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ANL/ESD/09-5

Multi-Path Transportation Futures Study: Vehicle Characterization and Scenario Analyses

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Main Text and Appendices A, B, C, D, and F

Energy Systems Division

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Multi-Path Transportation Futures Study: Vehicle Characterization and Scenario Analyses

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Main Text and Appendices A, B, C, D, and F

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prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Offices of Vehicle Technologies Program, Hydrogen, Fuel Cells,
and Infrastructure Technologies Program, and Planning, Budget, and Analysis

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Center for Transportation Research, Argonne National Laboratory

ACRONYMS AND DEFINITIONS

A/C	air conditioning
Acc	accessory
ACV	advanced conventional (gasoline) vehicle
ADV	Advanced Diesel Vehicle
AER	all-electric range
AEO	Annual Energy Outlook (EIA annual report)
Argonne	Argonne National Laboratory
ARCRP	Alternate Refrigerant Cooperative Research Project
ASCM	Automotive System Cost Model
AT	automatic transmission
ATV	advanced technology vehicle
AVL	An international automotive development and analysis company
Bbl	barrel
BCEndogenous	Base Case Endogenous
BEV	battery electric vehicle
BTU	British thermal unit
C/E	cost effectiveness
CAFE	Corporate Average Fuel Economy
CAFE Standards	Federal standards for fuel economy (in miles per gallon [MPG]) that light vehicle manufacturers are required to meet. In 2007, the standards were raised such that MPG targets will improve by 40% by 2020.
CNG	compressed natural gas
CI	compression ignited (diesel)
CO_2	carbon dioxide
CS	charge sustaining
CV	conventional vehicle
CVT	continuously variable transmission
DHEV	diesel HEV
DI	direct injection
DOE	U.S. Department of Energy
DPHEV	diesel PHEV
EERE	Office of Energy Efficiency and Renewable Energy (DOE)
EIA	Energy Information Administration
EIA-NEMS	The EIA version of the NEMS model
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
ETOH	ethanol
EV	electric vehicle
E85	A blend of 85% ethanol and 15% gasoline on a volume basis

FC	fuel cell
FC HEV	fuel cell HEV
FC PHEV	fuel cell PHEV
FCV	fuel cell vehicle
FFHEV	flex fuel HEV
FFV	flex fuel vehicle
GDP	gross domestic product
GGE	gasoline gallon equivalent
GHEV	gasoline HEV
GHG	greenhouse gas
GPRA	Government Performance and Results Act
GUI	graphical user interface
H_2	hydrogen
H2A	Database for the Hydrogen Fuel Cells and Infrastructure Technologies (HFCIT) technologies
HCCI	homogenous charge compression ignition
HEV	hybrid electric vehicle
HMM	Hydrogen Market Module (part of the NEMS-MP model)
HWFET	Highway Fuel Economy Test
ICE	internal combustion engine
kg	kilogram
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
L	liter
LCD	liquid crystal display
LDV	light-duty vehicle
Li	Lithium
LPG	liquid petroleum gas
LR	literature review
LT	light truck
LV	light vehicle (can be cars and light trucks)
m	meter(s)
MARKAL	Market Allocation Model
mbpd	million barrels per day
MIT	Massachusetts Institute of Technology
MMA	make and model availability
$MMTCO_2e$	million metric tonnes of carbon dioxide equivalent
MP	Multi-Path Transportation Futures Study
MPG	miles per gallon

MPGGE	miles per gallon of gasoline equivalent
mph	miles per hour
MSRP	manufacturers suggested retail price
NEMS	National Energy Modeling System
NEMS-H2	The NEMS model that has been extended to 2050 and which includes a hydrogen submodel
NEMS-MP	The integrated NEMS version used for this MP Study
NEMS-PDS	The Program Decision Support (or EERE) version of the NEMS model
NEMS-TSA	NEMS Transportation Stand-Alone model
NHTSA	National Highway Traffic Safety Administration (U.S. Department of Transportation)
OEM	original equipment manufacturer
ORNL	Oak Ridge National Laboratory
OSMM	Oil Security Metrics Model
PFCV	plug-in FCV
PG	program goals
PHEV	plug-in HEV
PHEVXX	A PHEV with an all-electric range of XX miles. For example, a PHEV40 has an all-electric range of 40 miles.
(P)HEV	Part of the name of a scenario with both HEVs and PHEVs
PSAT	Powertrain System Analysis Toolkit (developed by Argonne)
R&D	research and development
RFS	renewable fuels standard
RPE	retail price equivalent
SAE	Society of Automotive Engineers
SI	spark ignited (gasoline)
SOC	state of charge
STEPS	Sustainable Transportation Energy Pathways (a study similar to MP by researchers at UC-Davis)
SUV	sport utility vehicle
TAE	TA Engineering, Inc.
TDI	turbocharged direct injection
UDDS	Urban Dynamometer Driving Schedule
USABC	U.S. Advanced Battery Consortium
VCM	Vehicle Choice Model (a component of NEMS-TSA)
VISION	A light vehicle stock model developed by Argonne that estimates fuel use and GHGs
VMT	vehicle miles traveled

VT	Vehicle Technologies Program in EERE
VVTL	variable valve timing and lift
W	watt(s)

EXECUTIVE SUMMARY

Projecting the future role of advanced drivetrains and fuels in the light vehicle market is inherently difficult, given the uncertainty (and likely volatility) of future oil prices, inadequate understanding of likely consumer response to new technologies, the relative infancy of several important new technologies with inevitable future changes in their performance and costs, and the importance — and uncertainty — of future government marketplace interventions (e.g., new regulatory standards or vehicle purchase incentives).

This Multi-Path Transportation Futures (MP) Study has attempted to improve our understanding of this future role by examining several scenarios of vehicle costs, fuel prices, government subsidies, and other key factors. These are projections, not forecasts, in that they try to answer a series of "what if" questions without assigning probabilities to most of the basic assumptions. Some key conclusions are:

1. For a Reference Case that assumes no further government intervention in the marketplace, light-duty vehicle oil use — currently about 8.5 million barrels per day (mbpd) — will likely hold relatively steady through the early 2020s but should increase substantially thereafter, reaching about 12 mbpd by 2050. Two key assumptions for this case are that future oil prices return to high levels (~$100/barrel [bbl] in 2030) and that the Corporate Average Fuel Economy (CAFE) Standards passed in December 2007 are fully enforced.

2. The Reference Case projection is highly dependent on assumptions about future vehicle sales and stock, driving intensity, on-road vs. test fuel economy, and other determinants of fleet energy use – especially considering the 40+-year interval to the year 2050. For example, an alternative "Base Case" projection to the year 2050 using Argonne National Laboratory's VISION 2008 model (http://www.transportation.anl.gov/modeling_simulation/VISION/index.html) projects light-duty vehicle energy use to be about 9 mbpd in 2050 – a sharply different estimate based on assumed lower total vehicle stock, lower miles driven per vehicle, and higher stock fuel economy in 2050. VISION 2008 is based on AEO 2008, while this study used AEO 2007. AEO 2009 has even lower vehicle miles traveled (vmt)/vehicle and higher stock fuel economy levels than AEO 2008. Given the uncertainty associated with such projections, we consider results expressed as percentage reductions from the baseline to be more robust than those expressed as absolute values.

3. Gauging the potential for the future market success of new drivetrain technologies — and their effect on fleet fuel economy and greenhouse gas emissions — requires recognizing some basic relationships:

   a. **Since about 1987, virtually all technical improvements to U.S. light-duty vehicles have been directed to compensating for larger vehicle size, greater engine power, more vehicle features (four wheel drive, air conditioning, etc.), and improved structural stiffness — with essentially no improvement in fleet fuel economy.**

Unless these trends are impeded, future fuel economy improvements are likely to be disappointing. This assessment has assumed that, in all but the baseline scenario, the technical potential of new technologies will be directed to improving fuel economy rather than to improving acceleration performance or other vehicle attributes — but this assumption is in defiance of trends over the past two decades and deserves some healthy skepticism.

b. **The attractiveness of new technologies will hinge in large part on how future fuel savings are valued, and different actors will gauge these savings differently.** An average consumer today will value future savings far less than society would; and a technology that appears highly cost effective to society might appear too costly to that consumer.

c. **With multiple fuel-efficiency options to choose from, vehicle purchasers will judge each option based on its marginal attractiveness compared to its competitors – not on its absolute advantage over a lowest-common-denominator reference vehicle.** With cost curves of increasing slope, "good" technologies (e.g., hybrid electric vehicles [HEVs]) may be more attractive than "better" technologies (e.g., long-range, plug-in hybrids [PHEVs] or fuel cell vehicles [FCVs]) because the marginal benefits of moving beyond the "already-good" efficiency of a hybrid may be insufficient to compensate for the added cost – even if the more advanced technology vehicle is cost effective compared to today's conventional vehicles.

4. By using relatively optimistic cost estimates obtained by literature review (LR) and assuming gasoline prices of $3.15/gallon (and corresponding prices of competing fuels), an analysis of a 2030 midsize car shows that **both advanced conventional and full hybrid spark-ignited (SI) (gasoline) drivetrains are highly cost effective, but that going beyond the hybrid drivetrain will not yield incremental benefits that exceed the added costs, regardless of how one values future fuel savings**. For example, in Figure ES-1, note that the cost effectiveness[1] of the SI Full HEV is as high or higher than any of the more advanced drivetrain vehicles at all three discount rates. This relationship holds for a broad range of fuel prices. On the other hand, **at technology cost levels based on U.S. Department of Energy (DOE) program goals (i.e., the PG level) — which we judge to be very optimistic — it *is* cost effective to move well beyond an SI full hybrid drivetrain.** As shown in Figure ES-2, fuel cell vehicles with either hybrid or short-range (10-mile) plug-in hybrid drivetrains look especially attractive, although this finding is primarily because DOE goals for these drivetrains are quite aggressive.

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[1] Lifetime fuel savings minus the differential in vehicle sales price, referenced to today's SI conventional vehicle or other reference vehicle.

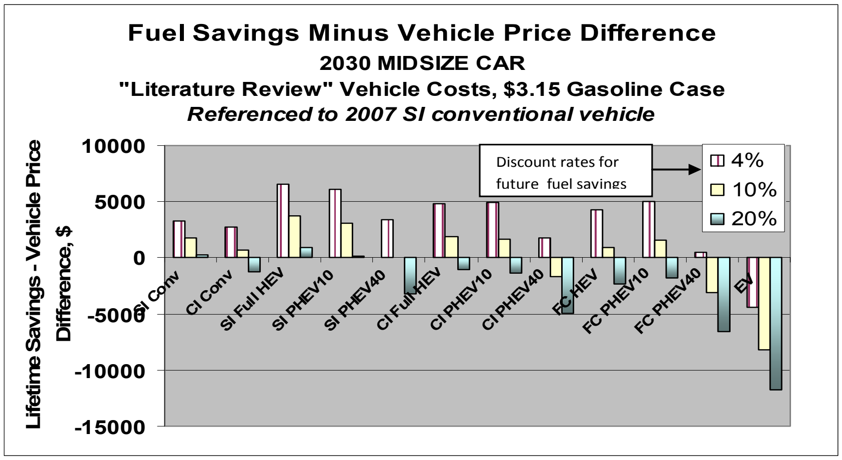

FIGURE ES-1 Cost Effectiveness of a 2030 Midsize Car, at Literature Review Costs

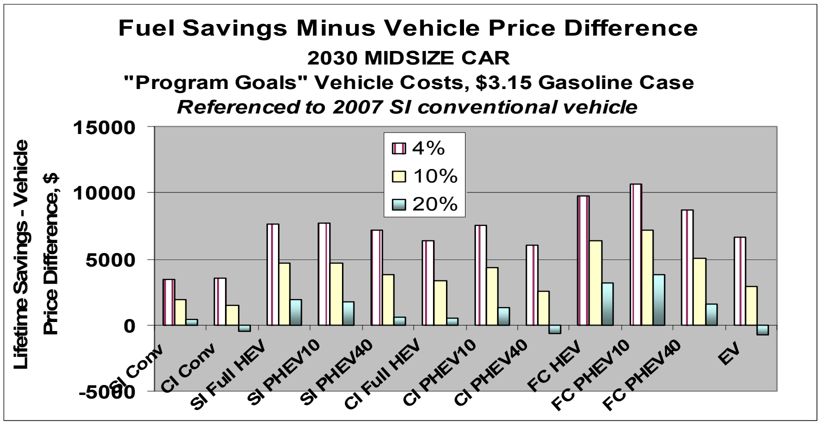

FIGURE ES-2 Cost Effectiveness of a 2030 Midsize Car, at Program Goal Costs

5. **Fuel price is a crucial determinant of vehicle cost-effectiveness.** As shown in Figure ES-3, for model year 2030, advanced vehicles with hybrid powertrains are not cost-effective for an average individual purchaser (20% discount rate) when gasoline prices are at or below $2.50/gallon. In other words, **low fuel prices can severely damage prospects for advanced drivetrain vehicles.**

6. **Moving high-technology vehicles into the marketplace will be challenging because of high initial costs.** Whatever the potential cost effectiveness of advanced drivetrains in 2030 — even with mass production and years of design and production experience — their high costs in the years immediately following their introduction are likely to demand strong purchase incentives by vehicle manufacturers or government (or both) to overcome their initial lack of cost-effectiveness.

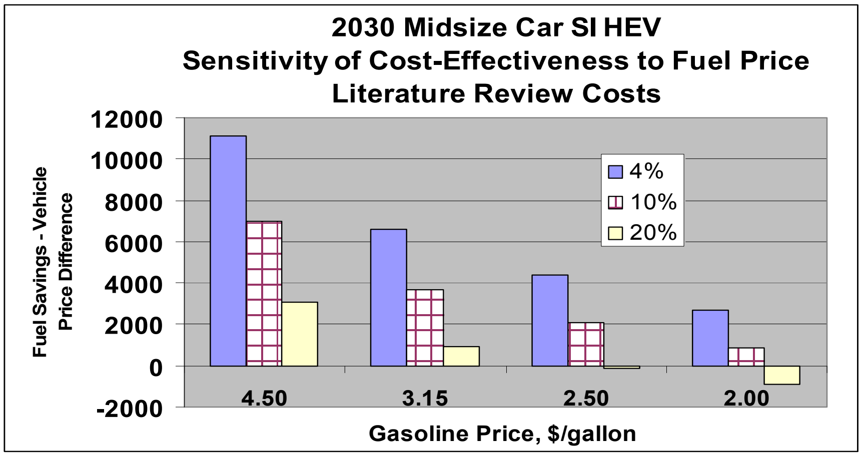

FIGURE ES-3 Sensitivity of Cost Effectiveness to Fuel Price, 2030 Midsize Car SI HEV, Literature Review Costs

7. The above conclusions about the cost effectiveness of individual vehicles imply that, without strong government intervention, **successful technology development would tend to favor "lower-level" drivetrain technologies — and thus yield moderate but limited reductions in fleet oil use and greenhouse gas (GHG) emissions — unless radical cost reductions are obtained**. Modeling with the National Energy Modeling System (NEMS) bears this conclusion out. Using the "literature review" technology costs and assuming relatively high oil prices (about \$100/bbl in 2030), reduced prices for ethanol and hydrogen, and essentially no change in consumer behavior regarding future fuel savings (but an easing of consumer concerns about "new" technologies), **advanced vehicle technologies do widely penetrate the fleet — but these technologies are dominated by advanced conventional and HEV drivetrains, with little or no penetration of PHEV40s[2] or FCVs.** For three different vehicle technology scenarios ("Mixed," "(P)HEV & Ethanol," and "Hydrogen [H2] Success"), these fleet changes reduce projected 2050 levels of light-vehicle (LV) oil use by about 2–3 mbpd (to 9–10 mbpd) (see Figure ES-4), a reduction of about 17–25%, and LV fuel cycle carbon dioxide (CO_2) emissions by 13–19% compared to the baseline (which assumes less progress in technology costs and performance).

8. Greater success in reducing technology costs – reaching the ambitious cost goals established by DOE, yielding "program goals" cost estimates – could result in substantial penetration of FCVs and, to a lesser extent, PHEV40s, yielding about a 4-mpbd (31–34%) reduction in LV oil use by 2050 and in reductions of CO_2 emissions of about 25% (Figure ES-5). Reductions in CO_2 emissions could be greater still in this case if the carbon intensity of the electricity and hydrogen used to fuel plug-in hybrids and fuel cell vehicles were reduced. In the scenarios examined, substantial "greening" of the grid was

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[2] PHEV10s, which appear to be relatively cost effective at higher fuel prices, were not incorporated in the scenario analyses because the version of the NEMS model used in this analysis allows consideration of only one type of PHEV.

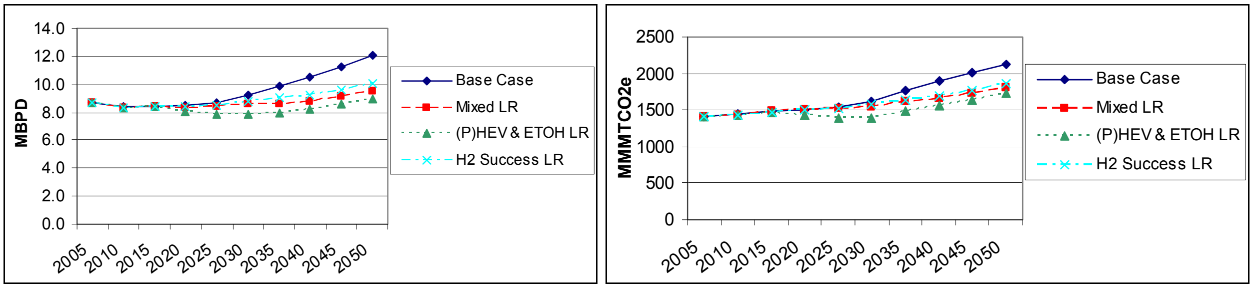

FIGURE ES-4 Light Vehicle Oil Use and Full-Fuel-Cycle CO_2 Emissions Assuming Literature Review Vehicle Costs and No Government Subsidies

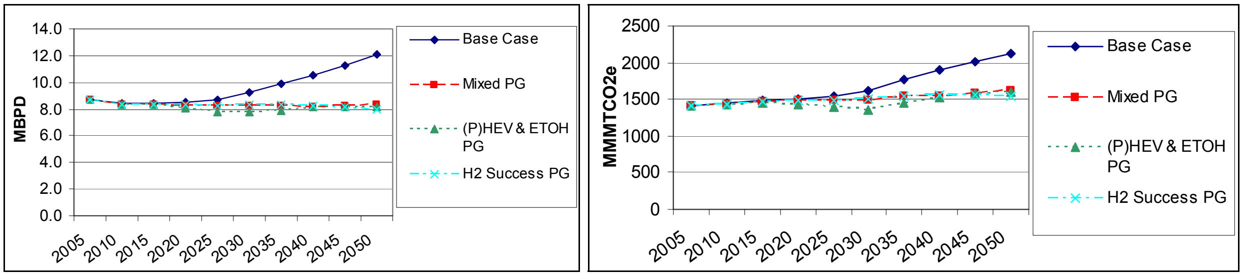

FIGURE ES-5 Light Vehicle Oil Use and Full-Fuel-Cycle CO_2 Emissions Assuming Program Goals Vehicle Costs and No Government Subsidies

not considered, and hydrogen production feedstock sources in 2050 include substantial quantities of natural gas and coal (although some coal-based CO_2 emissions are sequestered), along with biomass (about a quarter of the feedstock).

9. **Strong government intervention in the form of vehicle purchase subsidies could make a significant difference in the fleet results.** Assuming that "literature review" costs are achieved, long-term government purchase subsidies of $7,500/vehicle would allow significantly higher penetration of advanced drivetrain vehicles, with 2050 LV oil use reduced (when compared to the Base Case) by about 5 mbpd (42–45%), and LV fuel cycle CO_2 emissions reduced by about 22% for the (P)HEV & Ethanol Scenario, 29% for the Mixed Scenario, and 43% for the H2 Success Scenario (see Figure ES-6).[3] If the "program goals" costs are achieved, considerably smaller subsidies than those needed in the "literature review" cost case — a maximum of $4,000/vehicle by 2050, depending on the scenario — would drive 2050 LV oil use down (as compared to the Base Case) by 4–6 mbpd (35–49%). Similarly, these smaller subsidies would drive LV fuel cycle CO_2 emissions down by 23–25% for the Mixed and (P)HEV & Ethanol Scenarios and by more than 46% for the H2 Success Scenario (see Figure ES-7). However, the costs of the

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[3] Here again, the CO_2 reduction could be greater with greener electricity and hydrogen production.

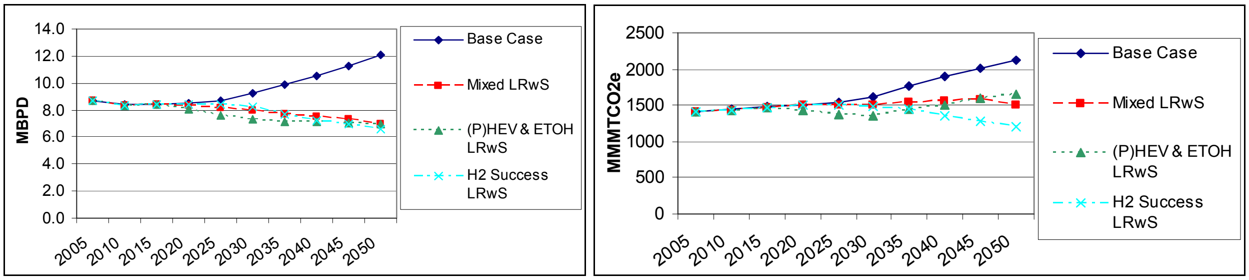

FIGURE ES-6 Light Vehicle Oil Use and Full-Fuel-Cycle CO_2 Emissions, Assuming Literature Review Vehicle Costs Plus Selected Government Subsidies

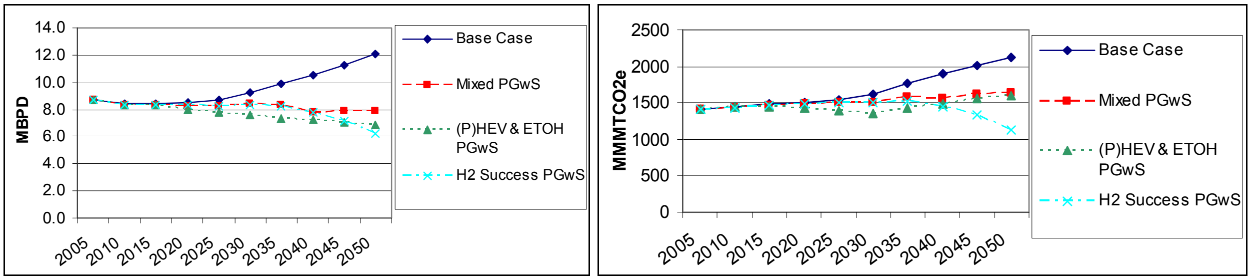

FIGURE ES-7 Light Vehicle Oil Use and Full-Fuel-Cycle CO_2 Emissions, Assuming Program Goals Vehicle Costs Plus Selected Government Subsidies

subsidies, in \$/bbl of oil saved and \$/ton of CO_2 reduced, would be high. With many caveats, we estimate these costs to be \$56–\$136/bbl if all the costs are assigned to saving oil and \$96–\$5,000/ton CO_2 if the costs are attributed to reducing CO_2 only.[4]

10. The above results were derived by using a Vehicle Choice Model (VCM) in NEMS that is based on our current understanding of consumer behavior. **Future changes in consumer behavior — especially in how they value future fuel savings – could have a dramatic impact on technology penetration and thus on future oil use and CO_2 emissions.** For example, with “literature review” costs, changing “payback” requirements in the Vehicle Choice Model from 3 to 4 years (i.e., its current value, which is reflective of today’s consumers) to 15 years would cause a “jump” in the 2050 passenger car share of SI PHEV40s and FCVs from negligible levels to about 10% each.

11. The results of the scenarios, especially those with strong vehicle subsidies, may appear quite disappointing compared to scenario results from recent studies showing much more substantial reductions in oil use and GHG emissions — in some studies, reaching levels

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[4] Note that the subsidy will yield multiple benefits – as well as some costs. Benefits include the energy security benefits of reduced oil use (as well as the private cost savings of the reduction); reduced emissions of greenhouse gases; and (probably) reduced emissions of criteria pollutants. A cost might be the increased congestion and additional road accidents associated with increased driving caused by lower fuel cost/mile. Were the costs distributed among multiple benefits (and costs), they would change from those presented here.

that are 80% below current levels by 2050, and possibly lower. The reasons for these differences include the following:

- **Model-driven vs. assumptions-driven results.** Many studies have assumed high levels of technology penetration at extremely rapid rates without subjecting these assumptions to vehicle choice modeling or other constraints. The NEMS vehicle choice model was used for this study.

- **Consumer behavior.** As noted above, the NEMS VCM has current consumer valuations of future fuel savings embedded within it. Many other studies evaluate technology cost effectiveness by considering lifetime fuel savings at zero or very low discount rates — implicitly assuming that future consumers value fuel economy much more than current consumers do (or that government regulations or subsidies push advanced technologies into the marketplace in spite of high costs). Future changes in consumer behavior are certainly possible.

- **Feedstock sources for alternative fuels.** Several studies have assumed that, by 2050, the electricity for PHEVs and the hydrogen for FCVs are both supplied solely by renewable sources, so that GHG emissions for these vehicles are zero or are greatly reduced. This study did not consider radical changes to the electric grid, and hydrogen feedstock supply sources are a combination of natural gas, coal, and biomass.

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1 INTRODUCTION

The Multi-Path Transportation Futures (MP) Study is aimed at comparing alternative ways to make significant reductions in oil use and carbon emissions from U.S. light vehicles from now to 2050. A key goal of the study is to make these comparisons on common ground as much as is possible and with analytic robustness. Phase 1 of the study was basically a scoping study, aimed at identifying key analytic issues and constructing a study design (see http://www1.eere.energy.gov/ba/pba/multi_path.html). The Phase 1 analysis included an evaluation of several pathways (single-technology vehicles and their associated fuels and fuel production systems, with changes over time as technologies develop) and scenarios (visions of substantial market penetration of one or multiple pathways, tracked over time); however, these analyses were limited in number and scope and were designed to be preliminary. Phase 2, which is described in this report, examines the full range of pathways of interest to the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE), with multiple scenarios aimed at illuminating the issues and impacts associated with a national effort to reduce U.S. dependence on oil use in transportation. The Phase 2 analysis expands the scope of the analysis: it examines the interactive effects of multiple pathways on each other and on oil and feedstock prices; focuses far more on costs; and substantially increases the number of metrics used to compare pathways and scenarios.

The report that follows contains discussions of:

- The scenarios (a qualitative discussion);
- Vehicle fuel economy and cost estimates;
- The version of the National Energy Modeling System (NEMS) model that is used;
- The projected levels of energy use, oil use, carbon dioxide (CO_2) emissions, and related characteristics of the scenarios as modeled in NEMS; and
- The energy security benefits of the scenarios as modeled in the Oil Security Metrics model.

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2 SCENARIOS

2.1 BACKGROUND

Scenario analysis is undertaken in the MP Study to help illuminate the issues and impacts associated with a national effort to reduce U.S. dependence on oil use in transportation. In this section, the underlying rationale of the scenarios is described.

2.1.1 General Conditions Applicable to All Scenarios

The MP study postulates a world in which oil supply instability and high prices have created a societal compact that places a high value on reducing the use of oil and providing substitutes for supporting the transportation system. Although actions taken in this world include vigorous efforts aimed at replacing automotive travel with other modes (e.g., non-motorized [walking and bicycling]) and mass transit, the effect on travel demand in the United States amounts to a change of only a few percentage points (it is of note that a doubling of transit use in the United States would reduce light vehicle travel by perhaps 2%, counting induced travel).

European and Japanese technology trends generally track those in the United States, although Europe has a greater focus on diesel-based drivetrains. Efforts to increase mass transit and non-motorized travel generally are stronger outside of the United States.

2.1.2 Global Warming

The perceived certainty of global warming increases in all scenarios, as does public recognition that the overall net effect of warming will be highly deleterious despite some climate “winners.”

2.1.3 Policies

Energy system responses to oil supply instability and global warming vary across scenarios depending on both varying outcomes of energy research and development (R&D) and different policy choices. Some scenarios envision large shifts to renewable fuels or hydrogen while others assume more restrained responses or a primary focus on efficiency rather than fuel shifting. However, all scenarios incorporate the vehicle fuel economy standards approved by Congress in December 2007 (i.e., the Energy Independence and Security Act of 2007 [EISA]). The EISA renewable fuels standard (RFS) is not explicitly modeled (see discussion in Chapter 6).

2.1.4 Vehicle-related Technologies

Each of the advanced technology vehicles (ATVs) has reduced cost and improved performance over time. To avoid excessive complexity in the model simulations, each technology attains the same level of technological success in each scenario. The advances anticipated are described briefly below and discussed further in Chapter 3.

Gasoline engines. Gasoline engines evolve substantially toward the efficiency of diesels, with enabling technologies such as camless valves, direct injection, expansion of computer power and in-cylinder measuring capability, turbocharging, and multi-cycle capability (especially via homogenous charge compression ignition [HCCI] operation).

Diesel engines. Diesels attain ultra-low levels of emissions based primarily on fuel quality and improvement in fuel injection systems and cylinder design, with tailpipe controls required at levels that do not unduly escalate costs.

Battery technology. Substantial improvements in lithium (Li) batteries occur, yielding enhanced safety and longevity, higher specific weight and power, and higher energy and power density at reduced cost. These batteries reduce the cost and improve the performance of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and electric vehicles (EVs).

Fuel cell drivetrains. Breakthroughs in fuel cell systems and hydrogen storage have occurred.

Vehicle load reduction. Sharp improvements occur in all scenarios in achieving reductions in weight and tire rolling resistance and in the efficiency levels of accessory systems and aerodynamics. Ultimately, in scenarios incorporating the most optimistic assumptions concerning vehicle technologies, the aerodynamic coefficient CD is reduced to 0.20 for leading-edge passenger cars by 2045, compared to about 0.30 as an overall fleet average today. Tire rolling resistance is reduced to 0.006 for leading-edge cars by 2030. The mass of the vehicle glider for both leading-edge cars and light trucks (LTs) is reduced by 30% by 2030.

2.2 THREE SCENARIOS OF TECHNOLOGY MIX

The study team first developed three hypothetical scenarios with different mixes of technology penetration, which are described below. These mixes, shown in Table 2-1, serve as goals for the actual modeling of scenarios using the NEMS model; the modeled scenarios attain technology mixes that are somewhat different from those of the hypothetical scenarios.

2.2.1 Mixed Scenario

In this scenario, government policy avoids picking “winners,” vehicle technology has advanced along a broad front, and no particular technology has become dominant. After some vehicle manufacturers introduce diesel vehicles meeting Tier 2/Bin 5 emissions standards without

TABLE 2-1 Potential Scenarios (in % of Sales)

		2030	2040	2050
Mixed				
Cars/LTs	Flex Fuel Vehicles (FFVs)?			
ACV	Yes	30.00	15.00	10.00
Diesel	No	16.00	14.00	14.00
Diesel (compression-ignited [CI]) HEV	No	4.00	6.00	6.00
SI HEV	Yes	30.00	20.00	15.00
SI PHEV40	Yes	16.80	34.50	25.00
FCV	No	0.027	7.35	21.00
Plug-in FCV	No	0.003	3.15	9.00
EV	No	0.00	0.00	0.00
Conventional vehicles (CVs)	No	3.17	0.00	0.00
E-85 FFV	Yes	0.00	0.00	0.00
Total		100.00	100.00	100.00
Total ethanol (billion gallons)				40 or more
H2 Success				
Cars/LTs	FFVs?			
ACV	No	20.00	14.00	5.00
Diesel	No	10.00	6.00	3.00
Diesel (CI) HEV	No	0.00	0.00	0.00
SI HEV	No	40.00	30.00	16.00
SI PHEV40	No	0.00	0.00	0.00
FCV	No	10.30	50.00	76.00
Plug-in FCV	No	0.00	0.00	0.00
EV	No	0.00	0.00	0.00
CVs	No	19.70	0.00	0.00
E-85 FFV	Yes	0.00	0.00	0.00
Total		100.00	100.00	100.00
Total ethanol (billion gallons)				No goal
(P)HEV & Ethanol				
Cars/LTs	FFVs?			
ACV	Yes	20.00	14.00	7.00
Diesel	No	5.00	5.00	3.00
Diesel (CI) HEV	No	0.00	0.00	0.00
SI HEV	Yes	40.00	40.00	40.00
SI PHEV40	Yes	25.00	41.00	50.00
FCV	No	0.00	0.00	0.00
Plug-in FCV	No	0.00	0.00	0.00
EV	No	0.00	0.00	0.00
CVs	No	10.00	0.00	0.00
E-85 FFV	Yes	0.00	0.00	0.00
Total		100.00	100.00	100.00
Total ethanol (billion gallons)				60 or more

requiring selective catalytic reduction controls in 2009, diesels quickly become a standard engine option across virtually all models. They do not dominate the market, however, because advances in gasoline engines allow spark-ignited (SI) engines to achieve considerably improved levels of efficiency while remaining substantially less expensive than diesels. Hybrid drivetrains, both grid-independent and plug-in, quickly attain nearly half of the light vehicle market as their price premiums drop because of a combination of mass production, sharp drops in battery costs, and new designs that sharply reduce transmission costs. Ethanol volumes continue to grow, and cellulosic ethanol begins to penetrate the market. Essentially all hybrids, plug-ins, and advanced conventional vehicles sold after 2015 are fully fuel flexible. Hydrogen fuel cell vehicles (FCVs) enter the market in 2020 and, while they establish a strong presence in larger cities, market penetration is less extensive in rural areas and smaller urban areas. Hydrogen supply infrastructure establishes a reasonable presence along interstates but does not penetrate much beyond this outside of urban areas.

Table 2-1 presents a likely mix of vehicle technologies and ethanol use for the Mixed Scenario in the long term. The advanced technology vehicles in this scenario include advanced conventional gasoline vehicles (ACVs), diesel vehicles, hybrids (gasoline and hybrid), plug-ins, and fuel cell vehicles. Neither EVs (although they are characterized in this study) nor vehicles operating on such alternative fuels as methanol, compressed natural gas (CNG), or liquid petroleum gas (LPG) are included in the scenario because they do not appear to have the capability to penetrate the light vehicle (LV) market significantly out to the year 2050.

2.2.2 Hydrogen Success Scenario

In this scenario, the federal government exerts significant influence in order to reduce the transport sector's dependence on oil. Accordingly, it moves swiftly to increase overall light vehicle efficiency and to push hydrogen into the LV market. To that end, it puts policies into place that include:

- Requiring that 50% of the vehicles in all government LV fleets are FCVs by 2030;
- Requiring that Federal agencies build hydrogen refueling stations at all fleet parking locations, with public access;
- Requiring hydrogen refueling stations to be built along all interstate highways, providing funds in the annual highway bill;
- Providing subsidies and loan guarantees for the building of hydrogen refueling stations elsewhere;
- Providing loan guarantees for hydrogen production facilities; and
- Providing tax deductions for the purchase of hydrogen fuel cell vehicles.

FCVs enter the market in 2020 in designs that provide high performance and added features beyond those offered by competing internal combustion engine (ICE)-based vehicles, and they experience no major product failures, quickly obtaining a high degree of consumer confidence. This early success causes all major auto companies to introduce FCVs into most of their market segments such that FCVs comprise 10% of new LV sales by 2030, eventually reaching 76% by 2050.

Table 2-1 presents what we consider to be a likely mix of vehicle technologies for the Hydrogen (H2) Success Scenario over the long term. Fewer types of advanced vehicle technologies are included here as compared to the Mixed Scenario because of the scenario's focus on FCVs.

2.2.3 (P)HEV & Ethanol Scenario

Strong pressure from farm states, coupled with early successes in reducing the cost of cellulosic ethanol, enable the country to come close to meeting the aggressive RFS passed by Congress in December 2007. Ethanol use rises quickly. At the same time, such factors as rapid improvement in lithium batteries, introduction of a variety of new hybrid drivetrain designs, and incentives provided by electric utilities (driven by benefits to utilities' load curves and regulation capacity delivered by PHEV use) lead to substantial increases in the production and sales of both HEV and PHEV vehicles. The rapid increase in ethanol availability convinces automakers to produce more flex-fuel vehicles, and by 2020 virtually 100% of new light vehicles have this capability. This combination essentially stifles attempts to introduce hydrogen into the LV market as it becomes increasingly clear that ethanol and electricity might be able to back virtually all petroleum-based fuels out of the market.

Table 2-1 presents a likely mix of vehicle technologies and ethanol use for the (P)HEV & Ethanol scenario over the long term. Fewer advanced vehicle technologies are included here as compared to the Mixed Scenario because of the scenario's focus on PHEVs and ethanol.

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3 VEHICLE CHARACTERIZATION

This chapter evaluates a set of vehicle characteristics — with the primary focus on fuel economy performance and cost — that will be used to compare and contrast a range of alternative vehicle/fuel pathways. The vehicle fuel economy, cost, and other characteristics are useful by themselves in evaluating vehicle/fuel pathways and also serve as key inputs to integrated modeling of scenarios of the future of U.S. light-duty vehicle fleet and multiple vehicle/fuel pathways when using the NEMS.

3.1 BASIC APPROACH

The goal of this study is to compare multiple fuel and vehicle pathways in as balanced a fashion as possible. However, realizing this goal is not straightforward and unambiguous. One approach to comparing alternative vehicles, for example, might be to optimize each pathway's vehicle design for the specific fuel and vehicle technology combination embodied by the pathway. This approach may lead to "competing" vehicles being quite different from one another. Pathways with low energy density fuels (hydrogen or electricity) have onboard energy storage challenges because high pressure storage tanks (or cryogenic tanks or adsorption tanks) and batteries are heavy and expensive; vehicles in these pathways will gain higher benefits (in terms of increased range or reduced storage system costs) from load reduction than would vehicles using energy-dense liquid fuels. This implies that an "optimal" electric vehicle or hydrogen vehicle would be more likely to use expensive weight reduction (and other load reduction) technologies than would vehicles powered by liquid fuels. Similarly, the cost of attaining acceleration goals or other vehicle performance goals — in terms of the financial costs of more powerful drivetrain components as well as the effects of volumetric requirements for larger fuel tanks and other components — may vary sharply between alternative pathways; this result might yield different minimum range requirements or minimum required acceleration times of 0–60 miles per hour (mph) for different vehicles. For example, an "optimum" electric vehicle might have a range substantially lower than that of a gasoline-powered vehicle in order to avoid the weight, volume, and cost penalties associated with a battery large enough to attain an extended range. In essence, this approach would explicitly recognize that some of the alternative vehicle/fuel pathways are unlikely to satisfy the needs of all vehicle purchasers and are, to a certain extent, niche vehicles — although for the pathways explored in this study, these niches represent a significant proportion of the fleet.

Trying to compare optimized pathways, however reflective they may be of what might actually occur in the marketplace, would create substantial analytical difficulties because of large uncertainties in the estimated costs, specific levels of power (or energy), and power (or energy) densities of future drivetrain technologies and in the complex tradeoffs that would have to be made in designing these future vehicles. Also, these variables and their tradeoffs will change over time, further complicating this approach.

To avoid these difficulties, we have chosen instead to design the vehicles in each pathway to be as similar as possible consistent with the differences in their fuels and drivetrains. The vehicles must satisfy the same core set of performance standards (with one exception: the EV range is set at 150 miles[5]), and they will have virtually identical "gliders" (a "glider" is a vehicle minus its powertrain and fuel storage system). Consequently, these vehicles will appear to their drivers and passengers to be virtually identical to each other, except where differences become inevitable as a result of the different pathway (e.g., differences in the time spent refueling or in refueling locations, small performance differences caused by the high low-end torque of electric motors and diesel engines, and so forth). The performance standards are kept constant over time, but the gliders do change as aerodynamic performance, materials development, and other factors change.

The vehicles modeled are considered "leading edge" vehicles — vehicles that are "best in class" for fuel economy and use technology newly introduced or newly updated — and which are assumed to be introduced to the fleet in limited numbers[6] at the modeled date. The overall vehicle designs, technology performance, and cost assumptions are based on technological optimism and an assumed strong design preference for fuel economy over performance. This preference flows from the assumed political context, which is one of urgency resulting from the failure at some point in the near future of world oil production to keep pace with continued growth in transportation demand. It is assumed that there is strong government and consumer demand for increased vehicle efficiency and perhaps alternative fuels, as well as general acceptance of the idea that vehicle acceleration performance will no longer increase with every new model redesign.

It is important to note that the fuel economy values needed to forecast fleetwide effects over time must be those of average rather than leading edge vehicles, so it will be necessary to translate the fuel economy values derived in this analysis into "average" values. The choice to evaluate leading edge vehicles was made because it is easier to imagine the design of a vehicle with a full set of the best-available technologies — and easier to elicit expert opinions on such vehicles — than it is to try to imagine instead what an average vehicle might be at some point in the future.

The underlying vehicle performance assumptions used were derived from available literature on future vehicle performance, with considerable weight given to the following: studies by the Energy Laboratory of the Massachusetts Institute of Technology (e.g., Weiss 2000 and various updates to that study, such as Kromer and Heywood 2007) and Energy and Environmental Analysis, Inc. (e.g., EEA 2006 and updates); advice given by industry advisers to the modelers who conducted the vehicle fuel economy analysis (using the Powertrain System Analysis Toolkit [PSAT] model discussed below); and talks and papers delivered at recent Society of Automotive Engineers conferences. We chose to pursue selection of these assumptions somewhat independently of EERE program goals (PGs) for vehicle performance and cost because we were seeking a comparison of technologies based on engineering assessments of their cost and performance. In contrast, many of the program goals are normative in nature, that is, they represent cost and performance levels required to allow them to compete directly with conventional ICE powertrains. As such, their use for comparative analysis would tend to hide differences among the technologies, since the goals were designed to minimize these differences.

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[5] On the urban dynamometer driving schedule (UDDS) (city) driving cycle.

[6] But they will be introduced in large enough numbers (i.e., at least a few tens of thousands of vehicles) to attain many of the cost benefits associated with mass production.

It is important to note that, for every vehicle/technology/date combination, we designate two sets of component performance and fuel economy results — “high,” which implies a successful development of the technology with most or all of the benefit devoted to improving fuel economy, and “medium” or “average,” which implies some pullback from the full efficiency benefit due to tradeoffs with competing priorities or somewhat less successful development. For the most part, we focus on the “high” values in our analysis.

3.2 FUEL ECONOMY ANALYSIS

3.2.1 Modeling System

The fuel economy evaluations were conducted by using the PSAT vehicle simulation model described further in Box 1. The model first “builds” the vehicle (sizing its drivetrain components) by incorporating specified performance goals and assumptions about vehicle load and drivetrain component characteristics and then calculates the vehicle’s fuel economy on different driving cycles.

3.2.2 Vehicle Types Examined

For the evaluation of leading edge vehicles, three vehicle classes are examined: midsize cars, midsize sport utility vehicles (SUVs, which are based on truck frames), and crossover SUVs (based on car frames, e.g., with unibody construction). However, performance and cost results of the crossover SUVs were not used for extrapolating performance and cost results to the whole vehicle fleet for data entry for integrated scenario modeling using NEMS.

Six drivetrain configurations are examined:

- Advanced conventional gasoline;
- Advanced conventional diesel;
- Full hybrid gasoline — no all-electric range (AER), a 10-mile AER, and a 40-mile AER;
- Full hybrid diesel — no AER, 10-mile AER, and 40–mile AER;
- Fuel cell hybrid — no AER, 10-mile AER, and 40–mile AER; and
- Electric vehicle.

Box 1 Powertrain Systems Analysis Toolkit

The PSAT is a vehicle simulation package developed by Argonne National Laboratory (Argonne) and sponsored by the U.S. Department of Energy. PSAT was designed to be a single tool that can be used to meet the requirements of automotive engineering throughout the development process, from modeling to control. PSAT can be used to optimize a vehicle and its components with regard to:

- Fuel consumption for any driving cycle or profile;
- Vehicle performance, including acceleration and grade;
- Drivetrain configuration;
- Realistic control strategy;
- Component technologies;
- Component sizing; and
- Transmission ratios.

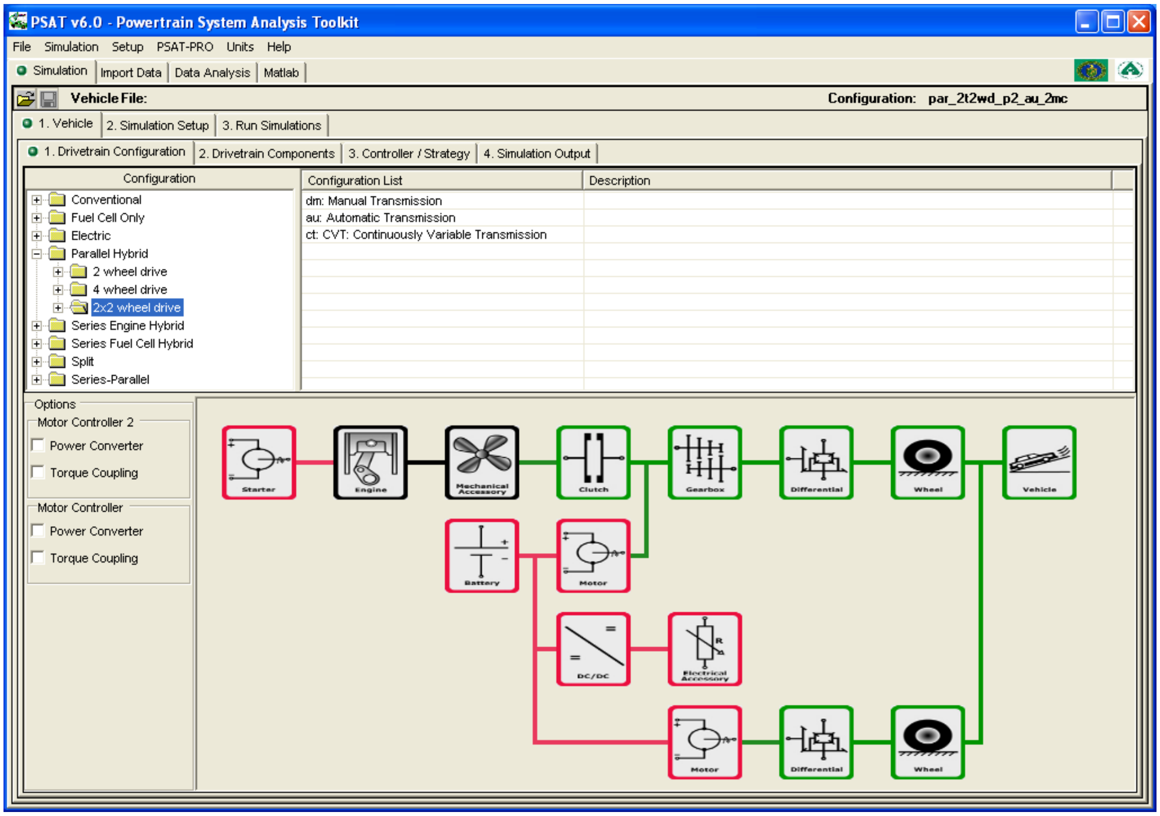
PSAT is DOE's primary vehicle simulation tool to support its FreedomCAR and Fuels Partnership activities. PSAT is also used within major automotive companies and suppliers to support advanced vehicle development programs. As part of the ChallengeX Competition, organized by General Motors and DOE, 17 universities are using PSAT to design powertrain configurations and develop control strategies.

PSAT is a forward-looking simulation package (also called driver-driven). A driver model follows any standard or custom driving cycle, calculating vehicle loads based on input data about the vehicle's aerodynamic and tire rolling resistance coefficients, weight, and accessory requirements and sending a power demand to the vehicle controller, which, in turn, sends a demand to the propulsion components. Models of the engine, transmission, and other components react to the demand and feed back their status to the vehicle controller, and the process iterates at low frequency to allow the vehicle to closely track the driving cycle.

PSAT enables automated powertrain configuration building. Based on the user's selection from the Graphical User Interface (GUI), the entire vehicle model is built on the basis of the powertrain, component models, initialization file, and control strategy choices (Figures B1-1 and B1-2). Several hundred pre-defined configurations can be compared quickly, including conventional, electric, fuel cell, and hybrids (parallel, series, power split, series-parallel). Light-, medium-, and heavy-duty vehicles can be simulated by using a large library of component data. PSAT also allows the users to implement proprietary component models, data sets, control strategies, or drive cycles through the interactive GUI. Component compatibilities are managed through a database.

PSAT uses a wide range of analysis tools including component operating points and Sankey diagrams (energy flow diagrams with the width of flow lines proportional to flow quantity). In addition, a simulation can be replayed through animation. By using test data from Argonne's Advanced Powertrain Research Facility, conventional and mild-hybrid vehicles have been validated within 2% and full hybrid vehicles within 5% for both fuel economy and battery state-of-charge on several driving cycles.

Box 1 (Cont.)



Configuration: par_2t2wd_p2_au_2mc

Configuration List	Description
dm: Manual Transmission	
au: Automatic Transmission	
ct: Continuously Variable Transmission	

☐ Power Converter
☐ Torque Coupling

☐ Power Converter
☐ Torque Coupling

FIGURE B1-1 Graphical User Interface with Drag & Drop

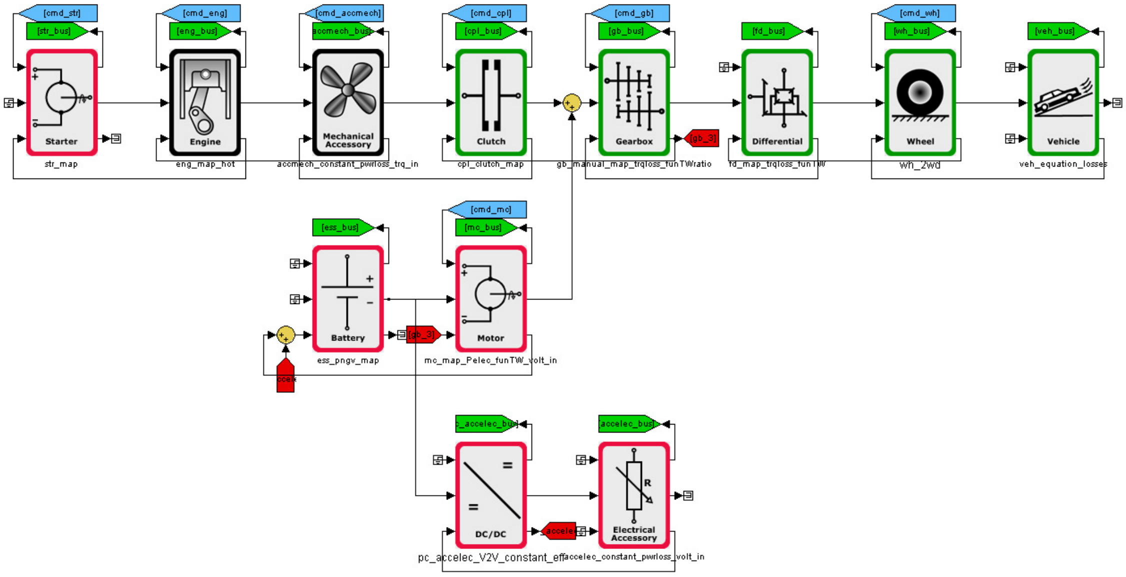


FIGURE B1-2 Example of Powertrain Model

The fuel economy analysis examines performance on the two U.S. Environmental Protection Agency (EPA) driving cycles used to establish compliance with CAFE Standards — the city cycle (Urban Dynamometer Driving Schedule [UDDS]) and highway cycle (Highway Fuel Economy Test [HWFET]). While it would be desirable to examine fuel economy performance on the new EPA battery of five driving cycles, these cycles had not been incorporated into PSAT at the time this study was conducted.

3.2.3 Basic Component Assumptions for the Three Vehicle Types

Table 3-1 provides the basic drivetrain component assumptions used for the three vehicle classes, from the present time to 2045. Table 3-2 provides the performance requirements, which are also applied to all vehicle types.

TABLE 3-1 Component Assumptions for Leading Edge Vehicles

Parameter	Current	2010		2015		2030		2045	
		Med	High	Med	High	Med	High	Med	High
DI GASOLINE									
Specific Power[1] (W/kg)	850	875	900	880	920	920	950	940	980
Peak Efficiency[2] (%)	37	37.5	38	38	39	38.5	40	39	41
DI DIESEL OR OTHER HC FUEL									
Specific Power[1] (W/kg)	420	440	460	460	480	470	500	480	520
Peak Efficiency[2] (%)	41	41	42	42	43	43	45	44	45
Aftertreatm't Ther. Eff.[3] Penalty (%)	2	1.5	1	1	0.5	0.5	0.5	0.5	0.5
FUEL CELL									
Specific Power FC system (W/kg)	500	550	600	600	650	650	700	700	750
Power Density (W/L)	500	550	600	600	650	650	700	700	750
Peak Fuel Cell System Efficiency (%)	60	60	60	60	60	62	65	65	70
ELECTRIC MOTOR									
Motor Specific Power (W/kg)	1110	1200	1300	1250	1600	1400	1800	1500	2000
Power Electronic Sp Power (W/kg)	3680	6000	12000	10000	13000	12000	14000	13000	15000
Motor+Controller Peak Efficiency	90	90	92	91	95	92	95	94	96
AUTOMATIC TRANSMISSIONS									
Gear Number	5	5	6	6	8	8	8	8	8
Gearbox Peak Efficiency (%)	95	96	97	97	98	97	98	97	98
PLANETARY GEARSET TRANSMISSIONS									
Gearbox Peak Efficiency (%)	97	97	98	97.5	98	98	98.5	98	98.5
SINGLE GEAR (FINAL DRIVE…)									
Final Drive Peak Efficiency (%)	97.5	97.5	97.5	97.5	98	98	98	98	98

[1] Engine power density represents the engine, as installed in the vehicle, with intake, exhaust systems, cooling pumps, fans, alternator, etc.

[2] All efficiencies on the engine maps are scaled by using the same ratio.

[3] Fuel economy penalty is applied to diesel because of aftertreatment losses.

TABLE 3-2 Performance Requirements for Leading Edge Vehicles, 2010–2045

Parameter	Unit	Value
0–60 mph	second	9 +/– 0.1
0–30 mph	second	3
30–60 mph	second	6
50–80 mph	second	9
Grade at 65 mph for 20 minutes	%	6
Maximum Speed	mph	> 110

3.2.3.1 ICE Engine Efficiency

From a reference peak of 37% for direct-injected SI engine efficiency, peak efficiency increases to 38% by 2010 and 41% by 2045. The 2010 efficiency values will likely require direct injection coupled with advanced valve control. The 41% efficiency level will likely also require advances in in-cylinder monitoring and control, possibly with camless valve actuation, to allow some use of more efficient thermodynamic cycles (e.g., HCCI operation) other than the conventional Otto cycle.

CI engine peak efficiency is assumed to be 42% in 2010, with a continued gradual increase thereafter, implying continuation of recent improvements in ultra-high-pressure fuel injection and valve control and substantial success in reducing engine friction.

3.2.3.2 Peak Fuel Cell System Efficiency

Current fuel cell systems achieve a peak efficiency of about 55%, generally at low load conditions. The 2010 peak efficiency of 60% matches the FreedomCar and Fuel Partnership goal for 2010 (U.S. Department of Energy 2006), with the High cases reaching 65% by 2030 and 70% by 2045. Achieving these rates of efficiency now appears to be very optimistic. A recent redrawing of DOE assumptions about future fuel cell efficiency for its benefits analysis projects a 2045 peak efficiency rate of 60%. Achieving the higher efficiencies in the later years (e.g., 65–70% in 2045) will require very substantial progress in reducing auxiliary loads, as well as continuing progress in stack efficiency. Although an earlier Massachusetts Institute of Technology (MIT) study (Heywood et al. 2003) projected a 71% system efficiency for an “advanced” fuel cell vehicle in 2020, more recent work by the same authors (Kromer and Heywood 2007) uses much lower peak efficiency values — 47% (conservative) to 52% (optimistic). The implication here is that the fuel economy values for fuel cell vehicles estimated in this analysis may be based on overly optimistic values for maximum fuel cell efficiency, even for a scenario deliberately designed to be optimistic about fuel cell progress.

3.2.3.3 Performance Requirements

Table 3-2 shows the performance requirements for the three vehicle types and all powertrains. Applying the same performance requirements to all powertrains is not standard practice, as analyses of fuel cell and battery electric vehicles often apply less rigorous performance requirements than are demanded of vehicles with ICE powertrains. As discussed above, to the extent that performance requirements normally applied to conventional vehicles would seriously compromise other consumer values (e.g., cost, space) when applied to an alternative drivetrain vehicle, there would be strong pressure to relax these requirements. On the other hand, vehicle performance clearly is an important determinant of value to customers. In this analysis, all vehicles satisfy the same minimum performance requirements (and, to the extent practical, the power of the prime mover [i.e., the engine or fuel cell], battery power, etc., are chosen to meet these requirements precisely).

The performance requirements, being constant over a 35-year period, reflect a sharp change from the trend witnessed from 1987 to 2007 of utilizing ever-increasing horsepower/weight ratios and reductions in 0-to-60 mph acceleration times. This sharp change from the trends of the past two decades is likely to be sustained only when there is some combination of high fuel prices, changes in consumer attitudes about performance, and the performance restrictions inherent in stringent new fuel economy standards. Until quite recently, this assumption would have been considered quite optimistic from the point of view of projecting potential future fuel economy levels, although the "constant performance" assumption is widely used in such analyses. However, recent market conditions characterized by higher (and volatile) gasoline prices, stringent new fuel economy standards, and some market shifts away from lower-efficiency vehicles may signal that the assumption is somewhat more realistic than it may previously have appeared.

3.2.4 Assumptions Regarding Midsize Cars

Table 3-3 provides values for the basic vehicle characteristics of the midsize car, projecting out from today to the year 2045. While the values for the current-year car are for an average vehicle, the characteristics in later years are those of "leading edge" vehicles. The following discussion addresses some of these characteristics in more detail.

TABLE 3-3 Midsize Car (Leading Edge) Characteristics

Parameter	Current	2010		2015		2030		2045	
		Medium	High	Medium	High	Medium	High	Medium	High
Midsize Car (Current -> Glider Mass = 990 kilograms (kg), Frontal Area = 2.2 square meters [m^2], Tire = P195_65_R15)									
Glider mass reduction (%)	0	5	10	10	20	15	30	15	30
Frontal area (m^2)	2.2	2.222	2.2	2.233	2.2	2.266	2.244	2.288	2.244
Drag coefficient(1)	0.29	0.27	0.26	0.26	0.25	0.24	0.22	0.24	0.2
Rolling resistance(2)	0.008	0.0078	0.0075	0.0075	0.007	0.007	0.006	0.0066	0.006
Electrical accessory (Acc) load, conventional configuration (watts [W])(3)	240	220	200	240	220	260	240	280	260
Electrical Acc load, all other configurations (W)(4)	220	210	200	230	220	250	240	270	260
Conventional air conditioning (A/C) (W)(5)	1,780	1,700	1,650	1,530	1,360	1,280	960	1,120	840
Electrical A/C (W)(5)	1,513	1,445	1,403	1,301	1,156	1,088	816	952	714

[1] The ICE HEV will have an increase of 5% for the low case only. The fuel cell HEV will have an increase of 10% for the low case and 1% for the high case.

[2] Additional term of 0.00012 × vehicle speed (in mph) will be used, but this term will remain constant over time.

[3] Includes controllers, measured on the UDDS driving cycle.

[4] Includes controllers and battery fans, measured on the UDDS driving cycle.

[5] Data provided by John Rugh (NREL), where it is assumed that for 50% of the time when the air conditioning (A/C) is on, the vehicle is undergoing a cooldown from a solar soak when the initial interior air and mass will be 60–80°C. The other 50% of the time, the vehicle is assumed to be in steady state operation. The humidity was 65% during the Alternate Refrigerant Cooperative Research Project (ARCRP) tests.

3.2.4.1 Glider Mass Reduction

Reductions in the leading edge vehicle's projected mass for the glider are quite aggressive, reaching 20% for the "high" case in 2015 and 30% for the high case in 2030. This level is considerably below the 50% level previously targeted by DOE for glider weight reduction,[7] but nevertheless reflects a sharp shift from a 20-year trend of gradual weight *increase* for both the car and light truck fleet. This level of weight reduction reflects the assumption of a flattening of the trend toward increased structural stiffness in new vehicle introductions and vehicle redesigns, as well as the increasing use of higher-strength steels, aluminum, and plastics; significant focus on structural design for weight reduction; and reductions in the use of four-wheel and all-wheel drive (for vehicles not designed for off-road travel) as universal adoption of electronic traction and stability control reduces the perceived value of these expensive and weight-adding features. Although the glider does not include the drivetrain, vehicle weights will be reduced further by

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[7] DOE recently has redefined its weight goals and now appears to be focusing on a weight reduction of 50% for the body-in-white (i.e., the vehicle structure and "skin" without the drivetrain, windows, interior furnishings and seats, dashboard, etc.); the target percentage reductions for the glider and the complete vehicle are likely to be considerably lower.

the lower engine power required by the reduced glider mass, coupled with continued increases in engine-specific power and the cessation of the trend toward increased performance. *We consider the assumed ("high") level of weight reduction as extremely aggressive, especially for the 2015 case, and credible only for a leading edge vehicle and for a vehicle that is designed in a market environment that will strongly reward increased fuel economy.*

3.2.4.2 Aerodynamic Drag Coefficient

Although the EPA does not publish data on the aerodynamic drag coefficient of the U.S. fleet, a drag coefficient of 0.3 is thought to be representative of the current fleet average for passenger cars. There are, however, several examples of substantially lower coefficients in the fleet for midsized or slightly larger models. For example, full-sized Lexus LS430 sedans, which retain conventional styling, have a drag coefficient of 0.26 (Carfolio 2008). The 2015 drag coefficient for the leading edge midsized sedan is 0.25. The coefficient is assumed to decrease gradually to 0.20 by 2045, which implies drag-reduction measures such as the elimination of side-view mirrors (replaced with cameras) and the smoothing of the vehicle underbody with some styling changes (but probably not radical ones). The less optimistic 2045 value of 0.24 reflects the possibility that customer resistance emerges to the styling changes needed to produce large reductions in drag.

3.2.4.3 Tire Rolling Resistance

The reference 2007 midsize sedan has tires with a 0.008 rolling resistance coefficient (C_{RR}), and the future coefficients are assumed to be reduced gradually to 0.006 by 2030. Although the 2010 "high" value of 0.0075 may appear quite modest, this value reflects recent consumer resistance to some low rolling-resistance tires because of perceived wear and handling problems. Note that MIT projects 2020 values of 0.006 for "advanced" tires (Heywood et al. 2003). There is little open literature on tire efficiency, so the projected values must be considered somewhat speculative.

3.2.4.4 Accessories

The accessory loads reflect two countervailing trends — the significant ongoing increase in vehicle electrification and features and the improvement in certain accessory efficiencies, especially for air conditioning. Coupled with improved window films and other insulation improvements, energy use for A/C could decline sharply over time. In addition, accessory loads from lighting will decline with the use of liquid crystal display (LCD) lighting, if costs for this type of lighting can be sharply reduced. Other accessory loads, however, may increase.

3.2.5 Crossover SUV Assumptions

Crossover SUVs are adapted from passenger car models and have unibody construction, in contrast to truck-based SUVs (usually adapted from pickup models) that have body-on-frame construction. In essence, they are similar to station wagons and can have vehicle characteristics similar to those of passenger cars. Table 3-4 provides values for the basic vehicle characteristics of the crossover SUV; projections are from today to the year 2045.

The primary difference in vehicle characteristics between crossovers and midsize passenger cars is the drag coefficient, which in current crossover models is considerably higher than those for midsize cars (i.e., an average of about 0.39 vs. about 0.3 for midsize cars). A search of manufacturer Web sites reveals the following aerodynamic drag coefficients for recent (primarily 2007) crossover SUVs:

Jeep Grand Cherokee SRT8 2006	0.39
Hyundai Santa Fe 2007	0.37 (reduced from previous 0.39)
Nissan X-Trail	0.37
Audi Q7	0.34
BMW X5 3.0Si	0.34 (down from previous 0.35 for 2004)
Saab 9000 Aero	0.32

TABLE 3-4 Crossover SUV (Leading Edge) Characteristics

Parameter	Current	2010		2015		2030		2045	
		Medium	High	Medium	High	Medium	High	Medium	High
Crossover SUV (Current -> Glider Mass = 1,160 kg, Frontal Area = 2.68 m^2, Tire = P235_65_R16)									
Glider mass reduction (%)	0	5	10	10	20	15	30	15	30
Frontal area (m^2)	2.68	2.7068	2.68	2.7202	2.68	2.7604	2.7336	2.7872	2.7336
Drag coefficient(1)	0.39	0.34	0.34	0.33	0.32	0.32	0.3	0.32	0.3
Rolling resistance(2)	0.0084	0.0078	0.0075	0.0075	0.007	0.007	0.006	0.0076	0.006
Electrical Acc load, conventional configuration (W)(3)	240	220	200	240	220	260	240	280	260
Electrical Acc load, all other configurations (W)(4)	220	210	200	230	220	250	240	270	260
Conventional A/C (W)(5)	1,780	1,700	1,650	1,530	1,360	1,280	960	1,120	840
Electrical A/C (W)(5)	1,513	1,445	1,403	1,301	1,156	1,088	816	952	714

[1] The ICE HEV will have an increase of 5% for the low case only. The fuel cell HEV will have an increase of 10% for the low case and 1% for the high case.

[2] Additional term of 0.00012 × vehicle speed will be used, but this term will remain constant over time.

[3] Includes controllers, measured on UDDS driving cycle.

[4] Includes controllers and battery fans, measured on UDDS driving cycle.

[5] Data provided by John Rugh (NREL), where it is assumed that for 50% of the time when the A/C is on, the vehicle is undergoing a cooldown from a solar soak when the initial interior air and mass will be 60–80°C. The other 50% of the time, the vehicle is assumed to be in steady state operation. The humidity was 65% during the ARCRP tests.

These values show that the 2010 C_D value of 0.34 is conservative, because it has already been met by the Audi Q7 and BMW X5. However, this value was selected as a 2010 target because the Audi and BMW are luxury vehicles that may not be fully representative of the fleet. While the Saab's value of 0.32 may indicate further downside potential, it was unclear whether this vehicle should be considered a true crossover SUV, and its C_D value was therefore disregarded in the projection.

3.2.6 Midsize SUV Assumptions

This vehicle type is built on a robust truck frame with substantial ground clearance, and its construction adds substantially to its weight and causes higher aerodynamic drag. In addition, its service characteristics (e.g., towing and off road capabilities) affects tire tread design and tends to add to rolling resistance. Consequently, the glider characteristics in Table 3-5 are inherently less efficient than those for the midsize passenger car and crossover SUV, although the potential for *improvement from baseline levels* is quite similar to the improvement potential for the other two vehicle types.

TABLE 3-5 Midsize SUV (Leading Edge) Characteristics

Parameter	Current	2010		2015		2030		2045	
		Medium	High	Medium	High	Medium	High	Medium	High
Midsize SUV (Current -> Glider Mass = 1,260 kg, Frontal Area = 2.88 m^2, Tire = P235_70_R16)									
Glider mass reduction (%)	0	5	10	10	20	15	30	15	30
Frontal area (m^2)	2.88	2.9088	2.88	2.9088	2.88	2.9664	2.9376	2.9952	2.9376
Drag coefficient(1)	0.41	0.39	0.38	0.38	0.37	0.37	0.35	0.35	0.33
Rolling resistance(2)	0.0084	0.0082	0.008	0.0078	0.0075	0.0078	0.007	0.0074	0.007
Electrical Acc load, conventional configuration (W)(3)	240	220	200	240	220	260	240	280	260
Electrical Acc load, all other configurations (W)(4)	220	210	200	230	220	250	240	270	260
Conventional A/C (W)(5)	2,200	2,100	2,000	1,890	1,680	1,581	1,186	1,384	1,038
Electrical A/C (W)(5)	1,870	1,785	1,700	1,607	1,428	1,344	1,008	1,176	882

[1] The ICE HEV will have an increase of 5% for the low case only. The fuel cell HEV will have an increase of 10% for the low case and 1% for the high case.

[2] Additional term of 0.00012 × vehicle speed will be used, but this term will remain constant over time.

[3] Includes controllers, measured on UDDS driving cycle.

[4] Includes controllers and battery fans, measured on UDDS driving cycle.

[5] Data provided by John Rugh of NREL, where it is assumed that for 50% of the time when the A/C is on, the vehicle is undergoing a cooldown from a solar soak when the initial interior air and mass will be 60–80°C. The other 50% of the time, the vehicle is assumed to be in steady state operation. The humidity was 65% during the ARCRP tests.

3.2.7 PSAT Modeling Concerns

The use of a vehicle simulation model to project the fuel economy of future advanced vehicles represents an opportunity to evaluate and compare these vehicles with improved accuracy. However, there are significant sources of uncertainty involved with this modeling, and these sources should be understood in gauging the accuracy of the results.

Input assumptions. The most obvious source of uncertainty is the set of input assumptions about key variables associated with vehicle efficiency — the variables describing vehicle loads (e.g., coefficients of aerodynamic drag and rolling resistance, weight reduction) and drivetrain efficiency (e.g., maximum engine and motor efficiency, engine specific power). Future changes in these variables involve difficult tradeoffs among cost, efficiency, durability, and other variables, as well as the inherently uncertain progress in technical advancement. The Multi-Path team specified many of the input variables for the modeling, particularly those associated with vehicle loads (C_D, C_R, and percentage of weight reduction), but had to rely on the PSAT team for most drivetrain variables. One remaining source of concern is the maximum efficiencies of the ICE engines. The PSAT team, with advice from industry, originally set SI (direct injection [DI] gasoline) engine efficiency to improve by 3 percentage points over the time frame (Table 3-1) and CI (DI diesel) efficiency to improve by 4 percentage points. This assumption appears to contradict widely shared industry predictions that SI engines will become more "diesel-like" in the future, with converging efficiencies between the two engine types. As shown in Table 3.1, the final value for the current-to-2045 increase in SI engine efficiency was raised to 4% to align more closely with recent industry projections.

Availability of engine maps. Another area of uncertainty is the process of translating projected levels of technical advancement into the mathematical format required by the simulation model. This is primarily a problem with drivetrain advances. For example, future spark-ignited engines are projected to have several technologies that will change the shape of engine maps (of torque vs. fuel consumption at varying engine speeds), as well as increase maximum engine efficiency. However, engine maps that show the individual effect of each of these technologies, or the combined effects of multiple technologies, generally are not available to the PSAT modeling team. In the absence of such maps, the PSAT team has been forced to adjust available maps from existing engines, shifting the fuel consumption surfaces uniformly downward (toward lower fuel consumption at each torque/speed combination) to capture the effect(s) of higher levels of maximum efficiency. This procedure inherently misses subtle but important effects of the technologies, such as in "flattening" the surfaces of the map's constant-fuel consumption contours so that engine operation away from the maximum efficiency point may not lose as much efficiency as would have occurred in less-advanced engines. This simplification of the modeling process — again, made necessary by the lack of data — reduces the ability of the model to capture interactive effects among and between multiple drivetrain improvements.[8] Examining the PSAT model run results for conventional SI drivetrains indicates that the estimated average increases in engine efficiency over the combined EPA driving cycles are considerably lower than projected by industry sources. In response, we decided to "correct" the fuel economy results for these drivetrains by estimating the effects of boosting cycle-average engine efficiency in accord with these industry projections. Box 2 describes these corrections.

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[8] For example, transmission improvements that allow engines to operate closer to maximum efficiency over a wider range of operating conditions may lose some of their benefits if a simultaneous engine improvement "flattens" the fuel consumption map. In other words, the engine improvement captures some of the losses that would otherwise have been captured by the transmission improvement.

Box 2 “Correcting” PSAT Fuel Economy Results for SI Conventional Drivetrain Vehicles

The PSAT fuel economy values for vehicles with conventional SI drivetrains are considerably lower than those projected for similar vehicles (with virtually identical load characteristics) by MIT (e.g., in Kromer and Heywood 2007). Examining the PSAT-generated values for engine efficiency shows that these efficiencies — which are determined for the EPA driving cycles by both the engine map and the modeled transmission characteristics — are quite low when compared to recent industry claims about both current transmissions (e.g., 6- to 8-speed transmissions from Mercedes, Toyota) and future advanced SI engines that will have improved valve control and the ability to shift away from the Otto cycle during part of engine operations, etc. The problem appears largely to be the result of the lack of engine maps for advanced engines, though perhaps there are some issues with the modeling of the transmissions as well. In any case, the PSAT fuel economy results for these vehicles have been adjusted by adjusting the engine cycle efficiencies upward to conform more closely to recent industry estimates of the efficiency increases associated with engine and transmission advances.

Table B2-1 shows how this adjustment was made for the “high fuel economy” case vehicles. The second column shows the assumed engine efficiency boosts, which are based on recent literature and industry statements. Column 3 shows the actual PSAT engine efficiencies (the model printout gives these efficiencies separately for each cycle; these were combined into a single efficiency for the combined cycle because most industry estimates of efficiency increases are based on the combined cycle). Column 4 shows the incremental efficiency boost over the reference for comparison to the value in column 2. And column 5 simply shows the increase to the PSAT incremental boost that would be necessary to match the value in column 2; this factor can be applied to the PSAT-modeled fuel economy (in column 6) to “correct” it to the value implied by the efficiency boost in column 2.

TABLE B2-1 Translating Assumed Engine/Transmission Efficiency Boost into Revised MPG Values for PSAT Output — “High Fuel Economy” Case

(1) Year of introduction for leading edge vehicle	(2) Assumed engine efficiency boost, as % over reference vehicle[1]	(3) PSAT engine efficiency over combined driving cycle (%)	(4) PSAT engine efficiency boost as % over reference vehicle	(5) Incremental increase to PSAT boost required to match assumed efficiency boost (%)	(6) PSAT unadjusted fuel economy (miles per gallon [MPG])	(7) New fuel economy assuming more efficient engine/ transmission (MPG)
Midsize Car						
Reference	–	20.6	–	–	28.9	–
2010	10	21.6	4.85	4.91	34.1	35.8
2015	18	22.7	10.19	7.09	35.2	37.7
2030	25	23.0	11.65	11.96	39.6	44.3
2045	30	23.4	13.59	14.45	41.1	47.0
Midsize SUV						
Reference	–	22.1	–	–	22.7	–
2010	10	22.9	3.62	6.16	26.2	27.8
2015	18	24.7	11.76	5.58	27.8	29.4
2030	25	25.6	15.84	7.91	30.8	33.2
2045	30	26.0	17.65	10.50	32.0	35.4
Crossover SUV						
Reference	–	22.0	–	–	24.3	–
2010	10	22.8	3.64	8.06	29.2	31.6
2015	18	24.0	9.09	8.17	30.5	33.0
2030	25	24.5	11.36	12.25	33.9	38.1
2045	30	25.2	14.55	13.49	34.8	39.5

[1] Engine efficiency boost over cycle is caused both by improved engine and improved transmission.

Box 2 (Cont.)

Assumptions:

- **2010:** stoichiometric direct injection (DI), improved valvetrain, 6-speed automatic transmission.
- **2015:** lean-burn DI, 6-speed automated manual transmission or 7-/8-speed automatic, lean-burn DISI.
- **2030:** lean-burn direct injection, camless valves, 7-/8-speed automatic or continuously variable transmission (CVT), with some HCCI at low loads.
- **2045:** same as 2030 but with greater range for HCCI operation.
- **All dates:** naturally aspirated engines; turbocharging would increase MPG boost.

Although the same engine maps were used by PSAT for vehicles with hybrid SI drivetrains, the derived fuel economy values appear to agree reasonably well with other results (e.g., MIT). A possible reason is that the primary problem with the engine maps — that they do not reflect improvements in off-peak engine operations — is minimized by hybridization, which keeps the engine quite close to peak efficiency. No correction was attempted for these hybrid drivetrain vehicles.

Table B2-2 repeats the adjustment process for the set of "Average Fuel Economy" vehicles, which represent somewhat lower expectations for improvements in the SI drivetrain but also in the glider, that is, there will be higher aerodynamic and drag coefficients, slightly less efficient tires, and a lower percentage of weight reduction.

Table B2-2 Translating Assumed Engine/Transmission Efficiency Boost into Revised MPG Values for PSAT Output — "Average Fuel Economy" Case

(1) Year of introduction for leading edge vehicle	(2) Assumed engine efficiency boost, as % over reference vehicle[1]	(3) PSAT engine efficiency over combined driving cycle (%)	(4) PSAT engine efficiency boost as % over reference vehicle	(5) Incremental increase to PSAT boost required to match assumed efficiency boost (%)	(6) PSAT unadjusted fuel economy (MPG)	(7) New fuel economy assuming more efficient engine/ transmission (MPG)
Midsize Car						
Reference	–	20.6	–	–	28.9	–
2010	8	21.4	3.88	3.97	31.6	32.9
2015	15	21.8	5.83	8.66	34.0	36.9
2030	20	22.5	9.22	9.87	33.61	36.9
2045	25	22.8	10.68	12.94	35.1	39.6
Midsize SUV						
Reference	–	22.1	–	–	22.7	–
2010	8	22.9	3.62	4.23	24.7	25.7
2015	15	23.1	4.52	10.03	26.4	29.0
2030	20	24.5	10.86	8.24	26.11	28.3
2045	25	24.7	11.76	11.85	27.6	30.9
Crossover SUV						
Reference	–	22.0	–	–	24.3	–
2010	8	22.4	1.82	6.07	27.2	28.9
2015	15	22.8	3.64	10.96	29.2	32.4
2030	20	23.7	7.73	11.39	28.61	31.9
2045	25	24.4	10.91	12.70	29.6	33.4

[1] The values for 2030 appear to be incorrect. It is likely that an input error was made in running the PSAT model for this year.

Box 2 (Cont.)

At the time this report was written, the PSAT team had just introduced new engine maps based on a recent paper by AVL (Bandel et al. 2006) into model runs made for DOE's R&D benefits calculations; these maps significantly raised the estimated fuel economy increases expected for future SI conventional drivetrains. Comparisons of the percentages in fuel economy increases over the Reference Case values for the "high" cases for the midsize car show the following:

Year	2010 (%)	2015 (%)	2030 (%)	2045 (%)
Original PSAT results	18	22	37	42
Corrected results	24	30	53	63
New AVL-based results	27	32	51	53

It appears that the AVL-based PSAT analysis provides a good way of improving the fuel economy analysis for conventional SI drivetrains at least until 2030, but does not capture potential longer-term improvements projected by industry analysts.

Multiplicity of hybrid designs. A source of uncertainty particularly associated with hybrid vehicles is the effect of different hybrid designs and control strategies on fuel economy. In designing a hybrid vehicle, considerable choice is available in the balance between the ICE and the electric part of the drivetrain, both in selecting power levels of the individual components (engine, battery, and motor) and in balancing use of the engine, battery, and motor in providing energy and powering the wheels. The task becomes even more complex when designing a plug-in hybrid, because concerns about battery longevity strongly enter the design process. For the Multi-Path Study, singular solutions to designing the vehicle components and the drivetrain control strategy are selected; the effect of different solutions on fuel economy (as well as cost and other factors) is an area well worth further investigation. The result of using singular design solutions has led to some odd fuel economy results among the various hybrid vehicles, and clearly it would be advantageous — although expensive — to perform some iteration in the designs to avoid anomalous results.

PHEVs and blended or EV operation. The PSAT analyses of PHEVs illuminated some difficult issues for the MP Study, as well as for other analyses that depend on PSAT and other vehicle simulation models for their PHEV energy consumption analyses. In PSAT runs for Phase 1 of this study, our concept of a PHEV was a vehicle that operated in pure EV mode until the battery was depleted and then shifted to charge sustaining mode, operating as a conventional hybrid vehicle until the vehicle could be recharged. Evaluating this type of PHEV is relatively straightforward because battery and motor power will be unambiguously defined by the performance requirements in EV mode, and this definition will determine engine power based on the performance requirements in HEV mode. On the basis of the advice of analysts who have examined PHEVs, however, our concept of PHEV design and operation has changed. For the latest set of PSAT runs, the concept has shifted to a vehicle that would operate first in charge-depleting mode with both engine and battery/motor engaged to varying degrees (the motor and battery would be the primary driver, but the engine would occasionally assist the electric drive during periods when a high level of power was demanded); as with the earlier concept, when the battery reached a predetermined depth of discharge, vehicle operation would shift to normal hybrid charge-sustaining mode. This "blended" concept has gained favor because it reduces the power requirements (and costs) for the electric motor (since it need not satisfy performance requirements without help from the engine) and battery (i.e., for a fixed energy storage requirement, demanding high power raises battery cost).

This blended concept introduces considerable variability into the analysis, because critical values such as the distance to full battery discharge — and thus the percent of miles "electrified," a crucial outcome of the analysis — will depend on how much the engine is used, which is determined by the control strategy adopted. For example, to keep engine efficiency at high levels, the control strategy might cause the engine to be operated at higher power levels than required merely to satisfy load requirements, which would cause engine recharging of the battery — extending the range to full battery discharge. In fact, the previous set of PSAT runs for these blended PHEVs yielded "distances to discharge" that, in some cases, were double the rated distance, with a PHEV40, for example, requiring 80 miles or more to full discharge. To avoid such results, we asked for a new set of runs with vehicle control strategies designed to maintain "distance to full discharge" (on the UDDS cycle) at no more than 20% higher than the rated distance (in other words, a blended mode PHEV40 would reach full discharge at no longer than 48 miles).

Accuracy of corrections for on-road operation. It has been shown that the EPA fuel economy values, which are based on the UDDS and HWFET city and highway cycles, are quite unrepresentative of values obtained by most drivers. This issue is strongly exacerbated when using the existing two-cycle procedure on advanced vehicles, because the original method (including adjustments) was based on data on conventional vehicles. The EPA has designed a new calculation procedure for on-road fuel economy based on five driving cycles, including the original two. The added cycles will take some account of the effects that use of accessories (especially air conditioning) and aggressive driving have on on-road fuel economy. However, the accuracy of the new procedure has not been established. While the Multi-Path Study had hoped to report fuel economy based on both the old two-cycle method and the new five-cycle method, the PSAT team was unable to add the new cycles to their calculations in time for these runs.

3.2.8 Fuel Economy Results for Leading Edge Vehicles

Tables 3-6 through 3-9 and Figures 3-1 through 3-4 show the average/medium and high fuel economy results from the PSAT analysis (with the results for the SI conventional drivetrain corrected to account for engine improvements not fully accounted for in the PSAT analysis). It is of note that the results for the PHEVs in Tables 3-6, 3-8, and 3-9 and Figures 3-1 and 3-2 reflect their efficiency in normal hybrid operation (charge sustaining or CS mode), *not* their benefits when drawing down their batteries and recharging from the electricity grid. Table 3-7 shows the fuel economy results for the leading-edge midsize passenger car from combined fuel and electricity usage, for the sake of comparison. Figures 3-3 and 3-4 graphically illustrate these results for the High and Average cases. Key conclusions from these results are:

- By 2030, it may be possible to achieve improvements to fuel economy of upwards of 50% without resorting to hybrid drivetrains or diesel (compression

TABLE 3-6 PSAT Fuel Economy Results for Leading Edge Midsize Passenger Cars (unadjusted combined MPG, SI Conventional results corrected; PHEV results reflect charge-sustaining/gasoline or hydrogen-only operation)

DRIVETRAIN	2007	2010		2015		2030		2045	
	Ref	avg	high	avg	high	avg	high	avg	high
SI Conv	28.9	32.9	35.8	36.9	37.7	36.9	44.3	39.6	47.0
CI Conv	37.5	40.9	44.4	44.2	46.4	44.9	53.8	47.4	54.6
SI Full HEV	46.0	50.6	62.0	60.2	72.2	66.4	83.1	70.9	88.6
SI PHEV10	46.4	49.9	61.2	60.0	72.3	66.3	81.6	71.1	86.7
SI PHEV40	45.3	48.7	60.8	58.7	71.0	65.4	80.3	70.3	85.8
CI Full HEV	48.5	53.0	66.6	64.5	75.8	71.8	89.0	76.9	91.3
CI PHEV10	49.5	52.8	66.5	64.1	78.1	73.1	92.0	78.9	95.7
CI PHEV40	48.0	51.3	64.8	62.6	76.8	71.3	90.5	77.8	94.4
FC HEV	57.7	64.5	76.0	73.4	87.6	83.6	107.1	94.2	120.8
FC PHEV10	60.3	67.6	79.3	76.7	91.3	87.5	111.8	98.1	126.1
FC PHEV40	57.4	64.4	76.2	73.8	88.1	84.1	108.3	95.1	122.2

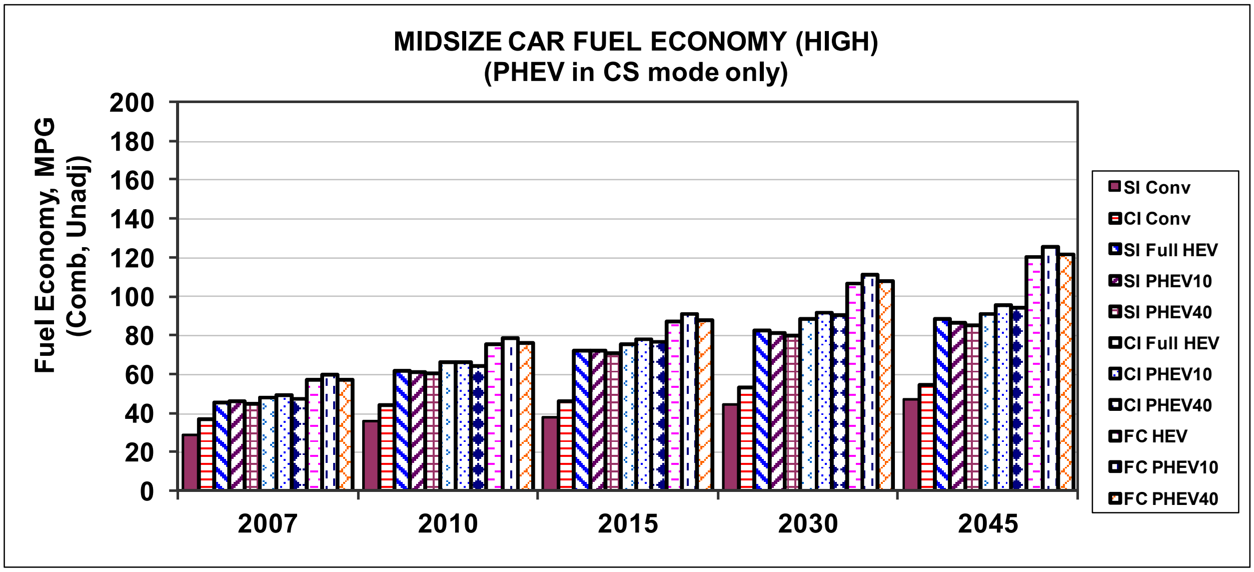

FIGURE 3-1 High Fuel Economy Values for Leading Edge Midsize Passenger Cars (unadjusted MPG; PHEVs in CS/gasoline or hydrogen-only mode)

ignition) engines. This result reflects sharp reductions in vehicle loads (aerodynamic, rolling resistance, and inertia/weight), improved transmissions that are already entering the fleet, and SI engine improvements that will move gasoline engines closer to diesels in efficiency.

- With more modest (although, given past trends, still optimistic) assumptions about engine improvements and the extent to which higher fuel economy will be preferred over other vehicle attributes, fuel economy improvements of 25% to 30% might be expected for non-hybridized SI drivetrains. This level of improvement would fall short of that needed to satisfy the new CAFE standards (35 MPG for the combined car and light truck fleet by 2020, or an improvement of about 40%), implying that shifts toward use of more hybrid and diesel drivetrains would be necessary to comply with the standards. The recent new target of 35.5 MPG by 2016 may increase the need for such shifts.

- In this time frame, a shift to diesel engines would allow fuel economy improvements of 55% to upwards of 80% (if the same vehicle load reductions were adopted).

- The addition of full hybrid drivetrains could allow fuel economy levels to approach 2.3 to 3 times that of current levels in this time frame if the efficiency of hybrid components continues to improve.

- Fuel cell drivetrains can improve efficiency still more on a miles-per-gallon-of-gasoline-equivalent (MPGGE) basis, although future fuel cell efficiencies are quite difficult to predict because the pace of continued technological progress and tradeoffs between efficiency and cost or performance are unclear. As noted above, the assumed maximum fuel cell system efficiencies adopted for these analyses appear to be more optimistic than projected in recent assessments, so the fuel economy results may not reflect our current understanding of fuel cell system efficiency. However, new PSAT runs that reflect lower maximum fuel cell efficiencies yielded similar high fuel economies; the lower fuel cell efficiencies were balanced in the newly modeled vehicles by lower drivetrain weight, improved regenerative braking, and improvements in control strategy.

- Plug-in hybrid drivetrains can yield fuel economy improvements similar to more conventional hybrid drivetrains when they are operating in charge-sustaining operation. Further, they can allow grid electricity to substitute for liquid fuels during a substantial portion of daily operation. In gasoline-equivalent terms (i.e., valuing each kilowatt-hour [kWh] of electricity as 3,413 British thermal units [BTUs], or about 34 kWh per gallon of gasoline equivalent [GGE]), PHEV40s can attain fuel economy levels above 100 MPGGE by 2030. In liquid fuel terms, for the "high" case, an SI PHEV40 in 2030 would use, on average, a gallon of gasoline every 150 or more miles,[9] yielding a five-fold or higher reduction in gasoline use compared to today's gasoline vehicles.

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[9] It is expected that a PHEV40 will "electrify" about half of its miles, on average. With a fuel economy of about 80 MPG during charge-sustaining operation (and little if any gasoline use during charge-depleting operation), a PHEV40 in 2030 would use about 1 gallon of liquid fuel for each 160 miles traveled. Assuming nightly recharging of its battery, the PHEV40 would also use about 14 kWh of electricity from the grid for each 160 miles (in average operation), based on charge-depleting electricity use of about 160 watt-hours (wh)/mile without accounting for charger losses.

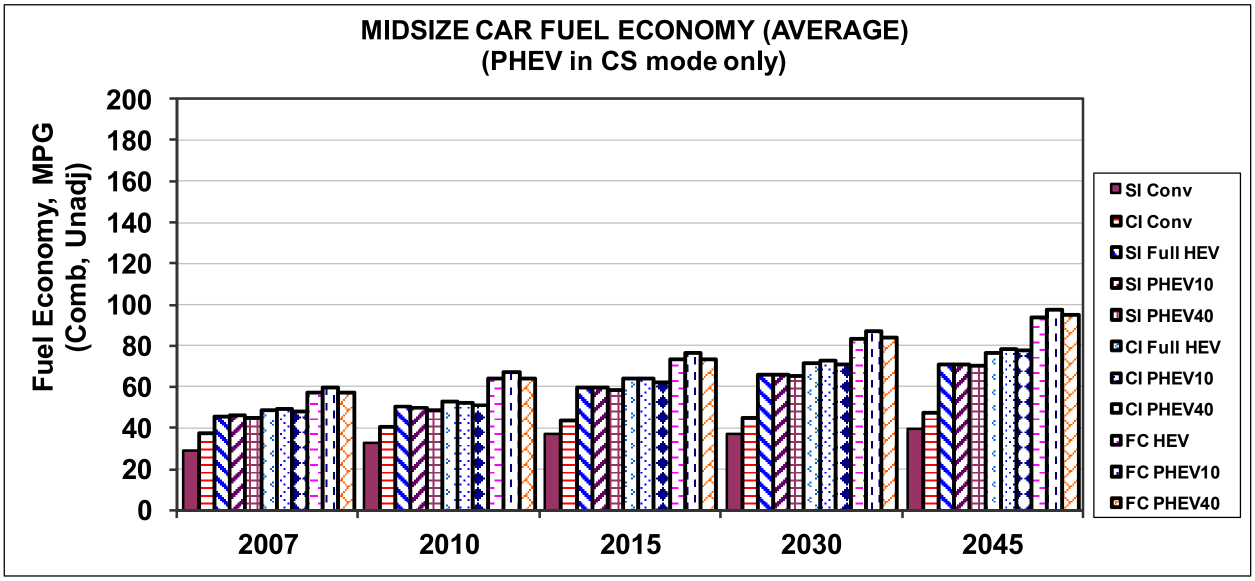

FIGURE 3-2 Average Fuel Economy Values for Leading Edge Midsize Passenger Cars (unadjusted MPG; PHEVs in CS/gasoline or hydrogen-only mode)

TABLE 3-7 PSAT Fuel Economy Results for Leading Edge Midsize Passenger Cars (unadjusted combined MPG), with PHEV Results Reflecting Both Fuel and Electricity Use

DRIVETRAIN	2007	2010	2010	2015	2015	2030	2030	2045	2045
	Ref	avg	high	avg	high	avg	high	avg	high
SI Conv	28.9	32.9	35.8	36.9	37.7	36.9	44.3	39.6	47.0
CI Conv	37.5	40.9	44.4	44.2	46.4	44.9	53.8	47.4	54.6
SI Full HEV	46.0	50.6	62.0	60.2	72.2	66.4	83.1	70.9	88.6
SI PHEV10	52.3	56.2	68.6	67.2	80.8	74.2	90.9	79.6	96.6
SI PHEV40	67.2	72.4	89.4	86.3	103.5	95.5	116.2	102.5	123.4
CI Full HEV	48.5	53.0	66.6	64.5	75.8	71.8	89.0	76.9	91.3
CI PHEV10	55.5	59.3	74.2	71.5	86.7	81.4	101.7	87.5	105.8
CI PHEV40	70.3	75.1	93.4	90.4	110.1	101.5	126.0	110.8	131.1
FC HEV	57.7	64.5	76.0	73.4	87.6	83.6	107.1	94.2	120.8
FC PHEV10	65.9	73.7	86.0	83.3	99.0	94.6	120.2	105.5	134.3
FC PHEV40	77.3	85.7	99.9	97.1	115.9	108.8	138.0	121.6	150.7
EV	97.0	119.5	122.0	129.5	142.0	144.3	163.0	155.8	171.0

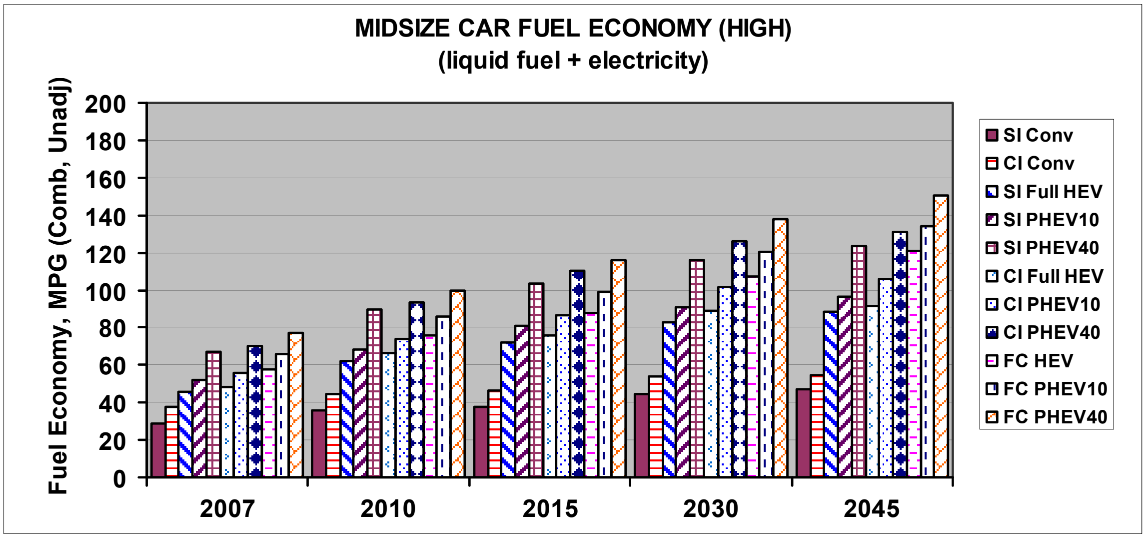

FIGURE 3-3 High Fuel Economy Values for Leading Edge Midsize Passenger Cars (unadjusted MPG), with Fuel Economy Values for PHEVs Reflecting Both Gasoline and Electricity Use (where 17.4% of miles for PHEV10s are electric, and 50.9% of miles for PHEV40s are electric)

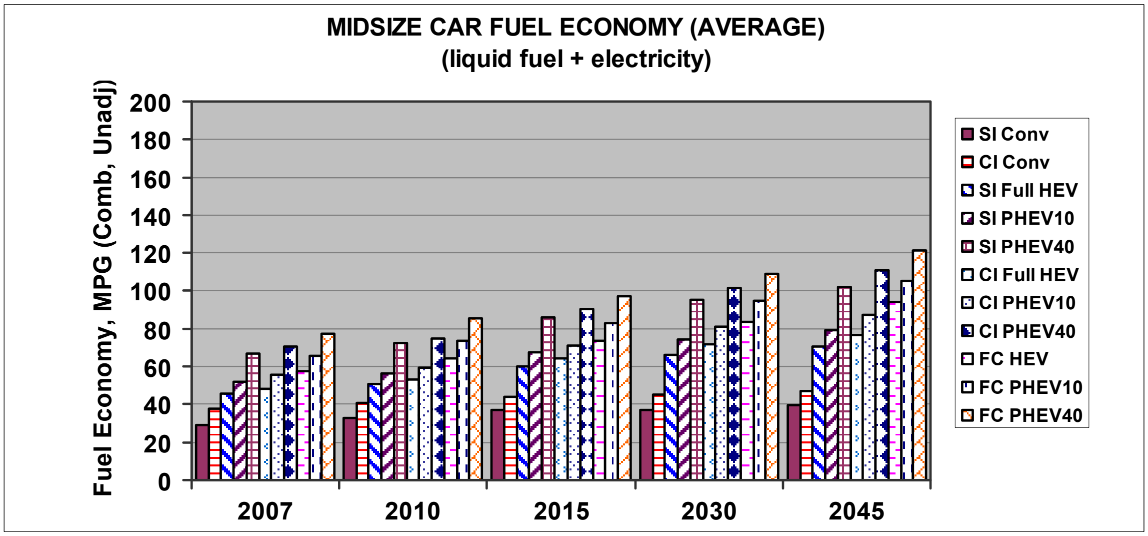

FIGURE 3-4 Average Fuel Economy Values for Leading Edge Midsize Passenger Cars (unadjusted MPG), with Fuel Economy Values for PHEVs Reflecting Both Gasoline and Electricity Use (where 17.4% of miles for PHEV10s are electric, and 50.9% of miles for PHEV40s are electric)

TABLE 3-8 PSAT Fuel Economy Results for Leading Edge Crossover SUVs (unadjusted combined MPG; SI Conventional results corrected; PHEV results reflect charge-sustaining/gasoline or hydrogen-only operation)

DRIVETRAIN	2007	2010		2015		2030		2045	
	Ref	avg	high	avg	high	avg	high	avg	high
SI Conv	24.3	28.9	31.6	32.4	33.0	31.9	38.1	33.4	39.5
SI Full HEV	36.5	42.5	49.9	49.2	57.9	53.5	65.6	55.0	67.5
SI PHEV10	36.7	42.4	50.5	49.7	58.3	53.4	65.3	55.1	67.5
SI PHEV40	35.7	41.4	49.2	48.4	57.2	52.4	64.2	54.2	66.3
CI Full HEV	37.4	43.5	53.5	52.6	61.0	56.8	70.3	58.7	70.8
CI PHEV10	38.5	43.8	52.7	51.6	62.6	57.7	71.6	60.2	72.4
CI PHEV40	37.9	42.9	51.9	50.7	61.8	56.8	70.8	59.2	71.6
FC HEV	45.1	52.3	60.4	59.1	69.9	66.2	83.9	71.9	91.9
FC PHEV10	46.4	54.1	62.3	61.1	72.1	68.3	86.5	73.8	94.7
FC PHEV40	44.5	51.9	59.9	58.9	69.6	65.7	83.6	71.0	91.6

TABLE 3-9 PSAT Fuel Economy Results for Leading Edge SUVs (unadjusted combined MPG; SI Conventional results corrected; PHEV results reflect charge-sustaining/gasoline or hydrogen-only operation)

DRIVETRAIN	2007	2010		2015		2030		2045	
	Ref	avg	high	avg	high	avg	high	avg	high
SI Conv	22.7	25.7	27.8	29.0	29.4	28.3	33.2	30.9	35.4
SI Full HEV	34.0	37.7	44.3	43.7	50.6	46.7	56.1	50.3	58.9
SI PHEV10	34.3	38.3	44.8	43.8	51.0	46.5	55.9	50.6	59.4
SI PHEV40	33.5	37.2	43.8	42.8	50.0	45.4	55.0	49.4	58.3
CI Full HEV	34.9	38.4	46.1	44.8	52.7	48.5	59.5	53.4	61.7
CI PHEV10	36.2	39.1	46.6	45.6	54.3	49.8	60.7	54.9	63.1
CI PHEV40	35.5	38.3	45.9	44.8	53.5	49.0	59.9	54.1	62.3
FC HEV	42.1	45.6	53.0	51.7	60.4	56.8	70.9	64.8	79.6
FC PHEV10	43.2	46.9	54.5	53.1	62.0	58.3	72.6	66.5	81.7
FC PHEV40	41.0	45.1	52.3	50.9	60.0	56.2	70.1	64.4	79.2

3.2.9 Rules for Estimating Average Vehicle MPG By Class, Technology, and Year

The discussion up to this point focuses on estimating the fuel economies of *leading edge* midsize passenger cars and midsize SUVs using a variety of drivetrain technologies in several target years. For the study's economic analyses, which use the NEMS model, it is necessary to translate this limited set of results into the format demanded by the model: fuel economy estimates for *average* vehicles that use that technology in each of *12* vehicle classes for the year of introduction and every five years afterwards, as well as 2040 and 2050. Box 3 describes a set of rules that were followed to estimate the fuel economy values for these average vehicles. The rules are meant to conform roughly to how the process of technology introduction and gradual improvement will play out — namely, after technologies are introduced into the fleet, the segment of each class using that technology will evolve as improved versions of the technology are introduced; new leading edge designs will be introduced and rolled into the segment, gradually replacing older designs. The final values developed for each of the 12 vehicle classes are presented in Appendix A.

Box 3 Rules for Estimating Fuel Economy of Average Vehicles Using Different Drivetrain Technologies

1. "Leading edge" vehicle fuel economies for midsize passenger cars and midsize SUVs with each of the 11 drivetrain types are obtained for 2010, 2015, 2030, and 2045 from the PSAT analysis.
2. To obtain leading edge fuel economy values for the intervening years, linear interpolation is used.
3. Leading edge "X" factors are defined as the ratios of the leading edge MPG to a reference (gasoline ICE) MPG, where the reference MPG is the new vehicle MPG for that vehicle class in the NEMS-MP Base Case (in that year). The NEMS-MP Base Case is further discussed in Chapter 6. The Base Case incorporates CAFE requirements passed in December 2007.
4. Average "X" factors are estimated that define the MPG multiple representing all of the new vehicles with specific drivetrain types in each class:
   a. When a drivetrain technology is first introduced to a vehicle class, all vehicles using that technology are leading edge vehicles, so the average X factor in that introductory year is the same as the leading edge X factor.
   b. As more advanced versions of these vehicles are introduced, they are rolled into the new vehicle fleet gradually. To estimate what the average X factor is in later years, a linear interpolation is made between the average X factor in the year of introduction and the average X factor in the year 2050, the latter defined as:
      2050 average X factor = (2030 leading edge X factor + 2×2045 leading edge factor)/3.
   c. When examples of an advanced drivetrain already exist in the fleet, the above procedure must be modified; this applies to diesels and SI HEVs in some vehicle classes.[2] For these classes, in any year following introduction of advanced technology vehicles, the average fuel economy of the vehicles in such classes will be lower than that of the leading edge vehicle because the average will combine the fuel economies of both the leading edge and the less-advanced vehicles. To address this issue, we assume that:
      i. The years 2010 through 2019 are the only years in which both types of vehicles will be produced;
      ii. By 2020, the average X factor of the vehicles in these classes will be the same as that of a 2020 advanced vehicle first introduced in 2010;
      iii. For these vehicles, the average X factors for the years 2010 through 2019 will be estimated by linear interpolation between the Base Case 2009 X factors and the 2020 X factor described in "ii" above;
      iv. Post-2020, the average X factors will be the same as those that would apply to an advanced vehicle first introduced in 2010.
5. The average X factors calculated for the midsize car and midsize SUV are applied to the six categories of cars and six of light trucks, respectively.

[1] Underlying this calculation is the assumption that the 2030 leading edge X factor will become the 2040 average X factor and that the 2045 leading edge X factor will become the 2055 average X factor (i.e., we have applied a "10 year roll-in" rule to each class and technology (and the formula uses linear interpolation to calculate the 2050 average X factor). In retrospect, this assumption of a 10-year roll-in seems pessimistic. Although 10 years is an optimistic timeline for a new technology to penetrate the light vehicle fleet, the "penetration" here occurs in one class only and in later years stands for improvements to technologies, not new technologies. This type of penetration should be capable of happening more quickly.

[2] The "advanced SI conventional" drivetrain is treated here as sufficiently different from current SI drivetrains to be considered a separate technology.

3.3 VEHICLE COST ANALYSIS

3.3.1 General Discussion

Vehicle costs obviously will be a crucial determining factor for commercializing the vehicle/fuel pathways examined in this study, and we have developed estimates of vehicle costs for each leading edge midsize car and midsize SUV examined in the study. The discussion here focuses on the results for midsize cars.

It should be recognized that cost estimates for vehicles with technologies that have yet to be commercialized and are undergoing rapid design changes are highly uncertain and controversial. Further, even currently available technologies may undergo substantial design or manufacturing changes over the time scale — four decades — examined in this study.

The primary sources of uncertainty in estimating vehicle costs are:

- **Uncertain design evolution, including potential for radical changes for some new technologies (fuel cells, batteries, hydrogen storage).** For example, the costs of fuel cells, which have already been reduced by an order of magnitude over the past several years, will require approximately another order of magnitude decrease — beyond cost reductions expected from mass production — to achieve levels sufficiently low to allow commercialization.

- **Effects of learning and scale in mass production**. Although “learning curves” have been developed that forecast cost reductions for each doubling of production, these curves are based on data from a subset of successful products rather than from the full range of products undergoing development (some of which may never achieve commercial success). There is no guarantee that the costs of fuel cells, batteries, and other new technologies will follow the same path.

- **Unpredictable changes in material costs.** Such materials could include platinum catalyst material, aluminum, etc.

The cost equations used in this analysis were developed with the underlying assumption of “technology success” — in other words, it is assumed that each of the technologies under examination has undergone a successful development process, is pushed into the marketplace relatively soon, and experiences cost reductions from learning and increased production scale quite quickly. Consequently, for those technologies that have not yet been commercialized (e.g., fuel cells, plug-in hybrids), there remains some risk that development will stall, costs will remain high, and full market success cannot be achieved; this risk is not incorporated into our analysis but should be recognized as a possibility for any of the advanced technologies. Further, for those development scenarios that assume considerable delay in market entry for some technologies, even the more conservative of the two cost scenarios may appear extremely optimistic.

As noted earlier, the scale of production will affect costs significantly. This analysis does not attempt to directly capture this effect except in the general sense that the components are assumed to be produced on a scale of *at least* tens of thousands, and estimated costs are lowered over time on the basis of the assumption that production will increase over time and that learning and increasing the scale of production will force continuing cost reductions. A more nuanced estimation procedure would adopt cost equations that include scale factors and use feedback loops that tie cost reductions directly to the projected volume of production. This level of sophistication is not used here. Instead, two cost cases — literature review (LR) and program goals (PG) — are developed that tie costs to specific dates (2010, 2015, 2030, and 2045) and do not vary when assumptions change about when the technologies enter the marketplace and how quickly their numbers grow. The LR case is based on a literature review of recent publications and discussion with analysts familiar with the technologies. The PG case assumes that DOE cost goals for advanced technologies are met (we interpret this as meaning that prototypes achieve these goals on the schedule dictated by DOE's Program Plans, with the first production models achieving the goals 5 years later). Some of these goals were derived in a normative fashion — their achievement was deemed necessary to allow technology commercialization — rather than being derived by examining engineering potentials. As a result, the probability of attaining the goals is quite unclear.

3.3.2 Automotive System Cost Model

Cost estimates were developed using the Automotive System Cost Model (ASCM), which was developed by Oak Ridge National Laboratory (ORNL) and calculates cost at a level of five major vehicle subsystems, consisting of more than 35 components based on the aggregation of several components under the definition of Uniform Parts Grouping (UPG) generally used by the automotive industry. The model uses measures of component "size" — weight, power, energy stored, or other measures — from PSAT runs to estimate cost and has been used in several studies for comparative cost assessments of different powertrain and body-in-white options for advanced technology vehicles (Das 2004, 2005; Rousseau et al. 2005).

In the cost calculation, the costs of glider and drivetrain components discussed here are vehicle manufacturing costs, which include the price of components purchased directly from suppliers and costs of assembly performed at the original equipment manufacturing (OEM) facility. Translating these costs into a manufacturer's suggested retail price equivalent (RPE) requires adding the costs of manufacturing overhead (research, design, development, and engineering costs plus division and corporate overheads and corporate profit) and dealer cost (dealer's invoice discount, holdback, and dealer incentives, distribution, advertising and dealer support costs, and dealer profits). **In this analysis, it is assumed that that RPE is 1.5 times vehicle manufacturing costs.**

There are differences among alternative cost analyses in defining the relationship between and definitions of "costs" and RPEs; these differences can lead to difficulties in interpreting cost results and comparing them to those developed in other analyses. As noted above, this analysis uses a factor of 1.5 to go from costs to RPEs. Other references may define the precise stage at which costs are estimated slightly differently, and they may use different multiplication factors to obtain retail prices. Unfortunately, because definitions are often quite vague, comparisons among alternative cost analyses can be difficult. And since many of the component cost assumptions used here were derived from the literature, it is not certain that all of the "translations" of these estimates were accurate. An additional complication for comparisons to European estimates is that the value of the euro in relation to the dollar has escalated dramatically over the past few years, such that 100 euros valued at a 2005 estimate of approximately US$120 would, by late May 2009, be valued at nearly US$138; it is not clear what the most appropriate cost comparison will be under such circumstances.

3.3.3 Glider Costs

In the Multi-Path cost analysis, vehicle costs are calculated by first estimating a cost for the glider — the vehicle minus its drivetrain — that can be used for all drivetrain variations for each of two vehicle classes (midsize passenger car and SUV) in a given year, and adding drivetrain component costs for each drivetrain type.

Glider costs are derived by estimating glider costs in the baseline year and adjusting these costs for weight reduction measures (based on drivetrain component and vehicle curb weight estimates from PSAT), aerodynamic improvements (including items such as camera replacements for outside mirrors for large reductions in C_D), and improved accessories and other measures to reduce accessory loads (e.g., window coatings). As a simplification, however, it is assumed that weight reduction measures are the primary source of changes in glider costs; other glider changes are assumed to be of sufficiently low cost — or part of the normal improvement cycle that occurs when models are updated — that their costs can be neglected.

The cost of reducing glider mass was estimated by considering different lightweight material options starting with major components of the body and then the chassis as defined in ASCM, coupled with extensive structural redesign. Secondary mass reductions associated with the primary mass reduction (e.g., a lower brake mass resulting from reduced braking requirements because of the lighter-weight glider), as well as any costs savings from these weight reductions, were accounted for in the estimates. The cost estimates are based on an assumption that the design changes and material substitution are used primarily for weight reduction rather than frame stiffening, increases in vehicle size (e.g., track width) at constant weight, or other alternative uses.

Under most vehicle weight-reduction scenarios considered, there were alternative lightweight material options sufficient to achieve the desired glider mass. Assuming a conventional steel unibody as the baseline vehicle body-in-white, lightweight material options, such as ultralight steel, aluminum, and carbon fiber-reinforced polymer composites, were used to obtain the desired 5%–30% glider mass weight reduction range. For weight reductions of up to about 15%, structural redesign and material substitution for the body-in-white and closure panels, coupled with secondary mass savings, were sufficient to achieve target weights for the glider. For larger weight reductions, lightweight material substitutions for other glider components were added (e.g., front and rear bumpers, suspension components, and instrument panel). The cost relationships included in ASCM for different lightweight body options are based on a detailed cost analysis by Ibis Associates, Inc. (2004). In most cases, reducing the glider weight resulted in a price increase in the range of $4.26–$6.61/kg of weight removed from the baseline glider.

In the ASCM analysis, for the high fuel economy case, the 2030 midsize passenger car achieves a glider mass reduction of 30% (for the conventional SI engine drivetrain, this result translates into a vehicle curb weight reduction of 21%), at a cost of about $1,300 ($4.41/kg of glider mass reduced). In comparison, the *King Review of Low-Carbon Cars* (King 2007) cites a 10% efficiency gain, which is equivalent to about a 15% weight reduction, as costing about 250 to 500 pounds sterling, or about $500 to $1,000 at 2008 conversion rates; these costs are stated to be production costs. Cheah et al. (2007) concludes that a 20% vehicle weight reduction through first-tier material substitution and a combination of vehicle redesign and component downsizing can be achieved at an overall cost of $2.00/kg, or less than half of the ASCM cost. However, the less-optimistic ASCM estimates appear reasonable in light of the difficult tradeoffs between weight reduction and competing attributes (e.g., structural stiffness) and recent increases in material costs for aluminum.

3.3.4 Drivetrain Costs

As noted above, drivetrain costs are estimated by using component cost equations with input variables (i.e., measures of component characteristics such as power, energy storage capacity, etc.) obtained from the PSAT model runs. The PSAT model produces extensive reports on drivetrain component sizes, such as, for example, engine kW (power [in kilowatts]) ratings, HEV battery kW ratings, PHEV and battery electric vehicle (BEV) battery kWh (energy) ratings, and so forth.

Table 3-10 provides the primary component cost equations used in the analysis. The table was provided in draft form by Sujit Das of ORNL and revised after discussions with Das, K.G. Duleep of Energy and Environmental Analysis, Inc., David Greene of ORNL, and others.

A simplification used in both the cost and fuel economy analyses is that the vehicle fleet is represented by singular examples of a few drivetrain technologies, that is, “hybrid electric vehicles” are represented by a single design rather than the multiple examples that exist in the marketplace even today (e.g., the Toyota “series/parallel” system found in the Prius; the two-mode hybrid designed jointly by General Motors, BMW, and DaimlerChrysler; the Integrated Motor Assist system found in the Honda Civic Hybrid; and so forth). Further, all vehicles regardless of drivetrain technology have the same performance requirements dictating minimum power capabilities. In the actual marketplace, there is a broad spectrum of vehicle performance, and different drivetrain technologies may compete somewhat differently at the upper and lower ends of this spectrum.

As shown in Table 3-10, the time progression of estimated costs for relatively conventional technologies — spark-ignited and compression-ignited internal combustion engines and automatic transmissions — is quite different from the progression of estimated costs for technologies recently introduced to the marketplace (e.g., hybrid drivetrains) or those not yet

TABLE 3-10 Major Assumptions for Advanced Technology Vehicle Cost Estimation: Vehicle Component Cost Targets (Factory Gate Price, 2008$)

Notes: The LR estimate reflects an optimistic outlook based on literature review and interviews with experts; PG estimate is still more optimistic and reflects LR estimates plus DOE and Advanced Battery Consortium goals, assuming that achievement of cost goals is reflected in manufactured products 5 years later. Some of these goals reflect perceived market requirements rather than engineering judgments, so PG values may not reflect engineering projections.
All cost targets are in factory gate prices; a factor of 1.5 should be used to convert to the RPE (Vyas et al. 2000).

Parameter/ Cost Case	Current	2010			2015			2030		2045	
		LR	PG	FC Goal	LR	PG	FC Goal	LR	PG	LR	PG
SI Engine[1] ($)	300+275×n+ 3×kW	315+290×n+ 3× kW	300+275×n+ 3× kW		345+315×n+ 2.75× kW	330+300×n+ 2.75× kW		375+345×n+ 2.7× kW	360+330×n+ 2.7× kW	375+345×n+ 2.7× kW	360+330×n+ 2.7× kW
CI Engine[2] ($/kW)	600+550×n+ 3× kW	630+575×n+ 3×kW	600+550×n+ 3×kW		660+605×n+ 2.75× kW	600+550×n+ 2.75× kW		690+630×n+ 2.75× kW	600+550×n+ 2.7× kW	690+630×n+ 2.75× kW	600+550×n+ 2.7× kW
Fuel Cell[3] ($/kW)	108	108	67	45	67	45	45	52	30	52	30
Hydrogen Storage[4] ($/kWh)	15	15	10	4	14	4	2	13	2	10	2
SI Emissions Control[5] ($/kW)	4	4	4		4	4		4.5	4	4.25	4
CI Emissions Control[6] ($)	7	9	7		8	6		6	5	5	4
High Voltage Battery[7]:											
HEV ($/kW max. power)	60	55	40	25	50	25	25	38	20	35	18
PHEV10 ($/rated kWh)	1,100	1,000	587	350	587	367		440	180	367	180

TABLE 3-10 (Cont.)

		2010			2015			2030		2045	
Parameter/ Cost Case	Current	LR	PG	FC Goal	LR	PG	FC Goal	LR	PG	LR	PG
PHEV40 ($/rated kWh)	900	800	480	350	500	300		375	160	300	160
BEV ($/rated kWh)	750	675	400		450	250		325	150	250	150
Motor [8]($/kW)	13	13	11.1	11.1	8.0	7.0	7.0	7.0	4.0	7.0	3.3
Electronics[9] ($/kW)	12	12	7.9	7.9	5.75	5.0	5.0	5.0	3.0	5.0	3.0
Transmission (above 5-speed automatic transmission [AT])	Assume $100 incremental cost for advanced transmissions (assuming cost reductions over time will allow moving from 6- to 7- to 8-speed transmissions at no additional cost except for the first $100 increment)										

[1,2] Engine cost estimates based on meeting of December 19, 2008 and e-mail communication of January 7, 2008 with K.G. Duleep, L. Cheah, C. Evans, A. Bandivadekar, and J. Heywood, (2007), *Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035*, Massachusetts Institute of Technology, MA. In the cost equations, n = number of cylinders, kW = rated engine power.

Program Goals (PG) case denotes a “best case” technology scenario. Although DOE has no formal goals for SI engines, it is assumed that substantial improvements will be added in in-cylinder monitoring and valve control, moving toward multiple cycle operation (ultimately toward HCCI operation under low- and moderate-load conditions). CI engines will be improved by the addition of higher pressure fuel injection and possibly sequential turbocharging; long-term costs are perhaps more uncertain with CI engines, and this uncertainty is reflected in the larger ranges of costs between the LR and PG cases with these engines.

There are no changes in costs under both scenarios beyond 2030 as no additional cost is assumed for HCCI operation in 2045.

[3] Fuel cell is defined as the system consisting of the fuel cell stack and the fuel cell stack’s auxiliary subsystems (e.g., sub-systems for air supply, fuel supply, thermal management, and other necessary functions, such as water management). The current fuel cell system is based on $108/kW for fuel cell stack and auxiliaries (TIAX estimate) as per Kromer and Heywood (2007).

FreedomCAR cost targets have been assumed under the PG scenario, but actual commercialization is assumed to begin 5 years after the target date. No cost reduction is assumed in the future after the FreedomCAR goal has been met. There are no changes in costs under both scenarios beyond 2030.

For 2010, the LR scenario is based on the latest estimate of $67/kW by TIAX (Kromer and Heywood 2007).

For 2030, LR estimate is based on the baseline assumption of $52/kWh by Kromer and Heywood (2007).

[4] PG scenario denotes meeting the FreedomCAR goal, but is delayed by 5 years for actual implementation as assumed in the case of a complete fuel cell system.

The LR scenario denotes that no significant reduction in hydrogen storage cost is anticipated until 2030 as indicated by Kalhammer (2007) and Kromer and Heywood (2007).

[5] Exhaust system includes emissions control electronics and estimates based on e-mail communication with K.G. Duleep on January 7, 2008. Cost targets under both scenarios do not change until 2030, when additional costs of aftertreatment systems for lean-burn engines have been included. The PG scenario assumed that there will not be any change in cost as HCCI engines will be used.

[6] Estimates provided by K.G. Duleep on January 7, 2008. The cost differential between the gasoline and diesel exhaust systems is assumed to decrease with time in the future.

TABLE 3-10 (Cont.)

[7] Includes battery auxiliaries (i.e., box, accessories, wiring, and cooling system) and assembly cost. Li-ion batteries are assumed to be used, and PHEV cost estimates are based on applying approximately the same multiplicative factors to the current BEV cost estimate. Battery cost increases with a reduction in cell size because of increasing contributions of inactive cell materials and manufacturing to total cell costs. Additional $400 for battery charger cost for PHEVs to be included.

The current cost of HEV batteries is based on Kromer and Heywood (2007).

The 2015 PG estimate for the BEV is based on the EPRI (2005) projection at a low annual production volume of 20K batteries. The PG scenario assumes that the cost targets of $25/kW for HEVs and $150/kWh for BEVs will not be met until 2015 and 2030, respectively, thereafter remaining constant.

The 2015 LR estimates for HEV correspond to Kalhammer (2007) near-term (5- to10-year) projections at high production volume, and estimates for BEV are assumed to be same as those assumed under the 2010 PG scenario. The 2030 LR estimates for HEV are based on "Baseline" scenario assumptions by Kromer and Heywood (2007), whereas the estimates for BEV are based on e-mail communication with M. Anderman on January 7, 2008.

[8,9] Based on communication with Mitch Olszewski, Powertrain Electronics Tech Team member for future scenarios.

The current plant gate cost of traction motor and power electronics is assumed to be $25/kW per communication with K.G. Duleep on January 4, 2008. The PG scenario assumes that FreedomCAR goals are met and do not lag by 5 years for mass production (as was assumed for the fuel cell system).

The LR case indicates cost increases possibly resulting from technological challenges to be met in the following areas (Olszewski 2007):

- Rise in coolant temperature,
- Permanent magnet price and copper price increase, and
- Alternative motor designs (not using permanent magnets) having a lower power density.

LR motor and electronics costs are assumed not to fall below the DOE target combined motor/electronics cost of $12/kW (as per a suggestion by K.G. Duleep during conference call on January 4, 2008).

introduced (plug-in hybrids, fuel cell drivetrains). Costs for the conventional technologies are assumed to be relatively stable over time, with some continued learning balanced by the addition of progressively more sophisticated electronic controls, valve control systems, and so forth. In contrast, costs for new technologies are assumed to decline over time, in some cases quite dramatically. We stress again that we consider this outcome to be optimistic but plausible, especially for the LR cost projections — but they are by no means inevitable. Indeed, the projection of relatively stable costs for the conventional drivetrains should also be considered optimistic, since industry has asserted that attainment of the National Highway Traffic Safety Administration's (NHTSA's) suggested CAFE targets for 2015 of 35.7 MPG for passenger cars and 28.6 MPG for light trucks will cause substantial drivetrain cost increases.

3.3.4.1 Spark-ignition and Compression Ignition Internal Combustion Engines

Costs for these engines vary strongly with cylinder count — a key determinant of the number of highly machined and high-value engine components — and (to a lesser degree) with engine power as long as the number of cylinders is unchanged. While the cost equations for spark-ignited engines reflect moderate increases in costs with sophisticated injection systems associated with direct injection engines, in-cylinder monitoring, more complex valve control systems, and so forth, it is also assumed that some aspects of these advances are associated with normal year-by-year engine improvements and will not raise costs. The equations for compression ignition engines reflect fewer likely changes resulting in a lower percentage increase in cost in the future compared to spark-ignited engines, with the program goals value reflecting some potential for avoiding cost increases even with higher pressure injectors and other advances. The LR cost value for diesels assumes sequential turbocharging to improve driving characteristics and somewhat less success in holding down the costs for improved injection systems.

SI engine costs for both LR and PG cases are somewhat optimistic compared to some alternative estimates, partly because of the assumption that some "normal" level of technology improvements will continue without cost increases. For the 2030 SI engine drivetrains for midsize passenger cars, engine costs increase by $181 (PG) to $256 (LR) compared to the 2007 reference costs. In comparison, Kromer and Heywood (2007) estimate that, for a similar midsize car, a 2030 advanced gasoline engine (with direct injection and variable valve timing and lift [VVTL]) will cost $700 more than a reference-case 2006 SI engine. On the other hand, EEA (2007) estimates that a naturally aspirated stoichiometric I4 DI gasoline engine with VVTL will have an RPE of $450, or a cost of about $265 (with a 1.7 multiplier) over its more conventional counterpart (note that these are current costs, not 2030 costs); EEA's costs are more aligned with those estimated here.

For CI engines, the LR cost estimate for 2010 is $4,200 for the engine plus the exhaust treatment system. UBS projects that the cost (engine plus exhaust treatment) for a U.S.-compliant diesel for a midsize passenger car will be about $3,000 to $4,000 (Warburton et al. 2007). EEA (2007) estimates that a similar engine plus exhaust aftertreatment will cost $2,200 (or $1,290 over a baseline SI I4 engine costing $1,100). The implication of these comparisons is that the MP Study's cost estimate for the CI engine may be pessimistic.

3.3.4.2 Fuel Cells

There currently are no fuel cells in mass production, so even the "current" cost value of $105/kW is uncertain — the assigned value is associated with a recent estimate from TIAX Corporation for one possible design. The short-term DOE goal is $45/kW, and the 2015 goal is $30/kW for a fuel cell system (i.e., the stack and all auxiliaries), and the PG estimates reflect the assumption that these values are achieved in commercial production 5 years afterward. In the LR scenario, the cost of hydrogen storage is not anticipated to be reduced significantly until 2030.

The 2030 fuel cell cost is estimated at $52/kW for the LR case and at $30/kW for the PG case, the latter reflecting the DOE goal. Kromer and Heywood (2007) use an estimate of $50–$75/kW for a 2030 fuel cell. CONCAWE and EUCAR (2005) has estimated a fuel cell *price* for "2010+" at 105 euros/kW, which translates into a *cost* of about $100/kW at the June 2009 euro/dollar exchange rate, or about $84/kW at the 2005 exchange rate ($1.20 per euro).

3.3.4.3 SI and CI Emissions Controls

The long-term costs of SI and CI emissions controls are affected by *both* technological progress and the evolution of emissions reduction requirements. If the future resembles the recent past, emission requirements will tighten with further progress in controls. SI emissions controls seem unlikely to escalate significantly over time, although a shift to lean-burn operation (to achieve further reductions in fuel use) will require added NO_x controls. This possibility is reflected in the small cost increases for 2030 and 2045, although progress in NO_x emissions controls for CI engines should be transferable and thereby allow these increases to be minimal. While the cost increases for CI emissions controls in the LR case reflect the need to satisfy new 50-state requirements, it seems likely that further improvements in engine design and reductions in engine-out emissions will eventually drive costs below today's levels — although further tightening of emissions requirements as technology advances may limit cost reduction or could even increase costs.

3.3.4.4 Batteries

Although batteries for HEVs have now been mass produced for about a decade, a shift to lithium-ion from nickel metal hydride can complicate cost projections. In addition, there currently are no mass-produced battery systems for battery electric or plug-in hybrid vehicles, making even current cost estimates controversial.

For this study, the battery cost estimates were based on a literature review and the cost goals of DOE and the U.S. Advanced Battery Consortium (USABC). However, some new goals have been set, especially for plug-in hybrids (which are a relatively new priority for these organizations).

The long-term (2030 and beyond) PG costs were based on Advanced Battery Consortium goals for EVs of "<$150/kWh" for "minimum goals for long-term commercialization"; a "long-term goal" of \$100/kWh has also been set (USABC 2008). In the shorter term (2010), the PHEV \$350/kWh goal was adapted from an early DOE goal of \$500/*available* kWh; that is, available energy is the energy that can actually be removed from the battery without significantly shortening its lifetime. For 2010, we assumed that about 70% of total rated energy is available (e.g., State of Charge [SOC] ranging from 95% to 25%); some may consider this value optimistic for this time frame. For the PG cost case for 2015, we assumed that a somewhat higher percentage of rated energy can be obtained; that the small PHEV10 battery will cost more per kWh than the PHEV40 battery; and that the large BEV battery will cost somewhat less per kWh than the PHEV40 battery. The difference in cost (as a percentage) between BEV and PHEV batteries was assumed to decrease in the future. As with other PG cost estimates, these values should be viewed as extremely optimistic for this time frame.

New goals have now been set by DOE for PHEVs. For a PHEV with a 10-mile range, the goal is a cost of \$1,700 for 3.4 kWh of available energy, or \$500/kWh. For a PHEV with a 40-mile range, the goal is \$3,400 for 11.6 kWh of available energy, or \$293/kWh (Howell 2008).

For the 2030 midsize car, the lithium ion battery for a parallel hybrid SI drivetrain is estimated to cost \$480 (in the PG scenario) or \$910 (in the LR scenario). This result compares to the MIT study's cost of \$750 to \$900 (Kromer and Heywood 2007). The high-energy battery for a PHEV40 is estimated to cost about \$1,600–\$3,700, or \$160–\$375/kWh, versus the MIT study's cost for a PHEV30 battery of \$2,200–\$2,800, or \$260–\$320/kWh. Finally, a long-distance battery for a BEV was estimated to cost \$5,900–\$12,800 or \$150–\$325/kWh as compared to the MIT study's cost of \$6,900–\$10,200, or \$200–\$250/kWh.

It is important to note that a major goal of current battery R&D is to extend battery lifetime. Although current experience with battery longevity in HEVs is very positive, the charging requirements for PHEVs and EVs appear likely to place substantial stress on their batteries and may significantly shorten battery lifetimes. If PHEV and EV batteries do not last for the lifetime of the vehicles, lifecycle costs for these vehicles will rise significantly. The vehicle cost estimates developed in this section do *not* include costs for battery replacement.

3.3.4.5 Traction Motor and Power Electronics

The short-term prospects for achieving cost reductions in traction motors and power electronics appear to be excellent, particularly for power electronics as costs for electronic components continue to decline. Materials cost increases could limit cost decreases in the longer term, as reflected in the LR cost values. For 2030, the motor/electronics combination is assumed to cost \$7–\$12/kW. In comparison, the MIT study uses a value of \$15/kW + \$200.

3.3.4.6 Comparison of Cost Increases for Hybrid Drivetrains

Since several cost estimates exist for the incremental cost or RPE of full hybrid drivetrains, it is useful to compare the MP Study results directly to these estimates. For the midsize passenger car, the incremental cost of a full hybrid drivetrain is \$2,230 (LR scenario)/\$1,480 (PG scenario) for the 2010 cost, while the 2010 incremental RPE is $3,345 (LR scenario)/$2,220 (PG scenario); for 2030, costs for key hybrid components are assumed to be sharply reduced, with an incremental drivetrain cost of $1,380 (LR scenario)/$710 (PG scenario) and an RPE of $2,070 (LR scenario)/$1,065 (PG scenario). As noted, the PG 2030 cost is based on ambitious DOE goals and may be viewed as highly optimistic.

Kromer and Heywood (2007) estimate that a similar hybrid midsize car will have an incremental drivetrain cost of $2,400–$2,600 as compared to a 2006 SI drivetrain. The CONCAWE and EUCAR (2005) study projects an incremental *price* of 1,500 euros for a "2010+" hybrid drivetrain; this figure might translate into a cost of about $1,400 (1,500/1.5 = 1,000 cost in euros, or approximately $1,400 at a dollars-to-euros exchange rate of 1.4). For a 2010 full hybrid, EEA (2007) projects an RPE increase of $3,900, or a cost increase of $2,300 (at EEA's conversion factor of 1.7). Costs for the LR case in this study are somewhat in the middle of this group: a bit more optimistic than Kromer and Heywood (2007), more pessimistic than the CONCAWE/EUCAR estimate, and quite similar to the EEA estimate.

3.3.5 Vehicle Cost Results

The results discussed here are for the case of a leading edge midsize car with high fuel economy; this case best reflects the basic context of the study: a future in which fuel economy is highly valued.

Figure 3-5a shows the estimated retail prices for midsize passenger cars with varying drivetrains for the LR costs case, while Figure 3-5b shows the PG costs case, which represents full attainment of DOE cost goals for the advanced drivetrains. Figures 3-6a and 3-6b show the drivetrain costs for each of these cases in order to provide a finer scale to examine the differences among the different drivetrain types. Tables 3-11a through 3-11f display the complete LR and PG costs case results for midsize cars/high fuel economy case for 2015, 2030, and 2045.

Examination of the figures and tables yields several insights about the *estimated* costs of these vehicles:

1. Even for the PG cost case — which we consider very optimistic, particularly in the early years — costs for the most advanced drivetrains (those not yet introduced except for a few demonstration vehicles) will be high enough at their introduction that commercialization can proceed only if the manufacturers or the U.S. government subsidize their purchase. It is important to note that these prices reflect an assumption that mass production is occurring — vehicles manufactured in numbers of a few hundreds or even a few thousands will cost considerably more, with the implication that such subsidies will be expensive (i.e., for the PG cost case, the subsidy cost will be perhaps $7,000 to $30,000 per vehicle multiplied by at least a few tens of thousands of vehicles per year, for several years, amounting to probably more than $1 billion dollars and possibly much more — and double this amount for the LR cost case).

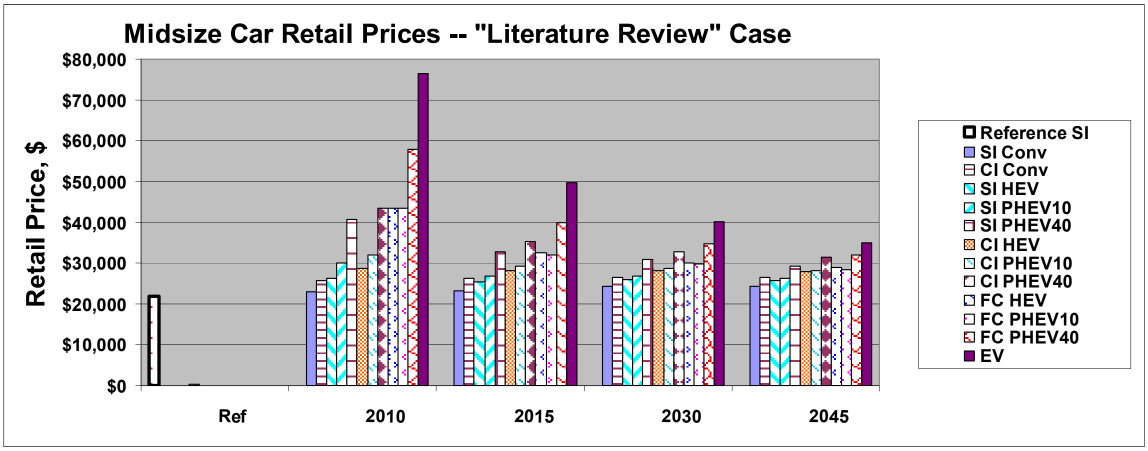

FIGURE 3-5a Midsize Car Retail Prices (in 2008$), Literature Review Costs Case, High Fuel Economy

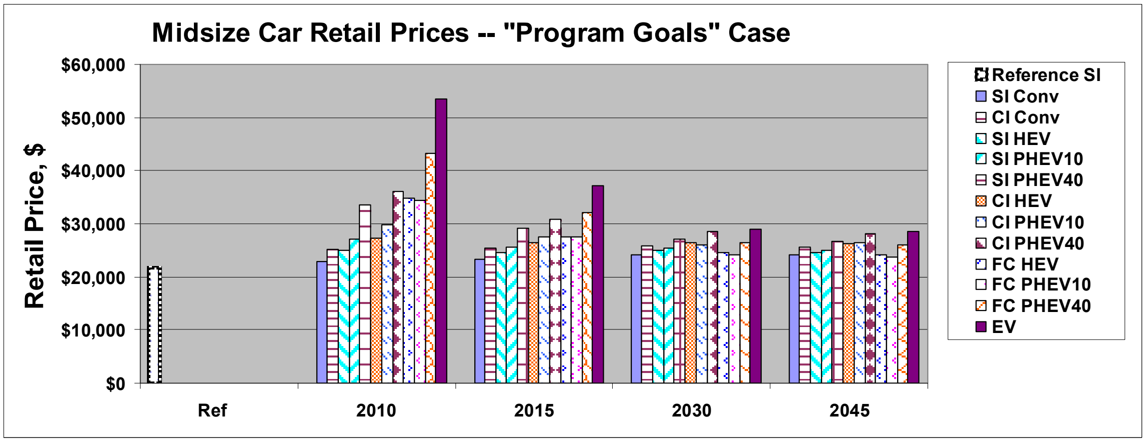

FIGURE 3-5b Midsize Car Retail Prices (in 2008$), Program Goals Costs Case, High Fuel Economy

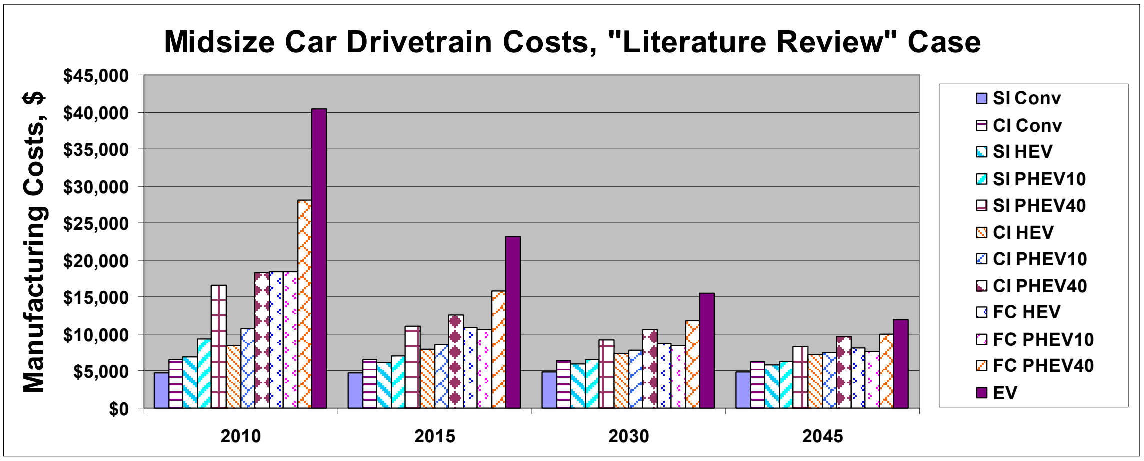

FIGURE 3-6a Midsize Car Drivetrain Costs (in 2008$), Literature Review Costs Case, High Fuel Economy

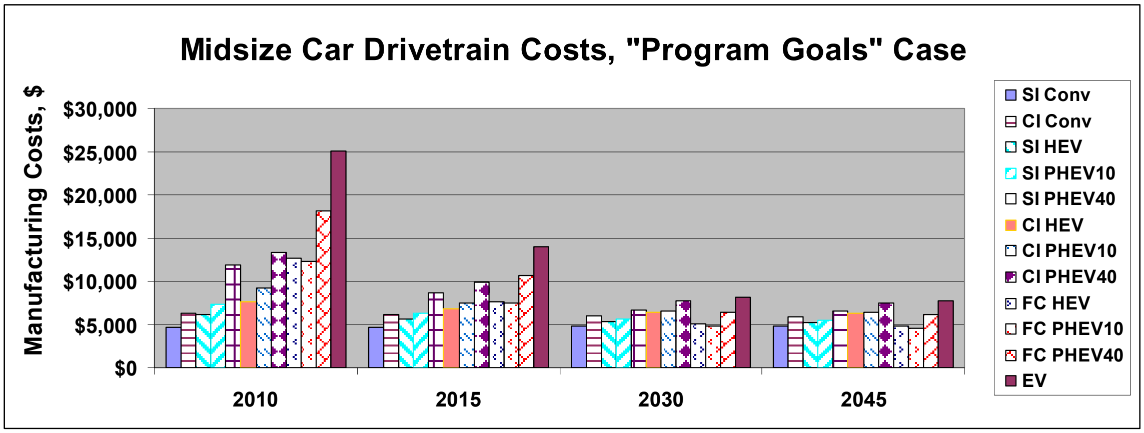

FIGURE 3-6b Midsize Car Drivetrain Costs (in 2008$), Program Goals Costs Case, High Fuel Economy

2. Comparing the two advanced technologies, fuel cell vehicles and battery-electric drivetrain vehicles with long electric ranges (i.e., PHEV40s and EVs), the fuel cell vehicles are expected to have more rapid declines in cost and price. While this is an assumption, it is based on the recent development history of both technologies. The difference between the two technologies could be greater still if the problem of limited battery lifetimes is not solved: under the 2030 LR cost case, the battery in a PHEV40 could cost the consumer more than $5,000 to replace, with an EV battery costing more than $15,000. On the other hand, only moderate infrastructure development is needed for battery recharging, particularly for PHEVs, whereas massive infrastructure development will be needed to support the refueling of hydrogen fuel cells. In other words, both technology pathways present difficult commercialization prospects, albeit for different reasons.

3. As noted earlier, an underlying assumption of this analysis is that costs for SI and CI conventional drivetrains will be relatively stable over time (though these will improve substantially in efficiency with the addition of a number of advanced components), while battery- and FC -based drivetrains will decline substantially in cost. The result, which is pre-ordained by this assumption, is that both the estimated drivetrain costs and the estimated retail prices of the range of vehicles examined here will tend to even out over time, as clearly shown by the figures. For the most optimistic PG cost case, it is projected that the retail price of fuel cell hybrids and short-range PHEVs will basically match the price of advanced SI conventional drivetrain vehicles by 2030; in the LR case, these advanced technology vehicles get to within about $6,000 of the advanced SI vehicle. The former result, the eventual disappearance of cost differences among the vehicles in the very low case, was essentially dictated by use of the DOE cost goals for these vehicles — the goals were explicitly derived to allow advanced vehicles to compete with conventional vehicles in retail price.

TABLE 3-11a Midsize Car (High Fuel Economy Case, LR Cost Case for 2015)

LITERATURE REVIEW COST CASE FOR 2015

COSTS		2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine		$1,761	$1,892	$3,360	$1,806	$1,806	$1,817	$3,271	$3,286	$3,292	$0	$0	$0	$0
Fuel Cell		$0	$0	$0	$0	$0	$0	$0	$0	$0	$5,527	$4,414	$4,576	$0
Generator		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Motor		$0	$0	$0	$208	$490	$504	$209	$338	$351	$827	$825	$853	$890
Controller Inverter		$0	$0	$0	$149	$352	$362	$150	$243	$253	$595	$593	$613	$640
Transmission		$1,200	$1,277	$1,273	$1,269	$1,325	$1,330	$1,263	$1,296	$1,301	$686	$669	$675	$611
High Voltage Energy Storage		$0	$0	$0	$1,309	$1,666	$5,526	$1,309	$1,714	$5,645	$1,224	$2,155	$7,423	$20,226
Fuel System		$376	$376	$376	$376	$376	$376	$376	$376	$376	$1,220	$1,090	$890	$0
Exhaust		$481	$418	$814	$293	$300	$300	$555	$599	$599	$0	$0	$0	$0
Drivetrain*		$4,616	$4,761	$6,621	$6,208	$7,113	$11,013	$7,931	$8,650	$12,615	$10,877	$10,544	$15,828	$23,165
Glider Cost		$9,955	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799
Vehicle Cost		$14,571	$15,560	$17,420	$17,007	$17,912	$21,812	$18,730	$19,449	$23,414	$21,676	$21,343	$26,627	$33,964
Vehicle Retail Price		**$21,857**	$23,340	$26,130	$25,511	$26,868	$32,718	$28,095	$29,174	$35,121	$32,514	$32,015	$39,941	$49,800
VEHICLE CHARACTERISTICS														
Engine Power Max	**W**	120267	104,454	101,700	73,225	75,100	77,122	69,362	74,908	77,036	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	82,491	65,884	68,294	0
Motor Power Max	**W**	0	0	0	25,968	61,302	62,955	26,153	42,257	43,934	103,393	103,126	106,687	111,294
High Voltage Energy Storage C	**W or Wh**	0	0	0	839	2,838	11,053	839	2,920	11,290	784	3,671	14,846	44,947
Vehicle Mass	**kg**	1474	1,267	1,307	1,288	1,329	1,389	1,334	1,355	1,416	1,350	1,339	1,426	1,479
Glider Mass	**kg**	990	792	792	792	792	792	792	792	792	792	792	792	792

[*] Includes final drivetrain, 12-volt (V) battery, wheels, and tires.

TABLE 3-11b Midsize Car (High Fuel Economy Case, PG Cost Case for 2015)

PROGRAM GOALS COST CASE FOR 2015

COSTS		2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine		$1,761	$1,817	$3,080	$1,731	$1,737	$1,742	$2,991	$3,006	$3,012	$0	$0	$0	$0
Fuel Cell		$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,712	$2,965	$3,073	$0
Generator		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Motor		$0	$0	$0	$182	$429	$441	$183	$296	$308	$724	$722	$747	$779
Controller Inverter		$0	$0	$0	$130	$307	$315	$131	$211	$220	$517	$516	$533	$556
Transmission		$1,200	$1,277	$1,273	$1,269	$1,325	$1,330	$1,263	$1,296	$1,301	$686	$669	$675	$611
High Voltage Energy Storage		$0	$0	$0	$654	$1,041	$3,316	$654	$1,072	$3,387	$612	$1,347	$4,454	$11,237
Fuel System		$376	$376	$376	$376	$376	$376	$376	$376	$376	$488	$436	$356	$0
Exhaust		$481	$418	$610	$418	$300	$308	$416	$416	$416	$0	$0	$0	$0
Drivetrain*		$4,616	$4,686	$6,137	$5,558	$6,313	$8,626	$6,812	$7,471	$9,818	$7,537	$7,453	$10,636	$13,981
Glider Cost		$9,955	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799	$10,799
Vehicle Cost		$14,571	$15,485	$16,936	$16,357	$17,112	$19,425	$17,611	$18,270	$20,617	$18,336	$18,252	$21,435	$24,780
Vehicle Retail Price		**$21,857**	$23,228	$25,404	$24,536	$25,668	$29,138	$26,417	$27,405	$30,926	$27,504	$27,378	$32,153	$37,170
VEHICLE CHARACTERISTICS														
Engine Power Max	**W**	120267	104,454	101,700	73,225	75,100	77,122	69,362	74,908	77,036	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	82,491	65,884	68,294	0
Motor Power Max	**W**	0	0	0	25,968	61,302	62,955	26,153	42,257	43,934	103,393	103,126	106,687	111,294
High Voltage Energy Storage C	**W or Wh**	0	0	0	839	2,838	11,053	839	2,920	11,290	784	3,671	14,846	44,947
Vehicle Mass	**kg**	1474	1,267	1,307	1,288	1,329	1,389	1,334	1,355	1,416	1,350	1,339	1,426	1,479
Glider Mass	**kg**	990	792	792	792	792	792	792	792	792	792	792	792	792

* Includes final drivetrain, 12-V battery, wheels, and tires.

TABLE 3-11c Midsize Car (High Fuel Economy Case, LR Cost Case for 2030)

LITERATURE REVIEW COST CASE FOR 2030

COSTS		**2007 Reference SI**	**Adv SI**	**Adv CI**	**SI HEV**	**SI PHEV10**	**SI PHEV40**	**CI HEV**	**CI PHEV10**	**CI PHEV40**	**FC HEV**	**FC PHEV10**	**FC PHEV40**	**EV**
Engine		$1,761	$2,017	$3,462	$1,937	$1,942	$1,947	$3,382	$3,396	$3,401	$0	$0	$0	$0
Fuel Cell		$0	0	0	0	0	0	0	0	0	3925	3135	3242	0
Generator		$0	0	0	0	0	0	0	0	0	0	0	0	0
Motor		$0	0	0	167	401	415	170	275	285	698	696	716	703
Controller Inverter		$0	$0	$0	$119	$287	$296	$122	$196	$204	$498	$497	$512	$502
Transmission		$1,200	$1,266	$1,266	$1,257	$1,310	$1,315	$1,252	$1,252	$1,287	$675	$660	$665	$675
High Voltage Energy Storage		$0	$0	$0	$908	$1,111	$3,677	$930	$1,146	$3,774	$843	$1,434	$4,941	$12,798
Fuel System		$376	$376	$376	$376	$376	$376	$376	$376	$376	$1,300	$1,300	$936	$0
Exhaust		$481	$437	$560	$437	$437	$437	$383	$414	$425	$0	$0	$0	$0
Drivetrain*		$4,616	$4,894	$6,462	$5,999	$6,662	$9,261	$7,413	$7,853	$10,550	$8,737	$8,520	$11,810	$15,476
Glider Cost		$9,955	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266	$11,266
Vehicle Cost		$14,571	$16,160	$17,728	$17,265	$17,928	$20,527	$18,679	$19,119	$21,816	$20,003	$19,786	$23,076	$26,742
Vehicle Retail Price		**$21,857**	**$24,240**	**$26,592**	**$25,898**	**$26,892**	**$30,791**	**$28,019**	**$28,679**	**$32,724**	**$30,005**	**$29,679**	**$34,614**	**$40,113**
VEHICLE CHARACTERISTICS														
Engine Power Max	**W**	120267	97102	93302	67393	69209	70986	63870	69000	70891	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	75476	60280	62355	0
Motor Power Max	**W**	0	0	0	23902	57343	59220	24471	39259	40737	99678	99484	102351	100492
High Voltage Energy Storage C	**W or Wh**	0	0	0	766	2526	9806	784	2604	10064	22195	3258	13176	39380
Vehicle Mass	**kg**	1474	1163	1204	1178	1215	1269	1228	1245	1300	1217	1210	1286	1318
Glider Mass	**kg**	990	693	693	693	693	693	693	693	693	693	693	693	693

* Includes final drivetrain, 12-V battery, wheels, and tires.

TABLE 3-11d Midsize Car (High Fuel Economy Case, PG Cost Case for 2030)

PROGRAM GOALS COST CASE FOR 2030

COSTS	2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine	$1,761	$1,942	$3,052	$1,862	$1,867	$1,867	$2,972	$2,986	$2,991	$0	$0	$0	$0
Fuel Cell	$0	0	0	0	0	0	0	0	0	2264	1808	1871	0
Generator	$0	0	0	0	0	0	0	0	0	0	0	0	0
Motor	$0	**0**	**0**	**96**	**229**	**237**	**97**	**157**	**163**	**399**	**398**	**409**	**402**
Controller Inverter	$0	$0	$0	$72	$172	$178	$73	$118	$122	$299	$298	$307	$301
Transmission	$1,200	$1,266	$1,260	$1,257	$1,310	$1,315	$1,252	$1,282	$1,287	$675	$675	$665	$675
High Voltage Energy Storage	$0	$0	$0	$478	$455	$1,569	$489	$469	$1,610	$444	$586	$2,108	$5,907
Fuel System	$376	$376	$376	$376	$376	$376	$376	$376	$376	$200	$200	$200	$0
Exhaust	$481	$388	$467	$388	$388	$388	$319	$345	$354	$0	$0	$0	$0
Drivetrain*	$4,616	$4,770	$5,953	$5,327	$5,595	$6,728	$6,376	$6,531	$7,701	$5,079	$4,763	$6,358	$8,083
Glider Cost	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955	$9,955
Vehicle Cost	$14,571	$14,725	$15,908	$15,282	$15,550	$16,683	$16,331	$16,486	$17,656	$15,034	$14,718	$16,313	$18,038
Vehicle Retail Price	**$21,857**	$24,054	$25,829	$24,890	$25,292	$26,991	$26,463	$25,992	$28,451	$24,518	$24,044	$26,436	$29,024

VEHICLE CHARACTERISTICS		2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine Power Max	**W**	120267	97102	93302	67393	69209	70986	63870	69000	70891	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	75476	60280	62355	0
Motor Power Max	**W**	0	0	0	23902	57343	59220	24471	39259	40737	99678	99484	102351	100492
High Voltage Energy Storage C	**W or Wh**	0	0	0	766	2526	9806	784	2604	10064	22195	3258	13176	39380
Vehicle Mass	**kg**	1474	1163	1204	1178	1215	1269	1228	1245	1300	1217	1210	1286	1318
Glider Mass	**kg**	990	693	693	693	693	693	693	693	693	693	693	693	693

* Includes final drivetrain, 12-V battery, wheels, and tires.

TABLE 3-11e Midsize Car (High Fuel Economy Case, LR Cost Case for 2045)

LITERATURE REVIEW COST CASE FOR 2045

COSTS		2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine		$1,761	$2,016	$3,462	$1,937	$1,938	$1,943	$3,379	$3,393	$3,398	$0	$0	$0	$0
Fuel Cell		$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,751	$3,033	$3,134	$0
Generator		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Motor		$0	$0	$0	$168	$396	$412	$169	$274	$284	$694	$693	$714	$685
Controller Inverter		$0	$0	$0	$120	$283	$294	$121	$195	$203	$496	$495	$510	$489
Transmission		$1,200	$1,265	$1,260	$1,257	$1,307	$1,307	$1,250	$1,250	$1,285	$671	$657	$662	$598
High Voltage Energy Storage		$0	$0	$0	$857	$894	$2,830	$857	$919	$2,912	$777	$1,162	$3,805	$9,484
Fuel System		$376	$376	$376	$376	$376	$376	$376	$376	$376	$890	$790	$376	$0
Exhaust		$481	$411	$467	$286	$289	$296	$314	$339	$348	$0	$0	$0	$0
Drivetrain*		$4,616	4866	6363	5799	6281	8256	7264	7544	9604	8077	7628	9999	12054
Glider Cost		$9,955	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266
Vehicle Cost		$14,571	$16,132	$17,629	$17,065	$17,547	$19,522	$18,530	$18,810	$20,870	$19,343	$18,894	$21,265	$23,320
Vehicle Retail Price		**$21,857**	$24,198	$26,444	$25,598	$26,321	$29,283	$27,795	$28,215	$31,305	$29,015	$28,341	$31,898	$34,980
VEHICLE CHARACTERISTICS														
Engine Power Max	**W**	120267	96659	93302	67260	67901	69644	62735	67831	69619	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	72126	58327	60277	0
Motor Power Max	**W**	0	0	0	24471	56592	58875	24471	39076	40508	22195	99066	101947	97862
High Voltage Energy Storage C	**W or Wh**	0	0	0	784	2435	9432	784	2504	9708	711	3167	12685	37935
Vehicle Mass	**kg**	1474	1163	1204	1178	1208	1261	1225	1242	1294	1200	1195	1267	1296
Glider Mass	**kg**	990	693	693	693	693	693	693	693	693	693	693	693	693

* Includes final drivetrain, 12-V battery, wheels, and tires.

TABLE 3-11f Midsize Car (High Fuel Economy Case, PG Cost Case for 2045)

PROGRAM GOALS COST CASE FOR 2045

COSTS		2007 Reference SI	Adv SI	Adv CI	SI HEV	SI PHEV10	SI PHEV40	CI HEV	CI PHEV10	CI PHEV40	FC HEV	FC PHEV10	FC PHEV40	EV
Engine		$1,761	$1,941	$3,052	$1,862	$1,863	$1,868	$2,969	$2,983	$2,988	$0	$0	$0	$0
Fuel Cell		$0	$0	$0	$0	$0	$0	$0	$0	$0	$2,164	$1,750	$1,808	$0
Generator		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Motor		$0	$0	$0	$79	$187	$194	$80	$129	$134	$327	$327	$336	$323
Controller Inverter		$0	$0	$0	$72	$170	$177	$72	$117	$122	$298	$297	$306	$294
Transmission		$1,200	$1,265	$1,260	$1,257	$1,307	$1,313	$1,250	$1,280	$1,280	$671	$657	$662	$598
High Voltage Energy Storage		$0	$0	$0	$440	$438	$1,509	$440	$451	$1,553	$400	$570	$2,030	$5,690
Fuel System		$376	$376	$376	$376	$376	$376	$376	$376	$376	$178	$158	$128	$0
Exhaust		$481	$387	$373	$269	$272	$279	$251	$271	$278	$0	$0	$0	$0
Drivetrain*		$4,616	4767	5859	5153	5411	6514	6236	6405	7529	4836	4557	6068	7703
Glider Cost		$9,955	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266	11266
Vehicle Cost		$14,571	$16,033	$17,125	$16,419	$16,677	$17,780	$17,502	$17,671	$18,795	$16,102	$15,823	$17,334	$18,969
Vehicle Retail Price		**$21,857**	$24,050	$25,688	$24,629	$25,016	$26,670	$26,253	$26,507	$28,193	$24,153	$23,735	$26,001	$28,454
VEHICLE CHARACTERISTICS														
Engine Power Max	**W**	120267	96659	93302	67260	67901	69644	62735	67831	69619	0	0	0	0
Fuel Cell Power Max	**W**	0	0	0	0	0	0	0	0	0	72126	58327	60277	0
Motor Power Max	**W**	0	0	0	24471	56592	58875	24471	39076	40508	22195	99066	101947	97862
High Voltage Energy Storage C	**W or Wh**	0	0	0	784	2435	9432	784	2504	9708	711	3167	12685	37935
Vehicle Mass	**kg**	1474	1163	1204	1178	1208	1261	1225	1242	1294	1200	1195	1267	1296
Glider Mass	**kg**	990	693	693	693	693	693	693	693	693	693	693	693	693

* Includes final drivetrain, 12-V battery, wheels, and tires.

Values for the high fuel economy case are stressed here because they are viewed as more plausible in the context of the future conditions postulated in this study, that is, a future in which fuel economy is very highly valued. Figure 3-7 shows the drivetrain costs for the "average" fuel economy case, where tradeoffs among competing attributes have yielded less-optimistic fuel economy results. Although this case yields consistently cheaper gliders (from about $300 to $700 cheaper depending on year), the drivetrains are more expensive — in some cases substantially so. This result occurs because the significantly greater loads (higher weight, increased tire rolling resistance, and aerodynamic drag) demand considerably more power output for identical performance. In 2015 for the LR cost case, the lower fuel economy raises costs for the SI hybrid by about $200; for the SI 40-mile range plug-in hybrid by $1,300; for the fuel cell vehicle by $2,300; and for the EV by $5,000. In 2045, the cost differentials are $400 for the SI hybrid; $700 for the 40-mile plug-in hybrid; $1,000 for the fuel cell vehicle; and $2,000 for the EV. In contrast, the average fuel economy case increases the cost of conventional SI drivetrains by only about $100 because engine costs vary substantially with power only when attaining higher power requires a significant change in engine design, such as increasing cylinder count or adding a turbocharger or supercharger. The net effect of these differential cost effects is that attaining only the average fuel economy levels not only reduces the fuel economy of each type of vehicle, but also — by increasing the cost penalty of purchasing advanced drivetrain vehicles — likely reduces the market penetration of these vehicles and thus may substantially increase fuel use and greenhouse gas (GHG) emissions for the fleet as a whole. In other words, **attaining maximum fuel economy levels — especially reducing vehicle loads so that drivetrain power demands are reduced — may be crucial to stimulating markets for advanced technology vehicles.**

It is worthwhile to reiterate that these insights reflect a series of *assumptions* about how technology costs could plausibly be reduced over time, given an underlying optimism regarding the likelihood of technology success.

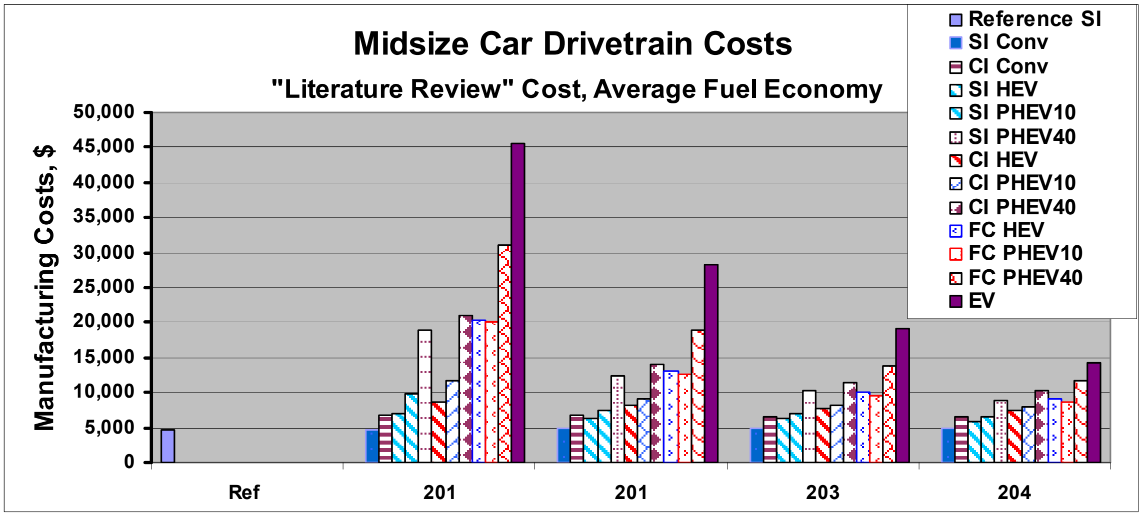

FIGURE 3-7 Midsize Car Drivetrain Costs (in 2008$), LR Costs Case, Average Fuel Economy

3.3.6 Scaling Cost Estimates to Multiple Vehicle Classes

As discussed above, cost estimates were developed for a midsize passenger car and midsize SUV with multiple drivetrain technologies based on PSAT vehicle simulations that defined drivetrain characteristics for these vehicles. The light-duty vehicle fleet is composed of hundreds of vehicle types grouped into multiple classes. In the NEMS model used in this study, the fleet is subdivided into 12 vehicle categories (six classes for cars and six for light trucks). To provide input data for NEMS analyses, the cost estimates for the two vehicle types must be scaled to the 12 vehicle classes in each of the years for which cost estimates were derived (2010, 2015, 2030, and 2045). Table 3-12 shows the 12 vehicle classes and their average horsepower ratings and average curb weights for 2007 new vehicles. The 2007 midsize passenger car and light truck evaluated in the PSAT and cost analyses do not match any of these vehicles exactly; they weigh 3,250 and 3,876 pounds, respectively, and their engine power ratings are 161 and 192 horsepower, respectively.

For the midsize cars and SUVs evaluated in this study, data are available from PSAT on fuel economy, power, and weight (and other physical variables) and from ORNL on drivetrain cost for each drivetrain technology based on these physical values. For the six classes of passenger car and six of light trucks, data on the following variables — but for conventional drivetrain vehicles only — are available for multiple years:

- Average fuel economy,
- Average weight,
- Average horsepower, and
- Average manufacturer's suggested retail price (MSRP).

TABLE 3-12 Average Horsepower and Curb Weight for 12 Vehicle Classes, New U.S. 2007 Light-Duty Vehicle (LDV) Fleet

	Power (horsepower)	Curb Weight (pounds)
Conventional Cars		
Minicompact	255	3,572
Subcompact	185	3,080
Compact	147	2,964
Midsize	194	3,447
Large	212	3,761
Two-seater	264	3,278
Average new car	180	3,283
Conventional Light Trucks		
Small pickup	164	3,892
Large pickup	226	5,275
Small van	191	4,420
Large van	206	4,849
Small utility	196	4,181
Large utility	239	5,442
Average new light truck	213	4,823

Scaling the cost estimates to the 12 vehicle categories is made more difficult because the midsize car and SUV have fairly similar-sized powertrains of 161 and 192 horsepower, which does not afford the possibility of obtaining a rough linear relationship between power and cost that might be scaled to other powertrains. Also, scaling factors that are appropriate for a single year may not be appropriate for other years, because the costs and physical attributes (e.g., specific power) of different powertrain technologies and different components of each powertrain change over time at different rates. Given these difficulties and a scarcity of data, a number of simplifications are made, a primary one being that scaling factors are derived from the 2007 relationships among the multiple vehicle types and applied in all years.

As noted above, only two categories of costs – glider weight reduction and changes in drivetrain technology – are estimated, ignoring possible costs from changes in aerodynamics, tires and accessories.

3.3.6.1 Cost of Glider Weight Reduction in Year Y

The cost of glider weight reduction is assumed to scale linearly with glider weight. Knowing the glider weight reduction cost for the midsize car evaluated with PSAT, we can calculate:

$\text{COST OF GLIDER WEIGHT REDUCTION}_{\text{car class x, year y}}$
$= [\text{COST OF GLIDER WEIGHT REDUCTION}_{\text{midsize car, y}}] \times$
$[\text{GLIDER WEIGHT}_{\text{x,y}}]/[\text{GLIDER WEIGHT}_{\text{midsize,y}}]$

For this estimate, glider weight includes the weight of wheels and tires (in PSAT analyses, wheels and tires are considered part of the drivetrain). An underlying assumption is that the glider weight reductions as percentages of the original glider weights are the same across vehicle class; thus, the ratios of glider weights across classes do not change over time. Because only the curb weight for each of the 12 vehicle classes is given, their glider weights must be estimated.

Assuming that SI drivetrain weight = K × power, then

$K = [\text{drivetrain weight}_{\text{midsize car}}]/[\text{power}_{\text{midsize car}}]$ for 2007, which we know from PSAT.

This result gives the glider weight for any vehicle class X in 2007 as:

$\text{Glider weight}_x = \text{curb weight} - \text{drivetrain weight} = \text{curb weight}_x - k \times \text{power}_x$

For year *y*,
$\text{COST OF GLIDER WEIGHT REDUCTION}_{\text{car class x}}$
$= \text{COST OF GLIDER WEIGHT REDUCTION}_{\text{midsize,y}} \times$
$[\text{2007 CURB WEIGHT}_x - K \text{ x power}_x]/\text{2007 GLIDER WT}_{\text{midsize}}$

3.3.6.2 Cost of Drivetrains (For Various Technologies) in Year Y

As discussed above, drivetrain costs have been calculated for midsize cars and SUVs in each year y and for multiple drivetrain technologies, and they must be scaled to 12 vehicle classes. Drivetrain costs will not scale well with any one factor. According to the cost equations used in the ORNL analysis (Table 3-1):

- Engine costs scale with number of cylinders, and somewhat with power; also, the number of cylinders scales roughly with power, although this relationship is strongly affected by the type of air injection system used (naturally aspirated, turbocharged, supercharged).

- Fuel cell costs scale with power.

- Hydrogen storage costs scale with volume of fuel required for a rated range, so they scale inversely with fuel economy (or directly, if fuel economy is stated in fuel consumption terms, e.g., liters [L]/100 kilometers [km]).

- HEV battery costs scale with power.

- PHEV and BEV battery costs scale inversely with fuel economy (actually with kWh, which are determined by how much energy is needed to obtain a constant stated range).

- Motor/controllers scale with power.

Also, there are substantial fixed costs in drivetrains, so costs should not be expected to vary with simple multiples of attributes like weight and power.

The following simple scaling rules are followed, where *W* is the 2007 ratio of the curb weights of the passenger car class to the PSAT midsize car (with conventional SI drivetrain) or of the light truck class to the PSAT midsize SUV, and *P* is the 2007 ratio of engine powers for the same vehicles. It is important to note that these scaling factors are recognized to be inaccurate; without further analysis, they are designed only to allow some logical differentiation between the way different drivetrain types are likely to vary with weight and power:

a The **conventional drivetrain** costs scale with $(1 + P)/2$; that is, the costs scale with power, but more slowly than by its simple direct ratio.

b For **hybrids, PHEV10s, and fuel cells HEVs and PHEV10s**, cost scales with $(1 + 2P)/3$; that is, costs scale a bit more directly with power than for conventional drivetrains. This scaling factor was chosen because the costs of high-power batteries, fuel cells, and electric motors scale more linearly with power than does the cost of engines and transmissions.

c For **PHEV40s**, costs scale with (1 + P + W)/3; the weight factor *W* is added because it roughly tracks with fuel efficiency (in consumption terms), and because high-energy battery costs vary roughly with energy storage capacity, which, in turn, depends on fuel efficiency (in consumption terms).

d For **battery EVs**, costs scale with (1 + P + 2W)/4; this scaling factor gives added emphasis to weight in scaling to recognize the added battery energy storage requirements for an EV.

3.3.7 Rules for Estimating Vehicle Prices By Class, Technology, and Year

As in the discussion of fuel economy, the analysis thus far has focused on leading edge vehicles rather than average vehicles in each class. To examine fleet effects, it is necessary to estimate how the technologies embodied in these leading edge vehicles penetrate the new vehicle fleet. The methodology used to translate the leading edge vehicle price estimates into estimates for all new vehicles in each class is identical to the method used for the fuel economy analysis (described in Box 3), except that the factors operated on in the methodology shift from leading edge X factors in the fuel economy analysis to incremental vehicle costs in the vehicle cost analysis. Incremental costs are estimated relative to the gasoline ICE costs of the NEMS-MP Base Case, which are estimated to increase over time almost completely as a result of added technologies associated with fuel economy improvement.[10] The final values developed for each of the 12 vehicle classes are presented in Appendix A.

3.4 OTHER VEHICLE ATTRIBUTES

A key purpose of the analysis of vehicle fuel economy and vehicle purchase price has been to assist in estimating the likely role each of the different types of vehicles will play in the future given different assumptions about future fuel prices and government policies. The Vehicle Choice Model (VCM) embedded in the NEMS model is used to estimate each vehicle type's penetration into the light duty fleet. The model bases its estimates of future vehicle sales on estimates of the value consumers place on fuel economy and first cost, as well as other vehicle attributes (though these are of considerably less importance). The other attributes are range, maintenance cost, acceleration capability, top speed, and luggage space. Table 3-13 shows attribute values assumed for midsize cars in the Mixed and (P)HEV& Ethanol Scenarios (see Chapter 6), presented as ratios referenced to the attributes exhibited by reference vehicles with conventional SI drivetrains in each analysis year. The attributes can vary by vehicle class. The full set of attributes used for all 12 vehicle classes are presented in Appendix A. The years of introduction for FCVs and FCV PHEV40s are earlier in the H2 Success Scenario; the other attributes are modified slightly to account for the earlier introduction.

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[10] We made very small adjustments to these costs to account for some expected safety improvements in the near term.

TABLE 3-13 Assumed Vehicle Attributes for Advanced Drivetrain Vehicles: Midsize Car, Mixed and (P)HEV & Ethanol Scenarios (Note: values < 1 mean "worse" for range, top speed, and luggage space and "better" for maintenance cost and acceleration.)

		Year of:				
Attributes		Market Intro.	Price Success	Price Mature	2040	2050
Advanced Diesel		**2011**	**2016**	**2021**	**2040**	2050
Range		1.20	1.20	1.20	1.20	1.20
Maintenance Cost		0.90	0.90	0.90	0.90	0.90
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		1.00	1.00	1.00	1.00	1.00
Luggage Space		1.00	1.00	1.00	1.00	1.00
Diesel Hybrid		**2015**	**2020**	**2025**	**2040**	2050
Range		1.35	1.35	1.35	1.35	1.35
Maintenance Cost		0.95	0.95	0.95	0.94	0.93
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		0.90	0.90	0.90	0.90	0.90
Luggage Space		0.95	0.95	0.95	0.95	0.95
Gasoline Hybrid		**2010**	**2015**	**2020**	**2040**	2050
Range		1.25	1.25	1.25	1.25	1.25
Maintenance Cost		1.05	1.05	1.05	1.04	1.03
Acceleration		**0.90**	0.90	0.90	0.90	0.90
Top Speed		0.90	0.90	0.90	0.90	0.90
Luggage Space		**0.95**	0.95	0.95	0.95	0.95
Advanced Gasoline		**2010**	**2015**	**2020**	**2040**	2050
Range		1.00	1.00	1.00	1.00	1.00
Maintenance Cost		1.00	1.00	1.00	1.00	1.00
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		1.00	1.00	1.00	1.00	1.00
Luggage Space		1.00	1.00	1.00	1.00	1.00
Fuel Cell (hydrogen)		**2023**	**2028**	**2033**	**2040**	2050
Range		1.00	1.00	1.00	1.00	1.00
Maintenance Cost		1.10	1.06	1.01	1.00	1.00
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		0.85	0.90	0.97	1.00	1.00
Luggage Space		0.90	1.00	1.00	1.00	1.00
FCV PHEV 40		**2025**	**2030**	**2035**	**2040**	2050
Range		1.00	1.00	1.00	1.00	1.00
Maintenance Cost		1.10	1.06	1.01	1.00	1.00
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		0.80	0.85	0.89	0.90	0.90
Luggage Space		0.80	0.90	0.90	0.91	0.93
SI Plug-in HEV 40		**2018**	**2023**	**2028**	**2040**	2050
Range		1.10	1.10	1.10	1.10	1.10
Maintenance Cost		1.10	1.08	1.05	1.05	1.03
Acceleration		1.00	1.00	1.00	1.00	1.00
Top Speed		0.90	0.90	0.90	0.90	0.90
Luggage Space		0.90	0.90	0.90	0.91	0.93

Of the five attributes shown, three — range, acceleration, and top speed — are actually calculated for each individual vehicle evaluated by the PSAT model; however, PSAT was not used to evaluate the reference vehicles (i.e., the average vehicles in the NEMS Reference Case). Consequently, because it was not possible to estimate the ratios in Table 3-13 directly, they are "assumed" values.

The five attributes vary as follows:

Range. It was assumed that vehicle manufacturers would use the Advanced Conventional SI vehicles as baselines and install fuel tanks adequate to obtain the required range, keeping the same volume tanks for diesel and hybrid versions — which would increase range — but possibly reducing tank size for plug-in hybrids because of space considerations. Because hydrogen storage is expected to be quite expensive, manufacturers are expected to minimize tank size (i.e., provide just enough storage volume for minimum range requirements). It is quite conceivable that optional (larger) tanks might be offered in some models, especially larger and/or more expensive models.

Maintenance cost. Diesels are expected to require less maintenance cost than conventional SI drivetrains, whereas the hybridization of drivetrains is expected to add to lifetime maintenance costs somewhat (although maintenance costs for the mechanical brakes should decrease because of the use of regenerative braking), and early fuel cell drivetrains are expected to further add to costs. These differences are reflected in the Table 3-13 values, with incremental costs declining over time as learning occurs. For those drivetrain technologies that have not yet been commercialized or that are likely to undergo substantial further development, estimates of maintenance costs must be considered speculative.

Acceleration. Acceleration capability has been assumed to be uniform across vehicle technologies. The PSAT analysis included vehicle powertrain "sizing" based on an assumed uniform acceleration capability; thus, assuming a uniform factor of 1.00 appears reasonable.

Top speed. Although there is a "top speed" requirement in the PSAT vehicle sizing analysis, this attribute is a minimum rather than a target (unlike the acceleration requirement), and the acceleration requirement will yield a higher top speed for some types of drivetrains. In particular, the hybrid drivetrains likely will have lower top speeds than conventional drivetrains because the acceleration requirement can be met with boost from the battery and motor, whereas the top speed requirement must obtain power only from the engine (i.e., the requirement is assumed to be a top cruising speed rather than an instantaneous value.

Luggage space. Especially in the early years of market penetration, hybrids' battery volume requirements and fuel cells' hydrogen storage requirements will subtract from luggage space area(s), with the penalty reduced over time.

3.5 TRADING OFF VEHICLE “FIRST COST” VS. FUEL SAVINGS

3.5.1 Description of the Analysis

Although consumers will choose among competing vehicles by considering a number of different attributes — and the NEMS vehicle choice model considers five attributes in addition to vehicle price and fuel economy — many analyses have estimated “cost-effective” levels of technology improvement by examining the simple tradeoff between technology retail price and the fuel savings associated with the technology, with fuel savings discounted over the vehicle’s lifetime. This tradeoff can be quite illuminating as long as its limitations are understood.

In this section, we examine this tradeoff in a simplified manner. Within the NEMS model analysis, a vehicle’s annual and lifetime miles and fuel prices change over time, and the fuel economies and prices of advanced drivetrain vehicles in any given year are compared to reference vehicles that evolve over time. In contrast, the analysis described in this section will hold the lifetime miles of new vehicles constant over time, will evaluate discounted fuel costs based on the simplifying assumption that fuel prices will stay constant over the vehicle’s lifetime, and will compare all new vehicles to a 2007 reference vehicle.

Basic assumptions are as follows:

- Vehicle lifetime = 15 years and 165,000 miles
- For each new vehicle, annual reduction in miles driven/year = 4%
- For a midsize passenger car, the reference vehicle — a 2007 model year vehicle with a conventional SI drivetrain — has a 24.7-MPG (adjusted) combined city/highway fuel economy and costs $21,867 at retail.

There is considerable controversy over the most appropriate way to calculate the value of the fuel savings associated with efficiency technology. Vehicle manufacturers have claimed that consumers behave, in their purchase decisions, as if they valued only about 3 years’ worth of fuel savings, whereas others have computed fuel savings over the lifetime of the vehicle in evaluating cost tradeoffs. With the calculation of fuel use over the vehicle’s lifetime, it is necessary to select an appropriate discount rate for comparing future fuel savings to current vehicle costs. Typically, analysts interested in weighing societal choices choose a low discount rate (4% is common) to simulate the high value society is thought to place on future benefits. In contrast, weighing business decisions may demand a considerably higher discount rate, as much as 15% or 20%. Individual vehicle purchasers are likely to demand a much higher discount rate than they would require from safe investments such as bank CDs, because the return on an investment in future fuel savings is made more risky by uncertainties regarding such factors as future fuel prices, the amount of time before the vehicle is sold, actual fuel economy obtained, and annual miles driven. And a key element in the consumer decision is simply whether or not potential vehicle purchasers view fuel efficiency as especially important and whether they believe that, when they choose to sell into the used vehicle market, fuel economy will be an important element of the vehicle's resale value. In this analysis, future fuel savings are discounted by 4%, 10%, and 20% to show how vehicle valuations can shift with changing discount rates. The 4% rate will be treated in the discussion that follows as the "societal" rate, and the 20% rate will be treated as the "individual" rate. However, it should be recognized that these rates can change as conditions and attitudes change. In addition, the individual rate should be viewed as representing an average vehicle purchaser, and there is a wide distribution of attitudes about future fuel savings — thus a wide range of appropriate discount rates — in the population of vehicle purchasers.

As an aside, it is important to note that the "societal" 4% discount rate would normally be applied to fuel savings valued *net of taxes*, since taxes are simply a transfer from consumer to government. However, society may also add "externality costs" to the value of fuel, and the value of externality costs is quite controversial. (Externality costs are costs [or benefits] to society that are not included in market price, e.g., damage from pollution.) This analysis values fuel savings at market price and includes taxes but does not include externality costs.

There is substantial uncertainty associated with all elements of the vehicle cost/fuel savings tradeoff. For example, future technology costs are highly uncertain. As discussed in Section 3.3, this analysis examines the tradeoff by using two groups of technology cost estimates, labeled "literature review" (LR) and "program goals" (PG). The PG technology costs are assumed to attain DOE FreedomCar cost targets, many of which are normative — that is, rather than being created on the basis of engineering evaluations of what could be possible with mass production and design changes, they were created as goals on the basis of what values would be needed to make advanced vehicles fully cost-competitive with conventional vehicles. The LR technology costs are based on a review of the literature and reflect our best judgment *at the time the estimates were made* of the likely outcome of successful progress in technology advancement and cost reduction. **It is important to note that they are not an estimate of "most likely" costs, because they ignore the very real possibility that research, development, and demonstration efforts for one or more technologies may not be fully successful.**

Future fuel prices are also uncertain, and the vehicles examined use a number of fuels — gasoline, diesel, hydrogen, electricity, and ethanol (although ethanol costs are not considered here) — that may vary in ways that may be somewhat independent of each other. Four differing fuel price cases are examined for 2030:

- **$4.50/gallon gasoline price case:** gasoline price is $4.50/gallon; diesel is $4.50/gallon of gasoline equivalent, or GGE (about $5.00/gallon[11]); hydrogen price is $3.75/kg (1 kg is approximately equivalent to 1 gallon of gasoline in energy content); and electricity is $.08/kWh (for nighttime recharging).

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[11] By assuming that diesel fuel will be priced about 12% higher, on a volumetric basis, than gasoline, the analysis may be overly pessimistic about the cost effectiveness of compression-ignition engine-based systems. Over the past few years, diesel prices have tended to be substantially higher than gasoline prices, although prior to that, diesel was often less expensive than gasoline on a volumetric basis. It is difficult to predict how gasoline/diesel price relationships will evolve in the future.

- **$3.15/gallon gasoline price case:** gasoline price is $3.15/gallon (approximately the 2030 price in the NEMS scenario with high oil prices); diesel is $3.15/GGE; hydrogen is $2.75/kg; and electricity is $.08/kWh.

- **$2.50/gallon gasoline price case:** gasoline price is $2.50/gallon; diesel is $2.50/GGE; hydrogen is $2.75/kg; and electricity is $.08/kWh.

- **$2.00/gallon gasoline price case:** gasoline price is $2.00/gallon; diesel is $2.00/GGE; hydrogen is $2.50/kg; and electricity is $.08/kWh.

These four cases may not capture the potential range of energy prices possible in 2030, and they do not capture the possibility that hydrogen prices may not rise and fall in the same manner as might oil prices (however, although hydrogen prices will depend somewhat on production and delivery technology, which may be fairly independent of oil prices, they will also depend on overall energy and feedstock prices).

Ideally, an examination of the vehicle cost/fuel savings tradeoff would evaluate a continuum of technology advances by searching for an optimum point at which the net benefit is maximized and the incremental costs of adding further technology outweigh any further benefits in fuel savings. This analysis has instead evaluated vehicles incorporating a series of technology *packages*, each incorporating multiple drivetrain improvements. Each package is associated with a specific drivetrain (e.g., advanced conventional SI, SI HEV, FCV, etc.). Within each vehicle class, gliders are identical and incorporate a group of technology advances, including weight reduction, improved tires and aerodynamics, and improved accessories.

This section first presents a series of charts that compare the cost effectiveness — lifetime fuel savings minus the difference in vehicle price — for leading edge midsize cars in 2030 with the different drivetrain technology packages for each of the four fuel price scenarios and for both of the technology cost cases. The reference vehicle is a 2007 midsize car with a conventional SI drivetrain. **A key to interpreting each graph is to recognize that the appropriate way to evaluate a vehicle with a particular technology package is to examine its cost effectiveness *compared to all other options*, not just to the reference vehicle. Even if a vehicle is cost effective when compared to the reference vehicle, there may be another, less-expensive option with a higher net benefit even though it offers less fuel savings. In that case, the *marginal* cost effectiveness of the first option is negative, and it is not an economically efficient choice.** In other words, if a simpler, less-expensive option can capture much of the potential fuel savings benefit at a relatively low cost/gallon saved, it may not make economic sense to try to capture the remaining available savings. In viewing the graphs, once the maximum level of cost effectiveness is reached, further technology additions or improvements — for example, larger batteries or a shift to a different (and more expensive) drivetrain technology — may save more fuel but at a cost that exceeds the value of the added savings.

3.5.2 2030 Midsize Cars vs. 2007 SI Conventional Midsize Cars, Literature Review Costs

Figures 3-8a through 3-8d show the net benefits of the full range of advanced vehicles when compared to the 2007 conventional drivetrain vehicle for leading edge midsize passenger cars (model year 2030) and LR costs for the four fuel price cases. (Tables with supporting values for Figures 3-8a–d through Figure 3-17 can be found in Section 3.8.)

The results show clearly the powerful effect of discount rates on the perceived cost effectiveness of the various advanced vehicles. For example, for the $4.50/gallon gasoline price case, at the "societal" (4%) discount rate, all advanced vehicles in 2030 are cost effective — that is, they have positive net benefits (lifetime fuel savings minus vehicle price difference). At the 20% discount rate, which better reflects (average) consumer decision-making, many of the options have little net benefit, and four have slipped into negative territory.

In the cases with the two highest fuel prices, the figures show that it makes sense to purchase the advanced conventional SI drivetrain car and the SI HEV at all three discount rates. The HEV, however, has the maximum cost effectiveness of the full range of drivetrain types. In other words, moving to still more advanced vehicles — for example, the PHEV10s — reduces net benefits (except at the 4% discount rate) even though the SI PHEV10 is a more cost-effective choice than the reference vehicle. This result does not mean that the SI PHEV10 is a poor investment — vehicle purchasers may value the PHEV's substitution of electricity for gasoline at a higher value than represented simply by the price of the fuels — but it is important to recognize that purchasers of vehicles with advanced drivetrains will be comparing them to the other options

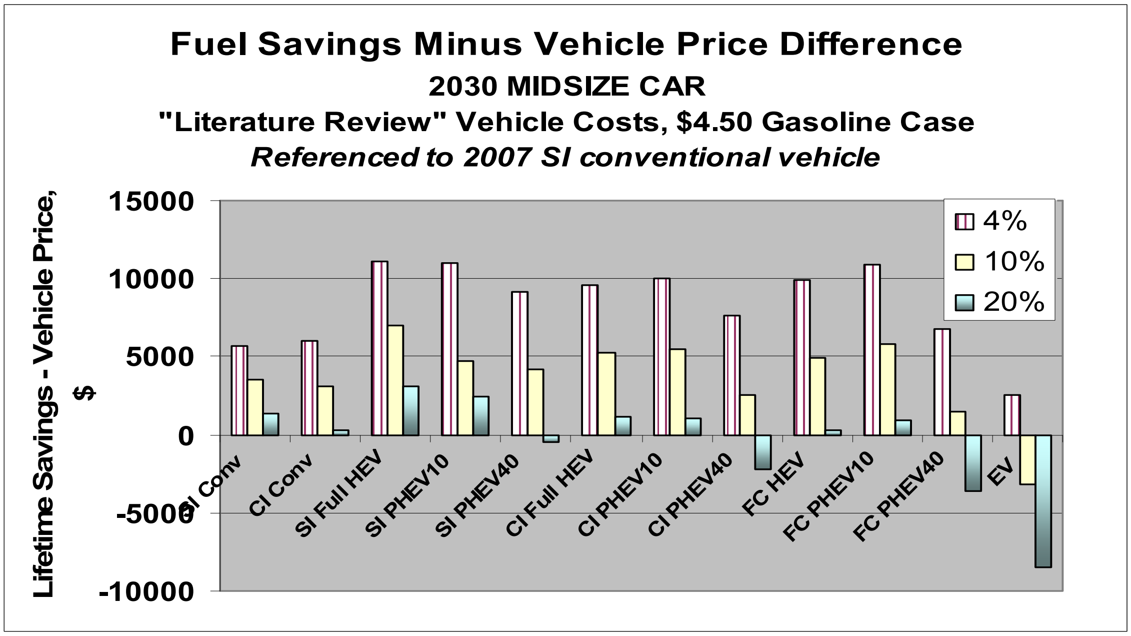

FIGURE 3-8a Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $4.50/gallon Gasoline Price Case

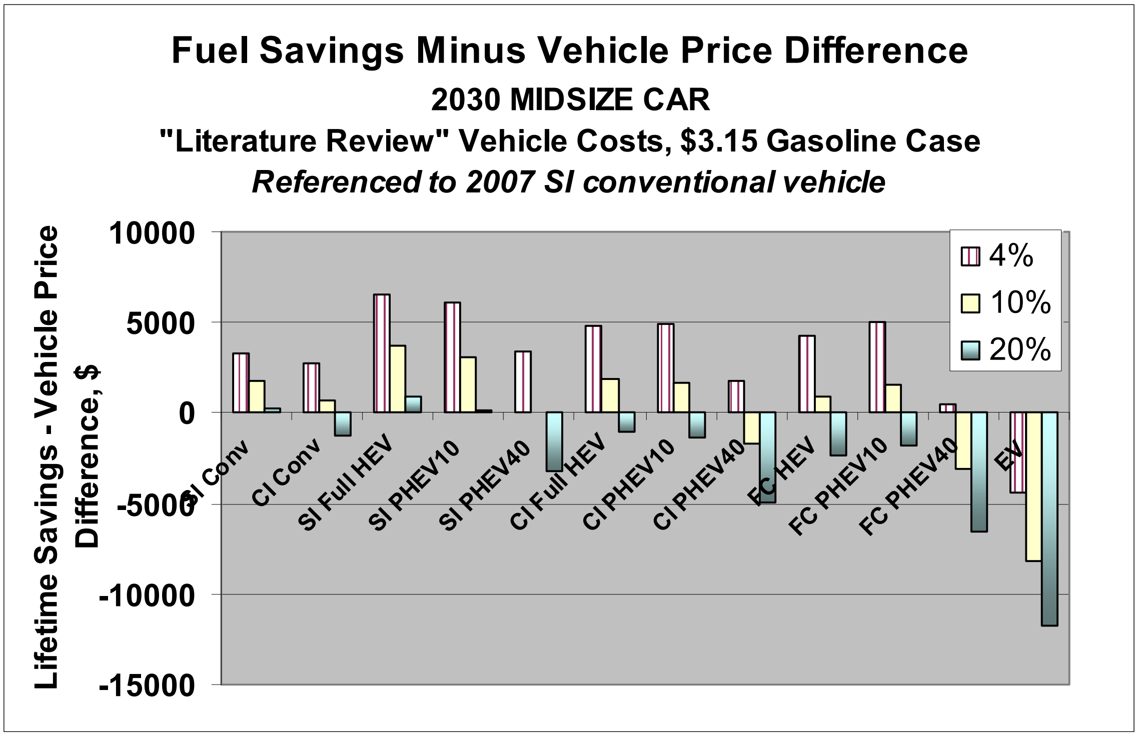

FIGURE 3-8b Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $3.15/gallon Gasoline Price Case

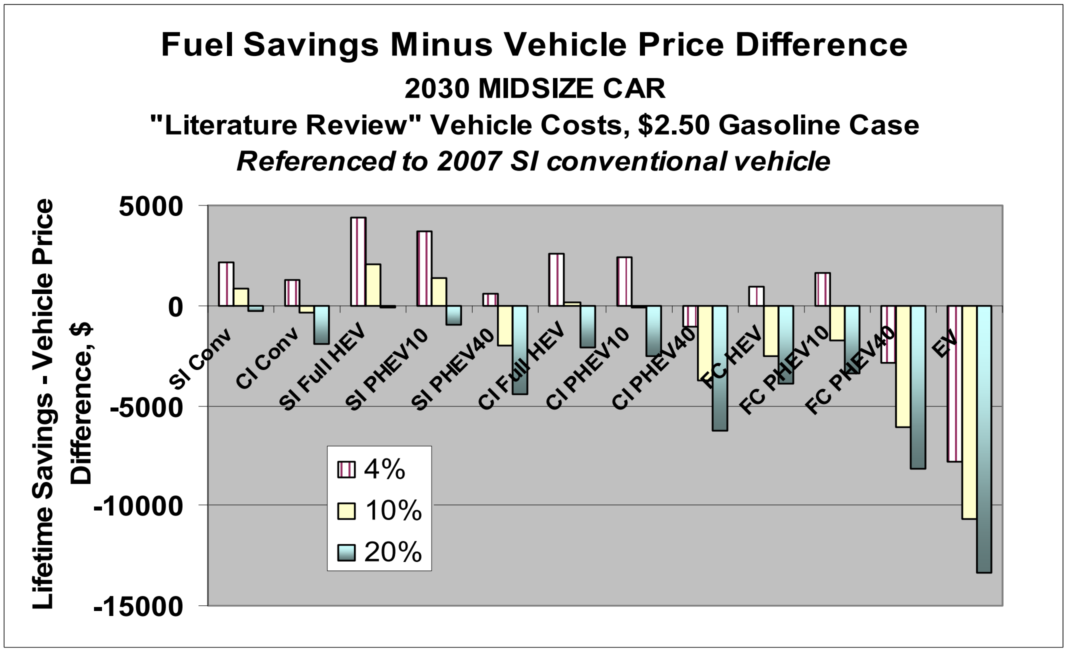

FIGURE 3-8c Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $2.50/gallon Gasoline Price Case

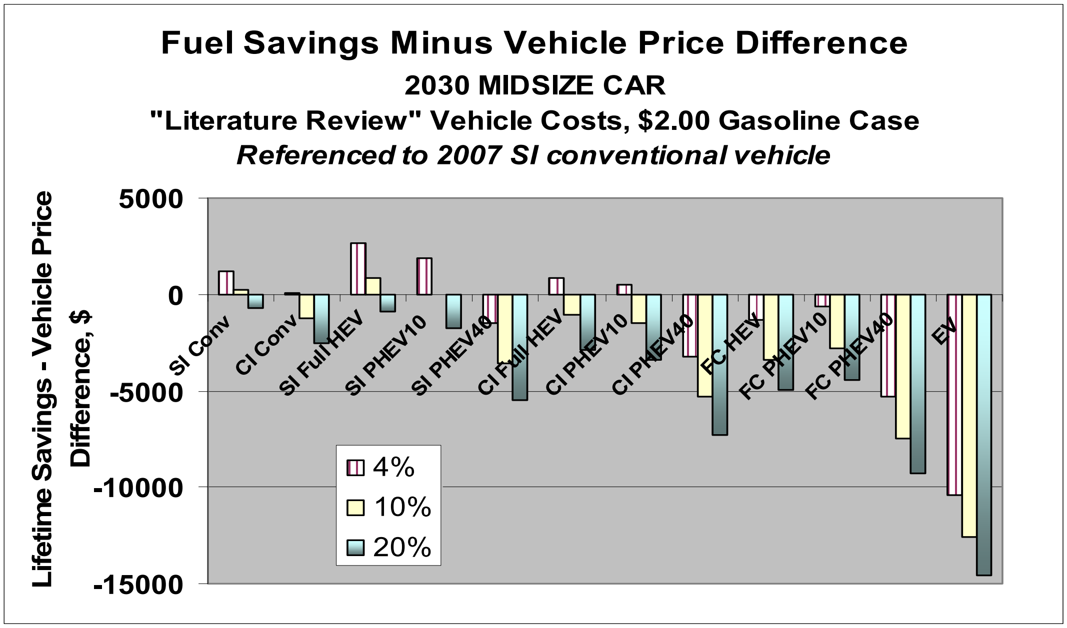

FIGURE 3-8d Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $2.00/gallon Gasoline Price Case

available for their consideration at the time. If an advanced conventional vehicle or HEV captures enough of the potentially available fuel savings, the additional cost of moving to PHEVs or FCVs may not appear attractive to the average vehicle purchaser.

Moving from individual (20%) discount rates to societal (4%) discount rates leads to an important shift in the relative attractiveness of the various vehicle/drivetrain options. While the fuel cell vehicles and the SI PHEV10 are substantially less attractive than the SI HEV at individual discount rates, they are virtually equal or only slightly less attractive at societal rates. This finding is not surprising, because the higher discount rates give more weight to first costs, and FCVs in particular are expected to be quite expensive.

At the lower fuel prices, cost effectiveness is reduced sharply across the board, and even the advanced conventional vehicles slide into negative cost-effectiveness territory at gasoline prices of $2.50/gallon and below for the "individual" 20% discount rate. Although again this result is not surprising, it has disturbing implications for the U.S. auto industry, which must comply with the new fuel economy standards even if fuel prices are low.

It must be noted here and in the analysis of PG costs considered below that the compression-ignition (diesel) vehicles suffer somewhat from a relatively high (assumed) diesel fuel price and comparatively pessimistic technology cost estimates.[12]

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[12] Discovered when we compared our estimates to others; see Section 3.3.4.

3.5.3 2030 Midsize Cars vs. 2007 SI Conventional Midsize Cars, Program Goal Costs

Figures 3-9a through 3-9d duplicate the format of Figures 3-8a through 3-8d but substitute the program goals technology costs for the literature review costs.

These results are very different from the literature review case, with all advanced vehicles in positive cost-effectiveness territory for both the 4% and 10% discount rates at gasoline prices as low as $2.50/gallon and with *marginal* cost effectiveness remaining positive well beyond the SI HEV. In other words, if program goal costs are achieved, it will make economic sense to all actors (that is, at all three discount rates) to purchase advanced drivetrain technologies well beyond HEV drivetrains, especially fuel cell-based drivetrains. Even at a 20% discount rate, most vehicles remain in positive territory; the fuel cell vehicles have extremely high net lifetime benefits, primarily because the DOE cost targets for these vehicles are very low.

In other words, at these costs, the SI HEV no longer represents the “best” vehicle. For at least the cases with the two highest fuel prices, the SI PHEV10 has similar net benefits at all discount rates, so moving beyond the HEV to a PHEV10 is at least neutral (approximately) in terms of marginal cost effectiveness. And the FCVs represent the most cost-effective vehicles, especially the FCV PHEV10. Of course, these results hinge on the validity of the PG costs for FCVs, given the nature of their derivation.

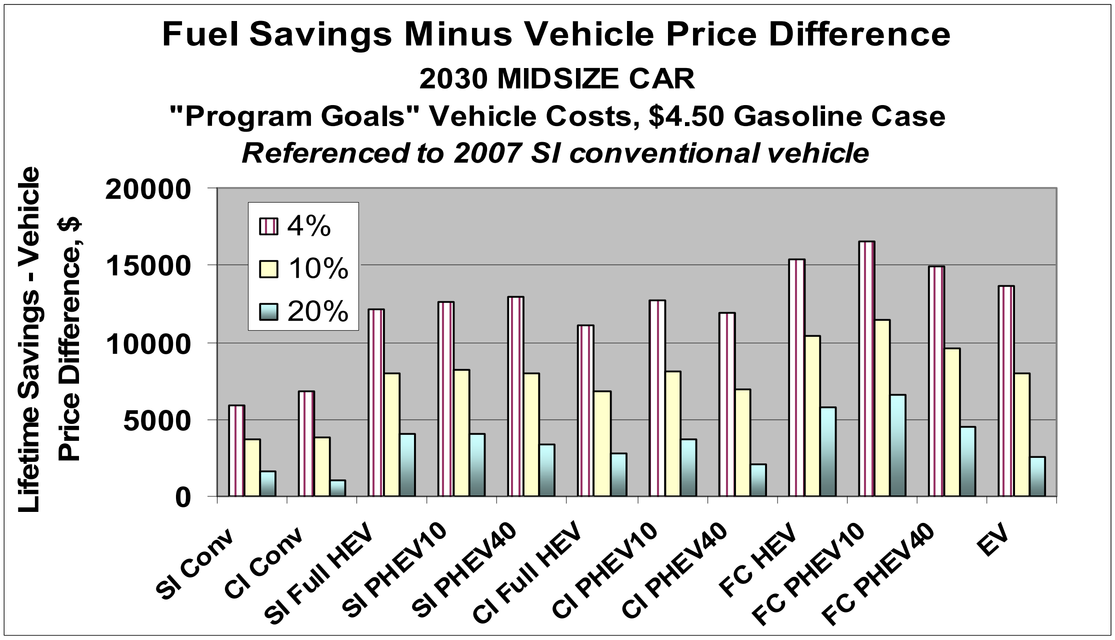

FIGURE 3-9a Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car (“Program Goals” Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $4.50/gallon Gasoline Price Case

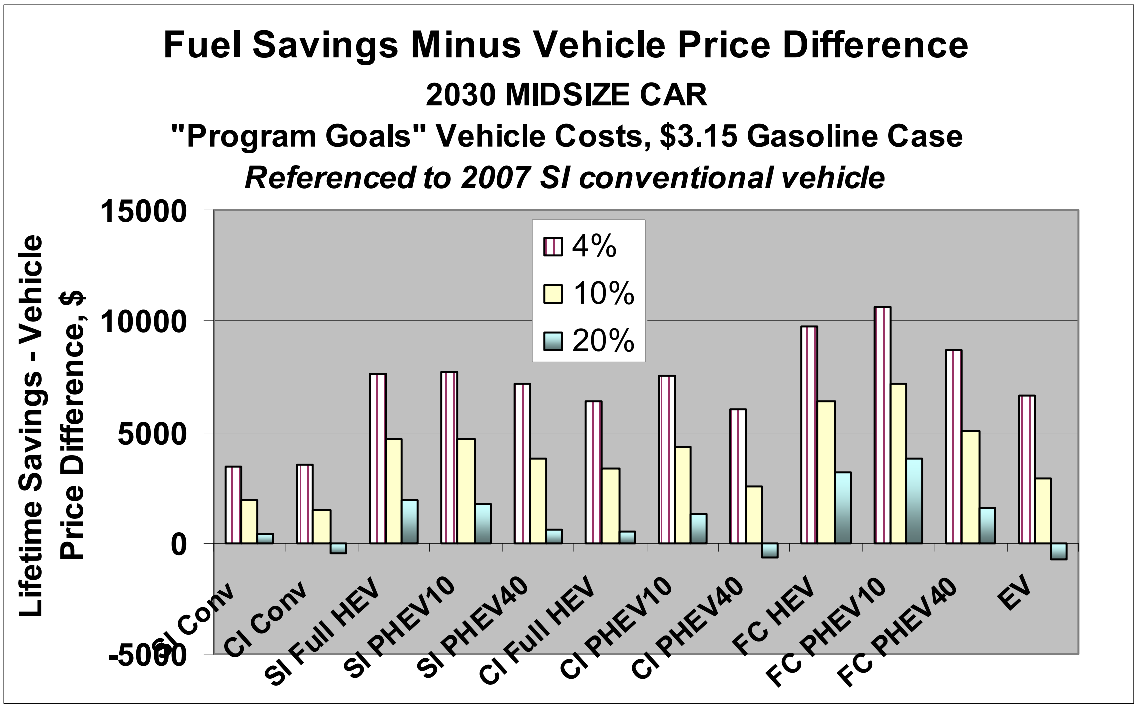

FIGURE 3-9b Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Program Goals" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $3.15/gallon Gasoline Price Case

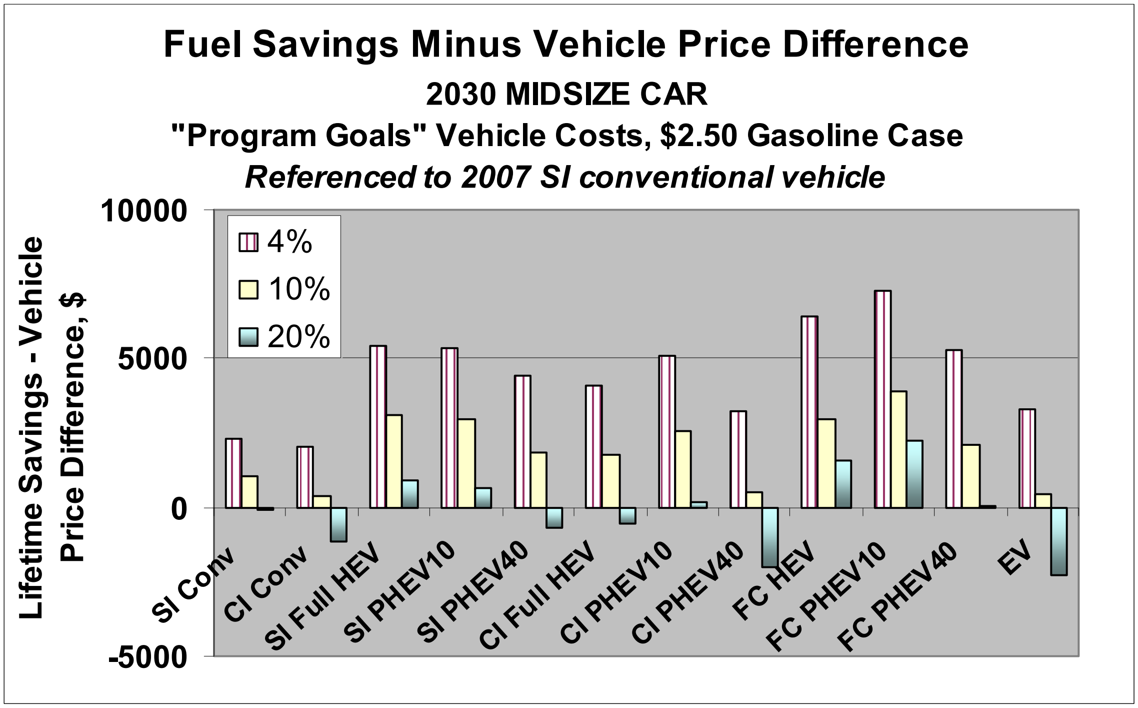

FIGURE 3-9c Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Program Goals" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $2.50/gallon Gasoline Price Case

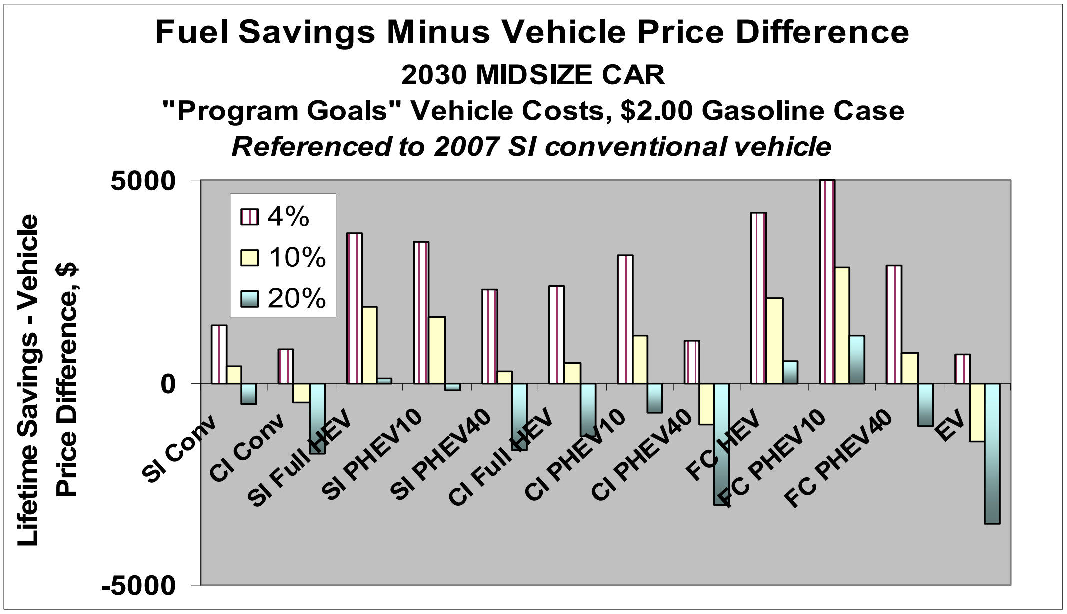

FIGURE 3-9d Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Program Goals" Vehicle Costs) Compared to a 2007 Conventional Drivetrain Midsize Car, for the $2.00/gallon Gasoline Price Case

For the $4.50/gallon gasoline price case, *all* of the evaluated vehicles are cost effective compared to the 2007 reference vehicle at all discount rates; however, for the most part, the longer-range electric drivetrain vehicles, the EVs and PHEV40s, have negative marginal net benefits compared to their shorter-range competitors (HEVs and PHEV10s). The primary difference between this case and the $3.15/gallon gasoline case is that, for both engine-driven and fuel cell drivetrains, the "best" vehicle becomes the PHEV10 for the higher-priced fuels case, as opposed to the HEV being the "best" vehicle for the $3.15 gasoline price case. However, the differences in net benefits are small enough such that, given the uncertainties in technology costs, the purchase decision between the two is relatively neutral.

At the lower fuel prices, the cost effectiveness of the ICE-based vehicles (compared to the 2007 reference vehicle) is marginal at the 20% discount rate. For the $2.50/gallon gasoline price case, the SI PHEV10 is positive, but it slips into negative territory for the $2.00/gallon gasoline price case, and even the SI HEV is barely positive at this fuel price level. Of more interest, the SI advanced conventional vehicle is not cost effective in either of the low fuel price cases (for the 20% discount rate). In both cases, however, the FCVs remain cost effective, and their marginal cost effectiveness as compared to the SI HEV is positive. In other words, if the average individual vehicle purchaser compares the SI HEV to the FCV or FCV PHEV10, she would prefer the fuel cell vehicles.

3.5.4 2030 Midsize Cars vs. 2030 SI Advanced Conventional

The analyses of cost effectiveness above, by using the 2007 conventional SI vehicle as the reference vehicle, show that the 2030 advanced drivetrains often will not be attractive economically despite their positive net benefits — because their *marginal* benefits as compared to the 2030 advanced conventional SI or SI HEV vehicles are negative. This finding can be more explicitly demonstrated by re-evaluating the cost effectiveness of the range of vehicles using the 2030 advanced conventional SI or SI HEV vehicles as the reference vehicles. We perform this comparison for the $3.15/gallon gasoline price case.

In other words, the 2030 advanced drivetrain vehicles are first compared to advanced versions of SI conventional drivetrain vehicles available in that year, with the idea that these "advanced conventional" vehicles represent the "first tier" of efficiency-focused technology and possibly the minimum acceptable level of technology if societal goals for oil security and climate change mitigation are very strong. These reference vehicles might be considered the "low-hanging fruit" for that year, and this comparison basically addresses the question of whether it makes financial sense to purchase anything more than this minimum level of efficiency-focused technology.

Figure 3-10 shows the cost-effectiveness graphs for the 2030 midsize car with the LR technology costs for the $3.15/gallon gasoline price case.

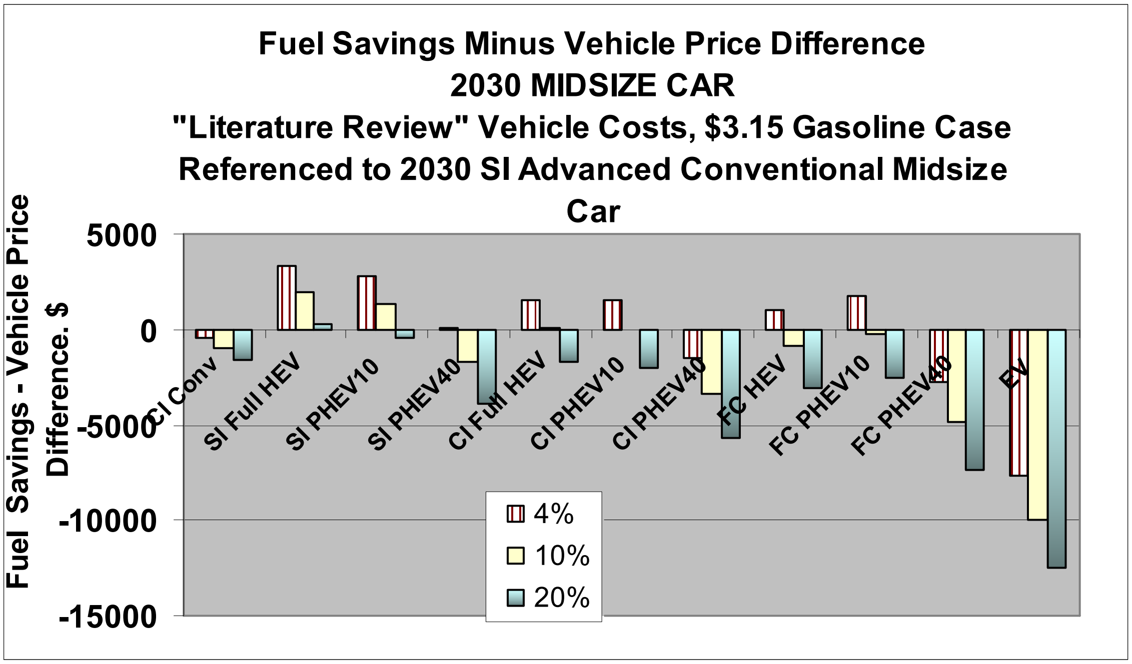

FIGURE 3-10 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs, High Fuel Costs) Compared to a 2030 Advanced Conventional Drivetrain Midsize Car

This graph makes the earlier point about marginal cost effectiveness a bit more clearly. Compared to the SI advanced conventional vehicle, only the SI HEV is unambiguously cost effective for all three discount rates. For the 20% "individual" rate, *all* of the more advanced (and more expensive) drivetrain types have negative net benefits — and even the SI HEV is just barely positive. In other words, for the average vehicle purchaser, there is little economic incentive to buy anything beyond an "advanced conventional" vehicle.

Figure 3-11 duplicates the above analysis with the PG vehicle costs, which reflect the achievement of DOE goals.

These results are very different, with all advanced vehicles except the diesel in positive cost-effectiveness territory for both the 4% and 10% discount rates. Even at a 20% discount rate, most vehicles remain in positive territory; the fuel cell vehicles remain above a net $2,000 in net lifetime benefits, primarily because the DOE cost targets for these vehicles are very low.

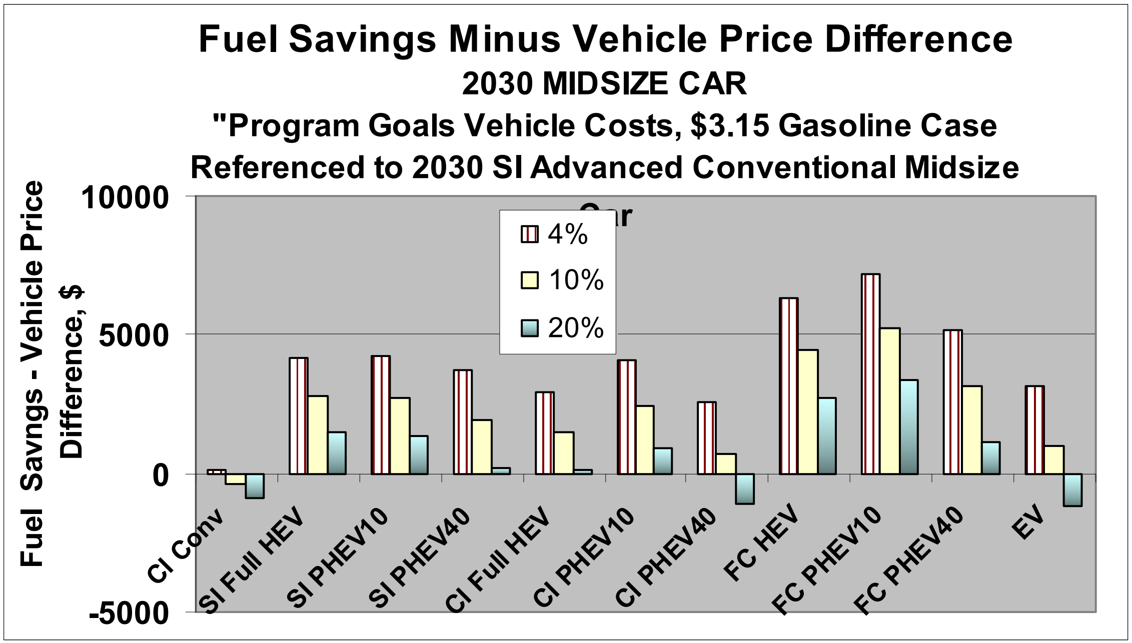

FIGURE 3-11 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Program Goals" Vehicle Costs, High Fuel Costs) Compared to a 2030 Conventional Drivetrain Midsize Car

3.5.5 2030 Midsize Cars vs. 2030 SI Full HEV Midsize Cars

This analysis examines the cost effectiveness of moving beyond SI full hybrids, under the assumption that such vehicles may easily become the baseline technology for the 2030 model year if cost reductions for batteries, motors, and electronic controls continue and fuel efficiency is a dominant factor in vehicle purchase decisions. Figure 3-12 shows the results of this analysis, assuming LR vehicle costs for the $3.15/gallon gasoline price.

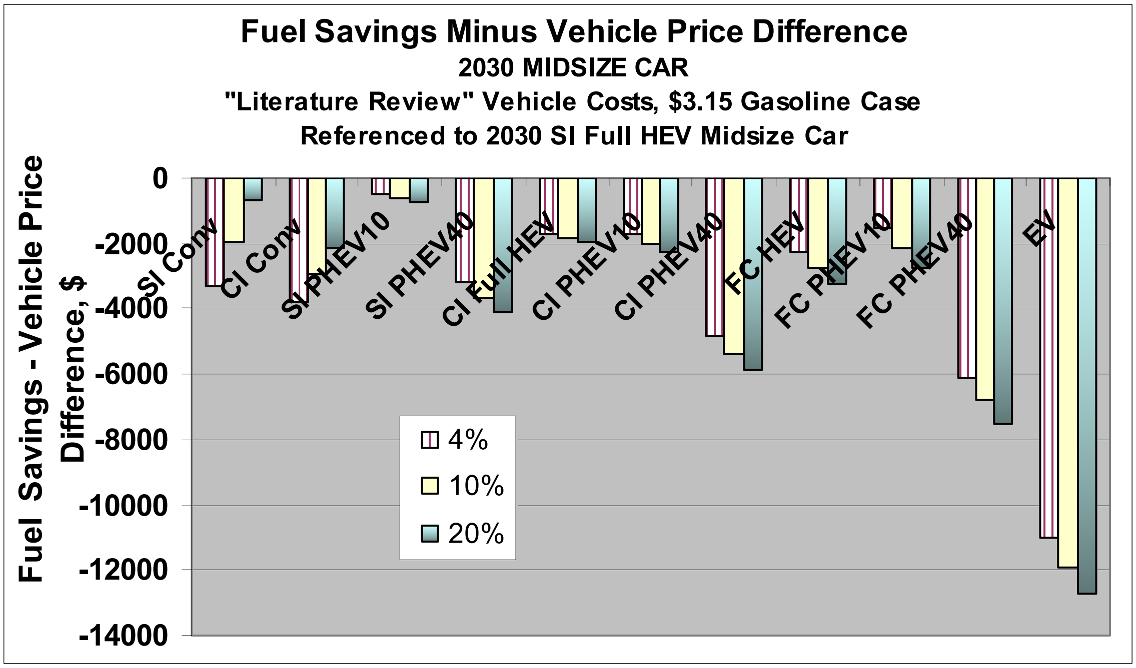

FIGURE 3-12 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Literature Review" Vehicle Costs, High Fuel Costs) Compared to a 2030 Full HEV Drivetrain Midsize Car

These results are sharply negative, indicating that moving beyond full hybrids to more complex drivetrains is not cost effective unless costs can be reduced below LR levels — even at societal discount rates.

Figure 3-13 shows the effects of achieving the lower PG costs.

Even with the PG costs (and high fuel prices), only the fuel cell vehicles (FCVs and FC PHEV10s) are cost effective. The implication is that, in the strict sense of a private decision regarding cost effectiveness, the case for moving beyond full hybrid drivetrains is negative for engine-driven plug-in vehicles and moderate for fuel cell vehicles. Although there are other (non-private) reasons for moving to these alternatives, including strong energy security and climate change considerations, it is hard to argue that consumers will be eager to adopt advanced vehicles without additional financial incentives. Fuel cell vehicles may constitute a possible exception, although even the case for these should be treated with caution because the assumed costs for the PG case are very low indeed.

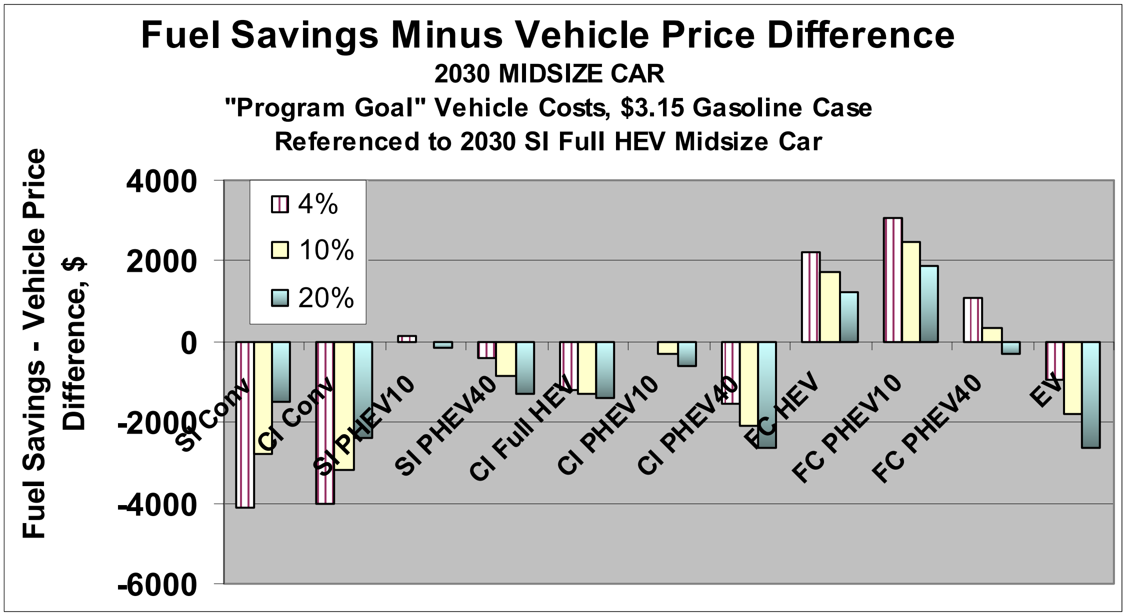

FIGURE 3-13 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car ("Program Goals" Vehicle Costs, Gasoline Price Point is $3.15/gallon) Compared to a 2030 Full HEV Drivetrain Midsize Car

3.5.6 Transition Costs — Cost Effectiveness in 2015

As noted earlier, the 2030 results discussed up to this point represent long-term results — what can be expected after substantial reductions in vehicle costs can be obtained by learning and mass production. Many of the advanced drivetrain technologies are likely to be very expensive when introduced; while cost reductions will be pursued vigorously in the laboratory and during development efforts, most new technologies experience further dramatic cost reductions in the years following their introduction. Consequently, the right-hand term of the cost-effectiveness measure — the incremental vehicle price — is likely to be much larger in 2015 than it will be in 2030. To get a sense for cost effectiveness during this transitional period, a final analysis focuses on net benefits in 2015, before many of the hoped-for cost reductions are achieved.

Figures 3-14 and 3-15 show the net benefits (referenced to a 2007 SI conventional midsize car) for a 2015 midsize car at both LR and PG vehicle costs for the $3.15/gallon gasoline price case. Hydrogen is still assumed to be $2.75/kg in the case as discussed in Section 3.5.1 (for 2030). However, it in fact might be higher than that in 2015, given that the potential cost-reduction effects of larger-scale centralized production, transport by pipelines, and learning will not have had a chance to take effect by 2015.

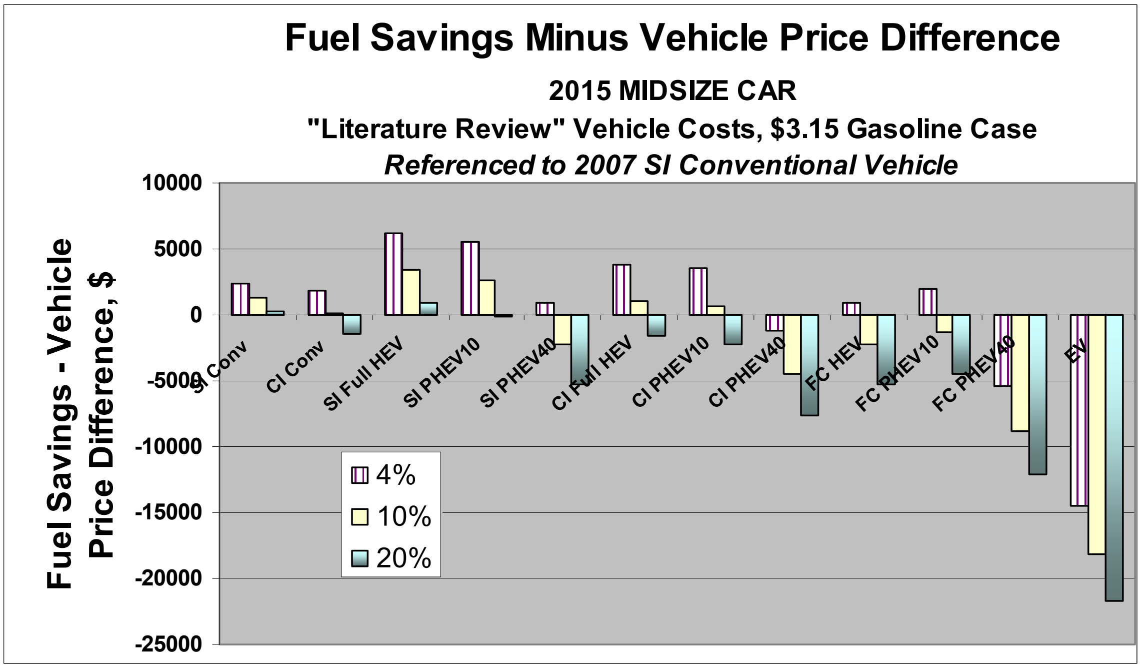

FIGURE 3-14 Fuel Savings Minus Vehicle Price Difference for a 2015 Midsize Passenger Car (“Literature Review” Vehicle Costs, for the $3.15/gallon Gasoline Price Case) Compared to a 2007 Conventional Drivetrain Midsize Car

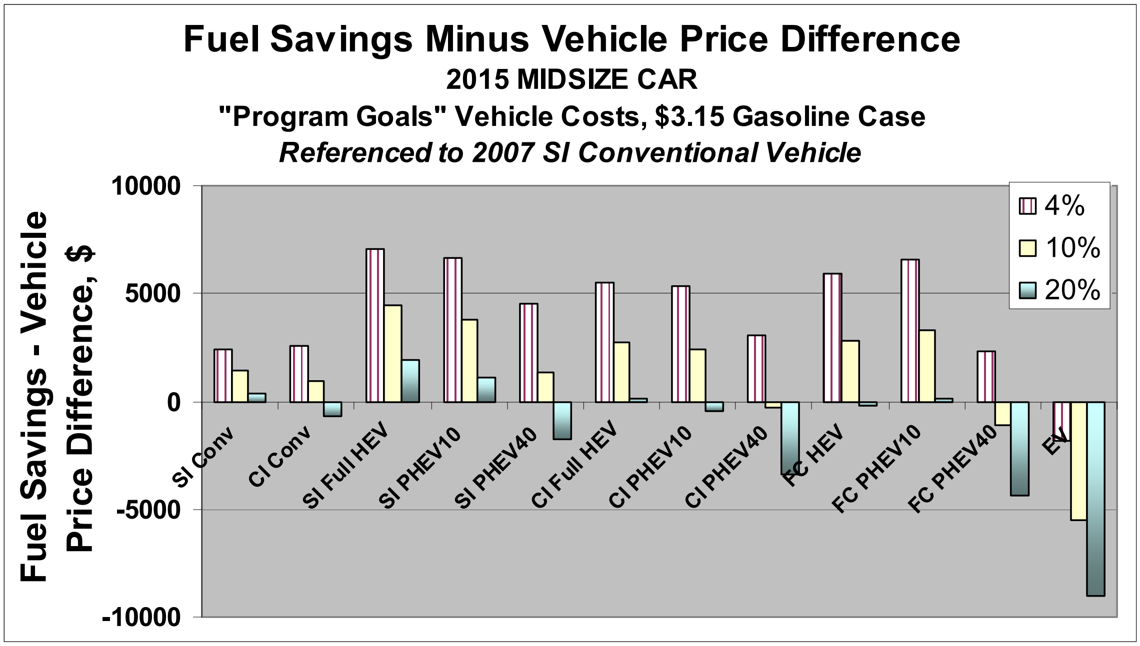

FIGURE 3-15 Fuel Savings Minus Vehicle Price Difference for a 2015 Midsize Passenger Car (“Program Goals” Vehicle Costs, for the $3.15/gallon Gasoline Price Case) Compared to a 2007 Conventional Drivetrain Midsize Car

For the LR vehicle costs, net benefits are quite similar to the 2030 case (see Figure 3-8b) for SI full hybrids and PHEV10s. For these vehicles, the vehicle prices are actually moderately lower than in 2030, because their higher drivetrain costs are more than balanced by lower glider costs; and the lower vehicle prices are balanced by reduced fuel savings. For the PHEV40s, fuel cell vehicles, and EVs, fuel savings are somewhat lower, and there are large increases in vehicle costs; net benefits are thus considerably lower (or more negative). For example, at 20% discount rates for fuel savings, the 2030 SI PHEV40 has a net benefit of about –$3,200; the 2015 SI has a net benefit of about –$5,300. Similarly, the 2030 EV has a net benefit of about –$11,800, compared to –$21,700 for the 2015 EV.

For the PG vehicle cost case, the patterns are basically the same. In the 2030 case, net benefits are positive for virtually every technology and discount rate combination, except for the CI conventional, CI PHEV40,[13] and EV drivetrains at the 20% discount rate — and the "negative" values are only about –$700 for each. For 2015, the net benefits are similar for the full HEVs and PHEV10s, but much lower for the fuel cell vehicles, PHEV40s, and EVs. For the EVs, for example, whereas net benefits in 2030 are positive for two of the three discount rates (+$6,600 for 4%, +$2,900 for 10%, and –$700 for 20%), in 2015 the net benefits are strongly negative for all three discount rates, ranging from –$1,900 for the 4% discount rate to –$9,000 for the 20% rate. In other words, a uniformly positive picture of cost effectiveness in 2030 is preceded by a very mixed picture in 2015, with a likely requirement for sharp subsidies for the more advanced drivetrains unless potential vehicle purchasers place much higher value on future fuel savings than they currently do, which would be equivalent to accepting a 10% or less discount rate in valuing these savings.

3.5.7 Summary and Conclusions about the Cost Effectiveness of Advanced Vehicles

An evaluation of whether or not advanced technology vehicles are seen as "cost effective" depends crucially on both the assumptions and methodology, including the choice of the discount rate to apply to future fuel savings, the degree of optimism applied to estimating future technology costs, and projected future fuel prices.

The choice of the discount rate to apply to future fuel savings should depend on who the "actor" is (whether society, industry, or a vehicle purchaser) and how high a priority that actor gives to such savings. A range of 4% to 20% is not too broad in examining actors ranging from society to individuals, especially with uncertainty about how future actors will value future fuel savings. This range yields very large differences in perceived cost effectiveness, sometimes pushing net benefits from strongly positive (at 4% "societal" discount rates) to solidly negative (at 20% rates for individuals). Of course, it must be noted that each category of actors incorporates a wide range of attitudes about future fuel savings, and thus a wide range of possible discount rates. Further, by focusing solely on vehicle price and fuel costs, a host of other variables in purchase decision are ignored, including different valuations of alternative fuels, which may vary widely among individuals, businesses, and governments.

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[13] As noted earlier, our cost estimates for diesels now seem somewhat pessimistic compared to those used in other analyses.

The high level of uncertainty associated with future technology costs and fuel prices yields a wide range of potential cost-effectiveness values for alternative technology vehicles. Even if technology cost estimates are held to a range incorporating only relatively optimistic values, the shift from considering estimates based on the current (optimistic) literature to estimates based on attaining DOE cost goals can cause the cost-effectiveness estimates to change dramatically.

In evaluating technology options, it is crucial to focus on the *marginal* cost effectiveness of the technologies compared to one another, unless one is simply trying to ascertain whether these technologies are less costly than current technology vehicles. For example, an SI PHEV40 might have a positive cost effectiveness compared to a current vehicle, but intermediate levels of technology —for example, advanced conventional drivetrains or hybrids without plug-in capability —might have higher values of net benefits (fuel savings minus vehicle price difference). An examination of marginal costs and benefits could potentially reveal that going beyond the intermediate technologies might not be attractive.

This analysis focuses on the cost effectiveness of advanced technology vehicles in 2030, a time frame that allows for substantial cost reductions from the effects of learning and mass production to have occurred. The analysis has estimated the net benefits — lifetime fuel savings minus the difference in vehicle price associated with advanced technologies — at three discount rates (4%, 10%, and 20%) that are applied to future fuel savings and four fuel price cases (associated with gasoline prices at $4.50, $3.15, $2.50, and $2.00 per gallon). As noted above, two sets of technology cost estimates — literature review and program goals — were used. The reference vehicle from which to estimate fuel savings and vehicle price differences was a 2007 vehicle with a conventional SI drivetrain.

Key conclusions are as follows:

1. When assuming LR technology costs, the SI HEV drivetrain vehicles generally have the highest cost effectiveness (net benefits), meaning that moving to vehicles with more advanced drivetrains will yield negative *marginal* costs — even though these more advanced vehicles might have positive net benefits (compared to current vehicles) at some discount rates for some fuel price cases.

2. When assuming PG technology costs, the purchase of vehicles with drivetrain technologies that are well beyond the SI HEV drivetrain can usually make sense. In particular, the fuel cell hybrids and PHEV10s have uniformly higher net benefits than the SI HEVs for all discount rates and fuel prices. For the combination of higher fuel prices and lower discount rates, the SI and CI PHEV10s and occasionally the PHEV40s also have higher net benefits, although in no cases are they higher than the fuel cell vehicles. Because the DOE cost goals for fuel cell systems appear to be normative — that is, the goals are based on what is thought to be needed for successful commercialization rather than on engineering estimates of what is achievable — it is important to examine the realism of these goals before accepting this potential for positive net benefits.

3. The effect of fuel prices on both the magnitude of the net benefits and the relative competitiveness of alternative drivetrain vehicles is profound. For example, for

technology costs at the LR level, at the highest fuel prices evaluated (when gasoline is $4.50/gallon), all technologies except the longest-range electric drivetrain vehicles have positive cost effectiveness (net benefits) compared to current conventional drivetrain vehicles at all discount rates. At the lower fuel prices (e.g., when gasoline is $2.50/gallon and below), virtually no advanced technologies — including SI advanced conventional drivetrain vehicles and HEVs — have positive net benefits at the 20% discount rate, and none beyond the SI PHEV10 are positive at the 10% discount rate. In other words, low fuel prices will severely compromise the prospects for advanced vehicles unless governments provide strong economic incentives or vehicle purchasers radically change their preferences for fuel savings (and thus their perceived discount rates for future savings).

4. When technology costs are at PG levels, cost effectiveness (at the highest fuel prices evaluated when gasoline is $4.50/gallon) is robustly positive for all technologies including EVs for all discount rates. At the lowest fuel prices (gasoline at $2.00/gallon), however, cost effectiveness is weak to negative at the 20% discount rate, even for the SI advanced conventional vehicle. (Fuel cell vehicles are the only exception — and this result must be interpreted in light of the aggressive cost goals for these vehicles.) In other words, even cost breakthroughs in many technology areas may not overcome the economic disincentives that low fuel prices pose for advanced efficiency technologies.

5. Whatever the *long-term* prospects for the advanced technologies may be, for successful commercialization to take place, the technologies must gain early market acceptance before the majority of their cost reductions (from the effects of learning and mass production) can occur. Examining the same vehicle types in 2015 (using the $3.15/gallon gasoline price case), for the LR technology costs, the “lower-level” technologies (e.g., advanced conventional vehicles, full hybrids) are about as cost effective as their 2030 counterparts; reduced glider costs are balanced by the combination of higher drivetrain costs and lower fuel savings. For the technologies beyond these, however, net benefits are strongly reduced, primarily because drivetrain costs are sharply higher. And for the PG costs, the 2030 picture of uniformly positive cost effectiveness is transformed to a mixed picture for 2015, with the “higher-tech” vehicles with larger batteries looking robustly cost effective only for the two lower discount rates and the EVs having positive net benefits only at the 4% rate. This result confirms the widely held belief that these technologies will have to be strongly subsidized — either by their manufacturers or the government — for several years before commercial success can be realized.

In summary, this analysis generally confirms that there will need to be a combination of factors in place for future advanced vehicle technologies to succeed — high oil prices, with consumers believing that prices will remain high over a substantial time period; significant reductions in technology costs; high consumer valuations of future fuel savings; and, in the early years following the advanced technology vehicles’ introduction, strong economic incentives for their purchase. These factors are especially important for fuel cell vehicles and vehicles with large batteries (PHEV40s, EVs); advanced conventional vehicles, full hybrids, and possibly PHEV10s could be successful with somewhat lesser attainment of these factors. Finally, the long-term success of EVs and PHEV40s appears especially tied to dramatic reductions in battery costs at levels beyond those generally predicted by most optimistic analysts. However, the fact of fuel cell vehicles being left out of this last group depends on the realism of DOE cost goals for fuel cell systems and hydrogen storage. The "program goals" technology cost assumptions assume these goals are met and, as noted before, the goals appear to be normative rather than actually having been derived from engineering analysis. It would be useful to re-examine these goals to obtain a better grasp of their realism.

3.6 COSTS OF REDUCING GREENHOUSE GAS EMISSIONS

Policymakers have been interested in comparing alternative policies and technologies by evaluating their "carbon costs" or "GHG costs" — the dollar amount required to reduce carbon emissions by one ton of CO_2 or its equivalent in total greenhouse gases. In addition, the GHG costs of individual technologies may be compared to the average GHG costs in various sectors of the economy or to the average charges incurred by auctioning off carbon or GHG credits in so-called carbon trading programs.

This analysis derives the GHG costs, measured in U.S. dollars per metric ton of CO_2 (or its equivalent in total GHGs) for most of the drivetrain technologies examined in this report for the 2030 model year. The analysis measures two types of costs:

- "Private" GHG costs are those paid by individual vehicle purchasers and are defined as the net of initial technology cost and lifetime fuel savings (referenced to advanced conventional vehicles of the same model year) divided by the lifetime reduced GHG emissions. Both fuel savings and GHG emissions reductions are discounted at the "individual" rate of 20%/year. Although this value may appear high, the recent behavior of average vehicle purchasers in valuing fuel economy translates into an apparent discount rate for future fuel savings of above 20%.

- "Social" GHG costs are those paid by governments in subsidizing vehicle purchases and are defined as the subsidy divided by the lifetime GHG reduction discounted at a "societal" rate of 4%.

For both private and social GHG costs, no account was taken of other external costs and benefits associated with using the technologies (e.g., reduced criteria emissions, congestion, and other societal costs associated with any rebound in driving caused by reduced fuel costs, etc.). In other words, this method essentially assigns the entire subsidy cost to GHG emissions reduction. It is important to note that some may argue that subsidy costs should be split among the multiple societal benefits (e.g., reduced greenhouse gases and improved energy security [associated with reducing oil imports]) — thus reducing the estimated costs for each benefit.

In the scenario analyses (using the National Energy Modeling System) described in Chapters 6 and 7 in the report, there was minimal market penetration of some key technologies — plug-in hybrids and fuel cell vehicles — when "literature review" costs were assumed and no vehicle purchase incentives were offered. A second scenario was run with the same costs but with purchase subsidies of $7,500/vehicle (selected vehicles only). The private (no subsidy) and social (subsidy) GHG costs for these two cases are shown in Figure 3-16. A similar set of analyses was conducted for the "program goals" cost case, although penetration of advanced drivetrains was much higher in the "no subsidy" scenario run for this case. A separate subsidy scenario case was run, however (with smaller, variable subsidies), to provide a scenario with even higher penetration of advanced drivetrains. The results for these two cases are shown in Figure 3-17.

Underlying assumptions of the GHG cost calculations are as follows:

- Hydrogen production is assumed to be 100% at the refueling stations, using natural gas as a feedstock; a sensitivity case assumes that 50% of hydrogen production is from central coal-based plants.

- Assumptions concerning the sources of the electricity for nighttime recharging of plug-in hybrids and EVs are as follows: 30% is provided by natural gas-based power plants, 62% by coal-based plants, and 8% by nuclear plants. Available renewable electricity — primarily hydro and wind power — is thus assumed to be fully utilized whether or not more electric drivetrain vehicles are added to the fleet, so that it would not be considered a source for recharge electricity.[14]

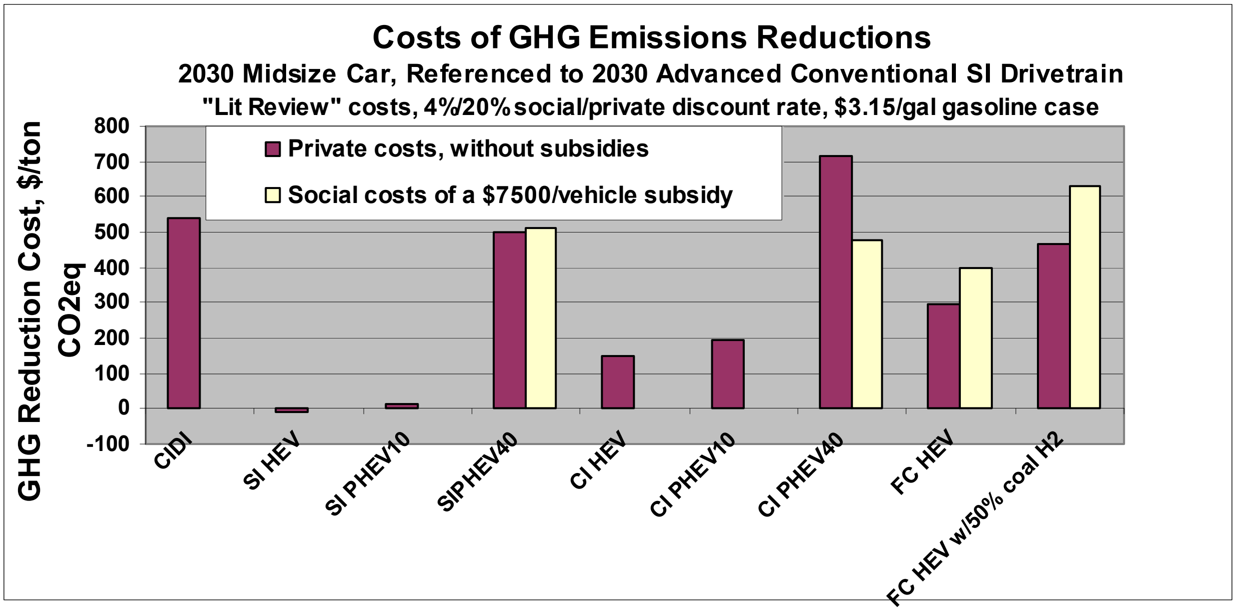

FIGURE 3-16 Cost of GHG Reduction for 2030 Drivetrain Technologies in a Leading Edge Midsize Car, LR Vehicle Costs, $/ton of CO_2 Equivalent

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[14] This assumption would break down if electric vehicles provided grid services (regulation, rolling reserves) that stimulated additional construction of renewable electric capacity.

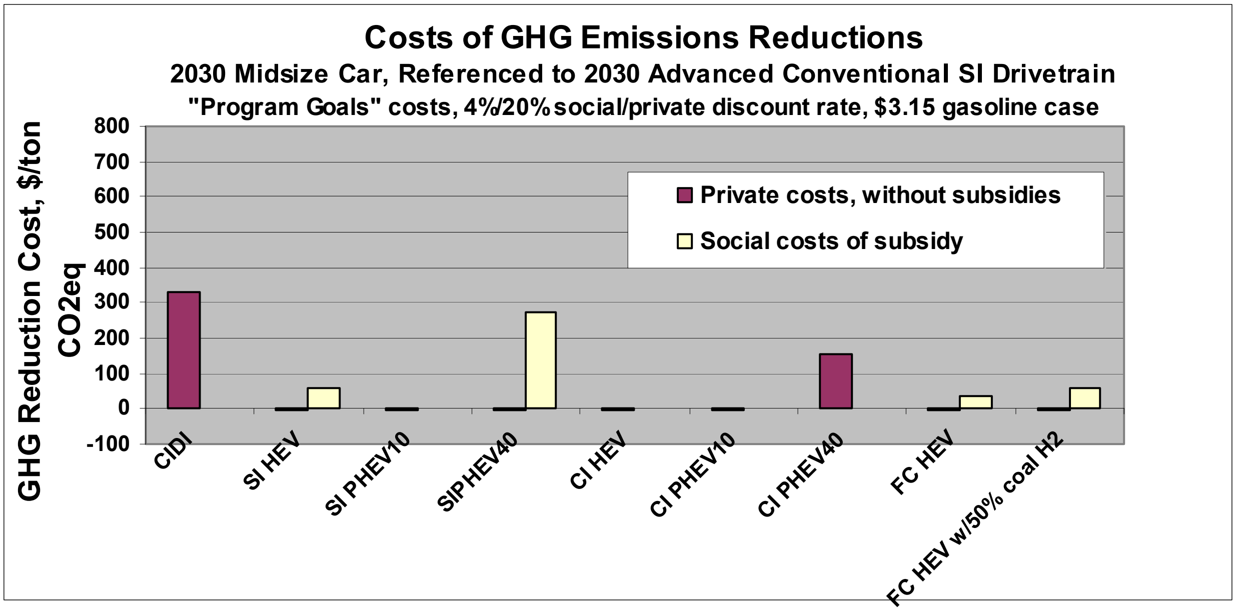

FIGURE 3-17 Cost of GHG Reduction for 2030 Drivetrain Technologies in a Leading Edge Midsize Car, PG Vehicle Costs, \$/ton of CO_2 Equivalent

- For natural gas-based electricity, 58% is from combined-cycle gas turbines and 28% is from simple-cycle turbines (vs. expected total generation of 48%/38%).

- In the calculation of private costs, gasoline prices are assumed to be a constant \$3.15/gallon over the vehicle lifetime.

- The fuel cycle GHG emissions of the fuels (on a “per gallon,” “per kWh, ” or “per kg” basis) are obtained from Argonne National Laboratory’s GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model. Gasoline GHG content is based on current reformulated gasoline; future changes in ethanol content or source (e.g., cellulosic) are not considered.

As shown in Figure 3-16, private GHG costs for the more advanced drivetrain vehicles — beyond the PHEV10s — will tend to be quite high unless technology costs are driven to levels well below LR levels. The SI HEVs are cost effective even at high private discount rates, and thus they have zero private GHG reduction costs; the SI PHEV10s have only modest GHG reduction costs of about \$12/ton. However, all of the other vehicles have private GHG costs above \$100/ton of CO_2 equivalent, which is a very high value compared to carbon or GHG costs in other sectors. The EVs, which are very expensive at LR costs, have GHG costs of \$2,800/ton.

The \$7,500/vehicle subsidy used to boost market penetration (and thus yield large GHG reductions) from technologies beyond simple hybrids translates into a high social GHG cost — \$400–\$600 per ton of CO_2 equivalent, values that are far higher than GHG reductions available from more conventional technologies and from other sectors. It is important to note, however, that only PHEV40s were included in the scenario analysis; PHEV10s would have been expected to do considerably better, because they are relatively cost effective at LR costs and when fuel prices are high.

Attaining the PG-level technology costs drives down both the private and social GHG costs of the alternative drivetrains. As shown in Figure 3-17, virtually all of the drivetrains are cost effective at the \$3.15/gallon gasoline energy price case. The exceptions are the CIDI conventional drivetrain, which suffers because it yields only modest fuel savings compared to the SI conventional reference vehicle, at significantly higher cost;[15] the CI PHEV40; and the EV (not shown in the figure), which has a private cost of about \$270/ton of CO_2 equivalent.

The scenario analyses using PG vehicle prices awarded subsidies of about \$1,000 to SI HEVs, \$4,000 to SI PHEV40s, and \$700 to FCVs (the latter subsidy was small because the PG costs for fuel cells are quite low) to boost market penetration of these drivetrains. The social GHG costs for the SI HEVs and FCVs are moderate — about \$40–\$60/ton of CO_2equivalent. The social costs for the SI PHEV40s, however, are high — about \$270/ton of CO_2equivalent, reflecting the high costs of the longer-range electric drivetrain vehicles.

3.7 REFERENCES FOR CHAPTER 3

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[15] Again, our CI technology cost estimates appear pessimistic.

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3.8 TABLES FOR FIGURES 3-8 THROUGH 3-17

3.8.1 Tables for Figures 3-8a through 3-8d

TABLE 3-14 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $4.50 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc rate	**4%**	**10%**	**20%**
SI Conv	5707	3500	1399
CI Conv	6033	3096	299
SI Full HEV	11134	6995	3054
SI PHEV10	11042	4666	2481
SI PHEV40	9137	4209	-485
CI Full HEV	9556	5269	1186
CI PHEV10	10040	5441	1061
CI PHEV40	7659	2606	-2206
FC HEV	9891	4971	286
FC PHEV10	10903	5796	932
FC PHEV40	6787	1457	-3620
EV	2540	-3132	-8534

TABLE 3-15 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc rate	**4%**	**10%**	**20%**
SI Conv	3280	1735	264
CI Conv	2802	746	-1212
SI Full HEV	6581	3684	925
SI PHEV10	6103	3065	172
SI PHEV40	3388	28	-3173
CI Full HEV	4840	1840	-1018
CI PHEV10	4869	1681	-1356
CI PHEV40	1771	-1676	-4959
FC HEV	4305	908	-2326
FC PHEV10	5025	1521	-1816
FC PHEV40	483	-3129	-6568
EV	-4442	-8210	-11798

TABLE 3-16 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $2.50 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc rate	**4%**	**10%**	**20%**
SI Conv	2111	885	-282
CI Conv	1247	-385	-1939
SI Full HEV	4389	2090	-100
SI PHEV10	3725	1336	-940
SI PHEV40	620	-1985	-4467
CI Full HEV	2570	188	-2080
CI PHEV10	2380	-130	-2520
CI PHEV40	-1064	-3738	-6284
FC HEV	943	-2552	-3898
FC PHEV10	1663	-1727	-3388
FC PHEV40	-2879	-6066	-8139
EV	-7804	-10655	-13370

TABLE 3-17 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $2.00 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc rate	4%	10%	20%
SI Conv	1212	231	-703
CI Conv	50	-1255	-2498
SI Full HEV	2703	864	-888
SI PHEV10	1896	5	-1795
SI PHEV40	-1509	-3534	-5463
CI Full HEV	823	-1082	-2896
CI PHEV10	464	-1523	-3416
CI PHEV40	-3245	-5324	-7304
FC HEV	-1294	-3417	-4944
FC PHEV10	-647	-2805	-4468
FC PHEV40	-5296	-7454	-9269
EV	-10390	-12535	-14579

3.8.2 Tables for Figures 3-9a through 3-9d

TABLE 3-18 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $4.50 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc Rate	4%	10%	20%
SI Conv	5893	3686	1585
CI Conv	6796	3859	1062
SI Full HEV	12142	8003	4062
SI PHEV10	12643	8258	4082
SI PHEV40	12937	8008	3314
CI Full HEV	11111	6824	2742
CI PHEV10	12727	8128	3748
CI PHEV40	11932	6880	2067
FC HEV	15378	10458	5773
FC PHEV10	16538	11431	6568
FC PHEV40	14965	9635	4558
EV	13630	7958	2556

TABLE 3-19 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc Rate	4%	10%	20%
SI Conv	3466	1921	450
CI Conv	3566	1510	-448
SI Full HEV	7589	4692	1933
SI PHEV10	7704	4666	1773
SI PHEV40	7188	3827	626
CI Full HEV	6396	3395	537
CI PHEV10	7556	4367	1330
CI PHEV40	6044	2597	-685
FC HEV	9792	6395	3161
FC PHEV10	10661	7157	3819
FC PHEV40	8661	5049	1610
EV	6647	2880	-709

TABLE 3-20 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $2.50 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc Rate	4%	10%	20%
SI Conv	2297	1071	-96
CI Conv	2010	379	-1175
SI Full HEV	5397	3098	908
SI PHEV10	5326	2936	661
SI PHEV40	4420	1814	-668
CI Full HEV	4125	1744	-524
CI PHEV10	5066	2556	166
CI PHEV40	3210	536	-2011
FC HEV	6430	2935	1589
FC PHEV10	7299	3908	2248
FC PHEV40	5299	2112	39
EV	3286	435	-2280

TABLE 3-21 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $2.00 Gasoline Price Case Referenced to a 2007 Midsize Car)

Disc Rate	4%	10%	20%
SI Conv	1398	417	-517
CI Conv	814	-492	-1735
SI Full HEV	3711	1872	120
SI PHEV10	3496	1606	-195
SI PHEV40	2291	266	-1663
CI Full HEV	2379	474	-1341
CI PHEV10	3151	1164	-729
CI PHEV40	1029	-1050	-3030
FC HEV	4193	2070	543
FC PHEV10	4989	2831	1168
FC PHEV40	2882	724	-1091
EV	700	-1446	-3489

3.8.3 Table for Figure 3-10

TABLE 3-22 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2030 SI Conventional Midsize Car)

Disc. Rate	4%	10%	20%
CI Conv	-478	-989	-1607
SI Full HEV	3301	1949	313
SI PHEV10	2823	1330	-476
SI PHEV40	108	-1708	-3904
CI Full HEV	1560	104	-1657
CI PHEV10	1589	-55	-2043
CI PHEV40	-1509	-3411	-5712
FC HEV	1025	-827	-3067
FC PHEV10	1745	-214	-2584
FC PHEV40	-2797	-4864	-7363
EV	-7722	-9945	-12536

3.8.4 Table for Figure 3-11

TABLE 3-23 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2030 SI Conventional Midsize Car)

Disc. Rate	4%	10%	20%
CI Conv	100	-412	-898
SI Full HEV	4123	2771	1483
SI PHEV10	4238	2744	1322
SI PHEV40	3722	1906	176
CI Full HEV	2930	1474	87
CI PHEV10	4090	2446	880
CI PHEV40	2578	676	-1136
FC HEV	6326	4474	2711
FC PHEV10	7195	5235	3369
FC PHEV40	5195	3128	1160
EV	3181	958	-1159

3.8.5 Table for Figure 3-12

TABLE 3-24 Fuel Savings Minus Change in Vehicle Price (Literature Review Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2030 SI Full HEV Midsize Car)

Disc Rate	4%	10%	20%
SI Conv	-3302	-1949	-661
CI Conv	-3779	-2938	-2137
SI PHEV10	-478	-619	-753
SI PHEV40	-3193	-3657	-4098
CI Full HEV	-1741	-1845	-1943
CI PHEV10	-1712	-2004	-2281
CI PHEV40	-4810	-5360	-5884
FC HEV	-2277	-2776	-3251
FC PHEV10	-1556	-2163	-2741
FC PHEV40	-6099	-6813	-7493
EV	-11024	-11894	-12723

3.8.6 Table for Figure 3-13

TABLE 3-25 Fuel Savings Minus Change in Vehicle Price (Program Goals Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2030 SI Full HEV Midsize Car)

Disc Rate	**4%**	**10%**	**20%**
SI Conv	-4124	-2771	-1483
CI Conv	-4024	-3182	-2381
SI PHEV10	114	-26	-161
SI PHEV40	-401	-865	-1307
CI Full HEV	-1194	-1297	-1396
CI PHEV10	-34	-325	-603
CI PHEV40	-1545	-2095	-2618
FC HEV	2202	1703	1228
FC PHEV10	3071	2464	1886
FC PHEV40	1071	357	-323
EV	-942	-1813	-2642

3.8.7 Table for Figure 3-14

TABLE 3-26 Fuel Savings Minus Change in Vehicle Price (2015) (Literature Review Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2007 SI Conventional Midsize Car)

Disc rate	**4%**	**10%**	**20%**
SI Conv	2320	1283	295
CI Conv	1870	194	-1401
SI Full HEV	6120	3455	916
SI PHEV10	5488	2624	-103
SI PHEV40	973	-2254	-5328
CI Full HEV	3846	1096	-1523
CI PHEV10	3578	607	-2223
CI PHEV40	-1159	-4460	-7604
FC HEV	942	-2221	-5234
FC PHEV10	1955	-1348	-4494
FC PHEV40	-5421	-8874	-12163
EV	-14494	-18162	-21655

3.8.8 Table for Figure 3-15

TABLE 3-27 Fuel Savings Minus Change in Vehicle Price (2015) (Program Goals Vehicle Costs, $3.15 Gasoline Price Case Referenced to a 2007 SI Conventional Midsize Car)

Disc rate	4%	10%	20%
SI Conv	2432	1395	407
CI Conv	2596	920	-675
SI Full HEV	7095	4430	1891
SI PHEV10	6688	3824	1097
SI PHEV40	4553	1326	-1748
CI Full HEV	5524	2774	155
CI PHEV10	5347	2376	-454
CI PHEV40	3037	-265	-3409
FC HEV	5952	2789	-224
FC PHEV10	6592	3288	142
FC PHEV40	2367	-1086	-4375
EV	-1864	-5532	-9025

3.8.9 Tables for Figures 3-16 and 3-17

TABLE 3-28 Literature Review Costs, $3.15 Gasoline Price Case

DRIVETRAIN	GHG COST, $/TON	
	W/O SUBSIDY	W/SUBSIDY
CIDI	540	
SI HEV	-10	
SI PHEV10	12	
SIPHEV40	499	509
CI HEV	151	
CI PHEV10	195	
CI PHEV40	715	480
FC HEV	295	399
FC HEV w/50% coal H2	464	628
EV	2820	

TABLE 3-29 Program Goal Costs, $3.15 Gasoline Price Case

DRIVETRAIN	GHG COST, $/TON		SUBSIDY, $
	W/O SUBSIDY	W/SUBSIDY	
CIDI	329		
SI HEV	0	58	1000
SI PHEV10	0		
SIPHEV40	0	271	4000
CI HEV	0		
CI PHEV10	0		
CI PHEV40	0		
FC HEV	0	37	700
FC HEV w/50% coal H2	0	59	700
EV	271		

4 OVERVIEW OF USE OF THE NEMS-MP MODEL FOR MP ANALYSIS

Phase 1 of the MP Study evaluated the oil savings and GHG emission reductions of various scenarios of advanced technology vehicles (ATVs) and fuels by "assuming" specific rates of market penetration of these technologies. The analysis was criticized because it did not (a) explicitly consider vehicle and fuel prices in developing those scenarios or (b) account for feedback effects between ATV penetration and fuel prices (i.e., advanced vehicles will reduce the volume and perhaps lead to changes in the types of fuels used). These concerns are addressed in Phase 2 through use of a version of the Energy Information Administration's (EIA's) NEMS model to evaluate several scenarios. The NEMS model includes a vehicle choice model (VCM, which officially is called the "consumer vehicle choice submodule") that uses vehicle and fuel prices (along with a number of other variables) to estimate vehicle market penetration. NEMS also provides an integrated analysis of the scenarios: that is, feedback effects are incorporated in the results.

4.1 NEMS-MP MODEL

EIA uses the NEMS model (EIA-NEMS) to develop projections of U.S. energy use to the year 2030. The results are reported each year in the *Annual Energy Outlook* (AEO). Several projections are reported, one of which — the Reference Case — can be characterized as "business-as-usual," although it includes commercialization of some advances in energy technologies. Another projection, the High Oil Price Case, is the same as the Reference Case but has more pessimistic assumptions about worldwide crude oil and natural gas resources and therefore incorporates higher oil and energy prices.

Each year, EERE uses the EIA-NEMS model and another model called MARKAL (for Market Allocation Model) to estimate the benefits of the EERE R&D programs in the context of EIA's projections. OnLocation runs a version of the NEMS model (NEMS-PDS, for Program Decision Support) for EERE to generate the benefit estimates through 2030. On-Location has also extended the NEMS model to 2050 for use in analyzing hydrogen energy futures (NEMS-H2). This version of the model has considerable detail about hydrogen, which is not yet included in the EIA-NEMS model but is being added. The NEMS-H2 model was chosen for Phase 2 of the Multi-Path Study because of that detail and the fact that we wanted to analyze scenarios out to 2050. More specifically, the model we are actually using is a variant of NEMS-H2 called NEMS-MP, which does not incorporate all of the updates made to NEMS-H2 since the inception of this Multi-Path Study. NEMS-MP is very specifically based on the EIA-NEMS model used to generate the AEO 2007 estimates, while NEMS-H2 has been updated to the NEMS model used to generate the AEO 2008 estimates.

4.2 NEMS-TRANSPORTATION STAND-ALONE MODEL

Because a run of the NEMS model (the original, NEMS-H2, NEMS-MP, others) can take as long as a day or more and because of our desire to evaluate the impact of varying numerous vehicle-and fuel-related variables more quickly than that in order to develop our scenarios, OnLocation developed a stand-alone version of the transportation model of NEMS (NEMS-TSA) for use in the MP Study. With NEMS-TSA, all of the variables included in the vehicle choice component of the NEMS model (e.g., vehicle prices, vehicle fuel economy, fuel availability) as well as other closely related variables (e.g., the percentage of miles that PHEVs operate on electricity, hydrogen [H_2] station availability) can be varied to generate initial vehicle market penetrations and fuel use estimates for a scenario relatively quickly. When satisfied with these initial scenarios of market penetration, the scenario values for the vehicle and related variables are then input to the full NEMS-MP model to develop final market penetration and fuel use estimates for the scenario, taking into account, in particular, feedback effects on fuel prices. (The NEMS-TSA model generates the same vehicle market penetration estimates as the full NEMS-MP model when the final fuel prices of the scenario are used as input to the NEMS-TSA model. Appendix D contains selected sensitivity runs conducted with the NEMS-TSA model.)

4.3 INTERRELATIONSHIP OF THE MODELS

In sum, this analysis first uses a stand-alone version of the transportation model of NEMS-MP that has been extended to 2050 to generate initial ATV and fuel-related market penetration estimates for a given scenario. Those same vehicle and related assumptions are subsequently input to the full NEMS-MP model extended to 2050 to generate the final results for the scenario. Figure 4-1 illustrates the inter-relationships.

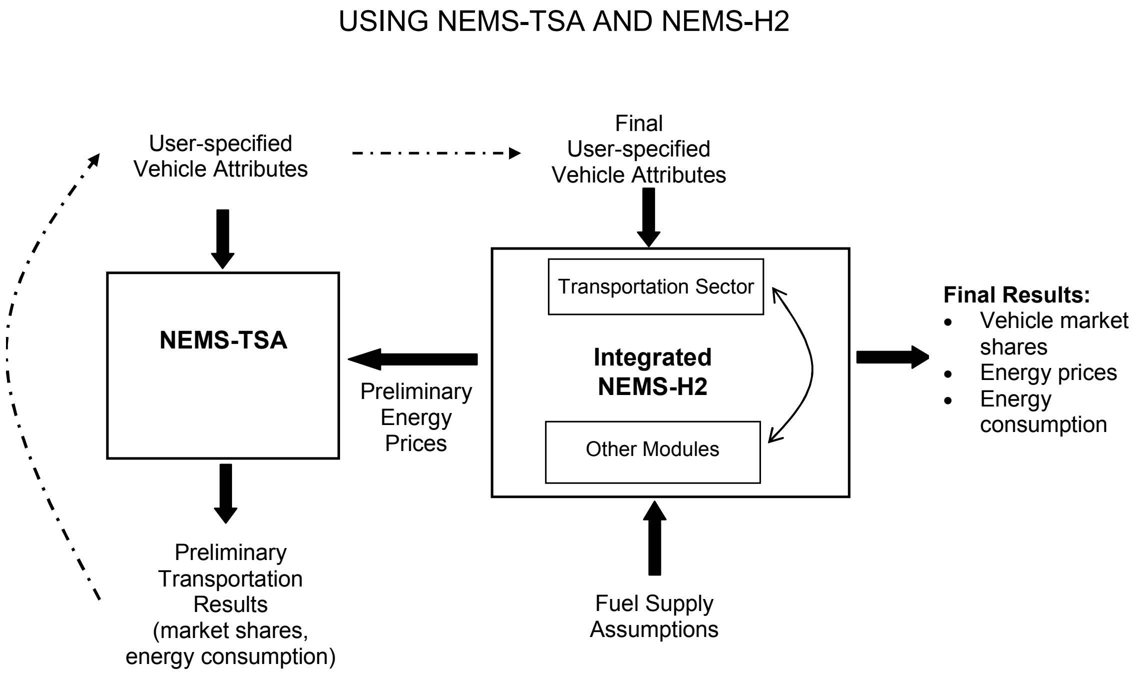

FIGURE 4-1 Using NEMS-TSA and NEMS-H2

5 BASE CASE AS MODELED IN NEMS-MP

5.1 DEVELOPMENT OF THE BASE CASE

In general, the Base Case for the MP Study is the AEO 2007 Reference Case, which has been:

- Modified by the oil prices of the AEO 2007 High Oil Price Case;
- Updated with EIA's summer 2007 analysis of biomass supply curves, cellulosic conversion costs, and corn costs;
- Updated with hydrogen cost estimates developed by the H2A effort;
- Extended to 2050; and
- *Updated to incorporate the CAFE requirements of the Energy Independence and Security Act of 2007 (EISA).*

While the MP Base Case uses the world oil prices of AEO's High Oil Price Case extended to 2050 (see Table 5-1), it does not assume the same restriction on oil and natural gas supplies as the AEO case does. (The reason for this is concern that the extension of the AEO resource constraints to 2050 would "destabilize" the model: i.e., it might not run.) The higher oil prices used in the Base Case in turn affect other fuel prices (e.g., electricity). The ethanol and hydrogen updates make use of more current and/or better documented information. The extension of the AEO case from 2030 to 2050 is generally based on extrapolations of the input assumptions for the years 2020 to 2030. However, some values are left flat post-2030 (i.e., interest rates).[16]

TABLE 5-1 World Oil Price (of imported crude oil) in MP Base Case (in 2005$)

Year	$/barrel	Source
2010	63	AEO 2007 High Oil Price Case
2020	83	AEO 2007 High Oil Price Case
2030	93	AEO 2007 High Oil Price Case
2040	104	Extension of AEO 2007 High Oil Price Case
2050	116	Extension of AEO 2007 High Oil Price Case

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[16] NEMS-MP was not run with the macroeconomic model, so the macroeconomic inputs are by assumption. The EIA-NEMS is linked to a macro model developed by Global Insight, Inc., which is a proprietary model and therefore not available for extension to 2050.

The Base Case was initially developed before the passage of the EISA in late 2007. Given the significance of the CAFE requirements and Renewable Fuel Standard (RFS) of that law, we attempted to incorporate these two requirements into the Base Case. The CAFE requirement that new light vehicles achieve a fuel economy of 35 MPG by 2020 has been incorporated. The standard is then held flat post-2020 to 2050. In contrast, we were uncomfortable with the results we were getting with the RFS and so left it out. (See Section 5.3 for further explanation.)

Besides the fuel prices and CAFE requirements, some other modifications are made to the AEO 2007 Reference Case. These modifications and the reasons for them are summarized in Table 5-2.

TABLE 5-2 Modifications Made to AEO 2007 Reference Case to Develop MP Base Case

Variable	AEO 2007 Reference Case	MP Base Case	Reason for Modification (Selected)
End Year	2030	2050	MP needs to extend to 2050 to see the full effect of some technologies.
Fuel Prices			
General		Oil prices of AEO 2007 High Oil Price Case (see Table 6-1)	The major changes implied by the MP scenarios are more likely at the higher oil prices.
H_2		H2A production and delivery cost estimates (August 2006) plus taxes. H2A values for “current” technology. Taxes similar to those for gasoline on a GGE basis (state and Federal). (Also includes updated biomass supply curves developed by EIA.)	H2A estimates are better documented. (For biomass supply curves, see below.)
Ethanol		Updated (July 2007) biomass supply curves, cellulosic ethanol conversion costs, and corn cost from EIA.	EIA updated its AEO 2007 estimates in an analysis of a Congressional proposal (S. 280) released July 2007.
Electricity for PHEVs	Transportation sector off-peak prices	Now tied to off-peak residential electricity prices.	We assume PHEVs will generally be charged off-peak at home.
Vehicle Technologies			
PHEV10s			
Range/% of operation on electricity	10 miles/13%	10 miles/17.4%	Uses the Society of Automotive Engineers (SAE) J1711 utility factor.
MPG		Assumes the same fuel economy as HEVs	EIA estimates are too high.
Ratio of MPGGE on electricity to MPG on gasoline		From PSAT 11/2007 runs. Uses near-term average PHEV10.	Updates EIA estimates (EIA value is 2.5 whereas the new value is 2.7).

TABLE 5-2 (Cont.)

Variable	AEO 2007 Reference Case	MP Base Case	Reason for Modification (Selected)
Price		Assumes that initially, the PHEVs cost $2K more than HEVs but that by 2030, they only cost $0.5K more.	EIA estimates are too high
% of customers who can plug-in at home	50%	35% to 2020, then rising to 50% by 2030, and then remaining flat.	We believe that 50% is too high in the near-term and therefore have chosen a phase-in to the 50% level.
Vehicle fuel economy standards	CAFE standards pre-EISA of 2007	CAFE standards set by EISA of 2007 and held flat post- 2020.	
Commercial LTs (all gasoline)	Fuel economy of these vehicles increases as the fuel economy of personal conventional gasoline LTs increases.	Increases proportionally as the fuel economy of conventional gasoline, advanced conventional gasoline, and gasoline HEV LTs increases.	It seems appropriate to tie the fuel economy of commercial light trucks to that of all LTs using gasoline, so that higher penetrations of high-efficiency gasoline vehicles, such as ACVs and HEVs, are also reflected in commercial LTs.
Sales to fleets	~ 20% of new cars and ~ 13% of new LTs are sold to fleets.	Reduced to 0.1%.	NEMS fleet module excludes key ATVs; rolling fleets into general vehicle population allows ATVs to be properly represented in the whole fleet.
E85 fuel availability	Station size is used to estimate fuel availability unless/until E85 prices drop below gasoline, in which case E85 fuel availability increases by a total of 1%.	Station size is used to estimate fuel availability unless/until E85 prices drop below gasoline, in which case E85 fuel availability increases 0.5% per year.	We think the EIA estimate is too limiting. It is important to note that the NEMS model only provides for one station size per fuel type throughout time.

5.2 SELECTED BASE CASE RESULTS

Table 5-3 presents some key estimates for three “base case” scenarios in the year 2030: (1) the AEO 2007 High Oil Price case, (2) a base case with all the modifications we made to the AEO 2007 Reference case to develop the MP Base Case *except* for the incorporation of the EISA CAFE standards (i.e., the MP Base Case without EISA CAFE), and (3) the final MP Base Case, which incorporates those standards. The focus is on 2030 since the AEO estimates do not go beyond that year. The key points to draw from Table 5-3 are as follows:

1. The MP Base Case without EISA CAFE is quite similar in total liquid fuels use to the AEO 2007 High Oil Price Case except for relatively small differences in the use of ethanol (both total volume and amount used in blends vs. E85) and in import share.

TABLE 5-3 Selected "Base Case" Estimates in 2030

	AEO 2007 High Oil Price Case	MP Base Case without EISA CAFE standards	MP Base Case with EISA CAFE standards	Estimated oil savings due to EISA CAFE (million barrels per day [mbpd])
Liquid Fuels Use (mbpd)				
Motor Gasoline (including blends)	10.47	10.78	9.99	0.79
Distillate Fuel Oil	5.85	5.96	5.88	0.08
E85	0.21	0.03	0.10	–
Total (includes other liquids)	24.60	24.52	23.68	0.84
Net Import Share (%)	49.2	45.7	44.5	–
Transportation Sector Energy Use (Quads)[1]				
Motor Gasoline (including blends)	19.04	19.51	18.04	0.77
Distillate Fuel Oil	9.54	9.77	9.60	0.08
E85	0.30	0.04	0.14	–
Liquids Fuels Subtotal (includes other liquids)	34.35	34.66	33.10	–
Ethanol Consumed in Gasoline and E85				
Quads	1.30	1.37	1.33	–
Billion Gallons	15.4	16.2	15.8	–
LV Oil Use[2] **(ethanol in blends and E85 excluded) (Quads)**	NA[3]	19.05	17.59	0.77
New LV MPG	NA	32.0	35.4	–
Diesel and gasoline HEV (GHEV) Share of New LVs (%)				
Cars	NA	14.8	14.8	–
LTs	NA	30.0	33.0	–
LT Share of New LVs (%)	NA	48.4	48.6	–
Oil Prices (2005$)				
World Oil Price (by assumption) ($/barrel)	$93	$93	$93	
Gasoline ($/GGE)[4]	$3.30	$3.26	$3.15	
Diesel in transportation sector ($/GGE)	$2.78	$2.81	$2.79	

[1] 1 Quad = 1 quadrillion (10^{15}) BTU.
[2] LV Oil Use includes Class 2B trucks.
[3] NA = Not available in AEO 2007 report although the amounts may be available in other AEO 2007 documentation.
[4] Price per gallon computed from price per million BTU and assumes 125,000 BTU/gal.

2. The EISA CAFE standards lead to a savings of approximately 0.85 mbpd of oil in 2030 in the final MP Base Case relative to a case without the standards. The savings are largely attributable to an increase in the fuel economy of all vehicles as opposed to any switch to vehicle technologies with higher fuel economies (e.g., diesels and gasoline HEVs) or a reduction in the LT share.

The oil savings may seem low if one compares them to the approximately 4 mbpd liquid fuel savings of the AEO 2008 Reference Case (which accounts for the CAFE standard) relative to the AEO 2007 Reference Case. But, the AEO 2008 Reference Case also accounts for the RFS. More important, the final MP Base Case uses the oil prices of the AEO 2007 High Oil Price Case — and the AEO 2007 High Oil Price Case saves approximately 2.3 mbpd relative to the AEO 2007 Reference Case.

More detailed characterization of the final MP Base Case will be presented in the following sections of the report when the results of the various scenarios are presented.

5.3 THE EISA RENEWABLE FUELS STANDARD

The EISA RFS requires that 36 billion gallons (or comparative gallon-based equivalent for gaseous fuels or electricity) of renewable fuels (e.g., conventional biofuels; cellulosic biofuel, which includes ethanol made from cellulosic biomass; biomass-based diesel; and other "advanced" biofuels) must be part of the annual U.S. transportation fuel supply by 2022, although the standard provides flexibility to reduce the volume required. In the AEO 2008, EIA estimated 32 billion gallons in 2022, consisting predominantly of ethanol from several feedstocks. We attempted to match EIA's estimate for the MP Base Case and in fact came close in one model run. We did so by modifying the growth rates of cellulosic ethanol production plants, modifying cellulosic ethanol conversion learning curves, and adjusting the model to provide extra credit for cellulosic ethanol production because of the RFS requirement.[17] However, while EIA projects the volume to remain at 32 billion gallons from 2022 through 2030, our preliminary base case did not. In our analysis, renewable fuel use continued to grow from the 32-billion-gallons and, in particular, took off after 2030: for example, in the model run in which we came closest to EIA's 2022 estimate, we found that 56 billion gallons of renewable fuel would be used in 2050.

Such high volumes would be inconsistent with and cause difficulties for some of our scenarios. For example, some of the assumptions that would have to be made to achieve the standard might not be consistent with the H2 Success scenario. Therefore, the RFS is not included in the Base Case. However, the Base Case still incorporates considerable use of renewable fuels: 23 billion gallons by 2030 (15.8 billion gallons of which is ethanol) and 32 billion gallons by 2050, although very little of this amount is cellulosic ethanol.

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[17] NEMS-MP does not include explicit constraints for the various EISA-specified fuel types that were developed by EIA for the AEO 2008. It also does not contain biomass-to-liquids technology as an option to meet the cellulosic requirements.

5.4 OIL PRICE IN THE BASE CASE

The world oil price has obviously increased since the beginning of Phase 2 of the MP Study (January 2007). The MP Base Case world oil price is $93/barrel (in 2005$) in 2030 (as in the AEO High Oil Price Case) and $116/barrel in 2050. Prices in 2008 have been higher. However, the AEO 2008 Reference Case, which was issued in early 2008, projects oil at $59/barrel (in 2006$) by 2030. The MP Base Case oil price is still above that level. We try specifically to consider the implications of higher oil prices than used in the model in our conclusions (Chapter 9).

The price of diesel fuel (on a GGE basis) is lower than that of gasoline in the MP Base Case, which is consistent with the AEO 2007 High Oil Price Case. However, many analysts believe that in the future, diesel fuel prices will be higher than those of gasoline. (Worldwide demand for diesel is projected to increase substantially.) If the diesel prices are higher, this will have a negative effect on the diesel vehicle penetration estimated in the MP scenarios. Again, we try specifically to consider the implications of these higher diesel fuel oil prices than used in the model in Chapter 9 in our conclusions.

6 SCENARIOS AS MODELED IN NEMS-MP: GENERAL

Chapter 2 provides a general description of each of the scenarios, and Table 2-1 provides likely market penetration estimates for various technologies in each of those scenarios. In order to model these scenarios in NEMS-MP and, in particular, to try to match the market penetration estimates ("goals") of Table 2-1, we went through an iterative process in which we first developed a set of specific assumptions about vehicle technologies and fuels that we thought were appropriate for each scenario. These assumptions were input to NEMS-TSA, and the results were reviewed. Not surprisingly, the market penetration estimates thus estimated generally did not match those of Table 2-1. We then added policies designed to encourage the market penetration of the vehicles of interest in each scenario (e.g., vehicle subsidies). We thus were able to come closer to our "goals." As a result of this approach and the fact that we have two separate sets of vehicle price estimates, we present four sets of results for each scenario in the following sections, as follows:

- Results assuming the vehicle prices developed by "literature review" as discussed in Chapter 3;
- Results assuming vehicle prices based on DOE "program goals," also discussed in Chapter 3;
- Results assuming "literature review" vehicle prices plus subsidies; and
- Results assuming "program goals" vehicle prices plus subsidies.

Table 6-1 presents an overview of the assumptions about vehicle technologies and fuels appropriate for each scenario. The table also summarizes variations in modeling assumptions between the Base Case and the scenarios. Some of these variations are significant and are discussed below.

6.1 FUEL PRICES

Several of the non-petroleum fuel production costs and resulting retail prices vary by scenario. Hydrogen production and delivery costs are more optimistic in the scenarios than in the Base Case but vary across scenarios, with the most optimistic costs being assumed in the H2 Success scenario. Similarly, ethanol prices are more optimistic in the scenarios than in the Base Case, with the (P)HEV & Ethanol scenarios incorporating the most optimistic costs. Electricity prices are tied to residential electricity prices in the Base Case and the scenarios. This assumption represents a change from the method used in EIA-NEMS, which ties EV and PHEV prices to transportation sector electricity prices.

TABLE 6-1 Key Technical and Modeling Assumptions for the Base Case and Scenarios

	FINAL MP BASE CASE	MIXED	H2 SUCCESS	(P)HEV & ETHANOL
Fuel Prices				
General	Oil prices of AEO 2007 High Oil Price Case.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.
H_2	H2A production and delivery cost estimates (August 2006) plus taxes. H2A values for "current" technology (also includes updated biomass supply curves developed by EIA). Includes state and Federal taxes similar to gasoline.	H2A production and delivery cost estimates (August 2006) plus taxes, but this scenario uses the "projected" cost estimates, where "Projected" estimates assume improvements in technology.	Uses the most optimistic H_2 costs: DOE H2 program goals.	Same as Mixed.
Ethanol				
Supply curves, etc.	Updated (August 2007) biomass supply curves developed by EIA. Updated (August 2007) cellulosic ethanol conversion costs from EIA. Updated (August 2007) corn costs from EIA.	Government Performance and Results Act (GPRA) 09 Base Case cellulosic ethanol conversion costs, which are more optimistic than EIA's Reference Case costs.	Same as Mixed.	Uses the most optimistic ethanol costs: Biomass program goals for cellulosic ethanol conversion costs. Reduced cellulosic ethanol growth constraints developed by EIA (August 2007).
Tax credit/import tariff	Both expire 2010.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.
Electricity for PHEVs	OnLocation has modified the method by which electricity prices for PHEVs (and EVs) are estimated. They are now tied to residential electricity prices.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.
Vehicle Technologies				
Advanced Conventional Gasoline Vehicles (ACVs)	Assumes that all technologies that might be used to improve conventional gasoline vehicle (CV) fuel economy will be used in conventional gasoline vehicles to meet CAFE. No distinct ACV category is included.	Advanced CVs superior to the CVs used to meet CAFE will be available in the Mixed scenario.	Same as Mixed.	Same as Mixed.

TABLE 6-1 (Cont.)

	FINAL MP BASE CASE	**MIXED**	**H2 SUCCESS**	**(P)HEV & ETHANOL**
PHEVs				
Range (miles)/% operation on electricity	10 miles/17.4%	40 miles/50.9%	Same as Mixed.	Same as Mixed.
MPG when operating on gasoline	Assumes the same fuel economy as that of HEVs.	From PSAT 11/07 runs. Use leading edge PHEV40 over time	Same as Mixed.	Same as Mixed.
Ratio of MPGGE on electricity to MPG on gasoline	From PSAT 11/07 runs. Uses near-term average PHEV10 (2.7X).	From PSAT 11/07 runs. Uses leading edge PHEV40 over time.	Same as Mixed.	Same as Mixed.
Cost	Assumes that initially the PHEVs cost $2K more than HEVs but that by 2030, they only cost $0.5K more.	See "Vehicle costs" (for all technologies) below.	Same as Mixed.	Same as Mixed.
% Customers can plug-in at home	35% to 2020, then rising to 50% by 2030 and then flat.	35% in 2020, 50% in 2030, 55% in 2040, and 65% in 2050.	38% in 2020, 55% in 2030, 65% in 2040, and 75% in 2050.	40% in 2020, 65% in 2030, 75% in 2040, and 85% in 2050.
Do ACVs, PHEVs, and GHEVs have flex fuel capability?	No	Yes. All ACVs and PHEVs when produced are flex fuel. By 2020, all HEVs produced are flex fuel.	No.	Same as Mixed.
Vehicle fuel economy standards	CAFE standards of EISA 2007; held essentially flat post-2020.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.
Vehicle fuel economies	Same as AEO 2007, except as affected by EISA CAFE.	From PSAT 11/07 runs.	Same as Mixed.	Same as Mixed.
Vehicle prices	Same as AEO 2007, except as affected by EISA CAFE.	From ORNL's vehicle cost model.	Same as Mixed.	Same as Mixed.
Years of introduction for advanced vehicles	Same as AEO 2007.	Based on GPRA 09 inputs, with revisions.	FCVs and plug-in FCVs are introduced earlier than in Mixed.	Same as Mixed.
Other vehicle attributes	Same as AEO 2007.	Based on GPRA 09 inputs, with revisions.	Same as Mixed, except for small revisions due to change in year of introduction.	Same as Mixed.
Commercial LT (all gasoline) Fuel Economy	Increases proportionally with increases in the fuel economy of conventional gasoline, advanced conventional gasoline, and gasoline HEV LTs.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.
Sales to Fleets	~ to 0.1%.	Same as Final Base Case.	Same as Final Base Case.	Same as Final Base Case.

TABLE 6-1 (Cont.)

	FINAL MP BASE CASE	MIXED	H2 SUCCESS	(P)HEV & ETHANOL
Vehicle Make and Model Availability				
Conventional gasoline vehicles (CVs)	Same as AEO 2007: available in 100% of all makes and models in all years.	Estimated endogenously (an option in the NEMS model). Therefore, can drop below 100% as other vehicles enter the market.	Same as Mixed.	Same as Mixed.
All other technologies	Same as AEO 2007: not available in all makes and models; hard-wired except that GHEVs and diesels increase with increases in oil price and FFVs increase if E85 price drops below gasoline price.	Estimated endogenously.	Same as Mixed.	Same as Mixed.
Vehicle Constant	Same as AEO 2007: Hard-wired. Advanced technologies are generally negative.	All advanced technologies as well as FFVs are set at "0."	Same as Mixed.	Same as Mixed.
H_2 Fuel Availability	Same as NEMS-H2 default value: 1,500 FCVs/station.	Station size is reduced to 750 FCVs/station, which increases H_2 availability.	Same as Mixed, except H_2 stations are "jump-started."	Same as Mixed.
E85 Fuel Availability	Station size is used to estimate fuel availability unless/until E85 prices drop below gasoline, in which case E85 fuel availability increases 0.5% per year.	Same as Final Base Case.	Same as Mixed.	Same as Mixed.

6.2 VEHICLE TECHNOLOGIES

The scenarios all use the same set of assumptions about fuel economies and vehicle prices for advanced technology vehicles. These estimates are different from the Base Case estimates. The bases for the scenarios' fuel economy and vehicle price estimates are discussed in Chapter 3 of this report. Appendix A provides the fuel economy multipliers and incremental price estimates for the advanced technology vehicles as actually input into the NEMS-MP model for the scenario analysis. Table 6-2 provides an example of those inputs: fuel economy multipliers and incremental prices for a medium car in the Mixed and (P)HEV & Ethanol scenarios. (As discussed in Chapter 3, the inputs for the diesels and GHEVs reflect a mix of baseline diesels and GHEVs with more advanced versions of those technologies.) The relationships for the medium car are representative of the other 11 vehicle classes.

TABLE 6-2 Incremental Vehicle Price and Fuel Economy X Factors for Advanced Drivetrain Vehicles: Medium Car, Mixed, and (P)HEV & Ethanol Scenarios (in 2005$)

	Mid-size (Medium) CAR				
	Year of:				
	Market Intro.	Price Success	Price Mature	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$1,951	$2,595	$3,086	$2,617	$2,370
"Program Goals" Incremental Price ($)	$1,845	$2,224	$2,496	$1,907	$1,597
Fuel economy X factor	1.30	1.38	1.45	1.46	1.47
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$5,257	$5,107	$4,956	$4,506	$4,205
"Program Goals" Incremental Price ($)	$3,496	$3,381	$3,267	$2,924	$2,695
Fuel economy X factor	2.24	2.27	2.30	2.39	2.45
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$2,343	$2,949	$3,556	$2,407	$1,833
"Program Goals" Incremental Price ($)	$2,240	$2,335	$2,429	$1,427	$926
Fuel economy X factor	1.41	1.75	2.10	2.26	2.34
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$531	$471	$410	$168	$47
"Program Goals" Incremental Price ($)	$417	$350	$283	$17	-$117
Fuel economy X factor	1.16	1.17	1.18	1.22	1.24
Fuel Cell (hydrogen)	**2023**	**2028**	**2033**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$7,640	$7,273	$6,906	$6,393	$5,660
"Program Goals" Incremental Price ($)	$2,115	$1,787	$1,458	$997	$340
Fuel economy X factor	2.65	2.74	2.83	2.96	3.14
FCV PHEV 40	**2025**	**2030**	**2035**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$12,240	$11,512	$10,783	$10,055	$8,598
"Program Goals" Incremental Price ($)	$4,145	$3,696	$3,248	$2,799	$1,902
Fuel economy X factor (liquid fuel)	2.74	2.83	2.92	3.00	3.18
Fuel economy X factor (electricity)	4.86	4.93	4.99	5.06	5.19
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Literature Review" Incremental Price ($)	$8,511	$8,051	$7,590	$6,484	$5,563
"Program Goals" Incremental Price ($)	$4,866	$4,518	$4,170	$3,335	$2,639
Fuel economy X factor (liquid fuel)	2.02	2.06	2.10	2.19	2.27
Fuel economy X factor (electricity)	5.25	5.32	5.39	5.55	5.69

Other attributes (i.e., maintenance cost, acceleration, luggage space, and range) of the advanced technology vehicles were also discussed in Chapter 3. The scenarios all assume the same values for these attributes. Again, these values are different from the Base Case. Appendix A provides the ratios for these attributes for the advanced technology vehicles in the scenarios relative to those of the Base Case vehicles. Table 3-13 in Chapter 3 provides the attributes for the same vehicle whose fuel economies and prices are shown in Table 6-2.

6.2.1 Unique PHEV Attributes

The PHEVs in the scenarios vary substantially from those in the Base Case. Part of the reason for this variation is that the NEMS-MP model can handle only one PHEV range at a time. The Base Case PHEVs are assumed to have a 10–mile all-electric range, which translates into operating 17% of total travel on electricity. PHEVs in the scenarios have a 40-mile all-electric range and operate 50% on electricity. In the Base Case, it is assumed that potentially up to 50% of U.S. households would be able to plug their PHEVs in at home. As shown in Table 6-1, while there are differences between the scenarios with respect to the percentage of households that can recharge PHEVs, all end up with higher percentages than the Base Case.

6.2.2 Flexible Fuel Vehicles

When estimating vehicle sales in the NEMS model, only one type of vehicle technology is classified as a flex fuel vehicle (i.e., capable of operating on gasoline and E85). That vehicle is today's FFV. We know that for some of our scenarios — with goals of as much as 60 billion gallons of ethanol use annually and introduction of advanced technology vehicles — other vehicles will also have to have flex fuel capability. OnLocation modified the NEMS-MP model to allow gasoline HEVs (GHEVs), ACVs, and PHEVs to operate as flex fuel vehicles. The specific modification allows us to input the percentage of these technologies' stock that we estimate will be flex fuel; that percentage can vary over time. (Given that stock, the price of E85 relative to gasoline and E85 fuel availability together determine the percentage of miles that these vehicles actually operate on E85.)

So, the percentage of stock that is flex fuel was estimated separately and then used to adjust the model results. We assumed no change was needed in the Base Case or in the H2 Success scenario. For the Mixed and (P)HEV & Ethanol scenarios, we assumed that all PHEVs and ACVs will be flex fuel from the start of their production, and thus, 100% of their stock will be flex fuel. None of these vehicles is being produced yet, and manufacturers are discussing the possibility of adding fuel flexibility to many vehicle lines. It would seem easiest to add flex fuel capability to a new line of vehicles. For GHEVs, the estimate was not so easy to make. But, again because manufacturers are committing to flex fuel vehicles and because of the Renewable Fuel Standard, we believe the production of flex-fuel HEVs will ramp up quickly. For these two scenarios, we assume that by 2020, all HEVs produced will be flex fuel. We also estimate that this assumption translates to flex fuel capability in about 70% of the GHEV stock by 2020 and in more than 95% of the stock by 2030 in these two scenarios.

6.3 COMMERCIAL LIGHT TRUCK FUEL ECONOMY

As indicated in Table 5-1 in the Base Case, we modified the manner in which the fuel economy of commercial light trucks (all of which NEMS assumes to be gasoline) is estimated in NEMS. In NEMS-MP, it increases in direct proportion to the increase in the fuel economy of all LTs using gasoline. We use this same method in the scenarios.

6.4 SALES TO FLEETS

As indicated in Table 5-1 in the Base Case, the share of vehicle sales to fleets assumed in NEMS was changed. Because key advanced technology vehicles are not included in the NEMS fleet module, we reduced the share to 0.1% in NEMS-MP. The same approach is used in the scenarios.

6.5 VEHICLE CONSTANT

The NEMS-MP vehicle choice model equation attempts to estimate the total "utility" of a particular vehicle type to the consumer. The equation includes several specific variables (vehicle price, fuel price, and other attributes) that influence consumer purchase behavior. It also includes a constant that is meant to capture variables that have been left out of the equation (e.g., how "green" a technology appears to the consumer) or are immeasurable. This constant varies by technology. For gasoline, the constant is "0." A negative constant implies that consumers are wary of the technology, which tends to reduce its market penetration: the larger the negative constant, the greater the reduction. Alternatively, a positive constant tends to increase the market penetration of a technology.

Table 6-3 presents constants used for various technologies in the Base Case and the scenarios. The Base Case constants are the same as those used in the AEO 2007 Reference Case. They are invariant throughout time. In all of the scenarios, we have reduced the negative constant to "0" for the advanced technologies of interest in the MP Study over a period of 10 years beginning in 2007 to simulate the effect of a market environment in which consumers are highly interested in fuel economy and welcoming toward new fuel-saving technologies. This approach is very similar to that used in EERE's Government Performance and Results Act (GPRA) analysis, although the start year is different in GPRA for different technologies.

For those technologies included in NEMS that are of little interest in this analysis, we assign a large negative constant. These are largely vehicles operating on methanol, CNG, and LPG — technologies that do not appear to have the capability to penetrate the LV market significantly out to the year 2050.

6.6 VEHICLE MAKE AND MODEL AVAILABILITY

In the AEO 2007 Reference Case, conventional gasoline vehicles are assumed to be available for production in 100% of all vehicle makes and models to the year 2030. In other words, even if the manufacturers were to increase production of hybrids and diesels significantly, the model assumes that conventional gasoline vehicles would be produced in all makes and models. The make and model availability (MMA) of all other technologies is assumed to be less than 100% and is essentially hard-wired. Two exceptions exist: (1) the MMA of HEVs and diesels is allowed to increase with increases in oil price, and (2) the MMA of FFVs increases if the price of E85 drops below gasoline prices. The MP Base Case makes the same assumptions as the AEO Reference Case, extending those assumptions to 2050.

TABLE 6-3 VCM Equation Constant in MP Base Case and Scenarios

MP Base Case		
Technology	Cars	LTs
CV	0	0
FFV	–1	–0.5
ACV	0	0
Diesel	–3.5	–0.6
GHEV	–2	–2
PHEV	–2	–2
Plug-in FCV	0.057	0.331
FCV	0.057	0.331
EV	–5	–5
Other	Negative	Negative
Scenarios		
Technology	Cars	LTs
CV	0	0
FFV	0	0
ACV	0	0
Diesel	0	0
GHEV	0	0
PHEV	0	0
FCV	0	0
Plug-in FCV	0	0
EV	0	0
Other	–50	–50

We modified these assumptions for the scenarios. Instead of using the hard-wired MMAs, the MMA for all technologies, including CVs, is estimated endogenously (an option in the NEMS model). This modification means that we allow the CV MMA to drop below 100% as other technologies enter the market in large numbers.

6.7 COMBINED EFFECT OF THE VEHICLE CONSTANT AND VEHICLE MMA

The impact of using two different approaches to estimating MMA and the vehicle constant assumptions is significant. Table 6-4 compares the market penetration shares of the MP Base Case with those of a base case in which every assumption is the same except that the MMA of all technologies is estimated endogenously and the constant for all the advanced vehicle technologies drops to “0” (Base Case Endogenous, or BCEndogenous). (Almost every assumption is the same: BCEndogenous includes advanced conventional gasoline vehicles, while the MP Base Case does not.) The sales mix between the two cases is quite different. By 2050, 70% of car sales are still of conventional gasoline vehicles in the MP Base Case, while the share is 34% (adding the CVs and ACVs together) in BCEndogenous. In the MP Base Case in 2050,

TABLE 6-4 Sales Projection of MP Base Case and Base Case Endogenous

	2010	2020	2030	2040	2050
Final MP Base Case					
New Car Sales 1/					
Conventional Gasoline ICE	88.6%	83.0%	77.9%	72.3%	70.0%
Adv Conv Gasoline	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	0.6%	1.1%	1.9%	2.0%	2.0%
Ethanol-Flex Fuel ICE	5.4%	5.1%	4.9%	5.9%	7.4%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	1.1%	2.3%	1.7%	1.7%
Electric-Diesel Hybrid	0.0%	0.2%	0.1%	0.1%	0.1%
Electric-Gasoline Hybrid	5.3%	9.4%	12.8%	17.9%	18.6%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.0%	0.0%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
New LT Sales 1/					
Conventional Gasoline ICE	73.9%	58.7%	51.8%	39.8%	36.8%
Adv Conv Gasoline	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	6.7%	10.5%	16.7%	26.9%	27.4%
Ethanol-Flex Fuel ICE	16.2%	15.0%	13.7%	13.7%	16.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.9%	1.7%	1.2%	1.3%
Electric-Diesel Hybrid	0.0%	0.0%	0.0%	0.0%	0.0%
Electric-Gasoline Hybrid	3.1%	14.9%	16.0%	18.3%	17.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Base Case with endogenous MMA and "0" constant					
New Car Sales 1/					
Conventional Gasoline ICE	59.1%	24.9%	27.4%	26.4%	26.9%
Adv Conv Gasoline	15.5%	16.2%	7.1%	6.8%	6.9%
TDI Diesel ICE	1.3%	16.5%	17.9%	18.7%	17.5%
Ethanol-Flex Fuel ICE	9.4%	7.3%	7.9%	7.6%	7.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	1.7%	6.2%	6.5%	6.8%
Electric-Diesel Hybrid	0.0%	14.7%	14.3%	14.9%	14.4%
Electric-Gasoline Hybrid	14.8%	18.7%	19.1%	18.9%	19.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
New LT Sales 1/					
Conventional Gasoline ICE	44.3%	25.0%	27.7%	26.2%	26.1%
Adv Conv Gasoline	5.8%	15.1%	2.9%	2.6%	2.6%
TDI Diesel ICE	17.4%	18.2%	19.4%	21.0%	19.8%
Ethanol-Flex Fuel ICE	24.7%	14.5%	16.5%	16.0%	16.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	2.3%	6.0%	6.2%	6.4%
Electric-Diesel Hybrid	0.0%	2.7%	7.5%	8.0%	7.9%
Electric-Gasoline Hybrid	7.7%	22.3%	20.0%	20.0%	20.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

diesel car sales are 2%, and diesel LT sales are 27%. In contrast, in BCEndogenous diesel car and LT sales are very similar to one another: 18% and 20%, respectively. There are additional examples in which considerable differences emerge starting as early as 2010.

The main point here is that, when reviewing the sales estimates of the scenarios in the following sections, the reader should realize that not all the differences between the MP Base Case and the scenarios are attributable to superior vehicle technology and/or lower-cost fuels. Rather, some of the differences are attributable to differences in the methodology used to estimate vehicle technology penetration.

(We continued to use the MMA methodology and the constants of the AEO Reference Case in the MP Base Case because we wanted our Base Case projections to be as consistent as possible with the AEO 2007 High Oil Price Case for energy use and oil use projections. We achieved that consistency, as shown in Table 5-2.)

6.8 FUEL AVAILABILITY

Fuel availability affects vehicle choice in the NEMS-MP model: the lower the availability of stations providing a specific fuel, the lower the market penetration of vehicles using that fuel. The NEMS model uses station size (the number of vehicles served per station by fuel type) to determine how many stations are "built." If the size is 100, then the model builds a station for every 100 vehicles in the vehicle stock. If the size is 1,000, then a station is built for every 1,000 vehicles in the stock. As more stations are built, fuel availability becomes greater. Fuel availability is a ratio of from 0 to 1.

6.8.1 Hydrogen

Unfortunately, the NEMS-MP model only provides for one such station size per fuel type throughout time. This constraint can depress the market penetration of technologies needing new fuels if the station size is set too high. We believe the station size of 1,500 vehicles for H_2 stations (which is similar to the typical station being evaluated by DOE's hydrogen program) unrealistically depresses the projected market penetration of FCVs in the early years. However, we left it that way in the MP Base Case since we knew that very few FCVs would penetrate the market even if we changed it.

For all of our scenarios, we took a more moderate view of the average H_2 station size and set it at 750 vehicles/station. For the H2 Success Scenario, we also "jump-start" (or "kick-start") station build-up. Consistent with other scenarios analyzed by DOE's hydrogen program, we assume that a policy is implemented that will ensure that 10% of all stations in large cities offer H_2 by 2024 and that 2% of all stations in small cities will offer it by 2029. This policy increases the number of stations over those that would be built with just the assumption of 750 FCVs/station. (The precise form of the policy has not been specified nor have its costs been estimated. Appendix B provides a very preliminary cost estimate of this policy.)

6.8.2 E85

The size of E85 stations is not much of a constraint as for H_2 stations: it is lower at 400 vehicles/station. In addition, the NEMS model used in the AEO Reference Case allows the fuel availability calculations for E85 to be overridden once the price of E85 drops below that of gasoline. In that case, the AEO 2007 allows fuel availability to increase by a total of 1% over what would otherwise be estimated. We believe that approach is too limiting and have modified that calculation for both the MP Base Case and the scenarios. Instead, we assume that if the price of E85 drops below that of gasoline, fuel availability will increase 0.5% per year. (Note that in the AEO 2008 version of NEMS, fuel suppliers are assumed to invest in new E85 fueling stations in order to sell the EISA required amounts of biofuels, and they are no longer tied to a specific number of flex-fueled vehicles.)

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7 KEY NEMS-MP RESULTS FOR THE BASE CASE AND SCENARIOS

The NEMS-MP model generates numerous results for each run of a scenario. This section starts with what we believe are the results of greatest interest to most readers. These include the following:

- The market penetration of advanced vehicle technologies;
- LV energy use, oil use, and CO_2 emissions;
- Ethanol use;
- U.S. liquid fuels supply and net imports;
- U.S. emissions of CO_2;
- World oil prices; and
- The cost effectiveness of the subsidies (where applicable).

These results are compared and contrasted across scenarios. The results are discussed in the following order:

- Scenario results when assuming the "literature review" vehicle prices;
- Scenario results when assuming the "program goals" vehicle prices;
- Scenario results assuming the "literature review" vehicle prices plus vehicle subsidies; and
- Scenario results assuming the "program goals" vehicle prices plus vehicle subsidies.

Where appropriate, we refer to the four versions or cases of each scenario as follows:

- "Literature Review No Subsidies" or "LR";
- "Program Goals No Subsidies" or "PG";
- "Literature Review With Subsidies" or "LRwS"; and
- "Program Goals With Subsidies" or "PGwS."

In reviewing the results discussed below, the reader should keep in mind the following comparisons among the scenarios (previously discussed in Chapter 6):

1. All the scenarios (and the Base Case) assume the high oil price of AEO 2007 extended (Table 5-1);
2. The vehicle fuel economies are the same across all scenarios, and those for ACVs, diesels, HEVs (gasoline and diesel), FCVs, and plug-ins (both gasoline and fuel cell) are higher than in the Base Case;

3. While the Mixed scenario has the most conservative assumptions with respect to ethanol and hydrogen fuel prices, the fuel prices in the Mixed scenario are lower than in the Base Case;

4. The (P)HEV & Ethanol scenario assumes both the most optimistic cellulosic ethanol prices and the most optimistic share of households that are able to plug in their vehicles;

5. The H2 Success scenario assumes the most optimistic H_2 prices, the earliest introduction of FCVs and plug-in FCVs, and "jump starting" of H_2 stations; and

6. ACVs, PHEVs, and GHEVS have flex fuel capability in the Mixed and (P)HEV & Ethanol scenarios.

NEMS-MP does not directly generate all the results of interest: some must be computed from the standard report variables. A brief attachment to this chapter discusses these computations. Finally, additional NEMS-MP results for each scenario and case can be found in Appendix E.

7.1 SCENARIOS WITH "LITERATURE REVIEW" VEHICLE PRICES AND NO SUBSIDIES

As a reminder, the scenarios with "literature review" vehicle prices use vehicle price estimates that have been developed through literature review. These prices do not necessarily meet DOE vehicle program goals (whereas the scenarios with "program goals" vehicle prices do assume these goals are met). The vehicle price estimates are the same across the three scenarios.

7.1.1 Vehicle Market Penetration

Table 7-1 presents sales shares for the Base Case and three scenarios. The estimates are weighted: they represent the combined car and LT sales totals of each technology as a percentage of total LV sales. The LT share varies over time and by scenario, but total LV sales are the same in all scenarios. (The drop-in LT share between 2005 and 2010 followed by a rebound is consistent with the LT share estimates of the AEO 2007.) Figures 7-1 and 7-2 compare the weighted shares in the years 2030 and 2050. Table 7-2 presents vehicle technology shares for the on-road (stock) fleet in the Base Case and three scenarios.

Some key points are as follows:

1. While 91% of new LV sales in 2005 are of conventional gasoline vehicles, these vehicles will represent just over 50% of sales by 2050 in the Base Case. By 2050, 46% of sales in the Base Case will be HEVs, diesels, and conventional flex fuel vehicles.

TABLE 7-1 Weighted Shares of Vehicle Sales in Base Case and Scenarios Using Literature Review Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	91.3%	82.2%	72.1%	65.3%	56.2%	52.2%
Adv Conv Gasoline	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	2.1%	3.3%	5.6%	9.5%	15.1%	16.1%
Ethanol-Flex Fuel ICE	3.8%	10.0%	9.5%	8.9%	9.1%	11.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	1.0%	2.0%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%
Electric-Gasoline Hybrid	1.4%	4.4%	11.6%	14.2%	18.0%	18.0%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	1.2%	0.0%	0.1%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Lit. Review Prices						
Conventional Gasoline ICE	91.3%	57.3%	24.5%	21.6%	18.1%	15.0%
Adv Conv Gasoline	0.3%	6.1%	26.7%	26.5%	24.4%	22.6%
TDI Diesel ICE	2.1%	8.9%	7.2%	7.2%	8.4%	9.3%
Ethanol-Flex Fuel ICE	3.8%	16.1%	11.6%	10.9%	10.6%	8.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.1%	0.2%	0.4%	0.8%
Electric-Diesel Hybrid	0.0%	0.0%	5.8%	5.8%	6.5%	7.1%
Electric-Gasoline Hybrid	1.4%	11.5%	24.2%	27.6%	31.5%	36.1%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Lit. Review Prices						
Conventional Gasoline ICE	91.3%	57.3%	24.0%	21.4%	18.1%	15.3%
Adv Conv Gasoline	0.3%	6.1%	26.1%	26.2%	24.3%	22.8%
TDI Diesel ICE	2.1%	8.9%	6.1%	6.7%	8.2%	8.3%
Ethanol-Flex Fuel ICE	3.8%	16.2%	14.7%	12.4%	11.2%	10.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.1%	0.3%	0.5%	1.2%
Electric-Diesel Hybrid	0.0%	0.0%	5.2%	5.6%	6.4%	6.6%
Electric-Gasoline Hybrid	1.4%	11.5%	23.7%	27.3%	31.2%	35.6%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-1 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Lit. Review Prices						
Conventional Gasoline ICE	91.3%	57.3%	24.5%	21.2%	16.1%	13.1%
Adv Conv Gasoline	0.3%	6.1%	26.7%	26.1%	22.6%	20.7%
TDI Diesel ICE	2.1%	8.9%	7.1%	7.2%	7.6%	8.5%
Ethanol-Flex Fuel ICE	3.8%	16.1%	11.6%	10.9%	15.1%	13.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.1%	0.2%	0.4%	1.0%
Electric-Diesel Hybrid	0.0%	0.0%	5.7%	5.8%	6.2%	6.9%
Electric-Gasoline Hybrid	1.4%	11.5%	24.1%	27.3%	30.2%	34.4%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Fuel Cell Hydrogen	0.0%	0.0%	0.2%	1.1%	1.6%	2.3%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
H2 without Jump Start Lit. Review Prices						
Conventional Gasoline ICE	91.3%	57.3%	24.5%	21.4%	16.4%	13.3%
Adv Conv Gasoline	0.3%	6.1%	26.7%	26.4%	23.0%	21.2%
TDI Diesel ICE	2.1%	8.9%	7.1%	7.3%	7.8%	8.8%
Ethanol-Flex Fuel ICE	3.8%	16.1%	11.6%	11.0%	15.3%	13.3%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.1%	0.2%	0.4%	1.0%
Electric-Diesel Hybrid	0.0%	0.0%	5.7%	5.9%	6.3%	7.0%
Electric-Gasoline Hybrid	1.4%	11.5%	24.2%	27.6%	30.7%	35.2%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
LT Share of Total Sales						
Base Case	50.1%	43.2%	44.9%	48.6%	51.4%	54.0%
Mixed Lit. Review Prices	50.1%	43.6%	45.0%	48.9%	51.8%	54.6%
(P)HEV & Ethanol Lit. Review Prices	50.1%	43.6%	46.0%	49.0%	51.9%	54.8%
H2 Success Lit. Review Prices	50.1%	43.6%	45.0%	48.8%	51.8%	54.6%
H2 without Jump Start Lit. Review Prices	50.1%	43.6%	45.0%	48.8%	51.8%	54.6%
Total LV sales (millions)	16.2	16.6	18.2	20.2	21.9	23.5

2. The Mixed and (P)HEV & Ethanol scenarios have very similar rates of technology penetration. For example, in each, conventional gasoline vehicles (CVs) are approximately 21% of LV sales in 2030, advanced gasoline vehicles (ACVs) are 26%, HEVs are 27%, diesels are 7%, and conventional flex fuel vehicles are 11%–12%. By 2050, CVs are 15% of sales in each scenario, ACVs are 23%, HEVs are 36%, diesels are 8%–9%, etc. In neither scenario do plug-ins or FCVs achieve much market penetration. (In fact, the penetration of PHEVs is higher in the Base Case; however, the PHEVs in the Base Case are PHEV10s, while those in the scenarios are PHEV40s.[18])

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[18] It is important to note that the version of NEMS used for both the Base Case and MP scenarios allows only one PHEV range; for the Base Case, the range chosen was 10 miles, and for the MP scenarios, 40 miles.

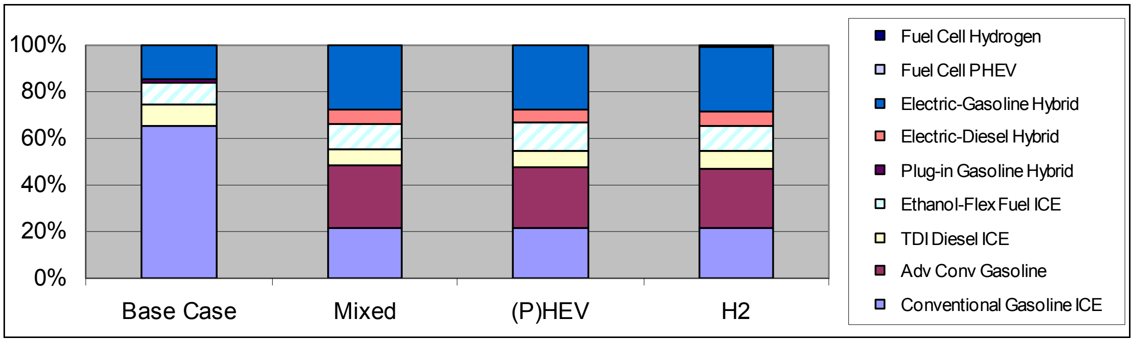

FIGURE 7-1 2030 Sales Shares (Literature Review, No Subsidies Cases)

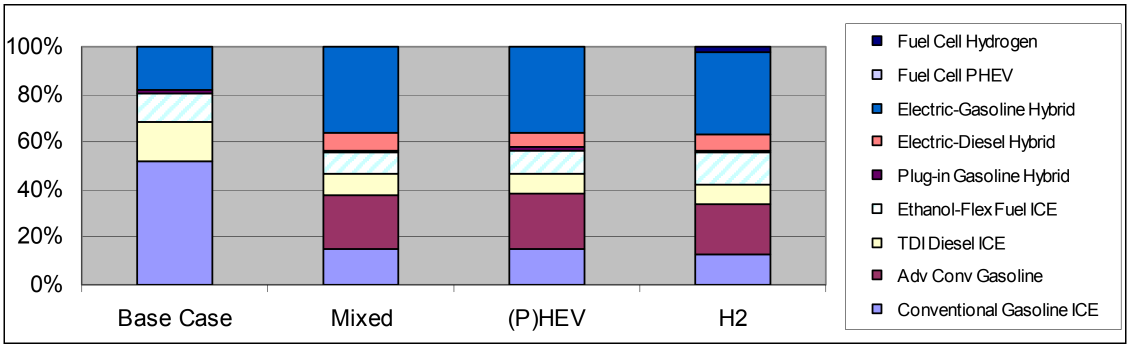

FIGURE 7-2 2050 Sales Shares (Literature Review, No Subsidies Cases)

3. The market penetration of the H2 Success scenario is similar to the Mixed and (P)HEV & Ethanol scenarios, with the exception that a few more FCVs are sold. However, the sales are not large: FCVs make up 1.1% of sales in 2030 and 2.3% in 2050. (There are also a few more conventional flex fuel vehicles, although there are not more vehicles capable of using E85 because in the other two scenarios, HEVs, ACVs, and PHEVs are assumed to be flex fuel vehicles.)

4. The market penetration of the H2 Success scenario would be even more similar to that of the Mixed and (P)HEV & Ethanol scenarios if we had not assumed that H_2 stations were "jump-started" in the scenario (as discussed in Section 6.8.1). The impact of the jump start can be seen when the H2 Success scenario is compared with a scenario called "H_2 without jump starting" as shown in Table 7-1. The FCV sales in the latter scenario (0.1% in 2030 and 0.2% in 2050) are the same as in the Mixed and (P)HEV & Ethanol scenarios.

5. By 2050, in the Mixed and (P)HEV & Ethanol scenarios, CVs will represent 19% of the total LV stock, while 24% will be ACVs, 31–32% will be gasoline HEVs, 8% will be diesels, 6% will be diesel HEVs, 10–11% will be conventional flex fuel vehicles, and less than 1% will be plug-ins or FCVs. The stock of the H2 Success scenario will be very similar except that 2.2% of the vehicles on the road will be FCVs or plug-ins. That share would be lower without jump-starting the H_2 stations.

TABLE 7-2 Weighted Shares of Vehicle Stock in Base Case and Scenarios Using Literature Review Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	95.6%	92.1%	83.0%	73.6%	65.1%	57.9%
Adv Conv Gasoline	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
TDI Diesel ICE	1.7%	2.2%	3.6%	6.0%	10.0%	13.8%
Ethanol-Flex Fuel ICE	1.8%	3.9%	7.8%	8.9%	9.1%	9.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	1.1%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
Electric-Gasoline Hybrid	0.2%	1.2%	5.0%	10.1%	14.1%	16.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.5%	0.5%	0.3%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Lit. Review Prices						
Conventional Gasoline ICE	95.6%	88.4%	53.1%	31.7%	23.2%	18.5%
Adv Conv Gasoline	0.1%	0.7%	15.1%	23.6%	25.3%	24.3%
TDI Diesel ICE	1.7%	3.0%	6.3%	6.9%	7.4%	8.4%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.1%	11.1%	10.9%	10.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%
Electric-Diesel Hybrid	0.0%	0.0%	1.9%	4.5%	5.7%	6.5%
Electric-Gasoline Hybrid	0.2%	2.2%	13.3%	22.0%	27.3%	31.7%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Lit. Review Prices						
Conventional Gasoline ICE	95.6%	88.4%	53.1%	31.6%	23.1%	18.7%
Adv Conv Gasoline	0.1%	0.7%	15.1%	23.3%	25.0%	24.3%
TDI Diesel ICE	1.7%	3.0%	6.0%	6.4%	6.9%	7.8%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.6%	12.6%	12.2%	11.1%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.1%	0.3%	0.6%
Electric-Diesel Hybrid	0.0%	0.0%	1.8%	4.2%	5.4%	6.1%
Electric-Gasoline Hybrid	0.2%	2.2%	13.2%	21.7%	27.0%	31.3%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-2 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Lit. Review Prices						
Conventional Gasoline ICE	95.6%	88.4%	53.1%	31.6%	22.4%	16.9%
Adv Conv Gasoline	0.1%	0.7%	15.1%	23.4%	24.5%	22.7%
TDI Diesel ICE	1.7%	3.0%	6.2%	6.9%	7.2%	7.9%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.1%	11.1%	12.3%	13.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%
Electric-Diesel Hybrid	0.0%	0.0%	1.9%	4.5%	5.6%	6.3%
Electric-Gasoline Hybrid	0.2%	2.2%	13.3%	21.9%	26.7%	30.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.5%	1.1%	1.7%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
H2 without Jump Start Lit. Review Prices						
Conventional Gasoline ICE	95.7%	88.6%	53.3%	31.7%	22.6%	17.1%
Adv Conv Gasoline	0.1%	0.7%	15.1%	23.5%	24.7%	23.1%
TDI Diesel ICE	1.7%	3.0%	6.2%	6.9%	7.3%	8.0%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.1%	11.1%	12.4%	13.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%
Electric-Diesel Hybrid	0.0%	0.0%	1.8%	4.5%	5.7%	6.4%
Electric-Gasoline Hybrid	0.2%	2.2%	13.2%	22.0%	27.0%	31.0%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

What do these numerical results mean? There are substantial differences in market penetration rates of advanced vehicle technologies between the Base Case and the scenarios. However, in spite of differences in assumptions about fuel prices between the scenarios, the scenarios show very little difference from one another in terms of advanced vehicle technology penetration. This illustrates well the point that vehicle price is the key determinant of vehicle choice in the NEMS-MP model (reflecting historic consumer preferences). It also indicates that for many, but not all, of the other results presented below, the scenario results should be similar to one another.

7.1.2 LV Energy Use and Oil Use

Table 7-3 presents LV energy use and oil use in the Base Case and the three scenarios. LV energy use will increase by 50% between now and 2050; most of that growth occurs after 2030. The scenarios save 2%–3% of that energy by 2030 and 9%–10% by 2050 (also see Figure 7-3).

Greater reductions are achieved in LV oil use. (The attachment to this chapter describes how LV oil use is estimated: i.e., the estimate does not include ethanol in blends.) In the Base Case, LV

TABLE 7-3 LV Energy Use, Oil Use, and Full-Fuel-Cycle CO_2 Emissions of Base Case and Scenarios Using Literature Review Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
LV Specific Results						
Annual						
LV Energy Use (quads)						
Base Case	16.95	17.15	17.38	18.90	21.70	25.01
Mixed Lit. Review Prices	16.95	17.09	17.27	18.33	20.30	22.45
(P)HEV & Ethanol Lit. Review Prices	16.95	17.09	17.31	18.49	20.51	22.82
H2 Success Lit. Review Prices	16.95	17.09	17.28	18.28	20.27	22.53
Savings (%)						
Mixed Lit. Review Prices	0.0%	0.4%	0.7%	3.0%	6.4%	10.2%
(P)HEV & Ethanol Lit. Review Prices	0.0%	0.3%	0.4%	2.1%	5.5%	8.7%
H2 Success Lit. Review Prices	0.0%	0.4%	0.6%	3.2%	6.6%	9.9%
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Lit. Review Prices	8.67	8.33	8.35	8.58	8.75	9.53
(P)HEV & Ethanol Lit. Review Prices	8.67	8.33	8.02	7.86	8.25	9.01
H2 Success Lit. Review Prices	8.67	8.33	8.41	8.78	9.26	10.05
Savings						
Mixed Lit. Review Prices	0.0	0.1	0.1	0.6	1.8	2.5
(P)HEV & Ethanol Lit. Review Prices	0.0	0.1	0.5	1.3	2.3	3.0
H2 Success Lit. Review Prices	0.0	0.1	0.1	0.4	1.3	2.0
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Lit. Review Prices	1419	1433	1513	1543	1652	1809
(P)HEV & Ethanol Lit. Review Prices	1419	1432	1424	1394	1557	1728
H2 Success Lit. Review Prices	1419	1433	1502	1570	1689	1853
Reductions (%)						
Mixed Lit. Review Prices	0.0%	0.4%	-0.1%	4.8%	12.7%	14.8%
(P)HEV & Ethanol Lit. Review Prices	0.0%	0.6%	5.8%	14.0%	17.7%	18.6%
H2 Success Lit. Review Prices	0.0%	0.5%	0.6%	3.1%	10.8%	12.7%
Cumulative						
Cumulative Oil Savings	***Million Barrels***			***Average MBPD***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Lit. Review Prices	1,657	12,642	14,299	0.2	1.7	0.9
(P)HEV & Ethanol Lit. Review Prices	4,117	16,782	20,899	0.4	2.3	1.2
H2 Success Lit. Review Prices	1,130	9,436	10,567	0.1	1.3	0.6
Cumulative LV full fuel cycle CO2 reductio	***MMTCO2E***			***Percent***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Lit. Review Prices	297	4,507	4,805	0.8%	11.9%	6.2%
(P)HEV & Ethanol Lit. Review Prices	1,962	6,514	8,476	5.0%	17.2%	11.0%
H2 Success Lit. Review Prices	319	3,807	4,126	0.8%	10.0%	5.4%

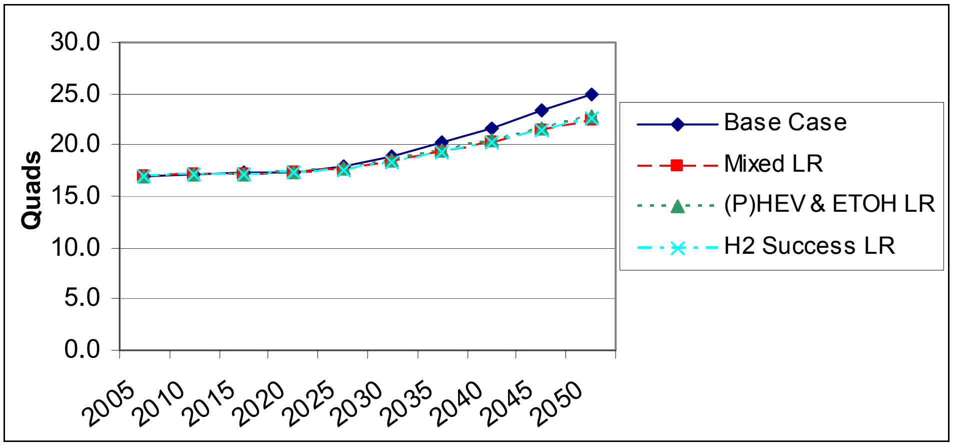

FIGURE 7-3 LV Energy Use (Literature Review, No Subsidies)

oil use essentially remains steady through 2025 and then increases. LV oil use is now 8.7 mbpd and does not exceed that level until 2030, when it is estimated to be 9.2 mbpd — primarily because of the new CAFE rules. But by 2050, with no further increase in vehicle fuel economy standards, LV oil use has risen to 12 mbpd. As shown in the tables as well as in Figure 7-4, LV oil use does not rise above its current level until about 2045 in the Mixed scenario and 2050 in the (P)HEV & Ethanol scenario. The H2 Success scenario has the highest level of LV oil use of the three scenarios, but even then it saves 2 mbpd relative to the Base Case in 2050. As further results will show, not as much ethanol is used in the H2 Success scenario as in the other two.

Cumulative oil savings are also presented in Table 7-3. The cumulative savings are all under 0.5 mbpd through 2030 — but then rise substantially. In the post-2030 period, the (P)HEV & Ethanol scenario has the greatest cumulative LV oil savings (2.3 mbpd).

7.1.3 LV Full-Fuel-Cycle CO_2 Emissions

While the NEMS-MP model does not provide estimates of all GHG emissions, it does provide estimates of CO_2 emissions. It also does not provide full-fuel-cycle CO_2 emissions for LVs; however, we developed a method that allows us to estimate what the full-fuel-cycle CO_2 emissions for LVs would be in each scenario. Please see the attachment to this chapter for an explanation of this method.

Table 7-3 and Figure 7-5 present LV full-fuel-cycle CO_2 emissions in the Base Case and the three scenarios. The trajectory of these emissions is similar to LV energy use in the Base Case, increasing by 50% between now and 2050 and with most of the growth occurring after 2030.

While the Mixed and H2 Success scenarios are similar to the Base Case through 2025, by 2050 the CO_2 emissions are lower by approximately 15%. The (P)HEV & Ethanol scenario lowers the LV full-fuel-cycle emissions compared to the Base Case right from the beginning of the scenario. It does not exceed the 2005 Base Case emissions until after 2030. Nevertheless, in 2050, it is only 19% below the Base Case emissions.

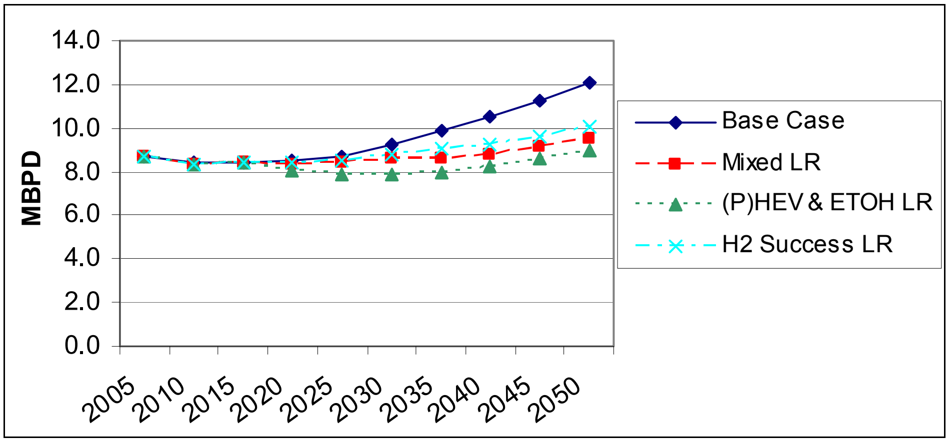

FIGURE 7-4 LV Oil Use (Literature Review, No Subsidies)

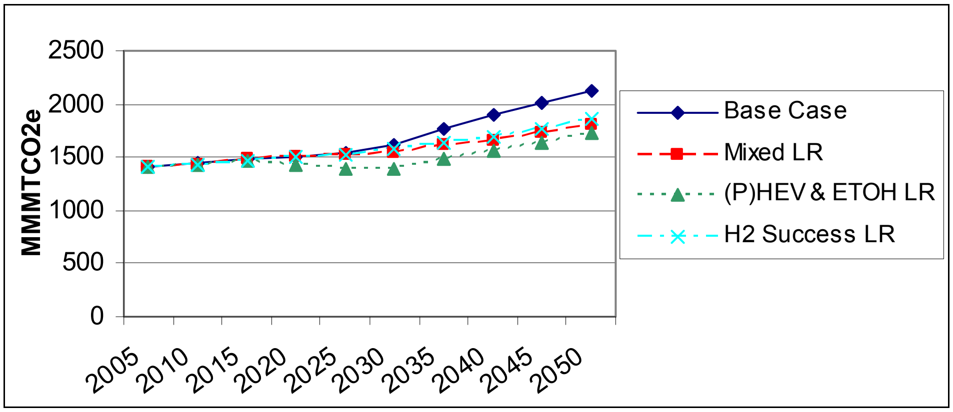

FIGURE 7-5 LV Full-Fuel-Cycle CO_2 Emissions (Literature Review, No Subsidies)

Cumulative CO_2 reductions are also presented in Table 7-3. As with the oil savings, the CO_2 reductions increase substantially after 2030. The (P)HEV & Ethanol scenario has the greatest cumulative LV full-fuel-cycle CO_2 reductions (11% for the complete 2005–2050 time period).

7.1.4 Ethanol Use

Table 7-4 and Figure 7-6 present total ethanol use in the Base Case and the three scenarios. The total renewable fuel volume required by the RFS by 2022 is also shown. For this analysis, the RFS is assumed to hold steady to 2050. We compare the two even though the RFS includes other fuels because ethanol is expected to play a major role in meeting the RFS.

There is growth in ethanol use in the Base Case: 16 billion gallons/year by 2030 and 24 billion gallons by 2050. It is not higher because cellulosic ethanol does not exceed 1 billion gallons per

TABLE 7-4 United States Total Energy, Oil, CO_2, and Gasoline Price Results for Base Case and Scenarios Using Literature Review Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
U.S. Total Results						
Ethanol Use (Billion gallons)						
Base Case	4.0	12.6	14.3	15.8	19.2	24.0
Mixed Lit. Review Prices	4.0	13.8	15.8	23.6	43.2	50.8
(P)HEV & Ethanol Lit. Review Prices	4.0	13.8	23.9	41.7	56.9	67.2
H2 Success Lit. Review Prices	4.0	13.8	14.7	17.9	30.2	38.3
RFS Standard (includes other fuels besides ethanol)	4.0	13.0	30.0	36.0	36.0	36.0
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Lit. Review Prices	20.5	20.3	20.8	21.6	23.1	25.9
(P)HEV & Ethanol Lit. Review Prices	20.5	20.3	20.5	20.8	22.6	25.4
H2 Success Lit. Review Prices	20.5	20.3	20.8	21.8	23.6	26.4
Savings						
Mixed Lit. Review Prices	0.0	0.1	0.1	0.7	1.9	2.5
(P)HEV & Ethanol Lit. Review Prices	0.0	0.1	0.4	1.5	2.4	3.0
H2 Success Lit. Review Prices	0.0	0.2	0.1	0.5	1.4	2.0
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Lit. Review Prices	60.5%	53.6%	46.4%	42.5%	45.0%	47.2%
(P)HEV & Ethanol Lit. Review Prices	60.5%	53.4%	44.4%	39.2%	43.4%	45.8%
H2 Success Lit. Review Prices	60.5%	53.6%	46.5%	43.4%	47.1%	50.2%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Lit. Review Prices	5945	6178	6702	7393	8289	9232
(P)HEV & Ethanol Lit. Review Prices	5945	6176	6613	7243	8194	9151
H2 Success Lit. Review Prices	5945	6177	6690	7419	8326	9276
Reductions (%)						
Mixed Lit. Review Prices	0.0%	0.1%	0.0%	1.0%	2.8%	3.3%
(P)HEV & Ethanol Lit. Review Prices	0.0%	0.1%	1.3%	3.0%	3.9%	4.1%
H2 Success Lit. Review Prices	0.0%	0.1%	0.1%	0.7%	2.4%	2.8%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Lit. Review Prices	2.33	2.59	2.88	3.02	3.29	3.59
(P)HEV & Ethanol Lit. Review Prices	2.33	2.59	2.78	2.98	3.26	3.49
H2 Success Lit. Review Prices	2.33	2.60	2.88	3.04	3.29	3.60
Reductions (%)						
Mixed Lit. Review Prices	0.0%	1.2%	1.0%	4.2%	6.9%	8.7%
(P)HEV & Ethanol Lit. Review Prices	0.0%	1.2%	4.5%	5.6%	7.8%	11.3%
H2 Success Lit. Review Prices	0.0%	1.2%	1.1%	3.6%	7.0%	8.5%

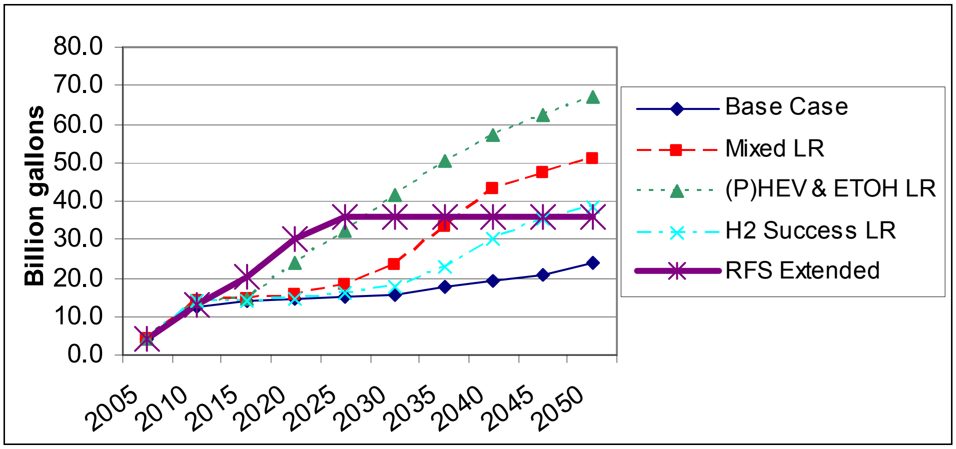

FIGURE 7-6 Ethanol Use (Literature Review, No Subsidies)

year until 2050 in spite of the fact that the Base Case incorporates many of EIA's updated biomass supply curves and cellulosic conversion costs (August 2007). (The feedstocks for ethanol for each scenario are discussed in Appendix E.)

The Mixed and H2 Success scenarios use somewhat more optimistic assumptions about cellulosic ethanol conversion costs and, consequently, are estimated to use substantially more ethanol, including cellulosic, than in the Base Case: 51 billion gallons and 38 billion gallons total, respectively, by 2050. The volume in the Mixed scenario is higher because there are many more vehicles capable of using E85 than in the H2 Success scenario.

Using the most optimistic assumptions concerning cellulosic ethanol, ethanol demand in the (P)HEV & Ethanol scenario will reach 42 billion gallons by 2030 and 67 billion gallons by 2050. The scenario would meet the total volume of renewable fuels required by the RFS solely with ethanol by 2030. Like the Mixed scenario, this scenario presumes the use of many flex fuel vehicles. Although this result is not shown in the table, half of the travel by flex-fuel vehicles is on E85 by 2050.

7.1.5 U.S. Liquid Fuels Supply (Excluding Ethanol)

Table 7-4 and Figure 7-7 present U.S. liquid fuels supply estimates for the Base Case and three scenarios. These estimates might be viewed as surrogates for petroleum supply since we have excluded the ethanol supply that is included in the direct NEMS-MP output. (The attachment to this chapter discusses other exclusions.) However, liquids from coal are included and are not insignificant in the later years in the Base Case and all the scenarios (i.e., more than 3 mbpd by 2050 in all cases).

U.S. liquid fuels (less ethanol) will grow by about 8 mbpd from today to 2050 in the Base Case. The scenarios reduce that growth by 2–3 mbpd by 2050, which amounts to almost the same reductions as are achieved for LV oil use alone.

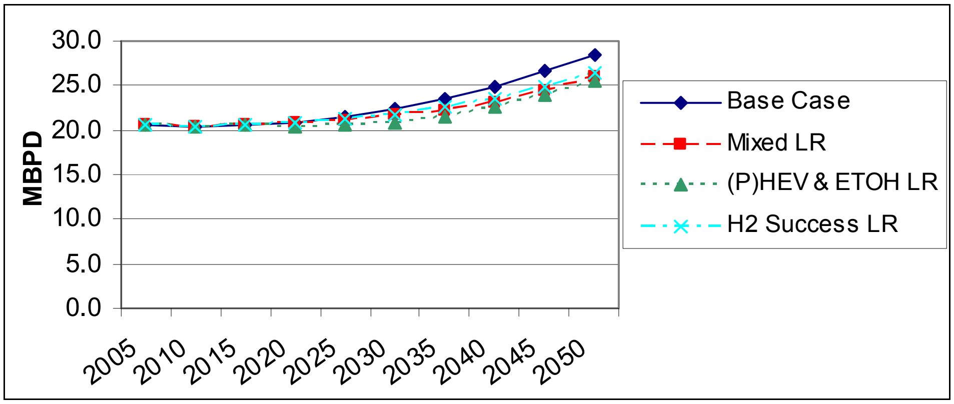

FIGURE 7-7 U.S. Liquid Fuels Supply Excluding Ethanol (Literature Review, No Subsidies)

7.1.6 Net Import Share of Product Supplied

Table 7-4 and Figure 7-8 present the percent of liquid fuel products imported. All possible sources of liquid fuel are included (i.e., ethanol is included in the calculations). In the Base Case, imports are projected to decline from a rate of 60% imported today to 44.5% in 2030 and then increase again to 53% by 2050. In the scenarios, the decline in import share is greater. The greatest reduction is achieved in the (P)HEV & Ethanol scenario: imports drop to as low as 38% in 2035. Nevertheless, in that scenario import levels are 46% by 2050, while the Mixed and H2 Success scenarios have import levels of 47% and 50%, respectively, by 2050.

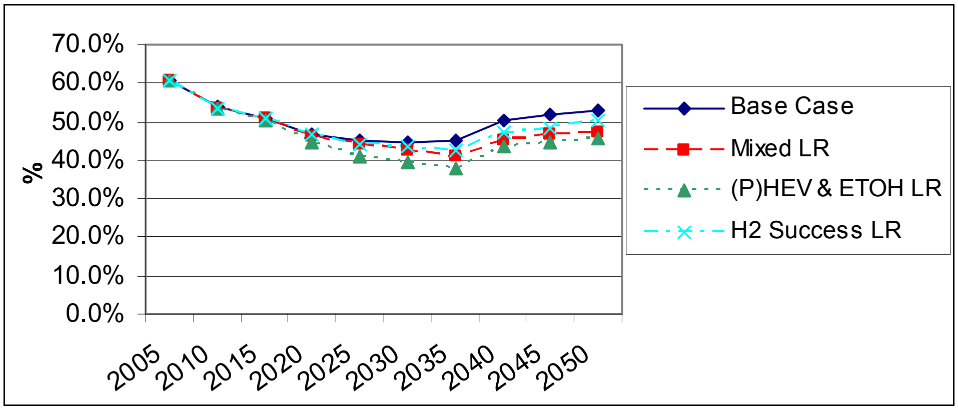

FIGURE 7-8 Net Import Share of Product Supplied (Literature Review, No Subsidies)

7.1.7 Total U.S. CO_2 Emissions

Table 7-4 and Figure 7-9 present total U.S. emissions of $CO_2$for the Base Case and the three scenarios. (These are the total CO_2 emissions for the U.S. economy; other greenhouse gas emissions are not included.) The Base Case CO_2 emissions are estimated to be 60% higher in 2050 than in 2005. That finding is consistent with the projected increase in U.S. energy use in the Base Case (not shown). The scenarios reduce the total CO_2 emissions in that year by about 3%–4%.

7.1.8 Gasoline Price

Table 7-4 and Figure 7-10 present the gasoline prices estimated for the Base Case and the reductions that occur in these prices with the scenarios. The gasoline prices of the Base Case are consistent with the world oil price of the AEO 2007 High Oil Price Case extended to 2050. As discussed in Section 5.4, oil prices in 2008 were higher than those of the Base Case and, by extension, gasoline prices in 2008 were higher than those shown here for the Base Case. However, the relative prices of the scenarios are important. From that perspective, gasoline prices are lower in all the scenarios, with those of the (P)HEV & Ethanol scenario being the lowest (about 12% lower than the Base Case in 2050).

These gasoline price reductions cannot be applied directly to the Base Case world oil price to estimate the world oil prices of the scenarios. The reduced gasoline demand of the scenarios will alter the refinery mix and potentially the markup currently used for gasoline. However, the gasoline price reductions estimated for the scenarios imply that the scenarios may also lead to reductions in world oil price.

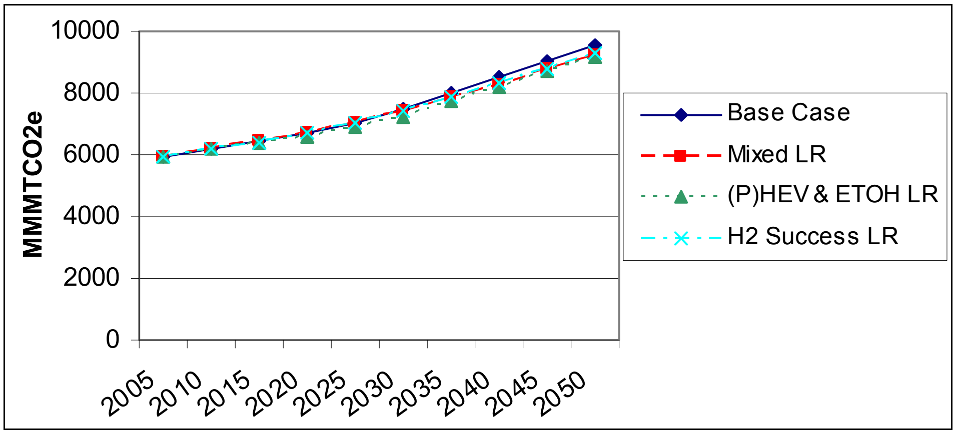

FIGURE 7-9 U.S. CO_2 Emissions (Literature Review, No Subsidies)

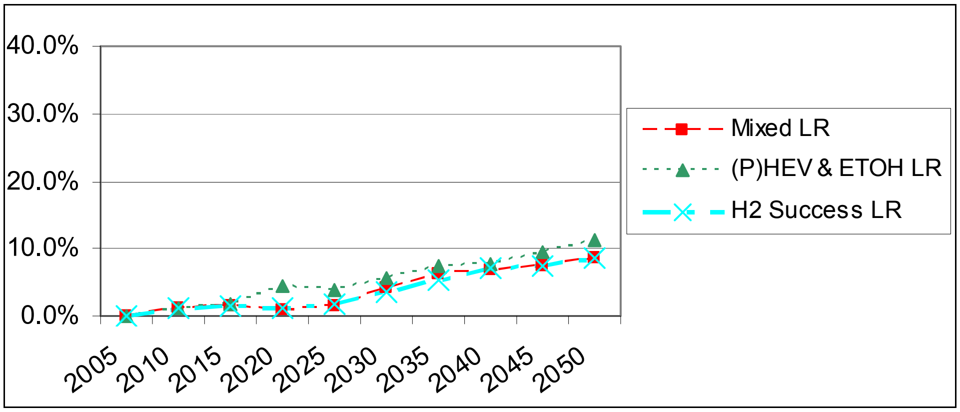

FIGURE 7-10 Gasoline Price Reduction from Base Case (Literature Review, No Subsidies)

7.1.9 Concluding Remarks about Impacts of Scenarios with "Literature Review" Vehicle Prices and No Subsidies

These scenarios with "literature review" vehicle prices lead to only modest reductions in U.S. and LV oil use, U.S. liquid fuel imports, U.S. and full-fuel-cycle LV CO_2 emissions, and gasoline prices. These reductions are limited by the relatively modest market penetration of advanced vehicles, which is directly related to (or caused by) the high estimated prices for these vehicles in the scenarios.

7.2 SCENARIOS WITH "PROGRAM GOALS" VEHICLE PRICES AND NO SUBSIDIES

The scenarios with vehicle prices at the "program goals" level use vehicle price estimates that reflect achievement of DOE vehicle program goals. The vehicle price estimates are the same across the three scenarios.

7.2.1 Vehicle Market Penetration

Table 7-5 presents shares of vehicle sales for the Base Case and three scenarios. As with the "Literature Review, No Subsidies" versions of the scenarios, the estimates are weighted: they represent the combined car and LT sales totals of each technology as a percentage of total LV sales. Figures 7-11 and 7-12 compare the weighted shares of total sales in the years 2030 and 2050. Table 7-6 presents shares of vehicle stock by vehicle technology for the Base Case and three scenarios.

TABLE 7-5 Weighted Shares of Vehicle Sales in Base Case and Scenarios Using Program Goals Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	91.3%	82.2%	72.1%	65.3%	56.2%	52.2%
Adv Conv Gasoline	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	2.1%	3.3%	5.6%	9.5%	15.1%	16.1%
Ethanol-Flex Fuel ICE	3.8%	10.0%	9.5%	8.9%	9.1%	11.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	1.0%	2.0%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%
Electric-Gasoline Hybrid	1.4%	4.4%	11.6%	14.2%	18.0%	18.0%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	1.2%	0.0%	0.1%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Program Goals Prices						
Conventional Gasoline ICE	91.3%	56.9%	18.6%	15.5%	13.3%	9.1%
Adv Conv Gasoline	0.3%	6.4%	22.8%	21.5%	19.0%	13.5%
TDI Diesel ICE	2.1%	9.0%	9.0%	9.2%	8.1%	7.0%
Ethanol-Flex Fuel ICE	3.8%	16.0%	8.9%	8.0%	8.7%	5.2%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	2.2%	3.0%	4.2%
Electric-Diesel Hybrid	0.0%	0.0%	12.2%	11.2%	9.9%	7.9%
Electric-Gasoline Hybrid	1.4%	11.6%	28.2%	31.4%	32.6%	27.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.1%	0.6%	3.2%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.9%	4.7%	22.4%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Program Goals Prices						
Conventional Gasoline ICE	91.3%	56.9%	18.7%	16.6%	14.0%	9.6%
Adv Conv Gasoline	0.3%	6.4%	22.7%	21.9%	19.4%	14.1%
TDI Diesel ICE	2.1%	9.1%	8.3%	7.3%	7.8%	6.4%
Ethanol-Flex Fuel ICE	3.8%	16.0%	10.1%	10.1%	8.2%	6.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	2.9%	4.6%	6.1%
Electric-Diesel Hybrid	0.0%	0.0%	11.7%	9.5%	9.2%	7.2%
Electric-Gasoline Hybrid	1.4%	11.6%	28.1%	30.8%	31.7%	26.9%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.1%	0.5%	3.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.8%	4.5%	20.7%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-5 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Program Goals Prices						
Conventional Gasoline ICE	91.3%	56.9%	18.5%	14.2%	10.5%	7.5%
Adv Conv Gasoline	0.3%	6.4%	22.6%	19.3%	14.3%	10.4%
TDI Diesel ICE	2.1%	9.1%	8.7%	8.4%	6.5%	5.2%
Ethanol-Flex Fuel ICE	3.8%	16.0%	8.7%	7.4%	9.3%	6.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	2.2%	3.0%	4.0%
Electric-Diesel Hybrid	0.0%	0.0%	12.0%	10.1%	7.9%	6.2%
Electric-Gasoline Hybrid	1.4%	11.6%	28.0%	28.4%	25.6%	21.6%
Fuel Cell PHEV	0.0%	0.0%	0.0%	1.1%	6.5%	5.7%
Fuel Cell Hydrogen	0.0%	0.0%	1.3%	8.8%	16.6%	32.5%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
H2 without Jump Start Program Goals Prices						
Conventional Gasoline ICE	91.3%	56.9%	18.6%	15.5%	12.6%	9.3%
Adv Conv Gasoline	0.3%	6.4%	22.8%	21.4%	18.5%	14.1%
TDI Diesel ICE	2.1%	9.1%	8.8%	9.2%	8.3%	6.7%
Ethanol-Flex Fuel ICE	3.8%	16.0%	8.9%	8.1%	11.0%	8.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	2.5%	3.9%	5.3%
Electric-Diesel Hybrid	0.0%	0.0%	12.1%	11.2%	10.0%	7.9%
Electric-Gasoline Hybrid	1.4%	11.6%	28.3%	31.2%	32.1%	28.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.1%	0.3%	2.2%
Fuel Cell Hydrogen	0.0%	0.0%	0.2%	0.8%	3.4%	17.2%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
LT Share of Total Sales						
Base Case	50.1%	43.2%	44.9%	48.6%	51.4%	54.0%
Mixed Program Goals Prices	50.1%	43.6%	45.3%	49.0%	52.3%	55.1%
(P)HEV & Ethanol Program Goals Prices	50.1%	43.6%	45.9%	50.0%	52.5%	55.2%
H2 Success Program Goals Prices	50.1%	43.6%	45.3%	49.0%	52.3%	55.2%
H2 without Jump Start Program Goals Prices	50.1%	43.6%	45.3%	49.0%	52.3%	55.2%
Total LV sales (millions)	16.2	16.6	18.2	20.2	21.9	23.5

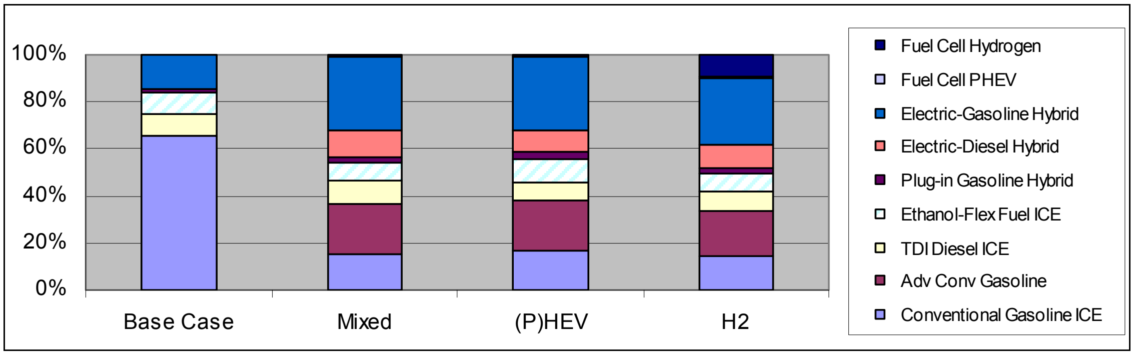

FIGURE 7-11 2030 Sales Shares (Program Goals, No Subsidies Cases)

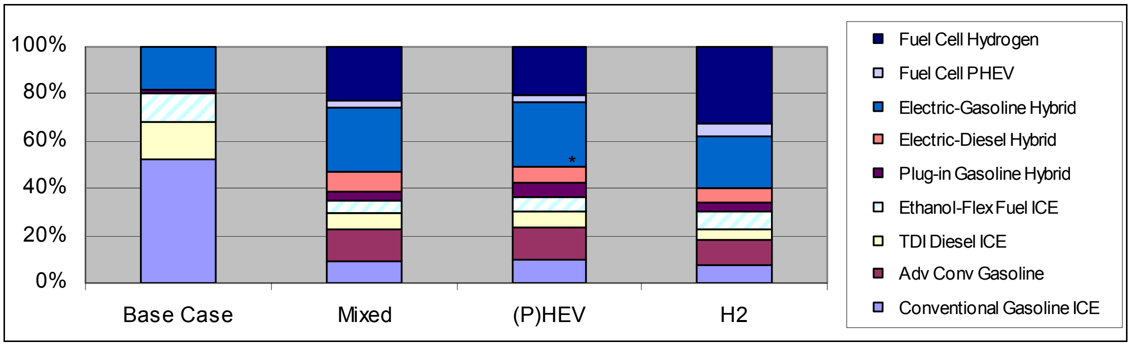

FIGURE 7-12 2050 Sales Shares (Program Goals, No Subsidies Cases)

A few key points are as follows:

1. As before, the market penetration of the various technologies is very similar when comparing the Mixed and (P)HEV & Ethanol scenarios. Although the (P)HEV & Ethanol scenario might have a few more plug-ins and conventional FFVs and correspondingly fewer diesels, the differences are small, both in sales and vehicle stock. In both scenarios, about 1% of sales in 2030 are of FCVs; however, by 2050, FCVs make up 21% of sales and 7%–8% of the stock. FCVs, gasoline HEVs, and ACVs make up 50% of sales by 2050. Gasoline plug-ins (PHEV40s) achieve no higher than 6% of sales by 2050 in these scenarios.

2. In the H2 Success scenario, more FCVs are sold: FCVs are 9% of sales in 2030 and 32% of sales in 2050. By 2050, FCVs are 20% of the LV stock. These percentages would be quite a bit lower if it were not for the “jump start” given to H_2 stations discussed in Section 6.7. (In fact, Table 7-5 indicates that the share of FCV sales without the “jump start” would be slightly lower than in the Mixed and (P)HEV & Ethanol scenarios.)

3. All the scenarios include plug-in FCVs: these vehicles did not penetrate the market in the “Literature Review, No Subsidies” version of this scenario. While the share is not high, it is there: 3% of sales by 2050 in the Mixed and (P)HEV & Ethanol scenarios and 6% in the H2 Success scenario (which is higher than the gasoline PHEVs in that scenario).

As discussed in Section 7.1.1, in spite of differences in assumptions about fuel prices between the scenarios, the Mixed, (P)HEV & Ethanol, and H2 Success “with no jump start of H_2 stations” scenarios show little difference from one another in terms of the market penetration of advanced vehicle technologies. This result again illustrates the point that vehicle price is the key determinant of vehicle choice in the NEMS-MP model. However, providing a “jump start” to H_2 stations does increase market penetration of FCVs and plug-in FCVs.

Because of the greater market penetration of advanced vehicle technologies with vehicle price estimates based on “program goals,” we should expect greater energy, oil, and CO_2 impacts than estimated with the “literature review” vehicle price assumptions. These impacts are discussed next.

TABLE 7-6 Weighted Shares of Vehicle Stock in Base Case and Scenarios Using Program Goals Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	95.6%	92.1%	83.0%	73.6%	65.1%	57.9%
Adv Conv Gasoline	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
TDI Diesel ICE	1.7%	2.2%	3.6%	6.0%	10.0%	13.8%
Ethanol-Flex Fuel ICE	1.8%	3.9%	7.8%	8.9%	9.1%	9.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	1.1%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
Electric-Gasoline Hybrid	0.2%	1.2%	5.0%	10.1%	14.1%	16.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.5%	0.5%	0.3%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Program Goals Prices						
Conventional Gasoline ICE	95.6%	88.4%	50.5%	26.8%	17.8%	13.4%
Adv Conv Gasoline	0.1%	0.7%	14.2%	20.2%	20.7%	18.2%
TDI Diesel ICE	1.7%	3.0%	7.0%	8.4%	8.7%	8.2%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.0%	8.9%	8.5%	7.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.9%	2.1%	3.2%
Electric-Diesel Hybrid	0.0%	0.0%	4.1%	9.1%	10.3%	9.6%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	25.3%	30.3%	31.1%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.2%	1.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.3%	1.4%	7.7%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Program Goals Prices						
Conventional Gasoline ICE	95.6%	88.4%	50.6%	27.0%	18.6%	14.1%
Adv Conv Gasoline	0.1%	0.7%	14.2%	20.2%	20.9%	18.7%
TDI Diesel ICE	1.7%	3.1%	6.9%	7.6%	7.6%	7.5%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.3%	10.3%	9.6%	8.1%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	1.1%	2.9%	4.6%
Electric-Diesel Hybrid	0.0%	0.0%	4.0%	8.4%	9.3%	8.8%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	25.1%	29.7%	30.3%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.3%	1.3%	6.8%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-6 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Program Goals Prices						
Conventional Gasoline ICE	95.6%	88.4%	50.5%	26.2%	16.1%	11.1%
Adv Conv Gasoline	0.1%	0.7%	14.2%	19.4%	17.9%	14.3%
TDI Diesel ICE	1.7%	3.1%	7.0%	8.1%	7.7%	6.4%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.0%	8.6%	8.6%	8.3%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.9%	2.1%	3.0%
Electric-Diesel Hybrid	0.0%	0.0%	4.1%	8.7%	9.1%	7.7%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	24.3%	26.5%	24.7%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.2%	2.7%	4.9%
Fuel Cell Hydrogen	0.0%	0.0%	0.2%	3.5%	9.4%	19.7%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
H2 without Jump Start Program Goals Prices						
Conventional Gasoline ICE	95.7%	88.6%	50.7%	26.8%	17.5%	13.1%
Adv Conv Gasoline	0.1%	0.7%	14.1%	20.2%	20.4%	17.9%
TDI Diesel ICE	1.7%	3.0%	7.0%	8.4%	8.7%	7.8%
Ethanol-Flex Fuel ICE	1.8%	4.9%	9.0%	8.8%	9.4%	9.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	1.0%	2.5%	3.9%
Electric-Diesel Hybrid	0.0%	0.0%	4.1%	9.1%	10.3%	9.4%
Electric-Gasoline Hybrid	0.2%	2.2%	14.7%	25.2%	30.0%	30.6%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.1%	0.7%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.4%	1.2%	6.6%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

7.2.2 LV Energy Use and Oil Use

Table 7-7 presents LV energy use and oil use in the Base Case and the three scenarios. All three scenarios save energy compared to the Base Case. Nevertheless, the savings seem modest: that is, just 14%–19% less than the 2050 Base Case levels (also see Figure 7-13).

Substantial reductions are achieved in LV oil use (also see Figure 7-14). LV oil use in the scenarios never exceeds the year 2005 Base Case LV oil use of 8.7 mbpd; it remains essentially at approximately 8 mbpd through 2050. By 2030, the Mixed and H2 Success scenarios save approximately 1 mbpd relative to the Base Case, while the (P)HEV & Ethanol scenario saves 1.5 mbpd. By 2050, the range in savings is 3.7–4.1 mbpd for all three scenarios, with the H2 Success scenario having the greatest savings in that year. The (P)HEV & Ethanol scenario has the greatest cumulative savings in LV oil use through 2050 (1.4 mbpd for the full 2005–2050 time period), although savings realized in the other two scenarios are close behind.

TABLE 7-7 LV Energy Use, Oil Use, and Full-Fuel-Cycle CO$_2$ Emissions of Base Case and Scenarios Using Program Goals Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
LV Specific Results						
Annual						
LV Energy Use (quads)						
Base Case	16.95	17.15	17.38	18.90	21.70	25.01
Mixed Program Goals Prices	16.95	17.09	17.01	17.52	18.89	20.79
(P)HEV & Ethanol Program Goals Prices	16.95	17.08	17.02	17.92	19.78	21.46
H2 Success Program Goals Prices	16.95	17.09	17.01	17.42	18.82	20.25
Savings (%)						
Mixed Program Goals Prices	0.0%	0.3%	2.1%	7.3%	13.0%	16.9%
(P)HEV & Ethanol Program Goals Prices	0.0%	0.4%	2.1%	5.2%	8.9%	14.2%
H2 Success Program Goals Prices	0.0%	0.4%	2.1%	7.8%	13.3%	19.0%
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Program Goals Prices	8.67	8.33	8.24	8.27	8.13	8.33
(P)HEV & Ethanol Program Goals Prices	8.67	8.33	8.07	7.73	8.10	8.15
H2 Success Program Goals Prices	8.67	8.33	8.30	8.32	8.27	7.98
Savings						
Mixed Program Goals Prices	0.0	0.1	0.2	0.9	2.4	3.7
(P)HEV & Ethanol Program Goals Prices	0.0	0.1	0.4	1.5	2.4	3.9
H2 Success Program Goals Prices	0.0	0.1	0.2	0.9	2.3	4.1
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Program Goals Prices	1419	1431	1477	1486	1538	1611
(P)HEV & Ethanol Program Goals Prices	1419	1438	1434	1356	1516	1594
H2 Success Program Goals Prices	1419	1429	1489	1510	1568	1535
Reductions (%)						
Mixed Program Goals Prices	0.0%	0.6%	2.3%	8.3%	18.7%	24.2%
(P)HEV & Ethanol Program Goals Prices	0.0%	0.2%	5.1%	16.3%	19.9%	25.0%
H2 Success Program Goals Prices	0.0%	0.7%	1.5%	6.8%	17.2%	27.7%
Cumulative						
Cumulative Oil Savings	***Million Barrels***			***Average MBPD***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Program Goals Prices	2,619	17,638	20,257	0.3	2.4	1.2
(P)HEV & Ethanol Program Goals Prices	4,343	19,093	23,436	0.5	2.6	1.4
H2 Success Program Goals Prices	2,358	17,742	20,099	0.2	2.4	1.2
Cumulative LV full fuel cycle CO2 reductio	***MMTCO2E***			***Percent***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Program Goals Prices	968	6,909	7,877	2.5%	18.2%	10.2%
(P)HEV & Ethanol Program Goals Prices	2,043	7,796	9,840	5.2%	20.5%	12.8%
H2 Success Program Goals Prices	809	6,954	7,763	2.1%	18.3%	10.1%

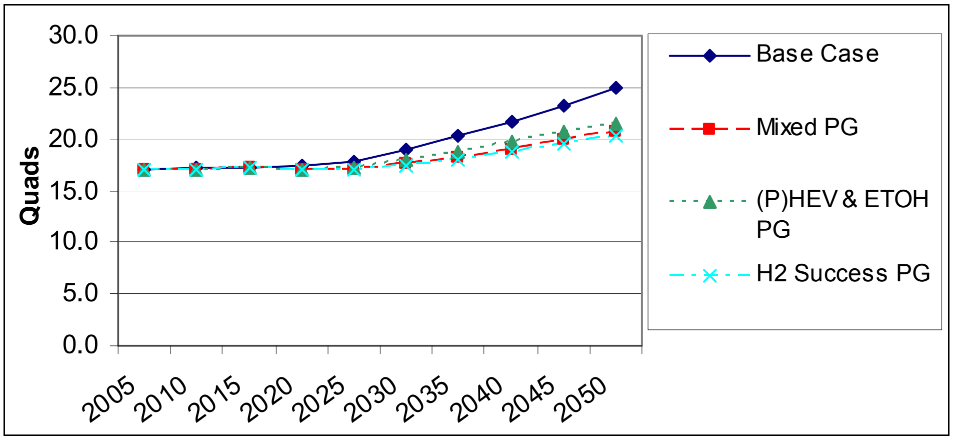

FIGURE 7-13 LV Energy Use (Program Goals, No Subsidies)

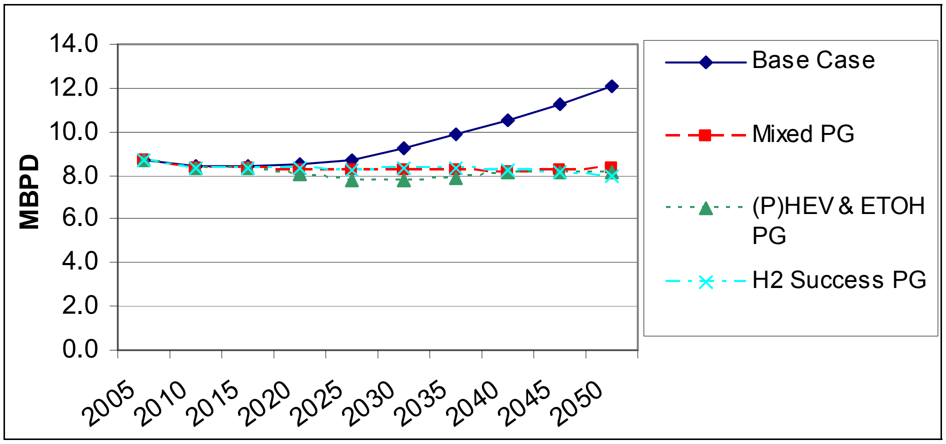

FIGURE 7-14 LV Oil Use (Program Goals, No Subsidies)

7.2.3 LV Full-Fuel-Cycle CO_2 Emissions

Table 7-7 and Figure 7-15 present LV full-fuel-cycle CO_2 emissions in the Base Case and the three scenarios. Substantial reductions are achieved: emissions are 24%–28% lower than Base Case levels by 2050. Still, the 2050 emissions are at best 8% higher (in the H2 Success scenario) than 2005 emissions. As with oil use, the (P)HEV & Ethanol scenario has the greatest cumulative reduction in LV full-fuel-cycle CO_2 emissions through 2050, although once again, reductions achieved in the other two scenarios are close behind the (P)HEV & Ethanol results.

7.2.4 Ethanol Use

Table 7-8 and Figure 7-16 present total ethanol use in the Base Case and the three scenarios. Ethanol volumes are lower than in the “Literature Review, No Subsidies” versions of the scenarios, in part because of the substantially increased market penetration of FCVs, which do not use ethanol. Ethanol use in the H2 Success scenario is now similar to that of the Base Case.

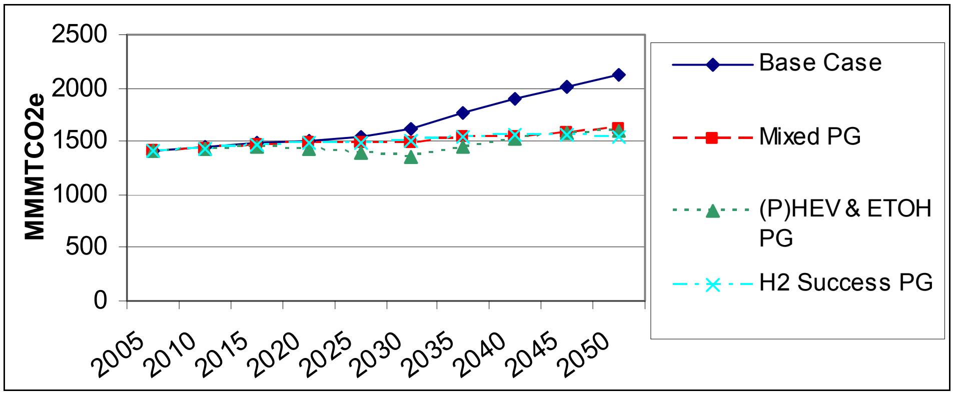

FIGURE 7-15 LV Full-Fuel-Cycle CO_2 Emissions (Program Goals, No Subsidies)

Both the Mixed and (P)HEV & Ethanol scenarios still eventually exceed the total volumes required under the RFS by relying on ethanol alone. The latter scenario ultimately uses close to 60 billion gallons of ethanol/year.

7.2.5 U.S. Liquid Fuels Supply (Excluding Ethanol)

Table 7-8 and Figure 7-17 present U.S. liquid fuels supply estimates for the Base Case and three scenarios. It bears repeating that these estimates might be viewed as surrogates for petroleum supply as we have excluded the ethanol supply that is included in the direct NEMS-MP output. However, liquids from coal are included and are not insignificant in the later years in the Base Case and all the scenarios.

U.S. liquid fuels (less ethanol) use will grow by about 8 mbpd from today to 2050 in the Base Case. The scenarios reduce that growth by about 4 mbpd by 2050 — almost the same reductions as are achieved for LV oil use alone.

7.2.6 Net Import Share of Product Supplied

Table 7-8 and Figure 7-18 present the percentages of liquid fuel products that are imported. All possible sources of liquid fuel are included: that is, ethanol is included in the calculations. The shares of imported liquid fuels are only just slightly lower than those estimated for the "Literature Review, No Subsidies" versions of the scenarios: that is, instead of imports ranging from 45.8% to 50.2% in 2050 in the "Literature Review, No Subsidies" cases, imports range from 44.6% to 49% in the "Program Goals, No Subsidies" cases.

TABLE 7-8 United States Total Energy, Oil, CO_2, and Gasoline Price Results for Base Case and Scenarios Using Program Goals Vehicle Prices without Subsidies

	2005	2010	2020	2030	2040	2050
U.S. Total Results						
Ethanol Use (Billion gallons)						
Base Case	4.0	12.6	14.3	15.8	19.2	24.0
Mixed Program Goals Prices	4.0	13.8	15.2	20.4	38.1	46.3
(P)HEV & Ethanol Program Goals Prices	4.0	13.8	19.3	37.3	49.3	59.0
H2 Success Program Goals Prices	4.0	13.8	13.9	14.8	22.2	26.8
RFS Standard (includes other fuels besides ethanol)	4.0	13.0	30.0	36.0	36.0	36.0
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Program Goals Prices	20.5	20.3	20.6	21.2	22.4	24.6
(P)HEV & Ethanol Program Goals Prices	20.5	20.3	20.4	20.7	22.3	24.5
H2 Success Program Goals Prices	20.5	20.3	20.7	21.3	22.6	24.3
Savings						
Mixed Program Goals Prices	0.0	0.1	0.3	1.1	2.6	3.8
(P)HEV & Ethanol Program Goals Prices	0.0	0.1	0.5	1.6	2.6	3.9
H2 Success Program Goals Prices	0.0	0.1	0.2	1.0	2.4	4.1
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Program Goals Prices	60.5%	53.5%	46.1%	42.3%	45.3%	46.8%
(P)HEV & Ethanol Program Goals Prices	60.5%	53.6%	44.8%	38.9%	43.9%	44.6%
H2 Success Program Goals Prices	60.5%	53.4%	46.7%	42.7%	46.8%	49.0%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Program Goals Prices	5945	6176	6666	7335	8175	9033
(P)HEV & Ethanol Program Goals Prices	5945	6182	6623	7205	8153	9016
H2 Success Program Goals Prices	5945	6174	6677	7359	8205	8958
Reductions (%)						
Mixed Program Goals Prices	0.0%	0.1%	0.5%	1.8%	4.2%	5.4%
(P)HEV & Ethanol Program Goals Prices	0.0%	0.0%	1.1%	3.5%	4.4%	5.6%
H2 Success Program Goals Prices	0.0%	0.2%	0.3%	1.5%	3.8%	6.2%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Program Goals Prices	2.33	2.59	2.84	2.99	2.99	3.28
(P)HEV & Ethanol Program Goals Prices	2.33	2.59	2.79	2.82	3.00	3.22
H2 Success Program Goals Prices	2.33	2.59	2.84	2.99	3.06	3.23
Reductions (%)						
Mixed Program Goals Prices	0.0%	1.2%	2.3%	5.1%	15.3%	16.5%
(P)HEV & Ethanol Program Goals Prices	0.0%	1.2%	4.3%	10.7%	15.1%	18.3%
H2 Success Program Goals Prices	0.0%	1.4%	2.3%	5.1%	13.4%	18.0%

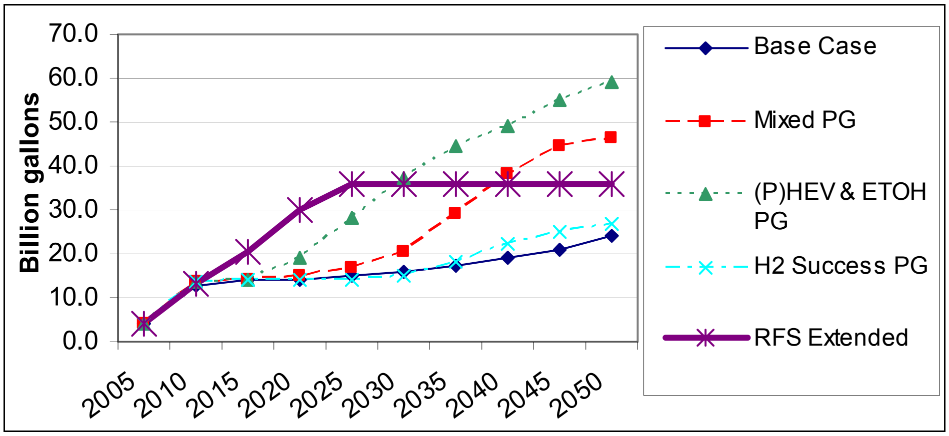

FIGURE 7-16 Ethanol Use (Program Goals, No Subsidies)

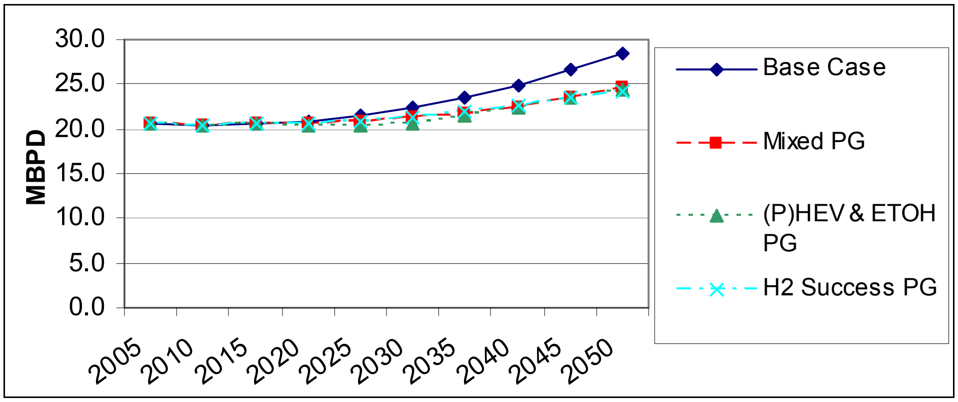

FIGURE 7-17 U.S. Liquid Fuels Supply Excluding Ethanol (Program Goals, No Subsidies)

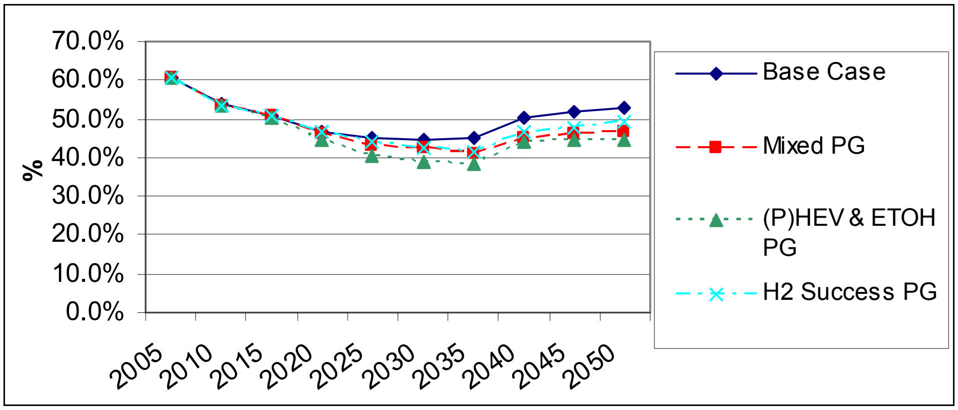

FIGURE 7-18 Net Import Share of Product Supplied (Program Goals, No Subsidies)

7.2.7 Total U.S. CO_2 Emissions

Table 7-8 and Figure 7-19 present total U.S. emissions of CO_2 for the Base Case and the three scenarios. The scenarios reduce the total CO_2 emissions by about 5%–6% from the Base Case by 2050.

7.2.8 Gasoline Price

Table 7-8 and Figure 7-20 present the gasoline prices estimated for the Base Case and scenarios. Not unexpectedly, gasoline prices are lower than the Base Case prices and lower than those in the "Literature Review, No Subsidies" versions of the scenarios. The gasoline prices of the (P)HEV & Ethanol scenario are the lowest over time of all the scenarios; however, by 2050, the gasoline price of the H2 Success scenario matches it, and both are 18% lower than the Base Case.

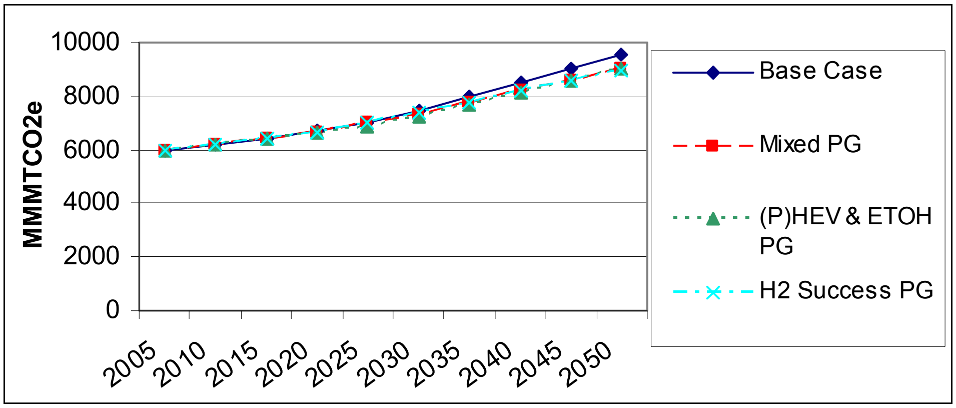

FIGURE 7-19 U.S. CO_2 Emissions (Program Goals, No Subsidies)

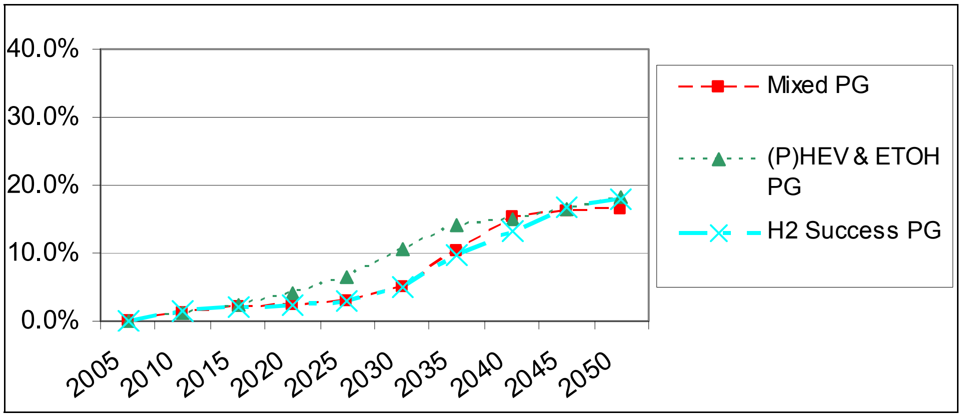

FIGURE 7-20 Gasoline Price Reduction from Base Case (Program Goals, No Subsidies)

7.2.9 Concluding Remarks about Impacts of Scenarios with "Program Goals" Vehicle Prices and No Subsidies

As with the "Literature Review, No Subsidies" versions of these scenarios, the "Program Goals, No Subsidies" cases clearly lead to reductions in total U.S. and LV oil use, U.S. imports of liquid fuels, total U.S. and full-fuel-cycle LV emissions of CO_2, and gasoline prices. The reductions are greater than with the "Literature Review, No Subsidies" cases. The fact that LV oil use and full-fuel-cycle CO_2 emissions might be held close to 2005 levels is significant. The fact that these results can be achieved with several technology mixes (i.e., each scenario being a mix of technologies) is also important. Nevertheless, it is clear that these "Program Goals, No Subsidies" versions of the scenarios are not doing much to reduce total U.S. CO_2 emissions.

7.3 SCENARIOS WITH SELECTED VEHICLE SUBSIDIES IN ADDITION TO "LITERATURE REVIEW" VEHICLE PRICES

7.3.1 Subsidies Used

One focus of this study is an evaluation of the impacts of reaching the vehicle market penetration goals set for the scenarios (first shown in Chapter 2, Table 2-1). Table 7-9 presents the goals for selected ATVs in the three scenarios and contrasts them with the market penetration levels actually achieved when the scenarios assume vehicle prices are at the "literature review" levels. As is obvious from Table 7-9, the "literature review" vehicle prices alone do not lead to achievement of the scenario market penetration goals. While Gasoline HEV market penetration is substantial for all three scenarios, the market penetration of PHEVs, FCVs, and fuel cell plug-ins is much lower than desired in all of the scenarios.

Therefore, using the NEMS-TSA model, we tested many subsidies in an effort to match the goals shown in the table. All the subsidies reduce the retail price of the targeted vehicles well below the "literature review" vehicle price estimates. All of the subsidies were assumed to start in 2015. The results of two sets of subsidy runs are also shown in Table 7-9; others are presented in Table 7-10. Our review of all of these runs indicates that substantial subsidies (e.g., $10,000 in 2015 that drops to $6,000 in 2030, a flat $7,500 subsidy throughout) for PHEVs and FCVs will be required for long periods of time if the scenario goals are to be achieved.

The first set of subsidies shown in Table 7-9 start with a $7,500 subsidy from 2015 to 2030, which then declines to $0 by 2050 for the key ATVs (i.e., PHEVs, FCVs, and/or fuel cell plug-ins) in each scenario. While market penetration for the key ATVs initially rises above the penetration with vehicle prices at the "literature review" level without subsidies, penetration backslides when the subsidies are slowly removed:

- In the Mixed scenario, PHEVs are 24% of sales by 2030 but are less than 1% by 2050, and FCVs are only 2% of sales by 2050 vs. a goal of 21%;

TABLE 7-9 Market Penetration of Key Technologies in Scenarios Using the Literature Review Vehicle Prices with and without Subsidies

							NEMS-TSA model runs					
				Results of full NEMS model run with NO subsidies			$7,500/vehicle subsidies through 2030 and then decline to $0 by 2050			$7,500/vehicle subsidies continue through 2050		
Mixed scenario	**Goals**			**Mixed without Subsidies**			**MPMixed41**			**MPMixed42**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies												
Gasoline HEVs	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
Diesel HEVs	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
PHEVs	NA	NA	NA	$0	$0	$0	$7,500	$7,500	$0	$7,500	$7,500	$7,500
FCVs	NA	NA	NA	$0	$0	$0	$7,500	$7,500	$0	$7,500	$7,500	$7,500
FC PHEVS	NA	NA	NA	$0	$0	$0	$7,500	$7,500	$0	$7,500	$7,500	$7,500
Sales %												
Gasoline HEVs	-	30.0%	15.0%	20.9%	27.6%	36.1%	21.02%	27.93%	35.31%	21.02%	28.29%	14.98%
Diesel HEVs	-	4.0%	6.0%	2.6%	5.8%	7.1%	2.58%	5.96%	7.18%	2.58%	6.04%	3.07%
PHEVs	-	16.8%	25.0%	0.0%	0.2%	0.8%	0.00%	23.63%	0.91%	0.00%	25.58%	27.89%
FCVs	-	0.0%	21.0%	0.0%	0.1%	0.2%	0.02%	1.22%	1.76%	0.02%	1.31%	38.62%
FC PHEVS	-	0.0%	9.0%	0.0%	0.0%	0.0%	0.00%	0.02%	0.08%	0.00%	0.01%	1.28%
FCVs & FC PHEVs combined		0.0%	30.0%	0.02%	0.1%	0.2%	0.02%	1.2%	1.8%	0.0%	1.3%	39.9%
PHEVs, FCVs & FC PHEVs combined		16.8%	55.0%	0.02%	0.3%	1.0%	0.02%	24.9%	2.7%	0.0%	26.9%	67.8%
(P)HEV & Ethanol scenario	**Goals**			**(P)HEV & ETOH without subsidies**			**MPEthPHEV25**			**MPEthPHEV26**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies												
Gasoline HEVs	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
PHEVs	NA	NA	NA	$0	$0	$0	$7,500	$7,500	$0	$7,500	$7,500	$7,500
Sales %												
Gasoline HEVs	-	40.0%	40.0%	20.9%	27.3%	35.6%	21.01%	21.97%	35.57%	21.01%	21.92%	12.50%
PHEVs	-	25.0%	50.0%	0.0%	0.3%	1.2%	0.00%	31.69%	1.34%	0.00%	34.26%	62.75%
Gasoline HEVs and PHEVs combined		65.0%	90.0%	20.94%	27.6%	36.7%	21.01%	53.7%	36.9%	21.0%	56.2%	75.2%
All flex fuel vehicles (includes GHEVs, PHEVs, ACVs and conventional FFs)		85.0%	97.0%	60.9%	66.2%	69.5%	60.99%	77.23%	69.54%	60.99%	78.30%	87.28%
H2 Success scenario	**Goals**			**H2 Success without subsidies**			**MPMixH2.19**			**MPMixH2.20**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies												
FCVs	NA	NA	NA	$0	$0	$0	$7,500	$7,500	$0	$7,500	$7,500	$7,500
FC PHEVS	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
Sales %												
FCVs	-	10.3%	76.0%	0.0%	1.1%	2.3%	0.02%	27.97%	8.15%	0.02%	32.23%	63.63%
FC PHEVS	-	0.0%	0.0%	0.0%	0.0%	0.1%	0.00%	0.00%	0.28%	0.00%	0.00%	0.00%
FCVs and FC PHEVs combined		10.3%	76.0%	0.02%	1.1%	2.4%	0.02%	28.0%	8.4%	0.0%	32.2%	63.6%

NA = Not applicable
- = don't have

TABLE 7-10 Market Penetration of Key Technologies in Scenarios Using the Literature Review Vehicle Prices with and without Subsidies: Additional NEMS-TSA Model Runs

Selected runs in which subsidies continue through 2050

Mixed scenario	**Goals**			**MPMixed38**			**MPMixed39**			**MPMixed40**			**MPMixed37**			**MPMixed27**			**MPMixed26**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies																					
Gasoline HEVs	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,000	$700	$500
Diesel HEVs	NA	NA	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,000	$700	$500
PHEVs	NA	NA	NA	$10,000	$6,000	$6,000	$10,000	$6,000	$6,000	$10,000	$6,000	$6,000	$10,000	$6,000	$6,000	$10,000	$6,000	$4,000	$5,000	$4,000	$2,000
FCVs	NA	NA	NA	$10,000	$7,000	$7,000	$10,000	$6,500	$6,500	$10,000	$6,250	$6,250	$10,000	$6,000	$6,000	$10,000	$6,000	$4,000	$8,000	$6,000	$2,000
FC PHEVS	NA	NA	NA	$10,000	$7,000	$7,000	$10,000	$6,500	$6,500	$10,000	$6,250	$6,250	$10,000	$6,000	$6,000	$10,000	$6,000	$4,000	$8,000	$6,000	$2,000
Sales %																					
Gasoline HEVs	-	30.0%	15.0%	-	26.9%	13.5%	-	27.0%	15.2%	-	27.0%	16.7%	-	27.1%	20.1%	-	27.0%	26.2%	-	32.3%	37.6%
Diesel HEVs	-	4.0%	6.0%	-	5.7%	2.8%	-	5.7%	3.2%	-	5.7%	3.4%	-	5.7%	4.1%	-	5.7%	5.3%	-	6.6%	7.6%
PHEVs	-	16.8%	25.0%	-	18.6%	18.9%	-	18.6%	21.6%	-	18.7%	23.9%	-	18.7%	29.1%	-	18.2%	17.3%	-	4.9%	3.7%
FCVs	-	0.0%	21.0%	-	1.6%	44.6%	-	1.3%	38.0%	-	1.1%	32.5%	-	1.0%	19.7%	-	1.0%	8.8%	-	1.0%	3.2%
FC PHEVS	-	0.0%	9.0%	-	0.0%	1.5%	-	0.0%	1.3%	-	0.0%	1.1%	-	0.0%	0.7%	-	0.0%	0.3%	-	0.0%	0.1%
FCVs & FC PHEVs combined		0.0%	30.0%		1.6%	46.1%		1.3%	39.3%		1.1%	33.6%		1.0%	20.4%		1.0%	9.1%		1.1%	3.3%
PHEVs, FCVs & FC PHEVs combined		16.8%	55.0%		20.2%	65.0%		19.9%	60.9%		19.8%	57.5%		19.7%	49.5%		19.2%	26.4%		6.0%	7.0%

(P)HEV & Ethanol scenario	**Goals**			**MPEthPHEV22**			**MPEthPHEV23**			**MPEthPHEV24**			**MPEthPHEV17**			**MPEthPHEV13**			**MPEthPHEV14**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies																					
Gasoline HEVs	NA	NA	NA	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$4,000	$3,500	$3,000	$0	$0	$0	$0	$0	$0
PHEVs	NA	NA	NA	$10,000	$9,000	$9,000	$10,000	$8,500	$8,500	$10,000	$8,125	$8,125	$10,000	$8,125	$7,500	$10,000	$8,000	$6,000	$8,000	$6,000	$5,000
Sales %																					
Gasoline HEVs	-	40.0%	40.0%	-	36.4%	18.9%	-	37.9%	20.9%	-	39.2%	22.9%	-	49.6%	33.2%	-	22.1%	14.7%	-	22.3%	18.0%
PHEVs	-	25.0%	50.0%	-	37.4%	66.6%	-	33.6%	62.5%	-	30.6%	58.9%	-	24.1%	46.8%	-	38.2%	50.0%	-	23.7%	38.6%
Gasoline HEVs and PHEVs combined		65.0%	90.0%		73.8%	85.5%		71.5%	83.4%		69.8%	81.8%		73.7%	79.9%		60.3%	64.7%		46.1%	56.6%
All flex fuel vehicles (includes GHEVs, PHEVs, ACVs and conventional FFs)		85.0%	97.0%		87.8%	92.7%		86.9%	91.8%		86.2%	91.1%		88.0%	90.4%		79.9%	82.7%		74.2%	79.0%

H2 Success scenario	**Goals**			**MPMixH2.18**			**MPMixH2.11**			**MPMixH2.17**			**MPMixH2.16**			**MPMixH2.10**			**MPMixH2.15**		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Subsidies																					
FCVs	NA	NA	NA	$10,000	$10,000	$10,000	$10,000	$8,000	$6,000	$9,000	$9,000	$9,000	$8,000	$8,000	$8,000	$8,000	$6,000	$2,000	$3,000	$5,000	$10,000
FC PHEVS	NA	NA	NA	$10,000	$10,000	$10,000	$10,000	$8,000	$6,000	$9,000	$9,000	$9,000	$8,000	$8,000	$8,000	$8,000	$6,000	$2,000	$3,000	$5,000	$10,000
Sales %																					
FCVs	-	10.3%	76.0%	-	65.9%	78.6%	-	48.6%	48.9%	-	57.3%	72.9%	-	40.9%	65.8%	-	14.2%	16.6%	-	8.6%	78.4%
FC PHEVS	-	0.0%	0.0%	-	0.4%	2.4%	-	0.4%	1.6%	-	0.4%	2.3%	-	0.8%	2.1%	-	1.0%	0.6%	-	0.1%	2.4%
FCVs and FC PHEVs combined		10.3%	76.0%		66.3%	81.1%		49.0%	50.5%		57.8%	75.2%		41.6%	67.9%		15.2%	17.2%		8.8%	80.9%

NA = Not applicable
\- = don't have

- In the (P)HEV & Ethanol scenario, PHEVs are 32% of sales by 2030 but drop to 1.3% by 2050;

- In the H2 Success scenario, FCVs are 28% of sales in 2030 but drop to 8% by 2050.

The second set of subsidies shown in Table 7-9 maintains the $7,500 per vehicle subsidy from 2015 through 2050 for the key ATVs in each scenario. In these runs, the market penetration of PHEVs, FCVs, and fuel cell plug-ins continues to grow through 2050. By 2050:

- In the Mixed scenario, PHEVs, FCVs, and plug-in fuel cell vehicles are 68% of sales, which is greater than the 55% goal;

- In the (P)HEV & Ethanol scenario, PHEVS are 63% of sales, which is greater than the 50% goal; and

- In the H2 Success scenario, FCVs are 64% of sales, which is a little lower than the goal of 76%.

We use the second set of subsidies in the following analysis because (1) the market penetration results are similar to what we hoped to obtain (though they change slightly in the full NEMS-MP runs) and (2) they are "fair" (i.e., all the technologies of greatest interest receive the same dollar-per-vehicle subsidy). Nevertheless, we need to reiterate that the vehicle subsidies are just "examples." Clearly, no one envisions maintaining significant subsidies on the order of thousands of dollars per vehicle for 35 years. However, the subsidies are indicative of the vehicle price reductions that the NEMS-MP model suggests will need to be achieved in order to reach the high market penetration of advanced vehicle technologies desired in the scenarios (all else being equal).

Table 7-11 illustrates the effect of the subsidies on the incremental prices input to NEMS-MP when using the medium car as an example. (The incremental prices of the subsidized vehicles are presented in italics in Table 7-11.)

7.3.2 Vehicle Market Penetration

Table 7-12 presents the sales shares for the Base Case and the three scenarios. Figures 7-21 and 7-22 show the shares for 2030 and 2050. There are slight differences in market penetration rates of the key ATVs between what is presented in Table 7-12 and what was projected by the NEMS-TSA model, as shown in Table 7-9. For example, instead of a 63.6% penetration rate for FCVs in the H2 Success scenario as projected by NEMS-TSA, the full NEMS-MP model run projects a rate of 59.3%. The bottom line, however, is that (1) the subsidies result in far greater penetration of ATVs in the three scenarios with subsidies than the same scenarios without subsidies and (2) as anticipated, the ATV penetration rates vary across scenarios.

TABLE 7-11 Incremental Vehicle Prices Used in Scenarios Assuming Literature Review Vehicle Prices including Prices with Subsidies: Medium Car (in 2005$)[1]

Mixed	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$1,951	$2,595	$3,086	$2,617	$2,370
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$5,257	$5,107	$4,956	$4,506	$4,205
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$2,343	$2,949	$3,556	$2,407	$1,833
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$531	$471	$410	$168	$47
Fuel Cell (hydrogen)	**2023**	**2028**	**2033**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$7,640	$7,273	$6,906	$6,393	$5,660
"LR with Subsidy"Incremental Price ($)	*$140*	*-$227*	*-$594*	*-$1,107*	*-$1,840*
FCV PHEV 40	**2025**	**2030**	**2035**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$12,240	$11,512	$10,783	$10,055	$8,598
"LR with Subsidy"Incremental Price ($)	*$4,740*	*$4,012*	*$3,283*	*$2,555*	*$1,098*
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$8,511	$8,051	$7,590	$6,484	$5,563
"LR with Subsidy"Incremental Price ($)	*$1,011*	*$551*	*$90*	*-$1,016*	*-$1,937*

(P)HEV & Ethanol	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$1,951	$2,595	$3,086	$2,617	$2,370
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$5,257	$5,107	$4,956	$4,506	$4,205
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$2,343	$2,949	$3,556	$2,407	$1,833
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$531	$471	$410	$168	$47
Fuel Cell (hydrogen)	**2023**	**2028**	**2033**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$7,640	$7,273	$6,906	$6,393	$5,660
FCV PHEV 40	**2025**	**2030**	**2035**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$12,240	$11,512	$10,783	$10,055	$8,598
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$8,511	$8,051	$7,590	$6,484	$5,563
"LR with Subsidy"Incremental Price ($)	*$1,011*	*$551*	*$90*	*-$1,016*	*-$1,937*

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[1] The incremental prices of the subsidized vehicles are presented in italics.

TABLE 7-11 (Cont.)

H2 Success	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$1,951	$2,595	$3,086	$2,617	$2,370
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$5,257	$5,107	$4,956	$4,506	$4,205
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$2,343	$2,949	$3,556	$2,407	$1,833
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$531	$471	$410	$168	$47
Fuel Cell (hydrogen)	**2017**	**2022**	**2027**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$9,211	$8,673	$8,135	$6,736	$5,660
"LR with Subsidy"Incremental Price ($)	*$1,711*	*$1,173*	*$635*	*-$764*	*-$1,840*
FCV PHEV 40	**2019**	**2024**	**2029**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$14,572	$13,608	$12,645	$10,525	$8,598
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Lit. Review"Incremental Price ($)	$8,511	$8,051	$7,590	$6,484	$5,563

[1] The incremental prices of the subsidized vehicles are presented in italics.

Some key points are as follows:

1. In the Mixed scenario, PHEVs and GHEVs make up more than 50% of sales by 2030. By 2050, these ATVs and FCVs account for nearly 80% of sales.

2. In the (P)HEV & Ethanol scenario, PHEVs and GHEVs again comprise 50% of sales by 2030, although there are more PHEVs than there are in the Mixed scenario. By 2050, PHEVs alone make up 60% of sales. Nearly 90% of all vehicles have flex fuel capability, which is important in this scenario if the ethanol goals of the scenario are to be met.

3. In the H2 Success scenario, FCVs account for one-third of sales by 2030 and for 60% by 2050.

As a result of the significant differences in sales by vehicle technology among the scenarios with subsidies, there are also significant differences in vehicle stock among the scenarios. Table 7-13 presents vehicle stock technology shares for the Base Case and the three scenarios with subsidies. By 2050, in the H2 Success scenario, about 50% of all vehicles on the road are FCVs. In the (P)HEV & Ethanol scenario, nearly one-half of the stock consists of PHEVs by 2050. There is more of a mix of technologies in the Mixed scenario: 24% of vehicles on the road are GHEVs, 28% are PHEVs, and 14% are FCVs.

TABLE 7-12 Weighted Shares of Vehicle Sales in Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Literature Review Vehicle Prices

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	91.3%	82.2%	72.1%	65.3%	56.2%	52.2%
Adv Conv Gasoline	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	2.1%	3.3%	5.6%	9.5%	15.1%	16.1%
Ethanol-Flex Fuel ICE	3.8%	10.0%	9.5%	8.9%	9.1%	11.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	1.0%	2.0%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%
Electric-Gasoline Hybrid	1.4%	4.4%	11.6%	14.2%	18.0%	18.0%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	1.2%	0.0%	0.1%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	91.3%	57.3%	23.0%	13.6%	11.0%	6.5%
Adv Conv Gasoline	0.3%	6.1%	25.0%	13.5%	10.3%	5.8%
TDI Diesel ICE	2.1%	8.9%	6.5%	4.0%	2.7%	1.5%
Ethanol-Flex Fuel ICE	3.8%	16.1%	10.5%	7.8%	6.6%	3.5%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	3.8%	25.5%	29.3%	28.4%
Electric-Diesel Hybrid	0.0%	0.0%	6.0%	6.0%	4.3%	2.3%
Electric-Gasoline Hybrid	1.4%	11.5%	25.2%	28.3%	26.1%	16.3%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.2%	1.1%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	1.3%	9.4%	34.6%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	91.3%	57.3%	22.7%	14.3%	12.0%	8.5%
Adv Conv Gasoline	0.3%	6.1%	24.3%	13.6%	11.2%	8.5%
TDI Diesel ICE	2.1%	8.9%	5.6%	3.2%	2.7%	2.5%
Ethanol-Flex Fuel ICE	3.8%	16.1%	13.6%	9.6%	7.5%	5.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	4.1%	33.2%	45.5%	60.2%
Electric-Diesel Hybrid	0.0%	0.0%	5.4%	4.1%	2.9%	2.0%
Electric-Gasoline Hybrid	1.4%	11.5%	24.2%	21.9%	18.2%	12.7%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-12 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	91.3%	57.3%	24.0%	15.5%	11.0%	8.4%
Adv Conv Gasoline	0.3%	6.1%	26.1%	16.8%	10.4%	8.1%
TDI Diesel ICE	2.1%	8.9%	7.0%	4.8%	2.4%	1.9%
Ethanol-Flex Fuel ICE	3.8%	16.1%	11.2%	8.7%	8.5%	6.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%
Electric-Diesel Hybrid	0.0%	0.0%	5.6%	3.7%	2.2%	1.9%
Electric-Gasoline Hybrid	1.4%	11.5%	23.6%	18.7%	14.3%	13.3%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	2.5%	31.6%	51.0%	59.3%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
LT Share of Total Sales						
Base Case	50.1%	43.2%	44.9%	48.6%	51.4%	54.0%
Mixed Lit. Review Prices with Subsidies	50.1%	43.6%	45.0%	48.9%	52.5%	55.5%
(P)HEV & Ethanol Lit. Review Prices with Subs	50.1%	43.6%	46.0%	49.8%	52.6%	55.4%
H2 Success Lit. Review Prices with Subsidies	50.1%	43.6%	45.0%	49.0%	52.7%	55.7%
Total LV sales (millions)	16.2	16.6	18.2	20.2	21.9	23.5

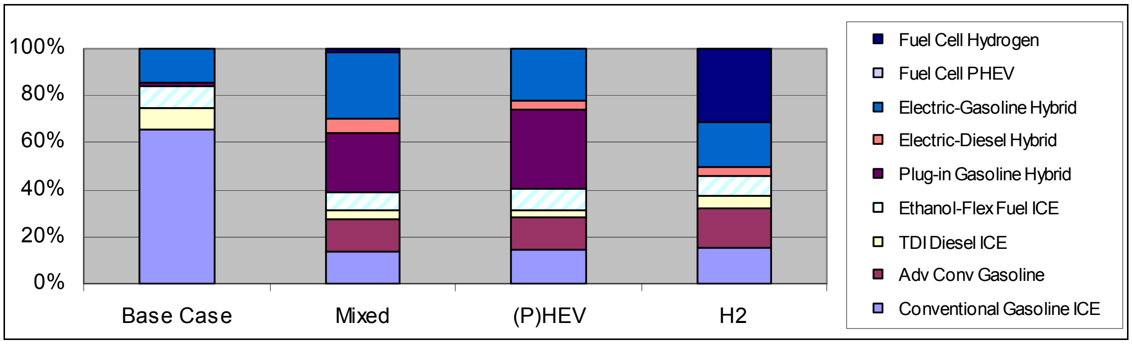

FIGURE 7-21 2030 Sales Shares (Literature Review with Subsidies Scenarios)

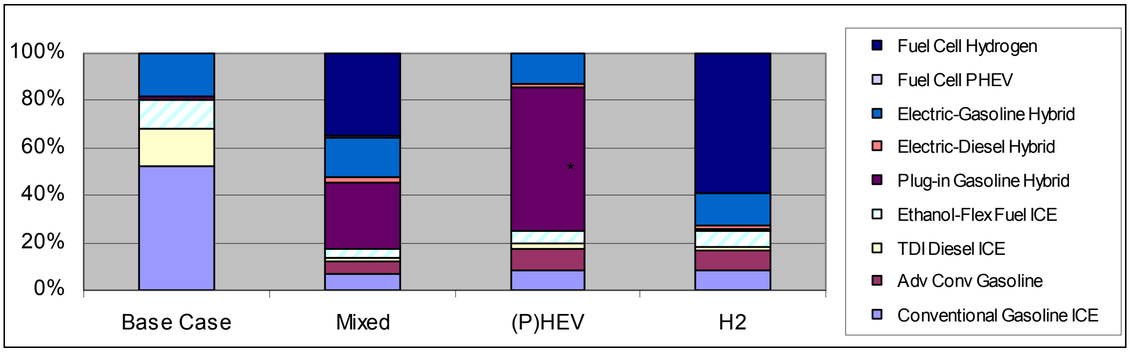

FIGURE 7-22 2050 Sales Shares (Literature Review with Subsidies Scenarios)

TABLE 7-13 Weighted Shares of Vehicle Stock in Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Literature Review Vehicle Prices

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	95.6%	92.1%	83.0%	73.6%	65.1%	57.9%
Adv Conv Gasoline	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
TDI Diesel ICE	1.7%	2.2%	3.6%	6.0%	10.0%	13.8%
Ethanol-Flex Fuel ICE	1.8%	3.9%	7.8%	8.9%	9.1%	9.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	1.1%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
Electric-Gasoline Hybrid	0.2%	1.2%	5.0%	10.1%	14.1%	16.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.5%	0.5%	0.3%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	52.9%	27.4%	16.6%	11.1%
Adv Conv Gasoline	0.1%	0.7%	15.0%	17.0%	13.8%	10.1%
TDI Diesel ICE	1.7%	3.0%	6.2%	5.3%	4.0%	2.8%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.0%	9.6%	8.1%	6.1%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.4%	11.5%	22.6%	28.0%
Electric-Diesel Hybrid	0.0%	0.0%	1.9%	5.0%	5.3%	4.1%
Electric-Gasoline Hybrid	0.2%	2.2%	13.4%	23.7%	26.8%	23.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.4%	2.7%	13.6%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	52.9%	27.4%	17.1%	12.2%
Adv Conv Gasoline	0.1%	0.7%	14.9%	16.7%	14.0%	11.2%
TDI Diesel ICE	1.7%	3.0%	6.0%	4.9%	3.5%	2.9%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.5%	11.0%	9.4%	7.5%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.4%	14.5%	31.0%	45.7%
Electric-Diesel Hybrid	0.0%	0.0%	1.8%	4.1%	3.8%	2.9%
Electric-Gasoline Hybrid	0.2%	2.2%	13.3%	21.2%	21.0%	17.5%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-13 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Lit. Review Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	53.0%	29.7%	17.5%	12.0%
Adv Conv Gasoline	0.1%	0.7%	15.1%	20.5%	15.5%	11.2%
TDI Diesel ICE	1.7%	3.0%	6.2%	6.1%	4.3%	2.8%
Ethanol-Flex Fuel ICE	1.8%	5.0%	10.1%	10.4%	9.2%	8.2%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
Electric-Diesel Hybrid	0.0%	0.0%	1.8%	3.8%	3.2%	2.5%
Electric-Gasoline Hybrid	0.2%	2.2%	13.2%	19.3%	17.1%	14.9%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.4%	10.1%	33.0%	48.3%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

These increases in total ATV stock from the "Literature Review, No Subsidies" versions of the scenarios imply that employing the subsidies will lead to further reductions in energy, oil use, and CO_2 emissions. How the two sets of scenarios compare is discussed where appropriate below.

7.3.3 LV Energy Use and Oil Use

Table 7-14 presents LV energy use and oil use in the Base Case and the three scenarios. The savings in energy use achieved by the three scenarios are fairly similar to one another (also see Figure 7-23) and are greater than savings achieved in the "Literature Review, No Subsidies" versions of the scenarios.

Savings in LV oil use are also greater than savings achieved in the "Literature Review, No Subsidies" cases, ranging from 5.1 to 5.4 mbpd by 2050 (also see Figure 7-24). The H2 Success scenario has the highest savings in 2050, using nearly one-half the levels of Base Case LV oil use. The (P)HEV & Ethanol scenario has the greatest cumulative savings in LV oil use over time: it averages savings of 1.8 mbpd for the 2005–2050 time period. Nevertheless, the average savings for the (P)HEV & Ethanol and H2 Success scenarios are very similar for the post-2030 time period.

7.3.4 LV Full-Fuel-Cycle CO_2 Emissions

Table 7-14 and Figure 7-25 present LV full-fuel-cycle CO_2 emissions in the Base Case and the three scenarios. All three scenarios achieve higher CO_2 reductions than those achieved in the "Literature Review, No Subsidies" versions of the scenarios. The H2 Success scenario achieves higher reductions (as compared to the Base Case) than the other two: 43% in 2050 vs. 22%–29%

TABLE 7-14 LV Energy Use, Oil Use, and Full-Fuel-Cycle CO_2 Emissions of Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Literature Review Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Specific Results						
Annual						
LV Energy Use (quads)						
Base Case	16.95	17.15	17.38	18.90	21.70	25.01
Mixed Lit. Review Prices with Subsidies	16.95	17.09	17.24	17.27	18.15	19.15
(P)HEV & Ethanol Lit. Review Prices with Subsidie	16.95	17.09	17.30	17.53	18.47	19.42
H2 Success Lit. Review Prices with Subsidies	16.95	17.09	17.27	17.90	18.81	20.06
Savings (%)						
Mixed Lit. Review Prices with Subsidies	0.0%	0.4%	0.8%	8.6%	16.4%	23.4%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0%	0.4%	0.4%	7.2%	14.9%	22.3%
H2 Success Lit. Review Prices with Subsidies	0.0%	0.4%	0.7%	5.3%	13.3%	19.8%
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Lit. Review Prices with Subsidies	8.67	8.33	8.33	7.96	7.51	6.97
(P)HEV & Ethanol Lit. Review Prices with Subsidie	8.67	8.33	8.02	7.30	7.17	6.97
H2 Success Lit. Review Prices with Subsidies	8.67	8.33	8.39	8.24	7.27	6.63
Savings						
Mixed Lit. Review Prices with Subsidies	0.0	0.1	0.1	1.3	3.0	5.1
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0	0.1	0.5	1.9	3.4	5.1
H2 Success Lit. Review Prices with Subsidies	0.0	0.1	0.1	1.0	3.3	5.4
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Lit. Review Prices with Subsidies	1419	1430	1511	1498	1554	1501
(P)HEV & Ethanol Lit. Review Prices with Subsidie	1419	1430	1425	1354	1511	1659
H2 Success Lit. Review Prices with Subsidies	1419	1421	1509	1484	1354	1205
Reductions (%)						
Mixed Lit. Review Prices with Subsidies	0.0%	0.7%	0.0%	7.6%	17.9%	29.3%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0%	0.6%	5.7%	16.4%	20.2%	21.9%
H2 Success Lit. Review Prices with Subsidies	0.0%	1.3%	0.2%	8.4%	28.5%	43.3%
Cumulative						
Cumulative Oil Savings	***Million Barrels***			***Average MBPD***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Lit. Review Prices with Subsidies	2,847	23,154	26,002	0.3	3.2	1.5
(P)HEV & Ethanol Lit. Review Prices with Subsidie	5,140	25,667	30,807	0.5	3.5	1.8
H2 Success Lit. Review Prices with Subsidies	2,052	24,539	26,591	0.2	3.4	1.6
Cumulative LV full fuel cycle CO2 reductions	***MMTCO2E***			***Percent***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Lit. Review Prices with Subsidies	639	7,028	7,667	1.6%	18.5%	10.0%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	2,142	7,522	9,664	5.5%	19.8%	12.6%
H2 Success Lit. Review Prices with Subsidies	691	10,949	11,640	1.8%	28.8%	15.1%

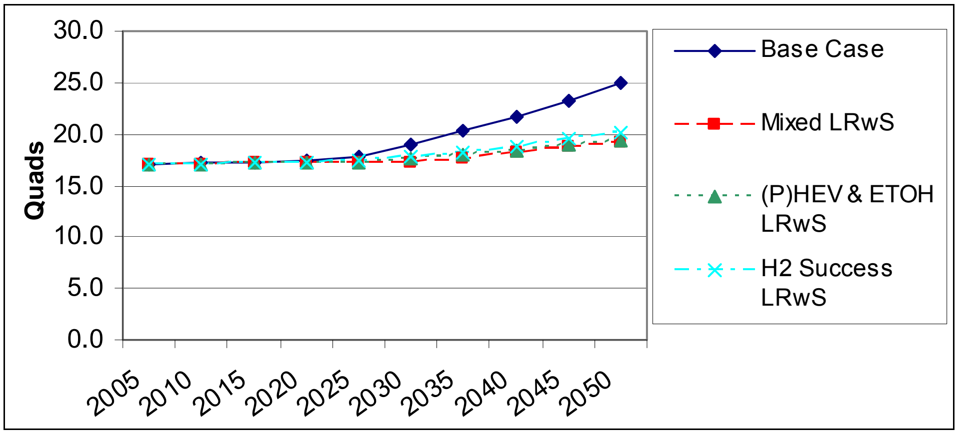

FIGURE 7-23 LV Energy Use (Literature Review with Subsidies)

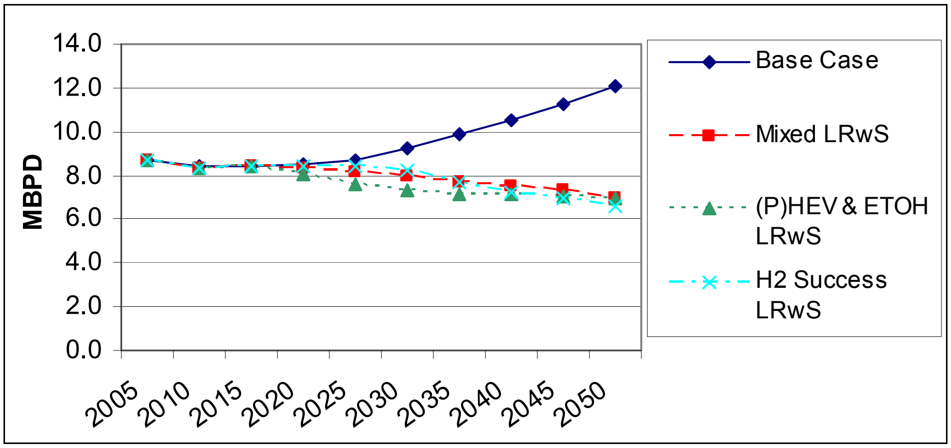

FIGURE 7-24 LV Oil Use (Literature Review with Subsidies)

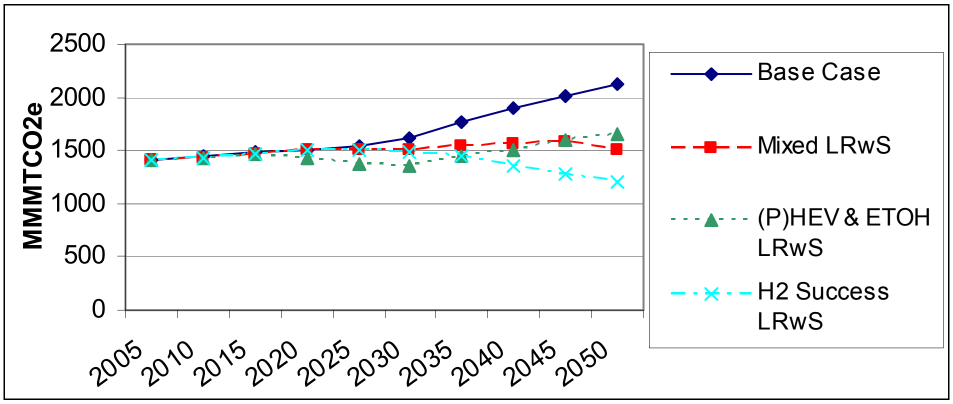

FIGURE 7-25 LV Full-Fuel-Cycle CO_2 Emissions (Literature Review with Subsidies)

for the other two, as well as higher cumulative reductions over time. However, in the near term (to 2030), the LV full-fuel-cycle CO_2 reductions of the (P)HEV & Ethanol scenario are the highest. It is not until after 2030 when emission levels in the H2 Success scenario begin to experience dramatic reductions. By 2050, the LV full-fuel-cycle CO_2 emissions in the H2 Success scenario are estimated to be 15% lower than 2005 Base Case levels.

7.3.5 Ethanol Use

Table 7-15 and Figure 7-26 present total ethanol use in the Base Case and the three scenarios. Ethanol volumes are lower than in the “Literature Review, No Subsidies” cases. However, the Mixed and (P)HEV & Ethanol scenarios still ultimately use more ethanol than the total volume of renewables required by the RFS. In 2050, the Mixed scenario uses 41 billion gallons/year and the (P)HEV & Ethanol scenario uses 57 billion gallons/year (an amount that is close to the 60 billion gallons/year goal of the scenario). The H2 Success scenario uses a volume that is similar to the Base Case.

7.3.6 U.S. Liquid Fuels Supply (Excluding Ethanol)

Table 7-15 and Figure 7-27 present estimates of the U.S. liquid fuels supply for the Base Case and the three scenarios. As stated previously, U.S. liquid fuels will grow by a total of about 8 mbpd from today to 2050 in the Base Case. The scenarios reduce that amount by about 5 mbpd by 2050, the same reductions as are achieved for LV oil use alone.

7.3.7 Net Import Share of Product Supplied

Table 7-15 and Figure 7-28 present the percentages of liquid fuel products that are imported. After 2020, the import level remains above 40%, even in the H2 Success scenario. (There is one exception: in 2030 in the (P)HEV & Ethanol scenario, the import share dips a little below 40%.)

7.3.8 Total U.S. CO_2 Emissions

Table 7-15 and Figure 7-29 present total U.S. emissions of CO_2 for the Base Case and the three scenarios. As with the LV full-fuel-cycle emissions, the (P)HEV & Ethanol scenario reduces CO_2 emissions the most in the early (to 2030) time period, while the H2 Success scenario achieves the highest reductions later. By 2050, total U.S. emissions of CO_2 are reduced by 10% in the H2 Success scenario.

TABLE 7-15 United States Total Energy, Oil, CO_2, and Gasoline Price Results for Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Literature Review Vehicle Prices

U.S. Total Results						
Ethanol Use (Billion gallons)						
Base Case	4.0	12.6	14.3	15.8	19.2	24.0
Mixed Lit. Review Prices with Subsidies	4.0	13.8	15.8	21.9	35.9	40.9
(P)HEV & Ethanol Lit. Review Prices with Subsidie	4.0	13.8	23.8	39.5	47.8	56.7
H2 Success Lit. Review Prices with Subsidies	4.0	13.8	14.7	17.0	21.9	24.5
RFS Standard (includes other fuels besides ethanol)	4.0	13.0	30.0	36.0	36.0	36.0
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Lit. Review Prices with Subsidies	20.5	20.3	20.7	21.0	21.8	23.3
(P)HEV & Ethanol Lit. Review Prices with Subsidie	20.5	20.3	20.5	20.3	21.5	23.3
H2 Success Lit. Review Prices with Subsidies	20.5	20.3	20.8	21.3	21.6	23.0
Savings						
Mixed Lit. Review Prices with Subsidies	0.0	0.1	0.2	1.3	3.1	5.1
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0	0.1	0.5	2.0	3.4	5.1
H2 Success Lit. Review Prices with Subsidies	0.0	0.1	0.1	1.0	3.3	5.4
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Lit. Review Prices with Subsidies	60.5%	53.6%	46.7%	41.9%	44.9%	46.6%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	60.5%	53.4%	44.4%	38.4%	43.1%	47.3%
H2 Success Lit. Review Prices with Subsidies	60.5%	53.6%	46.4%	42.6%	45.1%	49.1%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Lit. Review Prices with Subsidies	5945	6174	6699	7347	8191	8924
(P)HEV & Ethanol Lit. Review Prices with Subsidie	5945	6175	6614	7203	8148	9082
H2 Success Lit. Review Prices with Subsidies	5945	6165	6698	7333	7991	8628
Reductions (%)						
Mixed Lit. Review Prices with Subsidies	0.0%	0.2%	0.0%	1.6%	4.0%	6.5%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0%	0.2%	1.3%	3.6%	4.5%	4.9%
H2 Success Lit. Review Prices with Subsidies	0.0%	0.3%	0.0%	1.8%	6.3%	9.6%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Lit. Review Prices with Subsidies	2.33	2.59	2.88	3.00	2.98	3.08
(P)HEV & Ethanol Lit. Review Prices with Subsidie	2.33	2.59	2.78	2.84	2.93	3.14
H2 Success Lit. Review Prices with Subsidies	2.33	2.60	2.88	2.99	2.87	2.99
Reductions (%)						
Mixed Lit. Review Prices with Subsidies	0.0%	1.2%	1.0%	4.8%	15.7%	21.6%
(P)HEV & Ethanol Lit. Review Prices with Subsidie	0.0%	1.3%	4.6%	10.0%	17.2%	20.2%
H2 Success Lit. Review Prices with Subsidies	0.0%	1.2%	1.0%	5.1%	18.7%	24.0%

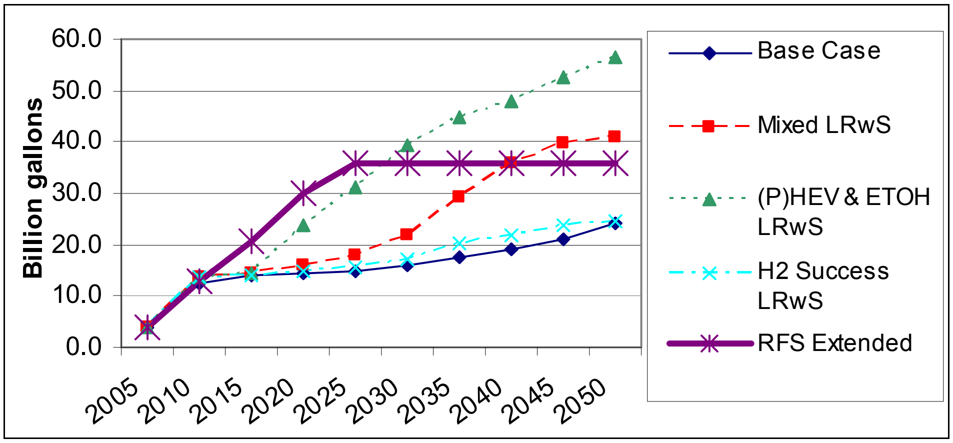

FIGURE 7-26 Ethanol Use (Literature Review with Subsidies)

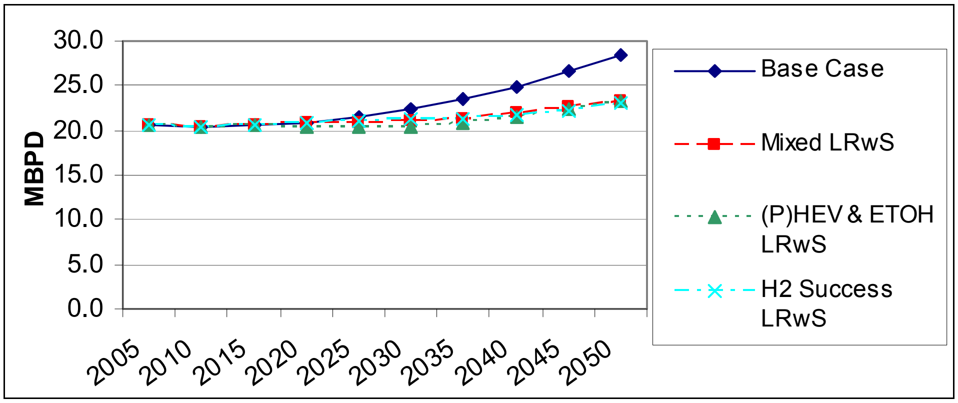

FIGURE 7-27 U.S. Liquid Fuels Supply Excluding Ethanol (Literature Review with Subsidies)

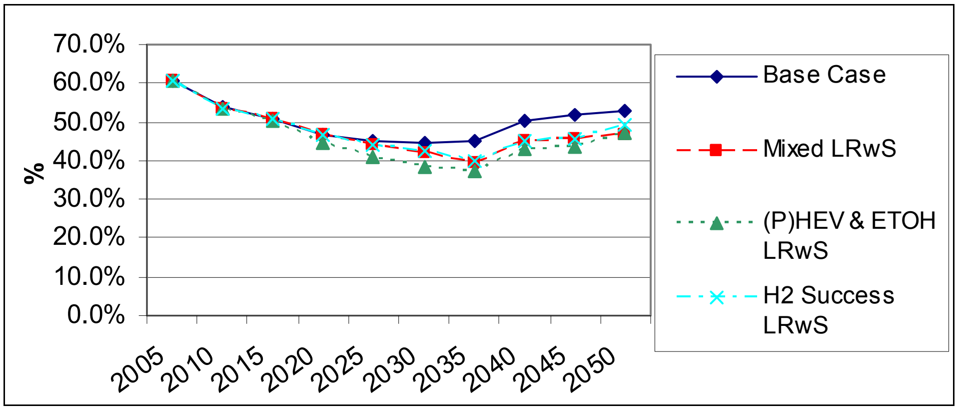

FIGURE 7-28 Net Import Share of Product Supplied (Literature Review with Subsidies)

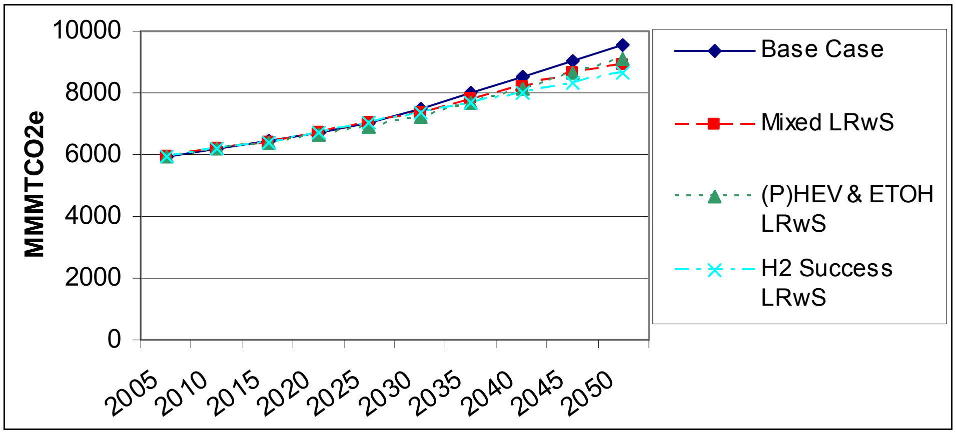

FIGURE 7-29 U.S. CO_2 Emissions (Literature Review with Subsidies)

7.3.9 Gasoline Prices

Table 7-15 and Figure 7-30 present the gasoline prices estimated for the Base Case and scenarios. Not unexpectedly, gasoline prices are lower than in the "Literature Review, No Subsidies" versions of the scenarios. The gasoline prices of the (P)HEV & Ethanol scenario are the lowest through 2030, but by 2050 are the highest.

7.3.10 Effectiveness of Subsidies

Table 7-16 presents, for each scenario, (1) an estimate of the cumulative vehicle subsidies from 2015 through 2050 and (2) the cumulative oil savings and reductions in CO_2 emission achieved with those subsidies in that time period and beyond to 2075. The oil savings and reductions in CO_2 emission achieved by the subsidies extend beyond 2050 because vehicles brought into the market by the subsidies will continue to operate until well after 2050. The year 2075 was chosen as an end point to ensure that both the potential oil savings and CO_2 reductions of these subsidized vehicles were fully accounted for.

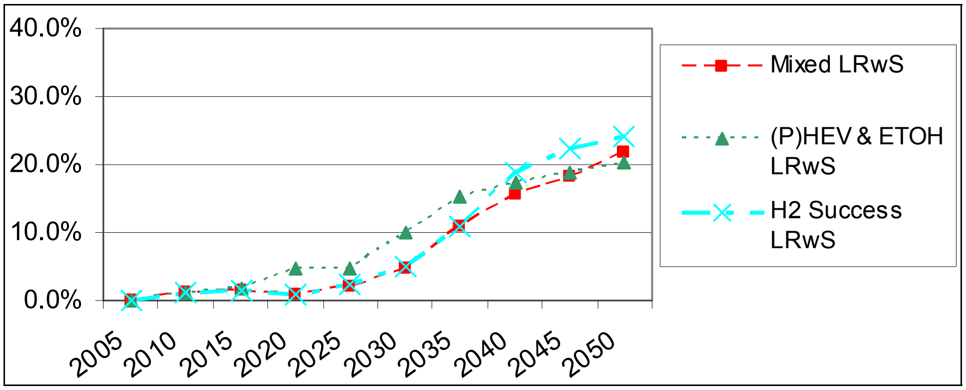

FIGURE 7-30 Gasoline Price Reduction from Base Case (Literature Review with Subsidies)

TABLE 7-16 Effectiveness of Subsidies in Scenarios with Selected Vehicle Subsidies in Addition to Literature Review Vehicle Prices

Effectiveness of subsidies (undiscounted)							
	From NEMS-MP						
	2030	2035	2040	2045	2050	Cumulative	Cumulative
Mixed						2015-2050	2015-2075
Annual subsidies (billion)	$40.6	$49.2	$63.8	$83.7	$112.7	$1,694	$1,694
LV oil savings (Quads)							
Mixed Lit. Review Prices	1.2	2.3	3.4	4.1	4.8		
Mixed Lit. Review Prices plus Subsidies	2.4	4.1	5.8	7.5	9.7		
Additional savings with subsidies	1.2	1.8	2.4	3.5	4.9	61.2	102.3
Additional savings with subsidies (billion barrels)						11.7	19.5
Subsidy/barrel saved						$145	$87
which also saves CO2 (MTCO2e/barrel)						0.24	0.27
LV full fuel cycle CO2 reductions (MMTCO2e)							
Mixed Lit. Review Prices	77.3	159.3	240.9	281.6	314.5		
Mixed Lit. Review Prices plus Subsidies	122.6	226.7	338.9	417.6	622.5		
Additional savings with subsidies	45.3	67.3	98.0	136.0	308.0	2,824.1	5,173.6
Subsidy/metric ton CO2e reduced						$600	$327
which also saves oil (barrel/MTCO2e)						4.1	3.8
(P)HEV & Ethanol							
Annual subsidies (billion)	$50.3	$61.3	$74.6	$89.6	$105.9	$1,898	$1,898
LV oil savings (Quads)							
(P)HEV & Ethanol Lit. Review Prices	2.6	3.5	4.4	5.1	5.8		
(P)HEV & Ethanol Lit. Review Prices plus Subsidies	3.7	5.1	6.4	8.1	9.7		
Additional savings with subsidies	1.1	1.5	2.1	2.9	3.9	51.8	83.2
Additional savings with subsidies (billion barrels)						9.9	15.8
Subsidy/barrel saved						$192	$120
which also saves CO2 (MTCO2e/barrel)						0.12	0.11
LV full fuel cycle CO2 reductions (MMTCO2e)							
(P)HEV & Ethanol Lit. Review Prices	226.4	279.8	335.4	359.7	395.4		
(P)HEV & Ethanol Lit. Review Prices plus Subsidies	266.4	330.8	381.6	407.1	464.1		
Additional savings with subsidies	40.0	50.9	46.2	47.4	68.7	1,192.3	1,701.6
Subsidy/metric ton CO2e reduced						$1,592	$1,116
which also saves oil (barrel/MTCO2e)						8.3	9.3
H2 Success							
Annual subsidies (billion)	$48.0	$76.7	$83.7	$92.6	$104.3	$1,934	$1,934
LV oil savings (Quads)							
H2 Success Lit. Review Prices	0.8	1.5	2.4	3.3	3.8		
H2 Success Lit. Review Prices plus Subsidies	1.9	4.1	6.2	8.3	10.4		
Additional savings with subsidies	1.0	2.6	3.8	5.1	6.5	83.9	136.5
Additional savings with subsidies (billion barrels)						16.0	26.0
Subsidy/barrel saved						$121	$74
which also saves CO2 (MTCO2e/barrel)						0.47	0.48
LV full fuel cycle CO2 reductions (MMTCO2e)							
H2 Success Lit. Review Prices	50.9	129.9	203.9	245.0	270.4		
H2 Success Lit. Review Prices plus Subsidies	136.9	326.5	538.7	718.8	918.5		
Additional savings with subsidies	86.0	196.6	334.8	473.8	648.1	7,453.4	12,466.6
Subsidy/metric ton CO2e reduced						$260	$155
which also saves oil (barrel/MTCO2e)						2.1	2.1

Note: Only the cumulative $/bbl or $/metric ton CO2 is shown because the subsidy expended during any year is "purchasing" future oil savings over the lifetime of vehicles purchased during that year. Note too that the $/bbl or $/metric ton estimates for the period 2015-2050 are overestimates because additional oil savings and CO2 reductions will accrue in the years following 2050 from vehicles purchased with pre-2051 subsidies. These additional savings and reductions are accounted for in the column presenting $/barrel and $/metric tion CO2 for the period 2015-2075. Oil savings and CO2 reductions for the years 2051-2075 were developed with the VISION model.

The estimates of oil savings and CO_2 reductions occurring after 2050 were generated by using the VISION model, not NEMS-MP. The VISION model generates estimates of fuel use and GHG emissions by LVs to 2100. The vehicle sales shares and vehicle fuel economies as estimated by the NEMS-MP model for the various scenarios and cases were input to VISION. So too were the NEMS-MP estimates (shares) of fuels used to produce ethanol, H_2, and electricity: we hold the 2050 shares constant after 2050. In the estimates of oil use and CO_2 emissions to 2075, only the oil use and CO_2 emissions of vehicles sold through 2050 are included.

The two models have substantially different assumptions about vehicle travel (e.g., VISION assumes newer vehicles travel more miles while NEMS-MP does not) and total LV stock by

2050 (i.e., NEMS estimates that there will be about 50 million more LVs than VISION does in that year). As a result, the 2050 fuel use estimates generated by the two models do not match; however, we developed ratios that allowed us to derive the post-2050 oil use estimates for the scenarios. For the CO_2 emissions estimates, there is an additional problem in that VISION provides GHG estimates, while NEMS-MP provides CO_2 estimates only. Further, the CO_2 factors vary somewhat between the two models. Despite these differences, we made some simplifying assumptions and developed post-2050 lifecycle CO_2 estimates for the scenarios.

As would be expected, the total cumulative subsidies of the three scenarios are substantial. The total for the (P)HEV & Ethanol and H2 Success scenarios are quite similar: nearly $2 trillion (undiscounted). The total for the Mixed scenario is not much lower at $1.7 trillion.

The table presents the subsidy per barrel of oil saved and per metric ton of CO_2 reduced for the three scenarios for both the time periods of 2015 to 2050 and 2015 to 2075. The discussion below focuses on the 2015–2075 time period. The calculations in Table 7-16 assign the total subsidy for each scenario to both barrels of oil saved and metric ton of CO_2 reduced (but also report the corresponding CO_2 reduced/barrel saved and barrel saved/ton of CO_2 reduced). Alternatively, another approach could be to consider apportioning the total subsidy between the two benefits (perhaps 50-50).

On either basis, the subsidies used to encourage additional market penetration of FCVs in the H2 Success scenario are the lowest and/or most effective of the three scenarios: specifically, $74/barrel and $155/metric ton for the 2015–2075 time period (without apportionment). The cost effectiveness (C/E) of the subsidies used in the Mixed scenario in terms of reducing LV oil use is similar to that of the H2 Success scenario: $87/barrel. However, the C/E of subsidies in the Mixed scenario to reduce LV full-fuel-cycle CO_2 emissions is considerably higher: $327/metric ton. The subsidies of the (P)HEV & Ethanol scenario are the highest of all: $120/barrel and $1,116/metric ton. None of these options is inexpensive.

(Note that the estimates of the C/E for LV oil reduction are more "robust" than those for LV full-fuel-cycle CO_2 emissions reduction. More assumptions are made to estimate the latter.)

Finally, the (undiscounted) cumulative vehicle subsidy for the H2 Success scenario as estimated in the table is nearly $2 trillion. This scenario assumes a "jump start" of H_2 stations in the early years of the scenario. That jump start is not without cost: for this case; we estimate the costs to range from $6 billion to $12 billion (see Appendix B). That subsidy should be added to the cumulative vehicle subsidy. However, it will not alter the relative effectiveness of the H2 Success scenario.

7.3.11 Concluding Remarks about Impacts of Scenarios with "Literature Review" Vehicle Prices Plus Subsidies

The subsidies examined lead to significant increases in ATV market penetration and reductions in U.S. and LV oil use, U.S. and full-fuel-cycle LV CO_2 emissions, and gasoline prices relative to the both the Base Case and the "Literature Review, No Subsidies" versions of the scenarios.

Even so, LV oil use is reduced from the Base Case by just 1–2 mbpd by 2030 and by approximately 5 mbpd by 2050. While these reductions are not insignificant, it means that there will still be many vehicles on the road relying on gasoline or diesel fuel. For example, in the H2 Success scenario, more than 40% of the vehicle stock in 2050 would still use one of these two fuels as their only energy source.

7.4 SCENARIOS WITH SELECTED VEHICLE SUBSIDIES IN ADDITION TO "PROGRAM GOALS" VEHICLE PRICES

7.4.1 Subsidies Used

Even use of the "program goals" vehicle price estimates did not result in achievement of the ATV market penetration goals set for the scenarios. Table 7-17 illustrates the difference between the 2050 market penetration achieved with the "program goals" vehicle prices and the scenario goals.

As described in Section 7.3.1, we used the NEMS-TSA model to estimate the amounts of vehicle subsidies required in each scenario that would result in market penetration estimates similar to the goals of the scenarios. However, for these runs, we only assumed subsidies would be available for the 2030–2050 time frame. Table 7-18 presents the subsidies used in the model runs. These subsidies reduce the retail price of the targeted vehicles below the "program goals" vehicle price estimates. Table 7-19 illustrates the effect of the subsidies on the incremental prices input to NEMS-MP by using the medium car as an example. (The incremental prices of the subsidized vehicles are presented in italics in Table 7-19.)

We need to reiterate that these vehicle subsidies are just "examples." No one envisions maintaining significant subsidies for 20+ years or setting up subsidies that actually increase over time (i.e., as is provided to FCVs in the H2 Success scenario). However, the subsidies indicate the levels of vehicle price reductions that, according to the NEMS-MP model, will need to be achieved in order to reach the high market penetration goals for advanced vehicle technologies desired in the scenarios (all else being equal).

In addition, we did not try to match the scenario goals exactly. Instead we focused on subsidizing the technologies of greatest interest: gasoline HEVs, gasoline plug-ins, and FCVs (including plug-in FCVs).

7.4.2 Vehicle Market Penetration

Table 7-20 presents the sales shares for the Base Case and the three scenarios. As expected, given that the subsidies vary considerably across the scenarios, the rates of market penetration of various technologies also vary considerably across the scenarios. The scenario goals for 2050 were not matched exactly, as shown in Figures 7-31 through 7-33 (which also compare the vehicle sales shares for the "literature review," "literature review with subsidies," and "program

TABLE 7-17 New Vehicle Sales Shares in Program Goals Cases vs. Scenario Goals

Weighted car and LT 2050 sales	Mixed PG	Mixed Goal	(P)HEV & Etoh PG	(P)HEV & Etoh Goal	H2 Succes PG	H2 Success Goal
Conventional Gasoline ICE	9.1%	0.0%	9.6%	0.0%	7.5%	0.0%
Adv Conv Gasoline	13.5%	10.0%	14.1%	7.0%	10.4%	5.0%
TDI Diesel ICE	7.0%	14.0%	6.4%	3.0%	5.2%	3.0%
Ethanol-Flex Fuel ICE	5.2%	0.0%	6.0%	0.0%	6.8%	0.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid 40	4.2%	25.0%	6.1%	50.0%	4.0%	0.0%
Electric-Diesel Hybrid	7.9%	6.0%	7.2%	0.0%	6.2%	0.0%
Electric-Gasoline Hybrid	27.5%	15.0%	26.9%	40.0%	21.6%	16.0%
Fuel Cell PHEV	3.2%	9.0%	3.0%	0.0%	5.7%	0.0%
Fuel Cell Hydrogen	22.4%	21.0%	20.7%	0.0%	32.5%	76.0%
All other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

0

TABLE 7-18 Vehicle Subsidies in Scenarios Using Program Goals Vehicle Prices Plus Subsidies

Vehicle	Year[1]	Mixed	(P)HEV & Ethanol	H2 Success
SI PHEV40	2030	$4,000	$5,000	-
	2050	$3,000	$4,000	-
FCV	2030	$700	-	$500
	2050	$700	-	$4,000
FC Plug-in	2030	$2,000	-	-
	2050	$2,000	-	-
SI HEV	2030	-	$1,000	-
	2050	-	$1,000	-

[1] Linear interpolation is used for years between 2030 and 2050. These subsidies are applied to the “program goals” vehicle price estimates.

goals” versions of each scenario with the scenario goals). However, the market penetration achieved is fairly close to the goals, at least for the technologies of greatest interest. In the Mixed scenario, gasoline PHEV sales are now close to the 2050 goal of 25%, while total sales of FCVs (including plug-ins FCVs) remain flat (although more plug-in FCVs are sold). In the H2 Success scenario, FCVs are 73% of sales by 2050, a level that is very close to the 76% goal. In the (P)HEV & Ethanol scenario, PHEVs almost reach the goal of 50% of vehicle sales. Fewer HEVs are sold in that scenario than desired: we found that if we increased the subsidy for HEVs, then PHEV sales dropped. Therefore, we allowed HEV sales to be lower than originally intended.

As a result of the significant differences in sales by vehicle technology among the scenarios with subsidies, there are also significant differences in vehicle stock shares. Table 7-21 presents vehicle technology shares of stock for the Base Case and the three scenarios. By 2050, in the H2 Success scenario, about 50% of all vehicles on the road are FCVs: in the “Program Goals, No Subsidies” case, FCVs were just 20%. In the (P)HEV & Ethanol scenario, more than one-third (38%) of the stock consists of PHEVs by 2050, a result that is a major change from the “Program

TABLE 7-19 Incremental Vehicle Prices Used in Scenarios Assuming Program Goals Vehicle Prices including Prices with Subsidies: Medium Car (in 2005$)[1]

Mixed	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$1,845	$2,224	$2,496	$1,907	$1,597
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$3,496	$3,381	$3,267	$2,924	$2,695
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$2,240	$2,335	$2,429	$1,427	$926
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$417	$350	$283	$17	-$117
Fuel Cell (hydrogen)	**2023**	**2028**	**2033**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$2,115	$1,787	$1,458	$997	$340
"PG with Subsidy" Incremental Price ($)	$2,115	$1,787	*$758*	*$297*	*-$360*
FCV PHEV 40	**2025**	**2030**	**2035**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$4,145	$3,696	$3,248	$2,799	$1,902
"PG with Subsidy" Incremental Price ($)	$4,145	*$1,696*	*$1,248*	*$799*	*-$98*
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$4,866	$4,518	$4,170	$3,335	$2,639
"PG with Subsidy" Incremental Price ($)	$4,866	$4,518	$4,170	*-$165*	*-$361*

(P)HEV & Ethanol	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$1,845	$2,224	$2,496	$1,907	$1,597
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$3,496	$3,381	$3,267	$2,924	$2,695
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$2,240	$2,335	$2,429	$1,427	$926
"PG with Subsidy" Incremental Price ($)	$2,240	$2,335	$2,429	*$427*	*-$74*
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$417	$350	$283	$17	-$117
Fuel Cell (hydrogen)	**2023**	**2028**	**2033**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$2,115	$1,787	$1,458	$997	$340
FCV PHEV 40	**2025**	**2030**	**2035**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$4,145	$3,696	$3,248	$2,799	$1,902
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$4,866	$4,518	$4,170	$3,335	$2,639
"PG with Subsidy" Incremental Price ($)	$4,866	$4,518	$4,170	*-$1,165*	*-$1,361*

[1] The incremental prices of the subsidized vehicles are presented in italics.

TABLE 7-19 (Cont.)

H2 Success	**Mid-size (Medium) CAR**				
	Year of:				
	Market Intro.	5 years later	10 years later	2040	2050
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$1,845	$2,224	$2,496	$1,907	$1,597
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$3,496	$3,381	$3,267	$2,924	$2,695
Gasoline Hybrid	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$2,240	$2,335	$2,429	$1,427	$926
Advanced Gasoline	**2010**	**2015**	**2020**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$417	$350	$283	$17	-$117
Fuel Cell (hydrogen)	**2017**	**2022**	**2027**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$3,887	$3,350	$2,812	$1,415	$340
"PG with Subsidy" Incremental Price ($)	$3,887	$3,350	$2,812	*-$835*	*-$3,660*
FCV PHEV 40	**2019**	**2024**	**2029**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$6,633	$5,870	$5,107	$3,428	$1,902
SI Plug-in HEV 40	**2018**	**2023**	**2028**	**2040**	**2050**
"Program Goals" Incremental Price ($)	$4,866	$4,518	$4,170	$3,335	$2,639

[1] The incremental prices of the subsidized vehicles are presented in italics.

Goals, No Subsidies" case, in which just 5% of the stock consists of PHEVs. Another 25% are GHEVs. There is more of a mix of technologies in the Mixed scenario: 26% are GHEVs, 22% are PHEVs, and 8% are FCVs (including plug-in FCVs). The stock of PHEVs in particular has increased over its share in the "Program Goals, No Subsidies" case (3%).

These increases in the stock levels of total ATVs from the "Program Goals, No Subsidies" versions of the scenarios imply that the energy, oil use, and CO_2 impacts of the scenarios with subsidies would be greater. We discuss how they compare below where appropriate.

7.4.3 LV Energy Use and Oil Use

Table 7-22 presents LV energy use and oil use in the Base Case and the three scenarios. The levels of savings in energy use for the three scenarios are fairly similar to one another (see also Figure 7-34) and greater than achieved in the "Program Goals, No Subsidies" cases.

LV oil use savings are also greater than achieved in the "Program Goals, No Subsidies" cases, ranging from 4.2 to 5.9 mbpd by 2050 (see also Figure 7-35). The H2 Success scenario achieves the highest level of savings in 2050, using half of the Base Case levels. The (P)HEV & Ethanol scenario has the greatest cumulative LV oil use savings over time: 1.8 mbpd for the 2005–2050 time period versus 1.5 mbpd for the H2 Success scenario. The Mixed scenario with subsidies experiences only modest reductions in oil use as compared to those achieved in its "Program Goals, No Subsidies" case.

TABLE 7-20 Weighted Shares of Vehicle Sales in Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	91.3%	82.2%	72.1%	65.3%	56.2%	52.2%
Adv Conv Gasoline	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
TDI Diesel ICE	2.1%	3.3%	5.6%	9.5%	15.1%	16.1%
Ethanol-Flex Fuel ICE	3.8%	10.0%	9.5%	8.9%	9.1%	11.9%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	1.0%	2.0%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%
Electric-Gasoline Hybrid	1.4%	4.4%	11.6%	14.2%	18.0%	18.0%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	1.2%	0.0%	0.1%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Program Goals Prices with Subsidies						
Conventional Gasoline ICE	91.3%	56.9%	18.6%	13.0%	11.5%	7.9%
Adv Conv Gasoline	0.3%	6.4%	22.8%	16.3%	13.2%	9.5%
TDI Diesel ICE	2.1%	9.0%	9.0%	6.9%	4.5%	3.9%
Ethanol-Flex Fuel ICE	3.8%	16.0%	8.9%	7.1%	6.2%	4.0%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	17.0%	24.2%	23.5%
Electric-Diesel Hybrid	0.0%	0.0%	12.2%	9.9%	7.2%	5.1%
Electric-Gasoline Hybrid	1.4%	11.6%	28.2%	28.8%	28.1%	20.4%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.2%	1.4%	8.3%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.9%	3.7%	17.6%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Program Goals Prices with Subsidies						
Conventional Gasoline ICE	91.3%	56.9%	18.4%	11.3%	9.4%	7.5%
Adv Conv Gasoline	0.3%	6.4%	22.4%	13.3%	10.1%	8.8%
TDI Diesel ICE	2.1%	9.1%	7.9%	4.7%	3.5%	3.8%
Ethanol-Flex Fuel ICE	3.8%	15.9%	11.6%	7.3%	5.3%	4.3%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	26.4%	41.7%	47.6%
Electric-Diesel Hybrid	0.0%	0.0%	11.4%	4.8%	2.5%	2.0%
Electric-Gasoline Hybrid	1.4%	11.6%	28.0%	31.5%	26.4%	20.9%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.6%	1.0%	4.5%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
H2 Success Program Goals Prices with Subsidies						
Conventional Gasoline ICE	91.3%	56.9%	18.4%	14.0%	7.9%	4.8%
Adv Conv Gasoline	0.3%	6.4%	22.5%	19.0%	9.2%	4.6%
TDI Diesel ICE	2.1%	9.1%	8.8%	8.2%	3.5%	1.6%
Ethanol-Flex Fuel ICE	3.8%	16.0%	8.7%	7.4%	5.9%	3.2%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	2.2%	1.7%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	12.1%	9.9%	4.4%	2.1%
Electric-Gasoline Hybrid	1.4%	11.6%	27.9%	27.9%	16.2%	9.2%
Fuel Cell PHEV	0.0%	0.0%	0.0%	1.0%	0.7%	0.2%
Fuel Cell Hydrogen	0.0%	0.0%	1.2%	10.4%	50.5%	72.9%
All other	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
LT Share of Total Sales						
Base Case	50.1%	43.2%	44.9%	48.6%	51.4%	54.0%
Mixed Program Goals Prices with Subsidies	50.1%	43.6%	45.3%	49.1%	53.3%	55.5%
(P)HEV & Ethanol Program Goals Prices with Subsidies	50.1%	43.5%	46.1%	50.1%	53.6%	55.6%
H2 Success Program Goals Prices with Subsidies	50.1%	43.6%	45.3%	49.0%	52.7%	56.6%
Total LV sales (millions)	16.2	16.6	18.2	20.2	21.9	23.5

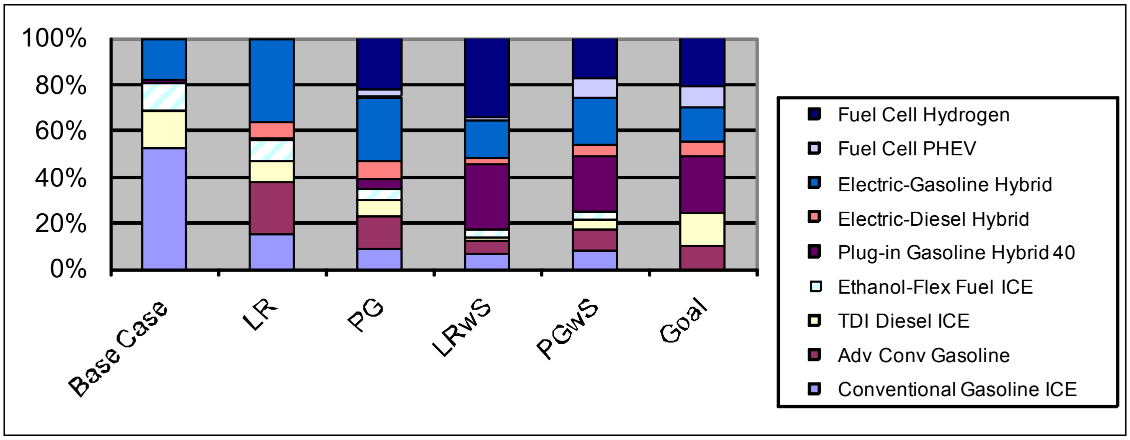

FIGURE 7-31 2050 LV Sales Versus Mixed Scenario Goals

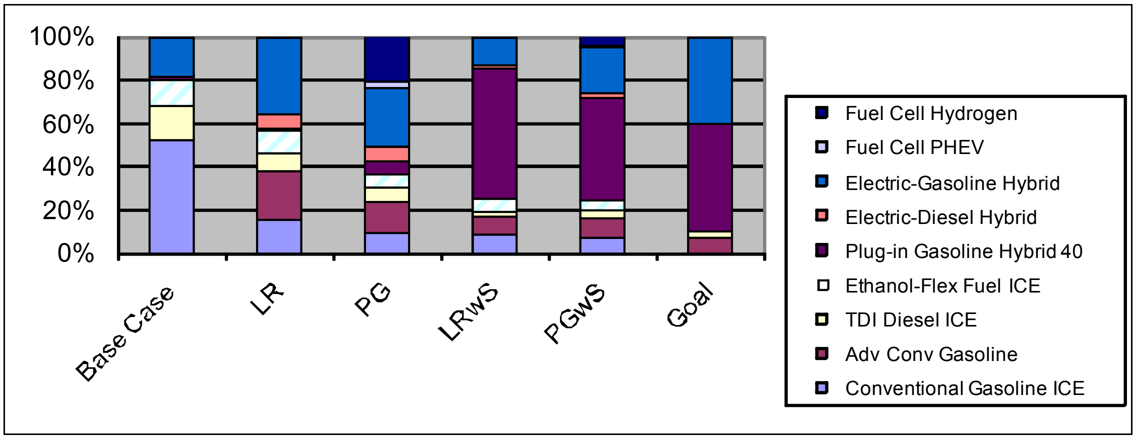

FIGURE 7-32 2050 LV Sales Versus (P)HEV & Ethanol Scenario Goals

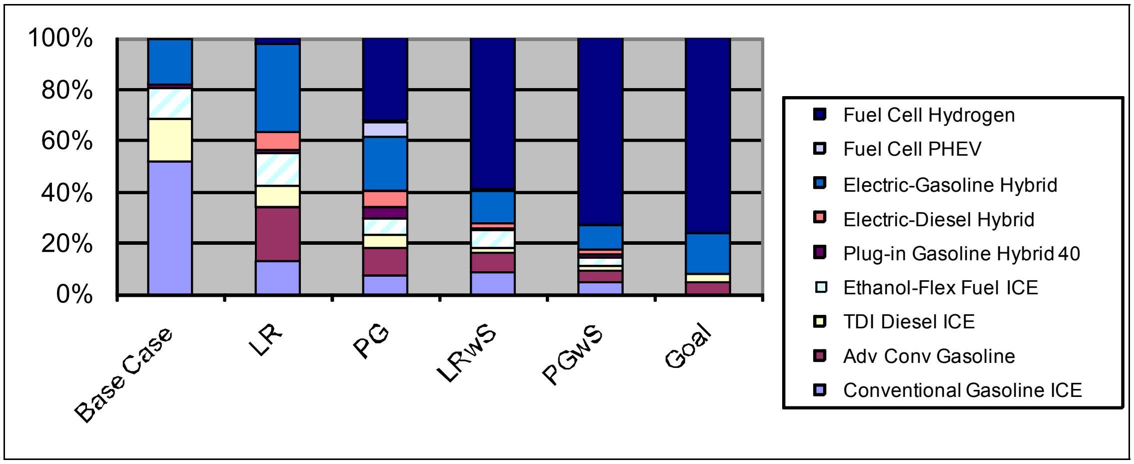

FIGURE 7-33 2050 LV Sales Versus H2 Success Scenario Goals

TABLE 7-21 Weighted Shares of Vehicle Stock in Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
Base Case						
Conventional Gasoline ICE	95.6%	92.1%	83.0%	73.6%	65.1%	57.9%
Adv Conv Gasoline	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
TDI Diesel ICE	1.7%	2.2%	3.6%	6.0%	10.0%	13.8%
Ethanol-Flex Fuel ICE	1.8%	3.9%	7.8%	8.9%	9.1%	9.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.3%	1.1%	1.5%	1.5%
Electric-Diesel Hybrid	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
Electric-Gasoline Hybrid	0.2%	1.2%	5.0%	10.1%	14.1%	16.8%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All other	0.5%	0.5%	0.3%	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed Program Goals Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	50.5%	26.6%	16.0%	11.6%
Adv Conv Gasoline	0.1%	0.7%	14.2%	19.9%	16.5%	13.2%
TDI Diesel ICE	1.7%	3.1%	7.0%	8.3%	6.6%	5.1%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.0%	8.8%	7.2%	5.8%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	1.8%	15.1%	22.2%
Electric-Diesel Hybrid	0.0%	0.0%	4.1%	9.1%	9.1%	7.4%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	25.2%	28.0%	26.2%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.4%	2.5%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.3%	1.2%	5.9%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(P)HEV & Ethanol Program Goals Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	50.6%	26.7%	15.1%	10.3%
Adv Conv Gasoline	0.1%	0.7%	14.2%	19.7%	14.6%	11.0%
TDI Diesel ICE	1.7%	3.1%	6.8%	7.4%	5.1%	4.0%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.5%	10.3%	7.6%	5.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	2.6%	24.0%	38.4%
Electric-Diesel Hybrid	0.0%	0.0%	3.9%	8.1%	5.4%	3.2%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	25.0%	27.7%	25.3%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
Fuel Cell Hydrogen	0.0%	0.0%	0.0%	0.2%	0.6%	1.9%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 7-21 (Cont.)

	2005	2010	2020	2030	2040	2050
H2 Success Program Goals Prices with Subsidies						
Conventional Gasoline ICE	95.6%	88.4%	50.5%	26.2%	15.4%	9.2%
Adv Conv Gasoline	0.1%	0.7%	14.2%	19.4%	16.5%	10.2%
TDI Diesel ICE	1.7%	3.1%	7.0%	8.1%	6.9%	4.0%
Ethanol-Flex Fuel ICE	1.8%	5.0%	9.0%	8.6%	7.7%	5.6%
Electric Vehicle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Gasoline Hybrid	0.0%	0.0%	0.0%	0.9%	1.8%	1.7%
Electric-Diesel Hybrid	0.0%	0.0%	4.1%	8.7%	8.2%	5.0%
Electric-Gasoline Hybrid	0.2%	2.2%	14.8%	24.2%	24.0%	16.7%
Fuel Cell PHEV	0.0%	0.0%	0.0%	0.2%	1.3%	0.8%
Fuel Cell Hydrogen	0.0%	0.0%	0.2%	3.6%	18.3%	46.7%
All other	0.5%	0.5%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

7.4.4 LV Full-Fuel-Cycle CO_2 Emissions

Table 7-22 and Figure 7-36 present LV full-fuel-cycle CO_2 emissions in the Base Case and the three scenarios. The emissions reduction achieved in the (P)HEV & Ethanol scenario is almost the same as that achieved in the "Program Goals, No Subsidies" version of the scenario: 25% less than Base Case levels by 2050. The Mixed scenario actually has slightly higher full-fuel-cycle CO_2 emissions than were achieved in the "Program Goals, No Subsidies" version of the scenario, although it still achieves a 23% reduction from the Base Case. The emission levels in the H2 Success scenario are the same or slightly higher than those of the Mixed and (P)HEV & Ethanol scenarios until after 2030 when dramatic reductions in emissions begin to occur. By 2050, the LV full-fuel-cycle CO_2 emissions in the H2 Success scenario are estimated to be 20% lower than 2005 Base Case levels. The H2 Success scenario achieves the greatest cumulative reduction in LV full-fuel-cycle CO_2 emissions through 2050 (14% for the 2005-to-2050 time period), although reductions achieved in the (P)HEV & Ethanol scenario are not far behind.

For the Mixed and (P)HEV & Ethanol scenarios, we expected greater reductions in LV full-fuel-cycle CO_2 emissions from the totals for the "Program Goals, No Subsidies" versions of the scenarios. While we are not certain why so little change occurred, we speculate that this result is attributable to the following:

1. The stock of PHEVs increases considerably in both scenarios;

TABLE 7-22 LV Energy Use, Oil Use, and Full-Fuel-Cycle CO$_2$ Emissions of Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Specific Results						
Annual						
LV Energy Use (quads)						
Base Case	16.95	17.15	17.38	18.90	21.70	25.01
Mixed Program Goals Prices with Subsidies	16.95	17.09	17.01	17.78	18.61	20.40
(P)HEV & Ethanol Program Goals Prices with Subsi	16.95	17.08	17.07	17.80	18.31	19.15
H2 Success Program Goals Prices with Subsidies	16.95	17.08	17.01	17.42	18.51	19.16
Savings (%)						
Mixed Program Goals Prices with Subsidies	0.0%	0.4%	2.2%	5.9%	14.3%	18.4%
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0%	0.4%	1.8%	5.8%	15.6%	23.4%
H2 Success Program Goals Prices with Subsidies	0.0%	0.4%	2.1%	7.8%	14.7%	23.4%
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Program Goals Prices with Subsidies	8.67	8.33	8.24	8.38	7.78	7.85
(P)HEV & Ethanol Program Goals Prices with Subsi	8.67	8.33	7.97	7.62	7.21	6.88
H2 Success Program Goals Prices with Subsidies	8.67	8.33	8.30	8.31	7.81	6.19
Savings						
Mixed Program Goals Prices with Subsidies	0.0	0.1	0.2	0.8	2.8	4.2
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0	0.1	0.5	1.6	3.3	5.2
H2 Success Program Goals Prices with Subsidies	0.0	0.1	0.2	0.9	2.7	5.9
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Program Goals Prices with Subsidies	1419	1434	1487	1508	1552	1642
(P)HEV & Ethanol Program Goals Prices with Subsi	1419	1438	1420	1362	1488	1597
H2 Success Program Goals Prices with Subsidies	1419	1427	1492	1497	1454	1137
Reductions (%)						
Mixed Program Goals Prices with Subsidies	0.0%	0.4%	1.6%	7.0%	18.0%	22.7%
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0%	0.1%	6.1%	16.0%	21.4%	24.8%
H2 Success Program Goals Prices with Subsidies	0.0%	0.9%	1.3%	7.6%	23.2%	46.5%
Cumulative						
Cumulative Oil Savings	***Million Barrels***			***Average MBPD***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Program Goals Prices with Subsidies	2,500	19,354	21,854	0.3	2.7	1.3
(P)HEV & Ethanol Program Goals Prices with Subsi	4,709	25,177	29,887	0.5	3.4	1.8
H2 Success Program Goals Prices with Subsidies	2,374	22,709	25,083	0.3	3.1	1.5
Cumulative LV full fuel cycle CO2 reductions	***MMTCO2E***			***Percent***		
	2005-2030	2031-2050	2005-2050	2005-2030	2031-2050	2005-2050
Mixed Program Goals Prices with Subsidies	725	6,233	6,958	1.9%	16.4%	9.0%
(P)HEV & Ethanol Program Goals Prices with Subsi	2,123	8,066	10,189	5.5%	21.3%	13.2%
H2 Success Program Goals Prices with Subsidies	802	9,975	10,777	2.1%	26.3%	14.0%

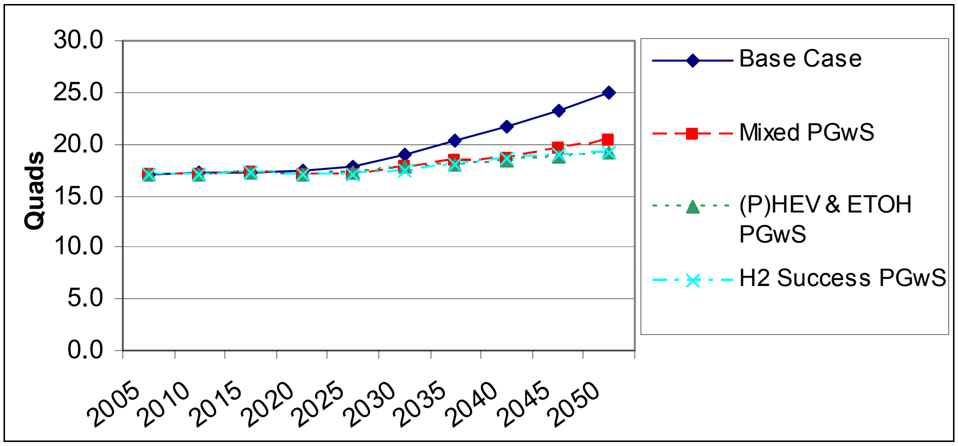

FIGURE 7-34 LV Energy Use (Program Goals with Subsidies)

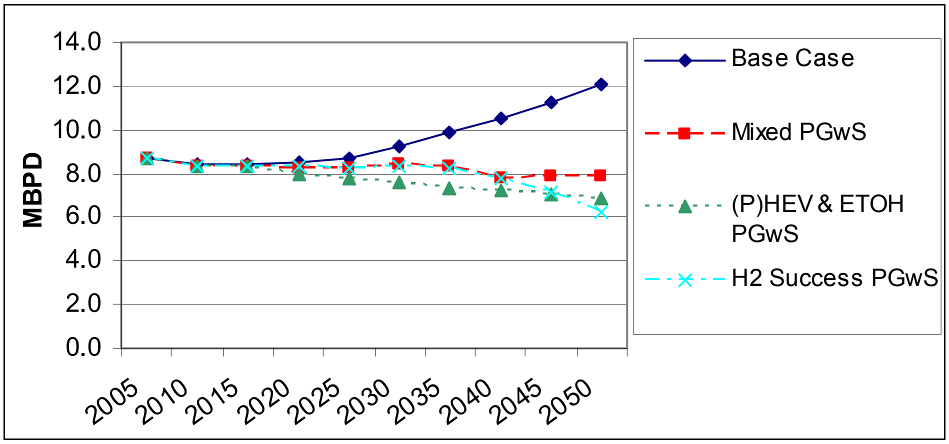

FIGURE 7-35 LV Oil Use (Program Goals with Subsidies)

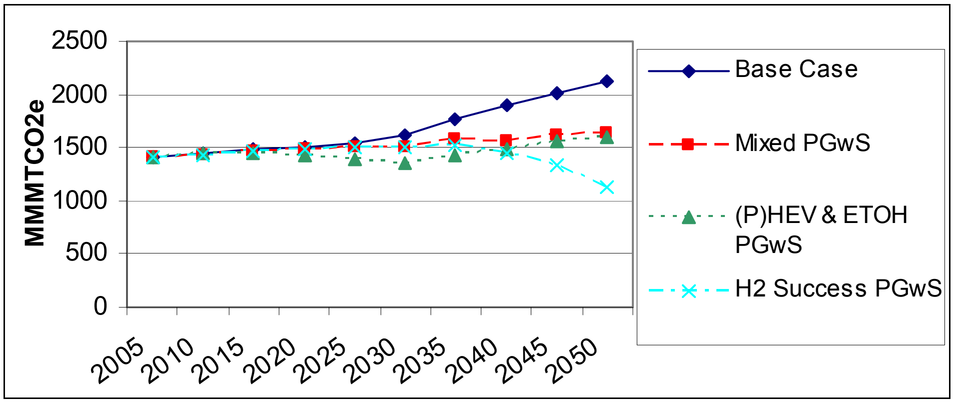

FIGURE 7-36 LV Full-Fuel-Cycle CO_2 Emissions (Program Goals with Subsidies)

2. Analysis of the model run results indicates that the marginal fuel used to generate electricity for PHEVs is coal. The PHEVs are assumed to be charged in the off-peak hours and, absent any additional policies, the general result in the NEMS-MP model is that coal will be used predominantly in those off-peak hours for additional electricity generation[19]; and

3. Ethanol use declines somewhat in each of the two scenarios (see Section 7.4.5). Whether from corn or cellulose, ethanol has lower full-fuel-cycle CO_2 emissions than gasoline. (The decline in ethanol use is presumed to be a minor factor.)

7.4.5 Ethanol Use

Table 7-23 and Figure 7-37 present total ethanol use in the Base Case and the three scenarios. Ethanol volumes are lower than in the "Program Goals, No Subsidies" versions of the scenarios. However, the Mixed and (P)HEV & Ethanol scenarios still ultimately use more ethanol than the total volume of renewables required by the RFS. Respectively, they use 46 billion gallons/year and 55 billion gallons/year in 2050. The H2 Success scenario uses less ethanol than the Base Case.

7.4.6 U.S. Liquid Fuels Supply (Excluding Ethanol)

Table 7-23 and Figure 7-38 present U.S. liquid fuels supply estimates for the Base Case and three scenarios. As stated previously, U.S. liquid fuels use will grow by about 8 mbpd from today to 2050 in the Base Case. The scenarios reduce that by 4–6 mbpd by 2050, an amount that represents almost the same reductions as are achieved for LV oil use alone.

7.4.7 Net Import Share of Product Supplied

Table 7-23 and Figure 7-39 present the percentages of imported liquid fuel products. After 2020, imports remain above 40% even in the H2 Success scenario. (There is one exception: in 2030 in the (P)HEV & Ethanol scenario, the import share dips a little below 40%.)

7.4.8 Total U.S. CO_2 Emissions

Table 7-23 and Figure 7-40 present total U.S. emission levels of CO_2 for the Base Case and the three scenarios. The total CO_2 emissions of the Mixed and (P)HEV scenarios have not changed significantly from the "Program Goals, No Subsidies" versions of the scenarios, while those of

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[19] It is important to note that the scenarios did not incorporate measures to reduce GHG emissions from the electricity sector; with such measures, penetration of PHEVs would have led to greater reductions on CO_2 emissions.

TABLE 7-23 United States Total Energy Use, Oil, CO_2, and Gasoline Price Results for Base Case and Scenarios with Selected Vehicle Subsidies in Addition to Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
U.S. Total Results						
Ethanol Use (Billion gallons)						
Base Case	4.0	12.6	14.3	15.8	19.2	24.0
Mixed Program Goals Prices with Subsidies	4.0	13.8	15.2	21.0	38.8	45.6
(P)HEV & Ethanol Program Goals Prices with Subsi	4.0	13.8	22.2	38.2	46.3	54.9
H2 Success Program Goals Prices with Subsidies	4.0	13.8	13.9	14.8	19.7	19.5
RFS Standard (includes other fuels besides ethanol)	4.0	13.0	30.0	36.0	36.0	36.0
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Program Goals Prices with Subsidies	20.5	20.3	20.6	21.2	22.1	24.1
(P)HEV & Ethanol Program Goals Prices with Subsi	20.5	20.3	20.3	20.6	21.5	23.2
H2 Success Program Goals Prices with Subsidies	20.5	20.3	20.7	21.3	22.1	22.5
Savings						
Mixed Program Goals Prices with Subsidies	0.0	0.1	0.3	1.1	2.9	4.3
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0	0.1	0.6	1.7	3.5	5.3
H2 Success Program Goals Prices with Subsidies	0.0	0.1	0.2	1.0	2.9	5.9
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Program Goals Prices with Subsidies	60.5%	53.5%	46.1%	42.1%	44.7%	47.8%
(P)HEV & Ethanol Program Goals Prices with Subsi	60.5%	53.6%	44.5%	38.8%	43.3%	45.8%
H2 Success Program Goals Prices with Subsidies	60.5%	53.4%	46.3%	42.7%	46.4%	45.3%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Program Goals Prices with Subsidies	5945	6179	6675	7357	8189	9064
(P)HEV & Ethanol Program Goals Prices with Subsi	5945	6183	6608	7211	8124	9020
H2 Success Program Goals Prices with Subsidies	5945	6171	6681	7346	8091	8560
Reductions (%)						
Mixed Program Goals Prices with Subsidies	0.0%	0.1%	0.4%	1.5%	4.0%	5.0%
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0%	0.0%	1.4%	3.5%	4.7%	5.5%
H2 Success Program Goals Prices with Subsidies	0.0%	0.2%	0.3%	1.7%	5.1%	10.3%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Program Goals Prices with Subsidies	2.33	2.59	2.84	2.96	2.85	3.15
(P)HEV & Ethanol Program Goals Prices with Subsi	2.33	2.60	2.77	2.80	2.80	3.05
H2 Success Program Goals Prices with Subsidies	2.33	2.60	2.84	2.99	2.88	2.80
Reductions (%)						
Mixed Program Goals Prices with Subsidies	0.0%	1.3%	2.4%	6.1%	19.3%	20.0%
(P)HEV & Ethanol Program Goals Prices with Subsi	0.0%	1.1%	4.8%	11.3%	20.9%	22.5%
H2 Success Program Goals Prices with Subsidies	0.0%	1.2%	2.4%	5.2%	18.4%	28.8%

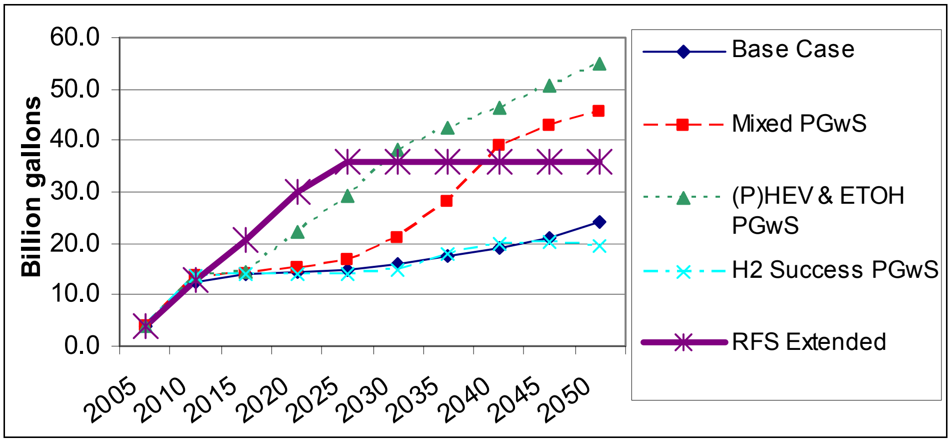

FIGURE 7-37 Ethanol Use (Program Goals with Subsidies)

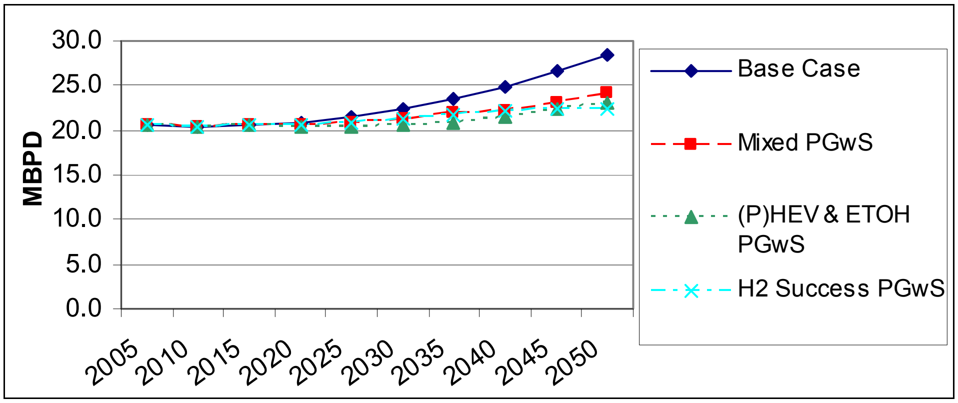

FIGURE 7-38 U.S. Liquid Fuels Supply Excluding Ethanol (Program Goals with Subsidies)

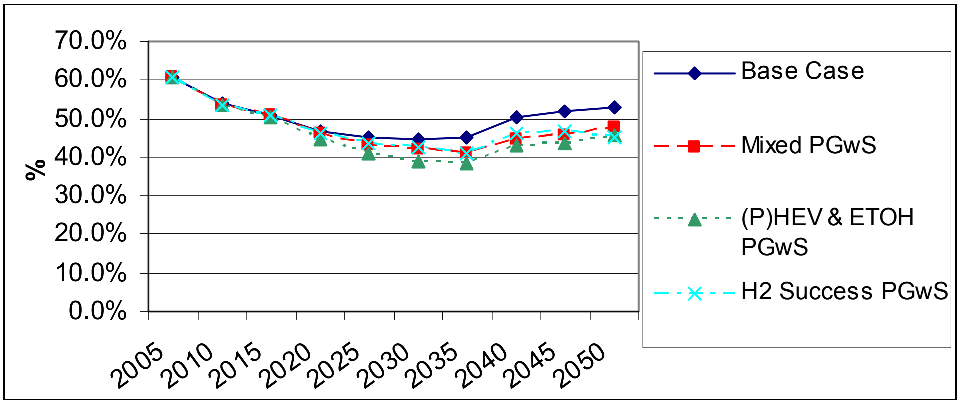

FIGURE 7-39 Net Import Share of Product Supplied (Program Goals with Subsidies)

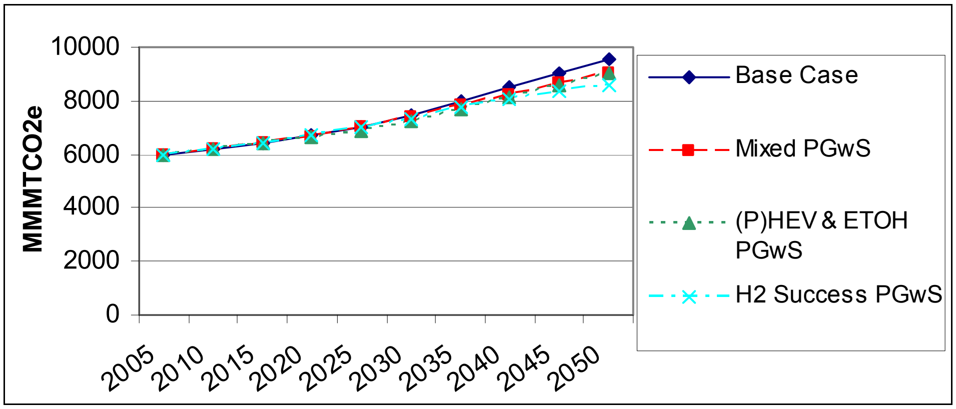

FIGURE 7-40 U.S. CO_2 Emissions (Program Goals with Subsidies)

the H2 Success scenario have achieved a substantial reduction. By 2050, total U.S. emissions of CO_2 are reduced by 10% in this version of the scenario versus 6% in the “Program Goals, No Subsidies” version of the scenario.

7.4.9 Gasoline Price

Table 7-23 and Figure 7-41 present the gasoline prices estimated for the Base Case and scenarios. As expected, gasoline prices are lower than those found in the “Program Goals, No Subsidies” versions of the scenarios. The gasoline prices of the (P)HEV & Ethanol scenario are the lowest over time of all of the scenarios; by 2050, however, the gasoline price of the H2 Success scenario is considerably lower.

7.4.10 Effectiveness of Subsidies

Table 7-24 presents, for each scenario, an estimate of the cumulative vehicle subsidies from 2030 through 2050 and the cumulative oil savings and CO_2 emission reductions achieved with those subsidies in that time period and beyond to 2075. The oil savings and CO_2 emission reductions achieved by the subsidies extend beyond 2050 because vehicles brought into the market by the subsidies will continue to operate beyond 2050. The year 2075 was chosen as an end point to ensure that the potential oil savings and CO_2 reductions of these subsidized vehicles were fully accounted for.

The estimates of post-2050 oil savings and CO_2 reductions were generated by using the VISION model and not NEMS-MP. Section 7.3.10 briefly describes how the VISION model was used to generate such estimates and addresses differences between the two models. That discussion will not be repeated here.

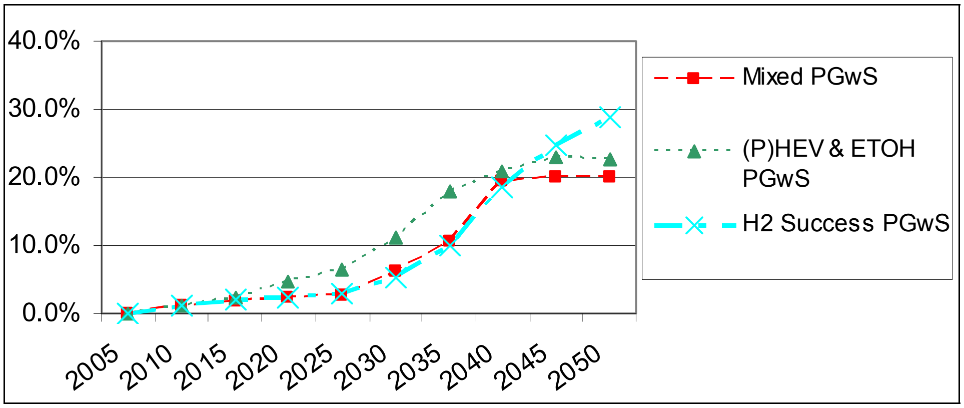

FIGURE 7-41 Gasoline Price Reduction from Base Case (Program Goals with Subsidies)

The total cumulative subsidies of the three scenarios are substantial (although not on the same scale as for the "Literature Review, With Subsidies" versions of the scenarios). The (undiscounted) totals range from approximately $400 billion for the Mixed scenario to nearly $1 trillion for the (P)HEV & Ethanol scenario.

Table 7-24 also presents the subsidy per barrel of oil saved and per metric ton of CO_2 reduced for the three scenarios for both of the following time periods: 2030 to 2050 and 2030 to 2075. In the discussion below, we focus on the time period of 2030 to 2075. The calculations in Table 7-24 assign the total subsidy for each scenario to both barrels of oil saved and metric tons of CO_2 reduced. Alternatively, it may be worthwhile to consider apportioning the total subsidy between the two.

On either basis, the subsidies used to encourage additional market penetration of FCVs in the H2 Success scenario are the lowest and/or most effective; even without apportionment, the oil and CO_2 emission reduction costs are only $56/barrel and $96/metric ton, respectively. The cumulative total subsidy for the Mixed scenario, while the lowest, leads to the highest $/barrel subsidy of the three scenarios and no reduction in CO_2 emissions compared to the "no subsidy" case. The subsidies of the (P)HEV & Ethanol scenario are "in the middle," but in particular are very high for CO_2 emissions reduction.

The (undiscounted) cumulative vehicle subsidy for the H2 Success scenario as estimated in the table is $586 billion. The H2 Success scenario assumes a "jump start" of H_2 stations in the early years of the scenario. That jump start is not without cost: for this case, we estimate the cost to be $8–11 billion (see Appendix B). That subsidy should be added to the cumulative vehicle subsidy. However, it will not alter the relative effectiveness of the H2 Success scenario.

TABLE 7-24 Effectiveness of Subsides in Scenarios with Selected Vehicle Subsidies in Addition to Program Goals Vehicle Prices

Effectiveness of subsidies (undiscounted)							
	From NEMS-MP						
	2030	2035	2040	2045	2050	Cumulative	Cumulative
Mixed						2030-2050	2030-2075
Annual subsidies (billion)	$13.9	$20.0	$19.7	$21.1	$23.3	$416	$416
LV oil savings (Quads)							
Mixed Program Goals Prices	1.8	3.0	4.6	5.8	7.1		
Mixed Program Goals Prices plus Subsidies	1.6	3.0	5.3	6.6	8.0		
Additional savings with subsidies	-0.2	-0.1	0.7	0.7	0.9	8.8	16.1
Additional savings with subsidies (billion barrels)						1.7	3.1
Subsidy/barrel saved						$248	$136
which also saves CO2 (MTCO2e/barrel)						-0.42	-0.31
LV full fuel cycle CO2 reductions (MMTCO2e)							
Mixed Program Goals Prices	134.6	237.9	354.6	427.7	512.9		
Mixed Program Goals Prices plus Subsidies	112.8	190.2	340.5	381.7	481.9		
Additional savings with subsidies	-21.9	-47.7	-14.0	-45.9	-31.1	-697.3	-959.9
Subsidy/metric ton CO2e reduced	No CO2 reduction achieved with subsidy						
which also saves oil (barrel/MTCO2e)							
(P)HEV & Ethanol							
Annual subsidies (billion)	$33.0	$44.6	$46.8	$48.2	$49.6	$946	$946
LV oil savings (Quads)							
(P)HEV & Ethanol Program Goals Prices	2.8	3.8	4.7	5.9	7.5		
(P)HEV & Ethanol Program Goals Prices plus Subsidies	3.0	4.7	6.4	8.1	9.9		
Additional savings with subsidies	0.2	0.9	1.7	2.2	2.4	32.1	49.6
Additional savings with subsidies (billion barrels)						6.1	9.5
Subsidy/barrel saved						$155	$100
which also saves CO2 (MTCO2e/barrel)						0.04	0.02
LV full fuel cycle CO2 reductions (MMTCO2e)							
(P)HEV & Ethanol Program Goals Prices	264.7	325.8	376.9	432.8	529.9		
(P)HEV & Ethanol Program Goals Prices plus Subsidies	259.0	350.5	405.1	438.0	526.7		
Additional savings with subsidies	-5.8	24.7	28.2	5.1	-3.2	263.4	188.6
Subsidy/metric ton CO2e reduced						$3,592	$5,016
which also saves oil (barrel/MTCO2e)						23.2	50.1
H2 Success							
Annual subsidies (billion)	$1.1	$6.1	$24.9	$44.5	$68.4	$586	$586
LV oil savings (Quads)							
H2 Success Program Goals Prices	1.7	2.9	4.3	6.0	7.8		
H2 Success Program Goals Prices plus Subsidies	1.7	3.1	5.2	8.0	11.2		
Additional savings with subsidies	0.0	0.2	0.9	2.1	3.4	26.0	55.0
Additional savings with subsidies (billion barrels)						5.0	10.5
Subsidy/barrel saved						$118	$56
which also saves CO2 (MTCO2e/barrel)						0.61	0.58
LV full fuel cycle CO2 reductions (MMTCO2e)							
H2 Success Program Goals Prices	110.5	223.5	324.8	445.0	588.7		
H2 Success Program Goals Prices plus Subsidies	124.0	243.3	438.8	671.5	986.4		
Additional savings with subsidies	13.5	19.7	114.0	226.5	397.8	3,035.3	6,115.0
Subsidy/metric ton CO2e reduced						$193	$96
which also saves oil (barrel/MTCO2e)						1.6	1.7

Note: Only the cumulative $/bbl or $/metric ton CO2 is shown because the subsidy expended during any year is "purchasing" future oil savings over the lifetime of vehicles purchased during that year. Note too that the $/bbl or $/metric ton estimates for the period 2030-2050 are overestimates because additional oil savings and CO2 reductions will accrue in the years following 2050 from vehicles purchased with pre-2051 subsidies. These additional savings and reductions are accounted for in the column presenting $/barrel and $/metric tion CO2 for the period 2030-2075. Oil savings and CO2 reductions for the years 2051-2075 were developed with the VISION model.

7.4.11 Concluding Remarks about Impacts of Scenarios with "Program Goals" Vehicle Prices Plus Subsidies

The subsidies examined lead to significant increases in ATV market penetration and to reductions in overall U.S. and LV oil use and gasoline prices relative to both the Base Case and the "Program Goals, No Subsidies" versions of the scenarios. However, only the H2 Success scenario further reduces LV full-fuel-cycle and total U.S. emissions of CO_2 from the levels achieved in the "Program Goals, No Subsidies" cases. Further review is needed of how electricity sources for PHEV charging are estimated in NEMS-MP and how the results might change with different underlying assumptions (including policies intended to reduce the carbon intensity of electricity generation) before we conclude that the increased use of PHEVs in these scenarios will not reduce CO_2 emissions by significant amounts.

7.5 CONCLUDING REMARKS: GENERAL

The scenario results using the four sets of vehicle prices ("Literature Review, No Subsidies," "Program Goals, No Subsidies," "Literature Review, With Subsidies," and "Program Goals, With Subsidies") should not be regarded as being equally probable. The "literature review" prices are just that and are the most likely of the four to be achieved (although even the LR estimates may be considered optimistic). The "program goals" prices are less likely to be realized than the "literature review" prices. The specific subsidies used in conjunction with both the "literature review" and "program goals" vehicle prices are quite substantial and required for long periods of time; these specific subsidies are thus unlikely.

Nevertheless, the LV oil savings and CO_2 emission reductions of the scenarios which use only the "literature review" vehicle prices are quite modest. If substantial oil savings are to be achieved by advanced technology LVs (and lower ethanol and H2 fuel prices), then some combination of lower vehicle prices and/or vehicle subsidies may be required. Table 7-25 compares the oil savings (and CO_2 reduction) results of the "Literature Review, With Subsidies" and "Program Goals, With Subsidies" versions of the scenarios. The levels of oil savings and CO_2 reductions realized are quite similar across versions. In other words, there are numerous combinations of vehicle prices and subsidies that could result in oil savings of approximately 1–2 mbpd by 2030 and 4–6 mbpd by 2050 (from the Base Case).

In addition, while the "Literature Review, No Subsidies" results might be regarded as the most likely, we would like to test the market penetration rates of advanced technology vehicles by using these vehicle price assumptions in a scenario with higher oil prices than we have used. As discussed, we used the AEO 2007 High World Oil Price estimates extended (i.e., to \$93 in 2030 and \$116 in 2050). Oil prices in 2008 were higher than these. Clearly, with significantly higher oil prices, the market penetration rates would be stronger, but it is not known by how much. The Mixed scenario would seem to be the most appropriate of the three scenarios to use for such a run.

Finally, we would also like to modify the PHEV technology assumptions and input the modified assumptions into another NEMS-MP model run. Without subsidies, PHEV40s achieved at most 1.2% of sales by 2050 with the "literature review" vehicle price assumptions and 6% of sales with the "program goals" assumptions. PHEV10s and PHEV20s will cost substantially less and should capture greater market share; however, again how much more is not known. Another sensitivity case using the NEMS-MP model could help answer that question.

TABLE 7-25 LV Oil Use Savings and LV Full-Fuel-Cycle CO_2 Emission Reductions in "Literature Review with Subsidies" and "Program Goals with Subsidies" Versions of Scenarios

	2010	2020	2030	2040	2050
Base Case LV Oil Use (mbpd)	8.42	8.48	9.21	10.53	12.06
Oil Savings of Scenarios using Literature Review Vehicle Prices plus Subsidies (mbpd)					
Mixed	0.1	0.1	1.3	3.0	5.1
(P)HEV & Ethanol	0.1	0.5	1.9	3.4	5.1
H2 Success	0.1	0.1	1.0	3.3	5.4
Oil Savings of Scenarios using Program Goals Vehicle Prices plus Subsidies (mbpd)					
Mixed	0.1	0.2	0.8	2.8	4.2
(P)HEV & Ethanol	0.1	0.5	1.6	3.3	5.2
H2 Success	0.1	0.2	0.9	2.7	5.9
Base Case LV Full-Fuel-Cycle CO_2 Emissions ($MMTCO_2e$)[1]	1440	1511	1621	1893	2123
CO_2 Reductions of Scenarios using Literature Review Vehicle Prices plus Subsidies (%)					
Mixed	0.7%	0.0%	7.6%	17.9%	29.3%
(P)HEV & Ethanol	0.6%	5.7%	16.4%	20.2%	21.9%
H2 Success	1.3%	0.2%	8.4%	28.5%	43.3%
CO_2 Reductions of Scenarios using Program Goals Vehicle Prices plus Subsidies (%)					
Mixed	0.4%	1.6%	7.0%	18.0%	22.7%
(P)HEV & Ethanol	0.1%	6.1%	16.0%	21.4%	24.8%
H2 Success	0.9%	1.3%	7.6%	23.2%	46.5%

[1] $MMTCO_2e$ = million metric tones of carbon dioxide equivalent.

ATTACHMENT TO CHAPTER 7: ADJUSTMENTS MADE TO DIRECT NEMS-MP OUTPUTS

LV Oil Use. NEMS-MP provides total levels of gasoline, diesel fuel, and E85 used by LVs (including commercial LTs [Class 2B]); these are summed. The gasoline includes ethanol blends, and the E85 includes gasoline, and we need to subtract out these ethanol volumes to determine LV oil use. NEMS-MP provides direct estimates of ethanol used in E85 (all by LVs). NEMS-MP also provides estimates of the total ethanol used in gasoline blends. However, some of these gasoline blends are used by medium trucks, school buses, and other vehicles, as well as in other economic sectors. We estimate the LV share of total gasoline consumption (e.g., 96% in the MP Base Case in 2005) and apply that to the total ethanol used in gasoline blends to estimate the volume of ethanol used in gasoline blends by LVs. That total is combined with the ethanol used in E85 by LVs, and the combined total is subtracted from the previously mentioned sum of gasoline, diesel fuel, and E85 to obtain LV oil use estimates.

Also, we convert all quads to million barrels per day at the gasoline conversion rate, even though some of the oil is in the form of diesel fuel.

LV Full-Fuel-Cycle CO_2 Emissions. For the most part, NEMS-MP reports energy-related CO_2 emissions based on the sector in which they are emitted, rather than allocating emissions to the point of end-use. The exception is for the electricity sector, where emissions are allocated to the end-use sectors on the basis of relative electricity purchases. This approach makes it difficult to trace the full-fuel-cycle CO_2 emissions for light vehicles (LVs).

Because of this complexity, we adopted a two=step process for determining LV fuel cycle emissions in our scenarios. First, we estimated the full-fuel-cycle LV emissions (including Class 2B commercial trucks) from a base case without CAFE by using information from several EPA reports on U.S. GHG emissions. Next, we assumed that all changes in U.S. CO_2 emissions in our other scenarios, including the Base Case with CAFE, were attributable to the LV sector because virtually all of the assumptions that we altered in these other scenarios relative to the Base Case without CAFE are LV-related. These derivations are described in Appendix C.

U.S. Liquid Fuels Supply. The U.S. liquid fuels supply reported by NEMS-MP includes H_2. H_2 probably has been included because its relative volume is very low and its use is for vehicles. However, with the potential for increased use of H_2 by LVs, it should be excluded from the liquid fuel supply calculations. This is the approach we have taken.

Net Import Share of Product Supplied. The net import share of liquid fuel product supplied reported by NEMS-MP includes H_2. We have taken H_2 out of the calculation because it is not a liquid fuel.

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8 ENERGY SECURITY BENEFITS AS MODELED IN OSMM

8.1 BACKGROUND

Strengthening America's energy security is one of three fundamental missions of the DOE's Office of Energy Efficiency and Renewable Energy. The first of EERE's portfolio priorities is to "dramatically reduce or even end dependence on foreign oil." To be able to measure the potential impacts of its research and development programs on U.S. oil dependence, EERE developed the Oil Security Metrics Model (OSMM) (Greene and Leiby 2006). Given estimates of program impacts on technology performance and on U.S. oil use, the OSMM simulates their effects on the costs of U.S. oil dependence, taking into consideration a multiplicity of uncertainties about future oil market conditions. Following the recommended approach of the National Academy of Science's Committee on Prospective Evaluation of Applied Energy Research and Development at DOE (NRC 2005), security benefits are estimated to be the difference between expected program benefits during disrupted market conditions and those during normal market conditions. Normal market conditions are represented by the 2008 Annual Energy Outlook (AEO) Reference Case (EIA 2008).

This section of the report discusses the expected oil security benefits of the three alternative technology scenarios (as opposed to the DOE R&D program) that are being analyzed in the MP Study. The MP Study considers various degrees of R&D success but only the cases using the "literature review" (LR) vehicle price estimates (as opposed to "program goals" price estimates) are evaluated here. Each scenario is analyzed with and without policies that subsidize petroleum-displacing, potentially low-emitting GHG technologies, for a total of six cases:

1. Mixed without subsidies
2. H2 Success without subsidies
3. (P)HEV & Ethanol without subsidies
4. Mixed with subsidies
5. H2 Success with subsidies
6. (P)HEV & Ethanol with subsidies.

As discussed in Chapters 5 and 6, the MP Base Case and scenarios were developed by using the high oil prices of the High Oil Price case of the AEO 2007. Recognizing the high degree of uncertainty associated with future oil prices, the oil security benefits below are estimated using three oil price cases from the 2008 AEO:

1. Reference Case — representing normal, undisrupted market conditions; prices are just under $60/bbl in 2030 and remain near that level to 2050.

2. High Oil Price Case — representing smaller global resources of conventional oil and a more constrained Organization of the Petroleum Exporting Countries (OPEC) production schedule; prices are just over $95/bbl in 2030 and continue increasing to $110/bbl by 2050. (These prices are very similar to those used in the development of the scenarios. See Section 8.2 below.)

3. Low Oil Price Case — representing more abundant global oil resources, a greater willingness of OPEC to produce, and success in producing petroleum fuels from unconventional resources; prices fall to $35/bbl by 2030 and decline further to $15/bbl by 2050.

The oil price cases span a very wide range of possible futures (Figure 8-1). In the high oil price case, oil savings will be much more valuable than in the reference case; in the low oil price case, oil savings will be much less valuable. Characterizing the uncertainty about future states of the world oil market is critical to estimating the potential energy security benefits of advanced, energy-efficient technologies.

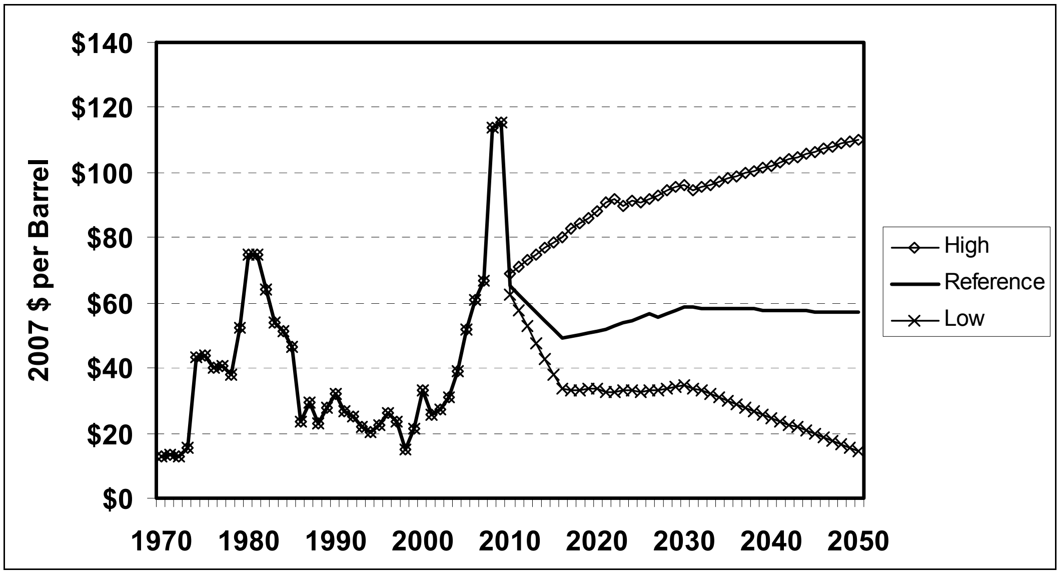

Figure 8-1 AEO 2008 World Oil Price Cases Extrapolated to 2050 by the OSMM

In each of these cases, oil supply disruptions may occur. Supply disruptions induce oil price shocks. Disruptions may last one or several years. In each succeeding year of a disruption, OPEC supply may increase or decrease. The stochastic model used to simulate disruptions was calibrated to historical disruptions as described in Greene and Leiby (2006). Thus, as a general rule, future oil prices will not follow the relatively smooth paths shown in Figure 8-1. Instead, future prices will generally be erratic and appear more like historical prices from 1970 to today.

8.2 ESTIMATED SCENARIO IMPACTS

Estimated impacts for the three scenarios in the context of the MP Base Case are shown in Table 8-1. These impacts have been discussed previously in Chapter 7. While the MP Base Case is based on the AEO 2007 Reference case, it assumes high oil prices similar to those of the AEO 2008 High Oil Price Case (i.e., $93/barrel in 2030 and $116 in 2050 [in 2005$]) and incorporates the latest CAFE standards. The three scenarios achieve petroleum reductions of 2 to 3 mbpd by

2050 in the cases without subsidies and 5 mbpd in the cases with subsidies. The (P)HEV & Ethanol scenario is expected to produce the most immediate and largest reductions in petroleum use over time in the cases both with and without subsidies. The H2 Success scenario with subsidies achieves the greatest annual reduction by 2050: — 5.4 mbpd.

It is important to note that if these scenarios had been developed with lower oil prices (i.e., like the Low and Reference oil price cases used in this analysis), the impacts shown likely would not have been as great. Lower impacts would result in smaller oil security benefits.

TABLE 8-1 Estimated Scenario Oil Savings Over MP Base Case (in mbpd) (Scenarios and Cases Use "Literature Review" Vehicle Prices)

Scenario	*2010*	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
Mixed w/o subsidies	0.1	0.0	0.1	0.3	0.6	1.2	1.8	2.1	2.5
PHEV & Ethanol w/o subsidies	0.1	0.1	0.5	0.9	1.3	1.9	2.3	2.7	3.0
Hydrogen Success w/o subsidies	0.1	0.0	0.1	0.2	0.4	0.8	1.3	1.7	2.0
Mixed with subsidies	0.1	0.0	0.1	0.5	1.3	2.2	3.0	4.0	5.1
PHEV & Ethanol with subsidies	0.1	0.1	0.5	1.1	1.9	2.7	3.4	4.2	5.1
Hydrogen Success with subsidies	0.1	0.0	0.1	0.3	1.0	2.2	3.3	4.4	5.4

Energy technology programs can enhance oil security not only by displacing oil use, but also by increasing the price elasticity of petroleum demand. All three scenarios are likely to impact the price elasticity of U.S. petroleum demand. Advanced automotive technologies extend the envelope of what is achievable and shift the supply curve for fuel economy to the right; thus, more fuel economy is available at a lower initial cost. This changes the fuel price elasticity of automotive fuel economy, which affects the long-run price elasticity of gasoline demand and, hence, the price elasticity of oil demand. Increased market penetration of biofuels and hydrogen (see Tables 8-2 and 8-3) can also increase the price elasticity of demand for petroleum fuels, depending on the relative prices of the fuels. A significant market penetration of hydrogen-fueled vehicles should also increase the price elasticity of demand for oil. However, the current version of the OSMM is not able to estimate the change in price elasticity that can be specifically attributed to hydrogen-powered vehicles. In addition, a methodology for estimating the elasticity impacts of PHEVs has not yet been incorporated in the model. For the sake of consistency and in order to err on the side of underestimating oil security benefits, the estimates presented below do not attempt to account for elasticity impacts except for increased non-petroleum fuel use, as shown in Table 8-2. PHEV benefits are based solely on petroleum displacement.

TABLE 8-2 Estimated Changes in Ethanol Use Over MP Base Case (mbpd on a GGE basis) (Scenarios and Cases Use "Literature Review" Vehicle Prices)

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
Mixed w/o subsidies	0.06	0.01	0.07	0.14	0.34	0.70	1.07	1.15	1.19
PHEV & Ethanol w/o subsidies	0.06	0.02	0.42	0.77	1.15	1.45	1.67	1.82	1.92
Hydrogen Success w/o subsidies	0.06	-0.00	0.02	0.05	0.09	0.24	0.49	0.63	0.63
Mixed Optimistic with subsidies	0.06	0.01	0.07	0.13	0.27	0.52	0.74	0.83	0.75
PHEV & Ethanol with subsidies	0.06	0.02	0.42	0.73	1.05	1.21	1.27	1.39	1.45
Hydrogen Success with subsidies	0.06	0.00	0.02	0.04	0.05	0.12	1.12	0.12	0.02

TABLE 8-3 Estimated Changes in Hydrogen Fuel Use Over MP Base Case (mbpd on a GGE basis) (Scenarios and Cases Use "Literature Review" Vehicle Prices)

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
Mixed w/o subsidies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PHEV & Ethanol w/o subsidies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen Success w/o subsidies	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.08
Mixed Optimistic with subsidies	0.00	0.00	0.00	0.00	0.02	0.04	0.14	0.34	0.82
PHEV & Ethanol with subsidies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen Success with subsidies	0.00	0.00	0.01	0.12	0.41	0.99	1.64	2.25	2.82

8.3 ESTIMATED OIL SECURITY BENEFITS

Oil security benefits are estimated as the difference between normal market benefits in normal, undisrupted oil markets and benefits in oil markets that assume occasional disruptions. Normal market benefits are assumed to be those obtained in the AEO 2008 Reference Case with no supply disruptions. Disrupted benefits allow for the possibility of supply reductions from the AEO's predicted OPEC oil output and include the High and Low World Oil Price Cases in addition to the Reference Case. Uncertainty about which price path is correct is represented by assigning a 40% probability to the Reference Case and a 30% probability to both the High and Low Oil Price Cases.

Stochastic supply shocks are generated by using the model described in Greene and Leiby (2006). In each year, if no shock is in progress, there is a 10% probability that a price shock will occur. If one occurs, its duration in years is also determined stochastically. For each year of the shock, supply may increase or decrease (although the probability of decrease is greater) by an amount chosen from a probability distribution calibrated to past OPEC supply reductions. There is also uncertainty about how OPEC might respond to reduced U.S. oil demand as a consequence of the success of EERE's technology programs. Two alternative strategies are simulated: (1) OPEC ignores the change, maintaining the production schedule of the original scenario, or (2) OPEC reduces production enough to restore the price of oil to that of the original scenario. These strategies are applied after supply disruptions have been incorporated in the scenario.

Reducing U.S. oil use and increasing the price elasticity of U.S. oil demand reduces the three costs of oil dependence:

1. Transfer of wealth,
2. Loss of potential gross domestic product (GDP), and
3. Price shock disruption costs.

The sum of the reductions in each of the three components is the estimated total oil market benefits. The difference between the total oil market benefits in disrupted markets and the total oil market benefits in an undisrupted market (Undisrupted Reference Case) is the energy security benefit. Oil security benefits are summarized in Tables 8-4 and 8-5. The rows in each table labeled "Disrupted Oil Market Benefits" contain the expected reduction in the sum of the three oil dependence costs based on 10,000 simulation runs that include the possibility of oil market disruptions and that switch among the three AEO oil price cases. These numbers include both the normal market reductions in oil dependence costs and the disrupted market benefits. The rows labeled "Undisrupted Market Benefits" contain the expected reduction in the sum of the three oil dependence costs in the absence of any supply disruptions and using only the Reference Case price projections. The first two columns show benefits assuming that OPEC maintains the original oil production path of the (disrupted or undisrupted) AEO Case. The third and fourth columns present cost estimates assuming OPEC adjusts output to maintain the oil price level of the disrupted AEO Case. The fifth and sixth columns are a simple average of the benefits under the two alternative assumptions about OPEC behavior. These estimates include the key oil security uncertainties not reflected in the usual DOE GPRA oil benefits analysis:

1. The potential for oil supply disruptions,
2. Uncertainty about the extent of conventional oil resources, and
3. Uncertainty about OPEC's willingness to expand oil production.

Future benefits are discounted to the present value at the rate of 3% per year.

Undisrupted market benefits are greatest when OPEC maintains its production schedule regardless of the change in U.S. oil demand. Energy security benefits are greatest when OPEC maintains the oil price trajectory that would have prevailed in the absence of a reduction in U.S. petroleum demand. Since OPEC's reaction to changes in U.S. oil demand are uncertain but likely to lie between one of these two strategies, the average of energy security benefits under the two alternative OPEC strategies is an appropriate measure of expected energy security benefits.

TABLE 8-4 Estimated Oil Security Benefits of MP Scenarios without Subsidies, 2010–2050

			Oil Market Benefits		
			(Billions of 2007$, Present Value Discounted at 3%/Year)		
Scenario	**Supply Shocks?**	**Oil Price Cases**	OPEC Maintains	OPEC Maintains	Average of OPEC Response
			Production	Price	Strategies
Mixed (LR Vehicle Prices without Subsidies)					
Disrupted Market Benefits	Yes	All three	$496	$455	$476
Undisrupted Market Benefits	No	Reference	$359	$271	$315
Security Benefit			**$137**	**$184**	**$161**
PHEV & Ethanol (LR Vehicle Prices without Subsidies)					
Disrupted Market Benefits	Yes	All three	$925	$860	$893
Undisrupted Market Benefits	No	Reference	$615	$476	$546
Security Benefit			**$310**	**$384**	**$347**
H2 Success (LR Vehicle Prices without Subsidies)					
Disrupted Market Benefits	Yes	All three	$345	$316	$331
Undisrupted Market Benefits	No	Reference	$266	$201	$234
Security Benefit			**$79**	**$115**	**$97**

TABLE 8-5 Estimated Oil Security Benefits of MP Scenarios with Subsidies, 2010–2050

			Oil Market Benefits		
			(Billions of 2007 $, Present Value Discounted at 3%/Year)		
Scenario	**Supply Shocks?**	**Oil Price Cases**	OPEC Maintains	OPEC Maintains	Average of OPEC Response
			Production	Price	Strategies
Mixed (LR Vehicle Prices with Subsidies)					
Disrupted Market Benefits	Yes	All Three	$836	$780	$808
Undisrupted Market Benefits	No	Reference	$632	$493	$563
Security Benefit			**$204**	**$287**	**$246**
PHEV & Ethanol (LT=R Vehicle Prices with Subsidies)					
Disrupted Market Benefits	Yes	All Three	$1,180	$1,108	$1,144
Undisrupted Market Benefits	No	Reference	$820	$648	$734
Security Benefit			**$360**	**$460**	**$410**
H2 Success (LR Vehicle Prices with Subsidies)					
Disrupted Market Benefits	Yes	All Three	$863	$808	$836
Undisrupted Market Benefits	No	Reference	$642	$500	$571
Security Benefit			**$221**	**$308**	**$265**

The MP scenario results are as follows:

- Expected energy security benefits range from just under $100 billion in present-value 2007 dollars in the Hydrogen Success scenario without subsidies to just over $400 billion in the PHEV & Ethanol scenario with subsidies.
- In general, ***total*** oil market benefits are smaller when OPEC attempts to respond to reduced U.S. oil demand by defending the price of oil. Oil security benefits, however, are ***larger*** in that case.
- For all three scenarios, expected energy security benefits are greater in the cases with subsidies than in those without subsidies.
- The (P)HEV & Ethanol scenario (with and without subsidies) generates the greatest energy security benefits.
- The Mixed scenario is second best of the no-subsidies cases, while the H2 Success scenario is second best of the cases with subsidies.
- As most of the savings occur in the out years, present values are less than half of the undiscounted sum of annual benefits.
- Because the benefit estimates are discounted to present value and because they are economic only, they can be directly compared with current GDP or with other reference points. The security benefits shown in the tables range from 0.6% to 3.3% of current GDP.

The security benefits thus estimated are additional to direct fuel cost savings from reduced petroleum use. The military and strategic benefits of reduced dependence on petroleum are probably equal or greater in value, although no attempt has been made to estimate them here.

8.4 IMPACTS ON THE VARIABILITY OF OIL DEPENDENCE COSTS OVER TIME

The energy security benefits of reducing oil demand and increasing its price elasticity are a consequence of reducing both the expected costs of oil dependence and their variance. Oil dependence costs as a percentage of GDP for the Base Case are shown in Figure 8-2. The variability of oil dependence costs in the Base Case as simulated by the OSMM is represented by the probability distribution of costs illustrated in Figure 8-2. Expected costs are shown by the yellow line. The area shaded brown represents an interval of +/– one standard deviation around the mean. The area shaded green extends this to a 90% confidence interval. There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded. Of course, the entire time-varying probability distribution is dependent on the assumptions incorporated into the OSMM.

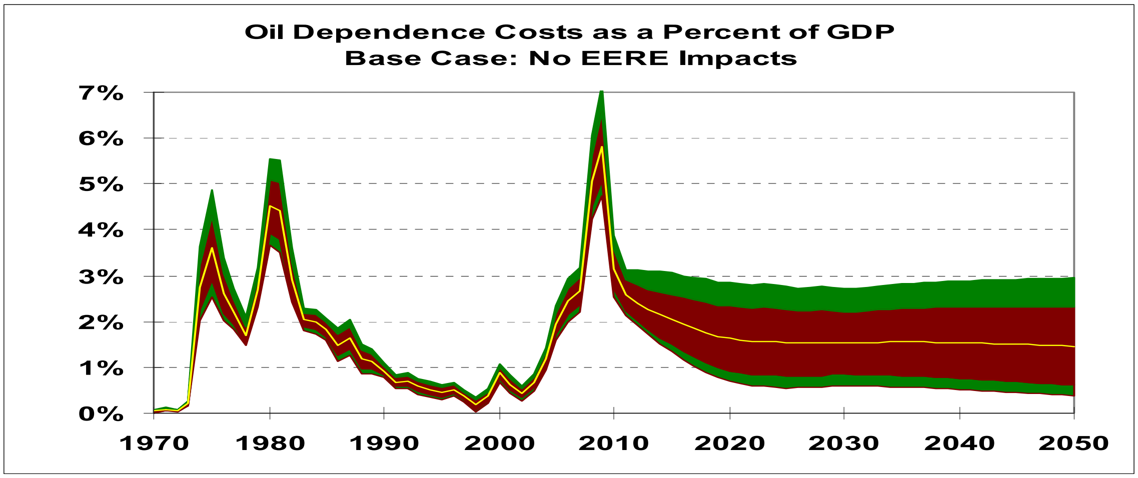

FIGURE 8-2 Base Case Distribution of Oil Dependence Costs[1]

[1] Yellow line = expected costs.
Brown area represents an interval of +/– one standard deviation around the mean.
Green area extends this to a 90% confidence interval.
There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

In the Base Case with no additional impacts over and above what may already be reflected in the AEO Reference, High Oil Price, and Low Oil Price cases, the expected costs of oil dependence fall rapidly from the current level of 6% of GDP to approximately 1.5% from 2020 to 2050. This drop reflects clearly the EIA's belief that current high oil prices will not be sustained. The 95th percentile remains in the vicinity of 3% of GDP. With GDP projected to exceed $20 trillion in 2030, annual expected oil dependence costs are almost $300 billion with a 5% probability of exceeding $550 billion.

Reducing oil dependence costs to less than 1% of GDP by 2030 with 95% probability has been proposed as a rigorous definition of "oil independence" (Greene et. al. 2007). By this standard, the United States will not achieve "oil independence" by 2030 or thereafter with the Base Case.

The impacts of the MP scenarios with and without subsidies on both expected costs and the variability of costs over time and on progress toward achieving "oil independence" are presented in Table 8-6 and Figures 8-3 through 8-14. (Table 8-6 simply contains selected data points from the figures.) The impacts, some of which are obvious but bear stating, are as follows:

- The scenarios, both with and without subsidies, lower the oil dependence costs as a percentage of GDP from those of the Base Case;
- Greater reductions are achieved in the 95th percentile than in the mean (expected) costs;
- Nevertheless, the scenarios alone do not achieve the goal of "oil independence," nor do they even come close;

TABLE 8-6 Oil Dependence Costs as a Percentage of GDP (%)

Scenario/Case	Current	2030	2050
Goal with 95% Probability	–	<1	<1
Base Case			
Mean	6	~1.5	~1.5
95th Percentile		~2.8	~3
No Subsidies – OPEC Maintains Price			
Mixed: Mean		1.4	1.2
: 95th Percentile		2.6	2.4
(P)HEV & ETOH[1]: Mean		1.3	1.1
: 95th Percentile		2.3	2.0
H2 Success: Mean		1.5	1.3
: 95th Percentile		2.6	2.6
No Subsidies – OPEC Maintains Production			
Mixed: Mean		1.4	1.2
: 95th Percentile		2.6	2.4
(P)HEV & ETOH: Mean		1.3	1.1
: 95th Percentile		2.3	2.1
H2 Success: Mean		1.5	1.3
: 95th Percentile		2.6	2.6
With Subsidies – OPEC Maintains Price			
Mixed: Mean		1.4	1.0
: 95th Percentile		2.4	2.0
(P)HEV & ETOH: Mean		1.3	0.9
: 95th Percentile		2.2	1.7
H2 Success: Mean		1.4	0.9
: 95th Percentile		2.5	1.9
With Subsidies – OPEC Maintains Production			
Mixed: Mean		1.4	1.0
: 95th Percentile		2.4	2.0
(P)HEV & ETOH: Mean		1.2	0.9
: 95th Percentile		2.2	1.8
H2 Success: Mean		1.4	0.9
: 95th Percentile		2.5	1.9

[1] ETOH = ethanol.

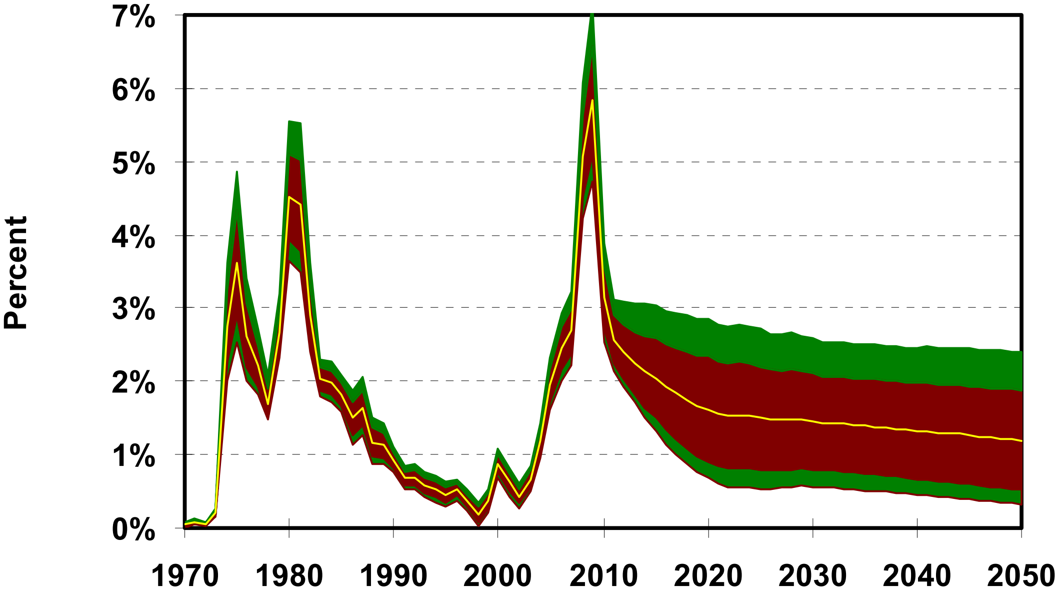

FIGURE 8-3 Oil Dependence Costs as a Percent of GDP, Mixed, No Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

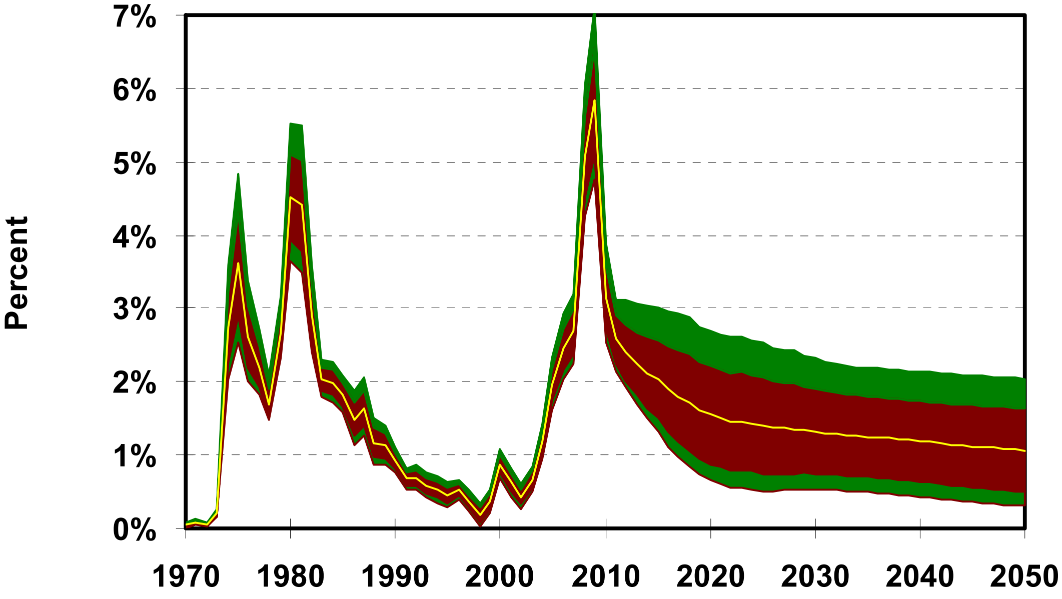

FIGURE 8-4 Oil Dependence Costs as a Percent of GDP, (P)HEV & Ethanol, No Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

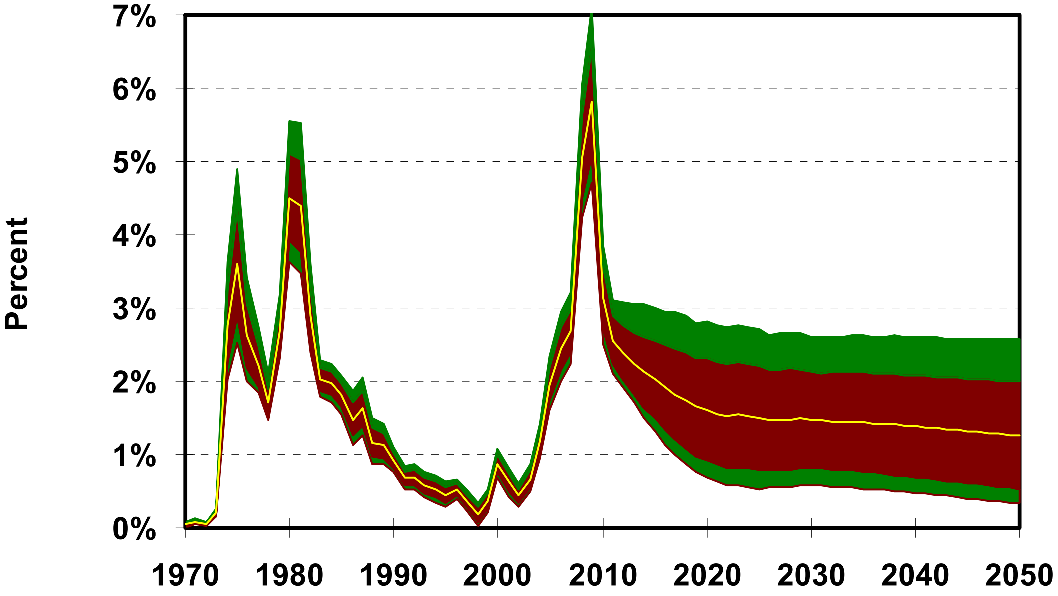

FIGURE 8-5 Oil Dependence Costs as a Percent of GDP, H2 Success, No Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

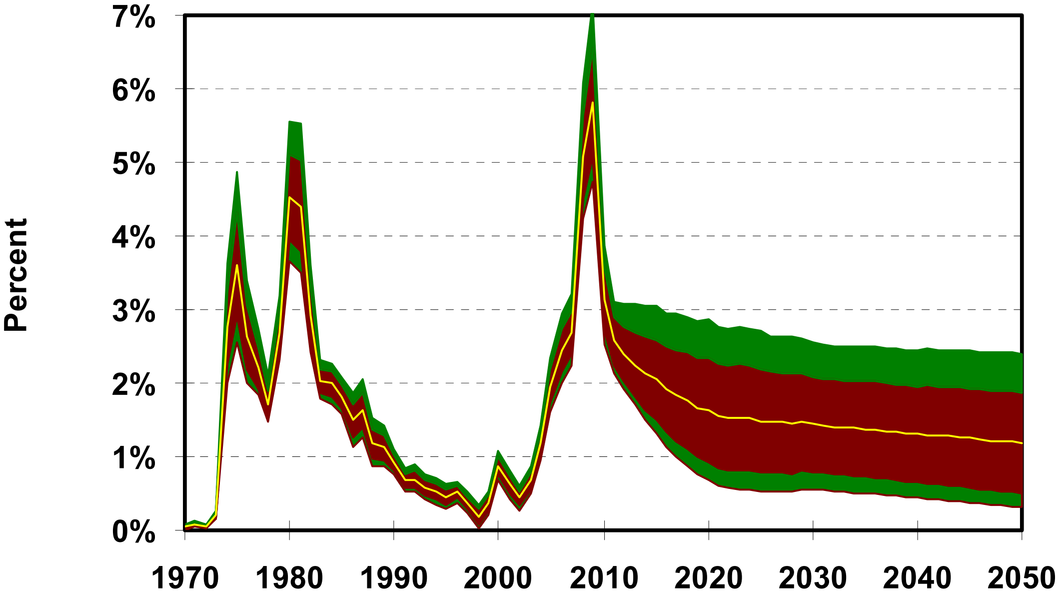

FIGURE 8-6 Oil Dependence Costs as a Percent of GDP, Mixed, No Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

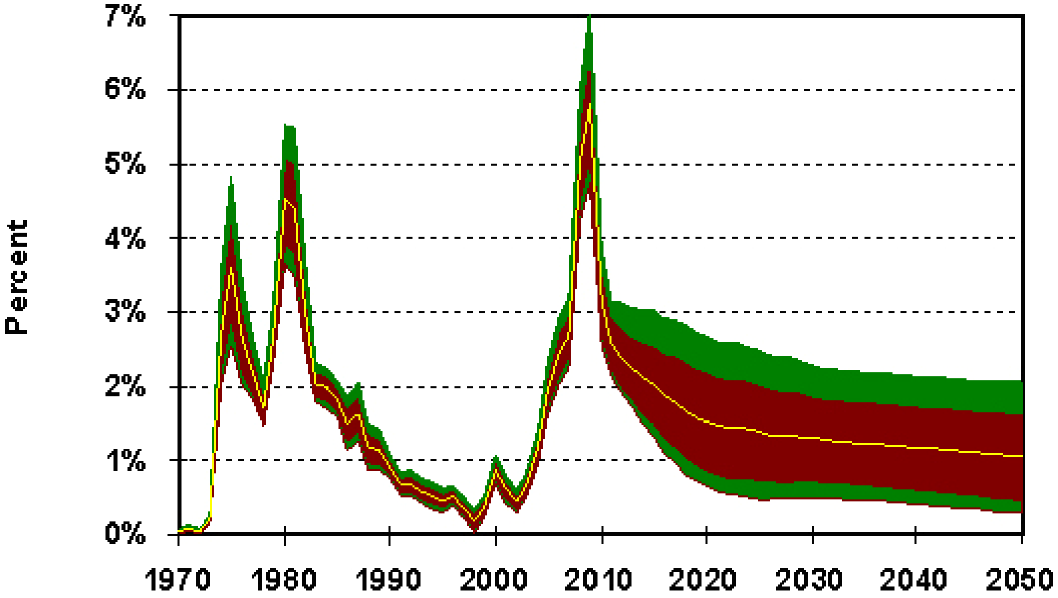

FIGURE 8-7 Oil Dependence Costs as a Percent of GDP, (P)HEV & Ethanol, No Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.
Brown area represents an interval of +/– one standard deviation around the mean.
Green area extends this to a 90% confidence interval.
There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

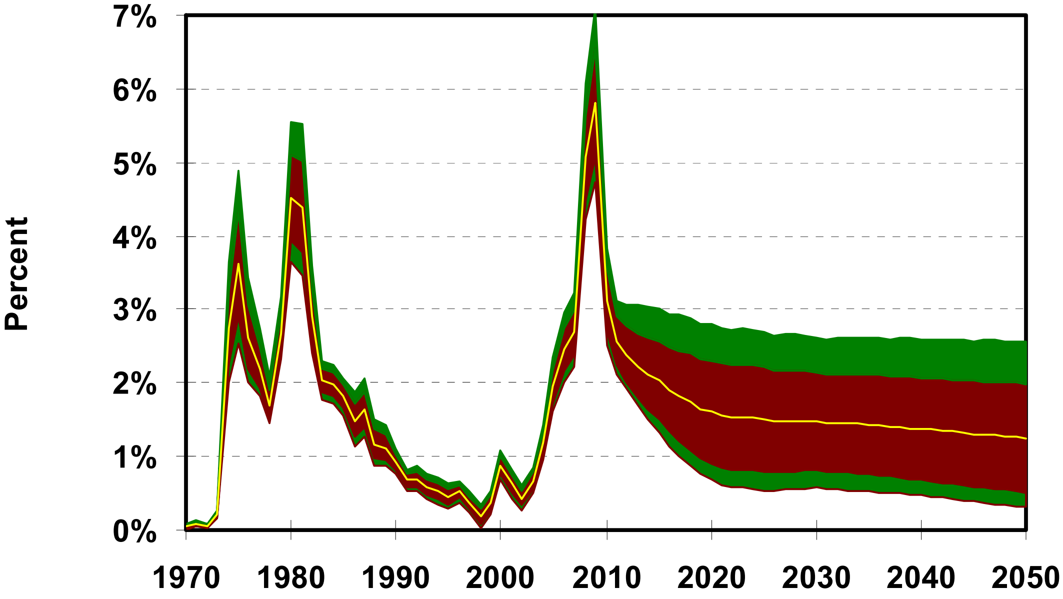

FIGURE 8-8 Oil Dependence Costs as a Percent of GDP, H2 Success, No Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.
Brown area represents an interval of +/– one standard deviation around the mean.
Green area extends this to a 90% confidence interval.
There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

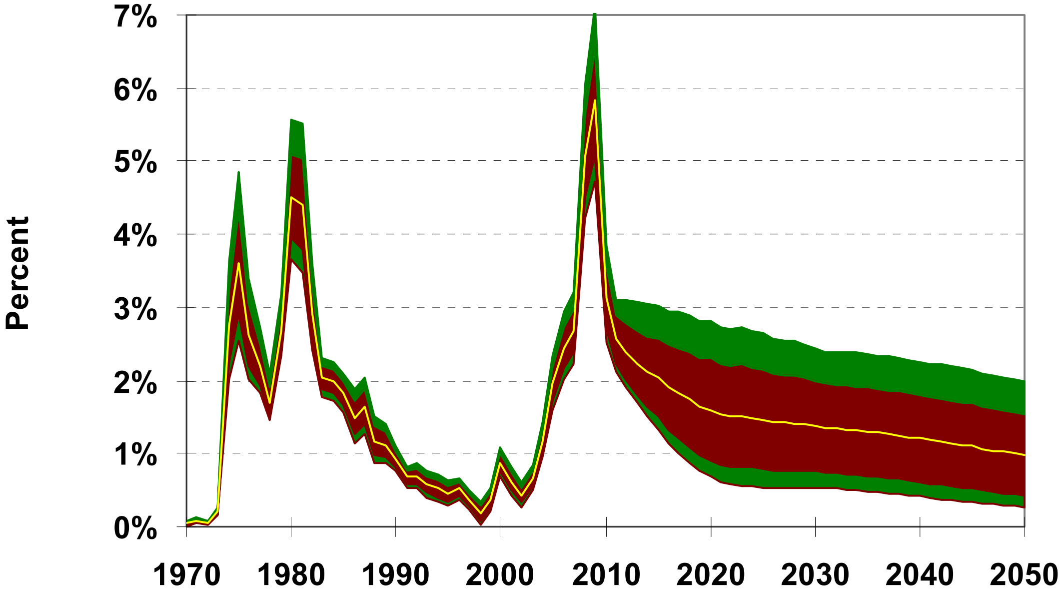

FIGURE 8-9 Oil Dependence Costs as a Percent of GDP, Mixed with Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

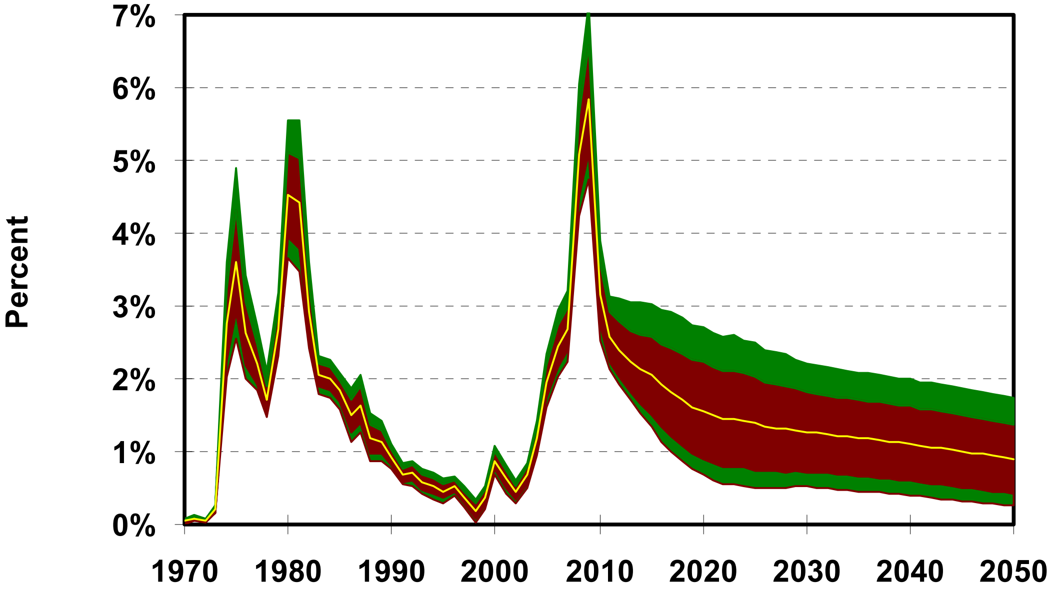

FIGURE 8-10 Oil Dependence Costs as a Percent of GDP (P)HEV & Ethanol with Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

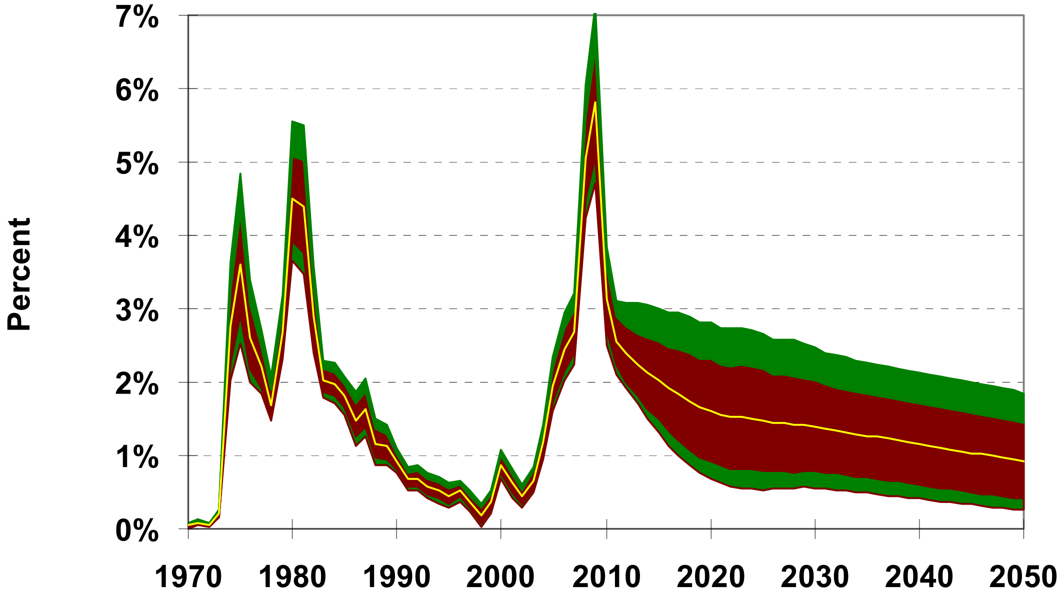

FIGURE 8-11 Oil Dependence Costs as a Percent of GDP, H2 Success with Subsidies: OPEC Maintains Price[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

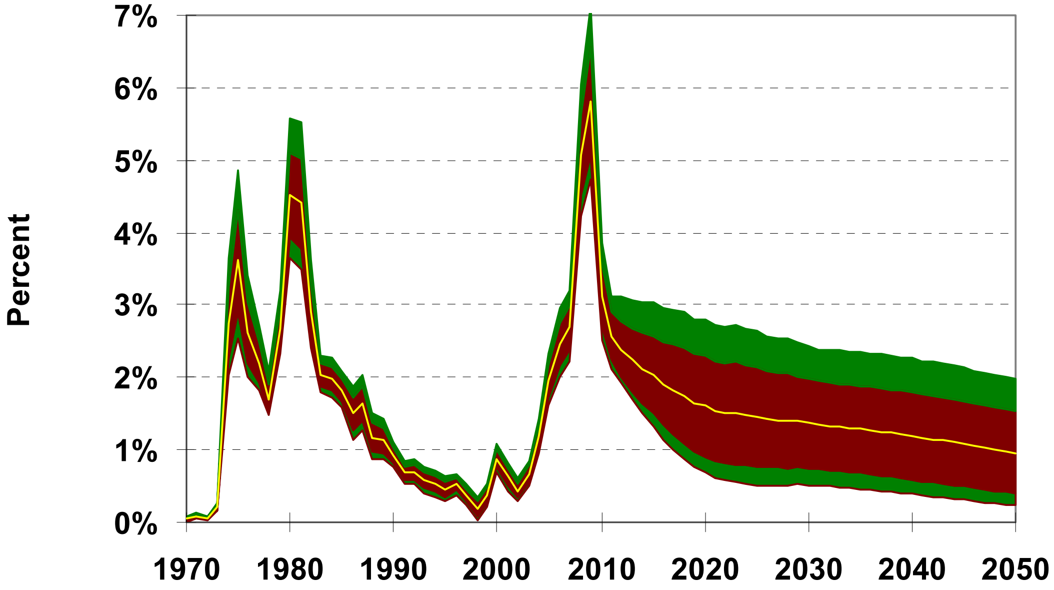

FIGURE 8-12 Oil Dependence Costs as a Percent of GDP, Mixed with Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

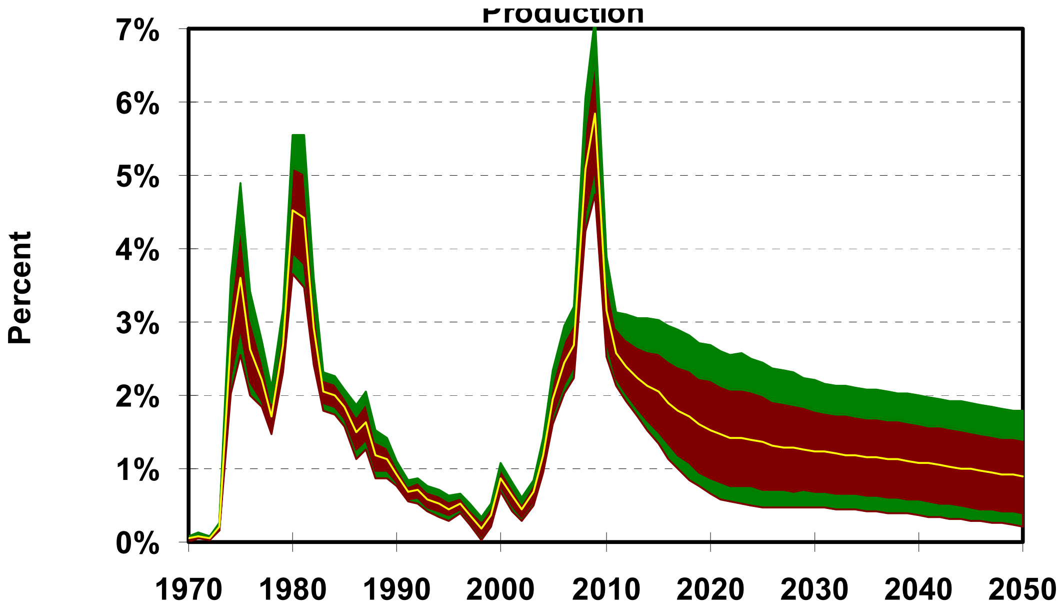

FIGURE 8-13 Oil Dependence Costs as a Percent of GDP, (P)HEV & Ethanol with Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

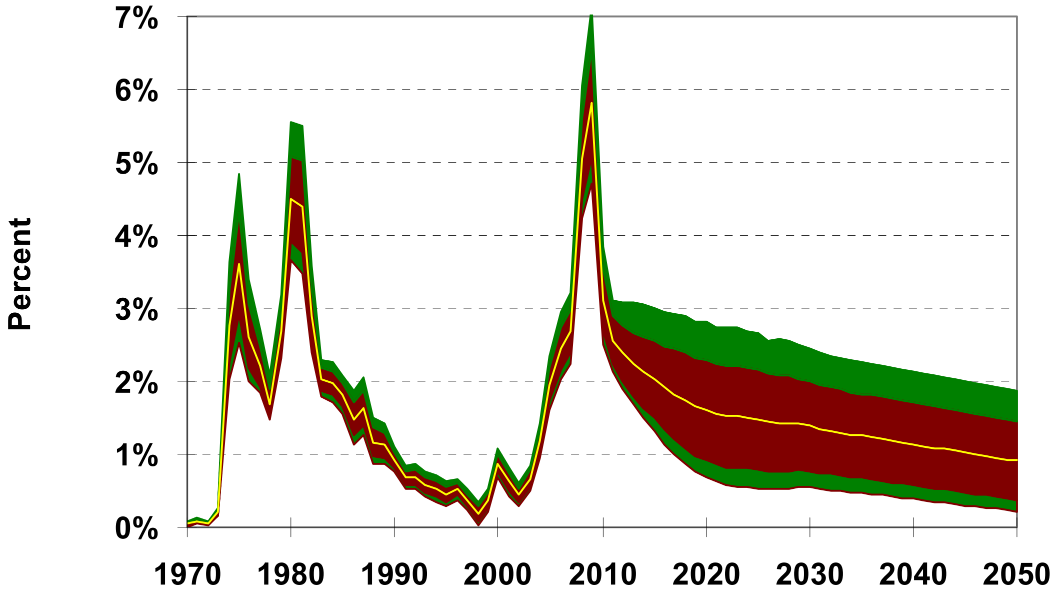

FIGURE 8-14 Oil Dependence Costs as a Percent of GDP, H2 Success with Subsidies: OPEC Maintains Production[1]

[1] Yellow line = expected costs.

Brown area represents an interval of +/– one standard deviation around the mean.

Green area extends this to a 90% confidence interval.

There is a 95% probability that costs will exceed the lower edge of the green area and only a 5% probability that the upper edge would be exceeded.

- The scenarios with subsidies achieve greater reductions than those without subsidies;

- There is very little difference in the results (whether the mean or 95th percentile results), regardless of whether OPEC chooses to maintain its original production schedule or maintain price;

- The (P)HEV & Ethanol scenario is best at lowering oil dependence costs as a percentage of GDP in all cases; and

- The Mixed scenario is generally next best in terms of lowering oil dependence costs, except that by 2050 in the subsidies cases, the H2 Success scenario is marginally better.

8.5 REFERENCES FOR CHAPTER 8

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9 SUMMARY AND CONCLUSIONS

9.1 INTRODUCTION

The Multi-Pathways Transportation Futures Study is aimed at comparing alternative vehicle and fuel technologies that can make significant reductions in oil use and GHG emissions from U.S. light vehicles from now to 2050. A key goal of the MP Study is to make these comparisons on "common ground" as much as is possible and with analytic robustness. The MP Study originated from requests for an analysis of technical alternatives to hydrogen fuel cell vehicles from a panel of the National Academy of Sciences, as well as a request by senior management of DOE's Office of Energy Efficiency and Renewable Energy for an integrated analysis of its research portfolio of vehicle- and fuel-related technologies.

The MP Study has focused on a limited set of fuels and vehicle technologies that appear able to reduce oil use and GHG emissions by a significant fraction if they could achieve a large share of new vehicle sales over the next few decades. The MP Study assumes a future where oil supply instability and high prices have created in the United States a societal compact that places a high value on reducing the use of oil and providing substitutes for supporting the transportation system. The vehicle technologies examined are:

- Advanced conventional vehicles (ACVs) with spark-ignited (SI) and compression-ignited (CI) engines, fueled by gasoline and diesel fuel from conventional and unconventional resources, with flex-fuel capability (using ethanol from corn and biomass);

- Hybrid-electric vehicles (HEVs), both grid-independent and plug-in (PHEVs) with 10- and 40-mile all-electric range[20];

- Hydrogen fuel cell vehicles (FCVs) with hybrid drivetrains (including plug-ins); and

- Battery-electric vehicles (EVs).[21]

In addition to advanced drivetrains, all of the vehicles incorporate a range of technologies to reduce their loads — including improved tires and aerodynamic design and weight reduction through improved materials and design.

The overall study examines vehicles and fuels at the level of individual vehicles and single fuel cycles and then integrates these analyses into scenario analyses encompassing multiple

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[20] While PHEV10s were examined in the fuel economy and cost analyses, they were not considered in the scenario analysis because the scenario model (NEMS; see discussion below) can accommodate only one PHEV, and PHEV40s were chosen as the representative PHEV.

[21] EVs were examined in the fuel economy and cost analyses; however, they play little role in the scenario analyses because of their high projected costs.

technologies and fuels introduced into the U.S. light-duty fleet over the time frame of 2010 to 2050. The vehicle analyses incorporate fuel economy evaluations by using Argonne's PSAT (Powertrain Systems Analysis Toolkit) simulation model and cost analyses by using literature reviews and Oak Ridge National Laboratory's Automotive System Cost Model (ASCM) as an organizing tool. The scenario analyses use a version of DOE's National Energy Modeling System (NEMS-MP) to obtain an integrated analysis of the effect of introducing multiple new technologies into the fleet — including the effect of reduced oil use on U.S. gasoline and diesel fuel prices.[22]

9.2 VEHICLE CHARACTERIZATION

9.2.1 Overview

The MP Study first evaluates a limited set of vehicles that can serve as building blocks for a set of scenario analyses examining the evolution of the whole U.S. light-duty vehicle fleet. Specifically, the MP Study has conducted fuel economy and cost analyses of three classes (midsize car, midsize SUV, crossover SUV) of "leading edge" vehicles with multiple drivetrain technologies and fuel types for the years 2010, 2015, 2030, and 2045 (leading edge vehicles are vehicles that are "best in class" for fuel economy and that use newly introduced or newly updated technologies; they are introduced to the fleet in limited numbers[23] at the modeled date, with the assumption that the technologies, if successful, would then gradually be rolled into the overall new vehicle fleet). Because the scenario analyses using the NEMS model require identification of the vehicle characteristics of *average* new vehicles in *12* separate vehicle classes (six passenger cars and six light trucks) in increments between 2010 and 2050, the results of these limited leading edge vehicle characterizations are used to extrapolate to the required characterizations of average vehicles in the 12 classes for each target year.

Although the leading edge vehicles use a variety of different drivetrain technologies, **the vehicles in each vehicle class (e.g., midsize car) are designed to be as similar as possible, consistent with the differences in their fuels and drivetrains**. The vehicles satisfy the **same core set of performance standards** (for example, 9-second 0–60 mph acceleration time, gradeability of 65 mph at a 6% grade for 20 minutes) and, for each model year, have **virtually identical "gliders"** (a "glider" is a vehicle minus its powertrain and fuel storage system). Consequently, the vehicles in each class appear to their drivers and passengers to be virtually identical to each other, except where differences are made inevitable by the differences in fuel and drivetrain technology (e.g., differences in the time spent refueling or in the location of

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[22] As discussed later, the model considered only those fuel price effects caused by refinery demand shifts; effects on global oil prices, and their subsequent impacts on U.S. fuel prices, were not considered.

[23] However, production volumes are large enough — at least a few tens of thousands of vehicles — to attain many of the cost benefits associated with mass production.

refueling, small performance differences caused by the unique torque characteristics of electric motors and diesel engines, and so forth).[24]

This analytical approach ignores potential niche markets (e.g., for limited performance or limited-range electric vehicles). Vehicles designed for niche markets could be important both for introducing new technologies into the wider marketplace (by allowing cost reductions and performance improvements through learning) and, for the longer term, for dense urban areas. Although niche vehicles deserve careful investigation, they are not considered in the study.

9.2.2 Fuel Economy Analysis

Evaluating the fuel economy of the various vehicles required (1) identifying key physical and drivetrain characteristics of the vehicles for each analysis year, (2) "building" the vehicles by sizing drivetrain components to satisfy key performance requirements, and (3) simulating the vehicle's operation on the EPA UDDS (city) and HWFET (highway) driving cycles. Identifying key physical and drivetrain characteristics involved both conducting a literature review and relying on the advice of industry experts. The PSAT model was used to size the drivetrain components and simulate the vehicle operations.

Identifying key physical and drivetrain characteristics is difficult because it demands projecting technology development over several decades, which is a function of progress in research and development as well as changes in market trends. This projection is especially problematic for those technologies — fuel cell vehicles, plug-in hybrids — that have not yet entered the market, at least not in mass-produced form. The MP Study used literature review and consultation with industry experts to project key technology characteristics for both the gliders (coefficients of aerodynamic drag and tire rolling resistance, weight reduction) and the drivetrain technologies (engine efficiency, battery-specific power, fuel cell maximum efficiency, etc.). Although two levels of drivetrain and glider characteristics — "high" and "medium" — were identified, the higher level reflects our best judgment of future vehicle characteristics *assuming that the future world evolves as the MP Study postulates, that is, that vehicle efficiency assumes a very high priority in both public policy and the marketplace.* Table 9-1 presents key drivetrain characteristics for leading edge vehicles. Table 9-2 presents key glider characteristics for leading edge midsize passenger cars. Note that these tables do not fully describe the character of these vehicles; for example, a primary efficiency characteristic of the advanced DI gasoline engines postulated in the MP Study is their ability to maintain engine efficiencies near their maximum over a wide range of operating conditions. Also, recent developments (the assumptions about technology characteristics were made in 2007 at the beginning of the Phase 2 analysis) have

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[24] An alternative way to compare competing drivetrain/fuel pathways is to optimize each pathway's vehicle design for the specific fuel and vehicle technology combination embodied by the pathway. This might yield, for example, conventional drivetrain vehicles with steel bodies competing with electric or hydrogen vehicles with more expensive aluminum or carbon fiber bodies, because the latter have fuel storage issues that justify spending more on lightweighting. We did not choose this type of comparison because it presents severe analytic difficulties. For example, the optimum choices would likely change over time with changing fuel prices and technology and material costs and would be sensitive to assumptions about the evolution of these costs and prices.

changed our view about some of these characteristics (for example, we now believe the maximum efficiency values postulated for fuel cells are about 5 percentage points too high). To the best of our knowledge, redoing the fuel economy analyses with updated vehicle characteristics would not significantly change the results.

TABLE 9-1 Drivetrain Characteristics for Leading Edge Vehicles

Parameter	Current	2010		2015		2030		2045	
		Med	High	Med	High	Med	High	Med	High
DI GASOLINE									
Specific Power(1) (W/kg)	850	875	900	880	920	920	950	940	980
Peak Efficiency(2) (%)	37	37.5	38	38	39	38.5	40	39	41
DI DIESEL OR OTHER HC FUEL									
Specific Power(1) (W/kg)	420	440	460	460	480	470	500	480	520
Peak Efficiency(2) (%)	41	41	42	42	43	43	45	44	45
Aftertreatm't Ther. Eff.(3) Penalty (%)	2	1.5	1	1	0.5	0.5	0.5	0.5	0.5
FUEL CELL									
Specific Power FC system (W/kg)	500	550	600	600	650	650	700	700	750
Power Density (W/L)	500	550	600	600	650	650	700	700	750
Peak Fuel Cell System Efficiency (%)	60	60	60	60	60	62	65	65	70
ELECTRIC MOTOR									
Motor Specific Power (W/kg)	1110	1200	1300	1250	1600	1400	1800	1500	2000
Power Electronic Sp Power (W/kg)	3680	6000	12000	10000	13000	12000	14000	13000	15000
Motor+Controller Peak Efficiency	90	90	92	91	95	92	95	94	96

TABLE 9-2 Key Glider Characteristics for Leading Edge Midsize Cars

Parameter	Current	2010		2015		2030		2045	
		Med	High	Med	High	Med	High	Med	High
MIDSIZE CAR (Current -> Glider Mass = 990 kg, Frontal Area = 2.2, Tire = P195_65_R15)									
Glider mass reduction (%)	0	5	10	10	20	15	30	15	30
Frontal Area (m2)	2.2	2.222	2.2	2.233	2.2	2.266	2.244	2.288	2.244
Drag Coefficient (5)	0.29	0.27	0.26	0.26	0.25	0.24	0.22	0.24	0.2
Rolling resistance(6)	0.008	0.0078	0.0075	0.0075	0.007	0.007	0.006	0.0066	0.006

The PSAT model was used to translate these assumptions about the physical characteristics of the vehicles into estimates of their fuel economy on the EPA fuel economy test procedure. Figure 9-1 shows a sample of the "high" results — the "all fuels" fuel economy (measured on the combined EPA cycle and without making adjustments to simulate "on-road" driving), in gasoline equivalent terms, for midsize cars operating on gasoline, diesel, electricity, and hydrogen.

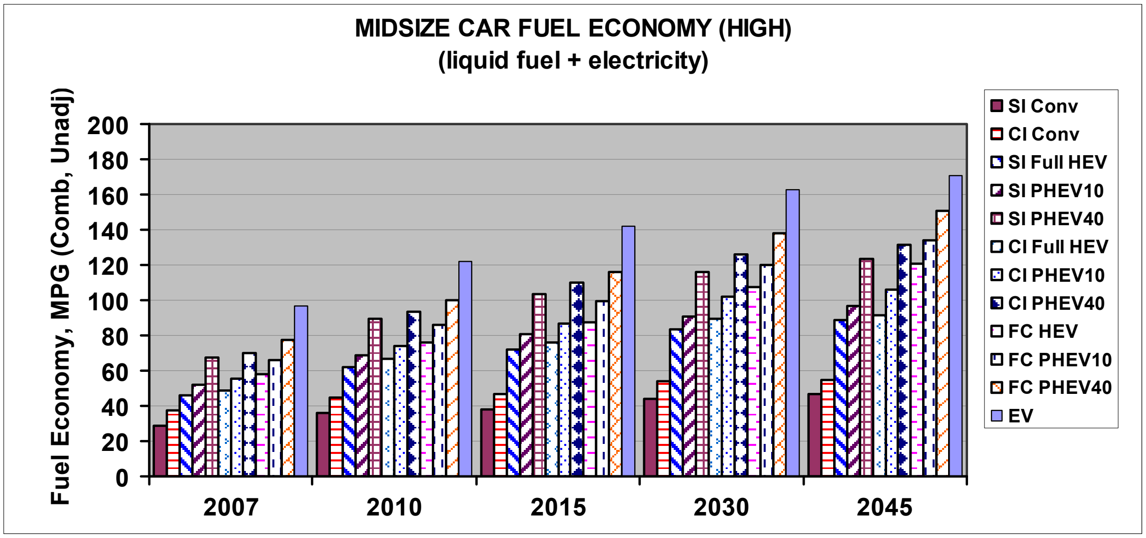

FIGURE 9-1 High Fuel Economy Values for Leading Edge Midsize Passenger Cars (Unadjusted MPG), with Fuel Economy Values for PHEVs Reflecting Both Gasoline and Electricity Use (For PHEV10s, 17.4% of miles are electric, and PHEV40s are 50.9% electric based on SAE J1711 utility factors)

Key conclusions of this analysis are as follows:

- By 2030, it may be possible to achieve fuel economy improvements of upwards of 50% (compared to the 2007 SI conventional vehicle) without resorting to hybrid drivetrains or diesel (compression ignition) engines. This result reflects sharp reductions in vehicle loads (aerodynamic, rolling resistance, and inertia/weight), improved transmissions that are already entering the fleet, and SI engine improvements that will move gasoline engines closer to diesels in efficiency.

- In this time frame, a shift to diesel engines would allow fuel economy improvements of 55% to upwards of 80%.

- The addition of full hybrid drivetrains could allow fuel economy to approach 2.3 to 3 times current levels in this timeframe if the efficiency of hybrid components continues to improve.

- Fuel cell drivetrains can improve efficiency, on a MPGGE basis, still more, although future fuel cell efficiencies are quite difficult to predict because the likely rate of continuing technology progress and tradeoffs between efficiency and cost or performance are unclear.[25]

- Plug-in hybrid drivetrains can yield fuel economy improvements similar to more conventional hybrid drivetrains when they are operating in charge-sustaining operation (i.e., after the electric portion of their daily driving is completed). Further, they can allow grid electricity to substitute for liquid fuels during a substantial portion of daily operation. In gasoline-equivalent terms (valuing each kWh of electricity as 3,413 BTUs,[26] or about 34 kWh per gallon of gasoline equivalent, or GGE), PHEV40s can attain fuel economy levels above 100 MPGGE by 2030. In liquid fuel terms, for the "high" case, an SI PHEV40 in 2030 would use, on average, a gallon of gasoline every 150 or more miles,[27] yielding a five-fold or higher reduction in gasoline use compared to today's conventional gasoline vehicles.

- Battery-electric vehicles, or EVs, provide the highest fuel economy (on a gasoline-equivalent basis) among the competing vehicles, although the fuel cycle energy use (and GHG emissions) depend, of course, on the electricity feedstock and the efficiency of electricity generation. For example, with electricity generated by a conventional coal-fueled power plant at 35% efficiency and taking transmission losses into account, the full-fuel-cycle ("well-to-wheels") energy use of an EV would be more than three times its "tank-to-wheels," or "vehicle only" energy use. In contrast, the fuel cycle energy use of a gasoline-fueled vehicle would be only about one quarter greater than its tank-to-wheels energy use.

- With more modest assumptions about engine and other improvements and the extent to which higher fuel economy will be preferred over other vehicle attributes (the "medium" values in Tables 9-1 and 9-2), fuel economy improvements of 25% to 30% might be expected by 2030 for SI non-hybridized drivetrains, and the level of improvements for other drivetrain types would decrease as well. With the new CAFE standards requiring

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[25] As noted above, the assumed maximum fuel cell system efficiencies adopted for these analyses appear to be more optimistic than projected in recent assessments, so the fuel economy results may not reflect our current understanding of fuel cell system efficiency. However, new PSAT runs that reflect lower maximum fuel cell efficiencies yielded similar high fuel economies; the lower fuel cell efficiencies were balanced by lower drivetrain weight, improved regenerative braking, and improvements in control strategy in the newly modeled vehicles.

[26] This valuation ignores conversion losses at the power station and transmission losses.

[27] It is expected that a PHEV40 will "electrify" about half of its miles on average. With a fuel economy of about 80 MPG during charge-sustaining operation (and little if any gasoline use during charge-depleting operation), the year 2030 PHEV40 would use about 1 gallon of liquid fuel every 160 miles. Assuming nightly recharging of its battery, the PHEV40 would also use about 14 kWh of electricity from the grid every 160 miles (in average operation), based on charge-depleting electricity use of about 160 wh/mile and without accounting for charger losses.

> 35 MPG for the combined car and light truck fleet (about a 40% improvement) 10 years earlier, shifts toward more hybrid and diesel drivetrains would clearly be necessary to comply with the standards.

9.2.3 Cost Analysis

The MP Study next evaluated future vehicle costs on the basis of the drivetrain component sizes (developed by the PSAT model in the fuel economy analysis) coupled with estimates of technology costs derived from literature reviews and consultation with experts. The analysis used ORNL's ASCM as an organizing tool, using a factor of 1.5 to go from costs to Retail Price Equivalents, or RPEs, which are used in the Vehicle Choice Model in NEMS. As with the fuel economy estimates, cost estimates for future vehicle technologies depend on uncertain technological progress, as well as on strong uncertainties concerning material costs. The cost equations used in the analysis were developed with the underlying assumption of "technology success," that is, that each technology undergoes a successful development process, is pushed into the marketplace relatively soon, and experiences cost reductions from learning and growing scale quite quickly. In other words, the analysis does *not* incorporate the risk that development will stall, costs will remain high, and full market success cannot be achieved — a possibility for any of the advanced technologies. Another important source of uncertainty is that cost (and fuel economy) estimates are based on a singular representation of technologies that have many variations. For example, "hybrid electric vehicles" are represented by a single design rather than the multiple examples that exist in the marketplace even today (e.g., the Toyota "series/parallel" system found in the Prius; the two-mode hybrid designed jointly by General Motors, BMW, and DaimlerChrysler; the Integrated Motor Assist system found in the Honda Civic Hybrid; and so forth). Further, all vehicles — regardless of drivetrain technology — have the same performance requirements dictating minimum power capabilities. In the actual marketplace, there is a broad spectrum of vehicle performance, and different drivetrain technologies may compete somewhat differently at the upper and lower ends of this spectrum.

It is important to note that this analysis holds performance essentially constant over time and does not account for the so-called "hedonic" costs of foregone future increases in performance. This assumption ignores the market reality that over the past few decades, increases in vehicle technical efficiency — which can be used either to improve fuel economy or to increase performance (or some combination of both) — have been used largely in a manner that emphasizes increasing performance. Vehicle designers believe that many potential buyers value performance more highly than fuel economy. By ignoring this market value for performance, our analysis may understate the cost of improving fuel economy.

There are two cost estimates for each technology (the cost equations for key drivetrain components are given in Table 3-10 and are not reproduced here). A relatively optimistic "Literature Review" (LR) estimate is based on the literature review and expert consultation, with the above outlook of technology success. A still more optimistic "Program Goals" (PG) estimate assumes that DOE cost goals for advanced technologies are met (prototypes are assumed to achieve these goals on the schedule dictated by DOE's Program Plans, with the first production models achieving the goals 5 years later). Some of these goals were derived in a normative fashion — they were set at a level deemed necessary to allow technology commercialization — rather than being derived by examining engineering potentials. As a result, the probability of attaining the goals is quite unclear. Also, we understand that DOE is re-examining the cost goals, and it is expected that some of them may increase. Although both estimates should be considered optimistic, the LR estimates are a better representation of our best analytical judgment.

Although details (across multiple years and the three vehicle classes) of the component cost estimates are given in the full report, some key highlights are as follows:

- In 2030, a glider mass reduction of 30% in a midsize passenger car (from extensive use of high-strength steel, aluminum, and other lightweight materials as well as computer-driven structural redesign) would cost about \$1,300. For the conventional SI engine drivetrain, this reduction in glider weight would translate into a *vehicle curb* weight reduction of about 21%.

- Costs for the conventional technologies (spark-ignited and compression-ignited internal combustion engines and automatic transmissions) are relatively stable over time, with the addition of progressively more sophisticated electronic controls, valve control systems, and so forth moderated by some continued learning.

- In contrast, with substantial opportunities for learning still remaining, costs for new technologies are assumed to decline over time, in some cases quite dramatically. Fuel cell costs are lowered from \$67–\$108/kW in 2010 to \$30–\$52/kW in 2030; HEV batteries from \$40–\$55/kW in 2010 to \$20–\$38/kW in 2030; and EV batteries from \$400–\$675/rated kWh in 2010 to \$150–\$325/rated kWh in 2030 (where the higher values are the LR values, the lower ones the PG values).

- Costs for advanced vehicles with rechargeable batteries do not include possible costs for replacing batteries, assuming instead that the lifetimes of batteries requiring full charge and discharge cycles will be lengthened to match the lifetime of the vehicles. If this degree of improvement is not achieved, the cost effectiveness of these vehicles will be seriously degraded.

Figures 9-2 and 9-3 show the estimated retail prices for leading edge midsize cars for both cost cases, assuming that the "high" fuel economy levels are achieved. Figure 9-4 shows the incremental price in 2030 of these cars over and above the price of a 2007 midsize car with a conventional SI drivetrain.

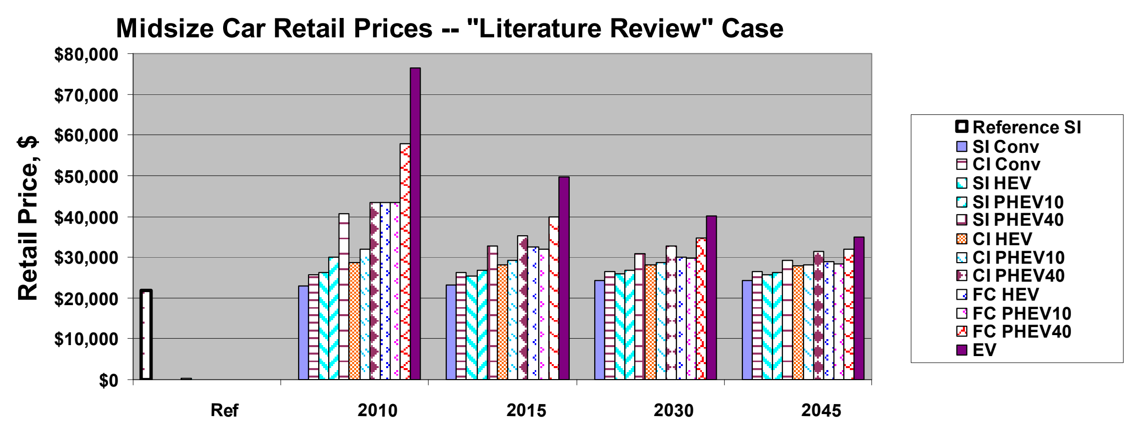

FIGURE 9-2 Leading Edge Midsize Car Retail Prices (in 2008$), Literature Review Costs, High Fuel Economy

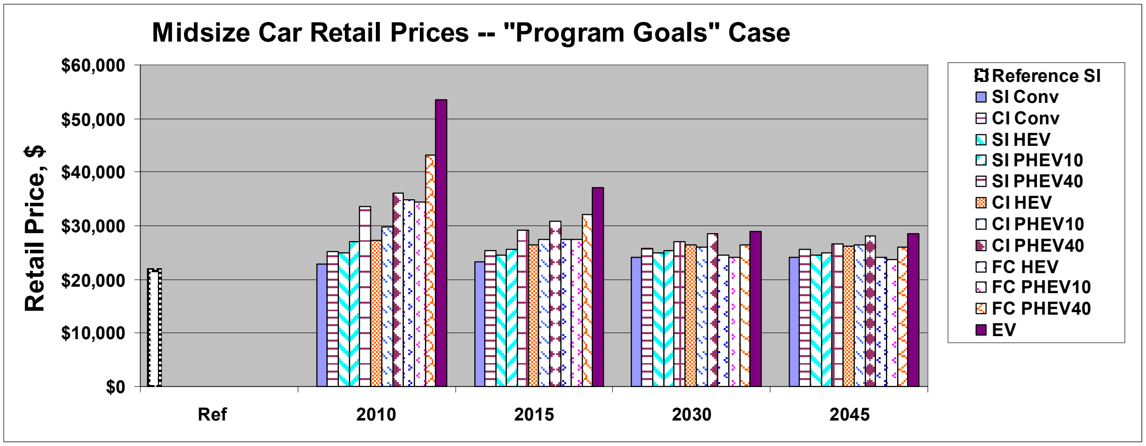

FIGURE 9-3 Leading Edge Midsize Car Retail Prices (in 2008$), Program Goals Costs, High Fuel Economy

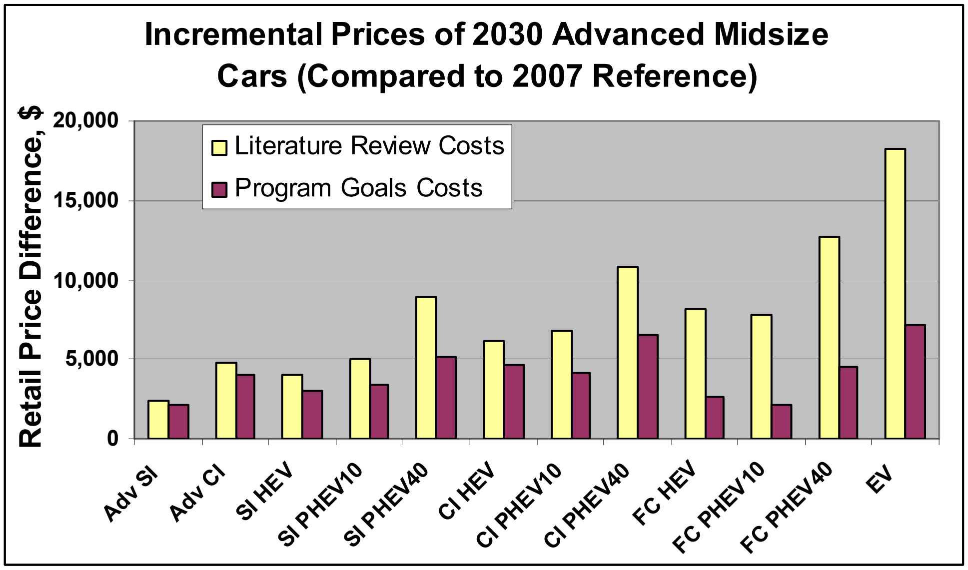

FIGURE 9-4 Incremental Prices of 2030 Advanced Technology Midsize Cars, Compared to a 2007 Midsize Car with a Conventional Drivetrain

The figures yield a number of insights:

1. Even in the Program Goals case, costs for the most advanced drivetrains (those not yet introduced except for a few demonstration vehicles) will be high enough at their introduction that commercialization can proceed only if the manufacturers or the government subsidize the purchase of these vehicles. Such subsidies will be expensive, although their affordability will depend on how quickly and dramatically costs and prices fall. The 2015 price differentials between PHEV40s, FCVs, and EVs and their primary competition — advanced conventional vehicles — range from $6,000 to $14,000 per vehicle for the PG cost case and from $9,000 to $26,000 for the LR cost case.

2. Two of the more advanced technologies — fuel cells and battery-electric drivetrains with long electric ranges (i.e., drivetrains for PHEV40s and EVs) — are expected to have rapid cost declines. While this is an assumption, it is based on the recent development history of both technologies. In the LR cost case, by 2030 fuel cell vehicles and SI PHEV40s would cost only about $6,000 more than advanced SI vehicles; EVs would remain much more expensive than advanced SI vehicles, with a differential of about $16,000 (both measured as retail price equivalents). For the PG cost case, 2030 fuel cell vehicles would compete well in price with the advanced SI vehicles, with SI PHEV40s within $3,000 of their price and EVs within $6,000. The battery-dependent vehicles will suffer considerably, however, if the problem of limited battery lifetimes is not solved: under the 2030 LR cost case, the battery in a PHEV40 could cost the consumer at least $5,000 to replace, while a battery in an EV could cost nearly $20,000.

What happens to the cost tradeoffs if efforts to improve fuel economy are less successful? For the "medium" fuel economy case, there are considerably greater cost disadvantages associated with the advanced technologies (beyond the "advanced conventional"). For this case, the greater vehicle loads (because of higher weight, increased tire rolling resistance, and more aerodynamic drag) demand considerably more power output for identical performance. In 2015, for the low LR cost case, the higher power requirements raise costs for the SI hybrid drivetrain by about $200[28]; for the SI 40-mile range plug-in hybrid drivetrain by $1,300; for the fuel cell drivetrain by $2,300; and for the EV drivetrain by $5,000. In 2045, the cost differentials are $400 for the SI hybrid; $700 for the 40-mile plug-in hybrid; $1,000 for the fuel cell; and $2,000 for the EV. In contrast, the conventional SI drivetrains see a cost increase of only about $100, because engine costs vary substantially with power only when higher power demands a significant change in engine design — increasing cylinder count or adding a turbocharger or supercharger. The net effect of these differential cost effects is that if the industry experiences more limited success in boosting fuel economy levels, the cost penalty of purchasing advanced drivetrains (beyond the "advanced conventional" drivetrain) will increase, which likely will reduce their market penetration and thus may substantially increase fuel use and GHG emissions for the fleet as a whole. In other words, **sharply reducing vehicle loads so that drivetrain power demands are reduced may be crucial to stimulating markets for advanced technology vehicles.**

9.2.4 Cost Effectiveness

An evaluation of whether or not advanced technology vehicles are seen as "cost effective" depends crucially on both the assumptions made and the methodology used, including the choice of the discount rate to apply to future fuel savings, the degree of optimism applied to estimating future technology costs, projected future fuel prices (which are highly uncertain), and the baseline level of technology to which advanced technologies are compared.

By using the fuel economy and cost analyses discussed above, the MP Study examined a simple measure of the cost effectiveness of the various drivetrain technologies — lifetime fuel savings minus the differential in vehicle sales price associated with technology improvements — while making the following basic assumptions:

- Fuel savings and vehicle cost estimates are based on the "high" values of fuel economy from the PSAT analysis.

- Fuel prices are assumed to remain constant over the lifetime of the vehicles. With high uncertainty about future fuel prices, four fuel price scenarios are used for 2030, ranging from moderate to relatively high prices. The higher-price scenario has gasoline at $4.50/gallon and hydrogen at $3.75/kg; the lowest-price scenario has gasoline at

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[28] That is, the cost differential between the SI hybrid drivetrains in the "high" and "average" fuel economy cases is $200, assuming "low" LR costs for both cases.

$2.00/gallon[29] and hydrogen at $2.50/kg; in addition, scenarios with $3.15/gallon and $2.50/gallon gasoline are examined (all assume electricity for nighttime recharging is $.08/kWh).

- Each vehicle is compared to three reference vehicles with increasing levels of fuel economy technology (for 2030, the reference vehicles are a 2007 conventional vehicle, a 2030 advanced SI conventional vehicle, and a 2030 advanced SI full HEV) to capture the marginal benefits of moving beyond different levels of improvements. In this summary, results are shown for the 2007 reference vehicle; results for the other reference vehicles can be inferred by examining the values in the figures for each technology relative to the value for the 2030 advanced conventional and SI HEV vehicles.

- Three discount rates (4%, 10%, and 20%) are used to examine the effects of the following: different points of view (society, individuals, businesses), different views of the likelihood that fuel economy will play a role in the vehicle resale market, and different valuations of the importance of future fuel savings. A discount rate of 4% is a commonly used value for a societal viewpoint; on average, individuals appear to use high discount rates — greater than 20% — in valuing future benefits of efficiency measures (although early adopters of a technology may appear to use zero or even negative discount rates).

The complete set of calculations is quite large, and Figures 9-5 through 9-7 display only a sampling of the results. Figures 9-5 and 9-6 show the cost effectiveness for 2030 midsize cars by using the LR and PG technology costs and relatively high fuel costs (for example, gasoline price of $3.15/gallon), with the 2007 conventional SI drivetrain vehicle as the reference vehicle. Figure 9-7 shows how the cost effectiveness of the 2030 SI hybrid drivetrain vehicle varies strongly with fuel prices.

Figure 9-5 shows the powerful effect of discount rates on the perceived cost effectiveness of the various advanced vehicles. At the “societal” (4%) rate, all advanced vehicles except for the EV are cost effective compared to the 2007 SI conventional vehicle. At a high (20%) discount rate that better reflects consumer valuation of future fuel savings, all of the options have little or negative net benefit. Figure 9-6 shows the effect of achieving the DOE cost goals (the assumption behind the “Program Goals” cost values), which move most advanced vehicles into positive cost-effectiveness territory for all discount rates.

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[29] The gasoline prices are not tied to any specific world oil price but are used for illustrative purposes. Although there is no precise formula matching world oil price to U.S. gasoline price (the latter also depends on U.S. demand for different oil products, worldwide product export availability, and other factors), a 2030 gasoline price of $3.15/gallon matches the 2030 Base Case gasoline price. The 2030 world oil price for this Case is $93/bbl (in 2005$). A gasoline price of $4.50/gallon would imply a world oil price on the order of $150/bbl if other factors affecting the gasoline price/crude price relationship have not changed substantially.

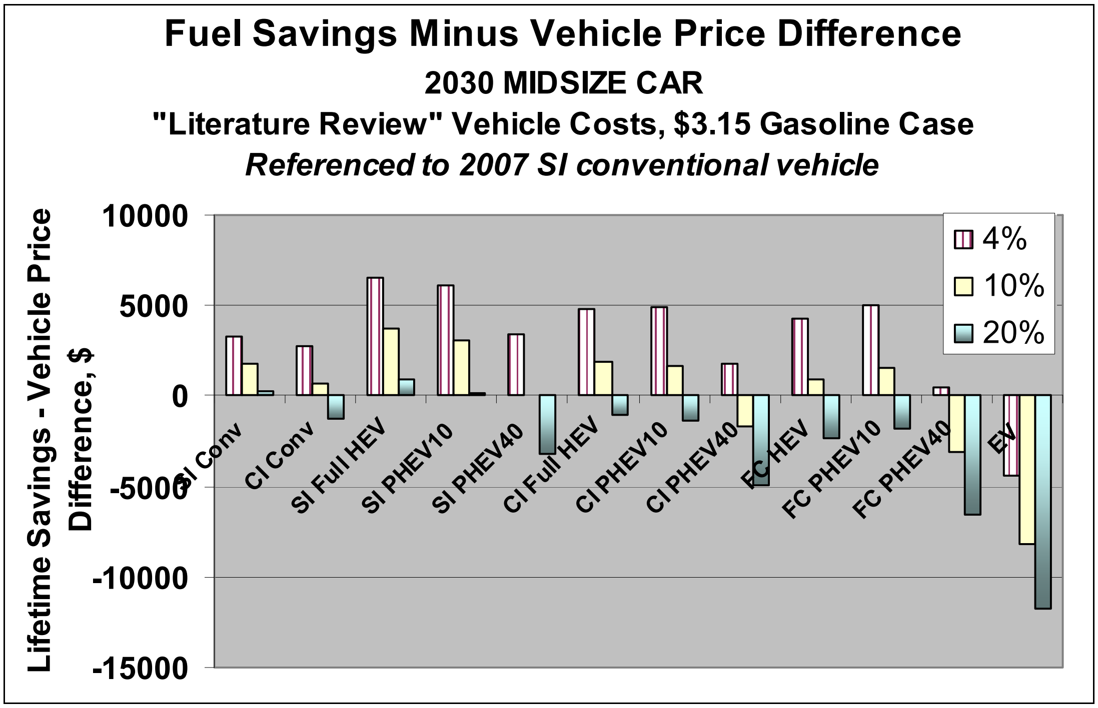

FIGURE 9-5 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car (Literature Review Vehicle Costs, $3.15/gallon Gasoline Fuel Cost Scenario) Compared to a 2007 Conventional Drivetrain Midsize Car

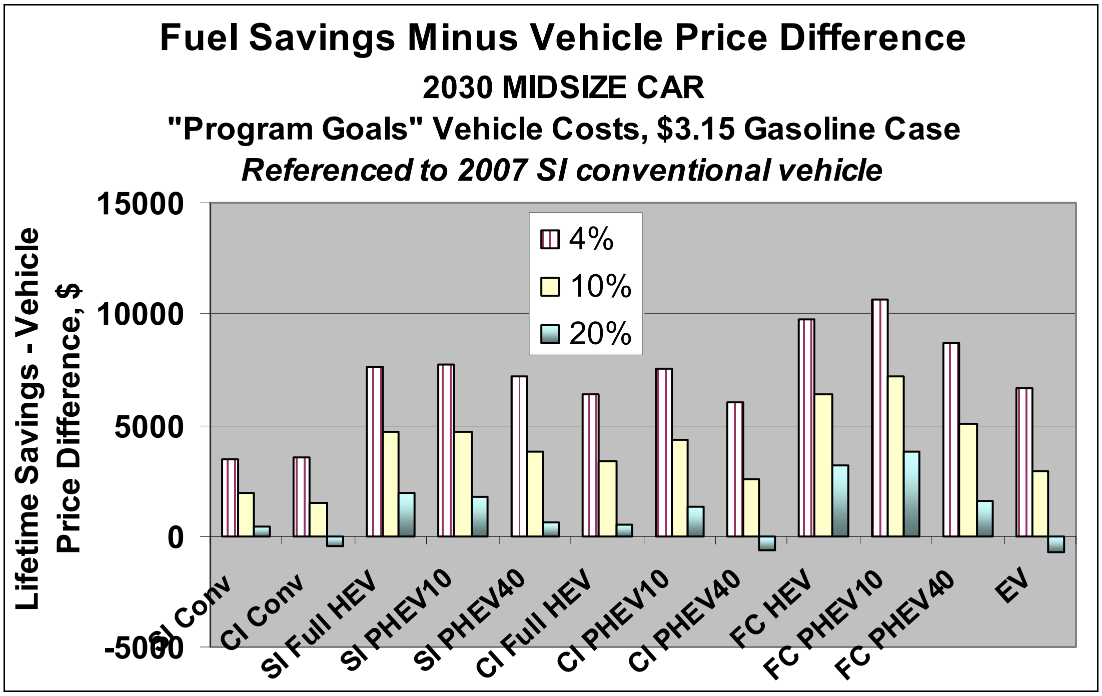

FIGURE 9-6 Fuel Savings Minus Vehicle Price Difference for a 2030 Midsize Passenger Car (Program Goals Vehicle Costs, $3.15/gallon Gasoline Fuel Price Scenario) Compared to a 2007 Conventional Drivetrain Midsize Car

A vehicle purchaser contemplating whether to buy a car with an advanced drivetrain — for example, a plug-in with a 40-mile range or a fuel cell vehicle — has multiple options at a lower level of technology, including a simple advanced conventional vehicle, a hybrid without recharge capability, or a plug-in with a lower range (e.g., a PHEV10). To that purchaser, a positive level of cost effectiveness (fuel savings minus vehicle price difference) compared to a 2007 conventional drivetrain vehicle is not especially relevant; however, how the advanced technology vehicle compares to its competitors (e.g., its *marginal* cost effectiveness) *is* relevant. In Figure 9-5, with LR costs, no vehicles with technologies at above the level of the SI full HEV achieve positive marginal cost effectiveness, even at societal discount rates. In other words, maximum benefit is attained by purchasing the SI full HEV, whereas purchasing a more advanced vehicle will cause total benefit to decline. With the more optimistic PG costs (Figure 9-6), marginal benefits continue to be positive at technologies well past the level of the SI full HEV. For example, the PHEV10 has slightly higher net benefits at the 4% discount rate (but not at the higher rates), and the FCV and FCV PHEV10 have substantially higher net benefits at all discount rates. On the other hand, even though the FCV PHEV40 has higher net benefits than the SI full HEV, it would not be wise to purchase the FCV PHEV40 on the basis of cost effectiveness because the FCV and FCV PHEV10 have significantly higher net benefits.

As noted above, Figure 9-7 shows how cost effectiveness varies with fuel price. With LR costs, at high fuel prices — for example, with gasoline prices at $4.50/gallon and hydrogen prices at $3.75/kg — the cost effectiveness of a 2030 SI HEV is extremely high — about $3,000 for the 20% discount rate and much higher for the lower rates. At the other end, a gasoline price of $2.00/gallon would greatly damage prospects for an SI HEV, as there would be negative cost effectiveness at the 20% discount rate.

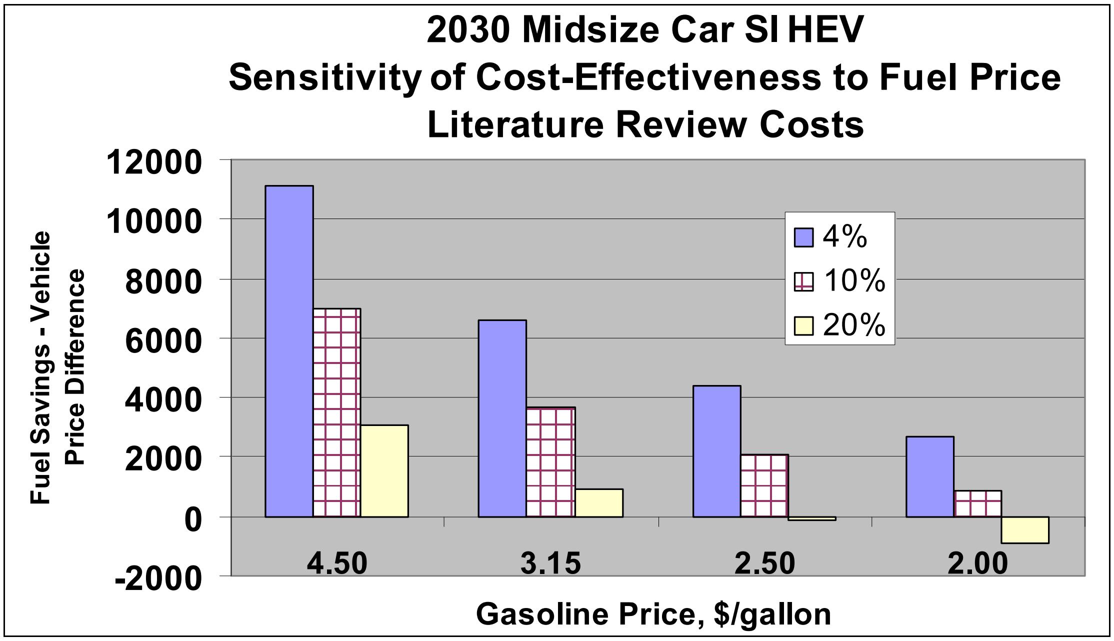

FIGURE 9-7 Fuel Savings Minus Vehicle Price Differential (2007 Conventional Drivetrain Reference Vehicle) for a 2030 Midsize Passenger Car (Literature Review Costs) at Different Fuel Costs

The cost-effectiveness analyses are discussed in detail in Chapter 3. The general conclusions of the analyses are as follows:

1. **The perceived cost effectiveness of new vehicle technologies depends critically on how one values future fuel savings; society is likely to look far more favorably on a new fuel-saving technology than would an average consumer.** A 4% to 20% range in discount rates applied to future fuel savings yields very large differences in perceived cost effectiveness, sometimes pushing net benefits from strongly positive (at 4%) to solidly negative (at 20%). A range of 4% to 20% is not too broad in examining actors ranging from society to consumers, especially considering uncertainties in how future vehicle purchasers of both new and used vehicles will value fuel economy.

2. **The high level of uncertainty associated with future technology costs and fuel prices also strongly affects perceived cost effectiveness.** Even though the technology cost estimates are held to a range incorporating only relatively optimistic values, moving from the "optimistic" (Literature Review) estimates to "very optimistic" (Program Goals) estimates can shift cost-effectiveness outcomes dramatically.

3. **Using advanced SI conventional and SI full hybrid vehicles as baselines — that is, examining the marginal cost effectiveness of moving beyond these midrange technologies — reveals that moving much beyond the technology level of full hybrids may not be especially attractive unless there are also major cost reduction breakthroughs.** In 2030, when using the Literature Review cost estimates and with the advanced conventional SI vehicle as the baseline, only the HEVs and (for the highest fuel prices) PHEV10s and, with lower discount rates on future fuel savings, the FC HEVs and FC PHEV10s have generally positive net benefits. The longer-range electric drivetrain vehicles — PHEV40s and EVs — do not appear to be cost effective (except for the SI and CI PHEV40s at the societal discount rate). With the full hybrid vehicle as a baseline, again with the LR cost estimates, the marginal net benefits (vehicle cost minus lifetime fuel savings) are negative for *all* of the more advanced vehicles, even at 4% (societal) discount rates applied to future fuel savings and high assumed fuel prices. And, with the hybrid as a baseline, even when achieving true breakthroughs in cost reduction (i.e., meeting all DOE cost goals), many of these technologies will be left with negative net benefits for at least the higher discount rates; the only exception would be the fuel cell hybrids (including plug-ins). Because the DOE cost goals for fuel cell systems appear to be normative — that is, the goals are based on what is thought to be needed for successful commercialization rather than on engineering estimates of what is achievable — it is important to examine how realistic these goals are before accepting the potential for positive net benefits.

4. **At lower fuel prices (e.g., gasoline prices of $2.50/gallon and below), even the SI HEVs will fail a cost-effectiveness test at the high "individual" discount rates and Literature Review costs.** And, although achieving Program Goals costs would allow SI HEVs and FCVs to achieve positive cost effectiveness, in reality, achieving these goals will require high production volumes to attain the necessary cost reductions from learning and mass production — volumes that are exceedingly unlikely to be obtained in the

absence of high fuel prices. **In other words, low fuel prices will severely damage prospects for advanced drivetrain vehicles.**

5. **Most advanced vehicles will *at least* be more cost effective than today's vehicles.** If we do not consider achieving true economic efficiency and just explore whether the advanced technologies would *at least* leave us better off economically than today's average vehicles, taking a position of moderate optimism about technology costs (i.e., the LR cost case) yields a "yes" answer, except in the case of EVs and, at the highest (20%) discount rate, of the PHEV40s at the higher fuel prices. And achieving the more ambitious DOE cost goals (the PG case) would yield a strong "yes" answer for all of the technologies.

6. **Although many advanced technologies will be cost effective in the long term, their initial costs will be quite high, and some may require subsidies from the vehicle manufacturers or the government for a considerable time after introduction.** Whatever their long-term prospects, the advanced technology vehicles, to be successfully commercialized, must gain early market acceptance before most cost reductions from learning and mass production can occur. In these early years, the advanced technology vehicles will suffer from higher differences in cost as compared to competing conventional vehicles; on the other hand, the potential fuel savings of the ATVs may be higher than in later years because the conventional vehicles may become substantially more efficient over time. When examining the same vehicle types in 2015 with the LR technology costs and with the 2015 advanced conventional SI vehicle as the reference vehicle, the net benefits for the lower-level technologies (e.g., advanced conventional diesel vehicles, full hybrids) are actually a bit higher than they will be in 2030; higher technology costs are more than balanced by higher fuel savings. For the technologies beyond PHEV10s, however, net benefits are strongly reduced at the higher discount rates — for these cases, the higher vehicle costs outweigh the greater fuel savings. And for the PG costs, the 2030 picture of uniformly positive cost effectiveness is transformed to a mixed picture in 2015, with the higher-tech vehicles with larger batteries looking robustly cost effective only for the lowest discount rates and the EVs attaining negative net benefits except at the 4% discount rate, where its benefits are slightly positive. In other words, the competitive position of the advanced technology vehicles looks considerably worse in 2015 than it does in 2030, and subsidies may be required before the results of the 2030 case — which demands high sales to capture scale and learning benefits — can ever actually occur.

To sum up, this analysis generally confirms that future advanced vehicle technologies will need a combination of factors to succeed: high oil prices, with consumers believing that prices will remain high over a substantial time period; significant reductions in technology costs; high consumer valuations of future fuel savings; and, in the early years following the introduction of ATVs, strong economic incentives for their purchase. These factors are especially important for fuel cell vehicles and vehicles with large batteries (e.g., PHEV40s, EVs). Advanced conventional vehicles, full hybrids, and possibly PHEV10s could be successful even with somewhat less favorable conditions. Finally, the long-term success of EVs and PHEV40s appears especially tied to dramatic reductions in battery costs — beyond those generally predicted by most optimistic analysts. However, fuel cell vehicles have been left out of this last "difficult prospects" group for the time being only as a function of the realism of DOE cost goals for fuel cell systems and hydrogen storage. The "very optimistic" PG technology cost assumptions assume that these goals are met and, as noted before, the goals appear more normative than having been derived from an actual engineering analysis. It would be useful to re-examine these goals to obtain a better grasp of how realistic they are.

9.2.5 Costs of Reducing GHG Emissions

The estimates of future fuel savings and technology costs can be translated into "GHG costs" — the dollar amounts required to reduce GHG emissions by one ton of CO_2 or its equivalent. However, the literature has not defined what these costs represent very well. For this study, we estimate costs from the perspective of a vehicle purchaser and from a societal perspective.

Consumers purchasing advanced vehicles that save fuel compared to some reference vehicle may be said to be paying for GHG emissions reductions, especially if the value of lifetime fuel savings is lower than the vehicle price premium associated with the advanced technology. The net costs — differential vehicle price minus lifetime fuel savings — were estimated for 2030 drivetrain technologies by assuming the following: LR and PG technology costs, the fuel price case associated with \$3.15/gallon of gasoline, and a 20% discount rate for future fuel savings; the lifetime GHG emissions reductions were also discounted at a 20% rate. This discount rate may be controversial: although it is moderate for an average vehicle purchaser, it can be argued that a purchaser concerned about GHG emissions may value future GHG emissions reductions (and fuel savings) more highly, thereby justifying a lower discount rate. The reference vehicle is the 2030 advanced conventional vehicle.

In the MP Study's scenario analysis (Chapter 7), the market penetration rates of fuel cell vehicles and longer-range electric drivetrain vehicles were minimal at the LR vehicle prices, although the high market penetration rate of advanced conventional vehicles yielded substantial reductions in oil use and GHG emissions from a reference case resembling the 2007 Annual Energy Outlook's high oil price case. An additional scenario was evaluated by assuming that subsidies of \$7,500/vehicle were awarded to boost the market penetration rates of fuel cell hybrid vehicles and SI and CI PHEV40s. For this subsidy scenario, the societal GHG cost can be said to be the subsidy divided by each vehicle's lifetime GHG emissions reduction. A "societal" discount rate of 4% was used in this case.

With the PG vehicle prices, the non-subsidy scenarios attained substantial penetration of both the longer-range plug-in vehicles and fuel cell vehicles, and significant reductions in oil use and GHG emissions from the reference scenario. A separate subsidy case — with smaller vehicle subsidies — was run to attain still higher levels of oil and GHG reductions than could be attained with the technology cost reductions alone. Although subsidies varied over time, the ones examined here are \$1,000 for the SI HEV, \$4,000 for PHEV40s, and \$700 for the FC HEV.

Figures 9-8a and 9-8b show the GHG costs given for the LR and PG vehicle prices, for the vehicle purchaser, and for the subsidy case, for society. Because fuel cycle emissions for hydrogen fuel cell vehicles depend heavily on the hydrogen feedstock, two feedstock cases — 100% natural gas and 50% natural gas/50% coal — were examined. GHG emissions estimates were obtained from Argonne's GREET model. Although the scenario analyses included fuel cell PHEVs, these vehicles are not included here because GREET does not evaluate them.

At the LR vehicle prices, vehicle purchasers would view GHG costs as negative or low for the SI HEV and SI PHEV10, because these vehicles save enough fuel to compensate for their added cost, even at a 20% discount rate for future fuel savings. All other drivetrain options exceed \$100/ton of CO_2 equivalent, which is a high value compared to carbon costs in other sectors.

Societal costs for the subsidized technologies are high because of the magnitude of the subsidy required; carbon GHG cost values range from about \$400–\$600/ton of CO_2 equivalent.

At PG vehicle prices, most of the advanced technology vehicles have fuel savings that exceed the vehicle price differential even at a 20% discount rate for future fuel savings and emissions reductions, so GHG costs are viewed by vehicle purchasers as zero. An exception, not shown in Figure 9-8b, is the EV, which will have GHG costs of more than \$200/ton CO_{2eq}. Subsidy costs are relatively high, ranging from \$40–\$60/ton for FCVs and SI HEVs to \$270/ton for the SI PHEV40.

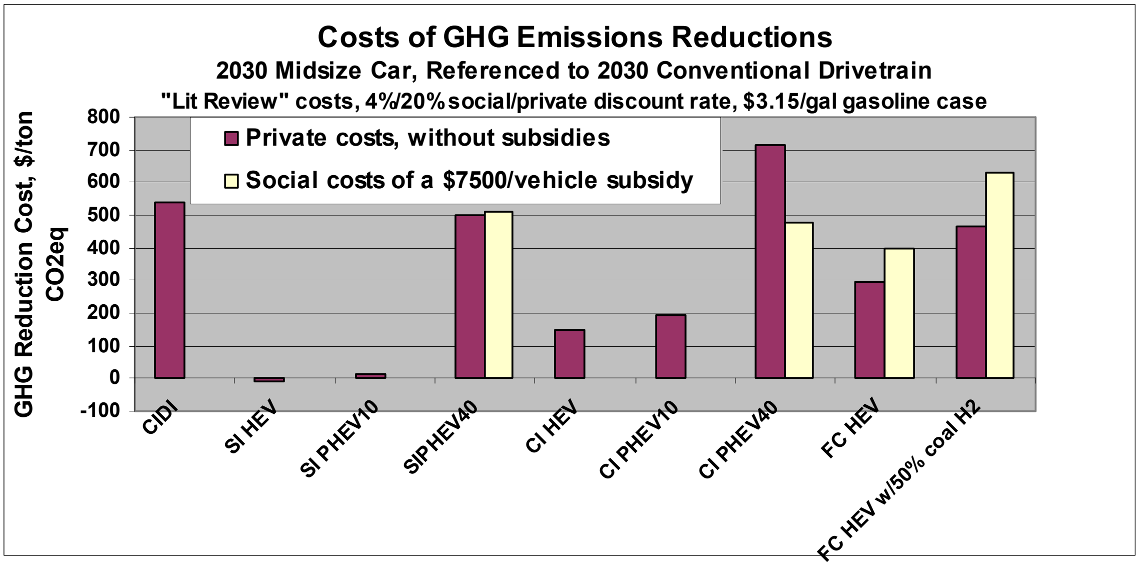

FIGURE 9-8a Costs of GHG Reductions for 2030 Advanced Drivetrain Vehicles, with and without Subsidies (LR technology costs, 20% discount rates for future fuel savings and carbon reductions for vehicle purchaser with no subsidy, 4% discount rate for future carbon reductions for government subsidy case, referenced to 2030 conventional drivetrain vehicle)

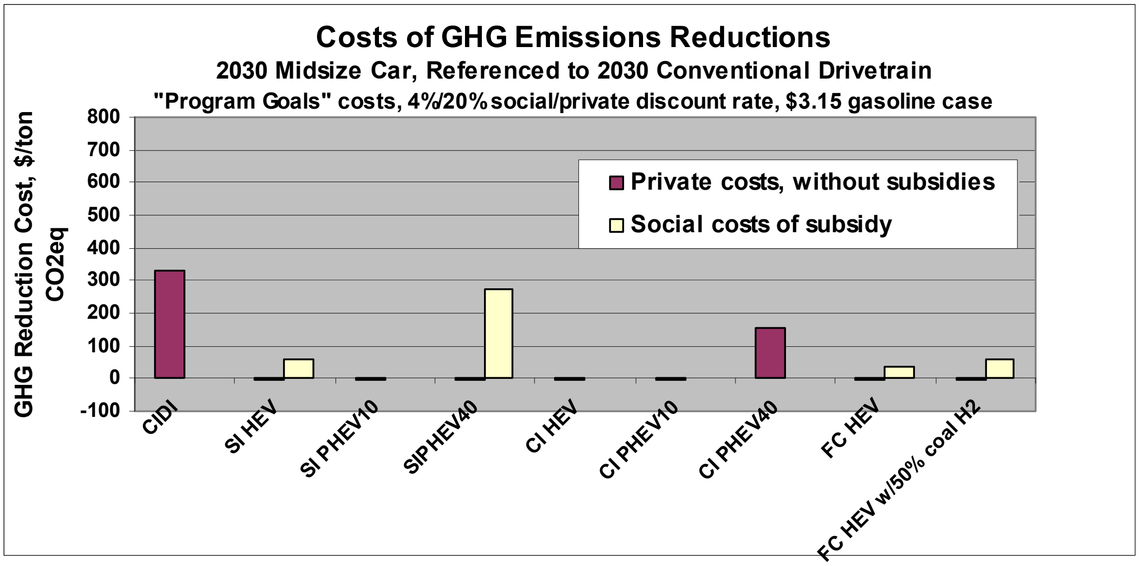

FIGURE 9-8b Costs of GHG Reductions for 2030 Advanced Drivetrain Vehicles, with and without Subsidies (Program Goals technology costs, 20% discount rates for future fuel savings and carbon reductions for vehicle purchaser with no subsidy, 4% discount rate for future carbon reductions for government subsidy case, referenced to 2030 conventional drivetrain vehicle)

9.3 SCENARIO ANALYSIS

9.3.1 Scenario Development

The scenario analysis translates the results of the vehicle characterizations into projections of future shifts in the U.S. light-duty vehicle fleet and the impacts of these shifts on U.S. oil use, GHG emissions, penetration of advanced vehicles and fuels, gasoline prices, and other factors. The analysis uses a version of EIA's NEMS model (called NEMS-MP) that differs from the basic NEMS model largely by being extended to 2050 and adding a detailed hydrogen module. The MP Study developed a Base Case to serve as a reference for comparison's sake, as well as several alternative scenarios that incorporate more optimistic assumptions about advanced technology performance and vehicle prices as well as policies to promote the penetration of these technologies.

The development of the scenarios required a number of iterative steps, because the NEMS model allows the analyst only to specify the conditions that will affect vehicle markets; it does not allow the analyst to specify actual market penetration rates of advanced vehicles, but instead *derives* these penetration rates by using a vehicle choice model (VCM). The study team first developed general ideas about a range of future scenarios, including goals for the market penetration rates of various ATVs. The scenarios were then run in NEMS-MP with both the "literature review" and "program goals" vehicle prices; in both sets of runs, market penetration rates of the more advanced technologies fell well short of scenario goals. The team then used iterative runs of a stand-alone version of the NEMS transportation module (NEMS-TSA), including the vehicle choice model, to estimate the vehicle subsidies required to achieve the approximate market penetration rates initially specified for the scenarios. The new set of scenarios, with the estimated subsidies, was then run in NEMS-MP. In all cases, the “high” fuel economy values for the advanced technologies were used.

The Base Case against which the scenarios are compared is a modified version of the AEO 2007 Reference Case; key modifications of the Base Case are that it:

- Uses the oil prices of the AEO 2007 High Oil Price Case;
- Has been updated with EIA’s summer 2007 analysis of biomass supply curves, cellulosic conversion costs, and corn costs, as well as with hydrogen cost estimates developed by DOE’s H2A effort (August 2006);
- Incorporates the Corporate Average Fuel Economy (or CAFE) requirements of the Energy Independence and Security Act of 2007.

Chapter 6 describes the basis for the Base Case.

The Base Case is essentially a business-as-usual case, although one with relatively high oil prices at \$93/bbl (gasoline price of \$3.15/gallon) in 2030 and \$116/bbl (\$3.93/gallon) in 2050 (in 2005\$). Table 9-3 presents some of its key characteristics. From 2005, total U.S. energy use and CO_2 emissions both grow by 25% in 2030 and by 60% in 2050. Total liquid fuel consumption grows from 21 mbpd to 23 mbpd in 2030 and to 30 mbpd by 2050. While this amount includes substantial growth in ethanol use, it is not to the level required by EISA.

The LV levels of energy use and oil use grow at low rates through 2030 primarily because of the EISA CAFE standards. But after 2030, with no further increases in CAFE standards and with increasing numbers of vehicles on the road and increasing levels of travel per vehicle, LV energy and oil use soar. By 2050, LV oil use increases by 3 mbpd over the 2030 level to 12 mbpd. LV full-fuel-cycle CO_2 emissions follow a similar pattern, with growth accelerating after 2030.

The diesel and gasoline HEV shares of the market grow substantially. By 2050, they make up one-third of the new vehicle sales; however, sales of other advanced technology vehicles (PHEVS, FCVs, etc.) are negligible.

As noted above, the Base Case is a modified version of the AEO 2007 Reference Case, which is extended to 2050. More recent versions of the AEO have lower projections of future light-duty vehicle energy use on the basis of lower projected miles traveled per vehicle (vmt) and higher levels of fuel economy for the vehicle stock. In addition, other projections to 2050 (those of Argonne’s VISION model [http://www.transportation.anl.gov/modeling_simulation/VISION/index.html]) have adopted more conservative assumptions about vmt/vehicle and vehicles sales from 2030 to 2050, yielding lower projections of vehicle stock and energy use. For example, an alternative “Base Case” projection to the year 2050 using VISION2008 projects light-duty

TABLE 9-3 MP Base Case

	2005	2010	2030	2050
U.S. Totals				
Energy Use (Quads)	100.2	106.1	125.8	160.9
CO_2 Emissions (MMTCO_2e)	5,945	6,184	7,470	9,546
Liquid Fuels Supply (excluding H_2 but including ethanol) (mbpd)	20.8	21.2	23.3	30.0
Ethanol Demand (Billion gallons)	4	12.6	15.8	24.0
LVs (results include commercial light trucks)				
Energy Use (Quads)	16.95	17.15	18.90	25.01
Oil Use (excludes ethanol; mbpd at gasoline conversion rate)	8.67	8.42	9.21	12.06
CO_2 Emissions (MMTCO_2e)	1,419	1,440	1,621	2,123
LVs (results exclude commercial light trucks)				
New LV MPG[1]	25.2	28	35.4	35.7
Diesel and GHEVs share of new LV sales (%)	3.5	7.7	23.7	34.1
Other ATVs sales share (%)	0	0	2.1	1.5
VMT (trillion miles)	2,655	2,766	4,069	5,584
Vehicle stock (millions)	220	242	320	386
VMT/vehicle	12,066	11,428	12,715	14,466

[1] Unadjusted EPA test values; on-road values are expected to be approximately 20% lower.

vehicle energy use to be about 9 mbpd in 2050 — a sharply lower estimate than that used here. Given the uncertainty associated with projections of energy use more than 40 years into the future, we recommend that readers of this report focus primarily on results expressed as percentage reductions from the baseline, as these are more likely to be robust than results expressed as absolute values.

It is against this backdrop that the alternative scenarios are evaluated. Three scenarios were developed in detail:

- Mixed
- (P)HEV & Ethanol
- H2 Success

The key technical and modeling differences between the Base Case and the scenarios are discussed in Chapter 6.

The major differences are:

- The advanced technology vehicles are "better" vehicles (with higher fuel economy and generally lower costs) in the scenarios than in the Base Case;

- The price of ethanol and H_2 differs between the scenarios and the Base Case:

  - The Base Case has the highest prices.

  - The Mixed, (P)HEV & Ethanol, and H2 Success scenarios have the same prices except:

    - The (P)HEV & Ethanol scenario has the most optimistic ethanol price estimates (derived from DOE Biomass program goals), and

    - The H2 Success scenario has the most optimistic hydrogen prices (derived from DOE H2 program goals).

- The percentage of households assumed to be able to recharge PHEVs varies across the scenarios, but it is higher in the alternative scenarios than in the Base Case;

- The H2 Success scenario assumes that H_2 stations are jump-started in the early years of the scenario in large and small cities (the scenario was also run through NEMS *without* station jump starts to examine the effects of the jump starts separately);

- All ACVs, SI HEVs, and SI PHEVs are flex fuel capable in both the Mixed and (P)HEV & Ethanol scenarios; and

- NEMS model assumptions that act as barriers to the penetration of advanced technology vehicles are lifted in the scenarios (i.e., wherever possible, we have eliminated hard-wired assumptions that restrict ATV market penetration). We believe that this change is consistent with the market changes postulated in the MP Study.

9.3.2 NEMS Modeling Results

Key results of the NEMS-MP runs are discussed in Chapter 7. The key parameters developed by the model runs include the following:

- The market penetration of advanced vehicle technologies;
- LV energy use, oil use, and CO_2 emissions;
- Ethanol use;
- U.S. liquid fuels supply and net imports;
- U.S. emissions of CO_2;
- Gasoline prices; and
- The cost effectiveness of vehicle subsidies (where applicable).

Other results (e.g., LV energy use by fuel type, ethanol production by feedstock, H2 production by central vs. distributed facilities, etc.) are presented in Appendix E. Tables 9-4 through 9-7 at the end of this section provide detailed quantitative results of the scenarios (LV oil use and full-fuel-cycle CO_2 emissions, U.S. liquid fuels supply, net import share of liquid fuels, total U.S. CO_2 emissions, and gasoline prices).

The results presented in Chapter 7 are driven largely by the underlying vehicle price assumptions. In Chapter 7, we first discuss the key results of the scenarios that use the "literature review" vehicle price assumptions; next, we discuss the results of the scenarios that use the "program goals" vehicle price assumptions; and finally, we discuss the results of the scenarios that incorporate vehicle subsidies with both sets of vehicle price assumptions. The reader can turn to Chapter 7 to see the results displayed in detail in that manner. Our emphasis here will be to highlight some of the overarching results, as follows:

1. **Market penetration of advanced technology vehicles can be significant in all scenarios.** For example, as shown in Figure 9-9, approximately 36% of the vehicles sold in the Base Case in 2050 are ATVs (although these vehicles do not have the same fuel economies and prices as those assumed for the alternate scenarios).[30] In the Mixed scenario, when assuming "literature review" vehicle prices, that share increases to 76%.

2. **The lower the cost of the ATVs, the higher the market penetration.** In the Mixed scenario and with the "program goals" vehicle prices (Figure 9-10), the share of ATV sales reaches 84% in 2050.

3. **With either the "literature review" or "program goals" vehicle price assumptions, the market penetration of the various ATVs is very similar across the Mixed, (P)HEV & Ethanol, and H2 Success (without station jump starts) scenarios.** This similarity exists in spite of the fact that there are substantial differences among the scenarios both in fuel prices and in the percentage of households assumed to be able to recharge PHEVs.

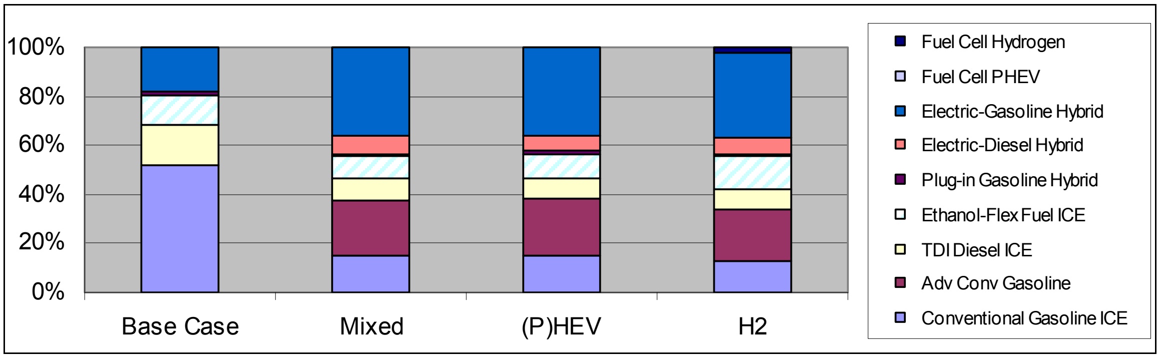

FIGURE 9-9 Vehicle Market Shares for 2050, Assuming "Literature Review" Prices

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[30] ATVs include all technologies shown in the figure except "Conventional Gasoline ICE" and "Ethanol Flex Fuel ICE."

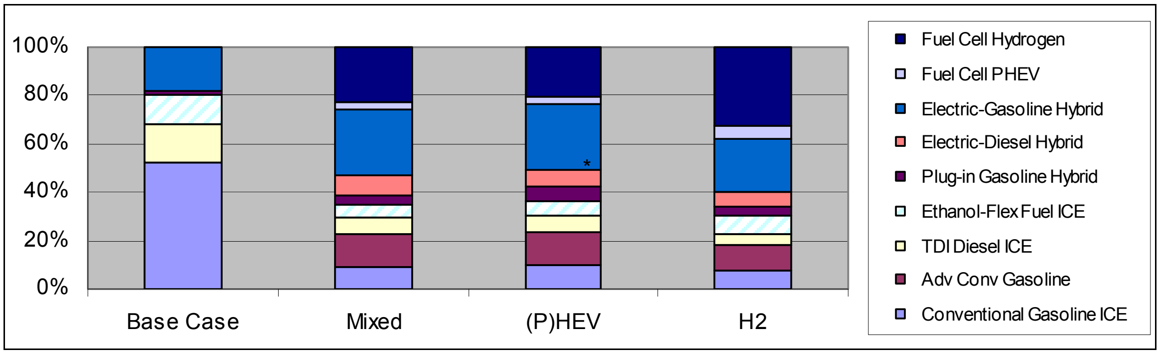

FIGURE 9-10 Vehicle Market Shares for 2050, Assuming "Program Goals" Prices

4. **Jump-starting H_2 station development is important.** FCV market penetration (sales) by 2050 rises from 17% in the H2 Success scenario without station jump starts (assuming "program goal" vehicle prices) to 32% in the H2 Success scenario with the jump starts and the same vehicle price assumptions. Because of the jump start of H_2 stations, the final H2 Success scenario (with jump starts) has greater FCV market penetration (and lower market penetration of other ATVs) than the Mixed and (P)HEV & Ethanol scenarios.

5. **The lower ethanol prices in the (P)HEV & Ethanol scenario do lead to substantially greater ethanol use in this scenario** (see Figure 9-11), even though the Mixed and (P)HEV & Ethanol scenarios have very similar rates of ATV market penetration. This higher ethanol use contributes to greater cumulative reductions in oil use and CO_2 emissions in the (P)HEV & Ethanol scenario.

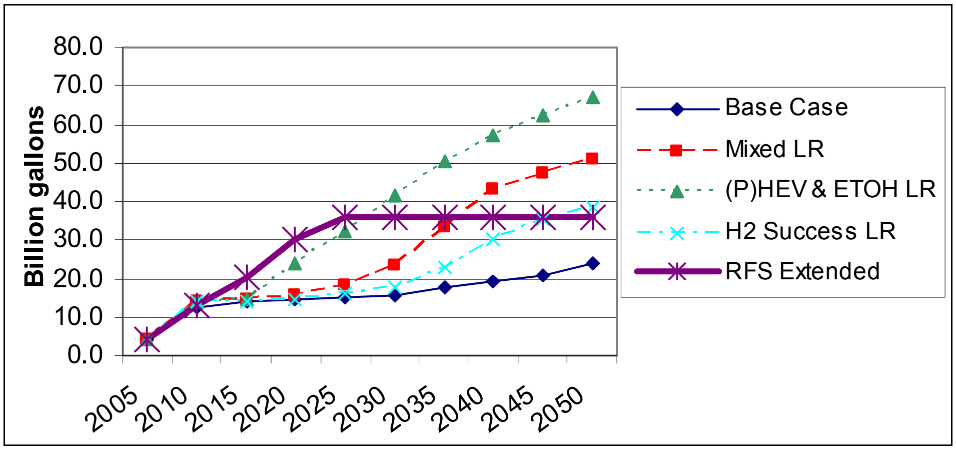

FIGURE 9-11 Ethanol Sales Volumes ("Literature Review" Vehicle Price Case)

6. **The scenarios with "literature review" vehicle prices lead to only moderate reductions from the Base Case** in all of the following: U.S. and LV oil use (2 to 3 mbpd by 2050, i.e., 17% to 25% reductions from the Base Case; see Figure 9-12), U.S. liquid fuel imports, U.S. total CO_2 emissions (3%–4%), LV full-fuel-cycle CO_2 emissions (13%–19%), and gasoline prices (~ 10%) (see Table 9-4 for full details, in 10-year increments). These reductions are limited by the relatively modest penetration of advanced vehicles other than SI hybrids, which is caused by the high estimated prices for these vehicles relative to the price of conventional gasoline vehicles in the scenarios.

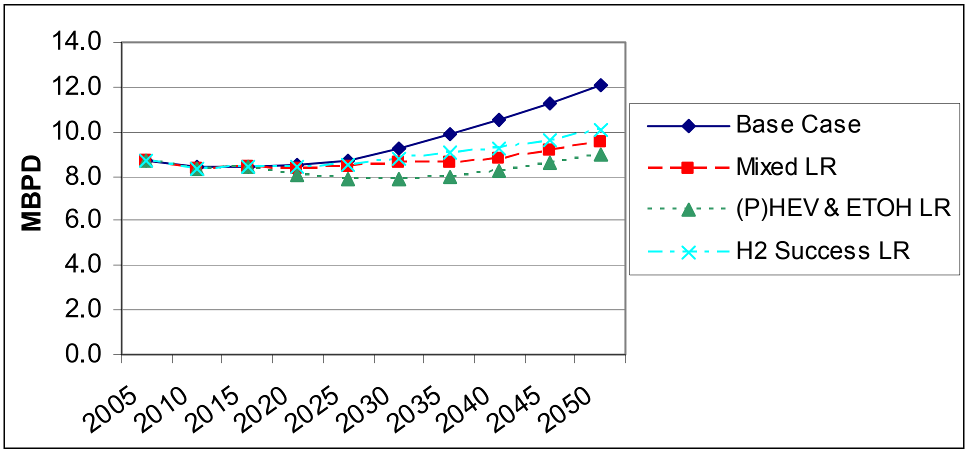

FIGURE 9-12 Light Vehicle Oil Use ("Literature Review" Vehicle Price Case)

7. **The scenarios with "program goals" vehicle prices lead to greater — but not dramatic — reductions** in U.S. and LV oil use (4 mbpd, or reductions of 31%–34%, by 2050; see Figure 9-13), U.S. liquid fuel imports, U.S. total CO_2 emissions (5%–6%), LV full-fuel-cycle CO_2 emissions (~25%), and gasoline prices (~18%) (Table 9-5). LV oil use and full-fuel-cycle CO_2 emissions might be held close to 2005 levels: that finding is significant. In addition, it is also important that these results can be achieved with several technology mixes (each scenario being a mix of technologies).

8. **If there's a winner among the three scenarios without subsidies with respect to reducing cumulative LV oil use, it is the (P)HEV & Ethanol scenario.** However, the other two scenarios are not far behind its results when the "program goals" vehicle prices are assumed. Most of the savings occur after 2030.

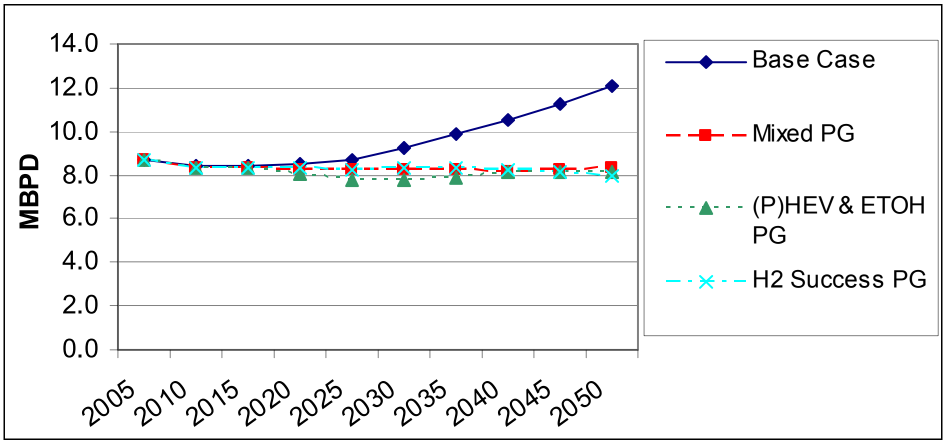

FIGURE 9-13 Light Vehicle Oil Use ("Program Goals" Vehicle Price Case)

9. **If there's a winner among the three scenarios without subsidies with respect to reducing cumulative LV full-fuel-cycle CO_2 emissions, it is again the (P)HEV & Ethanol scenario.** This scenario clearly provides the greatest cumulative reductions through 2030 and has the greatest cumulative reductions when assuming both the "literature review" and "program goals" vehicle prices (Figure 9-14).

10. **Adding vehicle subsidies does change which ATVs penetrate the market.** However, **if only "literature review" prices are achieved, the subsidies required to achieve the market penetration goals for the more advanced technologies (i.e., plug-in hybrids and fuel cell vehicles) envisioned for the three scenarios were both substantial and of unusual longevity: they essentially had to last forever to prevent the market shares for advanced vehicles from dropping significantly** (*assuming that both the assumptions underlying the vehicle choice model and the projected trajectories of technology costs are correct*). For example, achieving scenario goals for the "literature review" price cases required providing subsidies of $7,500/vehicle for PHEVs and FCVs from 2015 through 2050. In the Mixed scenario, allowing subsidies to begin dropping off in 2030 and to reach zero in 2050 caused PHEVs to drop from 24% of the market share in 2030 to less than 1% in 2050; similarly, in the H2 Success scenario, the same subsidy drop-off caused FCV shares to decline from 28% in 2030 to 8% in 2050 (Table 7-9). The total subsidies range from $400 billion to nearly $2 trillion for the various scenarios and vehicle price cases.

11. **Most of the subsidy cases examined lead to oil savings of approximately 5 mbpd by 2050 (a more than 40% reduction from the Base Case)**, as shown in Figure 9-15. (There is some variation among the cases in terms of the cumulative oil savings over time; see Tables 9-6 and 9-7 for details on oil use, CO_2 emissions, etc.) **The subsidy/barrel required to achieve this savings level ranges from $56/barrel to $136/barrel**, if neither CO_2 reduction nor other benefits associated with the subsidies are considered.

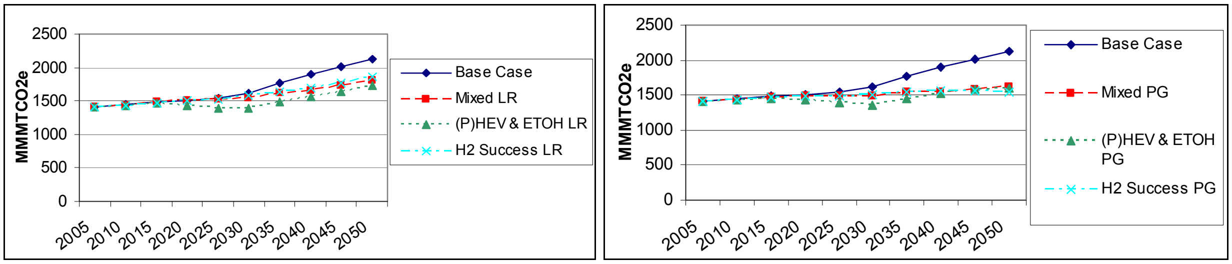

FIGURE 9-14 LV Fuel Cycle CO_2 Emissions, "Literature Review" and "Program Goals" Cases

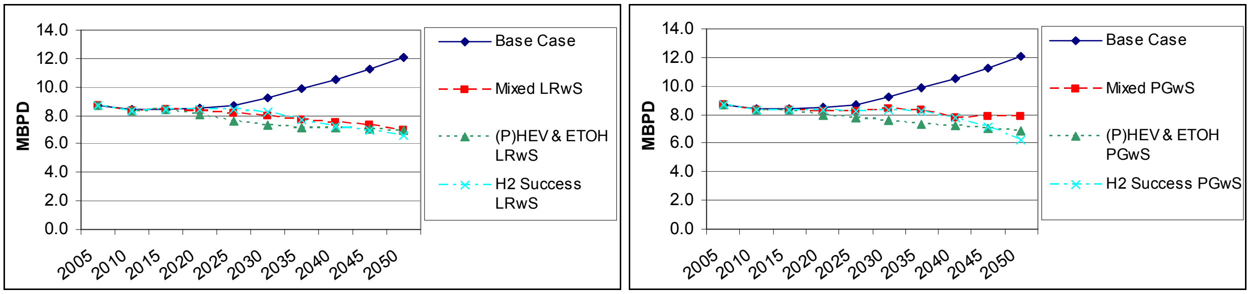

FIGURE 9-15 LV Oil Use for Both Subsidy Cases

12. **Excluding a single case in which subsidies yielded increased CO_2 emissions, the subsidy per metric ton of CO_2 reduced ranges from \$96/metric ton CO_2 (H2 Success, Program Goals with Subsidies) to \$5,016/metric ton CO_2 ([P]HEV & Ethanol, Program Goals with Subsidies),** again assuming that all the subsidy costs are attributed to CO_2 reductions. There is much greater variability among the cases in terms of achieving CO_2 reductions than there is for oil savings.

13. **All the scenarios resulted in energy security benefits, as estimated by the Oil Security Metrics Model developed by Oak Ridge National Laboratory.** In the model, energy security benefits are defined as the difference between the total market benefits of reducing U.S. oil use and increasing the price elasticity of U.S. oil demand in disrupted markets and in an undisrupted market. The benefits are reductions in the transfer of wealth to foreign countries, in the loss of potential GDP, and in disruption costs of a price shock. The model uses a distribution of three oil market forecasts (AEO 2008 Reference, High Oil Price, and Low Oil Price cases) for its "undisrupted market" and generates some supply disruptions for its "disrupted" market. Further details of the methodology are discussed in Chapter 8. Only the cases using the "literature review" vehicle prices were evaluated. The (P)HEV & Ethanol scenario, with and without subsidies, has the greatest energy security benefits of all the scenarios. Without subsidies, the Mixed scenario is second best; with subsidies, the H2 Success scenario is second best. Total cumulative benefits from 2010 to 2050 (in 2007\$) range from just under \$100 billion for the H2 Success scenario without subsidies to just over \$400 billion for the PHEV & Ethanol scenario with subsidies. These benefits are *in addition to* direct fuel cost savings from reduced petroleum use, as well as strategic and military benefits from reduced oil dependence.

TABLE 9-4 U.S. Oil Use, CO_2 Emissions, and Gasoline Price for Scenarios Using Literature Review Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Lit. Review Prices	8.67	8.33	8.35	8.58	8.75	9.53
(P)HEV & Ethanol Lit. Review Prices	8.67	8.33	8.02	7.86	8.25	9.01
H2 Success Lit. Review Prices	8.67	8.33	8.41	8.78	9.26	10.05
Savings						
Mixed Lit. Review Prices	0.0	0.1	0.1	0.6	1.8	2.5
(P)HEV & Ethanol Lit. Review Prices	0.0	0.1	0.5	1.3	2.3	3.0
H2 Success Lit. Review Prices	0.0	0.1	0.1	0.4	1.3	2.0
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Lit. Review Prices	1419	1433	1513	1543	1652	1809
(P)HEV & Ethanol Lit. Review Prices	1419	1432	1424	1394	1557	1728
H2 Success Lit. Review Prices	1419	1433	1502	1570	1689	1853
Reductions (%)						
Mixed Lit. Review Prices	0.0%	0.4%	-0.1%	4.8%	12.7%	14.8%
(P)HEV & Ethanol Lit. Review Prices	0.0%	0.6%	5.8%	14.0%	17.7%	18.6%
H2 Success Lit. Review Prices	0.0%	0.5%	0.6%	3.1%	10.8%	12.7%
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Lit. Review Prices	20.5	20.3	20.8	21.6	23.1	25.9
(P)HEV & Ethanol Lit. Review Prices	20.5	20.3	20.5	20.8	22.6	25.4
H2 Success Lit. Review Prices	20.5	20.3	20.8	21.8	23.6	26.4
Savings						
Mixed Lit. Review Prices	0.0	0.1	0.1	0.7	1.9	2.5
(P)HEV & Ethanol Lit. Review Prices	0.0	0.1	0.4	1.5	2.4	3.0
H2 Success Lit. Review Prices	0.0	0.2	0.1	0.5	1.4	2.0
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Lit. Review Prices	60.5%	53.6%	46.4%	42.5%	45.0%	47.2%
(P)HEV & Ethanol Lit. Review Prices	60.5%	53.4%	44.4%	39.2%	43.4%	45.8%
H2 Success Lit. Review Prices	60.5%	53.6%	46.5%	43.4%	47.1%	50.2%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Lit. Review Prices	5945	6178	6702	7393	8289	9232
(P)HEV & Ethanol Lit. Review Prices	5945	6176	6613	7243	8194	9151
H2 Success Lit. Review Prices	5945	6177	6690	7419	8326	9276
Reductions (%)						
Mixed Lit. Review Prices	0.0%	0.1%	0.0%	1.0%	2.8%	3.3%
(P)HEV & Ethanol Lit. Review Prices	0.0%	0.1%	1.3%	3.0%	3.9%	4.1%
H2 Success Lit. Review Prices	0.0%	0.1%	0.1%	0.7%	2.4%	2.8%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Lit. Review Prices	2.33	2.59	2.88	3.02	3.29	3.59
(P)HEV & Ethanol Lit. Review Prices	2.33	2.59	2.78	2.98	3.26	3.49
H2 Success Lit. Review Prices	2.33	2.60	2.88	3.04	3.29	3.60
Reductions (%)						
Mixed Lit. Review Prices	0.0%	1.2%	1.0%	4.2%	6.9%	8.7%
(P)HEV & Ethanol Lit. Review Prices	0.0%	1.2%	4.5%	5.6%	7.8%	11.3%
H2 Success Lit. Review Prices	0.0%	1.2%	1.1%	3.6%	7.0%	8.5%

TABLE 9-5 U.S. Oil Use, CO_2 Emissions, and Gasoline Price for Scenarios Using Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed Program Goals Prices	8.67	8.33	8.24	8.27	8.13	8.33
(P)HEV & Ethanol Program Goals Prices	8.67	8.33	8.07	7.73	8.10	8.15
H2 Success Program Goals Prices	8.67	8.33	8.30	8.32	8.27	7.98
Savings						
Mixed Program Goals Prices	0.0	0.1	0.2	0.9	2.4	3.7
(P)HEV & Ethanol Program Goals Prices	0.0	0.1	0.4	1.5	2.4	3.9
H2 Success Program Goals Prices	0.0	0.1	0.2	0.9	2.3	4.1
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed Program Goals Prices	1419	1431	1477	1486	1538	1611
(P)HEV & Ethanol Program Goals Prices	1419	1438	1434	1356	1516	1594
H2 Success Program Goals Prices	1419	1429	1489	1510	1568	1535
Reductions (%)						
Mixed Program Goals Prices	0.0%	0.6%	2.3%	8.3%	18.7%	24.2%
(P)HEV & Ethanol Program Goals Prices	0.0%	0.2%	5.1%	16.3%	19.9%	25.0%
H2 Success Program Goals Prices	0.0%	0.7%	1.5%	6.8%	17.2%	27.7%
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed Program Goals Prices	20.5	20.3	20.6	21.2	22.4	24.6
(P)HEV & Ethanol Program Goals Prices	20.5	20.3	20.4	20.7	22.3	24.5
H2 Success Program Goals Prices	20.5	20.3	20.7	21.3	22.6	24.3
Savings						
Mixed Program Goals Prices	0.0	0.1	0.3	1.1	2.6	3.8
(P)HEV & Ethanol Program Goals Prices	0.0	0.1	0.5	1.6	2.6	3.9
H2 Success Program Goals Prices	0.0	0.1	0.2	1.0	2.4	4.1
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed Program Goals Prices	60.5%	53.5%	46.1%	42.3%	45.3%	46.8%
(P)HEV & Ethanol Program Goals Prices	60.5%	53.6%	44.8%	38.9%	43.9%	44.6%
H2 Success Program Goals Prices	60.5%	53.4%	46.7%	42.7%	46.8%	49.0%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed Program Goals Prices	5945	6176	6666	7335	8175	9033
(P)HEV & Ethanol Program Goals Prices	5945	6182	6623	7205	8153	9016
H2 Success Program Goals Prices	5945	6174	6677	7359	8205	8958
Reductions (%)						
Mixed Program Goals Prices	0.0%	0.1%	0.5%	1.8%	4.2%	5.4%
(P)HEV & Ethanol Program Goals Prices	0.0%	0.0%	1.1%	3.5%	4.4%	5.6%
H2 Success Program Goals Prices	0.0%	0.2%	0.3%	1.5%	3.8%	6.2%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed Program Goals Prices	2.33	2.59	2.84	2.99	2.99	3.28
(P)HEV & Ethanol Program Goals Prices	2.33	2.59	2.79	2.82	3.00	3.22
H2 Success Program Goals Prices	2.33	2.59	2.84	2.99	3.06	3.23
Reductions (%)						
Mixed Program Goals Prices	0.0%	1.2%	2.3%	5.1%	15.3%	16.5%
(P)HEV & Ethanol Program Goals Prices	0.0%	1.2%	4.3%	10.7%	15.1%	18.3%
H2 Success Program Goals Prices	0.0%	1.4%	2.3%	5.1%	13.4%	18.0%

TABLE 9-6 U.S. Oil Use, CO_2 Emissions, and Gasoline Price for Scenarios Incorporating Selected Subsidies Along with Literature Review Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed LR Prices with Subsidies	8.67	8.33	8.33	7.96	7.51	6.97
(P)HEV & Ethanol LR Prices with Subsidies	8.67	8.33	8.02	7.30	7.17	6.97
H2 Success LR Prices with Subsidies	8.67	8.33	8.39	8.24	7.27	6.63
Savings						
Mixed LR Prices with Subsidies	0.0	0.1	0.1	1.3	3.0	5.1
(P)HEV & Ethanol LR Prices with Subsidies	0.0	0.1	0.5	1.9	3.4	5.1
H2 Success LR Prices with Subsidies	0.0	0.1	0.1	1.0	3.3	5.4
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed LR Prices with Subsidies	1419	1430	1511	1498	1554	1501
(P)HEV & Ethanol LR Prices with Subsidies	1419	1430	1425	1354	1511	1659
H2 Success LR Prices with Subsidies	1419	1421	1509	1484	1354	1205
Reductions (%)						
Mixed LR Prices with Subsidies	0.0%	0.7%	0.0%	7.6%	17.9%	29.3%
(P)HEV & Ethanol LR Prices with Subsidies	0.0%	0.6%	5.7%	16.4%	20.2%	21.9%
H2 Success LR Prices with Subsidies	0.0%	1.3%	0.2%	8.4%	28.5%	43.3%
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed LR Prices with Subsidies	20.5	20.3	20.7	21.0	21.8	23.3
(P)HEV & Ethanol LR Prices with Subsidies	20.5	20.3	20.5	20.3	21.5	23.3
H2 Success LR Prices with Subsidies	20.5	20.3	20.8	21.3	21.6	23.0
Savings						
Mixed LR Prices with Subsidies	0.0	0.1	0.2	1.3	3.1	5.1
(P)HEV & Ethanol LR Prices with Subsidies	0.0	0.1	0.5	2.0	3.4	5.1
H2 Success LR Prices with Subsidies	0.0	0.1	0.1	1.0	3.3	5.4
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed LR Prices with Subsidies	60.5%	53.6%	46.7%	41.9%	44.9%	46.6%
(P)HEV & Ethanol LR Prices with Subsidies	60.5%	53.4%	44.4%	38.4%	43.1%	47.3%
H2 Success LR Prices with Subsidies	60.5%	53.6%	46.4%	42.6%	45.1%	49.1%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed LR Prices with Subsidies	5945	6174	6699	7347	8191	8924
(P)HEV & Ethanol LR Prices with Subsidies	5945	6175	6614	7203	8148	9082
H2 Success LR Prices with Subsidies	5945	6165	6698	7333	7991	8628
Reductions (%)						
Mixed LR Prices with Subsidies	0.0%	0.2%	0.0%	1.6%	4.0%	6.5%
(P)HEV & Ethanol LR Prices with Subsidies	0.0%	0.2%	1.3%	3.6%	4.5%	4.9%
H2 Success LR Prices with Subsidies	0.0%	0.3%	0.0%	1.8%	6.3%	9.6%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed LR Prices with Subsidies	2.33	2.59	2.88	3.00	2.98	3.08
(P)HEV & Ethanol LR Prices with Subsidies	2.33	2.59	2.78	2.84	2.93	3.14
H2 Success LR Prices with Subsidies	2.33	2.60	2.88	2.99	2.87	2.99
Reductions (%)						
Mixed LR Prices with Subsidies	0.0%	1.2%	1.0%	4.8%	15.7%	21.6%
(P)HEV & Ethanol LR Prices with Subsidies	0.0%	1.3%	4.6%	10.0%	17.2%	20.2%
H2 Success LR Prices with Subsidies	0.0%	1.2%	1.0%	5.1%	18.7%	24.0%

TABLE 9-7 U.S. Oil Use, CO_2 Emissions, and Gasoline Price for Scenarios Incorporating Selected Subsidies Along with Program Goals Vehicle Prices

	2005	2010	2020	2030	2040	2050
LV Oil Use (excludes ethanol blends; MBPD at gasoline conversion rate)						
Base Case	8.67	8.42	8.48	9.21	10.53	12.06
Mixed PG Prices with Subsidies	8.67	8.33	8.24	8.38	7.78	7.85
(P)HEV & Ethanol PG Prices with Subsidies	8.67	8.33	7.97	7.62	7.21	6.88
H2 Success PG Prices with Subsidies	8.67	8.33	8.30	8.31	7.81	6.19
Savings						
Mixed PG Prices with Subsidies	0.0	0.1	0.2	0.8	2.8	4.2
(P)HEV & Ethanol PG Prices with Subsidies	0.0	0.1	0.5	1.6	3.3	5.2
H2 Success PG Prices with Subsidies	0.0	0.1	0.2	0.9	2.7	5.9
LV Full Fuel Cycle CO2 Emissions (MMTCO2e)						
Base Case	1419	1440	1511	1621	1893	2123
Mixed PG Prices with Subsidies	1419	1434	1487	1508	1552	1642
(P)HEV & Ethanol PG Prices with Subsidies	1419	1438	1420	1362	1488	1597
H2 Success PG Prices with Subsidies	1419	1427	1492	1497	1454	1137
Reductions (%)						
Mixed PG Prices with Subsidies	0.0%	0.4%	1.6%	7.0%	18.0%	22.7%
(P)HEV & Ethanol PG Prices with Subsidies	0.0%	0.1%	6.1%	16.0%	21.4%	24.8%
H2 Success PG Prices with Subsidies	0.0%	0.9%	1.3%	7.6%	23.2%	46.5%
Liquid Fuels Supply (excluding ethanol and H2) (MBPD)						
Base Case	20.5	20.4	20.9	22.3	25.0	28.4
Mixed PG Prices with Subsidies	20.5	20.3	20.6	21.2	22.1	24.1
(P)HEV & Ethanol PG Prices with Subsidies	20.5	20.3	20.3	20.6	21.5	23.2
H2 Success PG Prices with Subsidies	20.5	20.3	20.7	21.3	22.1	22.5
Savings						
Mixed PG Prices with Subsidies	0.0	0.1	0.3	1.1	2.9	4.3
(P)HEV & Ethanol PG Prices with Subsidies	0.0	0.1	0.6	1.7	3.5	5.3
H2 Success PG Prices with Subsidies	0.0	0.1	0.2	1.0	2.9	5.9
Net Import Share of Liqud Fuels Product Supplied (includes ethanol)						
Base Case	60.5%	54.0%	46.8%	44.5%	50.5%	53.1%
Mixed PG Prices with Subsidies	60.5%	53.5%	46.1%	42.1%	44.7%	47.8%
(P)HEV & Ethanol PG Prices with Subsidies	60.5%	53.6%	44.5%	38.8%	43.3%	45.8%
H2 Success PG Prices with Subsidies	60.5%	53.4%	46.3%	42.7%	46.4%	45.3%
Total CO2 Emissions (MMTCO2e)						
Base Case	5945	6184	6700	7470	8530	9546
Mixed PG Prices with Subsidies	5945	6179	6675	7357	8189	9064
(P)HEV & Ethanol PG Prices with Subsidies	5945	6183	6608	7211	8124	9020
H2 Success PG Prices with Subsidies	5945	6171	6681	7346	8091	8560
Reductions (%)						
Mixed PG Prices with Subsidies	0.0%	0.1%	0.4%	1.5%	4.0%	5.0%
(P)HEV & Ethanol PG Prices with Subsidies	0.0%	0.0%	1.4%	3.5%	4.7%	5.5%
H2 Success PG Prices with Subsidies	0.0%	0.2%	0.3%	1.7%	5.1%	10.3%
Gasoline Price ($/gallon)						
Base Case	2.33	2.63	2.91	3.15	3.54	3.93
Mixed PG Prices with Subsidies	2.33	2.59	2.84	2.96	2.85	3.15
(P)HEV & Ethanol PG Prices with Subsidies	2.33	2.60	2.77	2.80	2.80	3.05
H2 Success PG Prices with Subsidies	2.33	2.60	2.84	2.99	2.88	2.80
Reductions (%)						
Mixed PG Prices with Subsidies	0.0%	1.3%	2.4%	6.1%	19.3%	20.0%
(P)HEV & Ethanol PG Prices with Subsidies	0.0%	1.1%	4.8%	11.3%	20.9%	22.5%
H2 Success PG Prices with Subsidies	0.0%	1.2%	2.4%	5.2%	18.4%	28.8%

9.3.3 Limitations of NEMS-MP Results

Every model has its limitations, and the NEMS-MP model is no exception. In this section, key limitations of the NEMS-MP model are discussed to help the reader evaluate the robustness of the results reported. The uncertainty in the Base Case projections, discussed in Section 9.3.1, is a general limitation of all projections over such a long time frame.

1. **Macroeconomic analysis.**
   Large-scale changes in vehicle technology and a resulting major reduction in U.S. oil demand could have wide-ranging impacts on world oil price, vehicle sales, GDP, and other economic indicators — especially if these changes took place on a global scale. Although the EIA-NEMS model is linked to a macroeconomic model developed by Global Insight, Inc., NEMS-MP is not run with this model, because it extends only to 2030 and is proprietary and therefore not available for extension to 2050. Thus, the macroeconomic inputs in NEMS-MP are by assumption, and there are no differences between the scenarios in total vehicle sales, GDP, interest rates, or other macroeconomic projections. In addition, the world oil price is an input assumption in this version of the model (while U.S. gasoline prices vary across the scenarios, this result is because of changes in gasoline consumption and the resulting impact on refineries and gasoline imports). Thus, **differential effects of the scenarios on the overall U.S. and world economy cannot be examined.** It is important to note, however, that even *with* a global model, estimating impacts on world oil prices and other important variables would demand an evaluation of how the rest of the major world economies altered their transportation systems in response to development of the advanced vehicle technologies — a daunting task.

2. **Vehicle Choice Model.**

   a. The VCM equations are based on recent consumer behavior, which appears to apply a high discount rate to future fuel savings. As a result, vehicle price is the key driver of vehicle choice in the model. While vehicle price is crucially important to a consumer's vehicle purchase decision, its precise role compared to other factors remains controversial, especially for vehicles with radically new drivetrains. We do know that if the vehicle payback period is substantially lengthened in the NEMS VCM, then the market penetration rates of more expensive ATVs increase (see Appendix D). The payback currently used in the NEMS VCM is 3 to4 years (the value is not a precise input). *The Multi-Path Study postulates a future in which increased fuel economy is highly prized (e.g., used vehicles would be more valuable if they were more efficient); given this assumption, the default payback period in the model is probably too low.*

   b. Fuel availability affects vehicle choice in the NEMS-MP model: when the availability of stations providing a specific fuel is low, the market penetration of vehicles using that fuel is reduced. The NEMS-MP model provides for only one station size per fuel type throughout time, thus limiting the ability of the model to accurately portray fuel availability. We are hopeful that concerns about this limitation have been reduced by incorporating jump-starting of H_2 stations in the H2 Success scenario and increasing the availability of stations selling E85, but the handling of fuel availability for these two fuels merits review.

3. **Vehicle incremental prices.**
The incremental prices for average vehicles in the 12 car and LT classes in NEMS-MP were derived by extrapolating from detailed cost, and subsequently price, estimates for only two types of leading edge vehicles. The actual prices of the vehicles depend on parameters that change substantially over time, and costs for different types of drivetrains change at different rates; in contrast, the method of extrapolating the costs is invariant over time. Given the importance of vehicle prices in determining market penetration rates, the method we used to extrapolate these values should be evaluated.

4. **Fuel prices.**

   a. There have been wild swings in world oil prices recently (e.g., 2008). As indicated previously, we assume a price of \$93/barrel (a price of \$3.15/gallon for U.S. gasoline in the Base Case) in 2030 and of \$116/barrel (\$3.93/gallon) in 2050. If the world oil price is substantially higher or lower in those years, the market penetrations we have estimated would need to be revised. At the very least, it would be useful to conduct a sensitivity analysis with varying world oil prices.

   b. H2A has recently revised its hydrogen production estimates. However, given the primacy of vehicle prices in driving the VCM, we believe that unless the H_2 prices are substantially changed, they would have minimal effects on the estimated FCV market penetrations.

5. **Rebound effect and impact on travel and fuel use estimates.**
In the model, the rebound effect[31] is applied to the fleet as a whole, not to vehicle classes based on drivetrain technology. In other words, all vehicles in any analysis year have the same annual VMT regardless of their types of drivetrain technology, levels of fuel economy, and fuel price. With the correct application of the rebound effect, the model would have vehicles of different technologies and types of fuel being driven over differing annual vehicle miles on the basis of their differences in fuel cost/mile. The NEMS-MP approach thus distorts fuel use totals to some degree.

6. **PHEVs.**
Only one slot for PHEVs is available in NEMS-MP; thus, only one price, fuel economy level, and value for percentage of travel on electricity can be input to NEMS-MP. While PHEV40s — plug-ins with a 40-mile range — were selected, it would have been more realistic to include PHEVs with shorter “all-electric” ranges as well as a better representation of the likely development of this market. In addition, the share of PHEVs’ travel on electricity is not generated internally by the model but instead must be input.

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[31] Increase in vmt caused by a decreased driving cost/mile. The assumed elasticity of vmt with respect to the cost of driving is –0.05 in the short term (1 year) and –0.19 in the long term (after 10 years).

9.4 CONCLUSIONS

Projecting the future role of advanced drivetrains and fuels in the light vehicle market is inherently difficult given the following factors: the volatility and uncertainty of oil prices, our inadequate understanding of consumer response to technologies not yet in the marketplace, the relative infancy of several important new technologies from which many changes are yet to come in their performance levels and costs, and the importance — and uncertainty — of future government interference in the marketplace in the form of new regulatory standards and economic incentives for adoption of new technologies.

This MP Study has taken a stab at understanding this future role by examining a few limited scenarios that contemplate the effects of varying vehicle prices, fuel prices, government subsidies, and other key factors. These are projections, not forecasts, in that they try to answer a series of "what-if" questions without assigning probabilities to most of the basic assumptions. Some key conclusions that may be drawn from our analyses are as follows:

1. Taking account of new CAFE standards and assuming that future oil prices return to high levels (~$100/bbl in 2030) even without a strong emphasis on developing new drivetrain technologies, light-duty vehicle oil use — currently about 8.5 mbpd — will hold relatively steady through the early 2020s but will increase substantially thereafter, reaching 12 mbpd by 2050.

2. Even if optimistic progress is assumed in bringing down the costs and improving the performance of new drivetrain technologies, gauging the potential for future success of these drivetrain technologies requires recognizing some basic relationships:
   a. The attractiveness of new technologies will hinge in large part on how one values future fuel savings, and different actors will value these savings differently. An average consumer today will value future savings far less than society would; and a technology that appeared highly cost effective to society might appear too costly to that consumer.
   b. With a range of available technologies with increasing performance but also increasing price, technologies will be judged on their *marginal* attractiveness compared to competing technologies. With cost curves of increasing slope, "good" technologies (e.g., hybrids) may be more attractive than "best" technologies (e.g., long-range plug-in hybrids or fuel cell vehicles) because the marginal benefits of moving beyond the already-good efficiency of a hybrid may be insufficient to compensate for the added cost — even if the more advanced technology vehicle is cost effective compared to today's conventional vehicles.

3. Using relatively optimistic assumptions about future technology costs and performance and assuming high oil prices, reduced prices for ethanol and hydrogen, and the jump-starting of H2 stations, advanced vehicle technologies could reduce 2050 LV oil use by about 2–3 mbpd to 9–10 mbpd; in addition, LV fuel cycle CO_2 emissions would be reduced by 13%–19%. These results assume essentially no change in consumer behavior regarding future fuel savings (but an easing of consumer concerns about "new" technologies) and no further government market intervention.

4. Assuming the “literature review” vehicle price assumptions, long-term government subsidies of $7,500/vehicle would allow significantly higher penetration of advanced drivetrain vehicles, with LV oil use reduced (as compared to the Base Case) by about 5 mbpd and LV fuel cycle CO_2 emissions reduced by about 22% for the (P)HEV & Ethanol scenario, 29% for the Mixed scenario, and 43% for the H2 Success scenario.

5. Alternatively, more success in reducing technology costs — reaching the ambitious cost goals established by DOE, thus yielding the “program goals” vehicle price estimates — could result in about a 4-mpbd reduction in LV oil use by 2050 and in reduced CO_2 emissions of about 25%. Furthermore, subsidies for these lower-cost vehicles — considerably smaller than the subsidies needed in the “literature review” cases at a maximum of $4,000/vehicle by 2050, depending on scenario — could drive down (1) 2050 LV oil use (compared to the Base Case) by 4–6 mbpd and (2) LV fuel cycle CO_2 emissions by 23%–25% for the Mixed and (P)HEV & Ethanol scenarios and more than 46% for the H2 Success scenario.

6. Changes in how consumers value future fuel savings could have a dramatic impact on technology penetration — and thus on future oil use and CO_2 emissions. For example, with “literature review” vehicle prices, changing the “payback” requirements in the Vehicle Choice Model from 3 to 4 years (its current value) to 15 years would jump the 2050 passenger car share of SI PHEV40s and FCVs from negligible levels to about 10% each.

Appendix F contains additional discussion on lessons learned through the MP Study.

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APPENDICES

APPENDIX A: VEHICLE ATTRIBUTES USED IN NEMS-MP MODEL RUNS

APPENDIX B: PRELIMINARY ESTIMATE OF THE COST OF JUMP STARTING H_2 STATIONS IN THE H2 SUCCESS SCENARIO

APPENDIX C: BASIS FOR ESTIMATES OF FULL-FUEL-CYCLE CO_2 EMISSIONS FROM LIGHT VEHICLES

APPENDIX D: SELECTED SENSITIVITY RUNS WITH THE NEMS-MP VEHICLE CHOICE MODEL

APPENDIX E: OTHER NEMS-MP RESULTS FOR THE BASE CASE AND SCENARIOS (ISSUED SEPARATELY)

APPENDIX F: KEY LESSONS LEARNED FROM AND SIDE BENEFITS OF THE MP STUDY

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APPENDIX A: VEHICLE ATTRIBUTES USED IN NEMS-MP MODEL RUNS

The basis for the vehicle fuel economy and price estimates used in this study is discussed in Chapter 3 of the report. The fuel economy multipliers and incremental prices (over a baseline conventional gasoline vehicle) that reflect the discussion in Chapter 3 and that are input to the NEMS-MP model for the scenario analysis are provided in this appendix, as are the characterizations of the other vehicle attributes (range, maintenance cost, acceleration, top speed, and luggage space) that also are used in the model (Tables A-1 through A-4).

Two sets of estimates are provided reflecting the two sets of vehicle price estimates discussed in Chapter 3: "literature review" and "program goals." For both sets, the inputs for the Mixed scenario and (P)HEV & Ethanol scenario are the same. The inputs for the H2 Success scenario are similar to those of the Mixed and (P)HEV & Ethanol scenarios except that fuel cell vehicles (FCVs) and plug-in FCVs are assumed to be introduced earlier than they are in the Mixed and (P)HEV & Ethanol scenarios.

In sum, the following tables show:

- Vehicle attributes assuming "literature review" vehicle prices for the Mixed and (P)HEV & Ethanol scenarios (6 cars and 6 light trucks [LTs] for each technology);
- Vehicle attributes assuming "literature review" vehicle prices for the H2 Success scenario (6 cars and 6 LTs for each technology);
- Vehicle attributes assuming "program goals" vehicle prices for the Mixed and (P)HEV & Ethanol scenarios (6 cars and 6 LTs for each technology); and
- Vehicle attributes assuming "program goals" vehicle prices for the H2 Success scenario (6 cars and 6 LTs for each technology).

The vehicle attributes are presented generally as ratios relative to the attributes exhibited by MP Base Case conventional (gasoline) vehicles (CVs) in each analysis year. The only exception is the vehicle price attribute, which is presented as the incremental price of the advanced technology vehicle relative to the CV. The prices are in 2005 dollars. The fuel economy ratios and incremental prices of some diesel and gasoline HEV classes are weighted in the early years of the scenarios to account for fact that some models are already being produced in these classes. These models do not have the same attributes (specifically fuel economy and price) as those estimated for models with more advanced drivetrain and glider technologies, yet they must be accounted for because they will continue to be produced for a while.

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TABLE A-1 “Literature Review” Vehicle Input Assumptions for MP Mixed and (P)HEV & Ethanol Scenarios

"Literature Review" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2015**	**2020**	**2025**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$3,396	$3,307	$3,218	$2,951	$2,774	$3,014	$3,010	$3,006	$2,998	$2,991	$2,960	$ 2,891	$ 2,823	$ 2,603	$2,466
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.37	1.38	1.40	1.44	1.467	1.33	1.35	1.37	1.42	1.467	1.37	1.39	1.40	1.44	1.467
Diesel Hybrid	**2020**	**2025**	**2030**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$6,219	$6,123	$6,028	$5,838	$5,647	$6,200	$6,120	$6,040	$5,895	$5,735	$4,814	$ 4,702	$ 4,590	$ 4,299	$4,075
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.166	2.21	2.26	2.35	2.446	2.190	2.23	2.28	2.36	2.446	2.208	2.24	2.28	2.37	2.446
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$4,950	$4,692	$4,377	$3,325	$2,668	$3,857	$3,715	$3,572	$3,116	$2,831	$3,071	$ 2,896	$ 2,721	$ 2,127	$1,778
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.70	2.03	2.13	2.26	2.343	2.10	2.13	2.17	2.27	2.343	2.10	2.13	2.16	2.28	2.343
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$139	$119	$99	$31	-$9	$232	$236	$241	$257	$266	$276	$ 256	$ 236	$ 169	$129
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24
Fuel Cell (hydrogen)	**2032**	**2037**	**2042**	**2040**	**2050**	**2032**	**2037**	**2042**	**2040**	2050	**2028**	**2033**	**2038**	**2040**	**2050**
Incremental Price ($)	$8,179	$7,983	$7,787	$7,866	$7,474	$8,200	$8,010	$7,820	$7,896	$7,516	$6,521	$ 6,285	$ 6,050	$ 5,955	$5,484
Range	0.90	0.99		**0.98**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00		**1.00**	1.00
Maintenance Cost	1.02	1.00	1.00	**1.00**	1.00	1.02	1.00	1.00	**1.00**	1.00	1.06	1.01		**1.00**	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.98		**0.96**	1.00	0.90	0.98		**0.96**	1.00	0.90	1.00		**1.00**	1.00
Luggage Space	0.90	0.95		0.95	1.00	0.90	0.95		0.95	1.00	0.90	1.00		**1.00**	1.00
Fuel economy X factor (unadjusted)	2.94	3.00	3.05	3.03	3.14	2.94	3.00	3.05	3.03	3.14	2.82	2.90	2.97	3.00	3.14
FCV PHEV 40	**2034**	**2039**	**2044**	**2040**	**2050**	**2034**	**2039**	**2044**	**2040**	**2050**	**2030**	**2035**	**2040**	**2040**	**2050**
Incremental Price ($)	$10,175	$9,792	$9,410	$9,716	$8,951	$10,822	$10,435	$10,049	$10,358	$9,586	$9,752	$ 9,318	$ 8,884	$ 8,884	$8,017
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.02	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.06	1.01	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.85	0.88	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.80	0.85	0.85	0.86	0.93	0.80	0.85	0.85	0.86	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	3.03	3.07	3.12	3.08	3.18	3.03	3.07	3.12	3.08	3.18	2.93	2.99	3.05	3.05	3.18
Fuel economy X factor (electricity, unadjusted)	5.12	5.14	5.16	5.15	5.19	5.12	5.14	5.16	5.15	5.19	5.07	5.10	5.13	5.13	5.19
SI Plug-in HEV 40	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$7,524	$7,131	$6,738	$6,345	$5,558	$8,267	$7,861	$7,456	$6,970	$6,160	$7,010	$ 6,663	$ 6,316	$ 5,830	$5,136
Range	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.06	1.05		1.05	1.03	1.07	1.05		1.05	1.04	1.08	1.05		1.05	1.04
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	1.00	1.00		1.00	1.00	0.90	0.90		0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.09	2.12	2.16	2.19	2.27	2.07	2.11	2.15	2.19	2.27	2.05	2.09	2.13	2.19	2.27
Fuel economy X factor (electricity, unadjusted)	5.34	5.41	5.48	5.55	5.69	5.30	5.38	5.45	5.54	5.69	5.27	5.35	5.42	5.53	5.69

TABLE A-1 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	COMPACT					Mid-size (Medium) CAR					LARGE CAR				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2012**	**2017**	**2022**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,491	$2,199	$2,568	$2,055	$1,770	$1,951	$2,595	$3,086	$2,617	$2,370	$2,157	$2,798	$3,438	$2,991	$2,767
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.40	1.45	1.46	1.467	1.30	1.38	1.45	1.46	1.467	1.30	1.37	1.45	1.46	1.467
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**
Incremental Price ($)	$3,962	$3,812	$3,661	$3,210	$2,909	$5,257	$5,107	$4,956	$4,506	$4,205	$5,961	$5,805	$5,648	$5,179	$4,867
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.45
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$2,316	$2,497	$2,495	$1,498	$944	$2,343	$2,949	$3,556	$2,407	$1,833	$3,763	$3,928	$4,002	$2,913	$2,340
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	**0.90**	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.54	1.89	2.11	2.26	2.343	1.41	1.75	2.10	2.26	2.343	1.53	1.85	2.11	2.26	2.343
Advanced Gasoline	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$353	$276	$200	-$92	-$245	$531	$471	$410	$168	$47	$616	$579	$542	$401	$328
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.17	1.18	1.19	1.22	1.24	1.16	1.17	1.18	1.22	1.24	1.17	1.18	1.19	1.22	1.24
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$5,157	$4,930	$4,703	$4,567	$4,114	$7,640	$7,273	$6,906	$6,393	$5,660	$8,511	$8,123	$7,735	$7,192	$6,416
Range	0.90	1.00		**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02		**1.00**	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00		**1.00**	1.00	0.85	0.90	0.97	1.00	1.00	0.85	0.90	1.00	1.00	1.00
Luggage Space	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.79	2.86	2.94	2.99	3.14	2.65	2.74	2.83	2.96	3.14	2.65	2.74	2.83	2.96	3.14
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$9,041	$8,587	$8,132	$8,042	$7,133	$12,240	$11,512	$10,783	$10,055	$8,598	$13,385	$12,612	$11,840	$11,067	$9,522
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.80	0.85	0.89	0.90	0.90	0.80	0.85	0.89	0.90	0.90
Luggage Space	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.89	2.96	3.03	3.04	3.18	2.74	2.83	2.92	3.00	3.18	2.74	2.83	2.92	3.00	3.18
Fuel economy X factor (electricity, unadjusted)	5.03	5.07	5.11	5.11	5.19	4.86	4.93	4.99	5.06	5.19	4.86	4.93	4.99	5.06	5.19
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2018**	**2023**	**2028**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$6,457	$6,121	$5,785	$5,180	$4,508	$8,511	$8,051	$7,590	$6,484	$5,563	$8,784	$8,369	$7,954	$7,123	$6,293
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.05	1.05	1.03	1.10	1.08	1.05	1.05	1.03	1.10	1.05		1.05	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.02	2.06	2.10	2.18	2.27	2.02	2.06	2.10	2.19	2.27	2.00	2.04	2.09	2.18	2.27
Fuel economy X factor (electricity, unadjusted)	5.20	5.29	5.37	5.52	5.69	5.25	5.32	5.39	5.55	5.69	5.17	5.25	5.34	5.52	5.69

TABLE A-1 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	SMALL TRUCK (PICKUP)					CARGO (INCL. 2b) TRUCK (PICKUP)					SMALL VAN (MINIVAN)				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,939	$3,038	$3,087	$2,519	$2,219	$1,645	$2,873	$4,100	$3,901	$3,801	$3,828	$3,675	$3,522	$2,909	$2,603
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.30	1.36	1.40	1.39	1.382	1.31	1.35	1.40	1.39	1.382	1.41	1.40	1.40	1.39	1.382
Diesel Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$4,783	$4,594	$4,405	$3,802	$3,425	$6,398	$ 6,302	$ 6,206	$ 5,917	$5,725	$6,877	$6,530	$6,182	$4,863	$4,168
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.923	1.94	1.96	2.02	2.059	1.937	1.95	1.97	2.02	2.059	1.893	1.91	1.94	2.02	2.059
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,458	$2,319	$2,180	$1,736	$1,458	$3,629	$ 3,580	$ 3,531	$ 3,383	$3,285	$4,279	$3,993	$3,708	$2,567	$1,996
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.85	1.86	1.88	1.93	1.958	1.86	1.87	1.89	1.93	1.958	1.82	1.84	1.86	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$427	$402	$376	$290	$239	$811	$ 892	$ 972	$ 1,231	$1,392	$1,052	$979	$907	$617	$472
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.09	1.10	1.11	1.15	1.17	1.14	1.15	1.15	1.16	1.17
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2030**	**2035**	**2040**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$8,034	$7,721	$7,407	$7,219	$6,593	$10,594	$ 10,359	$ 10,124	$ 10,124	$9,653	$10,307	$9,818	$9,329	$8,644	$7,666
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00		**1.00**	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00	1.00	**1.00**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Luggage Space	**0.95**	1.00	1.00	**1.00**	1.00	**1.00**	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Fuel economy X factor (unadjusted)	2.33	2.38	2.44	2.48	2.59	2.40	2.45	2.49	2.49	2.59	2.23	2.30	2.36	2.46	2.59
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2032**	**2037**	**2042**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$15,237	$14,666	$14,095	$13,981	$12,840	$19,291	$ 18,757	$ 18,224	$ 18,438	$17,371	$19,041	$18,119	$17,196	$16,274	$14,429
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.88	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	2.35	2.40	2.45	2.47	2.57	2.41	2.46	2.50	2.48	2.57	2.26	2.32	2.38	2.45	2.57
Fuel economy X factor (electricity, unadjusted)	4.12	4.18	4.24	4.26	4.39	4.17	4.23	4.29	4.27	4.39	4.08	4.14	4.20	4.26	4.39
SI Plug-in HEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**
Incremental Price ($)	$8,605	$8,229	$7,853	$7,252	$6,500	$12,039	$ 11,589	$ 11,139	$ 10,419	$9,520	$11,037	$10,462	$9,887	$8,623	$7,474
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.05	1.05	1.05	1.03	1.10	1.07	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.55	4.60	4.65	4.74	4.84	4.55	4.60	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84

TABLE A-1 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	LARGE VAN					SMALL SUV					LARGE SUV				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,078	$3,022	$3,751	$3,245	$2,978	$2,167	$2,834	$3,338	$2,770	$2,471	$1,745	$2,972	$4,199	$3,887	$3,732
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.37	1.40	1.39	1.382	1.30	1.35	1.40	1.39	1.382	1.31	1.36	1.40	1.39	1.382
Diesel Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$6,971	$6,677	$6,383	$5,325	$4,738	$7,181	$6,796	$6,411	$4,870	$4,099	$7,191	$7,017	$6,843	$6,285	$5,936
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.899	1.92	1.94	2.02	2.059	1.897	1.92	1.94	2.02	2.059	1.923	1.94	1.96	2.02	2.06
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$4,062	$3,851	$3,639	$2,878	$2,455	$2,963	$3,279	$3,596	$2,459	$1,891	$4,313	$4,726	$4,620	$3,869	$3,399
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.82	1.84	1.86	1.92	1.958	1.41	1.63	1.86	1.92	1.958	1.58	1.81	1.87	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2012**	**2017**	**2022**	**2040**	**2050**
Incremental Price ($)	$816	$809	$803	$780	$766	$856	$788	$721	$450	$314	$1,069	$1,104	$1,139	$1,263	$1,333
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.14	1.15	1.15	1.16	1.17	1.11	1.12	1.12	1.15	1.17
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$10,060	$9,702	$9,345	$9,130	$8,414	$10,354	$9,855	$9,355	$8,655	$7,655	$12,451	$11,966	$11,480	$10,994	$10,022
Range	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.95	1.00	**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00	0.90	0.95	1.00	**1.00**	1.00
Luggage Space	0.95	1.00	1.00	1.00	1.00	0.90	1.00	1.00	**1.00**	1.00	0.95	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.33	2.38	2.44	2.48	2.59	2.23	2.30	2.36	2.46	2.59	2.28	2.34	2.40	2.47	2.59
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2027**	**2032**	**2037**	**2040**	**2050**
Incremental Price ($)	$18,475	$17,814	$17,154	$17,022	$15,701	$18,506	$17,593	$16,680	$15,767	$13,941	$22,057	$21,140	$20,224	$19,674	$17,841
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.87	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.87	0.90	0.90	0.90
Luggage Space	0.90	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95	0.90	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	2.35	2.40	2.45	2.47	2.57	2.26	2.32	2.38	2.45	2.57	2.30	2.36	2.42	2.45	2.57
Fuel economy X factor (electricity, unadjusted)	4.12	4.18	4.24	4.26	4.39	4.08	4.14	4.20	4.26	4.39	4.10	4.16	4.22	4.26	4.39
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$11,094	$10,618	$10,141	$9,284	$8,331	$10,577	$10,011	$9,445	$8,200	$7,068	$12,810	$12,281	$11,753	$10,802	$9,745
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.07	1.05	1.05	1.03	1.10	1.05	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.56	4.61	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84	4.56	4.61	4.65	4.74	4.84

TABLE A-2 “Literature Review” Vehicle Input Assumptions for the MP H2 Success Scenario

"Literature Review" Vehicle Input Asumptions for MP H2 Success Scenario

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2015**	**2020**	**2025**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$3,396	$3,307	$3,218	$2,951	$2,774	$3,014	$3,010	$3,006	$2,998	$2,991	$2,960	$ 2,891	$ 2,823	$ 2,603	$2,466
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.37	1.38	1.40	1.44	1.467	1.33	1.35	1.37	1.42	1.467	1.37	1.39	1.40	1.44	1.467
Diesel Hybrid	**2020**	**2025**	**2030**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$6,219	$6,123	$6,028	$5,838	$5,647	$6,200	$6,120	$6,040	$5,895	$5,735	$4,814	$ 4,702	$ 4,590	$ 4,299	$4,075
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.166	2.21	2.26	2.35	2.446	2.190	2.23	2.28	2.36	2.446	2.208	2.24	2.28	2.37	2.446
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$4,950	$4,692	$4,377	$3,325	$2,668	$3,857	$3,715	$3,572	$3,116	$2,831	$3,071	$ 2,896	$ 2,721	$ 2,127	$1,778
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.70	2.03	2.13	2.26	2.343	2.10	2.13	2.17	2.27	2.343	2.10	2.13	2.16	2.28	2.343
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$139	$119	$99	$31	-$9	$232	$236	$241	$257	$266	$276	$ 256	$ 236	$ 169	$129
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24
Fuel Cell (hydrogen)	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	2050	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$10,357	$9,842	$9,327	$8,504	$7,474	$10,255	$9,766	$9,277	$8,494	$7,516	$7,601	$ 7,223	$ 6,845	$ 6,240	$5,484
Range	0.90	0.99		**0.99**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00		**1.00**	1.00
Maintenance Cost	1.02	1.00	1.00	**1.00**	1.00	1.02	1.00	1.00	**1.00**	1.00	1.06	1.01		**1.00**	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.99		**0.99**	1.00	0.90	0.99		**0.99**	1.00	0.90	1.00		**1.00**	1.00
Luggage Space	0.90	0.95		0.95	1.00	0.90	0.95		0.95	1.00	0.90	1.00		**1.00**	1.00
Fuel economy X factor (unadjusted)	2.61	2.71	2.80	2.95	3.14	2.61	2.71	2.80	2.95	3.14	2.61	2.71	2.80	2.95	3.14
FCV PHEV 40	**2026**	**2031**	**2036**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**
Incremental Price ($)	$12,677	$11,901	$11,124	$10,503	$8,951	$13,735	$12,905	$12,075	$11,245	$9,586	$11,828	$ 11,095	$ 10,362	$ 9,483	$8,017
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.02	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.06	1.01	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.85	0.88	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.80	0.85	0.85	0.86	0.93	0.80	0.85	0.85	0.86	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.78	2.86	2.95	3.01	3.18	2.74	2.83	2.92	3.00	3.18	2.71	2.80	2.89	3.00	3.18
Fuel economy X factor (electricity, unadjusted)	4.90	4.96	5.02	5.07	5.19	4.86	4.93	4.99	5.06	5.19	4.82	4.89	4.96	5.05	5.19
SI Plug-in HEV 40	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$7,524	$7,131	$6,738	$6,345	$5,558	$8,267	$7,861	$7,456	$6,970	$6,160	$7,010	$ 6,663	$ 6,316	$ 5,830	$5,136
Range	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.06	1.05		1.05	1.03	1.07	1.05		1.05	1.04	1.08	1.05		1.05	1.04
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	1.00	1.00		1.00	1.00	0.90	0.90		0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.09	2.12	2.16	2.19	2.27	2.07	2.11	2.15	2.19	2.27	2.05	2.09	2.13	2.19	2.27
Fuel economy X factor (electricity, unadjusted)	5.34	5.41	5.48	5.55	5.69	5.30	5.38	5.45	5.54	5.69	5.27	5.35	5.42	5.53	5.69

TABLE A-2 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP H2 Success Scenario

	COMPACT					Mid-size (Medium) CAR					LARGE CAR				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2012**	**2017**	**2022**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,491	$2,199	$2,568	$2,055	$1,770	$1,951	$2,595	$3,086	$2,617	$2,370	$2,157	$2,798	$3,438	$2,991	$2,767
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.40	1.45	1.46	1.467	1.30	1.38	1.45	1.46	1.467	1.30	1.37	1.45	1.46	1.467
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**
Incremental Price ($)	$3,962	$3,812	$3,661	$3,210	$2,909	$5,257	$5,107	$4,956	$4,506	$4,205	$5,961	$5,805	$5,648	$5,179	$4,867
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.45
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$2,316	$2,497	$2,495	$1,498	$944	$2,343	$2,949	$3,556	$2,407	$1,833	$3,763	$3,928	$4,002	$2,913	$2,340
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	**0.90**	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.54	1.89	2.11	2.26	2.343	1.41	1.75	2.10	2.26	2.343	1.53	1.85	2.11	2.26	2.343
Advanced Gasoline	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$353	$276	$200	-$92	-$245	$531	$471	$410	$168	$47	$616	$579	$542	$401	$328
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.17	1.18	1.19	1.22	1.24	1.16	1.17	1.18	1.22	1.24	1.17	1.18	1.19	1.22	1.24
Fuel Cell (hydrogen)	**2022**	**2027**	**2032**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$5,913	$5,591	$5,270	$4,756	$4,114	$9,211	$8,673	$8,135	$6,736	$5,660	$10,175	$9,605	$9,036	$7,555	$6,416
Range	0.90	1.00		**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02		**1.00**	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00		**1.00**	1.00	0.85	0.90	0.97	1.00	1.00	0.85	0.90	1.00	1.00	1.00
Luggage Space	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.61	2.71	2.80	2.95	3.14	2.57	2.65	2.74	2.97	3.14	2.57	2.65	2.74	2.97	3.14
FCV PHEV 40	**2024**	**2029**	**2034**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$10,611	$9,943	$9,274	$8,471	$7,133	$14,572	$13,608	$12,645	$10,525	$8,598	$14,916	$13,986	$13,056	$11,382	$9,522
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.80	0.85	0.89	0.90	0.90	0.80	0.85	0.89	0.90	0.90
Luggage Space	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.71	2.80	2.89	3.00	3.18	2.57	2.67	2.76	2.98	3.18	2.60	2.70	2.80	2.98	3.18
Fuel economy X factor (electricity, unadjusted)	4.82	4.89	4.96	5.05	5.19	4.71	4.79	4.87	5.04	5.19	4.71	4.79	4.87	5.02	5.19
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2018**	**2023**	**2028**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$6,457	$6,121	$5,785	$5,180	$4,508	$8,511	$8,051	$7,590	$6,484	$5,563	$8,784	$8,369	$7,954	$7,123	$6,293
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.05	1.05	1.03	1.10	1.08	1.05	1.05	1.03	1.10	1.05		1.05	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.02	2.06	2.10	2.18	2.27	2.02	2.06	2.10	2.19	2.27	2.00	2.04	2.09	2.18	2.27
Fuel economy X factor (electricity, unadjusted)	5.20	5.29	5.37	5.52	5.69	5.25	5.32	5.39	5.55	5.69	5.17	5.25	5.34	5.52	5.69

TABLE A-2 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP H2 Success Scenario

	SMALL TRUCK (PICKUP)					CARGO (INCL. 2b) TRUCK (PICKUP)					SMALL VAN (MINIVAN)				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,939	$3,038	$3,087	$2,519	$2,219	$1,645	$2,873	$4,100	$3,901	$3,801	$3,828	$3,675	$3,522	$2,909	$2,603
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.30	1.36	1.40	1.39	1.382	1.31	1.35	1.40	1.39	1.382	1.41	1.40	1.40	1.39	1.382
Diesel Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$4,783	$4,594	$4,405	$3,802	$3,425	$6,398	$ 6,302	$ 6,206	$ 5,917	$5,725	$6,877	$6,530	$6,182	$4,863	$4,168
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.923	1.94	1.96	2.02	2.059	1.937	1.95	1.97	2.02	2.059	1.893	1.91	1.94	2.02	2.059
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,458	$2,319	$2,180	$1,736	$1,458	$3,629	$ 3,580	$ 3,531	$ 3,383	$3,285	$4,279	$3,993	$3,708	$2,567	$1,996
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.85	1.86	1.88	1.93	1.958	1.86	1.87	1.89	1.93	1.958	1.82	1.84	1.86	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$427	$402	$376	$290	$239	$811	$ 892	$ 972	$ 1,231	$1,392	$1,052	$979	$907	$617	$472
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.09	1.10	1.11	1.15	1.17	1.14	1.15	1.15	1.16	1.17
Fuel Cell (hydrogen)	**2020**	**2025**	**2030**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$9,661	$9,150	$8,638	$7,615	$6,593	$12,234	$ 11,738	$ 11,241	$ 10,646	$9,653	$11,145	$10,565	$9,986	$8,826	$7,666
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00		**1.00**	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00	1.00	**1.00**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Luggage Space	**0.95**	1.00	1.00	**1.00**	1.00	**1.00**	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Fuel economy X factor (unadjusted)	2.19	2.26	2.32	2.46	2.59	2.25	2.32	2.38	2.46	2.59	2.19	2.26	2.32	2.46	2.59
FCV PHEV 40	**2023**	**2028**	**2033**	**2040**	**2050**	**2026**	**2031**	**2036**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$17,980	$17,028	$16,076	$14,744	$12,840	$21,993	$ 21,030	$ 20,067	$ 19,297	$17,371	$20,624	$19,518	$18,412	$16,642	$14,429
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.88	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	2.21	2.28	2.34	2.44	2.57	2.28	2.34	2.40	2.45	2.57	2.19	2.26	2.32	2.43	2.57
Fuel economy X factor (electricity, unadjusted)	4.06	4.12	4.18	4.27	4.39	4.09	4.15	4.21	4.26	4.39	4.05	4.11	4.17	4.27	4.39
SI Plug-in HEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**
Incremental Price ($)	$8,605	$8,229	$7,853	$7,252	$6,500	$12,039	$ 11,589	$ 11,139	$ 10,419	$9,520	$11,037	$10,462	$9,887	$8,623	$7,474
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.05	1.05	1.05	1.03	1.10	1.07	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.55	4.60	4.65	4.74	4.84	4.55	4.60	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84

TABLE A-2 (Cont.)

"Literature Review" Vehicle Input Asumptions for MP H2 Success Scenario

	LARGE VAN					SMALL SUV					LARGE SUV				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,078	$3,022	$3,751	$3,245	$2,978	$2,167	$2,834	$3,338	$2,770	$2,471	$1,745	$2,972	$4,199	$3,887	$3,732
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.37	1.40	1.39	1.382	1.30	1.35	1.40	1.39	1.382	1.31	1.36	1.40	1.39	1.382
Diesel Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$6,971	$6,677	$6,383	$5,325	$4,738	$7,181	$6,796	$6,411	$4,870	$4,099	$7,191	$7,017	$6,843	$6,285	$5,936
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.899	1.92	1.94	2.02	2.059	1.897	1.92	1.94	2.02	2.059	1.923	1.94	1.96	2.02	2.06
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$4,062	$3,851	$3,639	$2,878	$2,455	$2,963	$3,279	$3,596	$2,459	$1,891	$4,313	$4,726	$4,620	$3,869	$3,399
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.82	1.84	1.86	1.92	1.958	1.41	1.63	1.86	1.92	1.958	1.58	1.81	1.87	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2012**	**2017**	**2022**	**2040**	**2050**
Incremental Price ($)	$816	$809	$803	$780	$766	$856	$788	$721	$450	$314	$1,069	$1,104	$1,139	$1,263	$1,333
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.14	1.15	1.15	1.16	1.17	1.11	1.12	1.12	1.15	1.17
Fuel Cell (hydrogen)	**2017**	**2022**	**2027**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$13,239	$12,508	$11,777	$9,877	$8,414	$11,207	$10,615	$10,023	$8,839	$7,655	$15,217	$14,430	$13,643	$11,596	$10,022
Range	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.95	1.00	**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00	0.90	0.95	1.00	**1.00**	1.00
Luggage Space	0.95	1.00	1.00	1.00	1.00	0.90	1.00	1.00	**1.00**	1.00	0.95	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.20	2.26	2.32	2.47	2.59	2.19	2.26	2.32	2.46	2.59	2.20	2.26	2.32	2.47	2.59
FCV PHEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$22,179	$21,022	$19,865	$18,014	$15,701	$20,068	$18,974	$17,880	$16,129	$13,941	$24,988	$23,712	$22,436	$20,394	$17,841
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.87	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.87	0.90	0.90	0.90
Luggage Space	0.90	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95	0.90	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	2.19	2.26	2.32	2.43	2.57	2.19	2.26	2.32	2.43	2.57	2.19	2.26	2.32	2.43	2.57
Fuel economy X factor (electricity, unadjusted)	4.05	4.11	4.17	4.27	4.39	4.05	4.11	4.17	4.27	4.39	4.05	4.11	4.17	4.27	4.39
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$11,094	$10,618	$10,141	$9,284	$8,331	$10,577	$10,011	$9,445	$8,200	$7,068	$12,810	$12,281	$11,753	$10,802	$9,745
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.07	1.05	1.05	1.03	1.10	1.05	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.56	4.61	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84	4.56	4.61	4.65	4.74	4.84

TABLE A-3 Program Goals Vehicle Input Assumptions for the MP Mixed and (P)HEV & Ethanol Scenarios

"Program Goals" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2015**	**2020**	**2025**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$2,510	$2,415	$2,321	$2,037	$1,848	$2,135	$2,127	$2,119	$2,101	$2,085	$2,281	$ 2,202	$ 2,122	$ 1,867	$1,707
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.37	1.38	1.40	1.44	1.467	1.33	1.35	1.37	1.42	1.467	1.37	1.39	1.40	1.44	1.467
Diesel Hybrid	**2020**	**2025**	**2030**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$4,041	$3,993	$3,944	$3,847	$3,750	$4,085	$4,051	$4,017	$3,955	$3,886	$3,119	$ 3,042	$ 2,966	$ 2,766	$2,612
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.166	2.21	2.26	2.35	2.446	2.190	2.23	2.28	2.36	2.446	2.208	2.24	2.28	2.37	2.446
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$4,307	$3,406	$2,999	$2,094	$1,529	$2,562	$2,445	$2,328	$1,955	$1,721	$2,012	$ 1,861	$ 1,711	$ 1,200	$899
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.70	2.03	2.13	2.26	2.343	2.10	2.13	2.17	2.27	2.343	2.10	2.13	2.16	2.28	2.343
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$2	-$26	-$54	-$149	-$205	$97	$94	$91	$80	$74	$164	$ 135	$ 105	$ 4	-$56
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24
Fuel Cell (hydrogen)	**2032**	**2037**	**2042**	**2040**	**2050**	**2032**	**2037**	**2042**	**2040**	2050	**2028**	**2033**	**2038**	**2040**	**2050**
Incremental Price ($)	$1,057	$983	$910	$939	$792	$1,259	$1,188	$1,117	$1,146	$1,003	$1,009	$ 855	$ 701	$ 640	$331
Range	0.90	0.99		**0.98**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00		**1.00**	1.00
Maintenance Cost	1.02	1.00	1.00	**1.00**	1.00	1.02	1.00	1.00	**1.00**	1.00	1.06	1.01		**1.00**	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.98		**0.96**	1.00	0.90	0.98		**0.96**	1.00	0.90	1.00		**1.00**	1.00
Luggage Space	0.90	0.95		0.95	1.00	0.90	0.95		0.95	1.00	0.90	1.00		**1.00**	1.00
Fuel economy X factor (unadjusted)	2.94	3.00	3.05	3.03	3.14	2.94	3.00	3.05	3.03	3.14	2.82	2.90	2.97	3.00	3.14
FCV PHEV 40	**2034**	**2039**	**2044**	**2040**	**2050**	**2034**	**2039**	**2044**	**2040**	**2050**	**2030**	**2035**	**2040**	**2040**	**2050**
Incremental Price ($)	$1,665	$1,603	$1,541	$1,591	$1,467	$2,228	$2,165	$2,103	$2,153	$2,028	$1,946	$ 1,875	$ 1,804	$ 1,804	$1,662
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.02	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.06	1.01	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.85	0.88	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.80	0.85	0.85	0.86	0.93	0.80	0.85	0.85	0.86	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	3.03	3.07	3.12	3.08	3.18	3.03	3.07	3.12	3.08	3.18	2.93	2.99	3.05	3.05	3.18
Fuel economy X factor (electricity, unadjusted)	5.12	5.14	5.16	5.15	5.19	5.12	5.14	5.16	5.15	5.19	5.07	5.10	5.13	5.13	5.19
SI Plug-in HEV 40	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$3,335	$3,126	$2,917	$2,708	$2,291	$4,052	$3,823	$3,594	$3,319	$2,860	$3,481	$ 3,274	$ 3,066	$ 2,776	$2,362
Range	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.06	1.05		1.05	1.03	1.07	1.05		1.05	1.04	1.08	1.05		1.05	1.04
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	1.00	1.00		1.00	1.00	0.90	0.90		0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.09	2.12	2.16	2.19	2.27	2.07	2.11	2.15	2.19	2.27	2.05	2.09	2.13	2.19	2.27
Fuel economy X factor (electricity, unadjusted)	5.34	5.41	5.48	5.55	5.69	5.30	5.38	5.45	5.54	5.69	5.27	5.35	5.42	5.53	5.69

TABLE A-3 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	COMPACT					Mid-size (Medium) CAR					LARGE CAR				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2012**	**2017**	**2022**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,353	$1,831	$2,050	$1,439	$1,100	$1,845	$2,224	$2,496	$1,907	$1,597	$2,102	$2,463	$2,825	$2,246	$1,956
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.40	1.45	1.46	1.467	1.30	1.38	1.45	1.46	1.467	1.30	1.37	1.45	1.46	1.467
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**
Incremental Price ($)	$2,504	$2,383	$2,262	$1,900	$1,658	$3,496	$3,381	$3,267	$2,924	$2,695	$4,085	$3,967	$3,849	$3,494	$3,258
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.45
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$2,062	$1,819	$1,574	$686	$193	$2,240	$2,335	$2,429	$1,427	$926	$3,545	$3,164	$2,811	$1,870	$1,374
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	**0.90**	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.54	1.89	2.11	2.26	2.343	1.41	1.75	2.10	2.26	2.343	1.53	1.85	2.11	2.26	2.343
Advanced Gasoline	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$254	$171	$89	-$223	-$387	$417	$350	$283	$17	-$117	$495	$452	$408	$243	$155
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.17	1.18	1.19	1.22	1.24	1.16	1.17	1.18	1.22	1.24	1.17	1.18	1.19	1.22	1.24
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$470	$304	$139	$39	-$293	$2,115	$1,787	$1,458	$997	$340	$2,627	$2,279	$1,931	$1,445	$750
Range	0.90	1.00		**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02		**1.00**	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00		**1.00**	1.00	0.85	0.90	0.97	1.00	1.00	0.85	0.90	1.00	1.00	1.00
Luggage Space	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.79	2.86	2.94	2.99	3.14	2.65	2.74	2.83	2.96	3.14	2.65	2.74	2.83	2.96	3.14
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$1,948	$1,804	$1,660	$1,631	$1,342	$4,145	$3,696	$3,248	$2,799	$1,902	$4,775	$4,300	$3,824	$3,349	$2,399
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.80	0.85	0.89	0.90	0.90	0.80	0.85	0.89	0.90	0.90
Luggage Space	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.89	2.96	3.03	3.04	3.18	2.74	2.83	2.92	3.00	3.18	2.74	2.83	2.92	3.00	3.18
Fuel economy X factor (electricity, unadjusted)	5.03	5.07	5.11	5.11	5.19	4.86	4.93	4.99	5.06	5.19	4.86	4.93	4.99	5.06	5.19
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2018**	**2023**	**2028**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$3,266	$3,044	$2,822	$2,423	$1,979	$4,866	$4,518	$4,170	$3,335	$2,639	$4,875	$4,593	$4,311	$3,747	$3,183
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.05	1.05	1.03	1.10	1.08	1.05	1.05	1.03	1.10	1.05		1.05	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.02	2.06	2.10	2.18	2.27	2.02	2.06	2.10	2.19	2.27	2.00	2.04	2.09	2.18	2.27
Fuel economy X factor (electricity, unadjusted)	5.20	5.29	5.37	5.52	5.69	5.25	5.32	5.39	5.55	5.69	5.17	5.25	5.34	5.52	5.69

TABLE A-3 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios

	SMALL TRUCK (PICKUP)					CARGO (INCL. 2b) TRUCK (PICKUP)					SMALL VAN (MINIVAN)				
		Year of:					Year of:					Year of:			
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,843	$2,700	$2,551	$1,897	$1,552	$1,589	$2,532	$3,475	$3,170	$3,017	$3,304	$3,127	$2,950	$2,240	$1,885
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.30	1.36	1.40	1.39	1.382	1.31	1.35	1.40	1.39	1.382	1.41	1.40	1.40	1.39	1.382
Diesel Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$3,229	$3,059	$2,889	$2,346	$2,006	$4,399	$ 4,337	$ 4,275	$ 4,089	$3,965	$5,353	$5,000	$4,647	$3,307	$2,602
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.923	1.94	1.96	2.02	2.059	1.937	1.95	1.97	2.02	2.059	1.893	1.91	1.94	2.02	2.059
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,335	$1,228	$1,121	$777	$563	$2,178	$ 2,177	$ 2,177	$ 2,176	$2,176	$3,247	$2,967	$2,687	$1,567	$1,008
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.85	1.86	1.88	1.93	1.958	1.86	1.87	1.89	1.93	1.958	1.82	1.84	1.86	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$310	$281	$252	$153	$95	$665	$ 738	$ 812	$ 1,047	$1,195	$948	$869	$790	$475	$317
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.09	1.10	1.11	1.15	1.17	1.14	1.15	1.15	1.16	1.17
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2030**	**2035**	**2040**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$1,943	$1,752	$1,561	$1,446	$1,064	$3,105	$ 3,028	$ 2,951	$ 2,951	$2,797	$3,506	$3,146	$2,786	$2,282	$1,561
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00		**1.00**	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00	1.00	**1.00**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Luggage Space	**0.95**	1.00	1.00	**1.00**	1.00	**1.00**	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Fuel economy X factor (unadjusted)	2.33	2.38	2.44	2.48	2.59	2.40	2.45	2.49	2.49	2.59	2.23	2.30	2.36	2.46	2.59
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2032**	**2037**	**2042**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$4,981	$4,808	$4,634	$4,600	$4,254	$6,996	$ 6,924	$ 6,852	$ 6,881	$6,737	$7,810	$7,250	$6,689	$6,129	$5,009
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.88	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	2.35	2.40	2.45	2.47	2.57	2.41	2.46	2.50	2.48	2.57	2.26	2.32	2.38	2.45	2.57
Fuel economy X factor (electricity, unadjusted)	4.12	4.18	4.24	4.26	4.39	4.17	4.23	4.29	4.27	4.39	4.08	4.14	4.20	4.26	4.39
SI Plug-in HEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**
Incremental Price ($)	$4,763	$4,505	$4,248	$3,836	$3,322	$7,280	$ 6,977	$ 6,674	$ 6,189	$5,583	$6,614	$6,191	$5,767	$4,834	$3,987
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.05	1.05	1.05	1.03	1.10	1.07	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.55	4.60	4.65	4.74	4.84	4.55	4.60	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84

TABLE A-3 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP Mixed and (P)HEV & Ethanol Scenarios	LARGE VAN					SMALL SUV					LARGE SUV				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,970	$2,644	$3,152	$2,550	$2,233	$2,062	$2,466	$2,754	$2,093	$1,745	$1,687	$2,620	$3,554	$3,134	$2,924
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.37	1.40	1.39	1.382	1.30	1.35	1.40	1.39	1.382	1.31	1.36	1.40	1.39	1.382
Diesel Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$5,302	$5,011	$4,720	$3,673	$3,091	$5,697	$5,298	$4,899	$3,304	$2,507	$5,187	$5,037	$4,887	$4,407	$4,107
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.899	1.92	1.94	2.02	2.059	1.897	1.92	1.94	2.02	2.059	1.923	1.94	1.96	2.02	2.06
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$2,868	$2,677	$2,486	$1,798	$1,416	$2,869	$2,713	$2,558	$1,444	$887	$3,771	$3,641	$3,433	$2,702	$2,245
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.82	1.84	1.86	1.92	1.958	1.41	1.63	1.86	1.92	1.958	1.58	1.81	1.87	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2012**	**2017**	**2022**	**2040**	**2050**
Incremental Price ($)	$685	$674	$663	$627	$605	$751	$677	$603	$305	$157	$936	$965	$994	$1,099	$1,158
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.14	1.15	1.15	1.16	1.17	1.11	1.12	1.12	1.15	1.17
Fuel Cell (hydrogen)	**2027**	**2032**	**2037**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**
Incremental Price ($)	$2,991	$2,775	$2,559	$2,430	$1,998	$3,442	$3,073	$2,704	$2,187	$1,449	$4,552	$4,220	$3,888	$3,556	$2,892
Range	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.95	1.00	**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00	0.90	0.95	1.00	**1.00**	1.00
Luggage Space	0.95	1.00	1.00	1.00	1.00	0.90	1.00	1.00	**1.00**	1.00	0.95	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.33	2.38	2.44	2.48	2.59	2.23	2.30	2.36	2.46	2.59	2.28	2.34	2.40	2.47	2.59
FCV PHEV 40	**2029**	**2034**	**2039**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2027**	**2032**	**2037**	**2040**	**2050**
Incremental Price ($)	$6,552	$6,353	$6,155	$6,116	$5,719	$7,407	$6,852	$6,297	$5,742	$4,632	$8,969	$8,514	$8,059	$7,786	$6,875
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.87	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.87	0.90	0.90	0.90
Luggage Space	0.90	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95	0.90	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	2.35	2.40	2.45	2.47	2.57	2.26	2.32	2.38	2.45	2.57	2.30	2.36	2.42	2.45	2.57
Fuel economy X factor (electricity, unadjusted)	4.12	4.18	4.24	4.26	4.39	4.08	4.14	4.20	4.26	4.39	4.10	4.16	4.22	4.26	4.39
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$6,554	$6,224	$5,893	$5,297	$4,636	$6,207	$5,790	$5,373	$4,456	$3,622	$7,822	$7,453	$7,085	$6,422	$5,685
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.07	1.05	1.05	1.03	1.10	1.05	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.56	4.61	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84	4.56	4.61	4.65	4.74	4.84

TABLE A-4 “Program Goals” Vehicle Input Assumptions for the MP H2 Success Scenario

"Program Goals" Vehicle Input Asumptions for MP H2 Success Scenario

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2015**	**2020**	**2025**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$2,510	$2,415	$2,321	$2,037	$1,848	$2,135	$2,127	$2,119	$2,101	$2,085	$2,281	$ 2,202	$ 2,122	$ 1,867	$1,707
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.37	1.38	1.40	1.44	1.467	1.33	1.35	1.37	1.42	1.467	1.37	1.39	1.40	1.44	1.467
Diesel Hybrid	**2020**	**2025**	**2030**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$4,041	$3,993	$3,944	$3,847	$3,750	$4,085	$4,051	$4,017	$3,955	$3,886	$3,119	$ 3,042	$ 2,966	$ 2,766	$2,612
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.166	2.21	2.26	2.35	2.446	2.190	2.23	2.28	2.36	2.446	2.208	2.24	2.28	2.37	2.446
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$4,307	$3,406	$2,999	$2,094	$1,529	$2,562	$2,445	$2,328	$1,955	$1,721	$2,012	$ 1,861	$ 1,711	$ 1,200	$899
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.70	2.03	2.13	2.26	2.343	2.10	2.13	2.17	2.27	2.343	2.10	2.13	2.16	2.28	2.343
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**	**2013**	**2018**	**2023**	**2040**	**2050**
Incremental Price ($)	$2	-$26	-$54	-$149	-$205	$97	$94	$91	$80	$74	$164	$ 135	$ 105	$ 4	-$56
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24	1.14	1.15	1.17	1.22	1.24
Fuel Cell (hydrogen)	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	2050	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$3,460	$2,984	$2,507	$1,745	$792	$3,534	$3,082	$2,630	$1,907	$1,003	$2,283	$ 1,934	$ 1,586	$ 1,028	$331
Range	0.90	0.99		**0.99**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00		**1.00**	1.00
Maintenance Cost	1.02	1.00	1.00	**1.00**	1.00	1.02	1.00	1.00	**1.00**	1.00	1.06	1.01		**1.00**	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.99		**0.99**	1.00	0.90	0.99		**0.99**	1.00	0.90	1.00		**1.00**	1.00
Luggage Space	0.90	0.95		0.95	1.00	0.90	0.95		0.95	1.00	0.90	1.00		**1.00**	1.00
Fuel economy X factor (unadjusted)	2.61	2.71	2.80	2.95	3.14	2.61	2.71	2.80	2.95	3.14	2.61	2.71	2.80	2.95	3.14
FCV PHEV 40	**2026**	**2031**	**2036**	**2040**	**2050**	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**
Incremental Price ($)	$3,600	$3,156	$2,711	$2,356	$1,467	$4,598	$4,084	$3,570	$3,056	$2,028	$4,170	$ 3,688	$ 3,206	$ 2,627	$1,662
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.02	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.06	1.01	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	0.85	0.88	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.80	0.85	0.85	0.86	0.93	0.80	0.85	0.85	0.86	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.78	2.86	2.95	3.01	3.18	2.74	2.83	2.92	3.00	3.18	2.71	2.80	2.89	3.00	3.18
Fuel economy X factor (electricity, unadjusted)	4.90	4.96	5.02	5.07	5.19	4.86	4.93	4.99	5.06	5.19	4.82	4.89	4.96	5.05	5.19
SI Plug-in HEV 40	**2025**	**2030**	**2035**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2023**	**2028**	**2033**	**2040**	**2050**
Incremental Price ($)	$3,335	$3,126	$2,917	$2,708	$2,291	$4,052	$3,823	$3,594	$3,319	$2,860	$3,481	$ 3,274	$ 3,066	$ 2,776	$2,362
Range	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.06	1.05		1.05	1.03	1.07	1.05		1.05	1.04	1.08	1.05		1.05	1.04
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	1.00	1.00		1.00	1.00	0.90	0.90		0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.09	2.12	2.16	2.19	2.27	2.07	2.11	2.15	2.19	2.27	2.05	2.09	2.13	2.19	2.27
Fuel economy X factor (electricity, unadjusted)	5.34	5.41	5.48	5.55	5.69	5.30	5.38	5.45	5.54	5.69	5.27	5.35	5.42	5.53	5.69

TABLE A-4 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP H2 Success Scenario

	COMPACT					Mid-size (Medium) CAR					LARGE CAR				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2012**	**2017**	**2022**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,353	$1,831	$2,050	$1,439	$1,100	$1,845	$2,224	$2,496	$1,907	$1,597	$2,102	$2,463	$2,825	$2,246	$1,956
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.40	1.45	1.46	1.467	1.30	1.38	1.45	1.46	1.467	1.30	1.37	1.45	1.46	1.467
Diesel Hybrid	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**
Incremental Price ($)	$2,504	$2,383	$2,262	$1,900	$1,658	$3,496	$3,381	$3,267	$2,924	$2,695	$4,085	$3,967	$3,849	$3,494	$3,258
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.446	2.239	2.27	2.30	2.39	2.45
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$2,062	$1,819	$1,574	$686	$193	$2,240	$2,335	$2,429	$1,427	$926	$3,545	$3,164	$2,811	$1,870	$1,374
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	**0.90**	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	**0.90**	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95	**0.95**	0.95	0.95	0.95	0.95
Fuel economy X factor (unadjusted)	1.54	1.89	2.11	2.26	2.343	1.41	1.75	2.10	2.26	2.343	1.53	1.85	2.11	2.26	2.343
Advanced Gasoline	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$254	$171	$89	-$223	-$387	$417	$350	$283	$17	-$117	$495	$452	$408	$243	$155
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.17	1.18	1.19	1.22	1.24	1.16	1.17	1.18	1.22	1.24	1.17	1.18	1.19	1.22	1.24
Fuel Cell (hydrogen)	**2022**	**2027**	**2032**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$1,364	$1,069	$773	$299	-$293	$3,887	$3,350	$2,812	$1,415	$340	$4,504	$3,935	$3,366	$1,887	$750
Range	0.90	1.00		**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02		**1.00**	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00		**1.00**	1.00	0.85	0.90	0.97	1.00	1.00	0.85	0.90	1.00	1.00	1.00
Luggage Space	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.61	2.71	2.80	2.95	3.14	2.57	2.65	2.74	2.97	3.14	2.57	2.65	2.74	2.97	3.14
FCV PHEV 40	**2024**	**2029**	**2034**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$3,632	$3,192	$2,751	$2,223	$1,342	$6,633	$5,870	$5,107	$3,428	$1,902	$6,417	$5,724	$5,032	$3,785	$2,399
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.10	1.06	1.01	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.80	0.85	0.89	0.90	0.90	0.80	0.85	0.89	0.90	0.90
Luggage Space	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93	0.80	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.71	2.80	2.89	3.00	3.18	2.57	2.67	2.76	2.98	3.18	2.60	2.70	2.80	2.98	3.18
Fuel economy X factor (electricity, unadjusted)	4.82	4.89	4.96	5.05	5.19	4.71	4.79	4.87	5.04	5.19	4.71	4.79	4.87	5.02	5.19
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2018**	**2023**	**2028**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$3,266	$3,044	$2,822	$2,423	$1,979	$4,866	$4,518	$4,170	$3,335	$2,639	$4,875	$4,593	$4,311	$3,747	$3,183
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.05	1.05	1.03	1.10	1.08	1.05	1.05	1.03	1.10	1.05		1.05	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90
Luggage Space	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93	0.90	0.90	0.90	0.91	0.93
Fuel economy X factor (liquid fuel, unadjusted)	2.02	2.06	2.10	2.18	2.27	2.02	2.06	2.10	2.19	2.27	2.00	2.04	2.09	2.18	2.27
Fuel economy X factor (electricity, unadjusted)	5.20	5.29	5.37	5.52	5.69	5.25	5.32	5.39	5.55	5.69	5.17	5.25	5.34	5.52	5.69

TABLE A-4 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP H2 Success Scenario

	SMALL TRUCK (PICKUP)					CARGO (INCL. 2b) TRUCK (PICKUP)					SMALL VAN (MINIVAN)				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$2,843	$2,700	$2,551	$1,897	$1,552	$1,589	$2,532	$3,475	$3,170	$3,017	$3,304	$3,127	$2,950	$2,240	$1,885
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.30	1.36	1.40	1.39	1.382	1.31	1.35	1.40	1.39	1.382	1.41	1.40	1.40	1.39	1.382
Diesel Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**
Incremental Price ($)	$3,229	$3,059	$2,889	$2,346	$2,006	$4,399	$ 4,337	$ 4,275	$ 4,089	$3,965	$5,353	$5,000	$4,647	$3,307	$2,602
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.923	1.94	1.96	2.02	2.059	1.937	1.95	1.97	2.02	2.059	1.893	1.91	1.94	2.02	2.059
Gasoline Hybrid	**2014**	**2019**	**2024**	**2040**	**2050**	**2015**	**2020**	**2025**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,335	$1,228	$1,121	$777	$563	$2,178	$ 2,177	$ 2,177	$ 2,176	$2,176	$3,247	$2,967	$2,687	$1,567	$1,008
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.98	0.98	0.98	0.98	0.98	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97
Fuel economy X factor (unadjusted)	1.85	1.86	1.88	1.93	1.958	1.86	1.87	1.89	1.93	1.958	1.82	1.84	1.86	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$310	$281	$252	$153	$95	$665	$ 738	$ 812	$ 1,047	$1,195	$948	$869	$790	$475	$317
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.09	1.10	1.11	1.15	1.17	1.14	1.15	1.15	1.16	1.17
Fuel Cell (hydrogen)	**2020**	**2025**	**2030**	**2040**	**2050**	**2024**	**2029**	**2034**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**
Incremental Price ($)	$3,452	$3,054	$2,656	$1,860	$1,064	$4,619	$ 4,268	$ 3,918	$ 3,498	$2,797	$4,289	$3,834	$3,380	$2,470	$1,561
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00		**1.00**	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	1.00	1.00	**1.00**	1.00	0.90	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Luggage Space	**0.95**	1.00	1.00	**1.00**	1.00	**1.00**	1.00		**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00
Fuel economy X factor (unadjusted)	2.19	2.26	2.32	2.46	2.59	2.25	2.32	2.38	2.46	2.59	2.19	2.26	2.32	2.46	2.59
FCV PHEV 40	**2023**	**2028**	**2033**	**2040**	**2050**	**2026**	**2031**	**2036**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$7,752	$7,104	$6,456	$5,549	$4,254	$9,307	$ 8,772	$ 8,236	$ 7,808	$6,737	$9,409	$8,623	$7,837	$6,580	$5,009
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.10	1.06	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90
Luggage Space	0.88	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	2.21	2.28	2.34	2.44	2.57	2.28	2.34	2.40	2.45	2.57	2.19	2.26	2.32	2.43	2.57
Fuel economy X factor (electricity, unadjusted)	4.06	4.12	4.18	4.27	4.39	4.09	4.15	4.21	4.26	4.39	4.05	4.11	4.17	4.27	4.39
SI Plug-in HEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**
Incremental Price ($)	$4,763	$4,505	$4,248	$3,836	$3,322	$7,280	$ 6,977	$ 6,674	$ 6,189	$5,583	$6,614	$6,191	$5,767	$4,834	$3,987
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.05	1.05	1.05	1.03	1.10	1.07	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.83	1.87	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.55	4.60	4.65	4.74	4.84	4.55	4.60	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84

TABLE A-4 (Cont.)

"Program Goals" Vehicle Input Asumptions for MP H2 Success Scenario

	LARGE VAN					SMALL SUV					LARGE SUV				
	Year of:					Year of:					Year of:				
Advanced Diesel	**2011**	**2016**	**2021**	**2040**	**2050**	**2011**	**2016**	**2021**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**
Incremental Price ($)	$1,970	$2,644	$3,152	$2,550	$2,233	$2,062	$2,466	$2,754	$2,093	$1,745	$1,687	$2,620	$3,554	$3,134	$2,924
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.32	1.37	1.40	1.39	1.382	1.30	1.35	1.40	1.39	1.382	1.31	1.36	1.40	1.39	1.382
Diesel Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$5,302	$5,011	$4,720	$3,673	$3,091	$5,697	$5,298	$4,899	$3,304	$2,507	$5,187	$5,037	$4,887	$4,407	$4,107
Range	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Maintenance Cost	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93	0.95	0.95	0.95	0.94	0.93
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.899	1.92	1.94	2.02	2.059	1.897	1.92	1.94	2.02	2.059	1.923	1.94	1.96	2.02	2.06
Gasoline Hybrid	**2012**	**2017**	**2022**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2014**	**2019**	**2024**	**2040**	**2050**
Incremental Price ($)	$2,868	$2,677	$2,486	$1,798	$1,416	$2,869	$2,713	$2,558	$1,444	$887	$3,771	$3,641	$3,433	$2,702	$2,245
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03	1.05	1.05	1.05	1.04	1.03
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.82	1.84	1.86	1.92	1.958	1.41	1.63	1.86	1.92	1.958	1.58	1.81	1.87	1.92	1.958
Advanced Gasoline	**2013**	**2018**	**2023**	**2040**	**2050**	**2010**	**2015**	**2020**	**2040**	**2050**	**2012**	**2017**	**2022**	**2040**	**2050**
Incremental Price ($)	$685	$674	$663	$627	$605	$751	$677	$603	$305	$157	$936	$965	$994	$1,099	$1,158
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	1.10	1.11	1.12	1.15	1.17	1.14	1.15	1.15	1.16	1.17	1.11	1.12	1.12	1.15	1.17
Fuel Cell (hydrogen)	**2017**	**2022**	**2027**	**2040**	**2050**	**2020**	**2025**	**2030**	**2040**	**2050**	**2017**	**2022**	**2027**	**2040**	**2050**
Incremental Price ($)	$5,974	$5,372	$4,769	$3,203	$1,998	$4,237	$3,772	$3,308	$2,379	$1,449	$7,143	$6,499	$5,855	$4,180	$2,892
Range	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.95	1.00	**1.00**	1.00	0.90	1.00	1.00	**1.00**	1.00	0.90	0.95	1.00	**1.00**	1.00
Luggage Space	0.95	1.00	1.00	1.00	1.00	0.90	1.00	1.00	**1.00**	1.00	0.95	1.00	1.00	1.00	1.00
Fuel economy X factor (unadjusted)	2.20	2.26	2.32	2.47	2.59	2.19	2.26	2.32	2.46	2.59	2.20	2.26	2.32	2.47	2.59
FCV PHEV 40	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**	**2022**	**2027**	**2032**	**2040**	**2050**
Incremental Price ($)	$10,295	$9,478	$8,661	$7,353	$5,719	$8,984	$8,207	$7,430	$6,187	$4,632	$11,931	$11,028	$10,125	$8,681	$6,875
Range	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.08	1.02	1.00	1.00	1.00	1.10	1.06	1.01	1.00	1.00	1.09	1.04	1.00	1.00	1.00
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.85	0.87	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.90	0.85	0.87	0.90	0.90	0.90
Luggage Space	0.90	0.95	0.95	0.96	0.97	0.83	0.93	0.93	0.94	0.95	0.90	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	2.19	2.26	2.32	2.43	2.57	2.19	2.26	2.32	2.43	2.57	2.19	2.26	2.32	2.43	2.57
Fuel economy X factor (electricity, unadjusted)	4.05	4.11	4.17	4.27	4.39	4.05	4.11	4.17	4.27	4.39	4.05	4.11	4.17	4.27	4.39
SI Plug-in HEV 40	**2021**	**2026**	**2031**	**2040**	**2050**	**2019**	**2024**	**2029**	**2040**	**2050**	**2021**	**2026**	**2031**	**2040**	**2050**
Incremental Price ($)	$6,554	$6,224	$5,893	$5,297	$4,636	$6,207	$5,790	$5,373	$4,456	$3,622	$7,822	$7,453	$7,085	$6,422	$5,685
Range	1.10	1.10		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Maintenance Cost	1.10	1.05		1.05	1.03	1.10	1.07	1.05	1.05	1.03	1.10	1.05	1.05	1.05	1.03
Acceleration	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.96	0.97	0.93	0.93	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.97
Fuel economy X factor (liquid fuel, unadjusted)	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93	1.77	1.80	1.82	1.88	1.93
Fuel economy X factor (electricity, unadjusted)	4.56	4.61	4.65	4.74	4.84	4.59	4.63	4.67	4.76	4.84	4.56	4.61	4.65	4.74	4.84

APPENDIX B: PRELIMINARY ESTIMATE OF THE COST OF JUMP STARTING H_2 STATIONS IN THE H2 SUCCESS SCENARIO

As discussed in Chapter 7, vehicle subsidies are needed to meet the vehicle penetration goals of the various scenarios. The H2 Success scenario assumes that there is an additional policy to jump start the availability of stations selling H_2. This policy is likely to incorporate some form of subsidy. The cost of that subsidy should be added to the cost of the vehicle subsidies in the H2 Success scenario in order to obtain a fair comparison of scenario costs.

The particular jump start policy that was assumed is consistent with U.S. Department of Energy (DOE) program analyses of potential transition policies. The scenario modeled ensures that 10% of all stations in large cities offer H_2 by 2024 and 2% of all stations in small cities offer it by 2029. Table B-1 presents the number of H2 stations thus estimated for each of the four versions of the H2 Success scenario. When contrasted with the number of stations estimated without the jump start policy, as presented in Table B-2, it is obvious that the jump start policy dramatically increases the projected number of H_2 stations.

For the Multi-Path (MP) Study analysis, we developed a preliminary estimate of the cost of subsidizing these stations. We used the following assumptions:

- The stations to be subsidized will be built to serve 750 fuel cell vehicles (FCVs) per day.
- The cost of these stations will be \$1.13 million (2005\$) in 2015 and \$0.75 million in 2030 (i.e., the costs to build the stations will decline over time).
- The full station cost will be subsidized.
- Subsidies for stations built in large cities will begin in 2010 and will be provided through 2024.
- Subsidies for stations built in small cities will begin in 2019 and will be provided through 2029.

The cumulative cost of subsidizing the jump starting of these stations is presented in Table B-3 under three conditions:

- All stations built will be fully subsidized.
- All stations built will be fully subsidized, except those that would have been built without the jump start.

- All stations built will be fully subsidized except those that would have been built to meet the greater demand resulting from the increased use of FCVs created by the jump start.

The latter two conditions attempt to minimize free riders (i.e., paying only as much subsidy as is needed to create additional stations). The three different conditions provide possible total costs that range from \$6.3 billion to \$12 billion. The total cost would be lower if we assumed that an amount less than a subsidy of the full station cost would generate the H_2 station totals estimated in Table B-1.

TABLE B-1 Total Number of H_2 Stations in the Early Years of the H2 Success Scenario Assuming the Jump Starting of Stations

	Stations Offering H2 in Early Years of the H2 Success Scenario Assuming Jump Starting of Stations											
	H2 Success Literature Review			**H2 Success Program Goals**			**H2 Success Literature Review With Subsidies**			**H2 Success Program Goals With Subsidies**		
	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)
2015	930	6	936	929	6	935	933	5	938	939	6	945
2020	5,655	148	5,806	5,518	145	5,679	5,661	149	5,843	5,612	147	5,776
2024	9,604	755	10,371	9,121	721	9,915	9,403	751	10,331	9,295	736	10,106
2029	9,958	1,566	11,556	10,052	1,444	11,704	23,503	3,490	28,048	10,100	1,476	11,798
2030	10,045	1,579	11,660	11,969	1,446	13,643	27,890	5,443	34,946	11,886	1,479	13,608

TABLE B-2 Total H_2 Stations in the Early Years of the H2 Success Scenario WITHOUT Assuming the Jump Starting of Stations

	Stations Offering H2 in Early Years of the H2 Success Scenario WITHOUT Jump Starting of Stations											
	H2 Success Literature Review			**H2 Success Program Goals**			**H2 Success Literature Review With Subsidies**			**H2 Success Program Goals With Subsidies**		
	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)	Large City	Small City	Total (includes rural)
2015	13	7	21	13	7	21	13	7	21	13	7	21
2020	32	20	59	56	44	120	103	80	220	56	44	120
2024	62	44	123	212	164	451	458	355	975	211	164	450
2029	108	78	218	557	428	1,180	1,720	1,291	3,590	556	428	1,178
2030	117	86	238	649	498	1,373	2,228	1,645	4,601	648	497	1,372

TABLE B-3 Cumulative Costs through 2030 of Jump Starting H_2 Stations (in Billions of 2005$)

Stations Subsidized	Cost for All	Cost for All Except Those Built without Jump Start	Cost for All Except Those Built in response to New FCV Demand Created by Jump Start
H2 Literature Review	$11.2	$11.0	$10.7
H2 Program Goals	$10.6	$10.0	$7.5
H2 Literature Review with Subsidies	$12.5	$11.0	$6.3
H2 Program Goals with Subsidies	$10.8	$10.2	$7.7

APPENDIX C: BASIS FOR ESTIMATES OF FULL-FUEL-CYCLE CO_2 EMISSIONS FROM LIGHT VEHICLES

For the most part, the National Energy Modeling System used for the Multi-Path Study (NEMS-MP) reports energy-related CO_2 emissions on the basis of the sector in which they are emitted, rather than allocating emissions to the point of end use. The exception is for the electricity sector, where emissions are allocated to the end-use sectors on the basis of relative electricity purchases. This makes it difficult to trace the full-fuel-cycle CO_2 emissions from light vehicles (LVs). For example, CO_2 emissions associated with fuel use in the petroleum-refining process and in biofuels production are reported as part of industrial sector emissions, as are emissions from hydrogen production. In theory, some of these emissions could be directly attributed to LVs because most or all of the product (e.g., ethanol or hydrogen) is consumed by these vehicles, while other emissions (e.g., emissions associated with refining of petroleum products) would have to be allocated among other uses.

Because of this complexity, we adopted a two-step process for determining LV fuel-cycle emissions in our scenarios. First, we estimated the full-fuel-cycle LV emissions (including those from Class 2B commercial trucks) from a Base Case without Corporate Average Fuel Economy (CAFE) standards by using information from several U.S. Environmental Protection Agency (EPA) reports on U.S. greenhouse gas (GHG) emissions. Then we assumed that all changes in U.S. CO_2 emissions in our other scenarios, including the Base Case with CAFE, were attributable to the LV sector, because virtually all the assumptions that we altered in these other scenarios relative to the Base Case without CAFE are LV-related. These derivations are described in more detail below.

This method is not perfect in that some of the fuel supply assumptions that we modified in the scenarios could potentially impact markets other than the LV market. The impact of our modifications regarding H_2 and ethanol deserve some discussion.

- Currently, the only end user of H_2 in the NEMS-MP model is LVs. So any reduction in H_2 prices in the scenarios will only increase LV hydrogen use.

- We varied the conversion costs of cellulosic ethanol, but even at reduced prices, ethanol is used predominantly by LVs, either in blends (LVs use 96% of the total gasoline blends) or in E85. The medium trucks, school buses, etc., that make up the remaining 4% of the gasoline market can only use ethanol in blends, and blend levels in the Base Case without CAFE are already 9.5% by 2015, which is the maximum blend level used in the model. Only total gasoline growth in these markets could increase their use of ethanol in blends. The NEMS-MP model growth projections for these markets, however, are very small. Therefore, we ignore the potential for increased ethanol use by this very small market.

- Finally, we do not vary biomass supply curves that would affect the power sector.

C.1 ESTIMATE OF LV FULL-FUEL-CYCLE CO_2 EMISSIONS AS A SHARE OF TOTAL U.S. CO_2 EMISSIONS IN A BASE CASE WITHOUT CAFE

EPA prepared an inventory of U.S. GHGs and estimates of GHG emissions from the transportation sector (EPA 2005, 2006). The latter report in particular included estimates of the CO_2 emissions from various components of the transportation life cycle (proportion relative to direct emissions). (One of the sources for the indirect emissions was Argonne's GREET model (Argonne 2001).) We used those two reports to derive an estimate of the LV full-fuel-cycle share of total U.S. CO_2 emissions for the year 2003, as presented in Table C-1. (Emissions from vehicle manufacturing are excluded.)

For the MP estimates, we assumed that the 2003 share (23.9%) was also applicable in 2005 (the first year of the MP estimates). That assumption may not be applicable in future years because of changes in economic activity or potential changes in ethanol use. With respect to changes in economic activity, we examined both the projected share of LV energy consumption in the Base Case without CAFE and the CO_2 emissions of the entire transportation sector relative to total U.S. emissions as potential indicators of change in activity. We found that the shares of each were quite stable through 2050. Because of that stability, we initially made no adjustments to the LV full-fuel-cycle share of total U.S. CO_2 emissions in the future.

With respect to ethanol, we did adjust the future LV full-fuel-cycle share of total U.S. CO_2 emissions to account for (a) the expectation that ethanol use by LVs will change over time and (b) the fact that ethanol has lower GHG emissions than does the gasoline it replaces. In the Base Case without CAFE, ethanol is 2% of total LV energy use in 2005; that share rises to 7.8% by 2050. While 97% of the ethanol is from corn in 2005, that share is down to 74% by 2050. We used the GREET model to estimate that the CO_2-emissions from ethanol made from corn is 15.2 million metric tons of CO_2 equivalent ($MMTCO_2$) per quad versus 25.9 $MMTCO_2$/quad for gasoline (where 1 quad = 1 quadrillion [10^{15}] BTU). Cellulosic ethanol is assumed to have no CO_2 emissions. Applying all these factors to the initial 23.9% share results in a small reduction in the share over time, as can be seen in Table C-2 (second row). By 2050, the share is 23.0%.

C.2 FINAL ESTIMATES OF LV FULL-FUEL-CYCLE CO_2 EMISSIONS IN THE MP BASE CASE WITH CAFE

Table C-2 presents the estimates of LV full-fuel-cycle CO_2 emissions in both the Base Case without CAFE and the final MP Base Case with CAFE. The share estimates developed above for the Base Case without CAFE are applied to the total U.S. CO_2 emissions for that case (from a NEMS-MP run), and LV full-fuel-cycle CO_2 emissions in $MMTCO_2e$ are derived for the Base Case without CAFE. Between 2005 and 2050, these emissions rise from 1,419 to 2,219 $MMTCO_2e$.

The total U.S. CO_2 emissions for the Base Case with CAFE (from another NEMS-MP run) are presented. They are lower than the Base Case without CAFE. As discussed above, all of these reductions are assumed to be LV-related. Therefore, these reductions are applied to the LV full-fuel-cycle CO_2 emissions of the Base Case without CAFE to derive LV full-fuel-cycle CO_2 emissions for the MP Base Case with CAFE. The reduction is small.

C.3 ESTIMATES OF LV FULL-FUEL-CYCLE CO_2 EMISSIONS IN THE MP SCENARIOS/CASES

For any scenario/case, the total U.S. CO_2 emissions of that case are compared with the total U.S. CO_2 emissions shown in Table C-2 for the Base Case with CAFE. The reductions achieved are all assumed to be LV-related. Therefore, these reductions are applied to the LV full-fuel-cycle CO_2 emissions of the Base Case with CAFE to derive LV full-fuel-cycle CO_2 emissions of the scenario.

C.4 REFERENCES

EPA (U.S. Environmental Protection Agency), 2005, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*, EPA-430-R-05-003, April 15.

EPA, 2006, *Greenhouse Gas Emissions for the U.S. Transportation Sector*, EPA-420-R-06-003, March.

Argonne (Argonne National Laboratory), 2001, *Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) 1.6 Model*, Center for Transportation Research, Argonne, IL, June.

TABLE C-1 Estimate of LV Full-Fuel-Cycle CO_2 Emissions as a Share of Total U.S. CO_2 Emissions in a Base Case without CAFE in 2003

	2003
	GHG
EPA LV GHG Direct	1112.5
Multiplier for Indirect LV GHG Emissions (GREET, from EPA report)	1.268
Total LV GHGs (Direct x Multiplier)	1410.7
Factor in 2Bs (EIA 2005)	1.036
Total LV GHGs	1461.4
EPA Total U.S. GHG	6900.2
LV total GHG share (no 2Bs)	20.4%
LV total GHG share (with 2Bs)	21.2%
	CO2
EPA estimate of GHG that is CO2	
Shares:	
Total U.S. (Inventory report, Table ES-2)	0.847
Transportation (Table 13)	0.954
EPA total CO2 emissions (derived from estimates EPA provided above)	
Total U.S.	5842
LVs (including 2Bs)	1394
LV share of total U.S. CO2 (with 2Bs)	23.9%

TABLE C-2 Final Estimates of LV Full-Fuel-Cycle CO_2 Emissions in MP Base Case with CAFE

	2005	2010	2020	2030	2040	2050
Base Case without CAFE						
Total US CO2 Emissions (MMTCO2)	5945	6185	6756	7617	8636	9641
LV full fuel cycle CO2 emissions share of US total	23.9%	23.3%	23.2%	23.2%	23.2%	23.0%
LV full fuel cycle CO2 emissions (MMTCO2)	1419	1441	1567	1768	2000	2219
Base Case with CAFE						
Total US CO2 Emissions (MMTCO2)	5945	6182	6705	7480	8538	9561
Reduction in Total US CO2 Emissions from Base case without CAFE (MMTCO2)	0	3	51	138	98	81
LV full fuel cycle CO2 emissions (MMTCO2)	1419	1438	1516	1630	1901	2138

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APPENDIX D: SELECTED SENSITIVITY RUNS WITH THE NEMS-MP VEHICLE CHOICE MODEL

D.1 INTRODUCTION

The vehicle choice model (VCM) used in the version of the National Energy Modeling System used for the Multi-Path Study (NEMS-MP) is the same as the Consumer Vehicle Choice Submodule used in NEMS and described in EIA (2006). The model uses various vehicle and fuel attributes and their coefficients (which reflect the consumer weighting of each of these attributes) to estimate the market penetration of conventional vehicles (CVs) and advanced technology vehicles (ATVs) into the future. The attributes include vehicle price, cost of driving per mile (fuel price divided by fuel efficiency), vehicle range, acceleration, maintenance costs, luggage space, home refueling capability, fuel availability, and vehicle make and model availability (MMA).

In this document, two sets of sensitivity runs made with the VCM are discussed:

- The effect of lengthening the vehicle payback implicitly used in the VCM, and
- A disaggregation of the impact of changes to the various variables used in the VCM on the market penetration of ATVs.

Other sensitivity runs may be added later. The analysis was conducted with the NEMS-Transportation Stand-Alone (TSA) model.

D.2 SENSITIVITY ANALYSIS OF CHANGES IN THE VEHICLE PAYBACK ASSUMPTIONS IMPLICIT IN NEMS-MP

This section describes how we estimated the implicit vehicle payback period used in the NEMS-MP VCM (because it is not an explicit input), analyzes how that payback period in the VCM might be lengthened, and provides an example of how lengthening it considerably affects vehicle market penetration results. The analysis was performed because in a future world of sustained high fuel prices, consumers may change the level of importance that they give to future fuel savings when purchasing new vehicles. Such a change would result in different ATV market penetration rates than those estimated to date in the MP Study.

D.2.1 Implicit Vehicle Payback Period Used in VCM

The VCM computes the "utility" value of each vehicle type on the basis of the vehicle attributes and the consumer weighting of each of them. The coefficients for the attributes reveal the assumed relative importance of each attribute. Table D-1 presents an example of these utilities for a large car as characterized in MP.

For these large cars, the vehicle price (in dollars) has a coefficient of –0.00082, while the cost of driving (in cents per mile) has a coefficient of –0.3898. One can use these values to compute the (simple) payback period a consumer is assumed to employ when valuing an increase in fuel economy relative to an increase in the price of the vehicle. Assuming that the vehicle is driven 12,000 miles per year, the annual equivalent utility would be –0.3898 × 100/12,000, which equals –0.00325. This result implies that the equivalence between the initial vehicle price and the cost of driving is similar to a payback of 4 (3.96) years: –0.00325/–0.00082. (If the vehicle is driven 15,000 miles annually, the payback is a little more than 3 years [i.e., 3.17 years]).

A specific numerical illustration might be useful. Suppose there are two vehicles, one of which costs $1,000 more but has higher fuel economy. The coefficients can be used to compute the point of equivalence or, in other words, the annual fuel cost savings that would be needed to make the second vehicle as attractive as the first. The extra $1,000 adds 1000 × –0.00082 = –0.82 to the utility of the vehicle (i.e., makes the utility more negative and the vehicle less attractive). The increase in equivalent cost per mile required to offset that disadvantage is equal to –0.82/–0.3898 or 2.1 cents per mile. This result is equivalent to a fuel savings of $252 per year if the vehicle is driven 12,000 miles per year. The simple payback period is $1,000/$252 or 3.96.

(For perspective on the amount of annual travel to assume, it is important to consider that in the MP Base Case, the average or stock LV travels 11,430 miles per year in 2010, 12,715 miles/year in 2030, and 14,466 miles/year in 2050.)

D.2.2 How to Increase the Payback Period in the VCM: General

To simulate a higher payback period, the coefficient for vehicle price can be decreased, or the cost of driving can be increased. But when either coefficient is changed, the relative importance of each of the other attributes in the VCM changes as well. If the coefficient for vehicle price is decreased, the overall weights of both the vehicle price and driving cost are reduced, and the importance of each of the other attributes is increased. If the coefficient for driving cost is increased, the importance of each of the other attributes shrinks.

For some of the new ATVs, these other attributes (especially fuel availability and MMA) can be significant in the vehicle's total utility. We believe it is important to try to keep the importance of these other attributes relatively stable while changing the relationship of driving cost to vehicle cost. Because vehicle price has the highest weighting of all the utilities, the effect of its reduction distorts the weights of the other attributes more than does increasing the coefficient for driving cost. Therefore, we recommend increasing the coefficient of the driving cost instead.

Table D-2 presents some of the analysis that was conducted to examine the impact of changing either the vehicle price coefficient (case 16) or the driving cost coefficient (case 15). Changing the driving cost coefficient clearly has less impact on the relative weight of the other attributes in the total utility of the vehicles than does changing the vehicle price coefficient. (Note: We are not saying "no impact," just less.) In this analysis, we changed the coefficients by a factor of four in an attempt to simulate a simple 15-year payback.

D.2.3 Example Results of Increasing the Vehicle Payback Period

We used the approach just discussed (increasing the driving cost coefficient by four times) to estimate the impact of an approximately 15-year payback on ATV penetration for two versions of the Mixed scenario: one using the MP "literature review" (LR) vehicle prices, and another using the "program goals" (PG) vehicle prices. The two sets of market penetration results for cars are shown in Tables D-3 (LR prices) and D-4 (PG prices). For each technology in the tables, four market penetration estimates are shown:

a. Results with the default NEMS payback assumptions;

b. Results with payback assumptions changed in the Manufacturer Technology Choice Submodule (MTCS) (that is what the Energy Information Administration [EIA] calls the submodule);

c. Results with payback assumptions changed in the VCM as well as in the MTCS; and

d. The goals for the scenario.

The MTCS is another component of NEMS in which the selection of individual technology components for each vehicle type determines the vehicle's price, fuel economy, and other attributes. In the MP scenarios, the MTCS is used only for conventional gasoline and flex fuel vehicles. The attributes for the ATVs are overwritten by user assumptions. In the MCTS, the present value of fuel savings over a 3-year period using a 15% discount rate is compared to each technology cost. We changed the parameters for these test runs to a 12-year period (the longest time period possible in the model) and a 3% discount rate. These changes generally had little effect on the market penetration results because they only impact the price and fuel economy of conventional vehicles, which is why we do not discuss the use of the MTCS more in this appendix.

However, the effect of increasing the weight consumers give to fuel savings in the VCM, where the competition among vehicle types occurs, is considerable. As shown in Table D-3 and Figure D-1, with the increased consumer valuation of fuel savings and assuming LR vehicle prices, by 2050, gasoline internal combustion engines (ICEs) and advanced gasoline ICEs are virtually driven out of the market, replaced by hybrid electric vehicles or HEVs (65%, including both gasoline and diesel) and approximately 10% each for diesels, plug-in HEVs (PHEVs), and fuel cell vehicles (FCVs). With the PG vehicle prices, as shown in Table D-4 and Figure D-2, the gasoline ICEs (conventional and advanced) are again driven from the market, but the dominant vehicles sold are FCVs (56%).

D.2.4 How to Increase the Payback Period in the VCM: Specific Recommendations

In undertaking the above analysis, when we changed the VCM payback assumption, we assumed that the change applied throughout time (i.e., from 2005 forward). We did so because the process of varying the payback assumption over time is cumbersome and we were just trying to get an idea of the impact of such a change. However, Table D-3 provides evidence that the payback assumption, if it is to be modified, should be modified over time. With a 15-year payback assumption, the sales of conventional gasoline, advanced conventional gasoline, and conventional flex fuel vehicles in 2010 represent 55% of all car sales versus 84% with the default payback assumption. This dramatic drop occurs even though very few of the advanced vehicles characterized in this study are assumed to be introduced by 2010. The result for 2010 is unreasonable. It could be corrected by keeping the default payback assumption in effect through 2010 and then gradually increasing the payback period in future years.

The driving cost coefficient that we used to simulate a 15-year payback might also be modified. In the analysis presented in Tables D-2 through D-4, we multiplied the NEMS driving cost coefficient by a factor of four to increase the implicit NEMS simple payback value of approximately 4 years to 15 years. We chose the fairly extreme test value of four in order to gauge its impact. To mimic the effect of a "social discount rate," a 3% discount factor might be applied, and the net present value of fuel savings might be calculated over 15 years. Assuming a car travels 12,000 miles/year, this step would mean multiplying the driving cost coefficient by 3.

Finally, the 4-year payback implicitly used in NEMS may well be too short for a study evaluating market penetration to 2050, a period over which time consumer attitudes may change; however, a 15-year payback may be too long. The average length of a new car loan is now 5 years and 4 months, which suggests consumers may begin to use this longer evaluation period. It may be appropriate to gradually increase the payback period to 6 years as a sensitivity test. For a 6-year period, the driving cost coefficient would be multiplied by 1.5, assuming that vehicles will travel 12,000 miles/year on average and that consumers will use simple payback.

D.2.5 Reference

EIA (Energy Information Administration), 2006, *The Transportation Sector Model of the National Energy Modeling System: Model Documentation,* DOE/EIA-M070(2006), July.

D.3 DISAGGREGATION OF THE IMPACT FROM CHANGES TO THE VARIABLES USED IN THE VCM ON ATV MARKET PENETRATION

Table D-5 illustrates the individual impacts on ATV market penetration (sales) from changes to various variables used in the NEMS-MP VCM. The reasons that we changed some of the values for these variables from the default values used in NEMS are discussed in Chapter 6.

The analysis was conducted in October 2007 and uses older versions of the NEMS-MP Base Case and Mixed scenario vehicle fuel economy and price estimates than are discussed in the current report. Even the market penetration goals for several of the technologies are different from those discussed in the current report. However, this disaggregation is just meant to be illustrative.

For each vehicle technology, the table presents the impact of changing individual variables on market penetration. The runs are as follows:

1. Fully Integrated Base: The market penetration of each technology in the Base Case as estimated in a full NEMS model run.

2. NEMSA Base: The market penetration of each technology in the Base Case from the NEMS-MP TSA model run. (The results of Runs #1 and #2 are virtually the same.)

3. Fleet Shares to 1%: The Base Case from Run #2 with the fleet share dropped to 1%.

4. Endogenous MMA: The results from Run #3 with vehicle Make and Model Availability (MMA) estimated endogenously (instead of being hard-wired in).

5. Mixed Vehicle Attributes: The results of Run #4 with all the improved vehicle characteristics of the Mixed scenario (i.e., vehicle fuel economies, prices, and other attributes) and with other Mixed scenario PHEV-related inputs (% operation on electricity and share of consumers who can plug-in their PHEVs). (Again, the values used in this run are not those of the final Mixed scenario.)

6. Mixed Flex Fuel Inputs: The results of Run #5 with the Mixed Scenario flex fuel share of advanced conventional vehicle (ACV), PHEVs, and gasoline HEV (GHEV) stock added in.

7. H2 Station Increase: The result of Run #6 with the Mixed Scenario change in H_2 station size (from 1,500 to 750 vehicles/station).

8. Mixed Fuel Prices: The result of Run #7 with the Mixed scenario fuel price assumptions (lower than those of the Base Case).

9. Mixed Alternate Constants: The results of Run #8 with changes to the "constants" used in the VCM for the various technologies. (The default values for ATVs in the Base Case are negative, which depresses ATV market penetration. In "Mixed Alternate Constants," they are revised to be the same as gasoline. See Section 6.5.)

10. NEMSA Mixed: The market penetration results when all the above changes made individually are made at one time. The results are exactly the same as those at the end of Run #9.

11. 40% Reduced Elec.: The results of Run #10 with the electricity price for PHEVs reduced by 40%.

12. Plug-in Avail (65%): The results of Run #11 with the share of households that can plug-in a PHEV raised from the flat 50% by 2030 and beyond (assumed in Run #5) to 65% by 2040 and then held steady.

13. Mixed Goal: The last row provides the market penetration goals for that technology in the Mixed scenario (as of October 2007).

Market penetration was affected by changes in all of these variables except for those in Run #6 (the Mixed Flex Fuel Inputs). As stated in Chapter 6, we estimated the share of ACVs, GHEVs, and PHEVs that would be flex fuel outside the VCM. Ideally, estimations of this share would be included in the VCM. The factors that had the greatest impact on ATV market penetration are:

- The "constant" in the VCM equation,
- Estimating MMA endogenously,
- Vehicle attributes, and
- H_2 station size.

The impact of changing the first two factors (changing the constants and estimating MMA endogenously) is further illustrated in Section 6.7. That section compares the market penetration results of the MP Base Case with a case in which all else is held equal except for these two changes. The ATV market penetration results are substantially different.

TABLE D-1 Example of Utilities: Conventional Gasoline Car, Large Class

Attribute	Coefficient	Attribute Value	Resulting "Utility"[1]
Vehicle Price	–0.00082	28,902.4	–23.72
Fuel Cost	–0.3898	6.284	–2.45
Range	–97.45	696.3	–0.14
Acceleration	–0.2408	7.9	–1.9
Maintenance	–.00249	1,274.83	–3.18
Luggage	1.7232	1	1.72
Home Refueling	0.3909	0	0
Fuel Availability 1	–20.149	1	0
Fuel Availability 2	–6.154	0	0
MMA	0.3	0.1	–0.69
Constant	0	0	0
Total			–30.36

[1] In most, but not all cases, the "resulting utility" for a specific attribute is the result of multiplying the attribute value by the coefficient. We do not discuss the other calculations here because this table is meant simply to be illustrative.

TABLE D-2 Example of Utilities Using Alternative Coefficients for Vehicle Price and Driving Cost

											Total utility	Vehicle price+fuel cost	Other attributes	Vehicle price and fuel cost share of total	Other attributes share of total
Gasoline ICE															
Case 14 - original logit coeff															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28902.4	6.284	696.3	7.9	0	1274.83	1	1	0	0.1	0					
-23.72	-2.45	-0.14	-1.9	0	-3.18	1.72	0	0	-0.69	0	-30.36	-26.17	-4.19	86%	14%
Case 15 fuel cost X4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-1.5592	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28902.4	6.284	696.3	7.9	0	1274.83	1	1	0	0.1	0					
-23.72	-9.8	-0.14	-1.9	0	-3.18	1.72	0	0	-0.69	0	-37.71	-33.52	-4.19	89%	11%
Case 16 vehicle price coefficient/4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00021	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28902.4	6.284	696.3	7.9	0	1274.83	1	1	0	0.1	0					
-5.93	-2.45	-0.14	-1.9	0	-3.18	1.72	0	0	-0.69	0	-12.57	-8.38	-4.19	67%	33%
Diesel Hybrid															
Case 14 - original logit coeff															
Diesel Hybrid (tech: 8)															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
30179	3	940	7.9	0	1185.59	0.95	0.317	0	0.0859	0					
-24.76	-1.17	-0.1	-1.9	0	-2.95	1.64	0	-0.01	-0.74	0	-29.99	-25.93	-4.06	86%	14%
Case 15 fuel cost X4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-1.5592	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
30179	3	940	7.9	0	1185.59	0.95	0.692	0	0.0397	0					
-24.76	-4.68	-0.1	-1.9	0	-2.95	1.64	0	0	-0.97	0	-33.72	-29.44	-4.28	87%	13%
Case 16 vehicle price coefficient/4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00021	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
30179	3	940	7.9	0	1185.59	0.95	0.839	0	0.3241	0					
-6.19	-1.17	-0.1	-1.9	0	-2.95	1.64	0	0	-0.34	0	-11.01	-7.36	-3.65	67%	33%
FC Hydrogen															
Case 14 - original logit coeff															
FC Hydrogen (tech: 14)															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28363.5	2	696.3	7.9	0	1274.83	1	0.009	0	0.0297	0					
-23.27	-0.78	-0.14	-1.9	0	-3.18	1.72	0.83	-5.1	-1.06	0	-33.71	-24.05	-9.66	71%	29%
Case 15 fuel cost X4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00082	-1.5592	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28363.5	2	696.3	7.9	0	1274.83	1	0.574	0	0.4974	0					
-23.27	-3.12	-0.14	-1.9	0	-3.18	1.72	0	0	-0.21	0	-30.10	-26.39	-3.71	88%	12%
Case 16 vehicle price coefficient/4															
PSPR	FlCost	VRng	Accl	HFuel	Maint	Lugg	FAvl1	FAvl2	MMAvail	Const					
-0.00021	-0.3898	-97.45	-0.2408	0.3909	-0.00249	1.7232	-20.149	-6.154	0.3	0					
28363.5	2	696.3	7.9	0	1274.83	1	0	0	0	0					
-5.82	-0.78	-0.14	-1.9	0	-3.18	1.72	1	-6.15	-4.14	0	-20.39	-6.60	-13.79	32%	68%

TABLE D-3 Sales Shares Using Different Payback Assumptions for the Mixed Scenario with Literature Review (LR) Vehicle Prices[1]

	Technology	2010	2020	2030	2040	2050
CARS MARKET PENETRATION						
MPMixed25	Ethanol-Flex Fuel ICE	9.24%	7.66%	6.66%	5.85%	4.51%
MPMixed43	Ethanol-Flex Fuel ICE	8.39%	4.56%	3.38%	2.70%	1.77%
MPMixed44	Ethanol-Flex Fuel ICE	4.62%	0.24%	0.13%	0.07%	0.03%
MP Mixed Goal	E-85 FFV	5.70%	5.40%	0.00%	0.00%	0.00%
MPMixed25	TDI Diesel ICE	0.88%	7.82%	7.65%	8.99%	10.06%
MPMixed43	TDI Diesel ICE	0.95%	9.92%	9.51%	10.75%	11.57%
MPMixed44	TDI Diesel ICE	13.98%	21.26%	16.73%	14.20%	8.95%
MP Mixed Goal	Diesel	0.44%	9.20%	16.00%	14.00%	14.00%
MPMixed25	Adv Conv Gasoline	7.53%	31.74%	32.63%	30.68%	28.41%
MPMixed43	Adv Conv Gasoline	10.42%	41.96%	41.91%	37.95%	33.85%
MPMixed44	Adv Conv Gasoline	15.98%	6.82%	6.49%	4.64%	3.33%
MP Mixed Goal	ACVs	0.00%	20.00%	30.00%	15.00%	10.00%
MPMixed25	Electric-Gasoline Hybrid	14.84%	22.89%	27.32%	32.41%	38.21%
MPMixed43	Electric-Gasoline Hybrid	16.48%	24.54%	28.89%	33.73%	39.18%
MPMixed44	Electric-Gasoline Hybrid	30.68%	36.85%	47.28%	51.80%	49.90%
MP Mixed Goal	SI HEV on Gasoline & SI HEV on E85/H2	3.57%	25.00%	30.00%	20.00%	15.00%
MPMixed25	Electric-Diesel Hybrid	0.01%	7.39%	6.93%	6.98%	6.59%
MPMixed43	Electric-Diesel Hybrid	0.01%	7.77%	7.21%	7.17%	6.68%
MPMixed44	Electric-Diesel Hybrid	0.79%	32.77%	25.23%	22.21%	14.61%
MP Mixed Goal	Diesel HEV	0.02%	0.07%	4.00%	6.00%	6.00%
MPMixed25	Plug-in Gasoline Hybrid	0.00%	0.09%	0.30%	0.57%	1.28%
MPMixed43	Plug-in Gasoline Hybrid	0.00%	0.06%	0.31%	0.59%	1.29%
MPMixed44	Plug-in Gasoline Hybrid	0.00%	0.26%	2.35%	4.85%	10.03%
MP Mixed Goal	SI PHEV & Diesel PHEV	0.00%	0.31%	16.80%	34.50%	25.00%
MPMixed25	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
MPMixed43	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
MPMixed44	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
MP Mixed Goal	EV	0.03%	0.03%	0.00%	0.00%	0.00%
MPMixed25	Fuel Cell PHEV	0.00%	0.00%	0.00%	0.01%	0.02%
MPMixed43	Fuel Cell PHEV	0.00%	0.00%	0.00%	0.01%	0.02%
MPMixed44	Fuel Cell PHEV	0.00%	0.00%	0.00%	0.03%	0.55%
MP Mixed Goal	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	3.15%	9.00%
MPMixed25	Fuel Cell Hydrogen	0.00%	0.05%	0.13%	0.18%	0.24%
MPMixed43	Fuel Cell Hydrogen	0.00%	0.05%	0.14%	0.19%	0.25%
MPMixed44	Fuel Cell Hydrogen	0.00%	0.04%	0.49%	1.52%	12.20%
MP Mixed Goal	Fuel Cell	0.00%	0.01%	0.03%	7.35%	21.00%
MPMixed25	Gasoline ICE Vehicles	67.50%	22.36%	18.38%	14.32%	10.69%
MPMixed43	Gasoline ICE Vehicles	63.75%	11.14%	8.64%	6.91%	5.40%
MPMixed44	Gasoline ICE Vehicles	33.94%	1.75%	1.29%	0.69%	0.39%
MP Mixed Goal	Conventional	90.24%	39.98%	3.17%	0.00%	0.00%
MPMixed25	Other	0.00%	0.00%	0.00%	0.00%	0.00%
MPMixed43	Other	0.00%	0.00%	0.00%	0.00%	0.00%
MP Mixed Goal	Other	0.00%	0.00%	0.00%	0.00%	0.00%
MP Mixed Goal	Other	0.00%	0.00%	0.00%	0.00%	0.00%

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[1] MPMixed25 is the NEMS-TSA run with the default vehicle payback assumptions.
MPMixed43 is the NEMS-TSA run with the payback changed in just the Manufacturer Technology Choice Submodule (MTCS).
MPMixed44 includes the payback change in the MTCS plus a change to the payback in the VCM (extending it to about 15 years).

TABLE D-4 Sales Shares Using Different Payback Assumptions for the Mixed Scenario with Program Goals (PG) Vehicle Prices[1]

	Technology	2010	2020	2030	2040	2050
	CARS MARKET PENETRATION					
SA6	Ethanol-Flex Fuel ICE	9.14%	6.03%	4.81%	4.99%	2.98%
SA14	Ethanol-Flex Fuel ICE	8.28%	3.19%	2.10%	1.99%	1.03%
SA15	Ethanol-Flex Fuel ICE	4.54%	0.13%	0.07%	0.07%	0.02%
MP Mixed Goal	E-85 FFV	5.70%	5.40%	0.00%	0.00%	0.00%
SA6	TDI Diesel ICE	0.85%	9.47%	9.40%	9.31%	9.51%
SA14	TDI Diesel ICE	0.92%	11.53%	11.09%	11.02%	10.93%
SA15	TDI Diesel ICE	13.48%	16.58%	11.03%	5.08%	1.81%
MP Mixed Goal	Diesel	0.44%	9.20%	16.00%	14.00%	14.00%
SA6	Adv Conv Gasoline	7.85%	26.81%	25.05%	24.03%	20.32%
SA14	Adv Conv Gasoline	10.82%	33.99%	30.55%	29.02%	23.83%
SA15	Adv Conv Gasoline	16.39%	4.22%	3.18%	3.08%	1.33%
MP Mixed Goal	ACVs	0.00%	20.00%	30.00%	15.00%	10.00%
SA6	Electric-Gasoline Hybrid	14.96%	25.07%	29.41%	33.14%	34.02%
SA14	Electric-Gasoline Hybrid	16.59%	26.42%	30.45%	34.12%	34.78%
SA15	Electric-Gasoline Hybrid	30.89%	29.93%	34.50%	31.59%	15.90%
MP Mixed Goal	SI HEV on Gasoline & SI HEV on E85/H2	3.57%	25.00%	30.00%	20.00%	15.00%
SA6	Electric-Diesel Hybrid	0.01%	15.44%	13.00%	10.98%	8.82%
SA14	Electric-Diesel Hybrid	0.01%	15.94%	13.29%	11.26%	9.02%
SA15	Electric-Diesel Hybrid	0.71%	46.47%	30.39%	12.75%	4.27%
MP Mixed Goal	Diesel HEV	0.02%	0.07%	4.00%	6.00%	6.00%
SA6	Plug-in Gasoline Hybrid	0.00%	0.37%	5.01%	5.08%	7.48%
SA14	Plug-in Gasoline Hybrid	0.00%	0.37%	5.15%	5.13%	7.49%
SA15	Plug-in Gasoline Hybrid	0.00%	1.45%	17.23%	15.25%	11.58%
MP Mixed Goal	SI PHEV & Diesel PHEV	0.00%	0.31%	16.80%	34.50%	25.00%
SA6	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
SA14	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
SA15	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
MP Mixed Goal	EV	0.03%	0.03%	0.00%	0.00%	0.00%
SA6	Fuel Cell PHEV	0.00%	0.00%	0.11%	0.31%	1.89%
SA14	Fuel Cell PHEV	0.00%	0.00%	0.11%	0.34%	1.86%
SA15	Fuel Cell PHEV	0.00%	0.00%	0.16%	2.65%	8.92%
MP Mixed Goal	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	3.15%	9.00%
SA6	Fuel Cell Hydrogen	0.00%	0.05%	0.73%	1.51%	7.32%
SA14	Fuel Cell Hydrogen	0.00%	0.04%	0.76%	1.61%	7.05%
SA15	Fuel Cell Hydrogen	0.00%	0.04%	2.62%	28.98%	55.91%
MP Mixed Goal	Fuel Cell	0.00%	0.01%	0.03%	7.35%	21.00%
SA6	Gasoline ICE Vehicles	67.18%	16.77%	12.49%	10.66%	7.65%
SA14	Gasoline ICE Vehicles	63.39%	8.50%	6.50%	5.50%	4.02%
SA15	Gasoline ICE Vehicles	33.98%	1.18%	0.82%	0.56%	0.25%
MP Mixed Goal	Conventional	90.24%	39.98%	3.17%	0.00%	0.00%
SA6	Other	0.00%	0.00%	0.00%	0.00%	0.00%
SA14	Other	0.00%	0.00%	0.00%	0.00%	0.00%
SA15	Other	0.00%	0.00%	0.00%	0.00%	0.00%
MP Mixed Goal	Other	0.00%	0.00%	0.00%	0.00%	0.00%

[1] SA6 is the NEMS-TSA run with the default vehicle payback assumptions.
SA14 is the NEMS-TSA run with the payback changed in just the Manufacturer Technology Choice Submodule (MTCS).
SA15 includes the payback change in the MTCS plus a change to the payback in the VCM (extending it to about 15 years).

TABLE D-5 Disaggregation of the Impact of Changes to VCM Variables

	Technology	2010	2020	2030	2040	2050
CARS MARKET PENETRATION						
Fully Integrated Base	Electric Vehicle	0.03%	0.03%	0.03%	0.03%	0.03%
NEMSA Base	Electric Vehicle	0.03%	0.03%	0.03%	0.03%	0.03%
Fleet Shares to 1%	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Endogenous MMA	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Vehicle Attributes	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Flex Fuel Inputs	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
H2 Station Increase	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Fuel Prices	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Alternate Constants	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
NEMSA Mixed	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
40% Reduced Elec	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Plug-in Avail (65%)	Electric Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Goal	EV	0.03%	0.03%	0.00%	0.00%	0.00%
Fully Integrated Base	Ethanol-Flex Fuel ICE	4.84%	4.83%	4.90%	5.96%	8.13%
NEMSA Base	Ethanol-Flex Fuel ICE	4.85%	4.82%	4.77%	6.68%	8.20%
Fleet Shares to 1%	Ethanol-Flex Fuel ICE	4.92%	4.90%	4.82%	7.04%	8.92%
Endogenous MMA	Ethanol-Flex Fuel ICE	7.41%	5.63%	6.58%	9.73%	10.59%
Mixed Vehicle Attributes	Ethanol-Flex Fuel ICE	8.13%	4.00%	3.34%	5.21%	4.49%
Mixed Flex Fuel Inputs	Ethanol-Flex Fuel ICE	8.13%	4.00%	3.34%	5.21%	4.49%
H2 Station Increase	Ethanol-Flex Fuel ICE	8.13%	4.00%	3.30%	3.80%	2.40%
Mixed Fuel Prices	Ethanol-Flex Fuel ICE	8.19%	4.10%	3.87%	9.32%	4.62%
Mixed Alternate Constants	Ethanol-Flex Fuel ICE	9.16%	4.06%	3.36%	3.91%	2.88%
NEMSA Mixed	Ethanol-Flex Fuel ICE	9.16%	4.06%	3.36%	3.91%	2.88%
40% Reduced Elec	Ethanol-Flex Fuel ICE	9.16%	4.06%	3.33%	3.84%	2.84%
Plug-in Avail (65%)	Ethanol-Flex Fuel ICE	9.16%	4.06%	3.33%	3.84%	2.82%
Mixed Goal	E-85 FFV	5.70%	5.40%	0.00%	0.00%	0.00%
Fully Integrated Base	TDI Diesel ICE	0.45%	0.88%	1.76%	1.84%	1.73%
NEMSA Base	TDI Diesel ICE	0.45%	0.89%	1.73%	1.81%	1.74%
Fleet Shares to 1%	TDI Diesel ICE	0.58%	1.14%	2.16%	2.24%	2.17%
Endogenous MMA	TDI Diesel ICE	0.14%	0.10%	0.18%	0.22%	0.21%
Mixed Vehicle Attributes	TDI Diesel ICE	0.18%	0.41%	0.54%	0.68%	0.67%
Mixed Flex Fuel Inputs	TDI Diesel ICE	0.18%	0.41%	0.54%	0.68%	0.67%
H2 Station Increase	TDI Diesel ICE	0.18%	0.41%	0.54%	0.52%	0.36%
Mixed Fuel Prices	TDI Diesel ICE	0.16%	0.35%	0.37%	0.28%	0.21%
Mixed Alternate Constants	TDI Diesel ICE	1.09%	23.24%	22.03%	20.87%	22.21%
NEMSA Mixed	TDI Diesel ICE	1.09%	23.24%	22.03%	20.87%	22.21%
40% Reduced Elec	TDI Diesel ICE	1.09%	23.24%	21.77%	20.42%	21.79%
Plug-in Avail (65%)	TDI Diesel ICE	1.09%	23.24%	21.77%	20.42%	21.62%
Mixed Goal	Diesel	0.44%	9.20%	20.00%	20.00%	20.00%
Fully Integrated Base	Adv Conventional Gasoline	6.02%	4.27%	2.20%	2.08%	1.96%
NEMSA Base	Adv Conventional Gasoline	6.02%	4.25%	2.18%	2.03%	1.96%
Fleet Shares to 1%	Adv Conventional Gasoline	7.38%	5.22%	2.68%	2.50%	2.41%
Endogenous MMA	Adv Conventional Gasoline	16.57%	24.77%	12.20%	11.32%	10.90%
Mixed Vehicle Attributes	Adv Conventional Gasoline	1.99%	28.57%	27.45%	26.06%	21.57%
Mixed Flex Fuel Inputs	Adv Conventional Gasoline	1.99%	28.57%	27.45%	26.06%	21.57%
H2 Station Increase	Adv Conventional Gasoline	1.99%	28.57%	27.31%	19.96%	11.78%
Mixed Fuel Prices	Adv Conventional Gasoline	1.98%	28.63%	27.41%	21.84%	13.44%
Mixed Alternate Constants	Adv Conventional Gasoline	1.69%	12.80%	11.12%	11.03%	9.70%
NEMSA Mixed	Adv Conventional Gasoline	1.69%	12.80%	11.12%	11.03%	9.70%
40% Reduced Elec	Adv Conventional Gasoline	1.69%	12.80%	10.99%	10.80%	9.52%
Plug-in Avail (65%)	Adv Conventional Gasoline	1.69%	12.80%	10.99%	10.80%	9.44%
Mixed Goal	ACVs	0.00%	20.00%	30.00%	15.00%	10.00%

TABLE D-5 (Cont.)

	Technology	2010	2020	2030	2040	2050
CARS MARKET PENETRATION						
Fully Integrated Base	Electric-Gasoline Hybrid	3.84%	6.62%	10.03%	14.05%	14.63%
NEMSA Base	Electric-Gasoline Hybrid	3.85%	6.93%	10.70%	14.67%	14.61%
Fleet Shares to 1%	Electric-Gasoline Hybrid	5.01%	8.62%	13.25%	18.21%	18.13%
Endogenous MMA	Electric-Gasoline Hybrid	9.87%	5.44%	6.38%	6.02%	5.98%
Mixed Vehicle Attributes	Electric-Gasoline Hybrid	16.33%	9.47%	7.13%	6.77%	5.73%
Mixed Flex Fuel Inputs	Electric-Gasoline Hybrid	16.33%	9.47%	7.13%	6.77%	5.73%
H2 Station Increase	Electric-Gasoline Hybrid	16.33%	9.47%	7.09%	5.25%	3.34%
Mixed Fuel Prices	Electric-Gasoline Hybrid	16.24%	9.64%	7.52%	6.59%	4.22%
Mixed Alternate Constants	Electric-Gasoline Hybrid	22.52%	36.47%	32.80%	31.87%	29.72%
NEMSA Mixed	Electric-Gasoline Hybrid	22.52%	36.47%	32.80%	31.87%	29.72%
40% Reduced Elec	Electric-Gasoline Hybrid	22.52%	36.47%	32.73%	31.80%	29.80%
Plug-in Avail (65%)	Electric-Gasoline Hybrid	22.52%	36.47%	32.73%	28.53%	26.04%
Mixed Goal	SI HEV on Gasoline & SI HEV on E85/H2	3.57%	25.00%	30.00%	20.00%	15.00%
Fully Integrated Base	Electric-Diesel Hybrid	0.01%	0.09%	0.07%	0.04%	0.03%
NEMSA Base	Electric-Diesel Hybrid	0.01%	0.08%	0.06%	0.03%	0.03%
Fleet Shares to 1%	Electric-Diesel Hybrid	0.02%	0.14%	0.10%	0.05%	0.05%
Endogenous MMA	Electric-Diesel Hybrid	0.01%	10.60%	12.73%	13.56%	13.62%
Mixed Vehicle Attributes	Electric-Diesel Hybrid	0.00%	17.97%	22.00%	22.52%	19.01%
Mixed Flex Fuel Inputs	Electric-Diesel Hybrid	0.00%	17.97%	22.00%	22.52%	19.01%
H2 Station Increase	Electric-Diesel Hybrid	0.00%	17.97%	21.90%	17.41%	10.99%
Mixed Fuel Prices	Electric-Diesel Hybrid	0.00%	16.65%	18.66%	14.74%	9.48%
Mixed Alternate Constants	Electric-Diesel Hybrid	0.00%	0.00%	0.00%	0.00%	0.00%
NEMSA Mixed	Electric-Diesel Hybrid	0.00%	0.00%	0.00%	0.00%	0.00%
40% Reduced Elec	Electric-Diesel Hybrid	0.00%	0.00%	0.00%	0.00%	0.00%
Plug-in Avail (65%)	Electric-Diesel Hybrid	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Goal	Diesel HEV	0.02%	0.07%	0.00%	0.00%	0.00%
Fully Integrated Base	Plug-in Gasoline Hybrid	0.00%	1.24%	1.22%	0.89%	0.84%
NEMSA Base	Plug-in Gasoline Hybrid	0.00%	1.19%	1.14%	0.83%	0.84%
Fleet Shares to 1%	Plug-in Gasoline Hybrid	0.00%	1.46%	1.39%	1.01%	1.02%
Endogenous MMA	Plug-in Gasoline Hybrid	0.00%	1.41%	2.44%	2.40%	2.42%
Mixed Vehicle Attributes	Plug-in Gasoline Hybrid	0.00%	0.02%	3.15%	3.54%	3.15%
Mixed Flex Fuel Inputs	Plug-in Gasoline Hybrid	0.00%	0.02%	3.15%	3.54%	3.15%
H2 Station Increase	Plug-in Gasoline Hybrid	0.00%	0.02%	3.14%	2.73%	1.80%
Mixed Fuel Prices	Plug-in Gasoline Hybrid	0.00%	0.02%	3.09%	2.80%	1.80%
Mixed Alternate Constants	Plug-in Gasoline Hybrid	0.00%	0.06%	9.74%	9.69%	9.22%
NEMSA Mixed	Plug-in Gasoline Hybrid	0.00%	0.06%	9.74%	9.69%	9.22%
40% Reduced Elec	Plug-in Gasoline Hybrid	0.00%	0.06%	10.41%	10.89%	10.53%
Plug-in Avail (65%)	Plug-in Gasoline Hybrid	0.00%	0.06%	10.41%	14.15%	14.78%
Mixed Goal	SI PHEV & Diesel PHEV	0.00%	0.31%	16.80%	34.50%	25.00%
Fully Integrated Base	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
NEMSA Base	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Fleet Shares to 1%	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Endogenous MMA	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Vehicle Attributes	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.44%	1.34%	7.11%
Mixed Flex Fuel Inputs	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.44%	1.34%	7.11%
H2 Station Increase	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.58%	8.23%	18.04%
Mixed Fuel Prices	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.48%	3.46%	13.21%
Mixed Alternate Constants	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
NEMSA Mixed	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
40% Reduced Elec	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Plug-in Avail (65%)	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed Goal	Plug-in Fuel Cell Vehicle	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE D-5 (Cont.)

	Technology	2010	2020	2030	2040	2050
CARS MARKET PENETRATION						
Fully Integrated Base	Fuel Cell Hydrogen	0.00%	0.05%	0.05%	0.04%	0.04%
NEMSA Base	Fuel Cell Hydrogen	0.00%	0.05%	0.05%	0.04%	0.04%
Fleet Shares to 1%	Fuel Cell Hydrogen	0.00%	0.05%	0.05%	0.05%	0.04%
Endogenous MMA	Fuel Cell Hydrogen	0.00%	0.05%	0.05%	0.04%	0.04%
Mixed Vehicle Attributes	Fuel Cell Hydrogen	0.00%	0.05%	1.06%	2.58%	12.85%
Mixed Flex Fuel Inputs	Fuel Cell Hydrogen	0.00%	0.05%	1.06%	2.58%	12.85%
H2 Station Increase	Fuel Cell Hydrogen	0.00%	0.05%	1.39%	16.67%	34.15%
Mixed Fuel Prices	Fuel Cell Hydrogen	0.00%	0.05%	1.28%	8.50%	31.55%
Mixed Alternate Constants	Fuel Cell Hydrogen	0.00%	0.05%	0.78%	2.37%	9.37%
NEMSA Mixed	Fuel Cell Hydrogen	0.00%	0.05%	0.78%	2.37%	9.37%
40% Reduced Elec	Fuel Cell Hydrogen	0.00%	0.05%	0.77%	2.27%	8.81%
Plug-in Avail (65%)	Fuel Cell Hydrogen	0.00%	0.05%	0.77%	2.27%	8.68%
Mixed Goal	Fuel Cell	0.00%	0.01%	0.03%	10.50%	30.00%
Fully Integrated Base	Gasoline ICE Vehicles	84.07%	81.25%	79.01%	74.29%	71.79%
NEMSA Base	Gasoline ICE Vehicles	84.07%	81.02%	78.59%	73.09%	71.73%
Fleet Shares to 1%	Gasoline ICE Vehicles	82.03%	78.40%	75.46%	68.77%	67.09%
Endogenous MMA	Gasoline ICE Vehicles	65.93%	51.69%	58.69%	55.61%	54.88%
Mixed Vehicle Attributes	Gasoline ICE Vehicles	73.29%	39.28%	34.62%	30.82%	24.80%
Mixed Flex Fuel Inputs	Gasoline ICE Vehicles	73.29%	39.28%	34.62%	30.82%	24.80%
H2 Station Increase	Gasoline ICE Vehicles	73.29%	39.28%	34.48%	25.07%	16.78%
Mixed Fuel Prices	Gasoline ICE Vehicles	73.34%	40.33%	36.99%	31.74%	20.92%
Mixed Alternate Constants	Gasoline ICE Vehicles	65.50%	23.29%	20.13%	20.22%	16.87%
NEMSA Mixed	Gasoline ICE Vehicles	65.50%	23.29%	20.13%	20.22%	16.87%
40% Reduced Elec	Gasoline ICE Vehicles	65.50%	23.29%	19.96%	19.94%	16.67%
Plug-in Avail (65%)	Gasoline ICE Vehicles	65.50%	23.29%	19.96%	19.94%	16.58%
Mixed Goal	Conventional	90.24%	39.98%	3.17%	0.00%	0.00%
Fully Integrated Base	Other	0.72%	0.74%	0.75%	0.78%	0.82%
NEMSA Base	Other	0.72%	0.74%	0.75%	0.78%	0.82%
Fleet Shares to 1%	Other	0.06%	0.08%	0.09%	0.13%	0.18%
Endogenous MMA	Other	0.08%	0.31%	0.75%	1.10%	1.34%
Mixed Vehicle Attributes	Other	0.08%	0.21%	0.27%	0.48%	0.61%
Mixed Flex Fuel Inputs	Other	0.08%	0.21%	0.27%	0.48%	0.61%
H2 Station Increase	Other	0.08%	0.21%	0.27%	0.36%	0.35%
Mixed Fuel Prices	Other	0.08%	0.23%	0.33%	0.72%	0.56%
Mixed Alternate Constants	Other	0.04%	0.04%	0.04%	0.04%	0.04%
NEMSA Mixed	Other	0.04%	0.04%	0.04%	0.04%	0.04%
40% Reduced Elec	Other	0.04%	0.04%	0.04%	0.04%	0.04%
Plug-in Avail (65%)	Other	0.04%	0.04%	0.04%	0.04%	0.04%
Mixed Goal	Other	0.00%	0.00%	0.00%	0.00%	0.00%

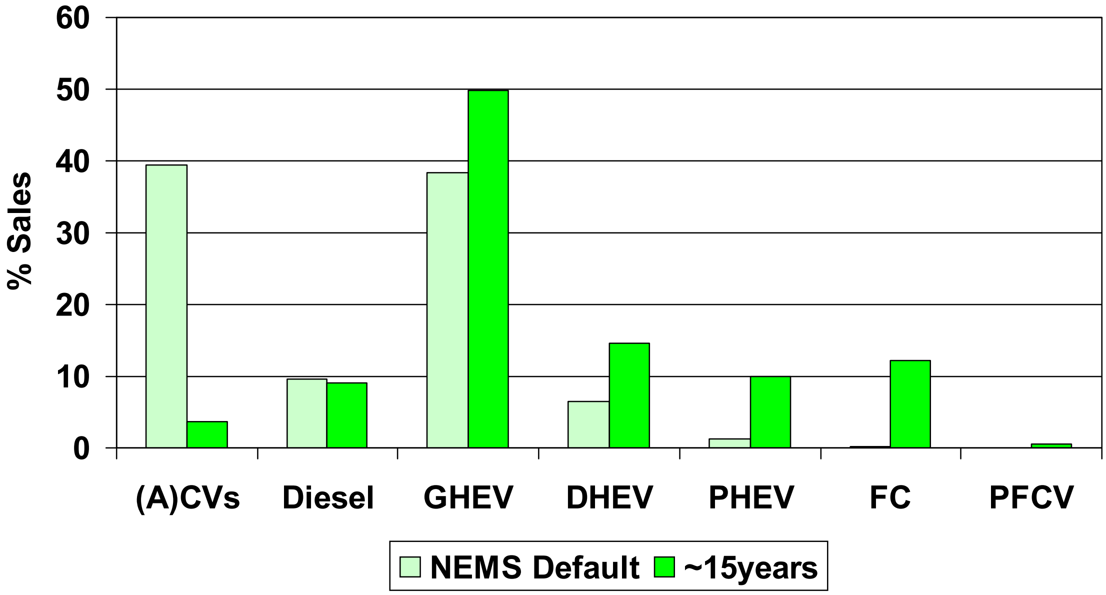

FIGURE D-1 Market Penetration by Vehicle Payback Period: Example (Cars, Mixed Scenario, Literature Review Prices, 2050)

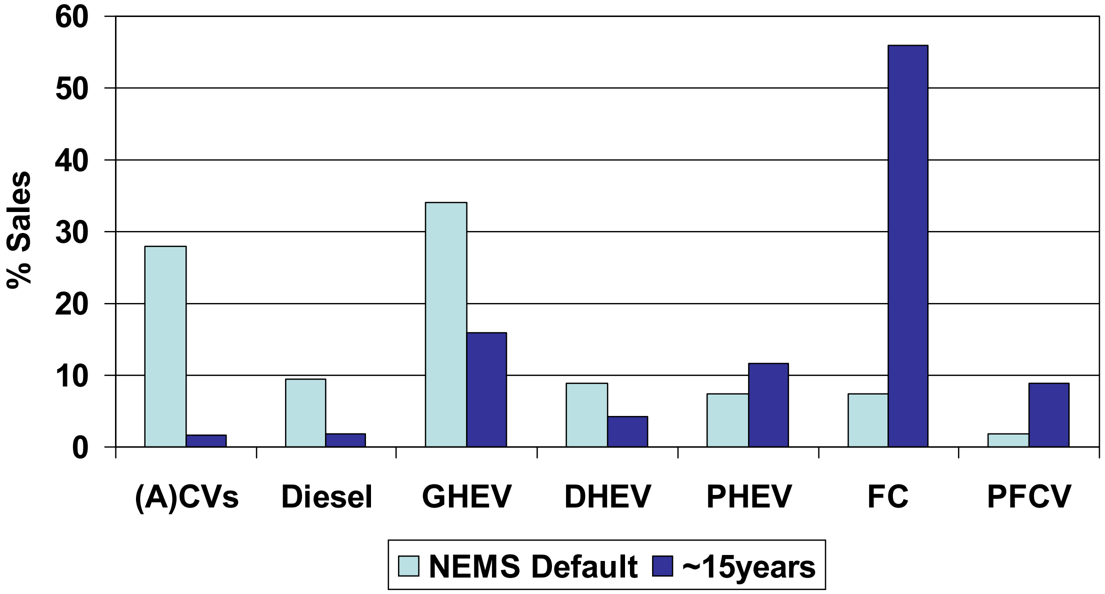

FIGURE D-2 Market Penetration by Vehicle Payback Period: Example (Cars, Mixed Scenario, Program Goals Prices, 2050)

APPENDIX E: OTHER NEMS-MP RESULTS FOR THE BASE CASE AND SCENARIOS

ISSUED SEPARATELY AS PART OF THE MP STUDY.

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APPENDIX F: KEY LESSONS LEARNED FROM AND SIDE BENEFITS OF THE MP STUDY

The purpose of this appendix is to provide a brief statement of the key lessons learned from and side benefits of the Multi-Path Study.

F.1 LESSONS LEARNED

1. In developing sets of input assumptions (technology costs, vehicle improvements, etc.) for futures analysis, it is very difficult to guarantee that the assumptions have a common basis. For example, when "expert teams" develop cost and performance assumptions for future vehicles and fuels, it is difficult to get every team member to understand the precise context for the assumptions (e.g., the level of optimism to be applied, the degree of government assistance that will likely be available, the amount of public support there will be for environmental goals, the level of consumer enthusiasm about environmental performance, and so forth). It is equally difficult for each team member to then apply this "context" to the development of the assumptions. In addition, although a literature review is a key source of information on which to base judgments about the assumptions, the available literature often does not provide sufficient detail about key factors affecting cost and performance estimates to allow good comparisons to be made among competing estimates. For example, it is often not clear what level of optimism underlies the cost and performance estimates, what interest rate was used to develop annualized plant costs, and so forth.

2. Vehicle price is the key determinant of vehicle market penetration estimates in the NEMS model; thus, developing good vehicle price estimates for input to the model is essential. Without such estimates, the market penetration estimates of a model like NEMS are of little value. Yet estimating future vehicle prices, particularly for advanced technologies, is very difficult (see 1 above). The vehicles must be characterized in detail, and component costs must be estimated as a function of time, research success, production volume, etc. Developing such estimates for all the technologies of interest to the U.S. Department of Energy (DOE) (i.e., advanced gasoline vehicles, diesels, hybrids [both gasoline and diesel], fuel cell vehicles [FCVs], and plug-in hybrid electric vehicles [PHEVs] of various ranges) is likely to be time-consuming, and the estimates will inevitably be quite uncertain, especially those associated with technologies that have not yet been commercialized.

3. Even with the best vehicle price estimates possible, the market penetration estimates developed by NEMS should be regarded with great care. The default vehicle payback period in the NEMS Vehicle Choice Model (VCM) is short: 3–4 years. This payback period may well reflect recent consumer behavior, but it is not compatible with a future in which consumers highly value reduced oil use. A longer payback period would result in greater penetration of higher-priced advanced technology vehicles (ATVs).

In addition, changing the assumptions about two other components of the VCM in particular can cause great changes in market penetration estimates. First, NEMS provides three methods to estimate the make and model availability of various vehicle technologies. These methods lead to different market penetration estimates. Second, the value assigned to the "constant" (which is meant to capture the effects of variables that are left out of the vehicle choice equation or that are immeasurable) has great impact. Third, the default values in NEMS for ATVs are typically negative, which reduces their market penetration.

4. It takes a long time to conduct a technically sound study, particularly when NEMS is used. Phase 2 of the MP Study was started in January 2007; while progress reports were issued in the interim, a complete draft report on the vehicle characterization and scenario analysis was not completed until March 2009. There are many reasons, but these should be noted in particular:

   - It took months to get PSAT results that satisfied us and some months to develop credible vehicle cost (and subsequently price) estimates. These are key inputs to the NEMS model.

   - The NEMS model had to be modified to address items we felt were necessary (i.e., the addition of fuel flexibility to various technologies, the charging of PHEVs at night and the assumption of residential electricity rates, and the incorporation of the new CAFE and RFS laws enacted in December 2007). These modifications took effort and time.

   - It took many runs of the NEMS-TSA model to develop the specific vehicle subsidies needed to generate the ATV market penetration in NEMS that we wanted for our scenarios.

   Unfortunately, the length of time required may lead to disinterest in the study on the part of those who want more "immediate" answers. Further, the delays create problems of data "freshness."

5. The large uncertainties associated with projections of future vehicle and fuel prices and performance imply that a considerable degree of sensitivity analysis should be conducted to allow information to be developed about how differences in the underlying assumptions about these prices and performance will change study results about the overall costs and benefits of competing policies and technologies. Unfortunately, the use of complex and time-consuming models such as NEMS makes it very difficult to conduct adequate sensitivity analysis. Also, the complexity of NEMS makes it difficult to evaluate the robustness of study results (i.e., to determine the extent to which results may arise from quirks or weaknesses in the model rather than from robust analysis).

F.2 SIDE BENEFITS

1. The PSAT modelers are now paying more attention to having uniform performance requirements for the vehicles being evaluated.

2. The MP vehicle cost equations have been incorporated into PSAT so that PSAT can provide (and has provided) vehicle price estimates as well as miles-per-gallon (MPG) estimates for Program Decision Support (PDS)/Risk.

3. The method used in MP for allocating these costs across six cars and six light truck (LT) categories was implemented for PDS10/Risk.

4. Some of the MP vehicle characteristics and other results were indirectly used in the McKinsey carbon abatement cost analysis. (McKinsey incorporated the PSD10/Risk vehicle price estimates into its analysis; the PDS10/Risk price estimates were largely based on MP.)

5. At least one change made to the embedded NEMS assumptions for MP has been incorporated into the model runs for PDS/Risk. Fleet vehicle choices are now being ignored because the NEMS fleet submodule does not include all the ATVs of interest to DOE; this aspect of the NEMS fleet submodel was discovered by the MP team.

6. The stand-alone NEMS transport sector model developed for MP allows fast analysis of ATV market penetration with changing variables (vehicle fuel economy, vehicle price, recharge availability, etc.). (Unfortunately, the model is tied to AEO 2007 inputs.)

7. We have an increased appreciation of the limitations of the NEMS model.

8. In response to MP concerns, PSAT modelers have improved the modeling of blended mode operation of plug-in hybrids, developing operating modes that reduce the distance needed to achieve battery depletion and that thus allow more daily miles to be "electrified."

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