ORNL/TM-2009/019

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PHEV Market Introduction Study

Final Report

January 2010

Funding provided by:

U.S. Department of Energy
Vehicle Technologies Program

U.S. Department of Energy
Office of Electricity Delivery & Energy Reliability

ORNL/TM-2009/019

Plug-in Hybrid Electric Vehicle
Market Introduction Study

Final Report

January 2010

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Oak Ridge, Tennessee 37831
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract No. DE-AC05-00OR22725

ACKNOWLEDGEMENTS

The Plug-in Hybrid Electric Vehicle (PHEV) Market Introduction Study is a collaborative effort among Sentech, Inc., Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), the University of Michigan Transportation Research Institute (UMTRI), and the U.S. Department of Energy (DOE). The following individuals from these organizations contributed to the preparation of this document:

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The project team would like to extend a special thank you to several industry stakeholders, including members of the study's Guidance and Evaluation Committee[1] who participated in discussions on policies, incentives, and regulations that they expect to help accelerate the market for PHEVs in the short term.

Much appreciation is also due to DOE's Jacob Ward for the extensive time spent exercising the Market Acceptance of Advanced Automotive Technologies (MA³T) Model to meet the specifications and timeline of this project. In addition, expedited results from UMTRI's Virtual Automotive Marketplace (VAMMP) model were achieved through its accelerated launch by John Sullivan.

Finally, results from the PHEV Market Introduction Study would not have been possible without DOE's foresight to fund ORNL and PNNL/UMTRI to develop the MA³T Model and VAMMP model. Within DOE, funding is provided by the Vehicle Technologies Program and the Office of Electricity Delivery and Energy Reliability.

[1] See list of Guidance and Evaluation Committee members at www.sentech.org/phev.

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Acronyms and Abbreviations

ABM	agent-based model
AER	all-electric range
AFV	alternative fuel vehicle
ARRA	The American Recovery and Reinvestment Act of 2009
CAFE	Corporate Average Fuel Economy
CD	charge depleting
CO_2	carbon dioxide
CPC	current policy case
CS	charge sustaining
DOE	U.S. Department of Energy
E85	85% ethanol blend gasoline
EISA	The Energy Independence and Security Act of 2007
EPAct	The Energy Policy Act of 2005
GHG	greenhouse gas
gpm	gallons per mile
GSA	U.S. General Services Administration
HEV	hybrid electric vehicle
HYFET	Highway Fuel Efficiency Test
ICE	internal combustion engine.
LDV	light duty vehicle
Li-ion	lithium-ion
MA^3T	Market Acceptance of Advanced Automotive Technologies
mpg	miles per gallon
OEM	original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PHEV	plug-in hybrid electric vehicle
PNNL	Pacific Northwest National Laboratory
R&D	research and development
SAE	Society of Automotive Engineers
SUV	sport utility vehicle
UDDS	Urban Dynamometer Driving Schedule
UMTRI	University of Michigan Transportation Research Institute
VAMMP	Virtual AutoMotive MarketPlace
VMT	vehicle miles traveled
VO	vehicle ownership

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PHEV Market Introduction Study: "What You Need to Know"

- **Team:** Oak Ridge National Laboratory; Sentech, Inc.; Pacific Northwest National Laboratory / University of Michigan Transportation Research Institute; U.S. Department of Energy.

- **Issue:** Existing policies in support of PHEVs appear to have a strong initial impact on the PHEV market with approximately 1 million PHEVs projected to be on the road in 2015 and 425,000 PHEVs sold in 2015 alone. At this penetration rate, PHEVs would account for 2.5% of all new vehicle sales in 2015, with PHEV-12s dominating overall PHEV market sales. To further accelerate and sustain the market, additional policy options must be considered to make PHEVs cost-competitive with enough appealing features to become a significant segment of new vehicles sold in the near term.

- **Objective:** Nine policies are applied to the current policy situation, and the market impact for each is assessed to determine which offers the greatest sales impact at the lowest cost of implementation.

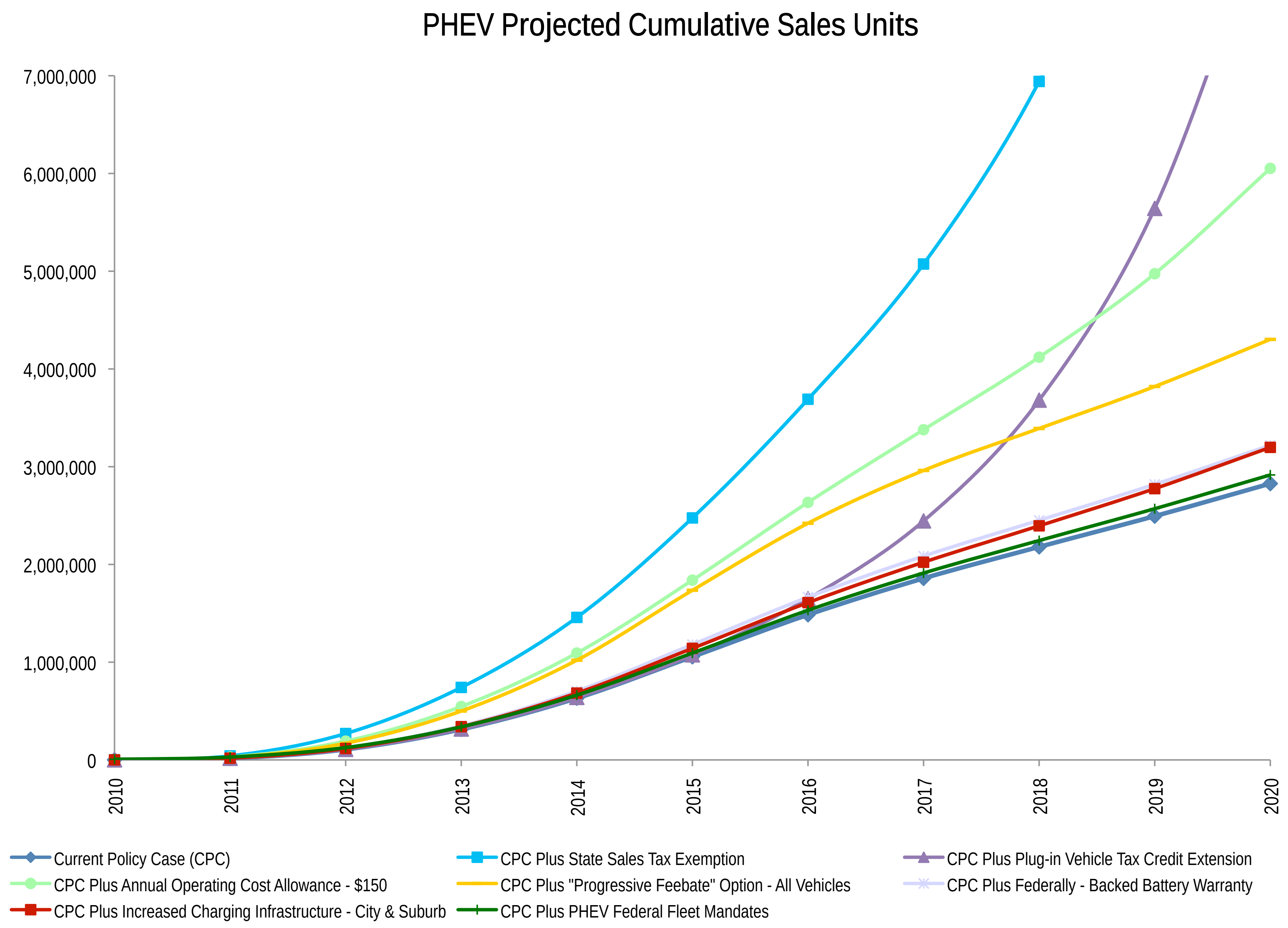
- **Results:** Incentives that directly or indirectly reduce the sticker price of PHEVs to within a competitive range of HEVs and conventional vehicles appear to have the strongest impact on market introduction sales. The policies that offer the greatest sales boost at the most affordable cost are:
  - State Sales Tax Exemption: Implementing a state sales tax exemption can result in an additional 10.4 million PHEVs on the road by 2020 at an average government investment of $1,750 per PHEV sold beyond the current policy case.
  - Feebate Program: An aggressive feebate program, combined with the current policy case, can result in an additional 1.5 million PHEVs on the road by 2020 and can be designed to be revenue-neutral.
  - Annual Operating Cost Allowance: Implementing a $150 annual operating cost allowance can result in an additional 3.2 million PHEVs on the road by 2020 at an average government investment of $2,800 per PHEV sold beyond the current policy case.

- **Possible Market Pinch Points:** Four probable pinch points were identified, which describe supply or industry deficiencies that could have potentially large effects on the success of a market. They are (1) supply chain insufficiencies; (2) infrastructure readiness; (3) consumer acceptance and education; and (4) gasoline prices.

- **Potential Funding Sources:** Potential sources of funding for policies adopted include (1) general revenues generated through personal and corporate income taxes; (2) fees assessed on vehicles with poor fuel economy; and/or (3) an increase in the tax on vehicle fuels, with the additional taxes being applied specifically for PHEV initiatives. It should be noted that a federal gasoline tax increase of 2¢ per gallon would generate enough revenue to pay for most all incentives investigated in this study.

- **Key Organizations:** The implementation of policies that support PHEV market introduction will require strong participation by multiple entities. The primary entities that will play a major role throughout the market introduction of PHEVs are the government, private industry, utilities, and vehicle purchasers.

- **Models:** ORNL's Market Acceptance of Advanced Automotive Technologies (MA^3T) Model and UMTRI's Virtual AutoMotive MarketPlace (VAMMP) Model were used to assess the policy options in this study. The MA^3T Model simulates competition of PHEVs against several other vehicle types by placing values on specific vehicle attributes, consumer cost savings, and predefined market conditions. The VAMMP model approaches market penetration projections from an agent-based perspective. *It should be noted that both models are driven purely by consumer demand and do not incorporate production capacity restraints.*



PHEV Projected Cumulative Sales Units
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Current Policy Case (CPC)
CPC Plus State Sales Tax Exemption
CPC Plus Plug-in Vehicle Tax Credit Extension
CPC Plus Annual Operating Cost Allowance - $150
CPC Plus "Progressive Feebate" Option - All Vehicles
CPC Plus Federally - Backed Battery Warranty
CPC Plus Increased Charging Infrastructure - City & Suburb
CPC Plus PHEV Federal Fleet Mandates

Executive Summary

Overview

Oak Ridge National Laboratory (ORNL), Sentech, Inc., Pacific Northwest National Laboratory (PNNL) / University of Michigan Transportation Research Institute (UMTRI), and the U.S. Department of Energy (DOE) have conducted a Plug-in Hybrid Electric Vehicle (PHEV) Market Introduction Study to identify and assess the effect of potential policies, regulations, and temporary incentives as key enablers for a successful market debut. The timeframe over which market-stimulating incentives would be implemented – and the timeframe over which they would be phased out – are suggested. Possible sources of revenue to help fund these mechanisms are also presented. In addition, pinch points likely to emerge during market growth are identified and proposed solutions presented. Finally, modeling results from ORNL's Market Acceptance of Advanced Automotive Technologies (MA^{3}T) Model and UMTRI's Virtual AutoMotive MarketPlace (VAMMP) Model were used to quantify the expected effectiveness of the proposed policies and to recommend a consensus strategy aimed at transitioning what begins as a niche industry into a thriving and sustainable market by 2030.

PROJECT TEAM
Oak Ridge National Laboratory
Sentech, Inc.
Pacific Northwest National Laboratory / University of Michigan Transportation Research Institute
U.S. Department of Energy

CLIENT
U.S. Department of Energy - Vehicle Technologies Program and Office of Electricity Delivery and Energy Reliability

STUDY DURATION
November 2008 – January 2010

FOR MORE INFORMATION
www.sentech.org/phev

The primary objective of the PHEV Market Introduction Study is to identify the most effective means for accelerating the commercialization of PHEVs in order to support national energy and economic goals. Ideally, these mechanisms would maximize PHEV sales while minimizing federal expenditures. To develop a robust market acceleration program, incentives and policies must be examined in light of

- clarity and transparency of the market signals they send to the consumer,
- expenditures and resources needed to support them,
- expected impacts on the market for PHEVs,
- incentives that are compatible and/or supportive of each other,
- complexity of institutional and regulatory coordination needed, and
- sources of funding.

Pinch Points

During the PHEV Market Introduction Study Workshop (December 2008), four key pinch points with the potential to disrupt the PHEV market introduction were identified:

1. Supply Chain Insufficiencies: Achieving ample production of affordable PHEV batteries may be the single greatest challenge to large-scale commercialization of PHEVs over the next decade. Batteries must reach a reasonable price in order for PHEVs to be competitive with conventional vehicles and hybrid electric vehicles (HEV) in forthcoming decades. In order to produce batteries that meet the required standards of durability, quality, and safety at a reasonable cost, many issues of the battery industry must be addressed. These issues

include (but are not limited to) technology maturation, increased domestic production, raw material availability, and market readiness.

2. Infrastructure Readiness: The introduction of PHEVs into the marketplace presents several new infrastructure challenges, which will affect most industry stakeholders to some degree. While a smart grid may not be essential to PHEV operation in the near term, the availability of simple and seamless PHEV charging equipment and practices in time for first generation PHEVs would be extremely beneficial. Smart grids, which include sensors and controls to manage PHEV charging and discharging, and infrastructure to support interconnection at locations throughout the grid, would eventually allow utilities and customers to maximize the benefits of PHEV technology.
3. Consumer Education and Workforce Training: Several new and unfamiliar characteristics associated with owning and operating PHEVs may leave some customers reluctant to purchase them initially. Furthermore, customers that do purchase PHEVs may not fully understand how to maximize its benefits (e.g., not recharging batteries on a regular basis). When almost any new product hits the market, the majority of consumers wait to observe how well the product truly performs (in this case, battery safety and durability will be closely observed) and how pleased the early adopters appear to be with their purchases before they actually choose to buy. Sales of first generation PHEVs are likely to show similar trends.
4. Price of Gasoline: The price of gasoline will likely have significant influence on PHEV market penetration. Historical trends show that as gasoline prices rise, passenger car sales also increase while sales of light trucks and sport utility vehicles (SUV) fall proportionally. This is evidence of consumers opting for more fuel-efficient vehicles to cut down on operating costs. Likewise, as gasoline prices drop, the sense of urgency fades and consumer interest in less efficient light-duty trucks and SUVs returns.

Key Policies, Incentives, and Regulations

Participants of the PHEV Market Introduction Study Workshop held in December 2008 identified over 75 policies, incentives and regulations of which nine were believed to have the most potential for boosting PHEV sales over the next 10 to 20 years. Each of these nine mechanisms was defined and investigated in depth in the current report to help visualize the overall effect on the market, specifically how they alleviate pinch points. Market impact analyses generated from both the MA^{3}T Model and the PNNL/ UMTRI's VAMMP model are used to project increases in future sales (if any) resulting from each studied mechanism. *It should be noted that both models are driven purely by consumer demand and do not incorporate production capacity restraints.*

The current policy case constructed for this study accounts for:

- The Plug-In Vehicle Tax Credit (ARRA, Sec1141, H.R.1) that offers between $2,500-7,500 in tax credits to consumers, based on battery energy storage capacity[2],
- $2 billion in advanced battery manufacturing grants (ARRA, H.R.1) to domestic automotive, battery, and component manufacturers[3], and
- $400 million for electric drive vehicles and electrification infrastructure demonstration and evaluation projects (ARRA, H.R.1).

[2] Established in Emergency Economic Stabilization Act of 2008; modified and extended in ARRA.
[3] Originally authorized but not funded under the Energy Independence and Security Act of 2007, Section 135.

To account for the aforementioned $2.4 billion in ARRA funding, ORNL exercises a "high technology" option built into its model to represent accelerated vehicle and component cost reductions. Similarly, UMTRI uses upstream subsidies available to manufacturers and their suppliers to more rapidly drive down production costs and PHEV sticker prices.

The three existing policy measures appear to have a strong initial impact on the PHEV market with approximately 1 million PHEVs projected to be on the road in 2015 and 425,000 PHEVs sold in 2015 alone, according to ORNL's modeling efforts. At this penetration rate, PHEVs would account for 2.5% of all new vehicle sales in 2015, with PHEV-12s dominating the overall PHEV market sales landscape (compared to the PHEV-20s and PHEV-40s also analyzed in this study). UMTRI's modeling efforts projected very similar annual PHEV sales of 2.6% in 2015 under their current policy case. To provide perspective, HEVs accounted for 2.4% of new vehicle sales in 2008. To help accelerate near term adoption of PHEVs, nine additional policy options are investigated in this study, summarized below:

1. State Sales Tax Exemptions: By exempting PHEV purchasers from the payment of state sales tax, the total cost to purchase a PHEV becomes more financially competitive with conventional vehicles and HEVs. Consumers may also become more inclined to purchase first-generation PHEVs instead of waiting to learn about experiences of early adopters. MA^3T Model results indicate that adding state sales tax exemptions to the current policy case can accelerate PHEV sales to a total of nearly 2.5 million units on the road by 2015 at an average federal investment of $1,750 per PHEV sold beyond the current policy case. UMTRI model results also project a significant sales boost from sales tax exemptions when combined with the upstream vehicle OEM subsidies included in their current policy case.
2. "Feebate" Program: A feebate program assesses fees for vehicles with poor fuel economy ratings to provide a source of funding for rebates applied to vehicles with high fuel economy rating, potentially incentivizing auto OEMs to design and manufacture more fuel-efficient vehicles, including PHEVs, even with a continuation of relatively low gasoline prices. For the "Progressive Feebate" option analyzed in this study, vehicles with fuel economy standards below the corporate average fuel economy (CAFE) standard are charged a fee while vehicles with fuel economies of over twice the CAFE standard receive a rebate. Using a rate of $1,000 per 0.01 gallon per mile, a feebate program can accelerate PHEV sales to nearly 1.75 million units by 2015 when combined with the current policy case. Feebate programs can be designed and implemented to achieve a "revenue-neutral" result.
3. Annual Operating Cost Allowances: An annual operating cost allowance can be designated for registered owners of PHEVs to help cover a portion of their lifetime vehicle ownership costs, including nonresidential parking fees, toll fares, registration costs, scheduled maintenance costs, and other vehicle-related operating expenses. According to MA^3T Model results, implementing a $150 annual operating cost allowance can result in an additional 3.2 million PHEVs on the road by 2020 at an average government investment of $2,800 per PHEV sold beyond the current policy case.
4. Extension of Existing Plug-in Vehicle Tax Credit: To avoid a major dip in PHEV sales shortly after 2015, the Plug-In Vehicle Tax Credit that offers between $2,500-7,500 in tax credits to consumers, based on battery energy storage capacity, could be extended at least through 2020 for all OEMs. Therefore, consumers could continue to take advantage of reduced vehicle prices beyond 2015, which is around the time when the tax credit phases out in the current policy case. The MA^3T Model projects that extending the Plug-in Vehicle Tax Credit through 2020 can result in an additional 6 million PHEVs on the road by 2020 at

an average government investment of $3,000 per PHEV sold beyond the current policy case. UMTRI's model projects PHEVs to reach a 2% fleet penetration and 4% of annual sales by 2020 if the Plug-in Vehicle Tax Credit is made available through this time.

5. Federally-Backed Battery Warranty: A PHEV battery warranty would allow battery manufacturers and the federal government to share financial risk from batteries that fail prematurely after purchase. This warranty may be necessary if the government wishes to expedite the deployment of batteries to help boost consumer confidence. MA^3T Model results indicate that a federally-backed battery warranty that covers half of premature failures can result in 1.2 million PHEVs on the road by 2015 when combined with the current policy case. The average federal investment per vehicle is completely dependent on the actual failure rate of PHEV batteries.
6. Charging Infrastructure Financial Incentives: Providing financial incentives to improve public and private charging infrastructure could help PHEVs obtain more widespread acceptance, especially for consumers who are unfamiliar with most charging practices. MA^3T Model results indicate that increased access to charging infrastructure will have a moderate effect on near term PHEV sales when combined the current policy case, totaling 1.15 million PHEVs on the road by 2015. Furthermore, installation of public charging infrastructure may be critical for central city sales.
7. Government Fuel Efficiency Regulations: Fuel efficiency regulations can be implemented to mandate government fleet requirements and promote the use of highly fuel-efficient PHEVs in federal fleets. MA^3T Model results suggest that mandating a 10-20% PHEV replenishment rate for federal fleets through 2020 does not have a significant effect on overall PHEV market sales. During the first couple of years in production, however, fleet mandates do represent a significant percentage of overall PHEV sales. Furthermore, fleet vehicles be valuable in increasing visibility and consumer acceptance of PHEVs.
8. Subsidies to Lower Initial Vehicle Price: A subsidy to lower the vehicle sticker price would allow PHEVs to become more cost-competitive with conventional vehicles and HEVs. Vehicle subsidies that reduce the price premium of PHEVs relative to an HEV, through 2020, are modeled in this study. Specifically, the price premium for PHEV-12s over HEVs is $1,500; for PHEV-20s it is $3,000; and for PHEV-40s it is $6,000. MA^3T Model results determined that these subsidies have little effect on future PHEV sales since the "high technology" case used in this study already achieved these cost differentials for most years.
9. Federal Gasoline Tax Increase: Gasoline tax increases may be used to raise capital to help offset the incremental cost of batteries, fund retooling of automotive facilities, support the scale-up of battery plants, and generate funding for other PHEV incentive programs. It may also have a large enough effect to alter consumer driving and purchasing habits. Two levels of gasoline tax increases are analyzed in this study: (a) nominal and (b) major.
    a. Nominal: A 1¢ per gallon tax increase translates roughly to $1.35 billion in annual government revenue. A federal gasoline tax increase of 1.5¢ per gallon could provide full funding for most of the incentives discussed in this report. Nominal increases in gasoline tax had little to no impact on PHEV sales and consumer habits, but the incentives that could be enabled from the additional tax revenue will.
    b. Major: The primary objective of a major gasoline tax increase (e.g., $1 per gallon) is to persuade consumers to purchase more fuel efficient vehicles, such as PHEVs. According to modeling results, a $1 per gallon tax increase would have only a marginal impact on PHEV sales; furthermore, it would present an excessive burden on consumers.

Potential Funding Sources

As indicated above, the cost to implement the policy and incentive options discussed in this study could be substantial. For example, state sales tax exemptions, annual operating cost allowances, and the Plug-in Vehicle Tax Credit extension have some of the largest projected costs of implementation among the policies analyzed; however, they are also expected to have among the largest benefits in terms of increased PHEV sales through the year 2020. It is assumed in this study that federal taxpayers would pay the costs associated with any initiative, or combination of initiatives, discussed above. In return, they would receive the public benefits derived from accelerating commercial sales of PHEVs.

Funds to pay for incentives, or to offset reduced revenues, could be collected by the government through a variety of mechanisms. The potential sources of funding suggested here are (1) general revenues generated through personal and corporate income taxes; (2) an increase in the tax on vehicle fuels, with the additional taxes being applied specifically to PHEV initiatives; and/or (3) fees assessed on vehicles with poor fuel economy, similar to a "gas guzzler" tax.

Key Organizations

The implementation of policies that support PHEV market introduction will require strong participation by multiple entities. Key organizations that have a crucial role in a successful PHEV policy adoption and implementation are summarized below:

1. Government: The federal government would be instrumental in the development and implementation of each policy described in this study. State government agencies, such as state energy offices or public utilities commissions, could take their own initiative in implementing some of the policies and could be affected by others.
2. Private Industry: Vehicle and component manufacturers must make a determination about actions they will take in response to consumer demand. In particular, battery developers and suppliers, drive train suppliers, and manufacturers of electronic and electrical equipment will need to be attentive to PHEV-related policy issues and market development. Electric utilities must engage with vehicle manufacturers, technology providers, and government agencies to assure standardization of vehicle recharging systems; they must also communicate with customers on optimal charging of their PHEVs in order to enhance electric distribution quality.
3. Vehicle Purchasers: Consumers must be motivated to make different vehicle purchase decisions than they would without a policy. They need to become knowledgeable and educated about PHEV benefits and costs and what to expect from the PHEV ownership experience. (This category ranges from large fleet managers to individual consumers.)

Market Impacts of Policy Options

The PHEV Market Introduction Study projects that, if no further policies are established in support of PHEVs, approximately 425,000 units will enter the light duty vehicle (LDV) fleet in 2015 alone, accounting for roughly 2.5% of LDV annual sales in that year. This translates to just over 1 million PHEVs sold by 2015, potentially meeting the Obama Administration's aggressive goal of 1 million plug-in hybrid vehicles on U.S. roads by 2015. However, additional policies, incentives, and regulations should be considered to accelerate demand and educate consumers on the financial and societal benefits associated with owning and operating a PHEV if they are to maintain a strong market presence beyond this time period.

With initial vehicle cost presenting the most significant market barrier for PHEVs, incentives that greatly reduce the incremental vehicle cost between PHEVs and HEVs appeared to have a strong impact in MA^{3}T Model results. For example, state sales tax exemptions that can potentially save the consumer thousands of dollars at the time of purchase had a large impact on PHEV sales in this study. PHEV-12s are especially appealing under these types of incentives because the price premium between a PHEV-12 and an HEV will continue to diminish in upcoming years, based on MA^{3}T Model assumptions, and additional reductions in sticker price would give PHEV-12s a clear competitive advantage by 2015. Legislation that would extend the existing Plug-in Vehicle Tax Credit through 2020 would also help to further reduce the price premium between PHEVs and competitive vehicles.

As an alternative to incentives received at the time of purchase, annual operating cost allowances appeared to have a major impact on annual PHEV sales. These annual payments to the consumer can be used towards various vehicle-related operating costs over the life of the vehicles, such as parking fees, toll fares, and fuel (e.g., electricity or E85) costs. Model results suggest that a payment of $150 per year over a ten year period is sufficient to see a significant increase in near-term PHEV sales.

A feebate program that rewards vehicles exceeding a given fuel economy pivot point with a $1,000 rebate per 0.01 gpm while assessing a similar fee on “gas guzzlers,” appeared to have a moderate to high impact on PHEV sales through 2020 when applied to the current policy case. When PHEV sales were projected using the “Standard Feebate” option, which uses the CAFE standard as the pivot point, an improvement of approximately 20% was seen. When the pivot point is extended to twice the CAFE standard, as demonstrated in the “Progressive Feebate” option, sales projections accelerate significantly to roughly 2 million PHEVs on the road by 2015. A neutral revenue stream can be designed for a feebate system, allowing the program to essentially pay for itself.

Federal government fleet mandates, with annual fleet replenishment rates of 10-20% for PHEVs through 2020, had little effect on overall PHEV market sales, because 10-20% of annual federal fleet acquisitions only accounts for 6,000 to 13,000 vehicles purchased each year. However, mandated fleet vehicles, although low in number, could be valuable in raising consumer awareness and acceptance. The inclusion of state, county, and local fleet vehicles in this mandate could significantly improve the market impact of government fleet mandates since these vehicles account for over five times the amount of existing federal fleet vehicles.

Incentives that do not directly affect the average consumer’s pocketbook, such as improved access to charging infrastructure in both central cities and suburbs, also do not appear to have a major effect on PHEV market demands. However, the low sales projections associated with increased charging access are partially due to the indiscriminate selection of locations that received upgrades. Realistically, charging infrastructure incentives would probably be targeted to specific individual homes and businesses with the highest likelihood of resulting in new PHEV sales, not simply by selecting locations at random.

The figure on page *xx* provides a graphic comparison of the projected cumulative PHEV sales attributable to policies, incentives, and regulations analyzed in this study that resulted in notable market impacts through 2020. For visual clarity, only the most promising scenarios are shown.

Cost of Implementation

With respect to implementation costs, required funding for each of the policy options ranged tremendously. Generally speaking, the incentives that resulted in the greatest market impact typically required the most funding. For example, policy options that each required over $1 billion in additional funding to implement, such as the Plug-in Vehicle Tax Credit extension and the state sales tax exemption, accumulated the most additional PHEV sales through 2020. In fact, these policy options are the most expensive to implement with $18 billion each in additional needed federal funding needed through 2020. In contrast, policy options that cost less than $1 billion in additional funding to implement, such as federal fleet mandates and federally-backed battery warranty, each netted less than 1.2 million PHEV sales by 2015 when combined with the current policy case.

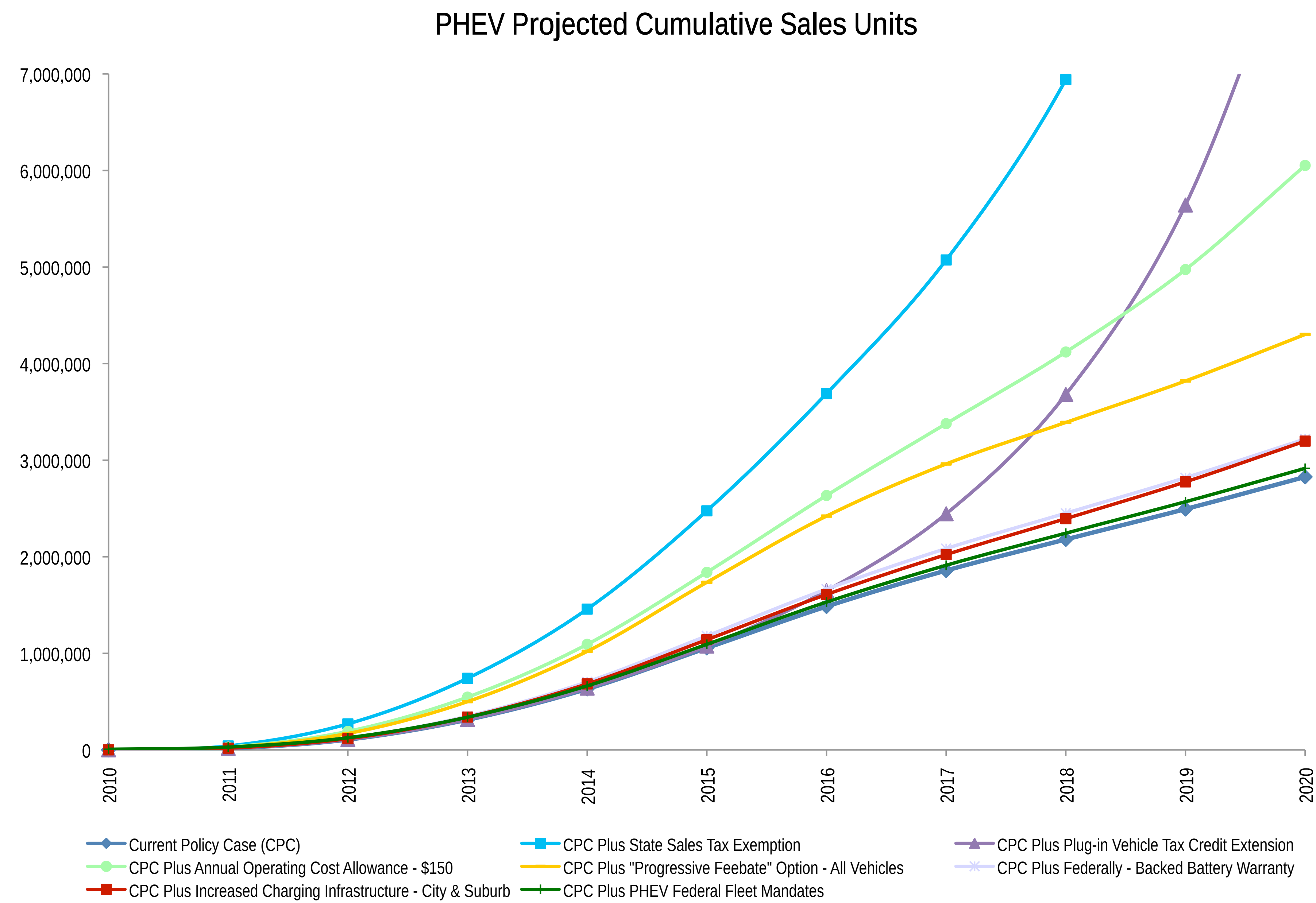
On a cost per PHEV basis using MA^{3}T Model assumptions, the policy options with the least expensive cost of implementation by the federal government beyond the current policy case appear to be the feebate program, which can be designed to be revenue-neutral; a federally-backed battery warranty ($150 per PHEV sold beyond the current policy case, assuming a 1% failure rate); and a state sales tax exemption ($1,750 per PHEV sold beyond the current policy case). Annual operating cost allowances ($2,800 per PHEV sold beyond the current policy case), federal fleet mandates ($2,900 per PHEV sold beyond the current policy case), extension of the Plug-in Vehicle Tax Credit ($3,000 per PHEV sold beyond the current policy case), and increased charging infrastructure ($4,300 per PHEV sold beyond the current policy case) appear to have the highest cost of implementation for the federal government. The excessive cost to introduce additional vehicle subsidies - over $50,000 per PHEV sold beyond the current policy case - that generated negligible sales is simply too great of an investment for the federal government to consider pursuing.

Societal Benefits

Testing has demonstrated that, if operated as intended, PHEVs can consume only a fraction of the petroleum-based fuel relative to conventional vehicles over their lifetime. In fact, on a vehicle to vehicle basis, PHEVs use an average of 80% less gasoline than conventional vehicles and 70% less than HEVs.[4] Over time, these savings can accumulate into significant displacements of petroleum, helping to stabilize the U.S. economy and strengthen energy security if petroleum imports from unreliable sources are consequently reduced. Furthermore, fewer GHGs will consequently be emitted from tailpipes in the United States, which contributes to improved public health and welfare.

Before such major societal benefits can be realized, PHEVs and other highly efficient vehicles (e.g., EVs, fuel cell vehicles) must comprise a significant portion of the LDV fleet. Currently, petroleum-dependent conventional drive ICEs overwhelmingly dominant vehicle sales in the United States, and millions are likely to remain on U.S. roads for years to come. HEV sales are projected to ramp up considerably between now and 2020, which will help diminish future sales of conventional drive ICEs, but it will simply take time to phase in PHEVs and other advanced vehicles that are capable of making a major impact in U.S. fuel savings and GHG emissions. Therefore, in the near term, these savings will be primarily reliant on fuel economy improvements mandated in conventional drive ICEs.

[4] "Plug-in Hybrid Electric Vehicle Value Proposition Study: Interim Report," ORNL/TM-2008/076, Sentech, Inc., January 2009.



PHEV Projected Cumulative Sales Units
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CPC Plus Increased Charging Infrastructure - City & Suburb
CPC Plus PHEV Federal Fleet Mandates

1. INTRODUCTION

The Plug-in Hybrid Electric Vehicle (PHEV) Market Introduction Study seeks to identify policy drivers that have the most potential for significantly boosting near-term sales of PHEVs with the least cost of implementation. This goal aligns with President Obama's recent call for 1 million plug-in hybrid cars to be on the road by 2015,[5] which may be achievable by not only offering incentives for consumers to buy the vehicles, but by also persuading vehicle manufacturers to accelerate near-term production capacity plans to meet demand potentially created by these incentives.

The PHEV Market Introduction Study is a supplement to the PHEV Value Proposition Study[6], which concluded that PHEVs possess enough advantageous qualities to be competitive with conventional vehicles and hybrid electric vehicles (HEV) by 2030. This is due in large part to the significant operating cost reductions and improved convenience achieved by substituting less expensive electricity for the majority of gasoline use. In addition to reduced fuel costs, PHEVs demonstrate lower total lifecycle cost, reduced greenhouse gas (GHG) emissions, and many unique attributes (e.g., emergency backup power, mobile power, potential battery recycling credit, etc.).

Given the conclusion that a viable business case exists for PHEVs, focus is now directed toward developing a plan to successfully and efficiently accelerate the introduction of these vehicles into the market. Collaboration among Oak Ridge National Laboratory (ORNL), Sentech, Inc., the University of Michigan Transportation Research Institute (UMTRI), and Pacific Northwest National Laboratory (PNNL) has led to the identification and assessment of how potential policies, regulations, and temporary incentives can be key enablers for a successful PHEV market debut. For each mechanism studied, the project team presents

- concept(s) for implementation,
- alleviated market and technological pinch points,
- recommended timeframe for implementation and phase out,
- projected reductions in petroleum-based fuel, and
- required revenue to initiate and sustain the incentive program.

Two consumer choice models, described in Chapter 3, were utilized in this study to help quantify the potential effectiveness of the investigated policies. Each model is designed to project PHEV market penetration using a unique approach (e.g., agent-based vs. market-based models). In each model, PHEVs with varying all-electric ranges (AER) compete for market share against a variety of powertrains including conventional vehicles, diesels, and HEVs. Based on results from these models, a consensus strategy has been developed, aimed at transitioning what begins as a niche industry into a thriving market by 2030.

[5] Obama-Biden Energy and Environment Agenda.
[6] Visit www.sentech.org/phev for information, publications, and future work related to this study.

2. OBJECTIVE

The primary objective of the PHEV Market Introduction Study is to identify the most effective means for accelerating the commercialization of PHEVs in order to support national energy and economic goals. Ideally, these mechanisms would maximize PHEV sales while minimizing capital and federal expenditures. To develop a robust market acceleration program, individual incentives and policies must be examined in light of

- clarity and transparency of the market signals they send to the consumer,
- expenditures and resources needed to support them,
- expected impacts on the market for PHEVs,
- incentives that are compatible with and/or supportive of each other,
- complexity of institutional and regulatory coordination needed, and
- sources of funding.

The goal is to develop an integrated set of federal, state, and private initiatives that (1) complement each other to increase the market share of PHEVs and (2) are consistent with other national energy, economic, and security programs. Chief among these are national initiatives to stimulate the economy, increase energy security, and reduce carbon emissions. Expanding the demand for innovative, more environmentally friendly vehicle technologies will create jobs and provide economic justification for the retooling and infrastructure investments needed to transform the U.S. vehicle industry.

PHEVs have the potential to significantly reduce the nation's reliance on imported petroleum. The United States currently imports two-thirds of its oil consumed annually,[7] but widespread use of PHEVs is projected to significantly reduce these imports. Improving energy independence would greatly enhance national security and is a high priority for the U.S. government. Domestic manufacturing and sales of advanced transportation technologies, such as PHEVs and their components, will also promote economic growth and security. Therefore, market growth of PHEVs is fully consistent with national policy.

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[7] "The World Factbook. United States." Central Intelligence Agency. Last updated on 18 December 2008.

3. Approach

PHEV stakeholders will be tasked with persuading consumers to modify driving behavior and possibly pay an initial price premium in exchange for much greater fuel efficiency and, therefore, long term financial savings. Traditionally, policies, regulations, and temporary incentives have proven to be key enablers in helping to accelerate consumer adoption of HEVs and alternative fuel vehicles (AFV). To best understand what strategies have been attempted or implemented for these vehicles, a collection of past policies, incentives, and regulations (categorized as federal, state/local, or private), was compiled in a *PHEV Market Introduction Study Pre-Workshop Discussion Paper*.[8] Examples of potential market pinch points that PHEV industry stakeholders may face are also briefly described in this paper.

On December 1-2, 2008, a PHEV Market Introduction Study Workshop was held in Washington, D.C. The first day of the workshop focused on the identification of pinch points likely to have a significant effect on the early stages of PHEV market introduction. On the second day, participants brainstormed policies, incentives, and regulations that could help overcome the identified pinch points. Ideas ranged from the simple expansion of existing policies to include PHEVs (e.g., high-occupancy vehicle lane access) to a "feebate" system that rewards customers for purchasing fuel-efficient vehicles. Workshop findings have been collected and compiled by ORNL and Sentech, Inc. in the report, *PHEV Market Introduction Study Summary of Workshop Results.*[9]

Two separate consumer choice models were used to simulate the market impacts of suggested policies, incentives, and regulations from the Workshop: the Market Acceptance of Advanced Automotive Technologies (MA^3T) Model and the Virtual AutoMotive MarketPlace (VAMMP) Model.

The MA^3T Model simulates competition of PHEVs against several other powertrains by placing values on specific vehicle attributes, consumer cost savings, and predefined market conditions. The MA^3T Model is a demand-driven model with no production capacity restraints incorporated. Therefore, the model may project high sales for a given incentive, even if the supply chain is not capable of producing enough vehicles to meet that demand. A more detailed description of the MA^3T Model can be found in Appendix A.

The VAMMP Model, created through collaboration between UMTRI and PNNL, approaches market penetration projections from an agent-based perspective. In this model, four classes of decision makers – consumers, government, fuel producers, and vehicle producers/dealers – interact with one another and the environment (especially the economic environment) based on their individual needs and/or organizational objectives. Similar to the MA^3T Model, the VAMMP Model does not have production capacity constraints on new vehicles; a predetermined used vehicle market does exist, however. More information on the UMTRI VAMMP Model can be found in Appendix B.

Using insights and recommendations from the PHEV Market Introduction Study Workshop, the two consumer choice models simulated sales of gasoline and diesel internal combustion engine (ICE) vehicles, HEVs, and PHEVs with varying AERs; both passenger cars and light trucks were

[8] Sentech, Inc. et al. "PHEV Market Introduction Study: Pre-Workshop Discussion Paper." November 2008. http://www.sentech.org/phev/pdfs/MIS_Pre-Workshop_Summary_Report.pdf

[9] Sentech, Inc. et al. "PHEV Market Introduction Study Summary of Workshop Results."

modeled. *It should be noted that electric vehicles (EVs) were not included in this study. Given the recent announcements by certain OEMs to aggressively pursue this vehicle platform, it is likely that EVs could displace a portion of HEV or PHEV projected sales in both the current policy case and the additional policy options investigated in Chapter 6*.

To establish a baseline for PHEV sales through 2020, a "current policy case" was created and used in this study to demonstrate what PHEV sales through 2020 would look like if no further funding or legislative action in support of PHEVs was taken beyond the current date. This current policy case accounts for the three major existing PHEV market accelerators:

- The Plug-In Vehicle Tax Credit (ARRA, Sec1141, H.R.1) that offers between $2,500-7,500 in tax credits to consumers, based on battery energy storage capacity[10];
- $2 billion in advanced battery manufacturing grants (ARRA, H.R.1) to domestic automotive, battery, and component manufacturers[11]; and
- $400 million for electric drive vehicles and electrification infrastructure demonstration and evaluation projects (ARRA, H.R.1).

In order for a PHEV to qualify for the minimum Plug-in Vehicle Tax Credit of $2,500, it must have a battery capacity exceeding 4 kWh, which equates to an AER of roughly 12 miles. Since it is unlikely that any manufacturer will choose to build a PHEV in the near term that does not qualify for the tax credit, a PHEV-12 was chosen as the base PHEV model. No additional PHEV-related policies, incentives, or regulations are included in the current policy case. Existing federal policies related to HEVs, however, are assumed to be in place through their anticipated phase-out periods.[12]

[10] Established in Emergency Economic Stabilization Act of 2008; modified and extended in ARRA.
[11] Originally authorized but not funded under the Energy Independence and Security Act of 2007, Section 135.
[12] Hybrid Motor Vehicle Credit, Energy Policy Act of 2005, Section 1341.

4. KEY MARKET PINCH POINTS

One segment of this study is to identify potential pinch points in which small supply or industry deficiencies could lead to potentially large barriers to market success. Such pinch points may exist in technology readiness, supply chain insufficiencies, infrastructure development, and attainment of the necessary workforce. This chapter highlights what workshop participants believed to be the most probable pinch points that must be addressed to ensure a seamless introduction for PHEVs.

4.1 Supply Chain Insufficiencies

Achieving ample production of affordable PHEV batteries may be the single greatest challenge to large-scale commercialization of PHEVs over the next decade. In order to produce batteries that meet the required standards of durability, quality, and safety at a reasonable cost, many issues of the battery industry must be addressed. These issues include (but are not limited to) technology maturation, increased domestic production, raw material availability, and market readiness.

Today, the United States relies heavily on foreign battery production. An increase in domestic production capacity of batteries and other critical components for PHEVs is necessary to reduce this reliance and establish a secure national supply. Measures should continue to be taken to ensure that dependence on foreign oil is not substituted with dependence on foreign batteries. Likewise, automotive original equipment manufacturers (OEM) may not be fully prepared to mass produce PHEVs and other electric vehicles domestically. For those that may be capable of introducing PHEVs on schedule, it could be years before profits are seen on these vehicles.

OEMs with plans to mass manufacture PHEVs are faced with the considerable task of retooling their older facilities to accommodate differences in the manufacture and assembly of these vehicles or building new manufacturing sites. Relationships with new suppliers, possibly with limited automotive industry experience, must also be established as production rates of some early technologies may need to be ramped up quickly to meet demand.

Raw materials needed for steady production of PHEVs must also be secured. The increased demand for lithium-ion (Li-ion) batteries for use in electronics (e.g., laptops, cell phones) has raised the question as to whether a sufficient international supply will be available as the market for electric vehicles, including PHEVs, grows. Some experts believe that if lithium prices continue to rise at a steep rate, the production cost of PHEVs and other electric vehicles will consequently increase.[13] Other research indicates that the international lithium supply will not be significantly strained until 2050.[14] Potential shortages in rare earth permanent magnet materials commonly used in power electronic and electric motor components may also compromise supply and increase vehicle cost.

As previously mentioned in Chapter 3, $2.4 billion in American Recovery and Reinvestment Act (ARRA) funding was recently awarded to 48 advanced battery and electric drive projects to further accelerate the domestic manufacturing and deployment of electric vehicles, batteries, and components, which will be instrumental in addressing the existing supply chain insufficiencies highlighted above. The current policy case used in this study accounts for this funding.

[13] "Electric Cars and Lithium Reserves: Only Enough for 1.5 Million Chevy Volts?" GM-Volt Website. Nov 1, 2008.
[14] Gaines, Linda. "Potential Demand for Lithium in Automotive Batteries." Argonne National Laboratory. Dec 4, 2008.

4.2 Infrastructure Readiness

The introduction of PHEVs into the marketplace presents new infrastructure challenges, which will affect most industry stakeholders to some degree. While a smart grid may not be essential to PHEV operation in the near term, the availability of simple and seamless PHEV charging equipment and practices in time for first generation PHEVs would be extremely beneficial. Smart grids, which include sensors and controls to manage PHEV charging and discharging, and infrastructure to support interconnection at locations throughout the grid, would eventually allow utilities and customers to maximize the benefits of PHEV technology by strategically managing bidirectional electricity flow between the vehicle and the grid. For example, smart chargers would know to charge the PHEV during non-peak hours when billing rates are lowest and could also permit electricity flow back to the grid during peak hours via vehicle-to-grid capabilities. Smart meters could also create value by differentiating electricity used for charging a PHEV and other household appliances. Therefore, consumers can quantify the amount of electricity substituted for gasoline, which could return value to the consumer in some policy cases.

According to a recent presentation by General Motors,[15] the majority of cars in the existing fleet are parked at home at any moment of the day, making residential areas the most obvious candidate location of charging PHEVs, especially since most owners are expected to charge overnight at their homes. According to the Energy Information Administration, just over half of all U.S. households have a house with a garage or carport where vehicles could be charged on the owner's property; approximately one-fifth of households have a house with no garage or carport. The remaining one-quarter of U.S. households are located in apartments or condominiums where charging capabilities may or may not be accessible by the tenant.[16]

Many residential garages or carports are also readily equipped with the basic infrastructure needed to charge a PHEV – electrical outlets. However, electrical codes may require a separate circuit dedicated to charging plug-in vehicles, which may involve additional wiring or panel upgrades. (This is especially true if the owner prefers 240V, or "Level II," charging capability.) Today, a significant waiting period and financial investment is associated with these upgrades, which may be viewed as a hindrance by some potential PHEV buyers. A plan to fast-track the permitting and installation period must be pursued to minimize this inconvenience to the consumer.

Apartment buildings/complexes often have designated parking for their tenants, but very few are currently equipped to offer charging to PHEVs or other electric vehicles. Without adequate installation of publicly- or privately-owned charging stations in residential areas to recharge PHEVs overnight, many potential consumers (potentially one-quarter of the market) will be less interested in purchasing a PHEV since reliable charging is unavailable where their vehicle is most often parked.

Likewise, very few businesses, which may include the PHEV owner's workplace or frequented retail shopping centers, are currently equipped with the charging infrastructure required to offer PHEV recharging in their parking areas. Businesses, where the average vehicle is parked most

[15] "The CO_2 Benefits of Electrification: E-REVs, PHEVs and Charging Scenarios." Society of Automotive Engineers (SAE) Document Number 2009-01-1311. Presented at SAE World Congress & Exhibition, April 2009.
[16] Table HC1-4a. Housing Unit Characteristics by Type of Housing Unit, Million U.S. Households, 2001. Residential Energy Consumption Survey 2001. Energy Information Administration, U.S. Department of Energy.

often besides home, may choose to offer free charging and/or have a charging station installed by a third party as a method to promote sales or satisfy employees. However, in cases where businesses choose to charge employees or customers for plugging into a station, communications between the charger and the utility would be necessary to authorize and bill PHEV owners.

Standards for interoperability, grid interface, communications protocols, and components must also be in place to provide optimal interaction between PHEV owners and the utilities. Auto OEMs will also need to abide by set standards to ensure that their vehicles have a universal plug capable of charging at any station. Similarly, utilities and charging station manufacturers must also ensure that one charger design is compatible with most vehicle designs.

To help accelerate charging infrastructure needs, a large portion of the ARRA funding has been allotted to the deployment of Level II and Level III charging stations in select markets across the nation. The increased presence of these chargers will help provide assurance to PHEV owners who may not currently have access to consistent charging, reduce charging anxiety along major U.S. interstate corridors, and encourage businesses to offer charging to employees and customers in the near future. Eventually, the presence of these charging stations must expand to cover other major population areas as PHEVs enter the marketplace.

4.3 Consumer Education and Workforce Training

Several new and unfamiliar characteristics associated with owning and operating PHEVs may leave some customers reluctant to purchase them initially. When almost any new product hits the market, the majority of consumers wait to observe how well the product truly performs (in this case, battery safety and durability will be closely observed) and how pleased the early adopters appear to be with their purchases before they actually choose to buy. Sales of first generation PHEVs are likely to show similar trends.

Without a near-term effort to educate potential customers about the benefits of PHEVs, many individuals may not be comfortable purchasing one, given the perceived differences from conventional vehicles and HEVs, in addition to the purchase price premium. Individuals will need information on key metrics such as fuel economy, range, and charging requirements so they will be more likely to opt for a PHEV once they are available for purchase. Simple comparison of PHEVs to conventional vehicles and HEVs will also be beneficial. By the time PHEVs are commercially available, individuals should understand that PHEVs may have a higher initial purchase cost, but over the life of the vehicle, they are the financially responsible choice and offer greater contributions to national security and the environment.

Consumers may also believe that battery replacement in a PHEV will be similar to that of a lead-acid battery in a conventional vehicle. PHEV batteries are expected to be designed to last the entire life of the vehicle, while most conventional batteries are generally warranted three to seven years. Given the high cost of PHEV lithium-ion batteries, potential consumers will likely demand a warranty of some kind to insure themselves against their battery's failing prematurely.

The market transition from conventional to plug-in vehicles will likely present the auto industry with substantive changes to auto manufacturing and maintenance practices. To help prepare for these industry adaptations, the educational system may need to accelerate the transition by training

increased numbers of electrical engineers and technicians skilled in servicing the batteries and electrical systems that will be introduced in future PHEV powertrain and charging systems. In addition to needed manpower, diagnostic equipment specific to PHEV operating systems will be necessary to properly service these vehicles. Technicians and engineers, in addition to PHEV repair and service locations, will need to be certified in order to service PHEVs, while avoiding any issues that could potentially tarnish the public's perception of PHEVs early in the market introduction phase.

4.4 Price of Gasoline

The price of gasoline will likely have a significant influence on PHEV market penetration. Historical trends show that as gasoline prices rise, the proportion of passenger car sales to total vehicle sales also increases (when compared to sales of light trucks and sport utility vehicles [SUV]). This is evidence of consumers opting for more fuel-efficient vehicles to cut down on operating costs, as shown in Figure 1.[17] Likewise, as gasoline prices drop, the sense of urgency fades and consumer interest in less efficient light-duty trucks and SUVs returns. The most fruitful market for PHEVs would likely occur if gasoline prices were consistently high and expected to remain high or increase further, translating to more financial savings to the consumer. However, if gasoline prices continue to decline, interest in high efficiency vehicles, such as PHEVs, is likely to fade to some extent as well. Significant gasoline price volatility alone may be a motivator for PHEV purchases because of consumer aversion to unpredictable energy costs.

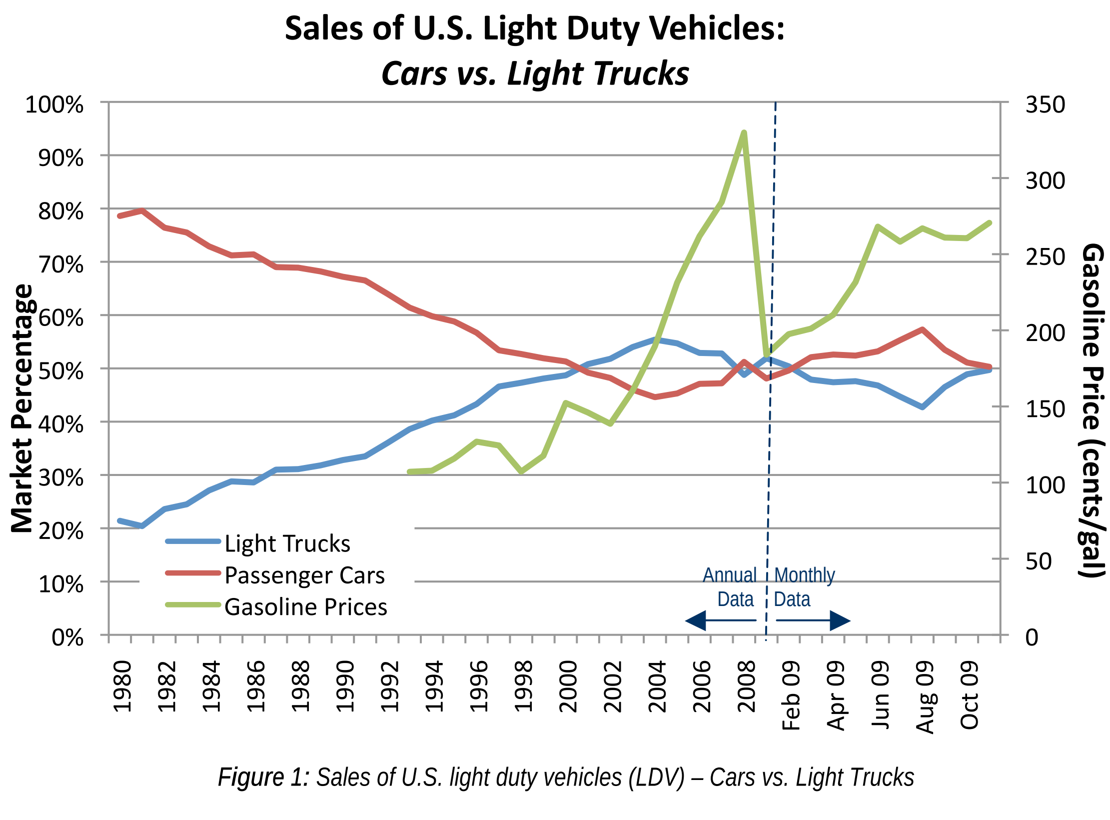

Figure 1: Sales of U.S. light duty vehicles (LDV) – Cars vs. Light Trucks

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[17] Energy Information Administration. Average Gasoline Retail Prices (all grades, all formulations); Ward's Automotive Data; Transportation Energy Data Book Ed 27-2008 Table 4.6.

5. Current Policy Case

Participants of the PHEV Market Introduction Study Workshop held in December 2008 identified over 75 policies, incentives and regulations of which nine were believed to have the most potential for boosting PHEV sales over the next 10 to 20 years. This chapter first defines the current policy case and then investigates the overall effect that the top nine mechanisms have on the vehicle market. Each investigation will include an explanation of how pinch points are alleviated, a possible concept for implementation, a recommended timeline, the estimated cost of implementation, and projected reductions in petroleum-based fuel use. Market impact analyses generated from both the MA^3T Model and the PNNL/ UMTRI's VAMMP model are used to project increases in future sales (if any) resulting from each studied mechanism. Potential sources of funding are presented in Chapter 7. Organizations which could have a role in implementing the various initiatives are discussed in Chapter 8.

Existing federal policies have the potential to result in approximately 1 million PHEVs on the road by 2015 at an average government investment of $5,000 per vehicle sold. Between 2015 and 2020, PHEV sales are projected to be sustainable without requiring federal aid.

As previously mentioned, the "current policy case" (CPC) provides a baseline in this study, accounting for:

- The Plug-In Vehicle Tax Credit (ARRA, Sec1141, H.R.1) that offers between $2,500-7,500 in tax credits to consumers, based on battery energy storage capacity[18],
- $2 billion in advanced battery manufacturing grants (ARRA, H.R.1) to domestic automotive, battery, and component manufacturers[19], and
- $400 million for electric drive vehicles and electrification infrastructure demonstration and evaluation projects (ARRA, H.R.1).[20]

No additional PHEV-related policies, incentives, or regulations are included in the current policy case. Existing federal policies related to HEVs, however, are assumed to be in place through their anticipated phase-out periods.[21] Market impacts of both passenger car and light truck PHEVs are assessed in the models, and the total market share for PHEVs is broken down into PHEV-12s, -20s and -40s. <u>*It should be noted that the models used to project future sales are driven purely by consumer demand and do not incorporate production capacity restraints.*</u>

The current policy case was modeled assuming the "high technology" option within the MA^3T Model. This option assumes PHEV R&D is continued and is successful, such that the component and vehicle costs drop rapidly. The alternative to this is the "low technology" case which presumes less investment and success in R&D, resulting in a slower decline in vehicle costs. In fact, the "low technology" case it projected to resemble what PHEV sales would look like if the aforementioned $2 billion in advanced battery manufacturing grants were never allocated.

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[18] Established in Emergency Economic Stabilization Act of 2008; modified and extended in ARRA.
[19] Originally authorized but not funded under the Energy Independence and Security Act of 2007 (EISA), Section 135.
[20] As authorized in EISA, Section 131.
[21] Hybrid Motor Vehicle Credit, Energy Policy Act of 2005, Section 1341.

Major characteristics of the "high technology" and "low technology cases for each of the vehicle types competing in the MA³T Model are presented in Tables 1 and 2, respectively, for selected years. As previously mentioned, EVs were not included in the study, but as they become commercially available, they may account for a portion of HEV or PHEV sales. More detailed data are provided in Appendix A.

Table 1: Summary of powertrains simulated in the MA³T Model, using the "high technology" case.

	RETAIL COST		FUEL ECONOMY (mpgge)		BATTERY SIZE (kWh)	
PASSENGER CARS	2015	2020	2015	2020	2015	2020
Gasoline SI ICE	$21,600	$21,527	35.2	36.7	-	-
Diesel CI ICE	$24,411	$24,570	46.4	48.9	-	-
Gasoline HEV	$21,829	$21,632	72.2	75.9	1.0	1.0
Advanced Gasoline SI ICE	$21,783	$21,611	52.4	54.6	1.0	1.0
Gasoline PHEV-12	$23,649	$23,132	78.9	82.3	4.1	4.0
Gasoline PHEV-20	$24,879	$24,173	84.1	87.8	5.6	5.4
Gasoline PHEV-40	$27,957	$26,776	97.2	101.6	11.1	10.6
LIGHT TRUCKS	2015	2020	2015	2020	2015	2020
Gasoline SI ICE	$22,134	$22,040	27.8	28.8	-	-
Diesel CI ICE	$25,789	$26,200	35.9	37.4	-	-
Gasoline HEV	$22,528	$22,292	50.6	52.4	1.2	1.1
Advanced Gasoline SI ICE	$22,449	$22,241	41.4	42.9	1.1	1.1
Gasoline PHEV-12	$25,120	$24,497	55.3	57.1	5.0	4.9
Gasoline PHEV-20	$26,798	$25,927	58.7	60.6	7.6	7.5
Gasoline PHEV-40	$30,990	$29,501	67.2	69.4	15.1	14.7

Table 2: Summary of powertrains simulated in the MA³T Model, using the "low technology" case.

	RETAIL COST		FUEL ECONOMY (mpgge)		BATTERY SIZE (kWh)	
PASSENGER CARS	2015	2020	2015	2020	2015	2020
Gasoline SI ICE	$22,086	$22,287	34.0	33.9	-	-
Diesel CI ICE	$25,168	$25,194	44.2	44.4	-	-
Gasoline HEV	$24,903	$23,756	60.2	62.3	1.0	1.0
Advanced Gasoline SI ICE	$23,008	$22,947	50.7	50.5	1.1	1.0
Gasoline PHEV-12	$23,702	$24,834	65.6	68.0	4.3	4.1
Gasoline PHEV-20	$26,062	$26,582	70.2	72.7	6.8	6.6
Gasoline PHEV-40	$30,063	$30,461	81.7	84.5	13.6	13.1
LIGHT TRUCKS	2015	2020	2015	2020	2015	2020
Gasoline SI ICE	$22,836	$23,043	26.4	26.3	-	-
Diesel CI ICE	$26,350	$26,389	34.2	34.2	-	-
Gasoline HEV	$25,329	$24,169	43.7	44.7	1.2	1.2
Advanced Gasoline SI ICE	$23,881	$23,805	39.3	39.2	1.2	1.2
Gasoline PHEV-12	$26,203	$26,771	47.7	48.7	5.6	5.4
Gasoline PHEV-20	$29,427	$29,138	50.7	51.7	9.0	8.7
Gasoline PHEV-40	$35,551	$34,362	58.2	59.3	18.3	17.8

As shown in Figure 2, PHEV sales under the "low technology" case are significantly decreased compared to the "high technology" case. For the subsequent analysis shown in this report, only the "high technology" case is considered.

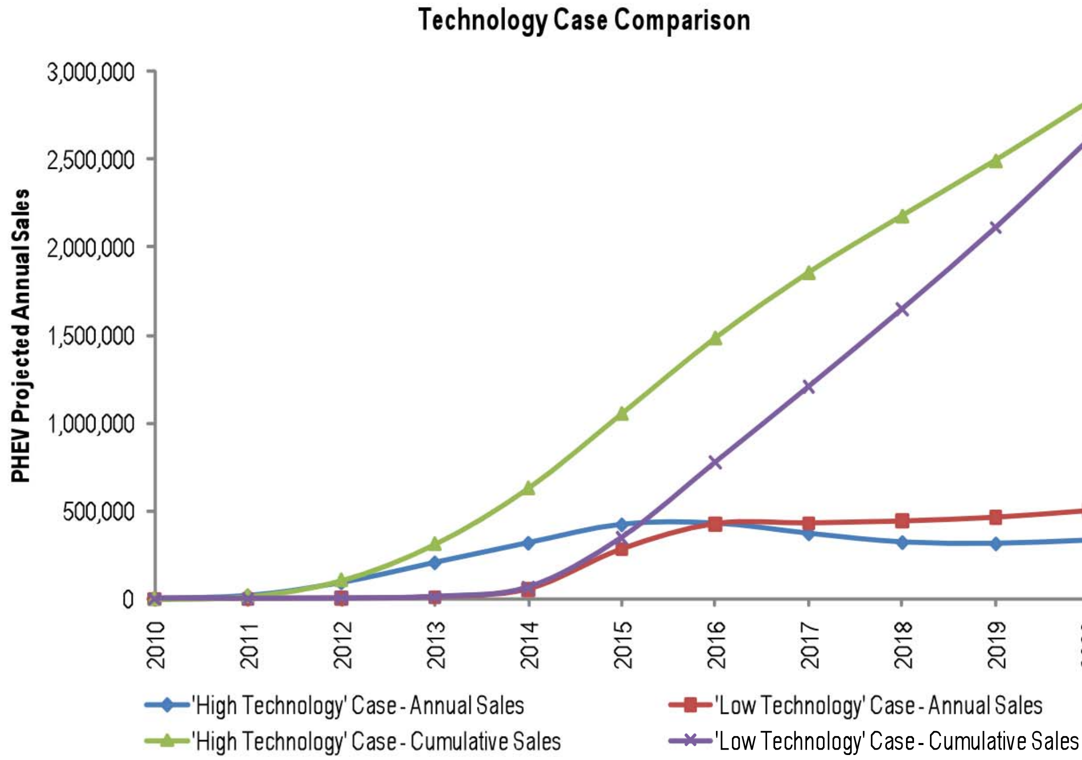

Figure 2: *Annual and cumulative PHEV sales using the MA3T Model's "low technology" and "high technology" cases.*

Figures 3 and 4 show the projected annual and comprehensive PHEV sales through 2020 by AER, using the MA³T Model, which estimates PHEV annual sales under the "high technology" case to quickly ramp up to 425,000 PHEVs sold in 2015, comprising approximately 2.5% of all new light duty vehicle (LDV) purchases in that year. After 2015, PHEV annual sales experience a moderate down slope since the federal tax credit is anticipated to phase out in this timeframe, once each manufacturer has sold 200,000 qualified plug-in electric vehicles for use in the United States. PHEV sales gain more traction in 2018 as the technology become more mature and purchase prices continue to decrease naturally. In 2020, PHEVs are projected to account for 1.6% of all new LDV purchases, with approximately 330,000 annual units (Figure 5).

In addition, UMTRI used its agent-based model to simulate an accelerated technology case, comparable to the MA³T Model's "high technology" case, which estimates that, given sufficient upstream support, PHEVs can account for up to 2.6% of annual LDV sales in 2015[22], with a fleet penetration level of 1.0% by this time. This accelerated case represents UMTRI's current policy case in this study, and, it, like the MA³T Model, is comprised of the three policy components listed on page 9. It should be noted that while ORNL has a "high technology" option built into its model to account for accelerated vehicle and component cost reductions, UMTRI used upstream subsidies available to manufacturers and their suppliers to more rapidly drive down production costs and PHEV sticker prices. See Appendix B for details and assumptions on UMTRI's current policy case.

[22] Assuming the same total annual LDV sales used in the MA³T Model.

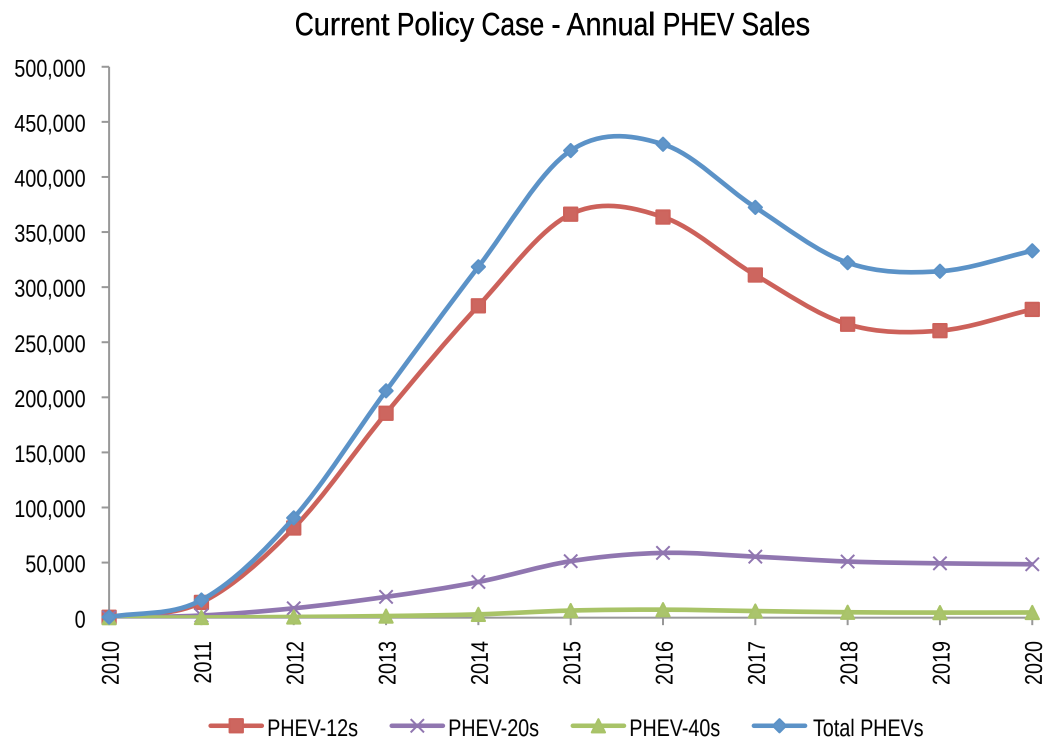

Figure 3: *Projected annual PHEV sales using the MA³T Model, broken down by AER.*

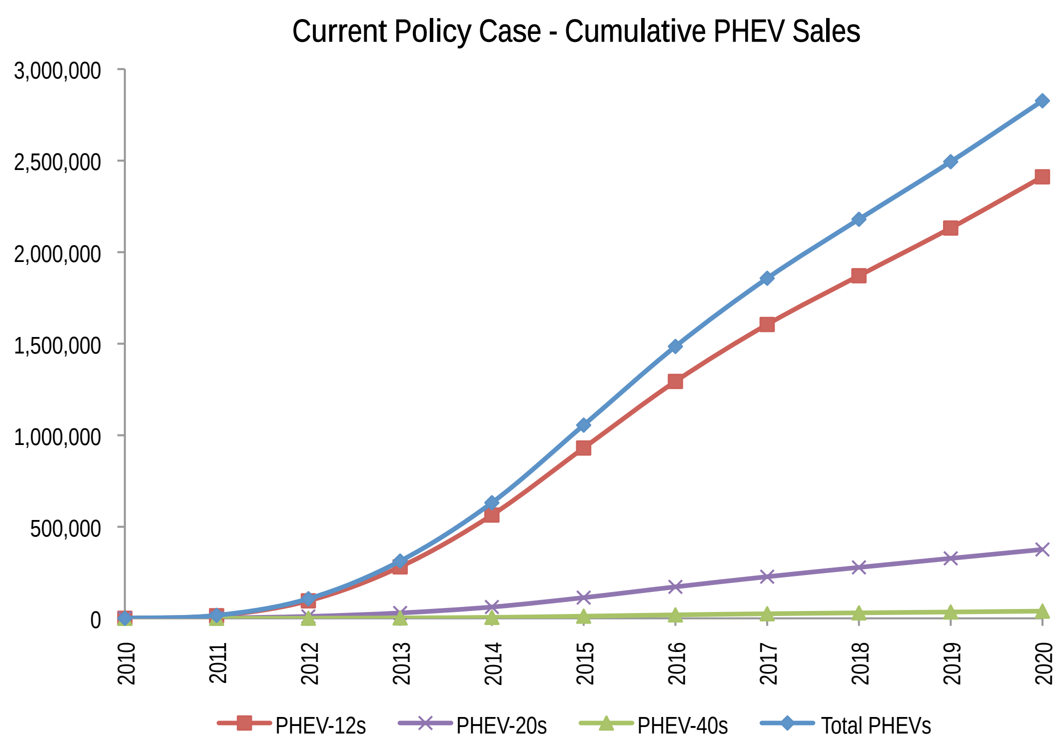

Figure 4: *Projected cumulative PHEV sales using the MA³T Model, broken down by AER.*

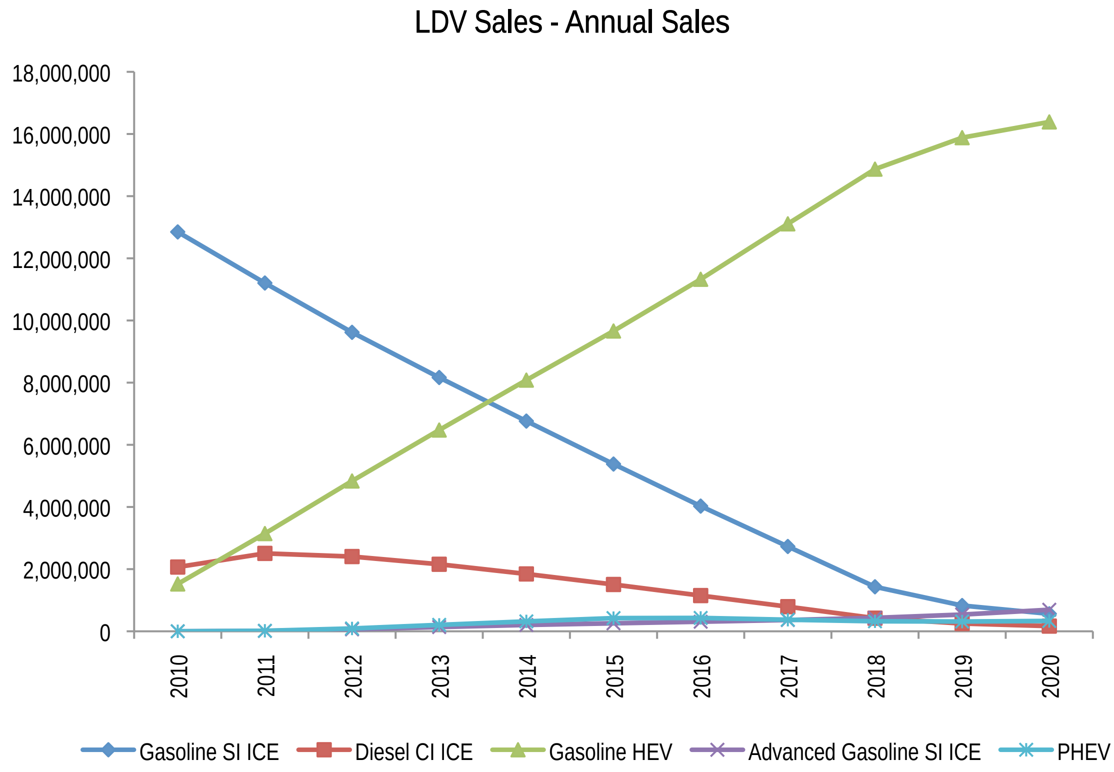

Figure 5: Projected annual LDV sales using the MA³T Model, broken down by vehicle type.

Under ORNL's current policy case ("high technology" case), approximately 1 million PHEVs are expected to be on the road in 2015 with the help of existing federal legislation, according to ORNL model results. Approximately 1.8 million additional PHEVs are projected to enter the market between 2015 and 2020. An estimated federal investment of just over $5 billion, or an average of $5,000 per PHEV sold, will be spent on the 1 million PHEVs that enter the market prior to 2015, which assumes that the $2.4 billion for battery/components investments by DOE is allocated and spent by 2015. PHEV sales between 2015 and 2020 are anticipated to be sustainable without further aid from the federal government. Therefore, an average federal investment per PHEV through 2020 can be calculated by dividing the total federal investment through 2020 ($5 billion) by the total number of PHEVs sold through 2020 (2.8 million units), which results in approximately $1,800 per PHEV. Funds necessary to initiate any supplementary policy programs, which are discussed in Chapter 6, will be in addition to this cost.

Appendices A and B document projected sales as modeled by ORNL's MA³T Model and PNNL/UMTRI's VAMMP Model, respectively, for the policy options analyzed.

6. KEY POLICIES, INCENTIVES AND REGULATIONS

Sections 6.1 through 6.9 investigate the market effects of applying the highest ranking policies from the December workshop in addition to the current policy case. In these sections, only the "high technology" case is considered.

6.1 State Sales Tax Exemption

- *Definition*
  Under this incentive, PHEVs purchasers are exempt from state sales tax. This incentive has previously been applied to the purchase of HEVs and other fuel-efficient vehicles in multiple states to accelerate market introduction and increase sales. Since a sales tax waiver would be implemented at the time of purchase, the consumer would see immediate financial benefits as opposed to end-of-year tax credits.

- *Alleviated Pinch Point(s)*
  By exempting PHEV purchasers from the payment of state sales tax, the total cost to purchase a PHEV becomes more financially competitive with conventional vehicles and HEVs. Consumers may also become more inclined to purchase first-generation PHEVs instead of waiting to learn about experiences of early adopters. When combined with the current policy case, the state sales tax exemption actually reduces the cost of the PHEV-12s to less than the cost of HEVs for the years 2018 through 2020, which contributes significantly to the high PHEV sales in those years.

Implementing a state sales tax exemption can result in an additional 10.4 million PHEVs on the road by 2020 at an average government investment of $1,750 per PHEV sold beyond the current policy case, according to the MA^{3}T Model.

- *Concept for Implementation*
  PHEVs purchased before 2020 would be eligible for an immediate exemption from state sales taxes, which vary from state to state. Some cities have additional sales taxes and may choose to apply the exemption to local sales tax as well. For this study, a 6% tax was used to represent the national average state sales tax. States would likely need to be reimbursed by the federal government, perhaps in the form of funding for transportation infrastructure improvements.

- *Potential Market Impact*
  Figures 6 and 7 show that offering state sales tax exemptions to consumers at the time of purchase could potentially boost PHEV sales significantly between 2012 and 2020, according to the MA^{3}T Model. In fact, MA^{3}T Model results show that applying this incentive in addition to the current policy could potentially accelerate PHEV sales to nearly 2.5 million cumulative units by 2015. Therefore, annual sales in 2015 rise to over double the number of PHEVs sold in ORNL's current policy case of just over 1

million PHEVs. See Appendix A for more detailed information on ORNL's projections for this incentive.

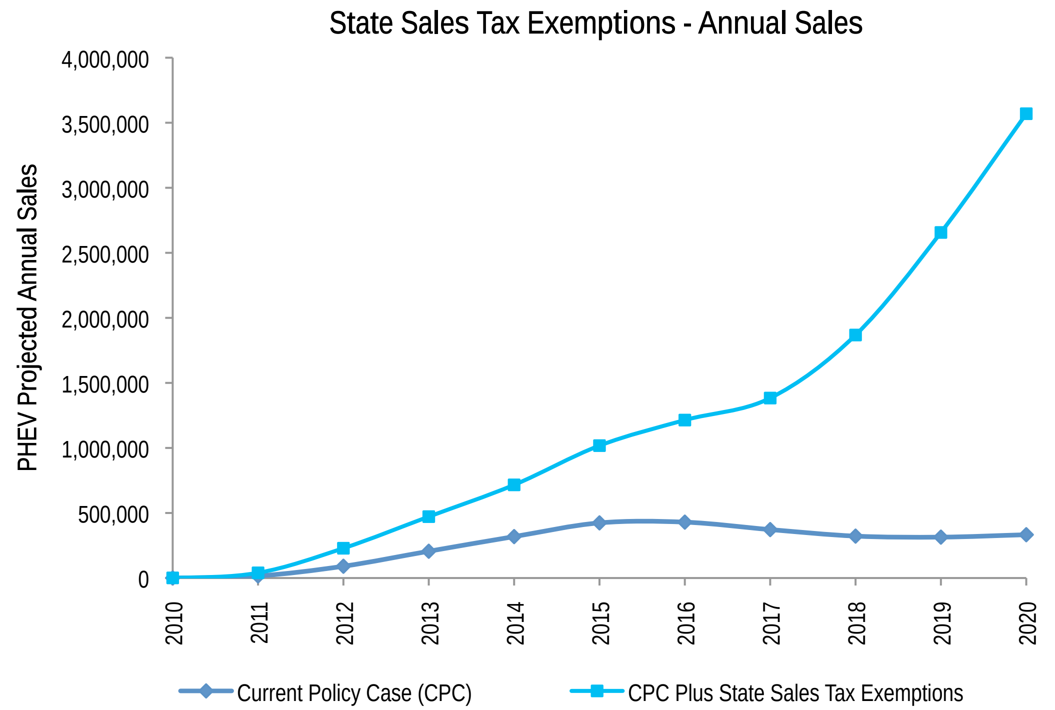

Figure 6: Projected annual sales for state sales tax exemptions (MA³T Model).

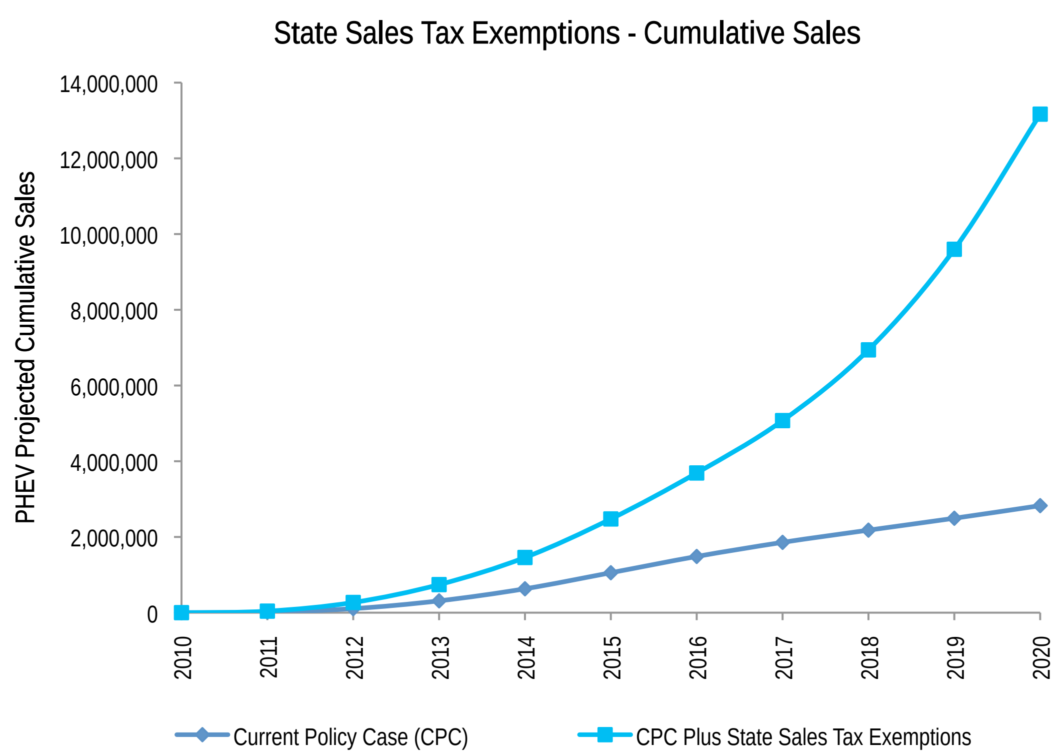

Figure 7: Projected cumulative sales for state sales tax exemptions (MA³T Model).

UMTRI researchers also investigated the market effects of sales tax exemptions on PHEV purchases using the VAMMP model. According to this model, a sales tax exemption superposed onto the current policy case results in a significant boost in PHEV sales. In fact, a 10% increase in fleet penetration and 20% increase in annual sales are projected by 2015, relative to UMTRI's current policy case, if sales tax exemptions were implemented. See Appendix B for more detailed information on UMTRI's projections on this incentive.

- *Estimated Cost of Implementation*
  Applying a sales tax waiver of 6% to each PHEV sold results in an additional 10.4 million PHEVs on the road by 2020 (13.2 million PHEVs sold in all), according to the MA³T Model. To implement this sales tax waiver, an estimated $18 billion in additional state and/or federal funding is required to reimburse each of the additional 10.4 million consumers who consequently buy a PHEV, or an average of $1,750 per PHEV sold beyond the current policy case.

  The estimated federal investment per PHEV to implement sales tax exemption under UMTRI's VAMMP model assumptions is comparable to ORNL's estimate of $1,750. A 6% discount applied to the PHEVs in UMTRI's current policy case ranging from $26,400 to $30,900 (post-manufacturing subsidies) results in an immediate tax exemption between $1,500 and $2,000 to the consumer. See Chapter 7 for information on potential sources of funding for this incentive.

- *Timeframe for Implementation*
  A state sales tax exemption could be implemented between 2010 and 2012 and continued for 5 to 10 years.

6.2 “Feebate” Program

- *Definition*
  In traditional feebate programs, fees assessed for vehicles with undesirable characteristics provide a source of funding for rebates applied to vehicles with desirable characteristics. The purpose of a feebate is to encourage consumers to purchase vehicles with higher fuel economy and lower emissions. Feebate systems can be designed and implemented to achieve a "revenue-neutral" result.

  Commonly, feebate designs consider two key parameters: (1) a rate, specified in dollars per gallons per mile, and (2) a "pivot point," defining the vehicles for which fees are assessed and the vehicles eligible for rebates. The pivot point may be set at a single value, or a range of values could be established within which neither a fee nor rebate applies. With this policy, fees paid by purchasers of low-fuel-economy vehicles would be used to pay the subsidies (rebates) associated with acquisition and use of high-fuel-economy vehicles, including PHEVs. A team of researchers at the University of California is currently performing an in-depth investigation of potential designs, implementation, and benefits of a feebate program for new passenger vehicles in California, with preliminary results expected in fall of 2009.[23]

- *Alleviated Pinch Point(s)*
  A feebate could incentivize auto OEMs to design and manufacture more fuel-efficient vehicles, including PHEVs, even with a continuation of relatively low gasoline prices. Feebates would provide a "market" incentive to increase fuel economy, while a set average fuel economy standard may only encourage auto OEMs to meet the required minimum. On the "demand-pull" side, a feebate could also create more market demand for PHEVs and other highly efficient vehicles by encouraging consumers to consider and purchase vehicles that are eligible for rebates.

- *Concept for Implementation*
  Two options for implementing a feebate policy are presented in this section. In the second of these options, two variants are applied.

  (1) <u>The "Standard Feebate" Option:</u>
  In this option, fees and rebates would be applied based solely on vehicle fuel economy. Using this approach, *PHEVs would not have any special treatment.* At the PHEV Market Introduction Study Workshop in December 2008, several OEMs expressed strong preference that the government not “pick a winner” in technology. They requested incentives for high performance vehicles to be based solely on fuel economy.

  For the “Standard Feebate” Option, rebates for PHEVs would be determined using the same formula applied to all vehicles affected by the application of the feebate system. Consumers desiring a rebate would have many vehicle choices, including PHEVs. As

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[23] Feebates Research Contract: Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California. California Environmental Protection Agency. Page last reviewed February 26, 2009.

a starting point for analysis, the feebate formula could be applied to each of the two vehicle classifications used for determining Corporate Average Fuel Economy (CAFE) standards – cars and light trucks. The pivot point would be the applicable CAFE standard, as shown in Figure 8. For this option, a standard rate of $1,000 per 0.01 gallon per mile (gpm) is used.[24]

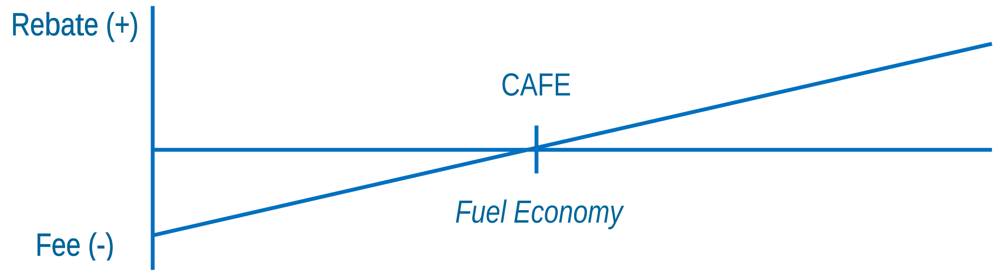

Figure 8: "Standard Feebate" option structure with pivot point at CAFE standard.

While decisions have not yet been made about how the fuel economy of PHEVs will be calculated by the U.S. Environmental Protection Agency, these vehicles are expected to earn high fuel economy ratings. PHEVs with a relatively large AER – say 20 miles or more – will likely have fuel economy ratings significantly higher than the CAFE standard and, therefore, higher than the fuel economy of the average production vehicle as well. Thus, PHEVs would be at the high end of the rebate schedule under a feebate policy that values fuel economy.

(2) The "Progressive Feebate" Option:
With this option, as with the "Standard" option, fees would be assessed on all vehicles that have a lower fuel economy than the applicable CAFE standard. However, rebates would be granted only for vehicles that have a significantly higher fuel economy than the CAFE standard. As a starting point for analysis, only vehicles with a miles-per-gallon (mpg) rating of at least 2 times the CAFE level would be eligible for a rebate. This is illustrated in Figure 9.

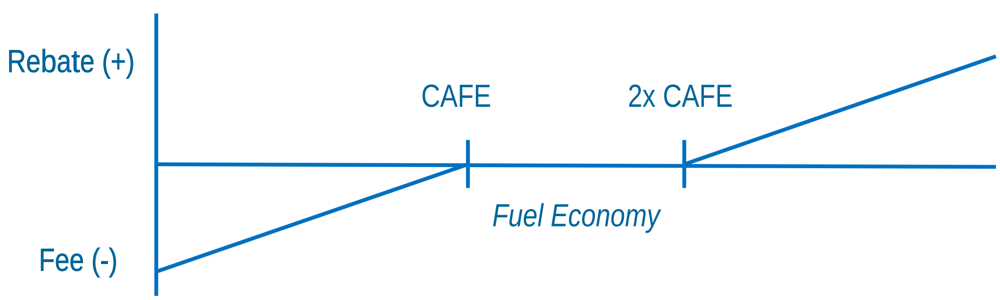

Figure 9: "Progressive Feebate" option structure with staggered pivot point.

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[24] Greene, David L. et al. "Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy." Energy Policy 33 (2005) 757-775.

The Progressive Feebate Option could be tailored to award rebates to either 1) all vehicles with fuel economies exceeding the pivot point or 2) only PHEVs. It is anticipated that few conventional drive vehicles will achieve a mileage rating twice that of the CAFE standard; therefore, PHEVs (and some very lightweight HEVs) would be among the only vehicles that benefit significantly from this option.

In considering and analyzing feebates, ordinarily, separate fee and rebate schedules are determined for each of the two vehicle classifications for which CAFE standards have been established. A variant of this – and the other options presented here – would be to establish separate schedules for a larger number of vehicle classes. With this variant, for example, the 11 LDV weight classes could be used. Thus, a full size sedan would "compete" for rebates only within its own weight class rather than within a set of vehicles that includes compacts and mid-size sedans.

- *Potential Market Impact*

Figures 10 and 11 display the projected sales increases using the MA^3T Model for both the “Standard Feebate” and “Progressive Feebate” options. The Standard Feebate option plot displays the projected market impact if all vehicles with a fuel economy exceeding the CAFE standard (27.5 mpg for cars; 23.5 mpg for light trucks) receive a $1,000 rebate per 0.01 gpm. HEV sales are particularly strong under this policy option since their fuel economy ratings qualify them to receive a favorable rebate. As a result, these HEV sales displaced some of the PHEV sales presented in the current policy case.

The two Progressive Feebate plots, on the other hand, represent the market impact if all vehicles (orange) or just PHEVs (light green) with a fuel economy exceeding 2x CAFE standard receive a $1,000 rebate per 0.01 gpm. Twice the CAFE standards are assumed to be 27.5 mpg X 2 = 55 mpg for cars and 23.5 mpg X 2 = 47 mpg for light trucks. These rebates are balanced by fees placed on conventional vehicles with fuel economies that fall below CAFE. Rates can be adjusted to obtain the desired market impact.

In the “Standard Feebate” option, approximately 1.25 million PHEVs are projected to be on the road by 2015 when combined with existing supportive PHEV policies. This translates to nearly a 20% improvement in sales over the current policy case. Although PHEVs are most generously rewarded in the “Standard Feebate” option, more competition is present since several vehicle types qualify for a rebate of some value. In the “Progressive Feebate” option, however, PHEVs may only have to compete with strong hybrids or no other vehicle types, depending on whether the feebate is set up to provide rebates to all vehicles or only PHEVs. If only PHEVs can receive rebates in the

Implementation of the “Standard Feebate” option combined with the current policy case can result in about 1.25 million PHEVs on the road by 2015, according to the MA^3T Model. Feebate programs are designed to be revenue-neutral.

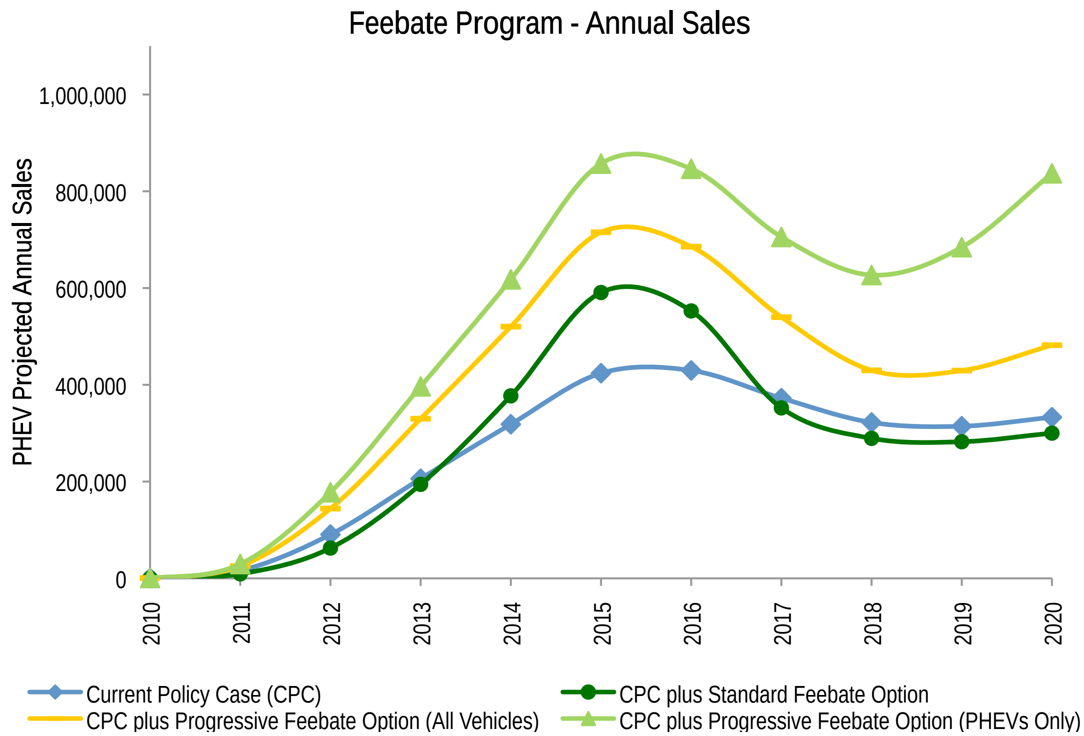

Figure 10: Projected effect of the "Standard Feebate" and "Progressive Feebate" options on annual PHEV sales (MA³T Model), using a rate of $1,000 per gpm.

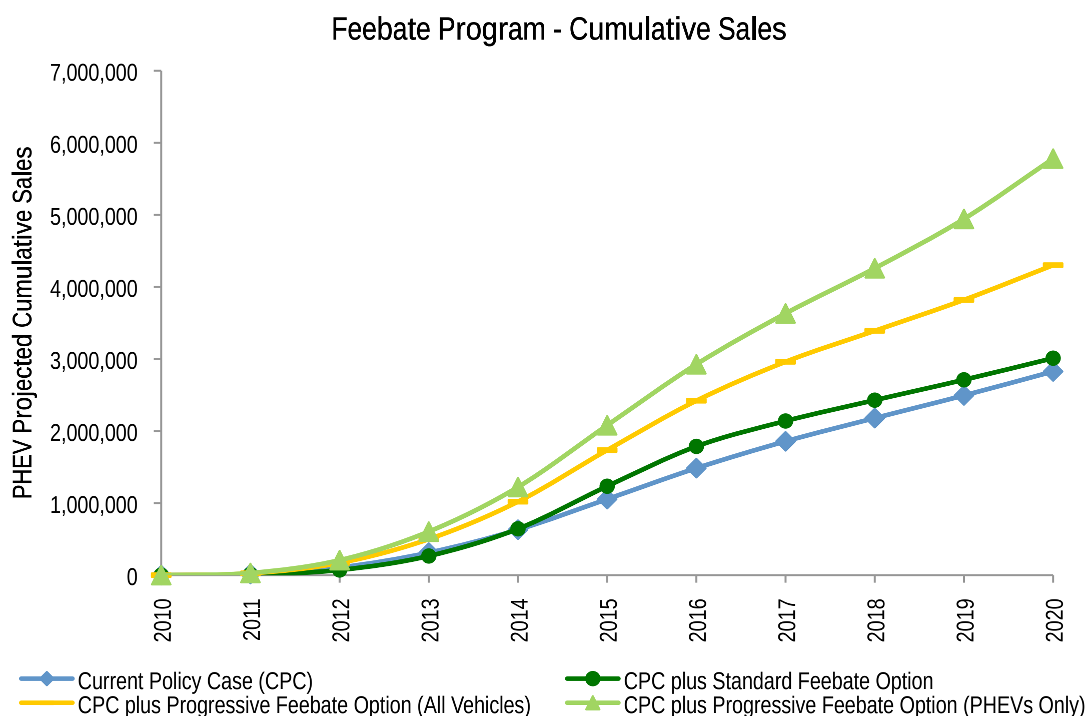

Figure 11: Projected effect of the "Standard Feebate" and "Progressive Feebate" options on cumulative PHEV sales (MA³T Model), using a rate of $1,000 per gpm.

"Progressive Feebate" option, the approximately 860,000 annual and 1.75 million cumulative units are projected for 2015. See Appendix A for more detailed information on ORNL's projections for this incentive.

- *Estimated Cost of Implementation*
  Government expenditures associated with a feebate program should be designed to be cost-neutral to the federal government by selecting rates and pivot points that result in a balance between fees collected and rebates awarded. These rates and pivot points would likely have to be adjusted on an annual basis as nationwide CAFE standards and LDV fuel economies improve.

- *Timeframe for Implementation*
  The feebate initiative could be implemented as soon as model year 2010. However, starting the implementation in model year 2011 or 2012 is probably more practical and would give vehicle manufacturers some time to prepare. The program should be in place for at least six years.

6.3 Annual Operating Cost Allowances

- *Definition*
  An annual operating cost allowance could be designated for registered owners of PHEVs to help cover a portion of their lifetime vehicle ownership costs. This specified annual credit could be applied to nonresidential parking fees, toll fares, registration costs, scheduled maintenance costs, and other vehicle-related operating expenses accrued throughout a consumer's length of ownership.

- *Alleviated Pinch Point(s)*
  Hyundai Motor America has included this type of incentive as part of its recent Hyundai Assurance Program, in which consumers may choose to accept cash back every month for a specified length of time instead of receiving an immediate rebate at the time of purchase. The primary objective of this program is to give consumers peace of mind that future payments may be covered temporarily if their primary source of income is lost. A basic operating cost allowance could offer similar peace of mind for consumers who purchase new PHEVs from the dealers. If annual cost allowances stay with the vehicle (instead of the original purchaser), used PHEV buyers, who do not get an instant rebate or tax credit, could benefit from this approach.

- *Concept for Implementation*
  Annual operating cost allowances could be distributed to registered vehicle owner(s) each year for 10 years beyond the date of purchase. To qualify, PHEVs must be purchased by 2020. OEMs could act as the official distributors of the annual allowances, which would be sent directly to the registered vehicle owner at the current time (not necessarily to the original purchaser). Federal government funds would likely partially, or fully, fund this program.

- *Potential Market Impact*
  Figures 12 and 13 show the projected nationwide effect of offering an annual operating cost allowance to purchasers for new PHEVs through 2020, as simulated in the MA^{3}T Model. In general, annual allowances of $150 or more have the potential to dramatically boost PHEV sales through 2020. In fact, MA^{3}T Model results show that implementing a $150 annual operating cost allowance could potentially accelerate PHEV sales to nearly 6 million cumulative units by 2020, in comparison to roughly 2.8 million cumulative PHEV sales by 2020 under the current policy case.

  Implementing a $150 annual operating cost allowance can result in an additional 3.2 million PHEVs on the road by 2020 at an average government investment of $2,800 per PHEV sold beyond the current policy case, according to the MA^{3}T Model.

  Increased PHEV sales from these allowances imply that consumers place high value on methods to reduce operating costs over the span of vehicle ownership, whether

through credits or rebates allotted to cover all or a percentage of operating costs. See Appendix A for more detailed information on ORNL's projections for this incentive.

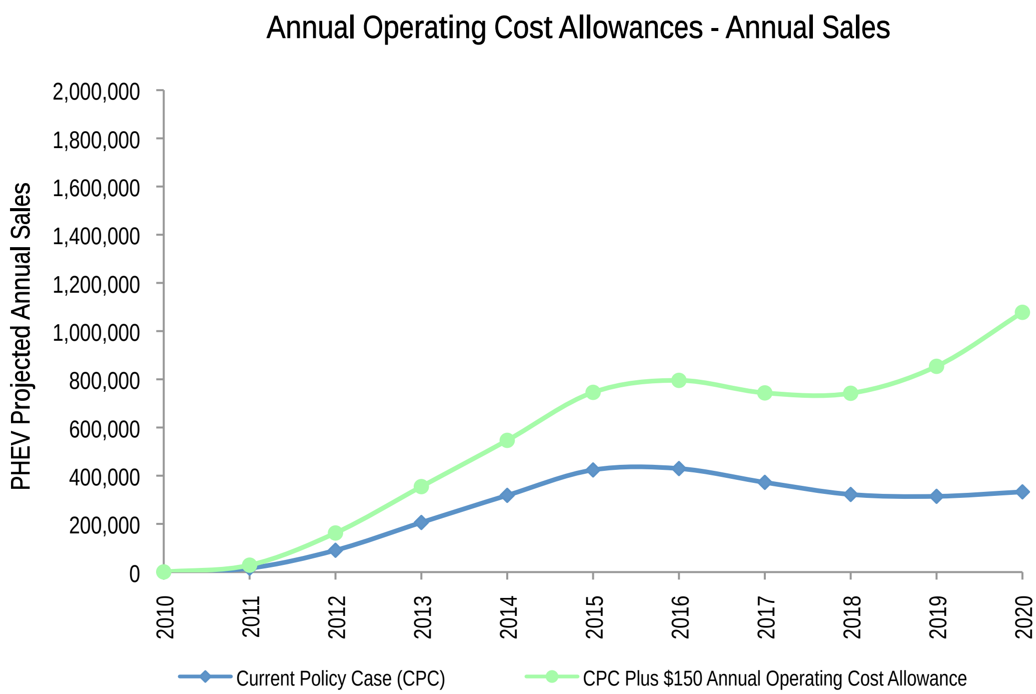

Figure 12: Projected effect of a $150 annual operating cost allowance on annual PHEV sales.

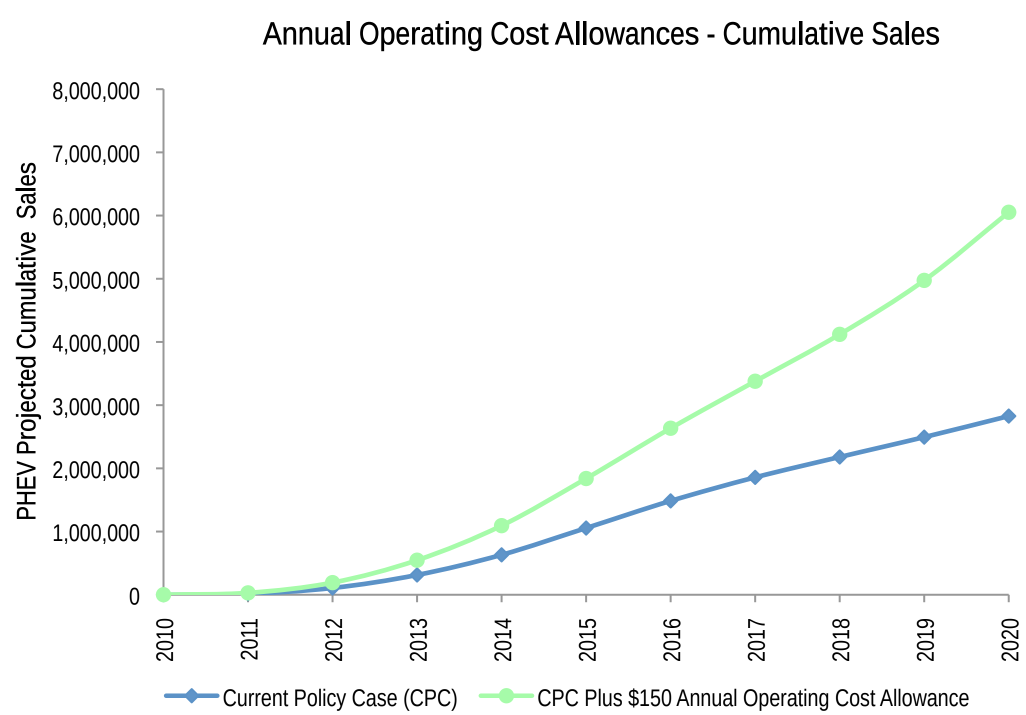

Figure 13: Projected effect of a $150 annual operating cost allowance on cumulative PHEV sales.

- *Estimated Cost of Implementation*
  Implementing a $150 annual operating cost allowance to all PHEV purchasers results in an additional 3.2 million PHEVs on the road by 2020 (6 million PHEVs sold in all), according to the MA^3T Model. To implement this allowance, an estimated $9 billion in additional federal funding is required to reimburse each of the 6 million projected consumers who consequently buy a PHEV, or an average of $2,800 per PHEV sold beyond the current policy case. See Chapter 7 for information on potential sources of funding for this incentive.

- *Timeframe for Implementation*
  Annual operating cost allowances could be implemented between 2010 and 2012. Two different scenarios would be (1) to continue for a set 10 year period (with an optional phase out period) or (2) to allow individual PHEVs bought between 2010 and 2020 to be eligible for allowances for 10 years past the initial purchase, allowing a natural phase-out process.

6.4 Extension of Existing Plug-in Vehicle Tax Credit

- *Definition*
  In this scenario, the Plug-In Vehicle Tax Credit (ARRA, Sec1141, H.R.1) that offers between $2,500-7,500 in tax credits to consumers, based on battery energy storage capacity, would be extended at least through 2020 for all OEMs. Therefore, consumers could continue to take advantage of reduced vehicle prices beyond 2015, which is around the time when the tax credit phases out in the current policy case.

- *Alleviated Pinch Point(s)*
  As demonstrated in Figure 3, a major dip in PHEV sales occurs soon after 2015 in the current policy case because OEMs are expected to approach the sales threshold of vehicles that can receive the tax credit around this time. If the tax credit were extended through 2020, PHEVs would continue to be cost-competitive with conventional vehicles and HEVs, and, as a result, annual PHEV sales would likely increase more linearly throughout their market introduction.

- *Concept for Implementation*
  Congress would first have to agree to extend the tax credit. Extending existing legislation is typically simpler to pass than introducing brand new legislation since it is already in the law. As part of the extension, a new endpoint would need to be established, either by setting a new cut-off date or new sales threshold (total plug-in vehicles sold or a limit for each OEM). A new phase-out strategy must also be created.

- *Potential Market Impact*
  Figures 14 and 15 demonstrate the impact on PHEV sales if the existing Plug-in Vehicle Tax Credit were extended through 2020, according to the MA^{3}T Model. Since the current policy case anticipates the tax credit to last through 2015, incremental sales from the extension only occur between 2015 and 2020. In fact, MA^{3}T Model results show that extending the existing Plug-in Vehicle Tax Credit in the current policy could potentially accelerate PHEV sales to nearly 8.8 million cumulative units by 2020, in comparison to roughly 2.8 million cumulative PHEV sales by 2020 under the current policy case. Annual PHEV sales in 2020 are projected to reach as high as 17.5%.

  Extending the Plug-in Vehicle Tax Credit through 2020 can result in an additional 6 million PHEVs on the road by 2020 at an average government investment of $3,000 per PHEV sold beyond the current policy case, according to the MA^{3}T Model.

  UMTRI model results also demonstrate how extending the Plug-in Vehicle Tax Credit through 2020 would affect PHEV market penetration. With the extension, annual sales could reach up to 4% in 2020 with nearly a 2% fleet penetration by this time. While these projections are less optimistic than ORNL's projections, UMTRI's results still

indicate that consistent growth of PHEV sales through 2020 is achievable by extending the existing tax credit beyond its anticipated phase-out period of approximately 2015.

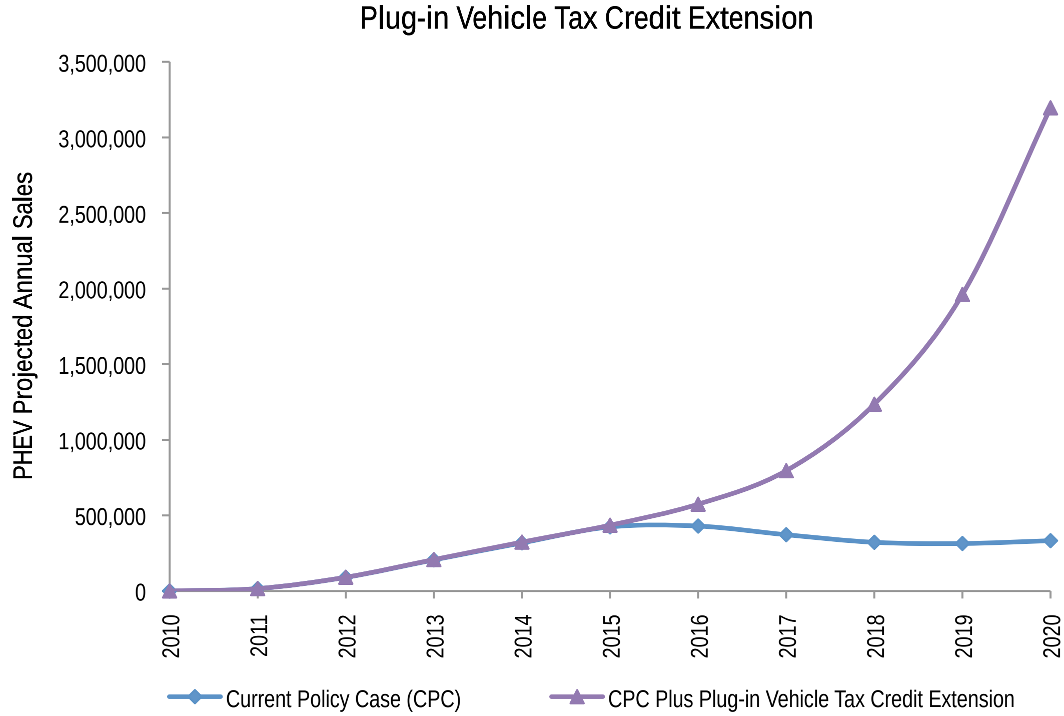

Figure 14: Projected annual sales for Plug-in Vehicle Tax Credit extension (MA³T Model).

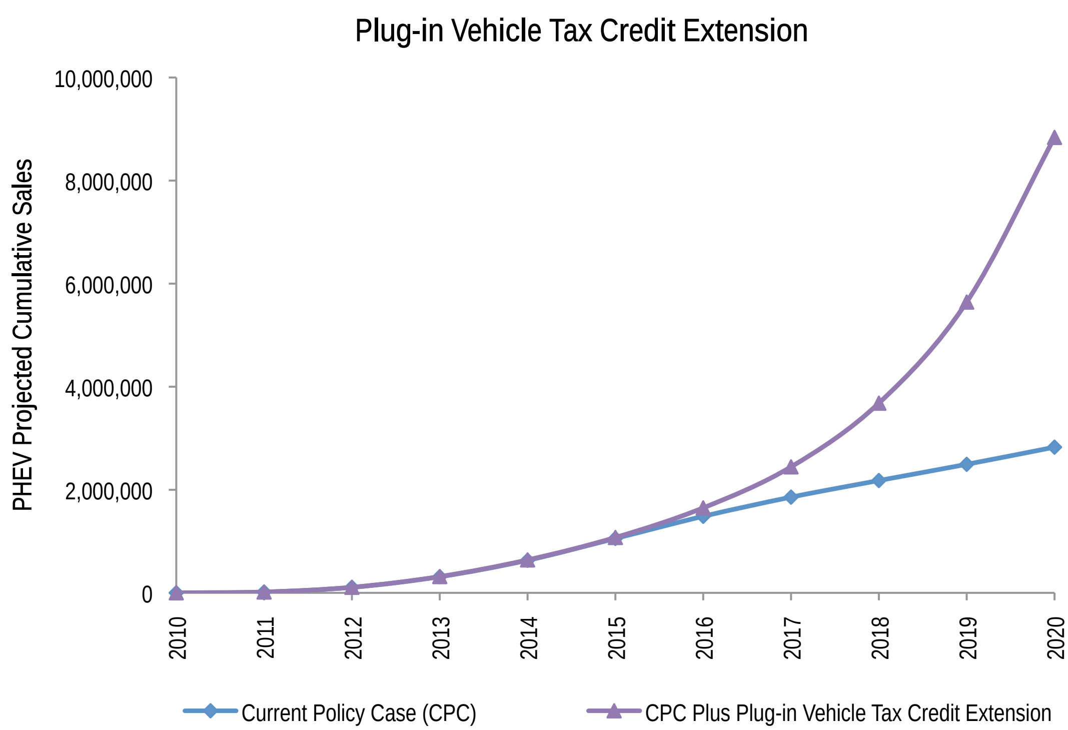

Figure 15: Projected cumulative sales for Plug-in Vehicle Tax Credit extension (MA^{3}T Model).

This incentive has a unique effect in that PHEV-40 passenger car sales between 2015 and 2020 are especially high during this period relative to other policy options investigated in this study with nearly 240,000 units sold in 2020 alone. This is primarily because PHEV-40s have matured significantly by this point, and the price premium over HEVs has narrowed; furthermore, PHEV-40s still qualify for the maximum $7,500 tax credit in this year, increasing their appeal compared to their PHEV-12 and PHEV-20 counterparts. See Appendix A for more detailed information on ORNL's projections.

- *Estimated Cost of Implementation*
  Extending the Plug-in Vehicle Tax Credit through 2020 results in an additional 6 million PHEVs on the road by 2020 (8.8 million PHEVs sold in all), according to the MA^{3}T Model. To implement this extension, an estimated $18 billion in additional federal funding is required to reimburse each of the additional 6 million consumers who consequently buy a PHEV, or an average of $3,000 per PHEV sold beyond the current policy case. See Chapter 7 for information on potential sources of funding for this incentive.

- *Timeframe for Implementation*
  An extension to the existing Plug-in Vehicle Tax Credit could be instated close to 2015, or once the tax credits are nearly exhausted, and extend through 2020.

6.5 Federally-Backed Advanced Battery Warranty

- *Definition*
  A PHEV advanced battery warranty would allow manufacturers and the federal government to share financial risk from batteries that fail prematurely after the PHEV purchase. This warranty may be necessary if the government wishes to expedite the deployment of batteries to help boost consumer confidence.

- *Alleviated Pinch Point(s)*
  By offering to assume a portion of the risk, the federal government will assist battery manufacturers in introducing PHEV batteries into the marketplace sooner than previously anticipated. Consumers will also be assured that they will not be financially responsible for a faulty battery.

- *Concept for Implementation*
  During the first year of production, a reasonable threshold for premature failures should be set. Beyond that threshold, the federal government could be responsible for reimbursing one half (or some other percentage) of the battery replacement cost. As the technology matures over the next decade, failures should decrease, and the government's associated risk should concurrently decrease until it becomes phased out completely.

- *Potential Market Impact*
  The MA^3T Model estimates that, while a battery warranty may be important for creating customer assurance, it will not significantly affect market acceleration of PHEVs (Figures 16 and 17). Approximately 1.2 million cumulative PHEV sales are projected to be sold by 2015 if the federally-backed battery warranty was implemented in addition to the current policy case. Compared to the current policy case with cumulative sales of approximately 1.05 million units, this incentive could only accelerate sales by approximately 10% through 2015.

A federally-backed battery warranty that covers half of premature failures can result in 400,000 additional PHEVs on the road by 2020, according to the MA^3T Model. The average cost per additional PHEV is completely dependent on the actual failure rate of PHEV batteries.

  By 2020, MA^3T Model results show that a battery warranty could potentially accelerate PHEV sales to nearly 3.2 million cumulative units by 2020, in comparison to roughly 2.8 million cumulative PHEV sales by 2020 under the current policy case. See Appendix A for more detailed information on ORNL's projections for this incentive.

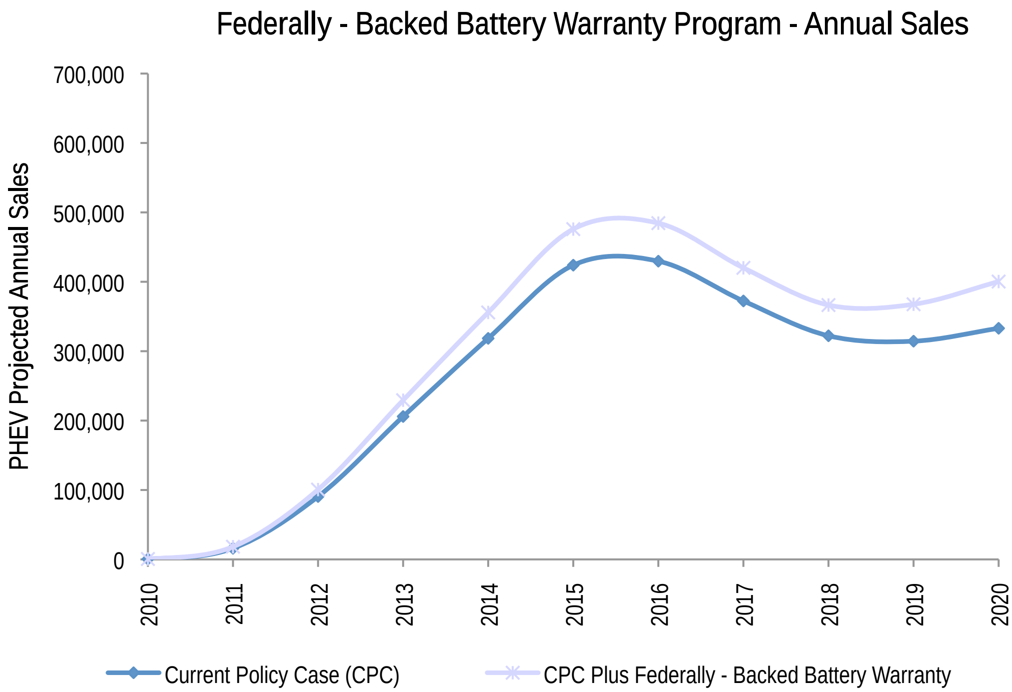

Figure 16: Projected effect of a government-sponsored battery warranty program on annual PHEV sales.

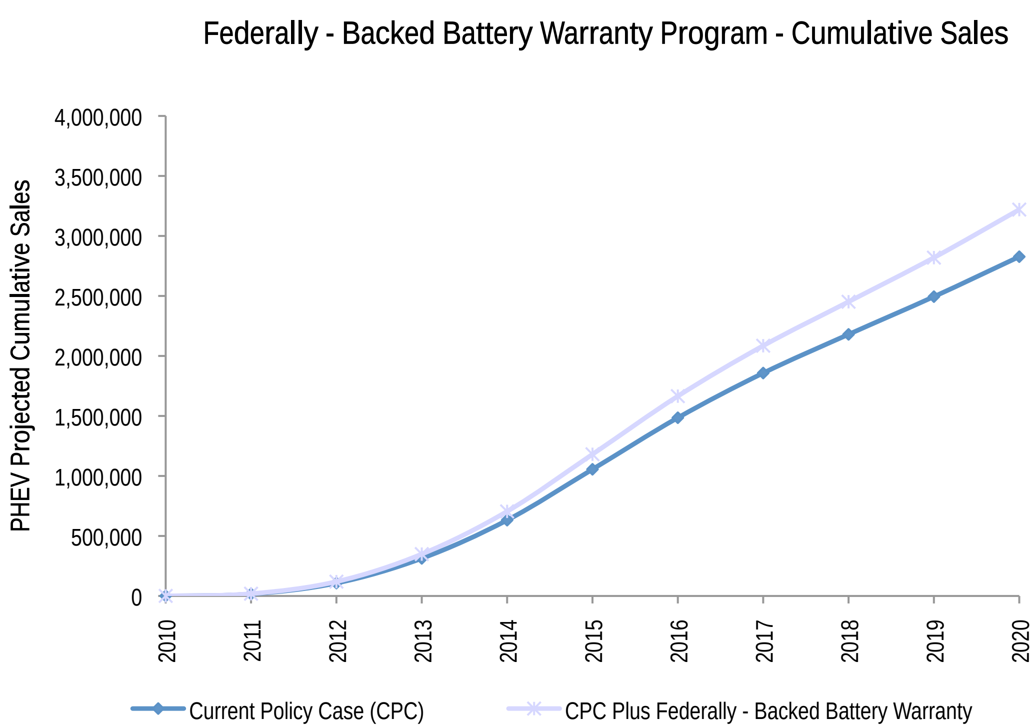

Figure 17: Projected effect of government-sponsored battery warranty program on cumulative PHEV sales.

- *Estimated Cost of Implementation*
  The cost to offer a PHEV battery warranty is dependent on the failure rate of the batteries once in the market. Therefore, a range of zero cost to several billions of dollars in paid out warranties may be possible. If the government agreed to cover half of battery replacement cost ($500/kWh for this study), and a 1% failure rate was assumed over the guaranteed lifetime of the battery, the actual cost to warranty all 3.2 million PHEVs (or approximately 12 million kWh) sold through 2020 would be nearly $60 million. This translates to an average of $150 to cover each PHEV sold beyond the current policy case. For a 10% failure rate, approximately $600 million in federal investment would be required, or $1,500 per PHEV sold beyond the current policy case. Finally, the maximum 100% failure rate would require approximately $6 billion in federal investment, or $15,000 per PHEV sold beyond the current policy case. See Chapter 7 for information on potential sources of funding for this incentive.

- *Timeframe for Implementation*
  Federally-backed warranties could be implemented in 2010 and continued for 5 to 10 years.

Implementing a $150 annual operating cost allowance to all PHEV purchasers results in an additional 3.2 million PHEVs on the road by 2020 (6 million PHEVs sold in all), according to the MA^3T Model. To implement this allowance, an estimated $9 billion in additional federal funding is required to reimburse each of the 6 million projected consumers who consequently buy a PHEV, or an average of $2,800 per PHEV sold beyond the current policy case.

6.6 Charging Infrastructure Financial Incentives

- *Definition*
  Financial incentives may be available to enhance residential and public charging infrastructure through tax credits, rebates, etc. for the manufacture, purchase, and/or installation of PHEV charging equipment. Such equipment may include public charging stations or smart metering systems in residential and non-residential parking garages in addition to nearby office buildings and retail shopping areas. Home electrical wiring upgrades may also qualify for infrastructure-related incentives.

- *Alleviated Pinch Point(s)*
  Providing financial incentives to improve charging infrastructure could help PHEVs obtain more widespread acceptance, especially for consumers who are unfamiliar with most charging practices. Increased access to public charging equipment where vehicles are parked for extended time periods may potentially persuade consumers who would not normally be interested due to lack of charging capabilities to consider purchasing PHEVs or other plug-in vehicles. A rebate to residential customers could provide wiring inspections and upgrades that enable proper charging of PHEVs at home. Similarly, apartment dwellers may be offered free or discounted charging if the property owner chooses to accept a tax credit to install the stations.

  As noted in Chapter 3, increased charging access would be most beneficial at the average consumer's residence and work location, since these are the locations where the largest percentage of vehicle charging would likely occur. However, charging access at retail shopping areas may also provide a convenient recharge, if only a partial one, during quick errands. Business owners may also be able to draw new customers to their stores by offering free charging, with the cost of installation possibly recouped by tax credits. Overall, increased access to charging infrastructure may have the potential to persuade consumers that would normally not consider purchasing a PHEV or other plug-in vehicles due to lack of charging capabilities.

- *Concept for Implementation*
  This scenario assumes that charging infrastructure rebates result in increased residential and public charging access for PHEV consumers. This may include home upgrades and increased access in parking garages and businesses. For central city areas, the MA^{3}T Model assumes that central city charging access increases by 25% (or about 9 million households) while charging access in suburban areas increases by 15% (also about 9 million households).

  It should be noted that locations for infrastructure upgrades are indiscriminately picked by the MA^{3}T Model, and the model also does not differentiate between public and private locations. In other words, just because charging infrastructure was provided or upgraded at a particular location does not mean consumers consequently purchased PHEVs. Realistically, charging infrastructure incentives would be targeted to specific homes and businesses with the highest likelihood new PHEV sales, not by simply selecting locations at random. Therefore, a more strategic approach to choosing

locations for improvements (e.g., current initiatives in San Francisco and Washington, D.C.) would likely result in a much stronger PHEV market impact than that indicated in this report. The Idaho National Laboratory has conducted extensive research on the infrastructure requirements to accommodate various PHEV demand, including placement of stations and level of charging available at stations, whose findings would be valuable to incorporate into future versions of the MA^{3}T Model.[25]

- *Potential Market Impact*
  Figures 18 and 19 demonstrate the increase in PHEV sales as a result of adding enhanced charging stations and locations to the current policy case, according to the MA^{3}T Model. This incentive appears to have a moderate effect on market introduction, with approximately 1.15 million PHEVs sold by 2015 when improvements were made in both suburbs and central cities. This is in comparison to the near 1.05 million cumulative units sold by 2015 under the current policy case. If infrastructure improvements were only made in selected suburbs, the model estimated 1.1 million units sold by 2015; in central cities, an estimated 1.075 million units are sold by 2015.

  Increased access to charging infrastructure (public and residential) combined with existing tax credits will have a moderate effect on PHEV sales through 2015, according to the MA^{3}T Model. Furthermore, installation of public charging infrastructure may be critical for central city sales.

  Higher city sales projections indicate that apartment dwellers, who are less likely to have existing charging access, find greater value to infrastructure improvements than suburban dwellers. Overall, an increase of only about 10% in PHEV sales between now and 2020 should be expected if improvements are made to both areas.

- *Estimated Cost of Implementation*
  Since the MA^{3}T Model indiscriminately picked locations to improve charging infrastructure, it is difficult to determine how many of these upgrades directly resulted in a PHEV purchase. Cities or companies would likely only make improvements in areas that are almost certain to result in increased sales. However, to provide a rough estimate, a normal residential inspection and circuitry upgrade may cost approximately $500, which would translate to roughly $1.6 billion in necessary federal funding required to provide a rebate to roughly 3.2 million consumers projected to purchase PHEVs through 2020. Since the MA^{3}T Model projects an additional 370,650 PHEVs to be sold as a direct result of this policy, $4,300 in federal investments would be required per PHEV sold beyond the current policy case. Incentives for public charging infrastructure would likely cost more than $500 per installation.

- *Timeframe for Implementation*

[25] U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity: Plug-in Hybrid Electric Vehicle Charging Infrastructure Review, Final Report. INL/EXT-0815058. November 2008.

Charging infrastructure financial incentives could be implemented between 2010 and 2015 and continued for 10 to 20 years.

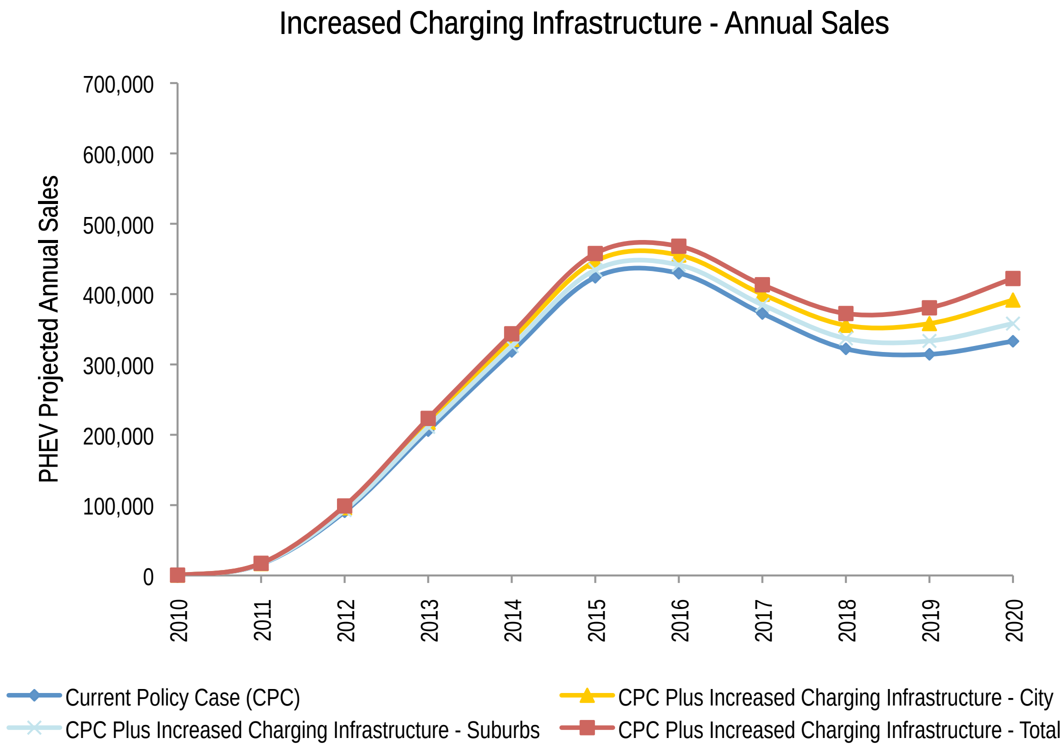

Figure 18: Projected effect of enhanced charging infrastructure on annual PHEV sales.

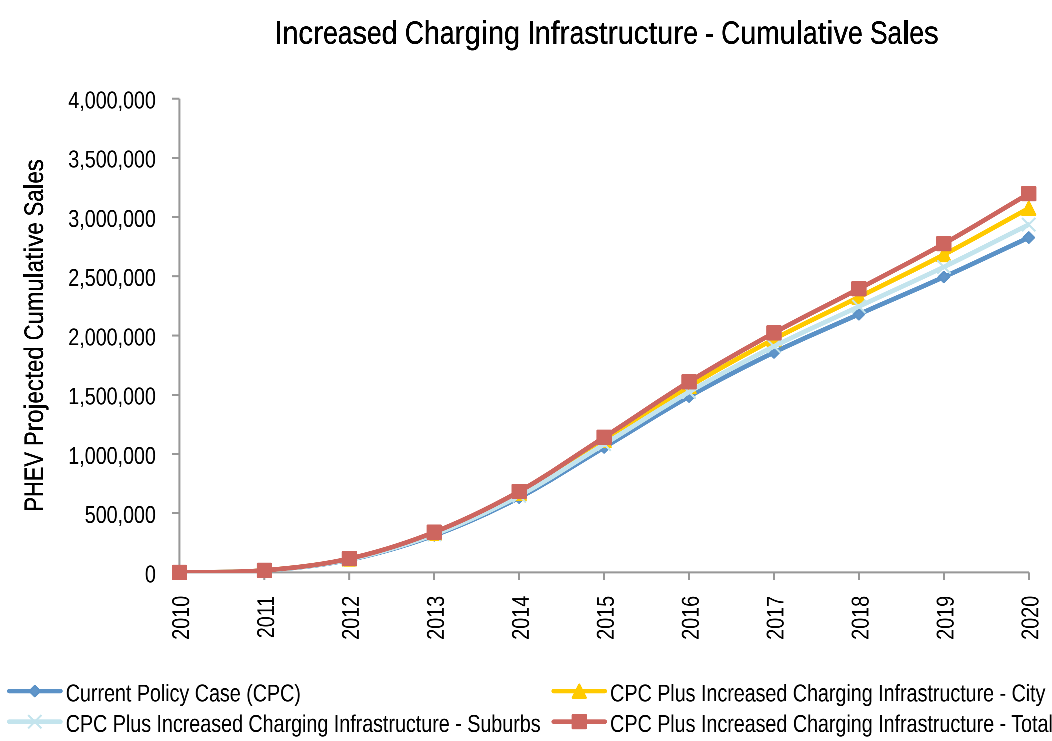

Figure 19: Projected effect of enhanced charging infrastructure on cumulative PHEV sales.

6.7 Fuel Efficiency Regulations for Government Fleets

- *Definition*
  Fuel efficiency regulations can be implemented that mandate government fleet requirements and promote the use of highly fuel-efficient PHEVs in federal fleets (e.g., U.S. Postal Service, U.S. Department of Defense). Essentially, federal fleets that purchase tens of thousands of vehicles annually could become early adopters of PHEVs. In a 2007 Executive Order, President Bush mandated that federal government agencies operating a fleet of 20 or more vehicles must purchase PHEVs when they become commercially available and are of reasonable cost relative to non-PHEVs.[26] Building upon this message, President Obama ordered federal agencies in October 2009 to reduce fossil fuel consumption by 1) increasing the use of lower GHG-emitting vehicles (e.g., AFVs) and 2) reducing the agency fleet's petroleum-based fuel consumption by at least 2 percent annually through the end of fiscal year 2020, compared to fiscal year 2005, for agencies with 20 or more motor vehicles.[27]

  Additional efficiency regulations or mandates may strengthen these Executive Orders in favor of PHEVs. Mandating that a small percentage of federal fleet acquisitions be PHEVs even before they are available at a reasonable cost could help boost market introduction. Otherwise, additional policy measures would likely have to be implemented in order for PHEVs to be considered a reasonable cost relative to non-PHEVs within upcoming years.

- *Alleviated Pinch Point(s)*
  By setting aggressive regulations for government fleets that favor PHEVs, a significant volume of PHEVs could be introduced more quickly into the market, helping to drive down the cost of the vehicles more rapidly. Government agencies acting as early adopters will also increase the visibility of PHEVs, and consumer acceptance and familiarity will more likely grow as a result.

- *Concept for Implementation*
  For this study, it is assumed that government fleets are required to replace 10% of retired vehicles with PHEVs beginning in 2010. This percentage steadily increases to a 20% replacement rate in 2020 (see Appendix A for the exact rate increase). According to the General Services Administration (GSA), approximately 65,000 – 70,000 new federal fleet vehicles are purchased each year, so a PHEV mandate of 10 to 20% of replaced vehicles would account for roughly 6,500 – 14,000 vehicles each year. Federal funding could be allocated for GSA to help cover the price premium that PHEVs have over competitive vehicles, thereby helping government fleets replace retired vehicles with PHEVs (once they become commercially available). Purchases that do not meet this requirement must be justified and approved.

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[26] Executive Order 13423, Fed. Reg. Vol. 72, No. 17 (Jan. 26, 2007).
[27] Executive Order 13514, Fed. Reg. Vol. 74, No. 194 (Oct. 8, 2009).

Federal government employees may be required to rent vehicles with a fuel economy of 2 times CAFE (e.g., PHEVs) whenever available while on travel. Rental companies would then likely make PHEVs available to maintain consistent business with federal government employees.

- *Potential Market Impact*
  The MA³T Model was used to determine the effects of the aforementioned PHEV mandates in addition to the current policy case. Figures 20 and 21 indicate that this replacement of retired fleet vehicles with PHEVs at the given rates does not have a significant effect on overall PHEV sales when applied to the current policy case. This is because 10 - 20% of the federal fleet annual acquisitions only account for 6,000 to 13,000 vehicles per year, translating to less than 1% of increased annual sales. While such small annual sales do little in the long term to help drive down the cost of PHEVs and their components, the near 7,000 PHEVs that would be mandated in the first couple of years may help to significantly jump-start economies of scale within the industry.

  Government fleet mandates would perhaps have much greater market impact if state, county, and local fleet vehicles were also required to abide, since these fleets have over 5 times the number of vehicles as the federal fleet. See Appendix A for more detailed information on ORNL's projections for this incentive.

Mandating a 10 - 20% PHEV replenishment rate for federal government fleets through 2020 (in addition to the current policy case) does not have a significant effect on overall PHEV market sales, according to the MA³T Model. However, these fleet vehicles may play a valuable role in increasing visibility and consumer acceptance of PHEVs.

- *Estimated Cost of Implementation*
  Using the PHEV fleet replenishment rates in the MA³T Model, approximately 88,750 PHEVs are acquired by the federal government by 2020 under this mandate. The model does not specify what percentages of the PHEV model sales are passenger cars or trucks, or what average AER is used. For cost estimation purposes, a 50/50 passenger car to truck split and an average AER of 20 miles is assumed for acquired PHEVs. To cover the incremental cost over a standard fuel-efficient fleet vehicle (in this case, an HEV), approximately $260 million in total additional incentive funding is needed, or $2,900 per PHEV.

  The estimated cost per PHEV is relatively large because nearly 7,000 PHEVs (10% of the annual federal fleet acquisitions) are mandated in 2010 under this scenario, at a time when the price premium is still high. If the mandated percentage started lower and more gradually increased to 20% over time, the total funding required would be lower. See Chapter 7 for information on potential sources of funding for this incentive.

- *Timeframe for Implementation*

Federal mandates could be implemented between 2010 and 2012 and continued through 2030.

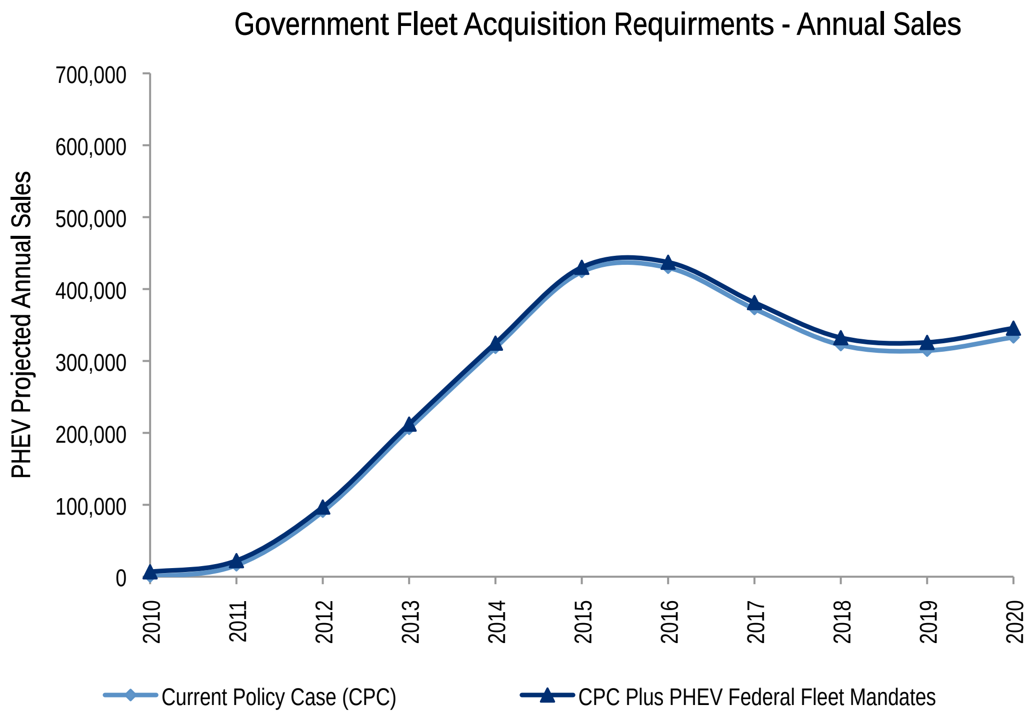

Figure 20: Projected effect of increased federal fleet mandates on annual PHEV sales.

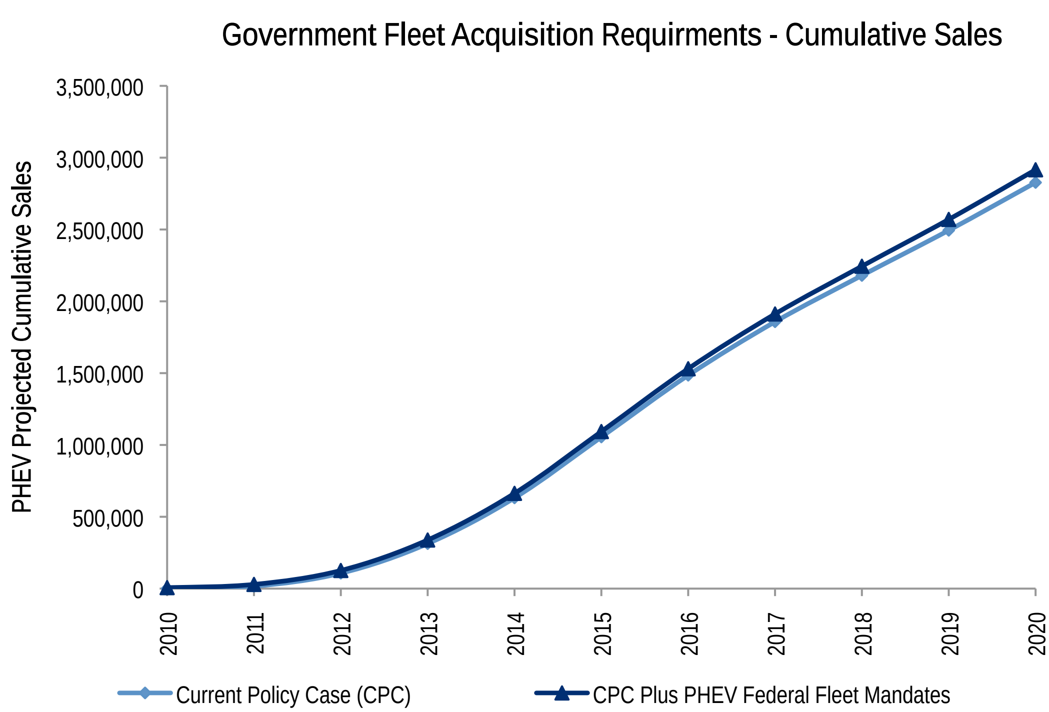

Figure 21: Projected effect of increased federal fleet mandates on cumulative PHEV sales.

6.8 Subsidies to Lower Initial Vehicle Price

- *Definition*
  The vehicle purchase price that a consumer pays can be subsidized in a variety of ways. The primary method analyzed for lowering the initial vehicle price is subsidizing the cost of the battery, which is estimated to account for up to $2,000/kWh retail price in 2008.[28] Other mechanisms may include purchase rebates, low-interest loans, grants, registration fee exemptions, etc.

- *Alleviated Pinch Point(s)*
  A subsidy to lower the vehicle sticker price would allow PHEVs to become more cost-competitive with conventional vehicles and HEVs. By providing the rebate to the manufacturer, the customer receives immediate benefit. If the rebate is given to the customer in the form of a tax credit or other longer-term monetary payback, the customer is faced with a higher immediate cost, which could reduce the attractiveness of a PHEV purchase from the customer's perspective. In fact, a recent study by Harvard University concluded that time-of-purchase savings are approximately twice as effective as a comparable tax credit received at the end of the year.[29]

- *Concept for Implementation*
  The primary goal of subsidies or rebates is to rapidly increase the adoption of an immature technology by offsetting its additional cost. The concept evaluated in this section is a rebate given to the manufacturer to offset the additional cost of the battery. The rebate allows manufacturers to lower the total cost of the vehicle, thereby enticing customers to purchase a vehicle that may otherwise be unaffordable. The rebate is calculated to offset the projected additional cost of the battery pack until high-volume manufacturing efficiencies are achieved, presumably after 2020. As manufacturing technology matures, the amount of the rebate would decrease over time until 2020, beyond which no additional rebate would be offered. The rebate would be available to PHEVs, as well as EVs, and would be based on the energy storage capacity of the batteries.

  The model is based on rebates that cover a portion of the cost premium of a PHEV compared to a HEV. Based on feedback from Workshop participants, a subsidy should be sufficient to allow a maximum cost differential of $1,500 between an HEV and PHEV-12, $3,000 between an HEV and PHEV-20, and $6,000 between an HEV and PHEV-40.

  During the workshop, it was agreed that introducing subsidies capable of achieving such small cost differentials between HEVs and PHEVs would likely result in a more competitive edge for PHEVs. Once modeling began, however, it became evident that these cost differentials have already been reached with this study's current policy case for many of the years through 2020, thanks to the high anticipated impact of the PHEV

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[28] "Battery Technology for Vehicles." Idaho National Laboratory. Presentation made on September 4, 2008.
[29] Gallagher, Kelly S. and Muehlegger, Erich. "Giving Green to Get Green: Incentives and Consumer Adoption of Hybrid Vehicle Technology." RWP08-009. John F. Kennedy School of Government – Harvard University. February 2008.

tax credits and major battery manufacturing support presented in ARRA. Therefore, for the years where vehicle purchase prices already fell within the maximum price differentials, no additional subsidies were applied in this section.

- *Potential Market Impact*
  As indicated in Figures 22 and 23, MA^3T Model concludes that implementation of this subsidy program in addition to the current federal incentive results in annual PHEV sales of roughly 425,000 and 333,500 units in 2015 and 2020, respectively. Cumulative PHEV sales for these years total approximately 1.1 million units by 2015 and 2.9 million units by 2020. These sales values have barely exceed those of the current policy case. As explained in *Concept for Implementation*, very few sales resulted from the introduction of these subsidies because the vehicle purchase prices under the current policy case already fulfilled the subsidy's designated price differentials between HEVs and PHEVs. Furthermore, in cases where the subsidy is applicable (once the Plug-in Vehicle Tax Credit phases out), the HEV becomes the most appealing vehicle type, from a financial standpoint. See Appendix A for more detailed information on ORNL's projections for this incentive.

- *Estimated Cost of Implementation*
  The subsidies for each vehicle are set so that the cost differential compared to an HEV is $1,500, $3,000 and $6,000 for a PHEV-12, -20 and -40, respectively. Each year, the necessary subsidy will vary depending on the actual costs of PHEVs and HEVs. To estimate the cost of implementation, however, the subsidies required to obtain these price premiums were summed for all PHEVs sold (that required the subsidy) between 2010 and 2020. As previously noted, a subsidy was not even needed in several years because the current policy case already resulted in sticker prices less than this subsidy's designated price premiums. This is especially true for most PHEV-12s, which accounted for the large majority of PHEV sales through 2020. Therefore, a low number of total subsidies were actually needed.

Vehicle subsidies to reduce the cost of PHEVs have potential to significantly increase sales in the near term only if they successfully reduce the price premium that PHEVs have relative to competitive vehicles.

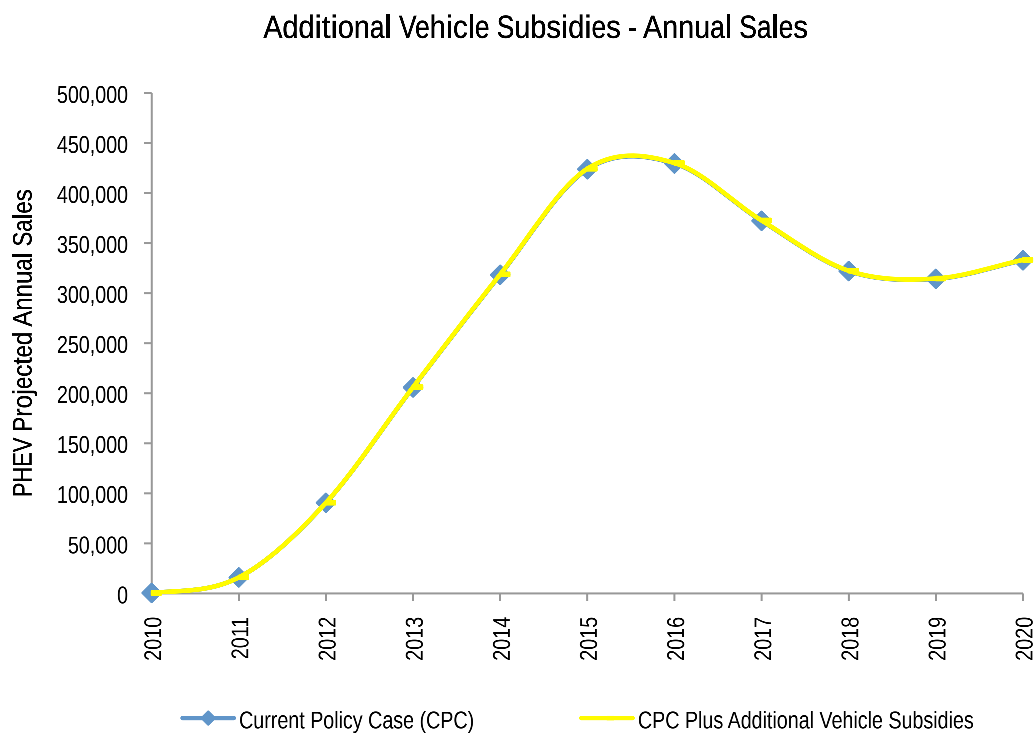

Figure 22: Projected impact of proposed vehicle subsidies on annual PHEV sales, according to the MA^{3}T Model.

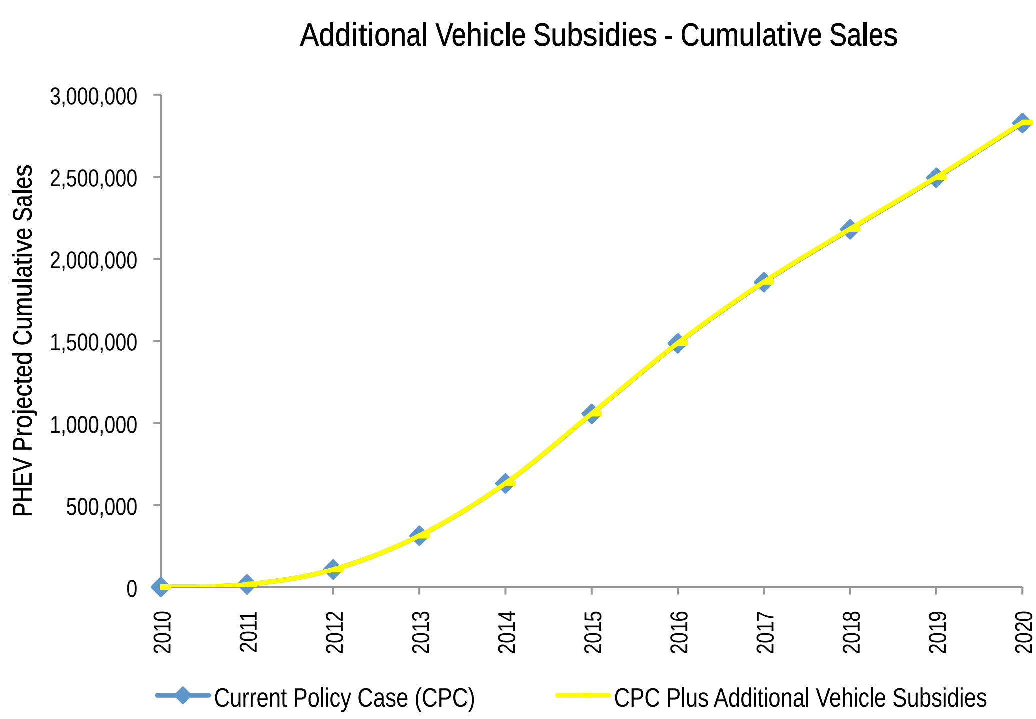

Figure 23: Projected impact of proposed vehicle subsidies on annual PHEV sales, according to the MA^{3}T Model.

Assuming ORNL sales projections, approximately $200 million would be required to cover these additional subsidies under the modeling parameters used. Since approximately 370,000 PHEVs were eligible for this subsidy, the cost of implementation for this government subsidy averages approximately $460 per PHEV sold between 2010 and 2020. However, when focusing on incremental PHEV sales, an excessive $58,400 is required to gain each of the nearly negligible 3,400 additional PHEVs that were sold as a direct result of this subsidy. This is simply too great of an investment for the federal government to ever consider pursuing.

- *Timeframe for Implementation*
  Subsidies to lower vehicle prices could be implemented in 2010 and continued for ten years when battery manufacturing technology is assumed to have matured sufficiently.

6.9 Federal Gasoline Tax Increase

- *Definition*
  The federal tax imposed on gasoline sales (currently set at 18.4¢ per gallon) could be increased by a designated amount to help support the market introduction of PHEVs. Although politically unpopular, even a 1-2¢/gal increase has the potential to fund most of the other incentives discussed in this study.

- *Alleviated Pinch Point(s)*
  Capital raised through a gasoline tax could be used to help offset the incremental cost of batteries. This would help lower vehicle sticker prices while the technology is maturing and manufacturing volume is increasing. Funding could also be directed towards the retooling of automotive facilities and scale-up of battery plants.

  If the gasoline tax were increased by a large amount (e.g., dollars, not cents) drivers of inefficient vehicles would be encouraged to purchase more fuel-efficient vehicles to avoid additional fuel costs. While this report does not necessarily support such substantial increases in federal gasoline taxes, the resultant income could be used as transfer payments to directly fund incentives for PHEVs and other high-efficiency vehicles.

- *Concept for Implementation*
  If the federal gasoline tax were raised by only 1 to 10¢ per gallon, a large amount of revenue could be generated to fund PHEV market introduction incentives. However, if the tax were increased by a much higher amount as mentioned previously, it could potentially change the overall driving habits of Americans and influence them to purchase more fuel-efficient vehicles. The two options below describe these two basic scenarios in more detail.

  ”Nominal” Increase in Federal Gasoline Tax Option:
  The amount of funding possible by implementing a 1 to 10¢ per gallon tax increase may be enough to subsidize the cost of nearly 1.5 million PHEV battery packs during the market introduction phase (10 years). Variations in gasoline taxes could be structured to match desired funding for other initiatives. Further, such a small increase in gasoline price would have little effect on consumer driving behavior and vehicle purchasing preferences. However, the incentives that could be enabled from the additional tax revenue should have a significant effect.

  According to the Department of Transportation, passenger cars and trucks consume over 135 billion gallons of gasoline each year in the United States (approximately 575 gallons per registered vehicle).[30] In Table 3, these values are used to calculate the gasoline tax increase required to fully fund policy programs of various sizes. The increase in taxes to the average individual driver is also documented.

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[30] Research and Innovative Technology Administration, Bureau of Transportation Statistics. Table 4-11: Passenger Car and Motorcycle Fuel Consumption and Travel and “Table 4-12: Other 2-Axle 4-Tire Vehicle Fuel Consumption and Travel. <http://www.bts.gov/publications/national_transportation_statistics/html/table_04_11.html>

Table 3: Gasoline Tax Increase Need to Fund Various PHEV Policies

Gasoline Tax Increase (per gallon)	Resultant Annual Funding for Policy Program(s)	Additional Annual Tax Paid by Average Driver
0.5¢	$675 million	$2.88
1¢	$1.35 billion	$5.75
2¢	$2.7 billion	$11.50
5¢	$6.75 billion	$28.75
10¢	$13.5 billion	$57.50

“Major” Increase in Federal Gasoline Tax Option:

From a funding source standpoint, a $1 per gallon tax increase has the potential to generate over $100 billion in revenue towards PHEV market introduction incentives. However, allocating $100 billion in new taxes to support PHEV initiatives is unrealistic and would impose an excessive burden on the consumer.

In addition to a large source of potential funding, a large tax increase may cause consumers to rethink their driving habits. For the first time since the 1970s and the early 1980s, the price of gasoline is considerably affecting consumer driving habits, such as U.S. vehicle miles traveled (VMT). Figure 24 reveals that, in the past two years, VMT not only leveled off, but actually reversed when average gasoline prices exceeded $3 per gallon.[31] It is not clear at this time whether the change in VMT is fully attributable to the gasoline price increase, since this coincided with the beginning of an economic recession. VMT continued to decline through the end of 2008 even as gasoline prices declined back to previous levels, which indicates that multiple variables play a role in VMT trends. It is unknown whether consumers would opt for more fuel-efficient vehicles to help counter the increased operating costs if gasoline prices were to remain above $3 per gallon levels for several consecutive years.

[31] “Traffic Volume Trends.” U.S. Department of Transportation Federal Highway Administration; “U.S. All Grade All Formulations Retail Gasoline Prices,” U.S. Energy Information Administration, Released 5/26/09.

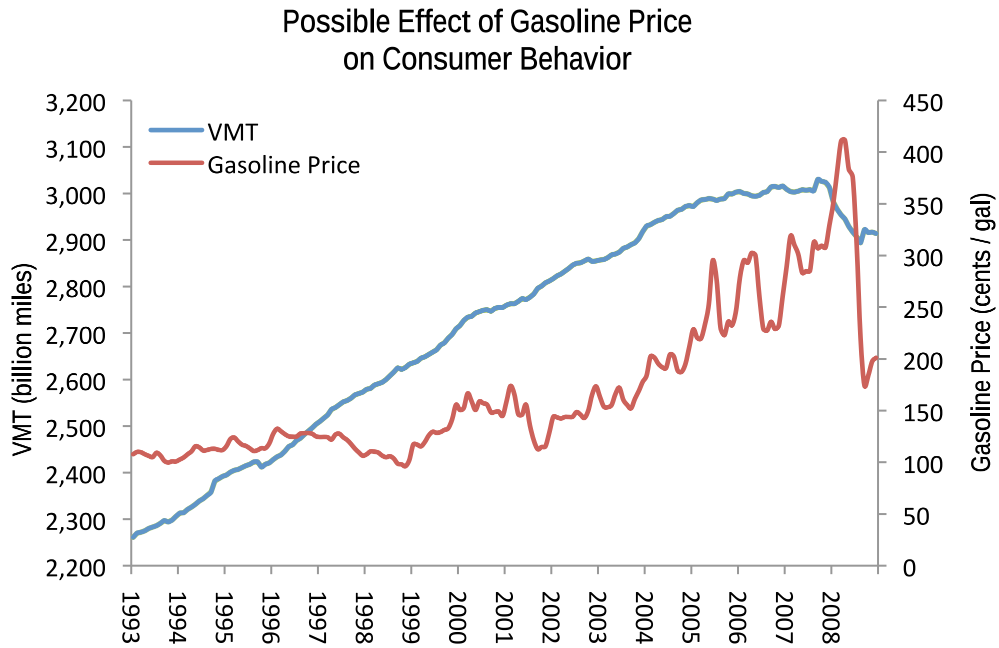

Figure 24: Consumer behavior is noticeably altered when gasoline prices exceed $3.00 per gallon.

- *Potential Market Impact*

  In Figures 25 and 26, the impacts from a series of nominal gasoline tax increases (ranging from 1 to 10¢ per gallon), as well as a $1 per gallon increase, has been projected using the MA³T Model. As the figure indicates, small increases between 1¢ and 10¢ have no significant effect on the PHEV market when combined with the current policy case and should not be used as a mechanism for changing consumer buying habits. However, the use of a nominal gasoline tax increase could indirectly boost PHEV sales by generating billions of dollars in federal funds. These funds, in turn, could be used by the government to break even on the initiation of other incentive programs analyzed in this report, such as state sales tax exemptions (Section 6.1) and initial vehicle price subsidies (Section 6.8).

According to MA³T Model projections, a federal gasoline tax increase of 1.5¢ per gallon could provide full funding for most of the incentives discussed in this report, which might indirectly increase PHEV sales.

A gasoline tax increase of $1 per gallon, on the other hand, has only a moderate impact on PHEV sales, according to the MA³T Model, and would be a burden on consumers.

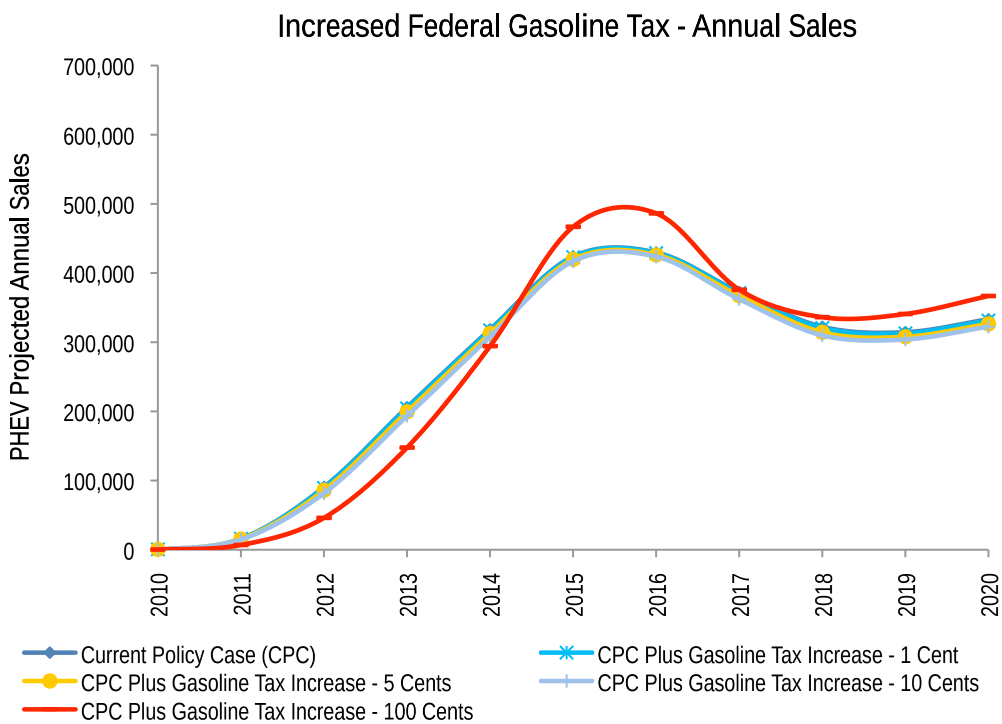

Figure 25: Projected effect of nominal increases in federal gasoline tax on annual PHEV sales.

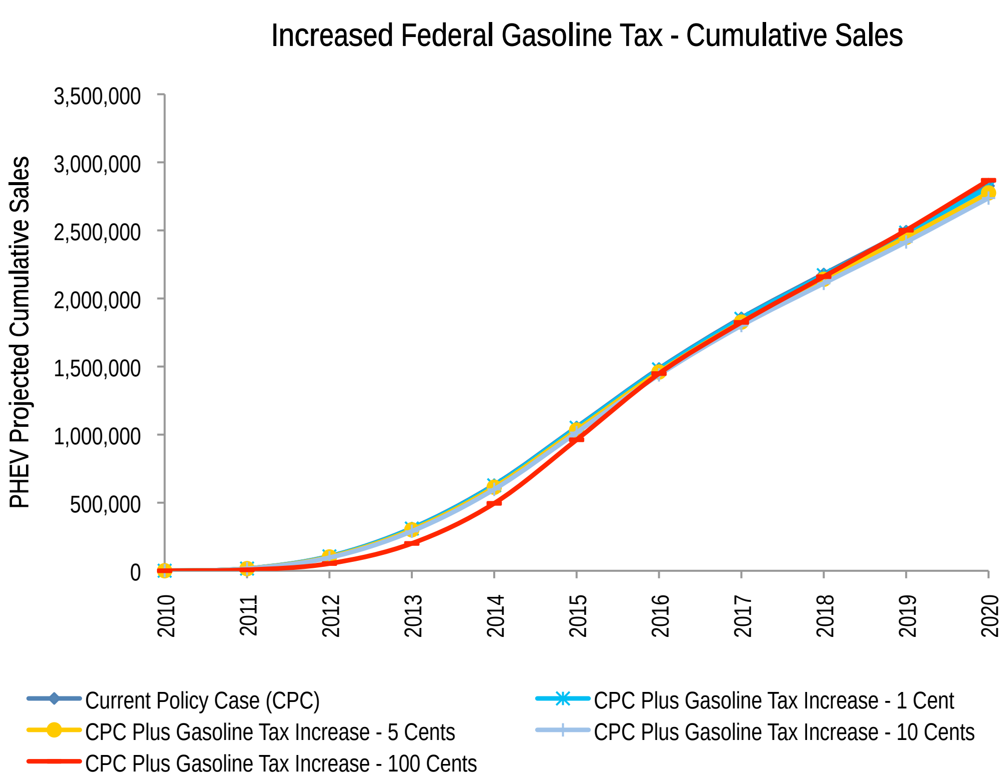

Figure 26: Projected effect of nominal increases in federal gasoline tax on cumulative PHEV sales.

Projections for a $1 per gallon increase in the federal gasoline tax appear to have a notable effect on consumer buying habits, significantly changing the overall shape of the penetration curve. Figure 25 suggests that a major gasoline tax increase through 2014 drives consumers to purchase fewer PHEVs than the base case and, instead, opt for HEVs (see Figure A-12 for projected HEV sales). By 2015, however, PHEVs increase in popularity, collecting enough cumulative sales to only break even with the current policy case of just over 1 million PHEVs sold. Furthermore, significant increases in gasoline tax have proven politically unpopular in the United States in the past, and there is no indication that the average U.S. voter is ready to accept the levels of fuel taxation that the rest of the developed world has implemented. See Appendix A for more detailed information on ORNL's projections for this incentive.

The VAMMP model was also used to investigate the effect of a major increase in gasoline price, whether due to increased petroleum costs or taxes. Upon a $2 per gallon increase in gasoline price (from $2 to $4 per gallon by 2040), consumer VMT decreased, gasoline consumption decreased, and fossil carbon emissions from transportation decreased (including those from electricity generation used to operate PHEVs). Further, consumer purchasing behavior tended toward buying more fuel-efficient vehicles, including PHEVs. Some consumers were even forced out of the vehicle-owning population. See Figures B-2 and B-3 and discussion in Appendix B.

- *Estimated Cost of Implementation*
  No direct cost of implementation is needed for a federal gasoline tax increase. The annual increase in fuel cost to consumers would be approximately $5.75, $28.75, $57.50, and $575.00 for a 1¢, 5¢, 10¢, and $1 per gallon tax increase, respectively, using 2006 gasoline consumption values.[32]

  Both ORNL and UMTRI's respective models produced estimates on a federal gasoline tax increase capable of covering the cost of certain incentives investigated in this study. Using ORNL model assumptions, a gasoline tax increase of 1.5¢ per gallon implemented between 2010 and 2020 could provide full funding for most any of the incentives discussed in this study in addition to the current policy case (e.g., the cost to simply implement a sales tax exemption). UMTRI's cost estimates, on the other hand, do not differentiate between the tax increases needed to fund the policies included in its base case, additional sales tax exemptions, and a Plug-in Vehicle Tax Credit extension; instead a comprehensive 6¢ per gallon tax increase through 2020 was projected. Therefore, a tax increase needed to implement the individual policies analyzed with UMTRI's model should each be considerably less than 6¢ per gallon.

- *Timeframe for Implementation*
  The tax increase could be implemented between 2010 and 2012; the tax rate structure could be adjusted over a period of years to provide necessary funding for PHEV incentive programs.

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[32] Research and Innovative Technology Administration, Bureau of Transportation Statistics. "Table 4-11: Passenger Car and Motorcycle Fuel Consumption and Travel." <http://www.bts.gov/publications/national_transportation_statistics/html/table_04_11.html>

7. Potential Sources of Funding

As indicated in Chapter 5, the cost to implement the policy and incentive options discussed could be substantial. For example, state sales tax exemptions, annual operating cost allowances, and the Plug-in Vehicle Tax Credit extension described in Sections 6.1, 6.3, and 6.4, respectively, have some of the largest projected costs of implementation among the policies analyzed; however, they are also expected to have among the largest benefits in terms of increased PHEV sales through the year 2020. These policy investments would be in addition to several billion dollars that has already invested towards the current policy case, counting tax credits applicable to 200,000 plug-in vehicles per vendor and $2.4 billion in battery manufacturing grants and vehicle demonstrations.

For the purposes of this paper, the assumption is that federal taxpayers will pay the costs associated with any initiative, or combination of initiatives, discussed in Chapter 6. In return, they would receive the public benefits derived from accelerating commercial sales of PHEVs. Funds to pay for incentives, or to offset reduced revenues, could be collected by the government through a variety of mechanisms; however, the potential sources of funding suggested here are

- **general revenues** generated through personal and corporate income taxes;
- an increase in the **tax on vehicle fuels**, with the additional taxes being applied specifically for PHEV initiatives; and/or
- **fees** assessed on vehicles with poor fuel economy.

In general, any PHEV incentive or other policy that involves new or extended funding by the federal government or regulation by one or more federal agencies must be authorized by legislation. For example, provisions related to energy-efficient vehicles and AFVs are included in the Energy Policy Act of 2005 (EPAct) and the Energy Independence and Security Act of 2007 (EISA). Title I of EISA, "Energy Security through Improved Fuel Economy," includes provisions on increased CAFE standards, improved vehicle technology, and federal vehicle fleets. In the subtitle on improved vehicle technology, the Secretary of Energy is directed to establish a program of support for PHEVs. EISA and ARRA likely provide authorization for most of the policies described in Chapter 6.

Funding for authorized programs and initiatives is provided through the appropriations process. Ordinarily, signed appropriations legislation is required before undertaking the discretionary spending needed to implement the policies presented in Chapter 6. This will always be the case when the source of funding is the government's general revenues. It is anticipated that appropriations would be used to pay the government's costs for the initiatives described.

A 1¢ per gallon increase in federal gasoline tax translates to approximately $1.35 billion in annual revenue that could be used to fund PHEV initiatives.

The other two potential sources of funding suggested here are introduced in Chapter 6. These are (1) a small increase in the federal gasoline (or, more generally, vehicle fuel) tax (see Section 6.9); and (2) fees collected from sellers or purchasers of low fuel economy vehicles, as part of a feebate program (see Section 6.2). An increase in the federal vehicle fuel tax could provide significant funding dedicated to PHEV vehicle subsidies or other PHEV incentive programs. As indicated in Section 6.9, a 1¢ per gallon increase, at current fuel use, would result in nearly $1.4 billion annually

in revenue that could be used to pay for PHEV initiatives. Likewise, a 5¢ per gallon increase translates to $7 billion each year in revenue, and a 10¢ per gallon increase results to $14 billion annually in revenue. Although it is expected to continue to be politically unpopular, a gasoline tax increase of only 1¢ to 10¢ per gallon is small relative to the recent "normal" fluctuations in petroleum fuel prices each year. It should be noted that both the ORNL and UMTRI models predict that an increase in federal gasoline tax within this range would easily fund most or all of the incentives investigated by each organization. The impact on lower income vehicle purchasers could possibly be alleviated through social programs.

Fees generated through a feebate program, "gas-guzzler" initiative, or other means could be used to pay for the subsidies that reduce the sticker price of a PHEV, offset tax credits for PHEV-related production investments, or fund other incentives included in Chapter 6. If a true feebate initiative, such as that described in Section 6.2, is authorized, then fees collected would be used to pay for rebates to sellers or purchasers of PHEVs and other high fuel economy vehicles. Such a program could be designed with the intention of achieving "revenue-neutrality," i.e., there would be no net income or cost to the federal government. It is possible that additional incentives (e.g., tax credits, toll exemptions) could also be fully or partially funded, depending on the size of the fees assessed.

8. KEY ORGANIZATIONS

The implementation of policies that support PHEV market introduction will require strong participation by multiple entities. With electric grid infrastructure becoming a critical component to PHEV operations, traditional synergies between auto manufacturers and the government must now expand to include collaboration with electric utilities and other related organizations. Anticipated preferences of vehicle consumers will also contribute to the selection of incentive types that should be pursued by policy makers.

8.1 Organizations with Interest in PHEV Market Introduction Policies

Key organizations that have a crucial role in a successful PHEV policy adoption and implementation are summarized below.

- *Government Agencies*
  All nine of the policies described and discussed in Chapter 5 share at least one characteristic: each policy results from an initiative taken on by one or more government entities. Depending on the particular policy, actions may be carried out by the federal government, one or more state governments, regional governments, and/or local governments. Elected representatives, responding to their constituents and exercising their collective judgment, determine if (1) the policy will contribute to achieving goals and objectives having a public benefit; and (2) that benefit is worth the costs incurred by implementation of the policy.

  The federal government would be instrumental in the development and implementation of each policy described in Chapter 6. State government agencies, such as state energy offices or public utilities commissions, could take their own initiative in implementing some of the policies and could be impacted by others. Policies of particular interest to the states are state sales tax exemption (see Section 6.1), annual operating cost allowances (see Section 6.3), charging infrastructure financial incentives (see Section 6.6), and subsidies to reduce the initial price of PHEVs (see Section 6.8). Regional authorities and local governments would also be directly affected by some policies, such as state sales tax exemptions, annual operating cost allowances, and charging infrastructure financial incentives.

- *Private Industry*
  Vehicle manufacturers, dealers, and suppliers clearly have a stake in, and would likely be impacted by, implementation of the policies described. To the extent that consumer demand for PHEVs is affected by policy, manufacturers must make a determination about actions they will take in response to that demand. In particular, battery developers and suppliers, drive train suppliers, and manufacturers of electronic and electrical equipment will need to be attentive to PHEV-related policy issues and development.

  Electric utilities, utility associations and partnerships, and electric cooperatives are also potentially affected by each of the policies. Many other private sector companies and organizations could also be affected by one or more of the policies addressed in this report:

- financial institutions, which may provide additional funding for the capital investments associated with charging infrastructure financial incentives (see Section 6.6);
- building developers and contractors, particularly in connection with charging infrastructure financial incentives (see Section 6.6);
- rental car companies, in connection with fuel efficiency regulations (see Section 6.7); and
- standards development and approval organizations.

- *Vehicle Purchasers*
  Each of the policies discussed above achieves its public benefits by motivating consumers to make different vehicle purchase decisions than they would without the policy.

8.2. Roles of Key Organizations

Identifying, quantifying, producing, and realizing the benefits of PHEVs will result from the activities of numerous organizations and individuals. Important among these are vehicle manufacturers and their suppliers, technology developers, elements of the federal government, electric utilities, and vehicle purchasers. The following is an overview of the roles and responsibilities which must be successfully addressed by each of these interests in order for PHEVs to achieve commercial success.

- *Vehicle Manufacturers and Suppliers*
  - Provide objective and candid inputs to government policy analysts and decision makers
  - Track, and contribute expertise to, technology development and cost reduction strategies, particularly with regard to batteries
  - Make the case to investors for funds required to support PHEV production
  - Produce high-quality, reliable, and cost-competitive PHEVs to meet consumer demand

- *Technology Developers*
  - Help improve PHEV technology so that the vehicles are competitive in every respect, including total cost of ownership
  - Assure that battery technology is mature enough so that the PHEV ownership experience will be positive
  - Assure that newly-developed PHEV technologies can be readily manufactured in large quantities and with high quality

- *Federal Government*
  - Objectively analyzes the costs and benefits resulting from the implementation of policies intended to achieve public goals and objectives, such as increased energy security, energy diversity, and environmental quality
  - Supports the research and development (R&D) of new technologies, which if commercialized have the potential for significant public benefits
  - Understands the potential impacts of policy options on parties of interest

- Provides factual information for decision makers considering investments in PHEVs, from large corporations to individual consumers
- Carries out legislated responsibilities for vehicle safety, emissions, and fuel economy
- Participates in the development of codes and standards required for PHEVs and related infrastructure
- Assures that policies expected to result in increased demand for PHEVs are timed to match the availability of vehicles having characteristics consistent with that demand

- *Electric Utilities*
  - Engage with vehicle manufacturers, technology providers, and government agencies to assure standardization of the utility interface for vehicle recharging systems
  - Provide information to their customers about electricity costs for operation of PHEVs available in their service territories
  - Assist their customers in acquiring easy-to-use, low-cost equipment for the re-charging of PHEV batteries

- *Vehicle Purchasers*
  - Become knowledgeable and educated regarding PHEV benefits and costs and what to expect from the PHEV ownership experience (This category ranges from large fleet managers to individual consumers.)

8.3 Views and Perspectives of Key Organizations

Discussions and deliberations during the December 2008 PHEV Market Introduction Study workshop resulted in assigning priority consideration to the nine policies described in Chapter 6. Since the workshop, these policies have been the subject of analysis and modeling activities. A number of organizations with a stake and/or interest in PHEVs participated in the workshop. These included organizations represented on the study project's Guidance and Evaluation Committee. In addition to the analytical work completed as part of this study, follow-up discussions were conducted with representatives of organizations that participated in the workshop. Some of the messages delivered during these meetings are presented in this section.

With respect to some potentially significant policies and issues related to the introduction of PHEVs, those in the organizations contacted do not have uniformly held views and perspectives. One of these issues is whether government policies should favor particular vehicle technologies or fuels, that is, "pick winners." Subsidies to lower the initial cost of PHEVs, addressed in Section 6.8, is an example of a policy that could provide a substantial benefit for PHEVs relative to other vehicle types. Some organizations stressed that government legislators and agencies should strive instead to define public benefit performance objectives, and then base policy decisions on how well alternative policies achieve those objectives. Examples of performance objectives cited include (1) barrels of oil consumption avoided and (2) reduction of carbon dioxide emissions.

Using this approach, incentives such as subsidies would be granted based on how well the vehicle achieves its performance objectives, rather than the fact that it is a PHEV or can use a specific

alternative fuel. Referring to the feebates policy described in Section 6.2, these organizations strongly prefer the "Standard Feebate" option. Regarding the existing tax credit policy, in which the credit is related to battery size, their preference would be for a tax credit which rewards vehicle fuel economy or the extent to which gasoline use is decreased. In general, there is support for consumer incentives consistent with the vehicle subsidies described in Section 6.8, but also disagreement about whether they should be concentrated on PHEVs.

Another policy with disparate opinions is in regard to incentives for charging infrastructure (see Section 6.6). Some organizations think such a policy should be enacted, while others do not. There was general agreement, however, that such a policy is not an initial PHEV market enabler, as there will be sufficient recharging infrastructure to support PHEV requirements at least through 2015.

There are also strongly divergent opinions on a policy that would provide government warranties for PHEV batteries (see Section 6.5). Some organizations believe it is a terrible idea; others think it is a great idea. Those with reservations about such a policy expressed a belief that vehicle manufacturers would still be held accountable in the event of extensive battery failures, even with batteries warranted by third parties.

All or most of those with whom policies were discussed agreed to the following:

- They could support government incentives for capital investment in the supply chain for advanced technology vehicles (included in the current policy case).
- A gasoline tax increase (see Section 6.9) would be a good policy and an efficient means to achieve desired public benefits. However, they also noted it would be hard for such a policy to navigate the legislative process. Some indicated that such a policy should not be adopted specifically for the benefit of PHEVs.

Comments were also provided on issues not directly related to the policies that are the focus of this report. For example, there was agreement that much work remains to be done on battery development and that government should continue to support battery R&D. Within some organizations, the view is that battery technology is "good enough" to proceed with commercial introduction of PHEVs. Others believe strongly that current battery technology does not support moving beyond use in test vehicles, certainly not warranting use in large-scale PHEV production. These organizations think there is still too much risk of large-scale failure.

Among the organizations contacted, there seems to be a consensus that selling 1 million PHEVs between now and 2015 is not realistic, regardless of policy. As previously mentioned, some believe that the public benefits sought from selling that many PHEVs could be better achieved by providing the right set of incentives based on overall vehicle performance objectives. Some vehicle manufacturers believe there should be assured unsubsidized sales before a company commits to production.

9. Conclusions

In his Energy and Environment Agenda, President Obama calls for 1 million plug-in hybrid cars on the road by 2015. The recently-enacted Plug-in Vehicle Tax Credit and the $2.4 billion in battery manufacturing and demonstration support, both presented in ARRA, will provide tremendous initial support for the PHEV market, potentially reaching the Obama Administration's aggressive goal. However, additional policies, incentives, and regulations should be considered to accelerate demand and educate consumers on the financial and societal benefits associated with owning and operating a PHEV if these vehicles are to maintain a strong market presence beyond 2015.

9.1 "Business as Usual"

Results of ORNL's modeling efforts indicate that, in the current policy case, annual PHEV sales are expected to reach a total of 1 million PHEVs sold by 2015 and 425,000 units sold in 2015 alone. At this penetration rate, PHEVs would account for 2.5% of all new vehicle sales in 2015, with PHEV-12s dominating the overall PHEV market sales landscape (compared to the PHEV-20s and PHEV-40s also analyzed in this study). UMTRI's modeling efforts projected very similar annual PHEV sales of 2.6% in 2015 under their current policy case. To provide perspective on these annual sales projections, HEVs accounted for approximately 2.4% of new vehicle sales in 2008. Sustainable market strategies are needed to further accelerate this market, making PHEVs cost-competitive with enough appealing features to become a significant segment of new vehicles sold by this time. To help determine which strategies offer the best combination of high market impact and low implementation cost, nine additional policy options were investigated in this study.

9.2 Market Impacts of Different Policy Options

With initial vehicle cost presenting the most significant market barrier for PHEVs, incentives that greatly reduce the incremental vehicle cost between PHEVs and HEVs appear to have a strong impact in ORNL's MA^3T Model results. For example, state sales tax exemptions that can potentially save the consumer thousands of dollars at the time of purchase had a large impact on PHEV sales in this study. PHEV-12s are especially appealing under these types of incentives because the price premium between a PHEV-12 and an HEV will continue to diminish in upcoming years, based on MA^3T Model assumptions, and additional reductions in sticker price would give PHEV-12s a clear competitive advantage by 2015. Legislation that would extend the existing Plug-in Vehicle Tax Credit through 2020 (Section 6.4) would also help to further reduce the price premium between PHEVs and competitive vehicles.

Instead of incentives received at time of purchase, annual operating cost allowances appear to have a major impact on PHEV sales. These annual payments to the consumer can be used towards various vehicle-related operating costs throughout the life of the vehicle, such as parking fees, toll fares, and fuel (e.g., electricity or E85) costs. Model results suggest that an annual payment of $150 over ten years is sufficient to see a significant increase in near-term PHEV sales.

A feebate program that rewards vehicles exceeding a given pivot point with a $1,000 rebate per 0.01 gpm, while assessing a similar fee on "gas guzzlers," appeared to have a moderate to high impact on PHEV sales through 2020 when applied to the current policy case. When PHEV sales were projected using the "Standard Feebate" option, which uses the CAFE standard as the pivot point, an improvement of approximately 20% was seen. When the pivot point is extended to twice

the CAFE standard, as demonstrated in the “Progressive Feebate” option, sales projections accelerate significantly to roughly 2 million PHEVs on the road by 2015. A neutral revenue stream can be designed for a feebate system, allowing the program to essentially pay for itself.

Federal government fleet mandates, with annual fleet replenishment rates of 10-20% for PHEVs through 2020, had little effect on overall PHEV market sales, because 10-20% of annual federal fleet acquisitions only accounts for 6,000 to 13,000 vehicles purchased each year. However, mandated fleet vehicles, although low in number, could be valuable in raising consumer awareness and acceptance. The inclusion of state, county, and local fleet vehicles in this mandate could significantly improve the market impact of government fleet mandates since these vehicles account for over five times the amount of existing federal fleet vehicles.

Incentives that do not directly affect the average consumer’s pocketbook, such as improved access to charging infrastructure in both central cities and suburbs, also did not appear to have a major effect on PHEV market demands. However, the low sales projections associated with increased charging access are partially due to the indiscriminate selection of locations that received upgrades. Realistically, charging infrastructure incentives would probably be targeted to specific homes and businesses with the highest likelihood of resulting in new PHEV sales, not simply by selecting locations at random.

9.3 Costs to Implement Different Policy Options

With respect to implementation costs, required funding for each of the policy options ranged tremendously. Generally speaking, the incentives that resulted in the greatest market impact typically required the most funding. For example, policy options that each required over $1 billion in additional funding to implement, such as the Plug-in Vehicle Tax Credit extension and the state sales tax exemption, accumulated the most additional PHEV sales through 2020. In fact, these two policy options are the most expensive to implement with $18 billion each in additional needed federal funding through 2020. In contrast, policy options that cost less than $1 billion in additional funding to implement, such as vehicle subsidies, federal fleet mandates, and federally-backed battery warranty, each netted less than 1.2 million PHEV sales by 2015 when combined with the current policy case. It should be noted that a federal gasoline tax increase of 1.5¢ per gallon implemented between 2010 and 2020 could provide full funding for most of the incentives discussed in this report, using ORNL model assumptions.

On a cost per PHEV basis (using ORNL’s modeling results), the policy options with the least expensive cost of implementation by the federal government beyond the current policy case appear to be the feebate program, which can be designed to be revenue-neutral; a federally-backed battery warranty ($150 per PHEV sold beyond the current policy case, assuming a 1% failure rate); and a state sales tax exemption ($1,750 per PHEV sold beyond the current policy case). Annual operating cost allowances ($2,800 per PHEV sold beyond the current policy case), federal fleet mandates ($2,900 per PHEV sold beyond the current policy case), extension of the Plug-in Vehicle Tax Credit ($3,000 per PHEV sold beyond the current policy case), and increased charging infrastructure ($4,300 per PHEV sold beyond the current policy case) appear to have the highest cost of implementation for the federal government. The excessive cost to introduce the additional vehicle subsidies described in Section 5.8 - $58,400 per PHEV sold beyond the current policy case - is simply too great of an investment for the federal government to consider pursuing.

9.4 Summary of Sales Projections

Summaries of annual and cumulative sales for each policy option, as projected by the MA³T Model, are presented in Tables 4 and 5, respectively. Each chart begins with the sales projections for the current policy case over the next decade, followed by mechanisms with increasing market impact. Table 6 shows the projected incremental sales and government investments that result from each of the new policy options. (Federal gas tax increases are not included in these tables, since their primary purpose is to fund incentives programs, not to directly affect consumer buying habits.)

Table 4: Summary of annual PHEV units sold as a result of each market mechanism, sorted by increasing sales.

Annual PHEV Sales	2010	2015	2020
Current Policy Case (CPC)	500	423,950	332,975
CPC + Additional Vehicle Subsidies	500	424,475	333,350
CPC + PHEV Federal Fleet Mandates	6,840	430,275	515,170
CPC + Increased Charging Infrastructure – City and Suburb	520	457,700	422,200
CPC + Federally-Backed Battery Warranty	600	475,900	400,375
CPC + "Progressive Feebate" Option – All Vehicles	750	715,400	481,875
CPC + Annual Operating Cost Allowance - $150	780	745,850	1,077,950
CPC + Plug-in Vehicle Tax Credit Extension	500	435,400	3,195,825
CPC + State Sales Tax Exemption	890	1,017,850	3,569,400

Table 5: Summary of cumulative PHEV units sold as a result of each market mechanism, sorted by increasing sales.

Cumulative PHEV Sales	2010	2015	2020
Current Policy Case (CPC)	500	1,055,375	2,827,050
CPC + Additional Vehicle Subsidies	500	1,056,850	2,830,475
CPC + PHEV Federal Fleet Mandates	6,839	1,093,400	2,915,800
CPC + Increased Charging Infrastructure – City and Suburb	520	1,141,225	3,197,700
CPC + Federally-Backed Battery Warranty	600	1,180,575	3,219,575
CPC + "Progressive Feebate" Option – All Vehicles	735	1,735,725	4,302,325
CPC + Annual Operating Cost Allowance - $150	781	1,839,150	6,052,175
CPC + Plug-in Vehicle Tax Credit Extension	500	1,074,775	8,838,225
CPC + State Sales Tax Exemption	893	2,475,725	13,167,475

Table 6: Summary of incremental sales and federal investments projected for each market mechanism through 2020.

Incremental Values through 2020	Total Federal Investment above CPC (in millions)	Total PHEV Sales Above CPC	Cost to Achieve Incremental Sales (per PHEV sold)
Current Policy Case (CPC)	-	-	-
CPC + Additional Vehicle Subsidies	$200	3,425	$58,400
CPC + PHEV Federal Fleet Mandates	260	88,750	$2,900
CPC + Increased Charging Infra. – City and Suburb	$1,600	370,650	$4,300
CPC + Federally-Backed Battery Warranty	0 – $60,000	392,525	0 – $15,000
CPC + Plug-in Vehicle Tax Credit Extension	$18,000	6,011,175	$3,000
CPC + Annual Operating Cost Allowance - $150	$9,000	3,225,125	$2,800
CPC + "Progressive Feebate" Option – All Vehicles[33]	-	1,475,275	-
CPC + State Sales Tax Exemption	$18,000	10,340,425	$1,750

[33] The cost of implement a feebate program can be designed as revenue neutral.

Finally, Figures 27 and 28 provide graphical comparisons of the projected annual and cumulative PHEVs sales, respectively, attributable to policies, incentives, and regulations analyzed in this study that resulted in notable market impacts through 2020. For visual clarity purposes, only the most promising scenario for each of these policy options is shown in the figures. To view all scenarios analyzed for each policy option, please refer back to the corresponding section in Chapter 6.

9.5 Societal Benefits

Testing has demonstrated that, if operated as intended, PHEVs can consume only a fraction of the petroleum-based fuel relative to conventional vehicles over their lifetime. In fact, on a vehicle to vehicle basis, PHEVs use an average of 80% less gasoline than conventional vehicles and 70% less than HEVs.[34] Over time, these savings can accumulate into significant displacements of petroleum, helping to stabilize the U.S. economy and strengthen energy security if petroleum imports from unreliable sources are consequently reduced. Furthermore, fewer GHGs will consequently be emitted from tailpipes in the United States, which contributes to improved public health and welfare.

Before such major societal benefits can be realized, PHEVs and other highly efficient vehicles (e.g., EVs, fuel cell vehicles) must comprise a significant portion of the LDV fleet. Currently, petroleum-dependent conventional drive ICEs overwhelmingly dominant vehicle sales in the United States, and millions are likely to remain on U.S. roads for years to come. HEV sales are projected to ramp up considerably between now and 2020, which will help diminish future sales of conventional drive ICEs, but it will simply take time to phase in PHEVs and other advanced vehicles that are capable of making a major impact in U.S. fuel savings and GHG emissions. Therefore, in the near term, these savings will be primarily reliant on fuel economy improvements mandated in conventional drive ICEs.

[34] "Plug-in Hybrid Electric Vehicle Value Proposition Study: Interim Report," ORNL/TM-2008/076, Sentech, Inc., January 2009.

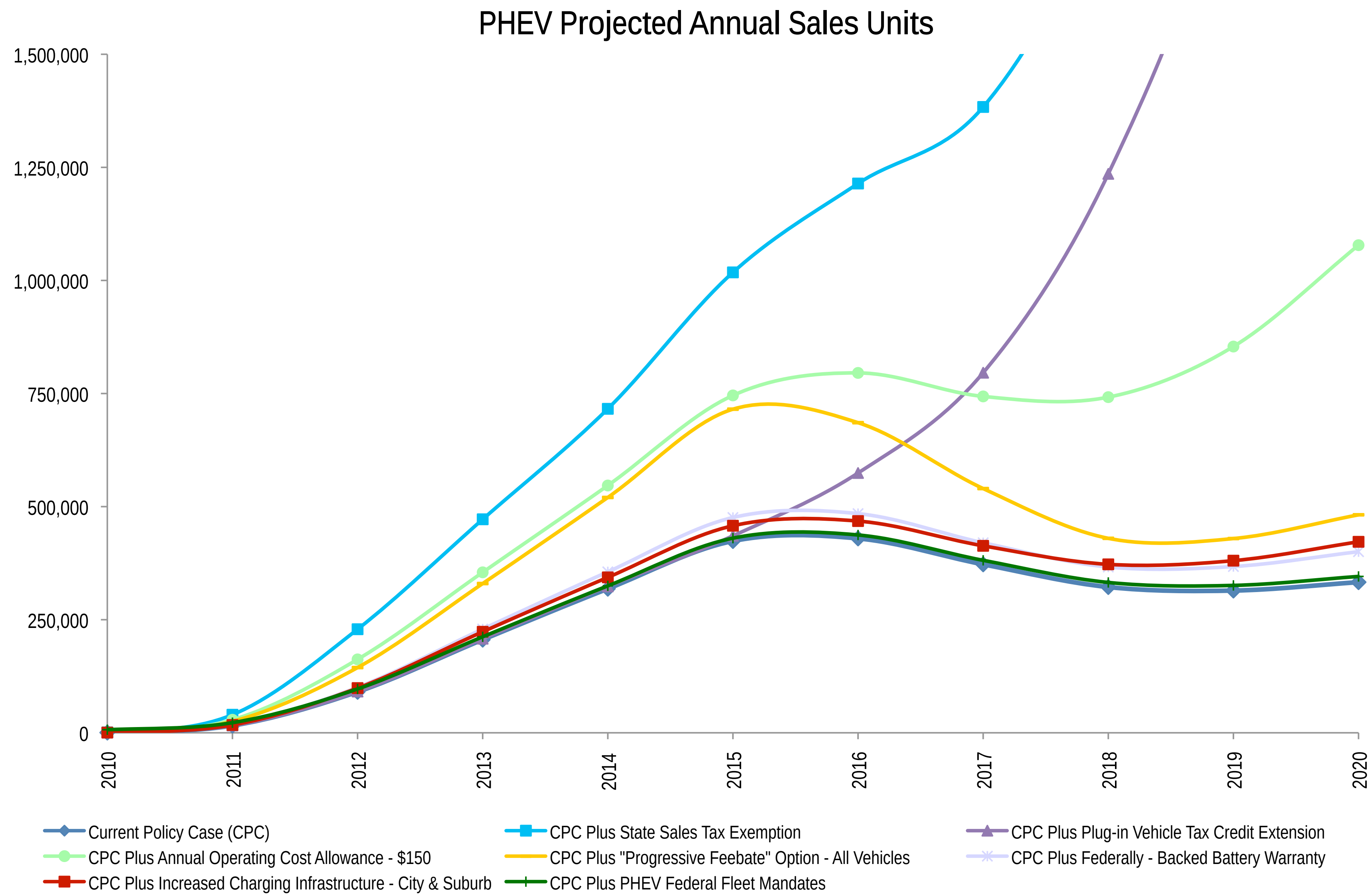

Figure 27: Projected annual PHEV sales resulting from each individual incentive analyzed in this report (see Chapter 5 for specific modeling parameters of each incentive).

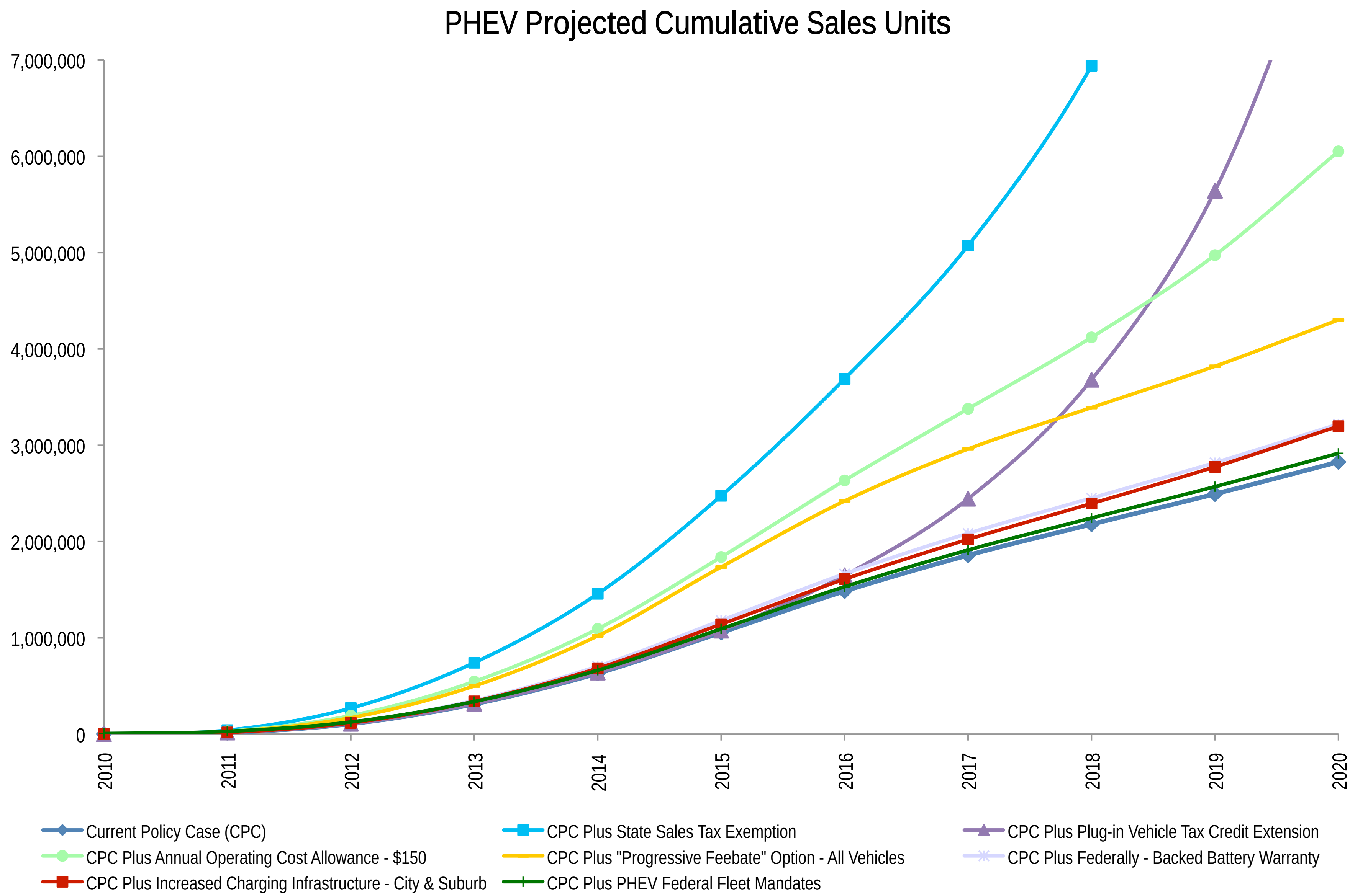

Figure 28: Projected cumulative PHEV sales resulting from each individual incentive analyzed in this report (see Chapter 5 for specific modeling parameters of each incentive).

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APPENDIX A. SUMMARY OF ORNL MODELING EFFORTS

Market Acceptance of Advanced Automotive Technologies (MA^{3}T) Model

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Introduction

The Market Acceptance of Advanced Automotive Technologies (MA^{3}T) Model, developed by Oak Ridge National Laboratory (ORNL), analyzes consumer choice among PHEVs and other conventional and advanced vehicle technologies. It was developed from a six-month project in response to the need of the U.S. Department of Energy for analytical tools to evaluate the potential of PHEV technology contributing to energy security and climate change mitigation. The model simulates competition of PHEVs against several other vehicle technologies, including gasoline and diesel internal combustion engine (ICE) vehicles, hybrid electric vehicles (HEV), battery electric vehicles, and fuel cell vehicles. The model projects PHEV sales for given scenarios of oil price, technology advancement, and policy.

Model Description

The MA^{3}T Model is currently a functioning Excel spreadsheet model of PHEV vehicle choice by light-duty vehicle consumers in the United States over the period of 2005 to 2050. Within the model, the United States is disaggregated into nine census divisions. Each census division is further disaggregated into three area types -- central city, suburban, and outside metropolitan statistical areas. The model considers three consumer types -- early adopters, early majority, and late majority -- and treats passenger cars and light trucks separately.

A large number of factors can potentially affect consumer decisions when choosing among all of the available vehicle technologies. The choice of which factors to include in a consumer choice model often comes down to consideration of policy needs, data availability, and project resources. In the MA^{3}T Model, the following factors have been incorporated:

- Vehicle attributes
  - Purchase price
  - Performance
  - Fuel economy
  - Fuel price
  - Vehicle capacity
  - Battery cost
  - Range
- Range of choice among makes and models
- Value of home refueling
- Availability of refueling infrastructure
- Subsidies and tax credits
- Housing type
- Vehicle and component supply constraint
- Consumer attitudes toward new technology
- Technology learning by doing
- Driving behavior among area types and census divisions

Additionally, efforts are being made to expand the model to consider the following issues:

- Vehicle-to-grid consideration
- Time-of-day electricity prices
- Fleet purchases
- Various monetary and non-monetary incentive policies
- Policy by geographic scope (federal vs. state)

ORNL Modeling Inputs/Assumptions

The MA^3T Model uses data published by the Energy Information Administration (Supplemental Tables to the Annual Energy Outlook 2007, Tables 11-19) as inputs for gasoline, diesel, and electricity prices, which are broken down by regions. A "high" oil price scenario was selected for this study.

Both passenger car and light truck PHEVs were analyzed in this study. PHEV cars available for purchase in ORNL's model begin with battery pack capacities ranging from approximately 4.5 kWh to 13 kWh currently, depending on the vehicle's all-electric range, but decrease in size over time; similarly, battery pack capacities for PHEV light trucks range from approximately 5.4 kWh to 18 kWh currently, also maturing in the approaching decades. Basic parameters input into the MA^3T Model are listed below.

Table A-1: Passenger car attributes by model year for ORNL's MA^3T Model "high technology" case, prior to applying the existing Plug-in Vehicle Tax Credit.

Vehicle Purchase Price	2005	2010	2015	2020
Gasoline SI ICE	$21,757	$21,757	$21,600	$21,527
Diesel CI ICE	$24,803	$24,803	$24,411	$24,570
Gasoline HEV	$22,837	$22,528	$21,829	$21,632
Advanced Gasoline SI ICE	n/a	$22,374	$21,783	$21,611
Gasoline PHEV-12	n/a	$26,040	$23,649	$23,132
Gasoline PHEV-20	n/a	$28,362	$24,879	$24,173
Gasoline PHEV-40	n/a	$34,167	$27,957	$26,776
Fuel Economy (mpgge)	**2005**	**2010**	**2015**	**2020**
Gasoline SI ICE	30.0	30.0	35.2	36.7
Diesel CI ICE	44.4	44.4	46.4	48.9
Gasoline HEV	62.0	62.0	72.2	75.9
Advanced Gasoline SI ICE	n/a	44.7	52.4	54.6
Gasoline PHEV-12	n/a	67.0	78.9	82.3
Gasoline PHEV-20	n/a	72.0	84.1	87.8
Gasoline PHEV-40	n/a	84.3	97.2	101.6
Acceleration (seconds; 0-60 mph)	**2005**	**2010**	**2015**	**2020**
Gasoline SI ICE	9.0	9.0	9.0	9.0
Diesel CI ICE	9.0	9.0	8.9	8.9
Gasoline HEV	9.0	9.0	9.0	9.0
Advanced Gasoline SI ICE	n/a	8.9	8.3	8.3
Gasoline PHEV-12	n/a	7.7	6.8	6.9
Gasoline PHEV-20	n/a	7.7	6.9	7.1
Gasoline PHEV-40	n/a	7.8	7.4	7.4
Battery Size (kWh)	**2005**	**2010**	**2015**	**2020**

Gasoline SI ICE	0	0	0	0
Diesel CI ICE	0	0	0	0
Gasoline HEV	1.0	1.0	1.0	1.0
Advanced Gasoline SI ICE	n/a	1.1	1.0	1.0
Gasoline PHEV-12	n/a	4.5	4.1	4.0
Gasoline PHEV-20	n/a	6.5	5.6	5.4
Gasoline PHEV-40	n/a	13.0	11.1	10.6

Table A-2: Light truck attributes by model year for the MA³T Model "high technology" case, prior to applying the existing Plug-in Vehicle Tax Credit.

Vehicle Purchase Price	2005	2010	2015	2020
Gasoline SI ICE	$22,478	$22,478	$22,134	$22,040
Diesel CI ICE	$26,503	$26,503	$25,789	$26,200
Gasoline HEV	$23,659	$23,322	$22,528	$22,292
Advanced Gasoline SI ICE	n/a	$23,153	$22,449	$22,241
Gasoline PHEV-12	n/a	$28,138	$25,120	$24,497
Gasoline PHEV-20	n/a	$31,352	$26,798	$25,927
Gasoline PHEV-40	n/a	$39,387	$30,990	$29,501
Fuel Economy (mpgge)	**2005**	**2010**	**2015**	**2020**
Gasoline SI ICE	21.5	21.5	27.8	28.8
Diesel CI ICE	34.2	34.2	35.9	37.4
Gasoline HEV	44.3	44.3	50.6	52.4
Advanced Gasoline SI ICE	n/a	32.0	41.4	42.9
Gasoline PHEV-12	n/a	48.9	55.3	57.1
Gasoline PHEV-20	n/a	51.9	58.7	60.6
Gasoline PHEV-40	n/a	59.4	67.2	69.4
Acceleration (seconds; 0-60 mph)	**2005**	**2010**	**2015**	**2020**
Gasoline SI ICE	9.0	9.0	9.0	9.0
Diesel CI ICE	9.0	9.0	9.0	9.0
Gasoline HEV	9.0	9.0	8.9	8.9
Advanced Gasoline SI ICE	n/a	7.8	7.8	7.8
Gasoline PHEV-12	n/a	7.7	7.2	7.1
Gasoline PHEV-20	n/a	7.6	7.2	7.1
Gasoline PHEV-40	n/a	7.5	7.2	7.0
Battery Size (kWh)	**2005**	**2010**	**2015**	**2020**
Gasoline SI ICE	0	0	0	0
Diesel CI ICE	0	0	0	0
Gasoline HEV	1.2	1.2	1.2	1.1
Advanced Gasoline SI ICE	n/a	1.3	1.1	1.1
Gasoline PHEV-12	n/a	5.4	5.0	4.9
Gasoline PHEV-20	n/a	9.0	7.6	7.5
Gasoline PHEV-40	n/a	17.7	15.1	14.7

Results

Table A-3: Projected PHEV sales for current policy case using the MA^3T Model.

HIGH Technology Case; Learning By Doing Reduced ~ 0% (A=0.1); Includes Existing Federal Tax Credit

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,968	11,205,052	9,618,156	8,165,255	6,762,653	5,380,873	4,027,508	2,728,424	1,431,982	828,528	562,596
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,784	2,506,145	2,404,752	2,156,486	1,845,141	1,505,782	1,149,099	791,915	421,876	249,946	167,391
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,553	3,144,135	4,835,693	6,475,048	8,081,215	9,661,251	11,325,933	13,109,372	14,868,829	15,881,683	16,388,008
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,531	62,507	136,794	203,917	256,820	308,304	363,264	431,741	538,099	692,903
Gasoline PHEV-12	0	0	0	0	0	374	13,862	81,395	185,520	283,038	366,206	363,621	311,006	266,331	260,498	279,793
Gasoline PHEV-20	0	0	0	0	0	107	1,970	8,520	18,893	32,415	51,267	58,797	55,378	50,951	49,318	48,467
Gasoline PHEV-40	0	0	0	0	0	19	185	655	1,474	3,012	6,465	7,272	6,008	4,925	4,605	4,715
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,163	16,882,879	17,011,679	17,139,469	17,211,391	17,228,664	17,240,533	17,365,366	17,476,635	17,812,677	18,143,873

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,170	6,268,454	5,381,757	4,490,220	3,601,082	2,739,095	1,929,716	1,191,174	507,231	241,597	140,379
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,172	1,043,040	1,022,452	911,332	760,666	597,547	434,685	279,610	128,908	68,020	41,578
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,210	1,270,864	2,041,259	2,852,432	3,652,555	4,446,656	5,285,085	6,173,793	6,999,315	7,499,334	7,673,637
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,388	53,742	117,268	170,420	206,544	236,201	257,664	265,230	280,717	303,877
Gasoline PHEV-12	0	0	0	0	0	299	12,644	76,850	175,475	264,940	336,146	323,328	260,920	197,362	167,580	156,837
Gasoline PHEV-20	0	0	0	0	0	82	1,736	7,828	17,465	29,837	46,838	53,066	48,997	43,658	41,076	39,247
Gasoline PHEV-40	0	0	0	0	0	18	183	651	1,461	2,974	6,344	7,074	5,765	4,607	4,211	4,224
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,200	8,606,309	8,584,539	8,565,653	8,482,473	8,379,170	8,269,154	8,217,925	8,146,310	8,302,535	8,359,779

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,798	4,936,598	4,236,400	3,675,035	3,161,571	2,641,778	2,097,792	1,537,249	924,752	586,931	422,217
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,105	1,382,300	1,245,154	1,084,475	908,235	714,414	512,304	292,967	181,926	125,813
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,873,271	2,794,434	3,622,615	4,428,660	5,214,596	6,040,848	6,935,579	7,869,515	8,382,349	8,714,371
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,143	8,765	19,526	33,496	50,276	72,103	105,600	166,511	257,382	389,026
Gasoline PHEV-12	0	0	0	0	0	75	1,217	4,545	10,046	18,099	30,060	40,293	50,085	68,969	92,918	122,956
Gasoline PHEV-20	0	0	0	0	0	25	234	692	1,428	2,579	4,428	5,731	6,381	7,292	8,242	9,220
Gasoline PHEV-40	0	0	0	0	0	1	2	4	12	38	121	198	243	319	394	491
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,963	8,276,570	8,427,140	8,573,816	8,728,918	8,849,494	8,971,379	9,147,441	9,330,325	9,510,142	9,784,094

Table A-4: *Projected PHEV sales for Section 6.1's state sales tax exemption program using the MA³T Model.*

Vehicle Price Reduced By 6%

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year–> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,688	11,204,771	9,625,178	8,172,016	6,767,450	5,383,709	4,017,894	2,678,038	1,345,342	745,211	482,587
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,740	2,499,965	2,391,269	2,143,265	1,833,884	1,496,484	1,139,432	773,722	395,575	224,448	143,267
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,494	3,126,950	4,714,014	6,250,638	7,746,536	9,145,212	10,639,345	12,250,777	13,543,680	13,819,055	13,534,993
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,305	52,272	101,569	147,358	185,431	229,609	279,322	323,902	367,495	413,604
Gasoline PHEV-12	0	0	0	0	0	642	33,772	201,740	414,437	617,180	860,081	1,035,690	1,221,314	1,728,553	2,528,937	3,448,335
Gasoline PHEV-20	0	0	0	0	0	201	5,383	24,453	51,648	86,826	132,181	149,624	138,403	120,967	111,314	105,782
Gasoline PHEV-40	0	0	0	0	0	50	743	2,737	5,894	12,174	25,575	28,936	23,798	18,603	16,208	15,290
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,173	16,882,888	17,011,663	17,139,467	17,211,407	17,228,674	17,240,529	17,365,375	17,476,623	17,812,668	18,143,858

Passenger Car Sales by Technology

Technology Type	Model Year–> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,082,928	6,261,516	5,358,087	4,458,017	3,566,284	2,704,068	1,893,681	1,142,817	454,204	201,927	109,011
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,137	1,038,759	1,007,597	893,287	742,856	580,744	419,768	264,431	114,430	56,521	32,160
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,158	1,261,401	1,962,323	2,690,977	3,397,781	4,040,866	4,742,523	5,505,242	6,035,935	6,112,157	5,859,445
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,177	43,814	82,865	115,367	138,049	163,250	186,466	191,021	187,215	177,708
Gasoline PHEV-12	0	0	0	0	0	531	31,507	192,429	392,665	574,393	776,645	892,675	974,823	1,231,305	1,642,265	2,089,009
Gasoline PHEV-20	0	0	0	0	0	159	4,883	22,837	48,125	80,197	120,572	134,329	121,024	100,584	87,760	78,781
Gasoline PHEV-40	0	0	0	0	0	45	715	2,662	5,719	11,754	24,559	27,557	22,375	17,120	14,675	13,664
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,207	8,607,959	8,589,749	8,571,654	8,488,632	8,385,504	8,273,783	8,217,178	8,144,600	8,302,520	8,359,778

Light Truck Sales by Technology

Technology Type	Model Year–> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,760	4,943,255	4,267,091	3,713,999	3,201,166	2,679,641	2,124,213	1,535,222	891,138	543,284	373,576
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,603	1,461,206	1,383,671	1,249,978	1,091,028	915,740	719,664	509,291	281,145	167,927	111,107
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,336	1,865,550	2,751,691	3,559,662	4,348,755	5,104,346	5,896,822	6,745,536	7,507,746	7,706,898	7,675,548
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,127	8,458	18,704	31,991	47,382	66,359	92,856	132,881	180,280	235,896
Gasoline PHEV-12	0	0	0	0	0	111	2,264	9,312	21,772	42,787	83,436	143,015	246,491	497,248	886,672	1,359,326
Gasoline PHEV-20	0	0	0	0	0	42	500	1,615	3,523	6,629	11,609	15,295	17,379	20,383	23,554	27,001
Gasoline PHEV-40	0	0	0	0	0	5	27	76	175	420	1,016	1,378	1,423	1,482	1,533	1,626
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,966	8,274,929	8,421,914	8,567,813	8,722,775	8,843,170	8,966,746	9,148,197	9,332,023	9,510,148	9,784,080

Table A-5: Projected PHEV sales for Section 6.2s feebate schemes using the MA³T Model.

For PHEV's Only: $1,000 rebate per 0.01 gallon/mile above 2x 2010 CAFE (27.5 mpg car, 23.5 mpg light truck) balanced by fees on conventional vehicles

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,207,746	15,841,300	15,372,876	14,863,378	13,787,238	12,442,159	10,798,243	9,253,968	7,841,434	6,479,573	5,138,256	3,855,696	2,674,081	1,470,792	914,866	649,923
Diesel CI ICE	3,350	38,605	193,179	632,951	1,406,460	2,355,500	2,790,819	2,646,804	2,358,174	2,006,089	1,626,265	1,235,592	860,558	467,158	289,730	199,241
Gasoline HEV	22,863	112,288	287,513	513,300	909,262	1,640,388	3,252,505	4,872,961	6,422,797	7,935,791	9,392,834	11,031,566	12,785,409	14,485,582	15,379,141	15,742,144
Advanced Gasoline SI ICE	0	0	0	0	0	366	11,708	59,950	120,357	171,991	214,032	271,244	339,748	426,134	544,507	715,452
Gasoline PHEV-12	0	0	0	0	0	418	16,968	99,886	212,706	314,315	410,044	439,301	420,966	440,045	523,429	675,636
Gasoline PHEV-20	0	0	0	0	0	327	12,613	77,968	183,784	303,253	446,423	405,807	282,710	183,968	156,569	155,204
Gasoline PHEV-40	0	0	0	0	0	5	38	109	207	390	808	1,335	1,880	2,938	4,423	6,241
All Technologies	16,233,959	15,992,193	15,853,568	16,009,629	16,102,960	16,439,163	16,882,893	17,011,645	17,139,460	17,211,402	17,228,662	17,240,541	17,365,353	17,476,616	17,812,665	18,143,841

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,088,287	8,750,860	8,780,473	8,322,062	7,670,650	7,044,744	6,164,135	5,206,180	4,271,081	3,360,056	2,496,375	1,721,540	1,056,139	441,522	218,293	129,754
Diesel CI ICE	2,531	24,651	102,753	276,148	535,959	852,371	1,063,778	1,027,568	899,943	736,196	564,378	401,878	256,495	115,704	62,751	38,974
Gasoline HEV	18,334	85,910	202,614	308,148	455,712	683,230	1,341,848	2,132,420	2,922,254	3,676,279	4,384,301	5,222,061	6,125,027	6,935,655	7,387,490	7,513,352
Advanced Gasoline SI ICE	0	0	0	0	0	250	9,392	50,093	97,547	131,641	152,370	181,756	209,770	224,702	240,893	261,651
Gasoline PHEV-12	0	0	0	0	0	336	15,505	93,902	198,428	286,612	360,448	367,767	324,531	289,874	294,931	330,914
Gasoline PHEV-20	0	0	0	0	0	268	11,706	74,370	174,895	284,911	410,484	360,851	236,682	131,493	93,959	79,307
Gasoline PHEV-40	0	0	0	0	0	5	38	108	207	389	806	1,327	1,856	2,855	4,207	5,811
All Technologies	8,109,152	8,861,421	9,085,840	8,906,358	8,662,321	8,581,204	8,606,400	8,584,642	8,564,355	8,476,085	8,369,163	8,257,180	8,210,499	8,141,804	8,302,524	8,359,763

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,459	7,090,440	6,592,403	6,541,316	6,116,588	5,397,415	4,634,108	4,047,788	3,570,354	3,119,517	2,641,881	2,134,156	1,617,942	1,029,270	696,573	520,169
Diesel CI ICE	819	13,954	90,426	356,803	870,501	1,503,129	1,727,041	1,619,235	1,458,230	1,269,892	1,061,887	833,714	604,063	351,454	226,979	160,267
Gasoline HEV	4,529	26,378	84,899	205,152	453,550	957,158	1,910,658	2,740,541	3,500,543	4,259,512	5,008,533	5,809,505	6,660,383	7,549,928	7,991,651	8,228,792
Advanced Gasoline SI ICE	0	0	0	0	0	116	2,316	9,857	22,810	40,350	61,661	89,489	129,978	201,432	303,614	453,801
Gasoline PHEV-12	0	0	0	0	0	82	1,464	5,984	14,278	27,703	49,596	71,534	96,436	150,171	228,498	344,722
Gasoline PHEV-20	0	0	0	0	0	59	907	3,598	8,889	18,343	35,939	44,956	46,028	52,474	62,610	75,897
Gasoline PHEV-40	0	0	0	0	0	0	0	0	0	1	2	7	24	83	216	430
All Technologies	8,124,807	7,130,772	6,767,728	7,103,271	7,440,639	7,857,959	8,276,493	8,427,003	8,575,105	8,735,317	8,859,499	8,983,361	9,154,854	9,334,812	9,510,141	9,784,078

For All Vehicles: $1,000 rebate per 0.01 gallon/mile above 2x 2010 CAFE (27.5 mpg car, 23.5 mpg light truck) balanced by fees on conventional vehicles

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,834,946	15,349,640	14,820,196	13,701,866	12,256,122	10,612,206	9,072,873	7,649,153	6,274,401	4,921,756	3,632,445	2,438,955	1,256,963	780,446	557,690
Diesel CI ICE	3,350	38,582	192,823	631,006	1,398,110	2,321,848	2,653,005	2,504,046	2,226,603	1,887,408	1,518,912	1,140,311	773,338	395,842	245,146	169,547
Gasoline HEV	22,863	118,662	311,101	558,442	1,002,980	1,860,090	3,582,311	5,241,264	6,832,562	8,382,335	9,888,495	11,551,581	13,331,578	15,058,229	15,958,640	16,452,191
Advanced Gasoline SI ICE	0	0	0	0	0	363	10,130	49,304	101,227	147,027	184,104	230,637	281,597	335,696	399,041	482,551
Gasoline PHEV-12	0	0	0	0	0	409	14,460	80,899	177,069	265,057	342,850	355,681	321,357	302,207	325,732	382,644
Gasoline PHEV-20	0	0	0	0	0	321	10,772	63,159	152,675	254,853	371,891	328,810	217,104	125,527	100,483	94,832
Gasoline PHEV-40	0	0	0	0	0	5	34	91	177	327	665	1,057	1,435	2,171	3,171	4,403
All Technologies	16,233,959	15,992,190	15,853,564	16,009,644	16,102,956	16,439,158	16,882,918	17,011,637	17,139,465	17,211,408	17,228,674	17,240,522	17,365,364	17,476,635	17,812,659	18,143,858

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,744,506	8,757,331	8,280,776	7,598,410	6,908,473	5,986,074	4,999,532	4,046,971	3,132,469	2,279,418	1,521,615	875,718	310,556	146,097	84,258
Diesel CI ICE	2,531	24,628	102,396	274,306	529,621	833,458	988,382	933,504	804,816	647,550	486,376	335,853	202,221	79,279	41,268	25,017
Gasoline HEV	18,334	92,284	226,111	351,276	534,286	838,425	1,624,170	2,496,810	3,339,741	4,119,377	4,843,462	5,668,238	6,540,929	7,306,433	7,726,556	7,879,890
Advanced Gasoline SI ICE	0	0	0	0	0	247	8,053	40,711	81,054	110,813	128,316	150,027	166,493	165,090	161,168	156,358
Gasoline PHEV-12	0	0	0	0	0	327	13,149	75,682	164,440	240,336	298,857	293,959	242,075	188,126	168,429	166,198
Gasoline PHEV-20	0	0	0	0	0	262	9,957	60,014	144,802	238,477	339,979	289,922	179,074	85,410	56,041	44,057
Gasoline PHEV-40	0	0	0	0	0	5	34	91	176	326	663	1,049	1,411	2,088	2,961	3,993
All Technologies	8,109,152	8,861,418	9,085,838	8,906,358	8,662,317	8,581,197	8,629,819	8,606,344	8,581,999	8,489,347	8,377,070	8,260,664	8,207,920	8,136,982	8,302,520	8,359,771

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,090,440	6,592,309	6,539,420	6,103,456	5,347,649	4,626,132	4,073,341	3,602,182	3,141,932	2,642,339	2,110,830	1,563,238	946,407	634,349	473,432
Diesel CI ICE	819	13,954	90,427	356,700	868,489	1,488,390	1,664,623	1,570,542	1,421,787	1,239,858	1,032,536	804,458	571,117	316,563	203,878	144,530
Gasoline HEV	4,529	26,378	84,990	207,166	468,694	1,021,665	1,958,141	2,744,455	3,492,821	4,262,959	5,045,033	5,883,343	6,790,649	7,751,796	8,232,084	8,572,301
Advanced Gasoline SI ICE	0	0	0	0	0	116	2,077	8,593	20,174	36,214	55,788	80,610	115,104	170,606	237,873	326,193
Gasoline PHEV-12	0	0	0	0	0	82	1,311	5,217	12,629	24,721	43,994	61,722	79,282	114,081	157,303	216,446
Gasoline PHEV-20	0	0	0	0	0	59	816	3,145	7,872	16,376	31,912	38,888	38,031	40,117	44,442	50,775
Gasoline PHEV-40	0	0	0	0	0	0	0	0	0	1	2	7	24	83	210	410
All Technologies	8,124,807	7,130,772	6,767,726	7,103,286	7,440,639	7,857,961	8,253,099	8,405,293	8,557,466	8,722,061	8,851,604	8,979,858	9,157,444	9,339,653	9,510,139	9,784,087

For All Vehicles: $1,000 rebate per 0.01 gallon/mile above 1x 2010 CAFE (27.5 mpg car, 23.5 mpg light truck) balanced by fees on conventional vehicles

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,739,603	14,852,675	13,353,389	11,752,425	10,142,128	8,498,211	6,961,234	5,537,830	4,184,677	2,876,872	1,644,646	708,362	394,457	262,660	198,862
Diesel CI ICE	3,350	55,256	338,484	1,210,668	1,868,517	2,276,213	2,336,915	2,185,602	1,907,841	1,547,048	1,133,714	703,080	339,556	196,364	135,729	102,423
Gasoline HEV	22,863	197,329	662,403	1,445,580	2,482,028	4,020,298	6,035,578	7,785,876	9,454,578	11,021,201	12,506,590	14,159,460	15,715,045	16,313,926	16,817,062	17,191,619
Advanced Gasoline SI ICE	0	0	0	0	0	155	2,915	16,413	44,920	81,267	120,686	180,658	250,100	282,531	314,837	350,832
Gasoline PHEV-12	0	0	0	0	0	210	5,284	34,988	103,915	190,815	278,049	292,884	234,674	212,498	216,815	236,678
Gasoline PHEV-20	0	0	0	0	0	167	3,979	27,507	90,289	186,185	312,271	258,901	116,284	74,898	62,768	59,562
Gasoline PHEV-40	0	0	0	0	0	2	11	36	90	202	487	893	1,344	1,945	2,799	3,891
All Technologies	16,233,959	15,992,188	15,853,562	16,009,637	16,102,970	16,439,173	16,882,892	17,011,657	17,139,463	17,211,394	17,228,668	17,240,522	17,365,365	17,476,619	17,812,670	18,143,867

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,670,267	8,417,793	7,462,130	6,624,692	5,763,798	4,797,907	3,851,204	2,955,652	2,107,929	1,323,075	639,661	184,483	74,870	40,030	25,570
Diesel CI ICE	2,531	36,111	188,211	571,178	841,402	1,011,723	1,023,131	932,879	780,426	593,601	396,499	212,509	77,424	36,467	22,281	15,274
Gasoline HEV	18,334	155,041	479,831	873,055	1,342,987	2,040,138	3,039,932	3,930,147	4,743,788	5,430,911	6,033,008	6,754,539	7,452,535	7,675,512	7,923,486	8,023,778
Advanced Gasoline SI ICE	0	0	0	0	0	111	2,375	13,873	37,363	64,170	88,024	123,658	157,353	157,294	150,963	139,282
Gasoline PHEV-12	0	0	0	0	0	171	4,838	32,973	97,908	176,706	248,790	248,093	176,494	139,535	125,100	119,981
Gasoline PHEV-20	0	0	0	0	0	139	3,701	26,289	86,541	176,830	290,822	231,512	92,005	51,368	37,900	32,098
Gasoline PHEV-40	0	0	0	0	0	2	11	35	90	202	487	893	1,344	1,940	2,773	3,800
All Technologies	8,109,152	8,861,419	9,085,835	8,906,363	8,809,081	8,816,083	8,871,895	8,787,399	8,701,768	8,550,349	8,380,705	8,210,865	8,141,638	8,136,986	8,302,533	8,359,783

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,069,336	6,434,882	5,891,259	5,127,733	4,378,330	3,700,304	3,110,030	2,582,177	2,076,748	1,553,797	1,004,985	523,879	319,587	222,630	173,292
Diesel CI ICE	819	19,145	150,273	639,490	1,027,115	1,264,490	1,313,784	1,252,723	1,127,415	953,447	737,214	490,571	262,132	159,897	113,448	87,149
Gasoline HEV	4,529	42,288	182,572	572,525	1,139,040	1,980,160	2,995,645	3,855,730	4,710,789	5,590,290	6,473,581	7,404,921	8,262,510	8,638,414	8,893,576	9,167,841
Advanced Gasoline SI ICE	0	0	0	0	0	44	539	2,541	7,557	17,097	32,662	57,000	92,747	125,237	163,874	211,550
Gasoline PHEV-12	0	0	0	0	0	39	446	2,015	6,007	14,109	29,259	44,791	58,180	72,963	91,715	116,697
Gasoline PHEV-20	0	0	0	0	0	28	278	1,219	3,748	9,354	21,449	27,390	24,279	23,530	24,868	27,464
Gasoline PHEV-40	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	91
All Technologies	8,124,807	7,130,769	6,767,727	7,103,274	7,293,889	7,623,090	8,010,997	8,224,258	8,437,695	8,661,045	8,847,963	9,029,657	9,223,727	9,339,633	9,510,137	9,784,084

Table A-6: *Projected PHEV sales for Section 6.3's annual operating cost allowances using the MA³T Model.*

$150 Credit Applied To Annual Vehicle-Related Expenses

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,770	11,204,853	9,621,737	8,168,987	6,765,428	5,382,592	4,021,648	2,736,684	1,443,881	824,108	551,264
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,753	2,502,827	2,397,653	2,149,236	1,838,850	1,500,547	1,143,479	791,611	424,193	248,205	163,851
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,510	3,134,957	4,772,775	6,350,821	7,894,494	9,393,926	11,027,824	12,789,435	14,506,343	15,454,867	15,829,333
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,413	57,241	115,677	165,944	205,755	251,995	303,997	360,195	431,644	521,469
Gasoline PHEV-12	0	0	0	0	0	436	17,567	99,367	209,241	305,289	389,525	399,833	364,054	346,510	373,131	435,647
Gasoline PHEV-20	0	0	0	0	0	317	10,964	61,814	143,229	236,957	347,215	385,336	370,714	387,966	473,530	634,919
Gasoline PHEV-40	0	0	0	0	0	28	312	1,079	2,271	4,427	9,099	10,405	8,860	7,539	7,191	7,391
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,172	16,882,893	17,011,667	17,139,463	17,211,389	17,228,659	17,240,521	17,365,356	17,476,626	17,812,676	18,143,874

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,013	6,265,024	5,370,516	4,474,579	3,584,762	2,724,205	1,915,118	1,190,466	512,788	240,687	137,774
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,150	1,040,822	1,015,017	902,016	751,616	589,565	428,164	277,388	129,320	67,414	40,660
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,174	1,265,935	2,001,337	2,765,517	3,516,102	4,247,853	5,064,336	5,952,110	6,772,091	7,255,799	7,385,975
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,279	48,650	96,697	133,587	157,778	184,270	208,314	218,487	227,061	233,947
Gasoline PHEV-12	0	0	0	0	0	351	16,051	93,505	196,064	281,204	348,963	344,109	292,655	243,678	227,035	231,650
Gasoline PHEV-20	0	0	0	0	0	245	9,758	57,062	131,794	214,252	305,206	324,821	290,655	264,726	278,058	323,208
Gasoline PHEV-40	0	0	0	0	0	26	306	1,061	2,225	4,306	8,771	9,919	8,318	6,911	6,474	6,566
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,208	8,607,175	8,587,148	8,568,893	8,485,828	8,382,340	8,270,737	8,219,907	8,148,001	8,302,528	8,359,780

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,757	4,939,829	4,251,222	3,694,408	3,180,666	2,658,387	2,106,530	1,546,219	931,093	583,421	413,490
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,603	1,462,005	1,382,636	1,247,220	1,087,234	910,982	715,315	514,223	294,873	180,791	123,191
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,336	1,869,022	2,771,438	3,585,305	4,378,392	5,146,074	5,963,488	6,837,325	7,734,251	8,199,068	8,443,358
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,134	8,591	18,980	32,357	47,978	67,726	95,683	141,708	204,583	287,522
Gasoline PHEV-12	0	0	0	0	0	85	1,516	5,862	13,177	24,085	40,562	55,724	71,399	102,832	146,096	203,997
Gasoline PHEV-20	0	0	0	0	0	72	1,207	4,752	11,434	22,705	42,008	60,515	80,059	123,240	195,472	311,711
Gasoline PHEV-40	0	0	0	0	0	2	6	18	46	122	329	486	542	628	717	825
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,964	8,275,718	8,424,519	8,570,570	8,725,561	8,846,319	8,969,784	9,145,449	9,328,625	9,510,148	9,784,094

Table A-7: *Projected PHEV sales for Section 6.4's extended plug-in vehicle tax credit using the MA³T Model.*

Existing Federal Tax Credit Extended Through 2020

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,968	11,205,052	9,618,195	8,165,312	6,762,709	5,380,921	4,017,365	2,665,019	1,328,813	752,499	485,396
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,784	2,506,129	2,404,698	2,156,415	1,845,072	1,505,719	1,146,408	774,700	392,778	227,357	144,342
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,553	3,144,082	4,835,110	6,473,275	8,077,127	9,652,082	11,210,042	12,803,897	14,156,163	14,450,108	13,827,363
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,530	62,458	136,455	202,901	254,554	292,387	325,767	363,230	421,037	490,927
Gasoline PHEV-12	0	0	0	0	0	374	13,861	81,322	185,005	281,493	362,670	452,879	594,644	906,345	1,514,745	2,675,931
Gasoline PHEV-20	0	0	0	0	0	107	2,023	9,122	21,130	37,851	62,446	97,651	146,931	209,722	255,242	281,496
Gasoline PHEV-40	0	0	0	0	0	19	196	756	1,870	4,252	10,281	23,801	54,425	119,575	191,679	238,393
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,163	16,882,873	17,011,662	17,139,462	17,211,405	17,228,674	17,240,534	17,365,383	17,476,627	17,812,667	18,143,848

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,170	6,268,437	5,381,659	4,490,003	3,600,727	2,738,560	1,919,023	1,146,236	444,422	200,704	105,598
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,172	1,043,029	1,022,388	911,212	760,495	597,318	431,783	268,867	113,544	56,709	31,346
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,210	1,270,832	2,040,880	2,851,136	3,649,336	4,439,032	5,183,810	5,893,741	6,389,309	6,402,539	5,878,326
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,388	53,695	116,935	169,424	204,332	220,799	221,538	203,127	190,298	177,466
Gasoline PHEV-12	0	0	0	0	0	299	12,643	76,778	174,965	263,408	332,648	402,162	499,501	693,233	1,054,949	1,719,520
Gasoline PHEV-20	0	0	0	0	0	82	1,785	8,401	19,595	34,980	57,323	88,866	131,867	183,092	214,129	222,932
Gasoline PHEV-40	0	0	0	0	0	18	194	751	1,853	4,196	10,092	23,239	52,846	115,301	183,197	224,579
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,200	8,606,308	8,584,552	8,565,700	8,482,567	8,379,304	8,269,682	8,214,595	8,142,028	8,302,525	8,359,767

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,798	4,936,615	4,236,536	3,675,309	3,161,982	2,642,361	2,098,342	1,518,784	884,391	551,795	379,798
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,100	1,382,310	1,245,202	1,084,577	908,402	714,625	505,834	279,234	170,648	112,996
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,873,250	2,794,230	3,622,139	4,427,791	5,213,050	6,026,232	6,910,156	7,766,854	8,047,569	7,949,037
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,143	8,764	19,520	33,477	50,222	71,588	104,230	160,103	230,739	313,461
Gasoline PHEV-12	0	0	0	0	0	75	1,217	4,544	10,040	18,084	30,022	50,717	95,142	213,112	459,796	956,411
Gasoline PHEV-20	0	0	0	0	0	25	238	722	1,535	2,871	5,123	8,785	15,063	26,630	41,113	58,564
Gasoline PHEV-40	0	0	0	0	0	1	2	5	17	56	189	563	1,579	4,273	8,482	13,814
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,963	8,276,565	8,427,110	8,573,762	8,728,838	8,849,370	8,970,852	9,150,788	9,334,599	9,510,142	9,784,081

Table A-8: *Projected PHEV sales for Section 6.5's federally-backed advanced battery warranty program using the MA³T Model.*

Battery Replacement Cost Halved Through 2015, Then Gradual Return Via Linear Interpolation To Original Estimate By 2030

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,206,180	15,836,367	15,376,241	14,921,278	13,958,877	12,678,405	11,034,488	9,456,881	7,994,335	6,579,144	5,184,994	3,820,077	2,517,906	1,225,913	728,284	505,175
Diesel CI ICE	3,350	37,323	179,909	569,761	1,237,301	2,034,611	2,375,917	2,265,235	2,026,614	1,727,858	1,400,868	1,056,563	712,503	355,853	217,134	148,967
Gasoline HEV	24,419	118,501	297,424	518,591	906,793	1,725,201	3,443,959	5,136,194	6,773,216	8,373,238	9,943,277	11,607,326	13,393,060	15,152,562	16,052,192	16,542,401
Advanced Gasoline SI ICE	0	0	0	0	0	356	10,252	52,771	115,928	175,336	223,612	272,071	321,797	375,814	447,478	546,936
Gasoline PHEV-12	0	0	0	0	0	420	15,136	87,176	199,255	303,328	391,034	389,704	335,671	294,398	300,310	335,282
Gasoline PHEV-20	0	0	0	0	0	141	2,695	11,789	26,429	45,058	69,627	78,175	71,326	62,275	58,586	56,646
Gasoline PHEV-40	0	0	0	0	0	39	440	1,618	3,693	7,440	15,248	16,620	13,104	9,806	8,671	8,439
All Technologies	16,233,949	15,992,191	15,853,574	16,009,630	16,102,971	16,439,173	16,882,886	17,011,664	17,139,471	17,211,402	17,228,659	17,240,536	17,365,366	17,476,621	17,812,655	18,143,846

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,086,981	8,743,861	8,764,099	8,298,360	7,639,096	7,007,140	6,193,322	5,300,306	4,399,050	3,502,160	2,634,376	1,821,102	1,085,321	411,632	203,052	121,277
Diesel CI ICE	2,531	24,628	102,484	274,482	527,251	824,607	993,214	963,041	854,269	709,084	552,061	395,557	247,391	104,126	56,978	35,825
Gasoline HEV	19,637	92,935	219,265	333,513	495,981	748,728	1,412,135	2,196,671	3,008,432	3,800,478	4,580,834	5,412,628	6,298,425	7,117,191	7,564,099	7,725,474
Advanced Gasoline SI ICE	0	0	0	0	0	249	8,374	45,338	99,157	146,089	179,228	208,205	229,013	232,170	237,310	244,826
Gasoline PHEV-12	0	0	0	0	0	339	13,857	82,392	188,439	283,492	357,553	343,909	277,307	210,688	185,927	180,756
Gasoline PHEV-20	0	0	0	0	0	109	2,389	10,864	24,473	41,480	63,481	70,235	62,550	52,311	47,469	44,255
Gasoline PHEV-40	0	0	0	0	0	34	416	1,559	3,564	7,153	14,584	15,733	12,198	8,862	7,679	7,355
All Technologies	8,109,149	8,861,424	9,085,848	8,906,355	8,662,328	8,581,206	8,623,707	8,600,172	8,577,384	8,489,935	8,382,117	8,267,368	8,212,205	8,136,980	8,302,514	8,359,768

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,199	7,092,506	6,612,142	6,622,918	6,319,781	5,671,265	4,841,166	4,156,575	3,595,286	3,076,984	2,550,618	1,998,976	1,432,585	814,281	525,232	383,898
Diesel CI ICE	819	12,695	77,425	295,279	710,050	1,210,004	1,382,702	1,302,194	1,172,345	1,018,774	848,807	661,006	465,112	251,727	160,156	113,142
Gasoline HEV	4,782	25,566	78,159	185,078	410,812	976,473	2,031,824	2,939,523	3,764,784	4,572,760	5,362,443	6,194,697	7,094,635	8,035,371	8,488,093	8,816,927
Advanced Gasoline SI ICE	0	0	0	0	0	107	1,879	7,433	16,771	29,246	44,383	63,866	92,784	143,644	210,168	302,110
Gasoline PHEV-12	0	0	0	0	0	81	1,280	4,784	10,816	19,836	33,481	45,795	58,364	83,710	114,383	154,526
Gasoline PHEV-20	0	0	0	0	0	32	306	924	1,957	3,579	6,146	7,940	8,776	9,964	11,117	12,391
Gasoline PHEV-40	0	0	0	0	0	5	23	58	129	287	664	887	906	944	992	1,084
All Technologies	8,124,800	7,130,767	6,767,726	7,103,275	7,440,643	7,857,967	8,259,179	8,411,492	8,562,087	8,721,467	8,846,542	8,973,168	9,153,161	9,339,641	9,510,141	9,784,078

Table A-9: Projected PHEV sales for Section 6.6's increased charging infrastructure financial incentives using the MA^{3}T Model.

Central City Charging Access Up 25% (About 9 Million Households, **Not All Of Which Purchase PHEVS)**

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,956	11,205,040	9,618,457	8,165,567	6,762,880	5,381,014	4,026,495	2,727,735	1,430,186	827,109	561,286
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,782	2,505,925	2,404,220	2,155,943	1,844,685	1,505,412	1,148,544	791,542	421,286	249,491	166,989
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,550	3,143,500	4,830,673	6,465,089	8,067,223	9,642,162	11,305,276	13,086,754	14,842,567	15,847,533	16,344,025
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,521	62,067	135,000	200,985	253,300	304,716	359,536	426,967	530,419	680,017
Gasoline PHEV-12	0	0	0	0	0	386	14,726	87,088	197,644	300,481	389,268	389,491	338,315	299,480	303,845	337,933
Gasoline PHEV-20	0	0	0	0	0	107	1,969	8,459	18,624	31,885	50,456	58,052	54,875	50,698	49,192	48,389
Gasoline PHEV-40	0	0	0	0	0	20	198	707	1,588	3,256	7,031	7,956	6,599	5,422	5,094	5,220
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,139	16,882,680	17,010,965	17,137,867	17,208,139	17,221,611	17,232,575	17,358,757	17,471,185	17,807,589	18,138,639

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,161	6,268,198	5,380,812	4,488,865	3,599,693	2,737,826	1,928,133	1,190,261	506,168	240,995	139,961
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,170	1,042,886	1,021,854	910,565	759,938	596,913	434,093	279,254	128,605	67,843	41,449
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,207	1,270,509	2,037,998	2,845,245	3,641,932	4,431,811	5,268,789	6,156,834	6,981,015	7,478,122	7,648,976
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,378	53,315	115,513	167,557	203,158	232,877	254,586	262,142	276,844	298,541
Gasoline PHEV-12	0	0	0	0	0	311	13,465	82,294	186,944	281,073	356,740	345,262	282,206	219,817	193,122	186,985
Gasoline PHEV-20	0	0	0	0	0	82	1,735	7,769	17,200	29,312	46,033	52,321	48,492	43,405	40,954	39,186
Gasoline PHEV-40	0	0	0	0	0	19	196	701	1,573	3,213	6,893	7,730	6,324	5,068	4,653	4,679
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,199	8,606,367	8,584,743	8,565,906	8,482,717	8,379,374	8,269,205	8,217,957	8,146,221	8,302,533	8,359,777

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,795	4,936,842	4,237,645	3,676,702	3,163,187	2,643,188	2,098,362	1,537,473	924,018	586,114	421,325
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,039	1,382,367	1,245,378	1,084,747	908,498	714,452	512,288	292,681	181,648	125,540
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,872,991	2,792,675	3,619,844	4,425,291	5,210,350	6,036,487	6,929,920	7,861,552	8,369,411	8,695,049
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,142	8,752	19,487	33,428	50,142	71,839	104,951	164,826	253,575	381,476
Gasoline PHEV-12	0	0	0	0	0	75	1,261	4,795	10,699	19,407	32,528	44,230	56,109	79,663	110,723	150,948
Gasoline PHEV-20	0	0	0	0	0	25	234	691	1,424	2,574	4,423	5,731	6,383	7,293	8,238	9,203
Gasoline PHEV-40	0	0	0	0	0	1	2	5	15	44	138	226	274	353	441	541
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,960	8,276,511	8,426,929	8,573,549	8,728,678	8,849,268	8,971,326	9,147,399	9,330,386	9,510,150	9,784,082

Suburban Charging Access Up 15% (About 9 Million Households, **Not All Of Which Purchase PHEVS**)

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,963	11,205,047	9,618,291	8,165,400	6,762,759	5,380,940	4,027,109	2,728,275	1,431,511	828,044	562,097
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,783	2,506,048	2,404,515	2,156,241	1,844,936	1,505,615	1,148,862	791,790	421,696	249,791	167,237
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,551	3,143,861	4,833,488	6,470,605	8,074,888	9,652,488	11,316,420	13,099,018	14,856,929	15,866,925	16,369,525
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,528	62,321	136,002	202,588	255,182	306,612	361,508	429,491	534,512	686,927
Gasoline PHEV-12	0	0	0	0	0	379	14,229	83,833	190,808	290,733	376,402	375,012	322,952	280,666	279,015	304,396
Gasoline PHEV-20	0	0	0	0	0	107	1,970	8,497	18,780	32,182	50,892	58,447	55,141	50,831	49,255	48,435
Gasoline PHEV-40	0	0	0	0	0	21	202	717	1,616	3,316	7,147	8,068	6,685	5,483	5,136	5,241
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,162	16,882,885	17,011,663	17,139,451	17,211,403	17,228,666	17,240,530	17,365,370	17,476,607	17,812,678	18,143,858

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,167	6,268,344	5,381,354	4,489,635	3,600,477	2,738,540	1,929,051	1,190,868	506,938	241,399	140,226
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,171	1,042,974	1,022,192	910,993	760,343	597,265	434,427	279,470	128,808	67,962	41,528
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,208	1,270,712	2,039,837	2,849,247	3,647,785	4,439,903	5,277,685	6,166,173	6,991,218	7,490,289	7,663,372
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,385	53,561	116,493	169,123	204,967	234,633	256,208	263,776	278,911	301,409
Gasoline PHEV-12	0	0	0	0	0	304	12,989	79,164	180,446	272,010	345,182	332,899	270,132	206,941	178,311	169,351
Gasoline PHEV-20	0	0	0	0	0	82	1,736	7,805	17,354	29,606	46,467	52,716	48,760	43,538	41,014	39,219
Gasoline PHEV-40	0	0	0	0	0	19	198	705	1,588	3,241	6,941	7,763	6,339	5,073	4,649	4,666
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,200	8,606,338	8,584,619	8,565,757	8,482,584	8,379,266	8,269,174	8,217,949	8,146,292	8,302,535	8,359,771

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,796	4,936,702	4,236,937	3,675,764	3,162,282	2,642,399	2,098,058	1,537,408	924,573	586,645	421,871
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,074	1,382,324	1,245,248	1,084,594	908,350	714,435	512,320	292,888	181,829	125,709
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,873,149	2,793,652	3,621,358	4,427,104	5,212,585	6,038,735	6,932,845	7,865,710	8,376,636	8,706,153
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,143	8,760	19,508	33,465	50,214	71,980	105,300	165,715	255,601	385,518
Gasoline PHEV-12	0	0	0	0	0	75	1,241	4,669	10,362	18,723	31,220	42,113	52,820	73,724	100,704	135,045
Gasoline PHEV-20	0	0	0	0	0	25	234	691	1,426	2,576	4,426	5,731	6,382	7,293	8,241	9,216
Gasoline PHEV-40	0	0	0	0	0	2	5	12	28	75	205	305	346	410	487	575
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,962	8,276,547	8,427,044	8,573,694	8,728,819	8,849,400	8,971,356	9,147,421	9,330,315	9,510,143	9,784,087

Both - Central City Access Up 25% & Suburban Charging Access Up 15% (About 9 Million Households, **Not All Of Which Purchase PHEVS**)

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,951	11,205,035	9,618,592	8,165,708	6,762,985	5,381,080	4,025,914	2,727,225	1,428,993	826,250	560,518
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,781	2,505,822	2,403,977	2,155,694	1,844,472	1,505,239	1,148,254	791,319	420,910	249,224	166,755
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,548	3,143,216	4,828,402	6,460,546	8,060,693	9,633,023	11,295,276	13,075,764	14,829,641	15,829,898	16,320,471
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,519	61,875	134,197	199,647	251,650	303,011	357,758	424,710	526,788	673,919
Gasoline PHEV-12	0	0	0	0	0	391	15,105	89,601	203,036	308,326	399,795	401,521	351,312	315,758	325,726	368,072
Gasoline PHEV-20	0	0	0	0	0	107	1,968	8,436	18,512	31,652	50,086	57,707	54,638	50,575	49,120	48,338
Gasoline PHEV-40	0	0	0	0	0	22	220	782	1,758	3,610	7,808	8,849	7,352	6,049	5,672	5,784
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,158	16,882,885	17,011,664	17,139,451	17,211,384	17,228,680	17,240,532	17,365,367	17,476,636	17,812,678	18,143,857

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,158	6,268,085	5,380,394	4,488,262	3,599,070	2,737,251	1,927,341	1,189,736	505,501	240,640	139,723
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,169	1,042,815	1,021,587	910,223	759,607	596,621	433,805	279,069	128,427	67,743	41,378
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,205	1,270,352	2,036,533	2,841,987	3,637,021	4,424,774	5,260,982	6,148,673	6,972,111	7,467,397	7,636,075
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,377	53,129	114,727	166,252	201,572	231,296	253,113	260,665	274,999	296,002
Gasoline PHEV-12	0	0	0	0	0	316	13,820	84,679	192,011	288,268	366,038	355,321	292,155	230,610	205,737	202,305
Gasoline PHEV-20	0	0	0	0	0	82	1,734	7,746	17,089	29,079	45,662	51,972	48,250	43,274	40,877	39,139
Gasoline PHEV-40	0	0	0	0	0	20	215	769	1,726	3,526	7,578	8,509	6,967	5,592	5,135	5,153
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,199	8,606,398	8,584,837	8,566,024	8,482,823	8,379,497	8,269,226	8,217,963	8,146,180	8,302,528	8,359,775

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,793	4,936,951	4,238,198	3,677,446	3,163,915	2,643,828	2,098,573	1,537,489	923,492	585,610	420,795
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,006	1,382,389	1,245,471	1,084,865	908,618	714,448	512,250	292,483	181,481	125,377
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,872,864	2,791,869	3,618,559	4,423,673	5,208,249	6,034,294	6,927,091	7,857,530	8,362,501	8,684,396
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,142	8,746	19,471	33,395	50,078	71,716	104,646	164,046	251,789	377,917
Gasoline PHEV-12	0	0	0	0	0	75	1,285	4,922	11,025	20,058	33,757	46,201	59,157	85,148	119,989	165,767
Gasoline PHEV-20	0	0	0	0	0	25	234	691	1,423	2,573	4,423	5,734	6,387	7,300	8,243	9,199
Gasoline PHEV-40	0	0	0	0	0	2	5	12	32	84	229	341	384	457	537	631
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,959	8,276,487	8,426,827	8,573,427	8,728,561	8,849,183	8,971,306	9,147,404	9,330,456	9,510,150	9,784,082

Table A-10: Projected PHEV sales for Section 6.7's government fleet acquisition requirements using the MA³T Model.

Increased PHEV Mandates In Federal Government Fleets Beginning In 2010

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,968	11,205,052	9,618,156	8,165,255	6,762,653	5,380,873	4,027,508	2,728,424	1,431,982	828,528	562,596
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,784	2,506,145	2,404,752	2,156,486	1,845,141	1,505,782	1,149,099	791,915	421,876	249,946	167,391
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,553	3,144,135	4,835,693	6,475,048	8,081,215	9,661,251	11,325,933	13,109,372	14,868,829	15,881,683	16,388,008
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,531	62,507	136,794	203,917	256,820	308,304	363,264	431,741	538,099	692,903
Gasoline PHEV-12	0	0	0	0	0	374	13,862	81,395	185,520	283,038	366,206	363,621	311,006	266,331	260,498	279,793
Gasoline PHEV-20	0	0	0	0	0	6446	8,309	14,859	25,232	38,754	57,606	66,404	64,253	61,093	60,728	61,145
Gasoline PHEV-40	0	0	0	0	0	19	185	655	1,474	3,012	6,465	7,272	6,008	4,925	4,605	4,715
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,445,502	16,889,218	17,018,018	17,145,808	17,217,730	17,235,003	17,248,140	17,374,241	17,486,777	17,824,087	18,156,551

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,170	6,268,454	5,381,757	4,490,220	3,601,082	2,739,095	1,929,716	1,191,174	507,231	241,597	140,379
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,172	1,043,040	1,022,452	911,332	760,666	597,547	434,685	279,610	128,908	68,020	41,578
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,210	1,270,864	2,041,259	2,852,432	3,652,555	4,446,656	5,285,085	6,173,793	6,999,315	7,499,334	7,673,637
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,388	53,742	117,268	170,420	206,544	236,201	257,664	265,230	280,717	303,877
Gasoline PHEV-12	0	0	0	0	0	299	12,644	76,850	175,475	264,940	336,146	323,328	260,920	197,362	167,580	156,837
Gasoline PHEV-20	0	0	0	0	0	3251.5	4,905	10,998	20,635	33,006	50,008	56,869	53,435	48,729	46,781	45,586
Gasoline PHEV-40	0	0	0	0	0	18	182.687463	650.887719	1,461	2,974	6,344	7,074	5,765	4,607	4,211	4,224
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,584,370	8,609,479	8,587,708	8,568,822	8,485,643	8,382,339	8,272,958	8,222,362	8,151,381	8,308,240	8,366,118

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,798	4,936,598	4,236,400	3,675,035	3,161,571	2,641,778	2,097,792	1,537,249	924,752	586,931	422,217
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,105	1,382,300	1,245,154	1,084,475	908,235	714,414	512,304	292,967	181,926	125,813
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,873,271	2,794,434	3,622,615	4,428,660	5,214,596	6,040,848	6,935,579	7,869,515	8,382,349	8,714,371
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,143	8,765	19,526	33,496	50,276	72,103	105,600	166,511	257,382	389,026
Gasoline PHEV-12	0	0	0	0	0	75	1,217	4,545	10,046	18,099	30,060	40,293	50,085	68,969	92,918	122,956
Gasoline PHEV-20	0	0	0	0	0	3194.5	3403.62694	3861.51399	4,597	5,748	7,598	9,535	10,818	12,364	13,947	15,559
Gasoline PHEV-40	0	0	0	0	0	1	2	4	12	38	121	198	243	319	394	491
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,861,133	8,279,739	8,430,310	8,576,986	8,732,087	8,852,664	8,975,182	9,151,878	9,335,396	9,515,847	9,790,433

Table A-11: Projected PHEV sales for Section 6.8's vehicle subsidy program using the MA³T Model.

Vehicle Subsidy Program To Lower Initial Vehicle Price

Passenger Car & Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	16,207,746	15,844,918	15,397,538	14,958,171	14,032,213	12,848,968	11,205,052	9,618,156	8,165,255	6,762,653	5,380,873	4,027,508	2,728,424	1,431,982	828,528	562,596
Diesel CI ICE	3,350	37,351	180,235	571,525	1,245,080	2,066,784	2,506,145	2,404,752	2,156,486	1,845,141	1,505,782	1,149,099	791,915	421,876	249,946	167,391
Gasoline HEV	22,863	109,924	275,788	479,931	825,672	1,522,553	3,144,135	4,835,693	6,475,048	8,081,215	9,661,251	11,325,933	13,109,372	14,868,829	15,881,683	16,388,008
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,531	62,507	136,794	203,917	256,820	308,304	363,264	431,741	538,099	692,903
Gasoline PHEV-12	0	0	0	0	0	374	13,862	81,395	185,520	283,038	366,206	363,621	311,006	266,331	260,498	279,793
Gasoline PHEV-20	0	0	0	0	0	107	1,970	8,520	18,893	32,415	51,267	58,797	55,378	50,951	49,318	48,467
Gasoline PHEV-40	0	0	0	0	0	19	185	655	1,474	3,012	6,465	7,272	6,008	4,925	4,605	4,715
All Technologies	16,233,959	15,992,193	15,853,561	16,009,627	16,102,965	16,439,163	16,882,879	17,011,679	17,139,469	17,211,391	17,228,664	17,240,533	17,365,366	17,476,635	17,812,677	18,143,873

Passenger Car Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,088,287	8,750,860	8,780,296	8,321,967	7,678,038	7,083,170	6,268,454	5,381,757	4,490,220	3,601,082	2,739,095	1,929,716	1,191,174	507,231	241,597	140,379
Diesel CI ICE	2,531	24,651	102,735	275,546	530,677	835,172	1,043,040	1,022,452	911,332	760,666	597,547	434,685	279,610	128,908	68,020	41,578
Gasoline HEV	18,334	85,910	202,807	308,847	453,612	662,210	1,270,864	2,041,259	2,852,432	3,652,555	4,446,656	5,285,085	6,173,793	6,999,315	7,499,334	7,673,637
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,388	53,742	117,268	170,420	206,544	236,201	257,664	265,230	280,717	303,877
Gasoline PHEV-12	0	0	0	0	0	299	12,644	76,850	175,475	264,940	336,146	323,328	260,920	197,362	167,580	156,837
Gasoline PHEV-20	0	0	0	0	0	82	1,736	7,828	17,465	29,837	46,838	53,066	48,997	43,658	41,076	39,247
Gasoline PHEV-40	0	0	0	0	0	18	183	651	1,461	2,974	6,344	7,074	5,765	4,607	4,211	4,224
All Technologies	8,109,152	8,861,421	9,085,838	8,906,360	8,662,327	8,581,200	8,606,309	8,584,539	8,565,653	8,482,473	8,379,170	8,269,154	8,217,925	8,146,310	8,302,535	8,359,779

Light Truck Sales by Technology

	Model Year-->															
Technology Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Gasoline SI ICE	8,119,459	7,094,058	6,617,242	6,636,204	6,354,175	5,765,798	4,936,598	4,236,400	3,675,035	3,161,571	2,641,778	2,097,792	1,537,249	924,752	586,931	422,217
Diesel CI ICE	819	12,700	77,500	295,979	714,403	1,231,612	1,463,105	1,382,300	1,245,154	1,084,475	908,235	714,414	512,304	292,967	181,926	125,813
Gasoline HEV	4,529	24,014	72,981	171,084	372,060	860,343	1,873,271	2,794,434	3,622,615	4,428,660	5,214,596	6,040,848	6,935,579	7,869,515	8,382,349	8,714,371
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,143	8,765	19,526	33,496	50,276	72,103	105,600	166,511	257,382	389,026
Gasoline PHEV-12	0	0	0	0	0	75	1,217	4,545	10,046	18,099	30,060	40,293	50,085	68,969	92,918	122,956
Gasoline PHEV-20	0	0	0	0	0	25	234	692	1,428	2,579	4,428	5,731	6,381	7,292	8,242	9,220
Gasoline PHEV-40	0	0	0	0	0	1	2	4	12	38	121	198	243	319	394	491
All Technologies	8,124,807	7,130,772	6,767,723	7,103,267	7,440,638	7,857,963	8,276,570	8,427,140	8,573,816	8,728,918	8,849,494	8,971,379	9,147,441	9,330,325	9,510,142	9,784,094

Table A-12: *Projected PHEV sales for Section 6.9's gasoline tax increases using the MA³T Model.*

Gas Price Increased By 1 Cent

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,207,396	15,843,021	15,392,230	14,946,670	14,008,185	12,801,560	11,157,644	9,573,746	8,122,209	6,720,985	5,340,704	3,988,823	2,691,565	1,397,262	812,130	553,415
Diesel CI ICE	3,378	37,671	181,816	576,656	1,256,313	2,083,473	2,510,154	2,405,762	2,156,134	1,843,410	1,502,551	1,144,336	785,688	414,123	246,365	165,547
Gasoline HEV	23,180	111,489	279,509	486,315	838,467	1,553,269	3,187,867	4,881,277	6,521,864	8,128,179	9,707,979	11,372,639	13,156,318	14,916,463	15,909,317	16,410,731
Advanced Gasoline SI ICE	0	0	0	0	0	358	11,346	61,339	134,817	201,616	254,429	305,862	360,572	428,296	531,971	682,795
Gasoline PHEV-12	0	0	0	0	0	375	13,710	80,342	183,975	281,531	364,830	362,279	309,403	264,308	258,636	277,828
Gasoline PHEV-20	0	0	0	0	0	109	1,982	8,545	19,005	32,665	51,712	59,315	55,811	51,267	49,635	48,812
Gasoline PHEV-40	0	0	0	0	0	19	185	652	1,470	3,010	6,471	7,281	6,008	4,912	4,605	4,722
All Technologies	16,233,954	15,992,181	15,853,555	16,009,641	16,102,965	16,439,163	16,882,888	17,011,664	17,139,474	17,211,396	17,228,677	17,240,535	17,365,365	17,476,632	17,812,659	18,143,850

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,088,003	8,749,386	8,776,606	8,315,504	7,666,623	7,062,806	6,248,439	5,361,450	4,469,747	3,580,880	2,719,430	1,910,699	1,173,257	491,151	235,263	137,303
Diesel CI ICE	2,556	24,899	103,749	278,249	535,932	843,276	1,046,935	1,024,488	912,351	760,736	596,699	432,981	277,190	125,925	66,778	40,972
Gasoline HEV	18,588	87,135	205,479	312,609	459,768	674,466	1,290,283	2,063,891	2,876,542	3,676,617	4,470,042	5,307,804	6,195,918	7,020,601	7,511,132	7,682,532
Advanced Gasoline SI ICE	0	0	0	0	0	249	9,242	52,758	115,634	168,599	204,748	234,486	255,917	263,052	277,635	299,593
Gasoline PHEV-12	0	0	0	0	0	300	12,511	75,874	174,066	263,618	334,998	322,226	259,563	195,540	166,195	155,641
Gasoline PHEV-20	0	0	0	0	0	84	1,748	7,854	17,576	30,077	47,256	53,537	49,372	43,898	41,308	39,494
Gasoline PHEV-40	0	0	0	0	0	18	183	648	1,458	2,973	6,350	7,082	5,763	4,592	4,210	4,230
All Technologies	8,109,147	8,861,420	9,085,834	8,906,362	8,662,323	8,581,199	8,609,341	8,586,963	8,567,375	8,483,500	8,379,522	8,268,817	8,216,980	8,144,758	8,302,521	8,359,765

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,393	7,093,635	6,615,624	6,631,166	6,341,562	5,738,754	4,909,205	4,212,296	3,652,461	3,140,105	2,621,275	2,078,124	1,518,308	906,112	576,867	416,112
Diesel CI ICE	822	12,772	78,067	298,407	720,381	1,240,197	1,463,219	1,381,274	1,243,783	1,082,674	905,852	711,355	508,499	288,198	179,587	124,575
Gasoline HEV	4,592	24,354	74,030	173,706	378,699	878,803	1,897,584	2,817,387	3,645,322	4,451,561	5,237,937	6,064,835	6,960,400	7,895,862	8,398,185	8,728,199
Advanced Gasoline SI ICE	0	0	0	0	0	109	2,104	8,581	19,182	33,018	49,682	71,375	104,655	165,244	254,336	383,202
Gasoline PHEV-12	0	0	0	0	0	75	1,199	4,468	9,909	17,912	29,832	40,053	49,840	68,768	92,441	122,187
Gasoline PHEV-20	0	0	0	0	0	25	234	691	1,429	2,588	4,456	5,778	6,439	7,369	8,327	9,318
Gasoline PHEV-40	0	0	0	0	0	1	2	4	12	38	122	198	244	320	395	492
All Technologies	8,124,807	7,130,761	6,767,721	7,103,279	7,440,642	7,857,964	8,273,547	8,424,701	8,572,099	8,727,896	8,849,155	8,971,718	9,148,385	9,331,874	9,510,138	9,784,085

Gas Price Increased By 5 Cents

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,206,346	15,836,687	15,373,148	14,903,305	13,914,782	12,614,112	10,970,195	9,397,591	7,951,495	6,555,790	5,181,517	3,835,719	2,545,882	1,260,247	747,316	516,983
Diesel CI ICE	3,419	38,508	186,987	595,187	1,298,576	2,146,419	2,525,156	2,409,472	2,154,402	1,836,160	1,489,292	1,124,943	760,423	382,657	231,802	158,006
Gasoline HEV	24,176	116,997	293,447	511,157	889,601	1,677,770	3,361,431	5,061,344	6,706,360	8,313,277	9,892,124	11,556,547	13,340,943	15,103,102	16,015,129	16,494,823
Advanced Gasoline SI ICE	0	0	0	0	0	361	10,741	57,370	127,910	193,467	245,917	297,174	351,067	416,315	510,595	647,618
Gasoline PHEV-12	0	0	0	0	0	382	13,226	76,835	178,802	276,572	360,448	357,936	303,841	257,043	252,268	271,333
Gasoline PHEV-20	0	0	0	0	0	111	1,948	8,411	19,051	33,140	52,905	60,903	57,222	52,411	50,964	50,343
Gasoline PHEV-40	0	0	0	0	0	20	182	636	1,453	2,996	6,479	7,300	5,985	4,856	4,591	4,739
All Technologies	16,233,941	15,992,192	15,853,582	16,009,649	16,102,959	16,439,175	16,882,878	17,011,660	17,139,473	17,211,402	17,228,683	17,240,522	17,365,363	17,476,631	17,812,665	18,143,845

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,087,156	8,744,480	8,763,625	8,291,926	7,623,302	6,983,002	6,168,371	5,279,989	4,387,741	3,500,084	2,640,907	1,835,001	1,102,190	427,839	210,281	125,124
Diesel CI ICE	2,588	25,450	106,635	287,001	554,285	872,587	1,060,255	1,030,941	914,999	759,845	592,368	425,462	267,032	113,725	61,689	38,511
Gasoline HEV	19,402	91,496	215,589	327,436	484,733	724,959	1,369,064	2,154,673	2,972,615	3,772,271	4,562,752	5,397,547	6,282,941	7,103,661	7,556,257	7,715,356
Advanced Gasoline SI ICE	0	0	0	0	0	252	8,776	49,439	109,957	162,176	198,364	228,368	249,666	255,151	266,603	284,446
Gasoline PHEV-12	0	0	0	0	0	307	12,094	72,649	169,390	259,337	331,432	318,711	254,784	188,716	161,205	151,495
Gasoline PHEV-20	0	0	0	0	0	86	1,725	7,752	17,661	30,576	48,418	55,021	50,614	44,759	42,294	40,597
Gasoline PHEV-40	0	0	0	0	0	19	180	633	1,443	2,962	6,366	7,109	5,746	4,535	4,192	4,244
All Technologies	8,109,146	8,861,426	9,085,849	8,906,363	8,662,320	8,581,212	8,620,465	8,596,077	8,573,806	8,487,251	8,380,606	8,267,218	8,212,974	8,138,385	8,302,521	8,359,773

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,119,190	7,092,207	6,609,523	6,611,379	6,291,480	5,631,110	4,801,824	4,117,602	3,563,754	3,055,705	2,540,611	2,000,718	1,443,691	832,408	537,035	391,859
Diesel CI ICE	831	13,058	80,352	308,186	744,291	1,273,832	1,464,901	1,378,531	1,239,403	1,076,315	896,924	699,481	493,392	268,932	170,113	119,495
Gasoline HEV	4,774	25,501	77,858	183,721	404,868	952,811	1,992,366	2,906,671	3,733,745	4,541,006	5,329,372	6,159,000	7,058,002	7,999,442	8,458,872	8,779,467
Advanced Gasoline SI ICE	0	0	0	0	0	109	1,965	7,931	17,952	31,292	47,554	68,806	101,401	161,164	243,992	363,172
Gasoline PHEV-12	0	0	0	0	0	75	1,132	4,186	9,412	17,235	29,016	39,226	49,056	68,327	91,063	119,838
Gasoline PHEV-20	0	0	0	0	0	25	223	659	1,391	2,564	4,487	5,882	6,607	7,652	8,670	9,746
Gasoline PHEV-40	0	0	0	0	0	1	2	3	10	34	114	191	239	321	399	495
All Technologies	8,124,795	7,130,766	6,767,733	7,103,286	7,440,639	7,857,963	8,262,413	8,415,583	8,565,667	8,724,151	8,848,077	8,973,304	9,152,389	9,338,246	9,510,144	9,784,072

Gas Price Increased By 10 Cents

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,205,016	15,828,249	15,347,543	14,844,890	13,788,698	12,361,416	10,717,500	9,159,623	7,721,761	6,334,325	4,968,842	3,632,039	2,353,164	1,157,053	693,492	483,973
Diesel CI ICE	3,501	39,807	194,381	620,712	1,355,328	2,227,361	2,547,262	2,416,852	2,153,548	1,827,038	1,471,381	1,098,167	725,273	362,088	221,380	152,111
Gasoline HEV	25,441	124,140	311,643	544,040	958,942	1,849,498	3,593,392	5,300,609	6,950,657	8,558,035	10,135,284	11,799,180	13,583,976	15,247,482	16,109,016	16,578,898
Advanced Gasoline SI ICE	0	0	0	0	0	362	10,014	52,892	120,035	184,126	236,197	287,430	340,708	400,148	484,740	606,411
Gasoline PHEV-12	0	0	0	0	0	388	12,610	72,766	172,816	270,983	355,776	353,179	297,099	250,810	246,526	265,254
Gasoline PHEV-20	0	0	0	0	0	115	1,920	8,307	19,227	33,932	54,716	63,221	59,189	54,196	52,888	52,422
Gasoline PHEV-40	0	0	0	0	0	20	175	611	1,418	2,963	6,476	7,317	5,945	4,838	4,614	4,791
All Technologies	16,233,958	15,992,196	15,853,567	16,009,642	16,102,968	16,439,160	16,882,874	17,011,659	17,139,462	17,211,402	17,228,672	17,240,532	17,365,355	17,476,615	17,812,656	18,143,860

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,086,116	8,738,144	8,746,660	8,260,799	7,565,340	6,874,989	6,057,457	5,167,956	4,275,936	3,390,588	2,534,997	1,733,509	1,007,741	385,056	191,385	114,934
Diesel CI ICE	2,650	26,295	110,724	298,999	578,980	910,972	1,078,506	1,040,386	919,022	758,764	586,360	414,938	252,828	106,208	58,191	36,637
Gasoline HEV	20,388	96,989	228,456	346,562	518,000	794,562	1,475,332	2,275,317	3,099,387	3,898,171	4,684,536	5,515,325	6,396,956	7,165,440	7,593,246	7,745,968
Advanced Gasoline SI ICE	0	0	0	0	0	254	8,212	45,685	103,466	154,783	191,021	221,413	242,660	245,936	254,356	267,677
Gasoline PHEV-12	0	0	0	0	0	313	11,553	68,883	163,942	254,474	327,594	314,743	248,720	183,653	157,379	148,164
Gasoline PHEV-20	0	0	0	0	0	89	1,704	7,666	17,849	31,345	50,113	57,118	52,280	46,163	43,750	42,102
Gasoline PHEV-40	0	0	0	0	0	19	173	607	1,409	2,930	6,366	7,128	5,705	4,515	4,212	4,293
All Technologies	8,109,154	8,861,428	9,085,840	8,906,360	8,662,320	8,581,198	8,632,937	8,606,501	8,581,012	8,491,055	8,380,986	8,264,175	8,206,890	8,136,971	8,302,519	8,359,775

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,118,900	7,090,105	6,600,883	6,584,091	6,223,358	5,486,427	4,660,043	3,991,667	3,445,824	2,943,737	2,433,845	1,898,530	1,345,424	771,997	502,107	369,039
Diesel CI ICE	851	13,512	83,657	321,713	776,348	1,316,389	1,468,756	1,376,466	1,234,526	1,068,273	885,021	683,229	472,445	255,880	163,189	115,474
Gasoline HEV	5,053	27,151	83,187	197,478	440,942	1,054,936	2,118,060	3,025,292	3,851,269	4,659,864	5,450,749	6,283,855	7,187,020	8,082,042	8,515,770	8,832,930
Advanced Gasoline SI ICE	0	0	0	0	0	108	1,802	7,207	16,569	29,344	45,176	66,017	98,048	154,212	230,384	338,734
Gasoline PHEV-12	0	0	0	0	0	75	1,057	3,883	8,874	16,509	28,182	38,435	48,380	67,157	89,147	117,090
Gasoline PHEV-20	0	0	0	0	0	26	217	641	1,378	2,587	4,602	6,103	6,909	8,033	9,138	10,320
Gasoline PHEV-40	0	0	0	0	0	1	2	3	10	33	111	189	240	323	402	498
All Technologies	8,124,804	7,130,768	6,767,727	7,103,282	7,440,648	7,857,962	8,249,937	8,405,158	8,558,450	8,720,347	8,847,686	8,976,357	9,158,465	9,339,644	9,510,137	9,784,085

Gas Price Increased By 100 Cents

Passenger Car & Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	16,171,160	15,589,690	14,618,514	13,033,156	11,432,192	9,821,895	8,177,980	6,656,998	5,236,890	3,879,807	2,563,200	1,291,858	568,377	320,594	215,130	163,548
Diesel CI ICE	5,976	77,512	404,761	1,292,587	1,861,204	2,167,685	2,176,762	2,009,454	1,728,395	1,371,530	967,000	536,065	260,158	151,771	105,699	80,132
Gasoline HEV	56,824	324,987	830,302	1,683,897	2,809,580	4,449,125	6,518,574	8,283,070	9,979,544	11,576,902	13,097,330	14,732,347	15,917,265	16,406,784	16,870,263	17,232,702
Advanced Gasoline SI ICE	0	0	0	0	0	142	2,731	16,108	46,949	88,783	134,221	193,996	243,704	261,329	280,766	300,690
Gasoline PHEV-12	0	0	0	0	0	197	5,178	36,331	116,339	224,935	334,849	329,363	247,437	220,596	225,510	247,807
Gasoline PHEV-20	0	0	0	0	0	92	1,572	9,312	30,141	66,320	123,944	147,360	121,812	109,773	109,389	112,499
Gasoline PHEV-40	0	0	0	0	0	12	94	400	1,218	3,102	8,132	9,544	6,626	5,782	5,920	6,487
All Technologies	16,233,960	15,992,189	15,853,577	16,009,640	16,102,977	16,439,149	16,882,890	17,011,673	17,139,476	17,211,380	17,228,675	17,240,533	17,365,379	17,476,629	17,812,677	18,143,865

Passenger Car Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,058,532	8,556,201	8,275,522	7,320,154	6,487,238	5,650,348	4,707,899	3,785,921	2,898,605	2,045,994	1,244,711	522,942	167,596	73,821	41,759	27,698
Diesel CI ICE	4,430	49,656	221,738	609,089	846,609	989,417	994,344	907,483	758,577	572,429	372,539	177,813	69,599	34,790	22,148	15,602
Gasoline HEV	46,191	255,573	588,589	980,162	1,482,805	2,180,775	3,156,674	4,028,055	4,850,986	5,562,110	6,202,720	6,903,462	7,430,378	7,618,713	7,856,857	7,953,228
Advanced Gasoline SI ICE	0	0	0	0	0	105	2,286	14,046	40,864	75,031	107,777	146,728	170,257	164,040	155,471	142,455
Gasoline PHEV-12	0	0	0	0	0	167	4,836	34,798	111,711	213,797	310,716	290,124	195,795	154,050	139,785	136,599
Gasoline PHEV-20	0	0	0	0	0	74	1,416	8,689	28,307	61,796	113,525	130,637	101,798	86,262	81,177	78,426
Gasoline PHEV-40	0	0	0	0	0	12	93	398	1,209	3,065	7,975	9,224	6,230	5,297	5,333	5,770
All Technologies	8,109,153	8,861,430	9,085,849	8,909,405	8,816,652	8,820,897	8,867,547	8,779,390	8,690,258	8,534,222	8,359,962	8,180,929	8,141,653	8,136,973	8,302,530	8,359,778

Light Truck Sales by Technology

Technology Type	Model Year--> 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline SI ICE	8,112,628	7,033,489	6,342,992	5,713,002	4,944,954	4,171,547	3,470,080	2,871,077	2,338,285	1,833,813	1,318,489	768,916	400,781	246,773	173,371	135,850
Diesel CI ICE	1,546	27,856	183,023	683,498	1,014,595	1,178,268	1,182,418	1,101,971	969,818	799,102	594,461	358,253	190,559	116,981	83,551	64,530
Gasoline HEV	10,633	69,414	241,713	703,735	1,326,776	2,268,350	3,361,900	4,255,015	5,128,558	6,014,792	6,894,610	7,828,885	8,486,887	8,788,071	9,013,406	9,279,474
Advanced Gasoline SI ICE	0	0	0	0	0	37	445	2,061	6,085	13,752	26,443	47,268	73,447	97,289	125,295	158,235
Gasoline PHEV-12	0	0	0	0	0	31	342	1,533	4,628	11,138	24,133	39,239	51,642	66,546	85,725	111,208
Gasoline PHEV-20	0	0	0	0	0	19	157	623	1,834	4,525	10,419	16,723	20,014	23,511	28,212	34,073
Gasoline PHEV-40	0	0	0	0	0	1	1	3	9	37	158	321	396	485	587	717
All Technologies	8,124,807	7,130,759	6,767,728	7,100,235	7,286,325	7,618,252	8,015,343	8,232,283	8,449,218	8,677,158	8,868,713	9,059,604	9,223,726	9,339,656	9,510,147	9,784,087

Appendix B. Summary of UMTRI Modeling Efforts

PHEV Penetration
Agent-Based Simulation
J. L. Sullivan
UMTRI

[Editor's Note: This summary was prepared prior to revision of UMTRI's modeling results to more accurately reflect the current policy situation. Therefore, the editor has made necessary edits to account for the changes that have resulted from incorporating a revised approach for this study's "base case."]

Introduction

Energy security and climate change issues have increased the call for improved energy efficiency from all sectors of the economy, especially the transportation sector. While vehicle manufacturers can, in principle, make their current vehicle offerings more fuel-efficient, historically they have not done so for reasons of poor auto market sensitivity to fuel economy. However, recent economic events have changed the automobile marketplace. Now, despite current gasoline prices at around $2 per gallon, there is nonetheless a greater demand for more fuel-efficient vehicles. The primary reason is anticipation of a return to higher ($3 to $4 per gallon) fuel prices when the recession is over. Unfortunately, simply making the existing fleet of conventional vehicle offerings more fuel-efficient will not adequately address energy security and climate change issues. New advanced technology vehicles such as PHEVs also need to be considered. Once having penetrated into the fleet to an adequate degree, these vehicles hold the promise of considerably improving fleet energy efficiency and reducing fleet carbon footprint. Because these vehicles cost a lot more than their conventional counterparts, especially in the near term, their market viability is in question, especially if no government policy initiatives are instituted to enable successful market penetration. To address this issue, the University of Michigan Transportation Research Institute (UMTRI) has developed an agent-based simulation to characterize the penetration of new vehicles into the marketplace under a variety of consumer, economic, and policy conditions.

Model Description

Agent-based models (ABM) can be applied to many complex systems such as the spread of disease, the evolution of organisms, emergence of behavior in social systems, financial markets, organizational behavior, and in our case, the automobile marketplace. UMTRI has been developing the Virtual AutoMotive MarketPlace (VAMMP) model. It is ABM that simulates the automobile marketplace, which is comprised of virtual decisions in software. The description that follows is brief; more complete publications on the model description are forthcoming. The VAMMP model is comprised of four classes of decision makers: consumers, government, fuel producers, and vehicle producers/dealers. These agents, virtual decision makers in software, interact with one another and the environment (especially the economic environment), based on their individual needs and/or organizational objectives. Briefly, every cycle (one month), consumers review the status of their driving mileage, fuel costs, and whether or not it is time to buy another car. If it is determined that there is a need to change mileage or buy a car, they act in a way to remain at least budget-neutral and meet their driving needs and model preferences. Nominally, agents can choose from twelve models of vehicles produced by three original equipment manufacturers (OEM). At the end

of each cycle, car dealers review sales and revenues, replenish the new car lots consistent with demand and adjust the prices of used cars based on virtual market supply and demand. The government monitors system-wide fuel use, carbon emissions and vehicle introductions and also implements policies (fuels, vehicle tax incentives, etc.) to meet objectives. Finally, fuel producers provide fuels for automotive applications and change prices both exogenously (petroleum induced gasoline price shock) and endogenously (competition between two fuel types).

<u>Consumers (vehicle buyers):</u> Consumers live and work in this virtual community and have home and work addresses, incomes, transportation budgets, vehicle preferences (size, performance, and sometimes make and special features), driving needs (city and highway driving for errands, commuting, and discretionary trips), and preferred duration of vehicle ownership. Their incomes follow the U.S. income distribution, and the transportation portions of those budgets (percent transportation) are a function of their income. All agents make transportation decisions that keep them within their budgets.

A critical component of this model is that consumer agents do interact with one another. Regarding the purchase of a PHEV, which most consumers would be leery of at least initially, agents take into consideration whether any of their friends or colleagues own one or whether the population of PHEVs on the road is high enough to reduce their hesitancy to purchase one. Agent attitudes towards PHEVs are committed, inclined, and neutral. When replacing their old car (on schedule), committed agents will buy one without reservation, inclined agents will add one to his/her list of potential vehicles for consideration, and neutral agents will buy one if the price is better than that for all other vehicles on their list. Neutral agents can be converted into inclined agents when enough PHEVs are around. No agent buys a vehicle outside of his or her budget.

<u>Cars</u> come in three sizes (small, medium, and large – denoted 1, 2, 3, respectively) and three performance levels (low, medium, and high – denoted 1, 2, 3, respectively). All vehicles have city and highway fuel economy as well as prices. Generally, large, high-performance vehicles (short 0 to 60 times) are priced higher and tend to have lower fuel economy than average, whereas just the opposite is the case for small, low-performing vehicles. Permuting this range of vehicle attributes results in nine vehicle segments, though all are not present (e.g., no large low performing vehicles are included). As there are three OEMs, some segments have vehicle entries made by competing OEMs. There are a total of 12 vehicle models in the vehicle population, though in some cases, new vehicles are added to the population. For example, the introduction of HEVs or PHEVs takes the vehicle model population beyond 12 models to between 13 and 15 vehicles. All cars have two stages to their lifetime, one as a new car and one as a used car. After these two stages, the vehicle is scrapped. The price for a new car ranges between about $12,000 for a small, low performance vehicle to $33,000 for a large, high-performance vehicle.

<u>Car lots:</u> Car lots come in two varieties, new and used. During every cycle, quantities of and revenues from vehicle sales are tracked. These numbers are used to generate demand and revenue-based values for restocking new car lots with vehicles acquired from OEMs on an unlimited basis with the various models available. On the other hand, used cars arise solely from the sale of cars completing their "new car stage." Generally speaking, used cars do not remain on the used car lot for much more than one cycle. The price of used cars varies over time, depending on supply vs. demand, and typically at a range of between 30% and 70% of the new car price.

In order to establish a value standard in the model, new car prices do not change during a simulation. However, OEMs can exogenously change the price of one of its models or respond endogenously to the change in price of a competitor's vehicle in the same segment. For used cars, demand and vehicle inventories are used to adjust vehicle prices on a cycle-by-cycle basis. Generally, if demand or revenue for a particular model is rising or flat, the used car dealer raises its price; if demand is falling or inventory exceeds a threshold, its price is decreased.

Government: The government's role in the model is to (1) monitor the amount of fuel sold, fleet vehicle fuel economy, and carbon emitted and (2) implement policies depending on various environmental and energy security considerations. In this study, we explore the following government policy instruments: subsidies for PHEV production, tax rebates on PHEV sales, gasoline tax increases, and sales tax exemptions.

Fuel Producers: There are two fuels germane to the PHEV market penetration case addressed herein, gasoline and electricity. Fuel prices are set exogenously and, in this simulation, gasoline prices rise from $2 to $4 per gallon; electricity prices remain fixed at 9.5¢/kWh.

An ABM is intended to simulate the behavior of a complex system comprised of many interacting players. For such a simulation to work properly, many assumptions are employed to meaningfully represent the behavior of the individual agents. Because these assumptions are too numerous to list, one must rely on model verification and validation exercises to see if the "model is right" and that we indeed have the "right model." We briefly cover two validation exercises below. However, some key assumptions are as follows:

- The population is fixed.
- Wages remain constant.
- All prices are in real dollar terms.
- No distinction between cars and trucks.
- Agent population follows U.S. income distribution.
- No limit of PHEV vehicle or component supply is assumed (i.e., adequate supply chain assumed).

In a forthcoming publication, details are to be presented on the validation of the VAMMP model, including the influence of fuel and vehicle prices on vehicle sales elasticities. For brevity, only two examples are cited demonstrating qualitatively that the virtual market behaves in expected ways to a pair of market stimuli (a fuel price increase and a vehicle price decrease). The results apply to a fleet of conventional vehicles.

- Case 1: When presented with escalating gasoline prices, agents move to a more fuel-efficient vehicle; some agents are actually eliminated from the vehicle-owning population due to being over budget.
- Case 2: In this case, agents are presented with identical vehicles in the same segment but made by different manufacturers. When one of them is discounted by 10%, the market share of the underpriced vehicle goes up appreciably and likewise the regularly priced vehicle loses its market share by a similar amount. However, when the price-disadvantaged manufacturer is allowed to respond endogenously to the price decrease, his/her market share is little affected. This model is not intended to simulate a specific

population of drivers, but to show likely responses of a typical population of U.S. drivers to various policies and market excitations.

Scenarios and Assumptions

The primary objective of this study is to explore the impact of various policy options on facilitating the penetration of PHEVs into the U.S. auto marketplace. The base case for this market simulation study is as follows: 1) PHEV prices represent actual OEM manufacturing costs plus profit; 2) the current federal Plug-in Vehicle Tax Credit program, for which most PHEVs qualify, is in force; (3) $2.4 billion in advanced battery manufacturing grants (assumed in this study to be in the form of subsidies) has been distributed among OEMs and their suppliers with R&D efforts in this area (ARRA, H.R.1).

The purpose of the Plug-in Vehicle Tax Credit is to encourage new car purchasers to buy a PHEV using a tax credit, which ranges between $2,500 and $7,500 and is computed as follows:

$$\textit{Tax credit} = \$2{,}500 + 417 * (\textit{batt\_cap} - 4),$$

where the units of 417 are in dollars per kilowatt-hour and the battery capacity is in kilowatt-hours. For the vehicles assumed in our model, the tax breaks are $2,780, $7,100, and $7,500 for PHEV-10s, PHEV-20s, and PHEV-40s, respectively.

[Editor's Note: The OEM subsidies accounted for in the current policy case are assumed to be primarily funded with the $2.4 billion in advanced battery manufacturing grants to domestic automotive, battery, and component manufacturers. These government subsidies are of sufficient magnitude to reduce vehicle sticker prices of PHEV-10s, PHEV-20s, and PHEV-40s to $1,500, $3,000 and $6,000, respectively, above their HEV counterparts fixed through 2020.]

In addition to the base case, UMTRI explored the potential impact of sales tax exemptions. The market impact that may result from implementing sales tax exemptions were superposed onto this base case described above. Sales tax is assumed to be 6%. The assumed fully accounted retail prices for the PHEVs, which include all OEM costs plus profit, are given in Table B-1. Those prices are derived from a University of Michigan (Department of Mechanical Engineering) incremental cost model for the prices of PHEVs relative to their HEV counterparts, which are in turn assumed to cost $3,000 more than their conventional counterparts. The subsidies for the OEMs to price PHEV-10s, PHEV-20s, and PHEV-40s at $1,500, $3,000, and $6,000 over comparable HEVs are $2,300, $6,000 and $18,800, respectively.

Table B-1: Fuel economies (mpg) for charge sustaining (CS) and charge depleting (CD) modes of operation.

Vehicle	CS-Cty	CS-Hwy	CD-Cty	CD-Hwy	Vehicle Price	Vehicle Class
PHEV-10	69.8	72	237	228	$28,700	C-class
PHEV-20	55.8	61.5	205	182	$36,400	Small SUV
PHEV-40	60.7	72.3	251	218	$49,700	C-class

In the first year of simulation time, a PHEV-10, PHEV-20, and PHEV-40 are introduced to the marketplace. The price of gasoline is $2 per gallon at the start of all simulations; for some

scenarios, the price rises in steps to $4 per gallon by simulation termination. Details of those scenarios are given below. In the cases where they do vary, it is assumed that a $1 per gallon increase occurs at 20 months and 100 months after the start of the simulation. As stated above, electricity prices (9.5¢/kWh) are constant for all scenarios, and only home charging is available. All simulations run for 360 cycles or 30 years of simulation time (i.e., each cycle is one month).

Fuel economies used in the model for the PHEVs are based on University of Michigan (Dept. of Mechanical Engineering) modeling results for vehicle energy consumption over three drive cycles: Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Efficiency Test (HYFET), and a "naturalistic" drive cycle. Though the latter of the three is presumably more representative of actual driving behavior, we used fuel economy values for the first two drive cycles because all vehicles on the road today have had their fuel economies evaluated using them. Those fuel economies are given in Table B-1. Though no fuel economy modeling was done directly for the small SUV example, its fuel economy was estimated based on the ratio of a comparable HEV and the reference C-class vehicle. Fuel economies listed for the charge-depleting (CD) mode are gasoline equivalent values.

To facilitate clear representation of the scenarios covered, we have adopted the following three-component nomenclature: A-B-C. The first character represents the price of gasoline at simulation termination, the second represents "yes" or "no" on a manufacturer subsidy, and the third represents "yes" or "no" on a sales tax exemption. For example, 4-Y-Y denotes $4 per gallon gasoline at simulation termination, a manufacturer subsidy, and a sales tax exemption is in place. These simulation details represent market circumstances added to the base case described above.

Results

The results from every run of an ABM represent the response of a specific instance or instantiation of the system, which in our case is the automobile marketplace. However, the modeler is simply not informed enough to know whether or not the modeled marketplace is sufficiently representative of the real one. Hence, it is customary in setting up such models to employ random numbers that are used to meaningfully represent the diversity of attributes and behaviors characteristic of most real systems and to run such models numerous times to establish the variation in results. We show an example of this in Figure B-1, the penetration curve of PHEVs into the marketplace. We typically use twenty runs to characterize a particular scenario and generate from them suitable statistics. All penetration curves represent the total PHEV population in the fleet, including both new and used cars. Another feature to notice in the figure is the S-shaped form of the penetration curves, though they have yet to reach their asymptotic limit. This form indicates that the fractional rate of penetration is proportional to those agents who are inclined to purchase a PHEV but have yet to do so. Hence, as this remaining population is depleted, the rate of penetration approaches zero.

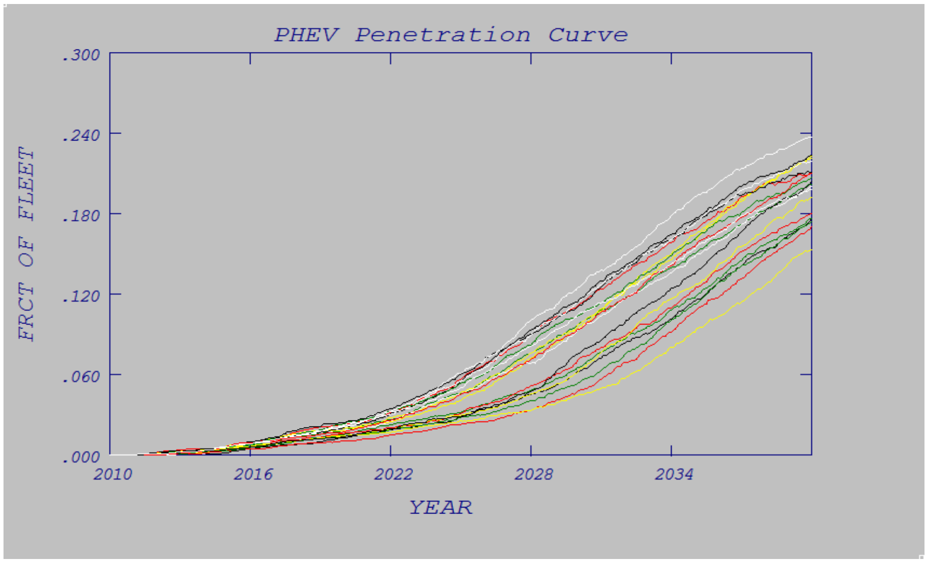

Figure B-1: *Example of PHEV penetration into the simulated marketplace; twenty runs.*

The central focus in this study is the degree of PHEV penetration into the marketplace in the years of 2015 and 2020, given the various market-incentivizing scenarios discussed in the previous section. Those results are presented in Table B-2.

Table B-2: *Projected PHEV fleet penetration and sales if vehicle manufacturer subsidies and state sales tax exemptions are implemented.*

Scenario	% Fleet Penetration		% Sales	
	2015	2020	2015	2020
4-Y-N	1.0	2.0	2.6	3.9
4-Y-Y	1.1	2.6	3.1	5.8
2-Y-N	1.1	2.4	3.1	3.8
2-Y-Y	1.3	3.2	3.5	5.9

[Editor's Note: For the purpose of this study, the 4-Y-N row represents PHEV market penetration a) under the base case when only considering the 2015 columns and b) if the Plug-in Vehicle Tax Credit was extended through 2020 when considering both the 2015 and 2020 columns. (The Plug-in Vehicle Tax Credit is expected to be exhausted near 2015.) The 4-Y-Y row represents PHEV market penetration if sales tax exemptions were superposed onto the 4-Y-N scenario. The 2-Y-N and 2-Y-Y rows indicate that the price of gasoline remains at $2 per gallon through 2020, which is not considered in the body of this report.]

It is conceded that for successful PHEV market penetration, some series of government incentives are necessary. How is this going to be paid for? Some suggest increasing the federal gasoline tax. That option is explored, and calculations were made to determine the size of a PHEV Incentives Fund necessary for the federal government to stimulate the market penetration of this new technology through the aforementioned vehicle manufacturing subsidies and sales tax exemptions. Cash inputs to the fund are based on an incremental gasoline tax, which in this case is estimated to be around 6¢ per gallon. (No discounting has been included in these calculations.) At this rate,

the fund would be revenue positive until around 2020, after which it would be in the red due to the increased growth rate of PHEV sales. With that said, it should be noted that a "sales tax break" policy has no direct effort on federal coffers as it is a state-sponsored program.

[Editor's Note: Both ORNL and UMTRI's respective models produced estimates on a federal gasoline tax increase that could cover the cost of certain incentives investigated in this study. Using ORNL model assumptions, a gasoline tax increase of 1.5¢ per gallon implemented between 2010 and 2020 could provide full funding for most any of the incentives discussed in this study ***in addition*** *to the current policy case (e.g., the cost to simply implement a sales tax exemption). UMTRI's cost estimates, on the other hand, do not differentiate between the gasoline tax increases needed to cover the cost to implement the policies included in its base case, additional sales tax exemptions, and a Plug-in Vehicle Tax Credit extension; instead a combined 6¢ per gallon tax increase through 2020 was estimated. Therefore, the tax increase needed to implement the individual policies investigated in this study should each be considerably less than 6¢ per gallon.]*

The simulations show that large increases (greater than $1 per gallon) in gasoline prices, whether induced by higher taxes or higher petroleum costs, result in consumers moving toward more fuel-efficient vehicles and some agents being forced out of vehicle ownership. Because these effects are seen more or less in the long term, results demonstrating them are not shown here; the focus here is on the next ten years.

The results presented above are contingent on the assumptions used in the model. One critical assumption is that the incremental price difference between HEVs and their conventional counterparts is around $3,000. A recent comparison of the prices of HEVs vs. conventional crossover SUVs published in the popular media showed incremental prices ranging from $4,000 to $9,000. However, because there is some ambiguity in comparing so-called "comparable" vehicles (especially HEVs and their conventional counterparts) given the latitude that car producers have in adding and subtracting various option packages, the $3,000 price differential was used. Further, at a PHEV workshop held in January 2009 in Ann Arbor, Michigan, a consensus was reached that this value is realistic.

Summary

The results of the agent-based modeling study of PHEV penetration into the U.S. auto marketplace show that PHEV subsidies and sales tax exemptions have a significant impact on PHEV penetration levels. Our simulation results show that a suitably incentivized auto marketplace can facilitate PHEV penetration levels into the U.S. automobile fleet. More specific results are as follows:

- By 2015, PHEV sales could reach approximately 2.5% with fleet penetration of around 1% under UMTRI's base case assumptions.
- By 2015, PHEV sales could reach approximately 3% with fleet penetration of around 2% if sales tax exemptions were superposed on the base case.
- By 2020, PHEV sales could reach approximately 4% with fleet penetration of around 2% if the Plug-in Vehicle Tax Credit (currently expected to phase out near 2015 in the base case) was extended through 2020.
- Without OEM and supplier subsidies, the base case would result in a fleet penetration level of less than 1% in ten years.

- Subsidies that ultimately help OEMs and their suppliers to drive down the initial cost of PHEVs are critical; sales tax exemptions can help if applied to scenarios where these OEM subsidies are in place.

Because the individual vehicle replacement rate is a limiting factor in any market turnover scenario, it will take time to turn over the fleet even if new vehicle technologies have marketplace acceptance. A gasoline tax increase of about 6¢ per gallon would support government funding to incentivize PHEV sales through the vehicle manufacturer subsidies, extended Plug-in Vehicle Tax Credits, and sales tax exemptions.