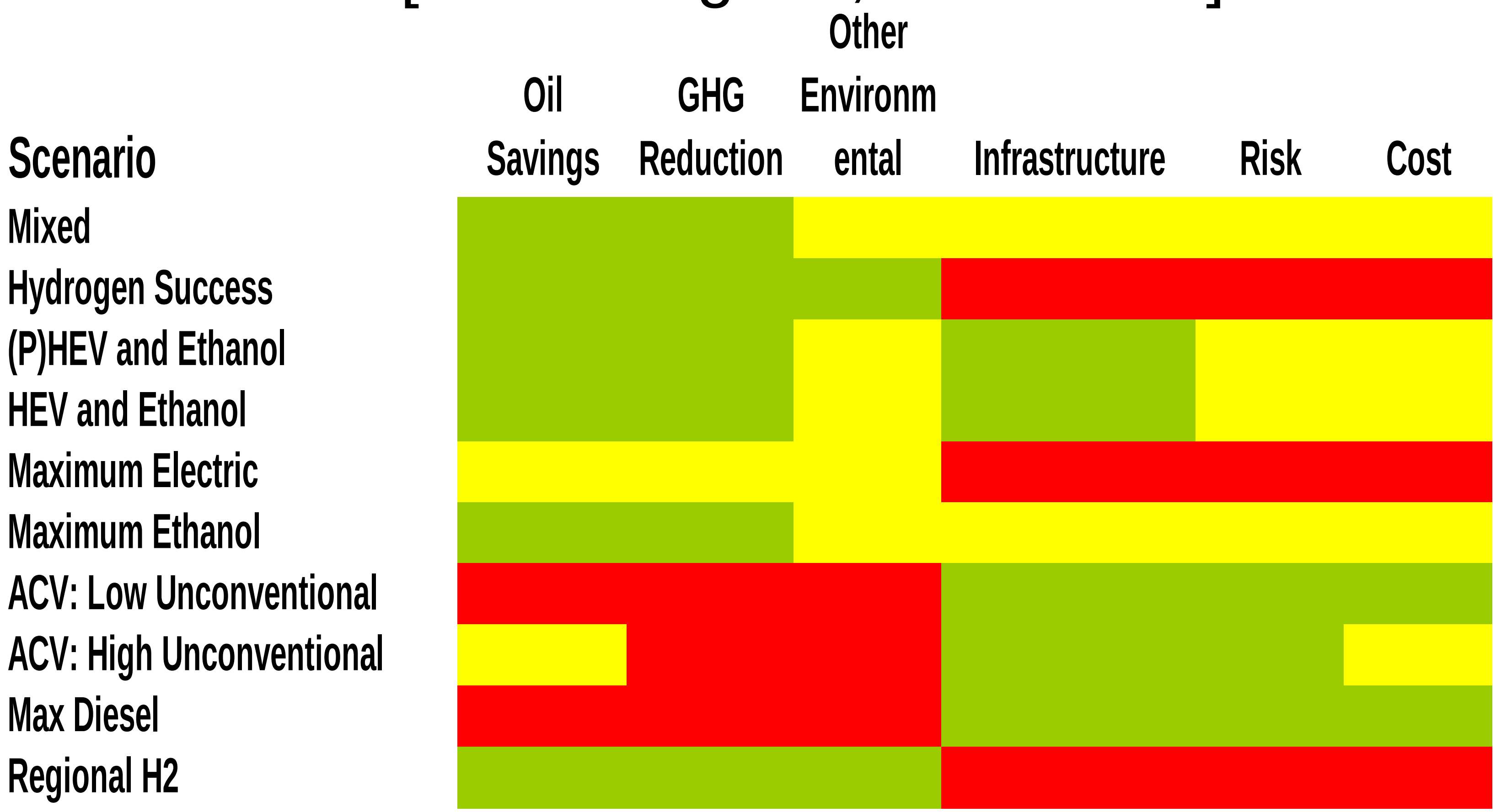
- Pathway characterization – literature review, interviews with experts
  - Physical characteristics
  - Costs
- Fuel economy analysis – PSAT runs and analysis, including revisiting glider and drivetrain assumptions
- Integrated analysis – including use of selected models (possibilities include NEMS, MARKAL, SEDS), evaluation of model results, application to scenarios
- Adding new pathways, with characterization
- Developing new scenarios
- Developing methodology for scenario evaluation criteria:
  - Environmental impacts
  - Risk analysis of pathways, scenarios
  - Competing uses for feedstocks
  - Various market factors Potential for fuel use in existing vehicles
  - Potential for large stranded assets
  - Vehicle multifuel capability
  - Sustainability of pathways

Conclusions

1. There are many technologies that EERE is supporting which can have a significant impact on oil use and GHG emissions.
2. The benefits from combining technologies exceeds the benefits of the individual technologies.
3. The 2030 oil savings by pathways range from 0.4 to 3 mbpd
4. Many of the pathways could have oil savings in the range of 4 to 6 mbpd by 2050. The FCV pathway oil savings could be as high as 10 mbpd by 2050.
5. Of the ten scenarios analyzed, (P)HEV Ethanol has the largest 2030 oil and GHG savings (37% and 32%, respectively) and H2 Success and Regional H2 have the largest 2050 oil and GHG savings (83% and 70%, respectively).
6. These results need to be tempered by the costs and risks associated with the technologies. Also, the scenario outcomes depend strongly on assumptions about technology introduction, rates of market penetration, and so forth…which require further parametric analysis to examine the range of plausible assumptions.

A Possible Format for Showing Results

[Green is good, red is bad.]



This Format Includes Numerical Scores

This is an illustrative format where green is best (5 or 4 points), yellow in the middle (3 points) , and red is worst (2 or l points) and where all six criteria have equal weight.

Scenario	Oil Savings	GHG Reduction	Other Environmental	Infrastructure	Risk	Cost	SUM
Mixed	4	4	3	3	3	3	**20**
Hydrogen Success	5	4	4	1	1	1	**16**
(P)HEV and Ethanol	4	5	3	4	3	3	**22**
HEV and Ethanol	4	5	3	4	3	3	**22**
Maximum Electric	3	3	3	2	2	2	**15**
Maximum Ethanol	4	4	3	3	3	3	**20**
ACV: Low Unconventional	2	1	1	5	5	5	**19**
ACV: High Unconventional	3	1	1	5	4	3	**17**
Max Diesel	1	1	1	5	4	5	**17**
Regional H2	4	4	4	1	1	1	**15**

Appendix

Selected Acronyms

ACV	Advanced conventional vehicle
AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
CG	Conventional gasoline
CI	Compression ignition
CIDI	Compression ignition direct injection
DOE	Department of Energy
E85	85% ethanol/15% gasoline
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
ESE	Energy, Science and Environment
EV	Electric vehicle
FCV	Fuel cell vehicle

Selected Acronyms (continued)

FF/FFV/FF HEV	Flexible-fuel/ Flexible-fuel vehicle/ Flexible fuel HEV
G. H2	Gaseous hydrogen
GGE	Gasoline gallon equivalent
GHEV	Gasoline hybrid electric vehicle
GHG	Greenhouse gas
GI	Grid-independent
GPRA08	Fiscal Year 2008 estimates developed under Government Performance and Results Act of 1993
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
H2	Hydrogen
HEV	Hybrid vehicle
LV	Light vehicle (cars and light tricks together)

Selected Acronyms (continued)

MIT	Massachusetts Institute of Technology
MPG	Miles per Gallon
MPGe	Miles per Gallon Equivalent
NETL	National Energy Technology Laboratory
PHEV	Plug-in Hybrid Vehicle
(P)HEV	Denotes a scenario that has HEVs and PHEVs
PHEV20	PHEV with 20 mile battery range
PHEV40	PHEV with 40 mile battery range
PSAT	Powertrain System Analysis Toolkit
RFG	Reformulated gasoline
SI	Spark ignition
VMT	Vehicle miles of travel
WTW	Well-to-wheels

Review panel members and outside experts have been identified who can contribute to study

Review panel will:

- **Provide *both* technical reviews *and* assistance** in gathering information on specific technologies and fuels
- Play a significant role in the development of the analysis **plan for Phase 2**

Review Panel:

- Phil Patterson, PAE
- Jeff Dowd, PAE
- Tien Nguyen, PAE
- Fred Joseck, HFCIT Program
- Lee Slezak, FCVT Program
- Zia Haq, Biomass Program
- Thomas Jenkin, NREL, PAE Center
- David Shen, TMS, PAE Center

Secondary DOE/Lab Review Team (Baldwin, Greene, Gronich, Hassell, Benioff, Sheehan, Santini, Key, McLarty, Leifman, and Beschen)

Outside Experts Team: people who can provide information for use in this study and may wish to provide reviews of various aspects of the study. Over 30 people are on this team.

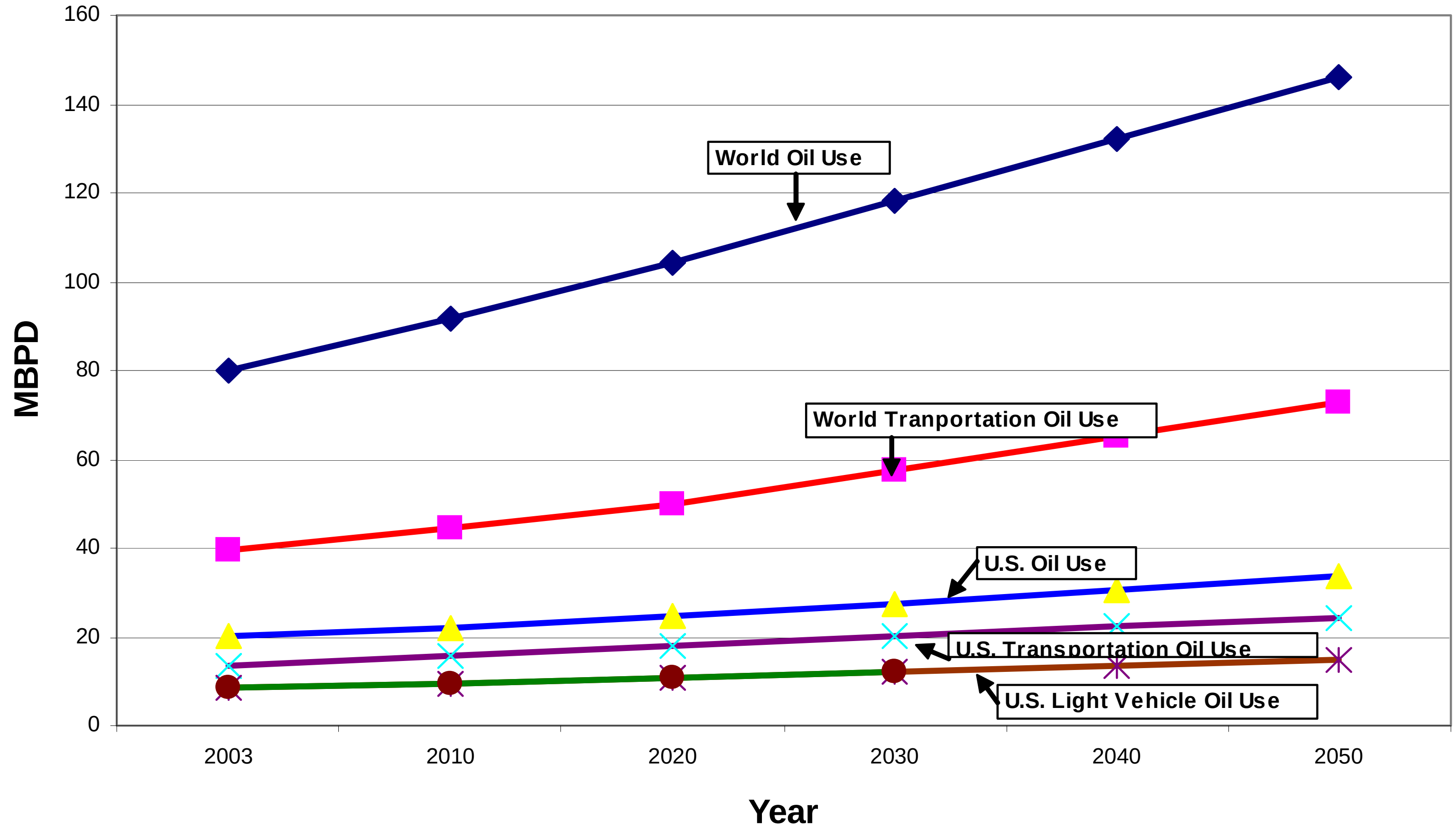
Multi-Path Outside Experts Team

**Jeff Alson, EPA; David Andress, DAA; Bill Babiuch, TMS;
Michael Ball, Transport Canada; Nazeer Bhore, ExxonMobil;
Eldon Boes, Senate Legislative Fellow; Jay Braitsch, FE/DOE;
John Davidson, EPA; Sujit Das, ORNL;
Carmen Difiglio, Policy Office/ DOE; KG Duleep, EEA; Mark Duvall, EPRI;
Anthony Eggert, UC-Davis; Chip Friley, BNL;
Lew Fulton, Dave Goldstein, EVAA; Robert Graham, EPRI;
John Heywood, MIT; Larry Johnson, ANL; Joe Kaufman, ConocoPhillips;
Mike Lawrence, JFA; Paul Leiby, ORNL; John Maples, EIA;
Jim McMahon, LBL; Andrew Nichols, PNNL; Joan Ogden, UC-Davis; Terry Penney, NREL; Rob Pratt, PNNL; Jonathan Rubin, U of Maine;
Art Rypinski, DOT; Keith Sargent, EPA; Walter Short, NREL;
Dan Sperling, UC-Davis; Rogilio Sullivan, FCVT/DOE;
Michael Wang, ANL; Bob Williams, Princeton;
Frances Wood, OnLocation**

The Oil Used in U.S. Light Vehicles Is about 42% of U.S. Total Oil Use Today and in the Future

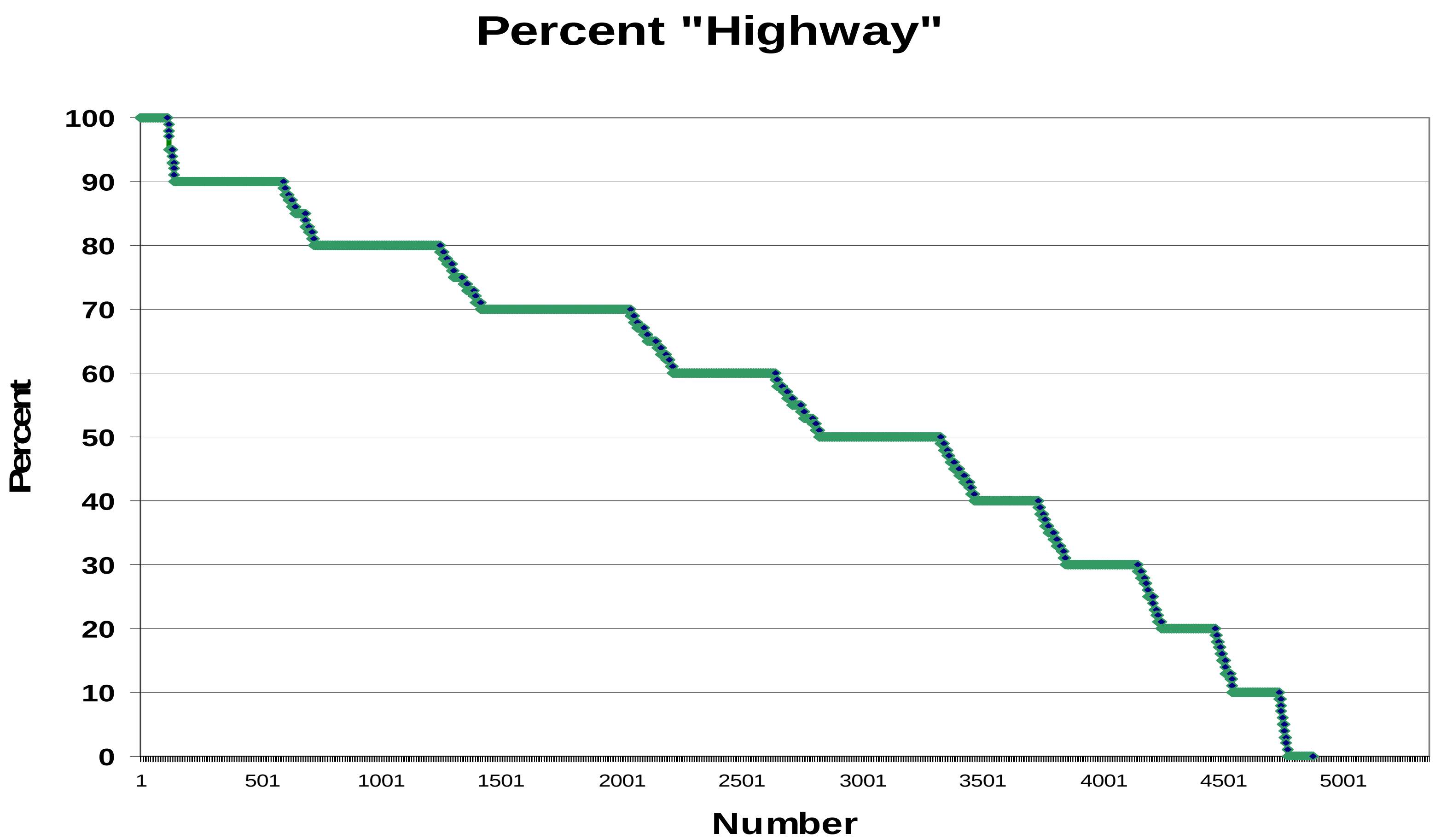
EIA Projected Oil Use in the World and the U.S.

(U.S. Light Vehicle Oil Use as % of World Oil Use Remains at about 10% throughout the Period)



Market Factor for HEVs

Many people have added their MPG data to the “My MPG” data base on the **fueleconomy.gov** website. The graph below shows the number of respondents (x-axis) and the % of highway driving they do. About 25% of the respondents say 80% or more of their driving is “highway” rather than “city”.



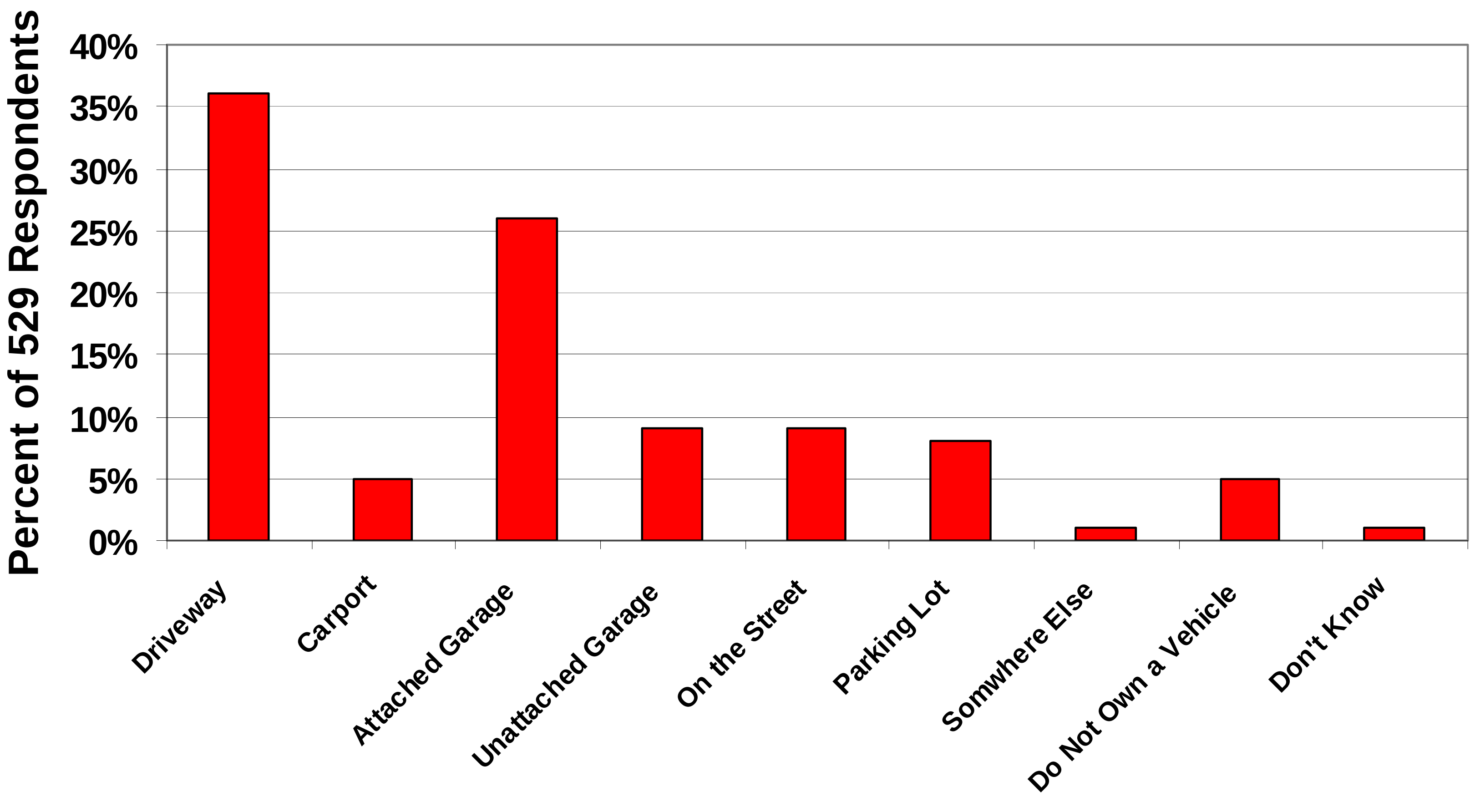
Greatest Potential PHEV Charging Capability for Households

(35% is best, 15% second best, and 1 % third best)

- **59%** single family detached house
  - 29% attached garage (**best** PHEV candidate)
  - 14% detached garage (**second best** PHEV candidate)
  - 3% a carport (**third best** PHEV candidate)
- **10%** single family attached house
  - 6% attached garage (**best** PHEV candidate)
  - 1% detached garage (**second best** PHEV candidate)

Where Is Your Most Used Vehicle Parked Each Night?

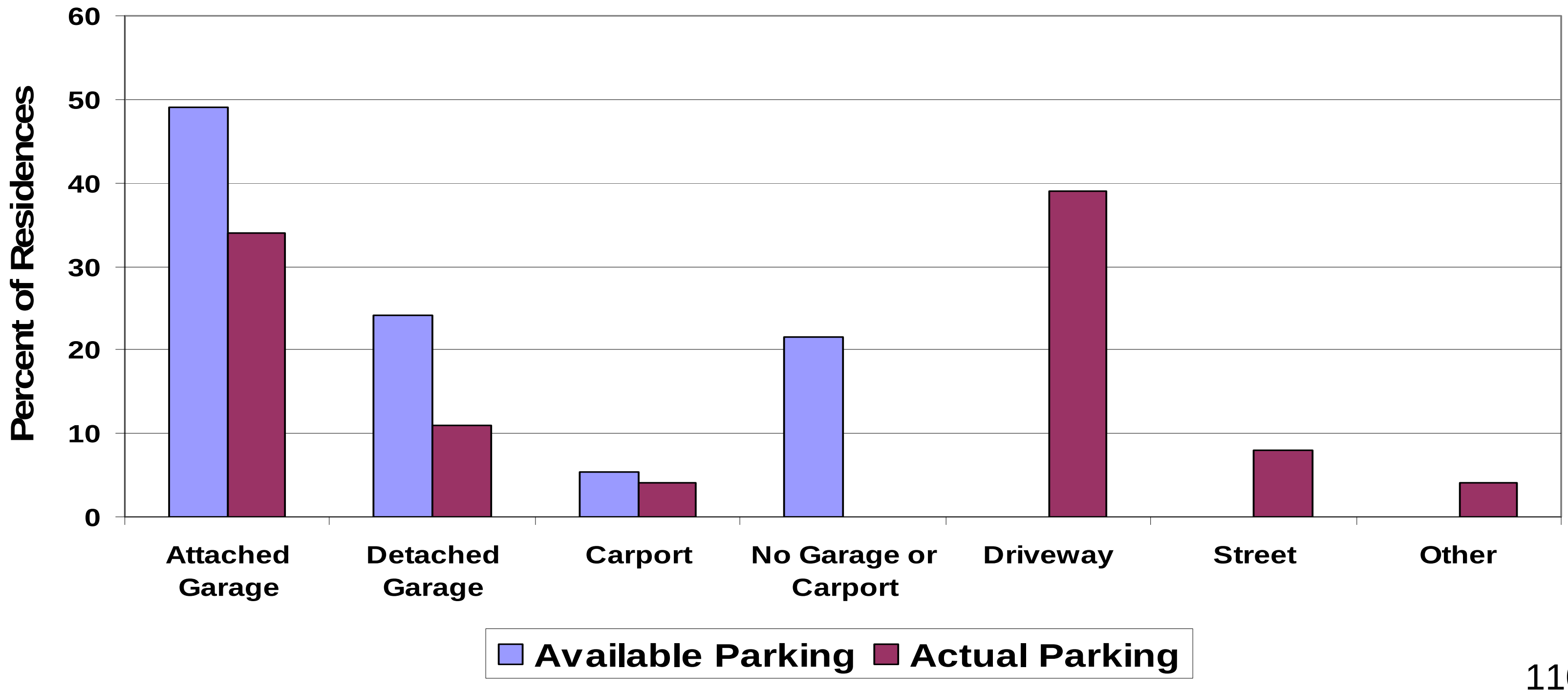
(ORC Survey April 22, 2006)



A major attraction of the PHEV is the ability to charge the batteries at home over night. But as shown below, most households in detached residences do not park their most used vehicle in a place where it could easily be charged.

Available Parking Facilities and Actual Parking (of the most used vehicle) for People in Detached Residences

(59% of all households live in detached residences)



Where people park their most used vehicle varies by what type of residence they occupy (ORC Survey 04/22/06):

Attached Single Family, Detached Single Family. Mobile Home, or Multi-Family

Where do you park your most used vehicle each night?

	All	Highest	Lowest
Driveway	36%	Mobile Home 61%	Multi-family 17%
Carport	5%	Attached 16%	Detached 4%
Attached Garage	26%	Attached 34%	Mobile Home 4%
Unattached Garage	9%	Attached 11%	Multi-family 2%
On the Street	9%	Multi-family 13%	Mobile Home 4%
Parking Lot	8%	Multi-family 38%	Detached 1%
Somwhere Else	1%		
Do Not Own a Vehicle	5%	Multi-family 13%	Detached 2%
Don't Know	1%		

Planned UC-Davis Pathway Study

- Dan Sperling, Joan Ogden, and others
- Released study design in late 2006: http://steps.its.ucdavis.edu/STEPS_Program%20Overview_Sept06.ppt
- Will launch study on January 1, 2007
- Similar to our Multi-Path study
- We plan to interact with them

European Pathway Study

- **The European Commission, Joint Centre and others performed a joint evaluation of the Well-to-Wheels energy use and greenhouse gas (GHG) emissions for a wide range of potential future fuels and powertrains options. The first version was published in December 2003. The second version was published in May 2006. The objectives of both versions was to:**
  - Establish, in a transparent and objective manner, a consensual well-to-wheels energy use and Greenhouse gas (GHG) emissions assessment of a wide range of automotive fuels and powertrains relevant to Europe in 2010 and beyond.
  - Consider the viability of each fuel pathway and estimate the associated macro-economic costs.
  - Have the outcome accepted as a reference by all relevant stakeholders.

- The website for this study is: http://ies.jrc.ec.europa.eu/wtw.html

European WTW Study vehicle costs for "2010+" are considerably higher than ours.

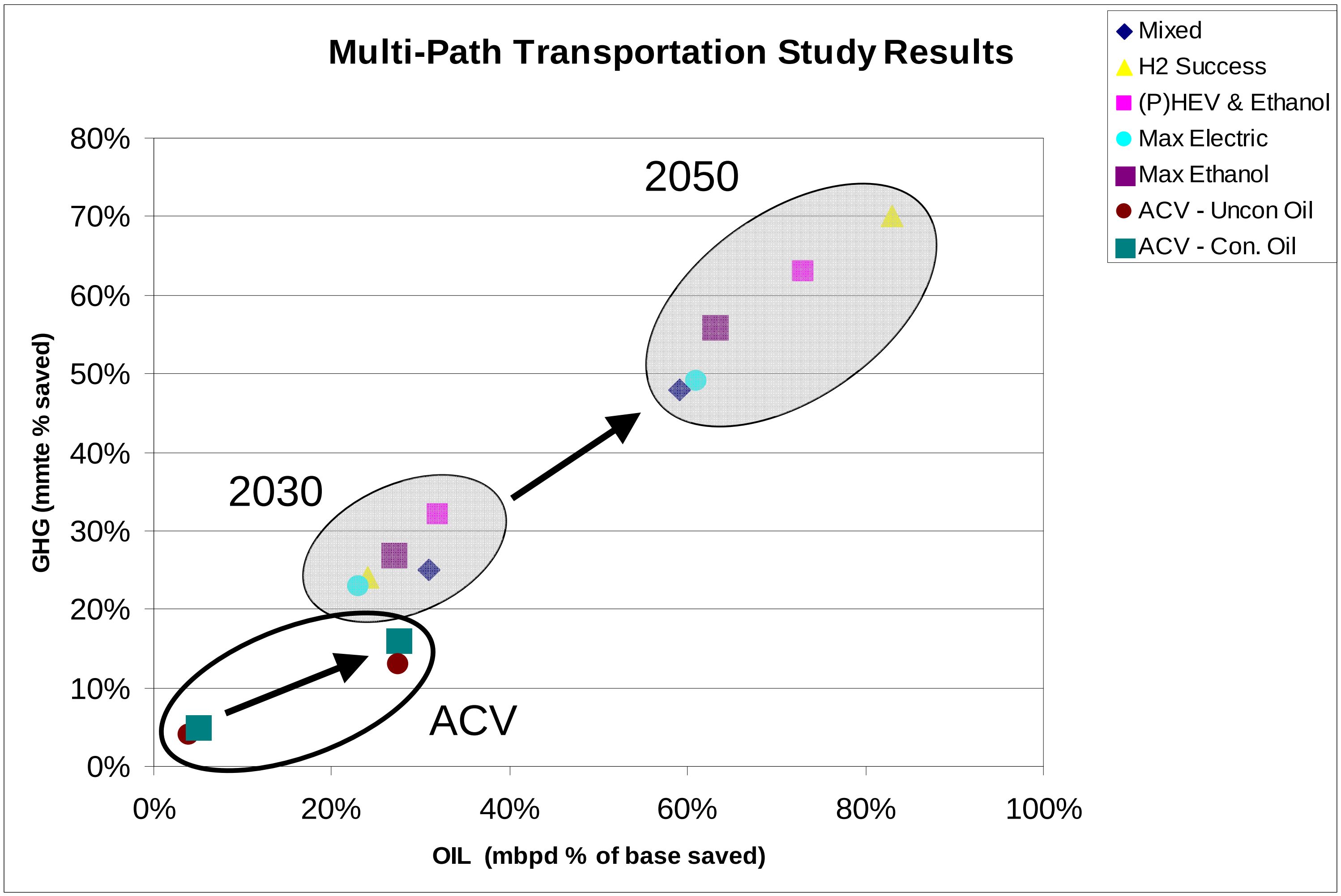
- The European study's costs are for drivetrain changes only – vehicles have no weight reduction measures or other load reduction.

Drivetrain type	2015	2030	2045	EU WTW
	Multi-Path			
Advanced gasoline	1600	2200	2000	1600
Advanced diesel	2800	3300	3000	3600
Gasoline HEV	3900	3900	3500	9300
Diesel HEV	5000	4900	4400	11,700
FCV HEV	7000	5500	4800	20,700

VISION Model Is Publicly Available

- Excel **spreadsheet model** developed by ANL for PAE
- Publicly **available** at http://www.transportation.anl.gov/software/VISION/index.html
- **210 people** had downloaded this model, as of July 2006.
- The website includes a **published report** describing the model

- Improvements in Conventional Vehicles Do Not Provide Sufficient Oil Reduction to Achieve an Energy Security Goal
- DOE"s Advanced Vehicle Technologies All Lead to Increased Energy Security, and in General Reduce GHG Emissions
- Benefits of Combining Technology (e.g., PHEV & Ethanol) Exceeds Benefits of Individual Technologies



Note: Technical Risk Varies by Technology, but Is Not Reflected Here