# The Future Impacts of Electric Drive Vehicles: A Case Study of Normative Scenario Modeling

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## Abstract

Over the past several years, institutions in the energy and environmental fields have turned to "normative scenario modeling" to explore and articulate technological futures. Through backcasting techniques, the results of these studies allow organizations to refine their strategic operations to achieve long-term technological and economic goals. This paper describes a study recently conducted for EPRI (Electric Power Research Institute) designed to evaluate the environmental, energy, and macroeconomic impacts of an electric transportation future. The study applies a normative scenario modeling approach to study an aggressive, but plausible, future scenario where 50% of all vehicles operating in the U.S. in the year 2025 are electric drive vehicles. This paper presents the methodology and results of this study and demonstrates how normative scenario modeling can be used to investigate technology futures.

## Introduction

Electric vehicle (EV) technology has significantly evolved over the past two decades. In the mid-1980s, EVs were thought of as battery-powered sub-compact cars that received power from the utility grid, stored that power in expensive and heavy battery packs, and used that power in a vehicle with a range of only 30-40 miles. However, spurred by concerns about energy security and the environment, car companies began to tinker with the traditional EV vision. What emerged in the late 1990s were hybrid electric vehicles (HEVs), including Honda's *Insight* and *Civic* and Toyota's *Prius*, which operate using a gasoline engine in tandem with an electric-drive system. These vehicles are cleaner and more efficient than conventional gasoline vehicles.

HEVs on the market today are "grid-independent" and rely on the on-board internal combustion engine to recharge their batteries. They are gaining moderate success in the U.S., with expected annual sales over 150,000 vehicles/year by 2003. (Energy Information Administration 2001) Unfortunately, they are still 100% petroleum dependent. Tomorrow's HEVs, on the other hand, will likely include "plug-in" capabilities that will allow them to connect to the utility grid to recharge their batteries if desired. Charging HEVs from the grid will reduce the nation's dependence on petroleum and provide increased fuel diversity.

All these vehicles (traditional EVs, grid-independent HEVs, and "plug-in" HEVs) are classified as "electric drive vehicles" (EDVs). The classification also includes fuel cell vehicles (FCVs) which convert hydrogen and oxygen directly into electricity used for propulsion. Although the future prospects for EDVs are promising, there are still some technical, economic, and regulatory hurdles that must be overcome before markets fully embrace them. But, what if markets do embrace them? What are the benefits of EDVs operating in our transportation sector?

And do these benefits justify policy interventions to support and spur the market for these vehicles?

In 2002, EPRI (Electric Power Research Institute) conducted a study to explore these "what-if" questions. In particular, they asked: What if 50% of the vehicles operating in the U.S. in 2025 were EDVs? EPRI was particularly concerned with the economic, environmental, and energy implications of such a future. This paper discusses the method and results of that EPRI project. The project represents a case study in the use of normative scenario modeling. From the project, EPRI was able to identify the potential impacts of an EDV future and is now preparing to create that future through a strategic planning initiative.

## Background

### *Study Purpose*

As mentioned in the previous section, EDVs come in various types:

?? *All-Electric Battery EDVs* – these "traditional" electric vehicles are 100% "plug-in" systems that charge their batteries solely by connecting to the electric utility grid.

?? *Internal Combustion Engine Hybrid EDVs* – these vehicles have an on-board internal combustion engine (ICE) used in conjunction with an electric battery/motor system to share the driving load. The battery pack can be charged on-board using the ICE, or the pack can be charged by connecting to the grid through a plug-in system.

?? *Fuel cell vehicles (FCVs)* – these vehicles use fuel cells to convert hydrogen and oxygen directly into electricity. FCVs use this electricity to power an electric propulsion system. In addition FCVs may also incorporate a separate battery pack that is charged by the fuel cell stack or charged by the grid using a "plug-in" system.

Electric drive vehicles are more efficient than conventional vehicles and thus present an opportunity to reduce U.S. reliance on imported petroleum. (Note that this study focused on the role of EDVs in the U.S. transportation sector; however, the results may be applicable to other industrialized countries). Reducing petroleum imports positively affects the U.S. balance of trade and gross domestic product (GDP). Electric drive vehicles also reduce, and could quite possibly remove, the negative effects of petroleum supply disruptions and price shocks. In addition, because they are cleaner than conventional vehicles, EDVs reduce tailpipe emissions, especially in urban areas where these emissions contribute to health problems and property damage.

In this study, EPRI was interested in understanding the impacts associated with a future transportation sector that relied heavily on EDVs. EPRI was especially concerned with evaluating macroeconomic impacts on the U.S. economy, as well as the environmental impacts associated with displacing conventional vehicles with EDVs. In sum, EPRI wanted to evaluate how a significant penetration of EDV technologies translates into economic benefits to the country. To explore these impacts, we applied a form of *normative scenario modeling*.

### *The Use of Scenarios in Related Research*

Scenario planning is a common tool for futures researchers. Some of the definitions of scenario planning, as identified previously in this journal include: (Chermack, Lynham et al. 2001)

- ?? "[A]n internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome." (Porter 1980)
- ?? "[A] tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out." (Schwartz 1991)
- ?? "[A] disciplined methodology for imagining possible futures in which organizational decisions may be played out." (Shoemaker 1995)

In each of these definitions we see that scenario planning helps us envision a future in order to develop plans, programs, or policies that allow us to respond to, change, or (in the case of *normative* or *desirable futures*) create that future.

Currently, a number of organizations are using future scenarios in the energy and transportation fields. In some of these cases there is an upfront recognition that the scenarios do not reflect predictions, but "thought-constructs" for planning purposes. In others, the scenarios read more like forecasts, and although useful, carry a heavy burden of uncertainty and can possibly distort our view of the future. (Dublin 1999)

It is beyond the scope of this paper to present details on each of the many analyses that apply scenario methods. However, the list below represents a sample of the organizations using scenario approaches to study energy and transportation futures.

1) ***American Public Transit Association (APTA)***. In 2001 APTA used scenarios to help the organization consider possible urban futures and their impact on public transit. APTA developed scenarios for transportation and urban development out to year 2050. The four scenarios considered were: *Boundless Sprawl*—where low-density automobile-dominant development continues; *Dying Cities*—where urban areas enter economic decay; *Community-Oriented Growth*—where small communities take shape, including pedestrian friendly transportation alternatives; and, *Reinventing the City*—where a new urban environment takes hold, characterized by efficient mass transit. There are no explicit quantitative analyses presented by APTA (i.e., no modeling work) nor is there discussion about particular vehicle technologies. For APTA, the scenario building activity was used as a thought exercise and a planning exercise.

2) ***DOE: Energy 2050.*** The U.S. Department of Energy (DOE) is currently completing a project called *Energy 2050*. (Birkey and Greene 2001) Based on the premise that cheap oil is quickly being depleted, DOE uses scenario analysis to evaluate strategies that the

U.S. can take to make a shift to alternative transportation technologies. As the authors suggest:

> "It is not the intention of presenting these strategies either to predict the future or prescribe it…Our point is to demonstrate that plausible alternatives exist, although achieving them will require continued advances in the technologies of vehicles and fuels, as well as effective public policies." (p.ES-2)

3) ***DOE: Quality Metrics.*** The DOE Office of Transportation Technologies (OTT) produces a periodic "Quality Metrics" (QM) report to help identify the impacts that certain OTT policies and programs will have on energy independence and environmental quality.(U.S. Department of Energy 2001) DOE's QM work applies engineering-economy models to project future alternative fuel vehicle (AFV) demand. The time horizon for the most recent report is 2030. Assumptions regarding vehicle efficiencies, emissions, and costs allow DOE to quantify oil displacement, environmental benefits, and economic impacts (including GDP and labor impacts) of this AFV penetration.

4) ***DOE: Five Lab Study.*** DOE recently completed a study entitled *Scenarios for a Clean Energy Future*. This study is also known as the "Five Lab Study" since it combined expertise at five DOE labs to assess how technologies and policies can be used to achieve a clean, secure energy future. (Brown, Levine et al. 2001) The study employs a forecasting approach where technological development and policy actions are "created" and their impacts are modeled out to the year 2020 using the National Energy Modeling System (NEMS). The study identifies a portfolio of policies and technologies that allow the U.S. to reduce petroleum dependence and meet carbon reduction goals by 2010 cost-effectively. (Greene and Plotkin 2001)

5) ***IIASA/WEC: Global Energy 2100.*** The International Institute for Applied Systems Analysis (IIASA) and the World Energy Council (WEC) conducted a five-year study that considers six alternative global energy scenarios extending to the year 2100. (Nakicenovic, Grubler et al. 1998) This work represents a continued effort by both groups to better understand the future using a scenario-based approach. (Häfele, Anderer et al. 1981; World Energy Council 1993) The main objective of the IIASA/WEC work is to look at near term activities (now to 2020) and their impact on energy consumption and emissions in the long-term (2050 and beyond). The approach is based on a dynamic systems model that models the interaction among technological change, demographic change, and socioeconomic change.

6) ***IPCC: Emissions Scenarios.*** The Intergovernmental Panel on Climate Change (IPCC), a body established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), has also been active in using scenarios to assess the technical and socioeconomic factors and impacts of climate change. These IPCC "emissions scenarios" are used to drive long-term climate circulation models (out to year 2100). In 1996, IPCC began to develop a set of emissions scenarios that would provide both a contextual setting and emissions data for their climate models. These scenarios build off a baseline emissions estimate and then explore different rates of technological change, economic growth, and demographic trends. (Nakicenovic, Alcamo et al. 2000)

7) ***Shell Oil: Scenarios to 2050.*** Shell Oil was one of the first energy companies to explicitly integrate scenarios into corporate planning. Recently, Shell released a document that explores several energy scenarios out to 2050. (Shell International Limited 2001) Shell considered two energy development scenarios: (1) the evolution of energy

from coal, to gas, and ultimately to renewable and/or nuclear power (the *"Dynamics as Usual"* case); and (2) the evolution from fossil fuels to a "hydrogen economy," where fuel cells provide power and carbon is sequestered (the *"Spirit of the Coming Age"* case). In both cases, three fundamental conditions drive the energy transition: (1) energy resource scarcity; (2) new technology development; and, (3) social and personal priorities.

8) ***WBCSD: Long-Term Energy Futures.*** In the past five years, the World Business Council for Sustainable Development (WBCSD) has published two reports related to long-term scenarios of energy development. In collaboration with many companies, the WBCSD used scenarios as a way of "strategic conversation" among business and government. (WBCSD 1997; WBCSD 1999) The scenarios are used to think through possible and desirable energy futures. In its first report, "Global Scenarios 2050: Exploring Sustainable Development," the WBCSD outlined three scenarios that focus on overall economic development. In its follow-up report, "Energy 2050, Risky Business," WBCSD focused on the energy sector for each of the scenarios in its sustainable development report.

## Methodology

### *Scenario Writing*

In studying the future impact of EDVs on society, we first articulated two possible futures through a creative scenario writing exercise. These two scenarios are included in the appendix of this article. The first future represents a "business-as-usual" case, where conventional technologies still dominate and the U.S. continues to rely extensively on foreign petroleum. The second scenario is one where EDVs prosper and consumers receive the benefits of a clean, domestic transportation fuel.

Written as newspaper accounts in the year 2025, this exercise helped us identify “high leverage” variables and their potential influence on political and economic stability. Notice also in each case the use of “wildcard” events to demonstrate how diverse fuel sources can temper the impact of sudden political or economic events. For example, each case begins with a move by OPEC to raise world oil prices. In the first case (business-as-usual) this event will have significant economic implications. In the second case, where EDVs are abundant, the impacts from this event are more moderate since drivers can turn to other fuels for transportation services.

These scenarios were used to express thoughts on how a future based on electric transportation would differ compared to one that was predominantly petroleum-based. These scenarios were shared with industry leaders for review and comment. By telling a “story” using scenarios, we were able to stimulate the imaginations of decision-makers and acquire new insights on how an EDV future would diverge from our business-as-usual path. Those insights ultimately influenced how our detailed modeling analysis proceeded.

### *Overview of the Analysis*

To conduct the formal analysis, we applied the modeling approach identified in Figure 1. The approach involves the integration of a series of models that are used to determine the energy, environmental, and economic impacts of a “desirable” future where 50% of all vehicles operating in the U.S. are EDVs, and 50% of those have plug-in capabilities. We call this scenario: *EDV Future*. This future is compared with a reference (“business-as-usual”) case derived from forecasts to 2025 published by the Energy Information Agency in its *Annual*

*Energy Review (AEO)*.[1] (Energy Information Administration 2001) We call that reference case *AEO 2025*. The modeling effort followed the steps outlined below.

?? *Step 1. Define a desirable future*. This step involves identifying: (1) the percentage of vehicles that are EDVs by vehicle class and technology type in year 2025; and, (2) the percentage of EDVs that have grid-connect ("plug-in") capabilities.

?? *Step 2. Calculate vehicle populations (Vehicle Population Model)*. This step uses a Vehicle Population Model to quantify vehicle populations by vehicle class and technology type based on input from Step 1 and forecasts of total vehicle populations in 2025.

?? *Step 3. Calculate the energy impacts (Energy Impact Model)*. Once vehicle populations have been identified by class and type, the Energy Impact Model calculates petroleum displacement and electricity consumption attributable to *EDV Future*. The model uses Argonne National Lab's Greenhouse Gas and Regulated Emissions and Energy Use in Transportation (GREET) model along with assumptions about plug-in characteristics for grid-connected EDVs to conduct this analysis.[2]

?? *Step 4. Calculate the environmental impacts (Environmental Impact Model)*. Energy use output by fuel from Step 3 is then sent to the Environmental Impact Model. The model applies emissions factors to determine the well-to-wheels emissions for the vehicle population.

?? *Step 5. Calculate the economic impacts (Economic Impact Model)*. The Economic Impact Model conducts five major calculations:[3]

- *Step 5a. Calculate GDP Impacts*. The model employs national input-output Gross-Domestic Product (GDP) multipliers to determine GDP impacts due to the displacement of oil by electricity and other fuels.
- *Step 5b. Calculate Labor Impacts*. The model uses national input-output labor multipliers to determine labor impacts due to the displacement of oil by electricity and other fuels.
- *Step 5c. Calculate Balance of Trade Impacts*. The model uses estimates of future world oil prices to calculate balance of trade impacts due to the displacement of oil by electricity and other fuels.
- *Step 5d. Calculate Environmental Cost Impacts*. The model uses estimates of alternative emissions control costs and estimates from the literature to calculate the economic value of reduced emissions.

[1] The Energy Information Agency only extends its forecasts to 2020. We extended these forecasts to 2025 using a linear extrapolation.
[2] The GREET model is a model that calculates total "well-to-wheel" emissions for alternative fuel vehicles. Wang, M. Q. (1999). GREET 1.5 -- Transportation Fuel-Cycle Model, Volume 1. Argonne, IL, Argonne National Lab.
[3] The Economic Impact Model is largely based on models used by the U.S. Department of Energy in their Quality Metrics work. U.S. Department of Energy (2001). Quality Metrics -- Final Report. Washington, DC, Office of Transportation Technologies.

– *Step 5e. Miscellaneous Calculations*. The model uses estimates from the literature to calculate miscellaneous benefits of oil displacement, including demand/disruption costs and military costs associated with protecting petroleum reserves in foreign countries.

FIGURE 1 HERE.

### *Defining a Desirable Future*

The first step in the analysis was to define a *desirable* future (*EDV Future*). This scenario was compared to *AEO 2025* to determine the potential impacts of EDVs on energy consumption, emissions, and the economy. We defined a desirable future as one where 50% of all vehicles operating in the U.S. are EDVs. In addition, we consider a future where 50% of those EDVs are capable of connecting to the utility grid for recharge (i.e., “grid-connected” or “plug-in” EDVs). We created this scenario by adjusting vehicle populations within each vehicle class and technology type to achieve the 50% EDV level. We put most of our emphasis, as EIA did, on increased use of hybrid-electric vehicles (HEV). In defining future populations, we left EIA estimates for other types of AFVs (e.g., CNG, LPG, M85, E85) in tact.

*Table 1* presents some important macro-level data about society and transportation in the year 2025. Table 2 and Figure 2 demonstrate how the *EDV Future* set of vehicle populations differ from the *AEO 2025* reference case for light-duty cars and trucks. Important differences are highlighted in bold in Table 2.

[TABLE 1 HERE.]

[TABLE 2 HERE.]

[FIGURE 2 HERE.]

Unlike EIA, we define a future where 50% of the HEVs and FCVs are grid-connected.[4] This feature will allow the HEVs and FCVs to connect to the grid to charge an on-board battery pack. The size of the battery pack will define the vehicle's All-Electric Range (AER). Vehicles with large AERs can use all-electric power from batteries for longer distances. For this analysis, we conservatively assume that grid-connected HEVs all have a 20-mile AER. (EPRI 2001) That study demonstrated that the ability of HEVs to connect to the grid reduces the vehicle's dependence on petroleum and increases the vehicle's efficiency.

We recognize the *EDV Future* scenario is very ambitious, but we believe it is still plausible given the enthusiasm for HEVs, the stated commitments by some of the auto companies, and regulatory and price signals expected in the future.

## The Results

The penetration of EDVs in U.S. transportation markets will have significant national energy security and macroeconomic repercussions, primarily arising from the displacement of imported petroleum with domestically produced electricity. Based on the modeling schematic presented in Figure 1, we analyzed energy, environmental, and economic impacts of *EDV Future* relative to *AEO 2025*. In this section of the paper, results are shown for the year 2025. Unless

[4] The reader will note that unlike EIA, we have eliminated fuel-cell vehicles (FCV) that use gasoline or methanol from our analysis (*EDV Future* has them at 0% in Table 2). We instead emphasize the FCV-Hydrogen option. One can argue whether the FCV future in 2025 is based on gasoline, methanol, hydrogen, or some other fuel; however, EIA projects that FCV-gasoline and FCV-methanol populations are expected to be *less than 0.02%* of the total vehicle population. Their impact on oil displacement and the environment is negligible.

otherwise noted, all economic valuations are presented in 2002 dollars (using adjustments provided by EIA).

### *Petroleum Displacement and Imports*

In *EDV Future* the U.S. transportation sector relies less on conventional gasoline and diesel vehicles and more on grid-connected and grid-independent hybrid vehicles. Because of this, the amount of petroleum consumption is greatly reduced. As Figure 3 illustrates, a movement towards more efficient EDVs can reduce petroleum consumption in the U.S. by over *1.5 billion barrels* of oil per year (over 4 million barrels per day), compared to *AEO 2025*. This is approximately a 20% reduction in petroleum consumption from the EIA reference case.

[FIGURE 3 HERE.]

This reduction in petroleum consumption has obvious impacts on the U.S. balance of trade. EIA projects the price of oil in 2025 to be about $26.00 per barrel (2002$) with 66% of U.S. oil consumption imported. Under these assumptions, the reduction in petroleum consumption due to *EDV Future* will translate into a *net reduction* in the U.S. balance of trade of *over $25 billion per year* by 2025.

### *GDP Impacts*

The shift from a transportation sector exclusively dependent on petroleum to one that allows the supplemental use of domestically produced electricity will also have significant impacts on the nation’s gross domestic product (GDP). GDP shifts will occur as consumers send fewer oil dollars overseas and instead use those dollars for electricity consumption and other household expenditures. Employing methods used by the U.S. Department of Energy (DOE) (U.S. Department of Energy 2001), it is estimated that the *EDV Future* scenario will provide a net benefit to GDP of over *$38 billion per year* by 2025. Figure 4 shows the GDP benefits by vehicle class. Note that these benefits are solely due to the shift from conventional vehicles to EDVs and do not include potential benefits from new infrastructure and auto manufacturing developments.

[FIGURE 4 HERE.]

### *Labor Impacts*

Labor impacts will also be significant. By applying a labor multipliers (U.S. Department of Energy 2001), we calculated a *net increase* in jobs will exceed *440,000 jobs/yr* by 2025 under *EDV Future* as compared to *AEO 2025*. Although some jobs are lost in the petroleum-related sectors of the economy, there will be jobs gained in non-petroleum fuel sectors and sectors that benefit from increased household expenditures. In addition, more job creation may be expected (especially in the manufacturing sectors) as domestic auto producers begin to manufacture EDVs, although the impacts in the automotive industry are not explicitly analyzed here. Figure 5 identifies labor impacts by vehicle class.

[FIGURE 5 HERE.]

### *Environmental Benefits*

EDVs will be much cleaner than conventional vehicles. Using the GREET model referenced earlier, we estimated emissions reductions of our *EDV Future* as compared to *AEO 2025*. An emissions analysis was conducted for the following pollutants: greenhouse gases (GHGs), volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM-10), and sulfur dioxide ($SO_2$).

Figure 6 shows emissions impacts of *EDV Future* compared to *AEO 2025*. (In this figure, positive values show emissions *reductions* due to the *EDV Future* scenario). Relative to *AEO 2025, EDV Future* will significantly reduce emissions of GHGs, VOCs, CO, and NOx; PM-10 impacts are negligible, and $SO_2$ emissions will increase slightly. The increase in $SO_2$ is due to electricity production, which will be generated in part from coal-burning power plants. However, it should be noted that under Title IV of the Clean Air Act Amendments of 1990, $SO_2$ emissions from power plants have been capped from now until the foreseeable future. Thus, although the figure indicates that EDV use will increase $SO_2$ emissions, power plants that produce that electricity will need to find $SO_2$ reductions elsewhere. Therefore, we expect to see no net increase in $SO_2$ nationally due to EDVs.

[FIGURE 6 HERE.]

There are several methods that can be used to monetize these environmental impacts. Here, a “control cost” method was used. In this method, the costs of controlling emissions represent a proxy to their “value”. In order to obtain control costs, we relied on literature review and information from emissions trading markets (e.g., $SO_2$ allowance market, NOx markets, international GHG markets). DOE has used a similar approach for monetizing environmental impacts. (U.S. Department of Energy 2001)

With this method, we estimate that the monetized annual emissions benefits of *EDV Future* are valued at over *$9 billion per year* in 2025 (2002$), as compared to *AEO 2025*. Monetized impacts by pollutant type are shown in Table 3).

[TABLE 3 HERE.]

### Military and Oil Disruption Cost Impacts

The U.S. Department of Energy has placed an economic value on oil displacement due to: (1) reductions in military expenditures needed to protect Persian Gulf oil supplies; and (2) reductions in the "oil import premium" due to demand (monopolistic) and disruption costs of oil dependence. (U.S. Department of Energy 2001) We did not conduct an extensive analysis of these costs, but instead use DOE estimates and apply them to the oil displacement figures obtained in our *EDV Future* scenario. DOE estimates that military expenditures are approximately $5/bbl and oil displacement and disruption costs are another $5/bbl. Applying these approximations, we acquire an annual savings of *over $15 billion per year* due to *EDV Future*, as compared to *AEO 2025*.

### Summary of Results

Our findings show extensive macroeconomic benefits due to a future that is less petroleum-dependent and more electricity-based. Table 4 summarizes the macroeconomic benefits of *EDV Future*.

[TABLE 4 HERE.]

Achieving this future is not only possible, but plausible. With continued technological advancement, the U.S. transportation sector can very rapidly move from its current reliance on petroleum to a future where petroleum, electricity, and other fuels provide a clean domestic, and secure fuel supply.

## Conclusion: Using Normative Scenario Modeling

An obvious question that arises after a normative scenario analysis is conducted is: What next? Other than being intellectually stimulating, what benefits does the analysis offer? We believe such analyses offer many benefits, including the following:

1) *Establishes whether the ends justify the means*. We now have some estimates of what the benefits are for an electric transportation future. If these benefits were miniscule, one could argue that, even under the best case circumstances, resources that would normally be used to promote EDVs should be directed elsewhere. One the other hand, if the rewards are great—and in this case we would argue they are—there is justification for continued efforts by government and the private sector to expand EDV markets.

2) *Provides targets at which to aim*. There is an old saying that you better know where you are going, or else you will never know when you get there. This analysis provides something concrete in terms of what it means to have an electric transportation future. Although the numbers are not predictions, they do resemble "metrics" that can help us determine whether our "heading" and our "bearing" are consistent.

3) *Provides a basis for technology and policy backcasting*. The market penetration values we obtained could also be used as a basis for technology and policy backcasting. Beginning with energy, economic, or environmental outcomes, the model could be used to backcast the EDV populations needed to achieve those outcomes. For example, if our goal was to reduce petroleum imports by 70%, we could use our model to determine what suite of EDV technologies and market penetration rates are needed to achieve that goal.

4) *Provides information for discussion and debate*. It is often hard to debate and discuss alternative futures because of a lack of concreteness. This study translates a nebulous concept of the future into a numerical analysis. One may not agree with the numbers, nor think they are reasonable—but having the model and the analytical results allows us greater clarity and focus for discussions and debate.

5) *Is the benefit in the outcome or the process?* The process of modeling a desirable future forces discussion on a variety of important topics, ranging from organizational goals to outlooks of the future to the impacts of technology on society. By way of forcing discussion on these topics, the *process* of articulating and modeling a desirable future offers many rewards.

Although the future described in this paper may not come to fruition, the effort is still fruitful. We now have some clarification of our desired future; we have some quantitative assessment of what that future means in terms of economic, environmental, and energy impacts; we have a model and a method that can be used to study alternative futures; and we have a target "starting point" that can be used for backcasting. In all, the use of normative scenario modeling represents an extremely helpful activity and provides decision makers with added insight and information to help make decisions in a very uncertain environment.

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# Appendix—Two Alternative Futures

## *1. Second Oil Crisis in Decade Has Americans Questioning Driving Habits and Vehicles Once Again*

WASHINGTON, June 1, 2025 –World oil prices rose once again yesterday as OPEC voted to curb production in order to achieve a $45 per barrel price. This is the third production decrease since December 2024, when prices were at $33 per barrel. Prices are expected to increase to $42 per barrel on the spot market today.

U.S. consumers and businesses are once again wondering what impact this latest decision will have on the U.S. economy, which has been in a downturn ever since the December price increase. Many Americans are wondering why they did not respond to the Iraqi Oil Crisis of 2015 more aggressively.

Data from the Energy Information Administration (EIA) show that the U.S. transportation sector still relies almost completely on petroleum. In 2023, the most recent date for which data are available, 96% of all transportation energy was derived from petroleum.

Despite increased drilling in the Arctic National Petroleum Reserve (ANPR), which began in 2010, oil production there has been minimal and has met less than 4% of total U.S. demand.

Demand has continued to be met by oil imports. In 2024, the U.S. consumed about 25 million barrels of oil per day, with almost 70% of that imported. Imports came most notably from Saudi Arabia, the Republic of Iraq, Russia, and other OPEC nations. At an average world oil price of $33/barrel in 2024, these imports added over $211 billion to the U.S. trade deficit, up from $85 billion two decades ago.

Blame for increased petroleum consumption in the U.S. has been placed on Americans' driving habits. The number of miles traveled by light duty vehicles annually has increased more than 50% over the past twenty-five years, from 2.3 trillion miles in 2000 to about 3.7 trillion miles today. These trends have not offset the moderate energy efficiency increases of vehicles during this same time period. The average efficiency for vehicles today is 27.2 MPG, as opposed to 24.0 MPG in 2000.

Today, many Americans are recalling events of the past 25 years, and particularly the last oil crisis that occurred in 2015. At that time, a war between Israel and Iraq caused significant supply disruptions, and the price of crude oil doubled overnight as Saudi Arabia withheld sales to the U.S. in light of U.S. assistance to the Israeli war effort. That war also created the religious and nationalist movements that ultimately merged Iraq and Iran into what is now the Republic of Iraq.

Some economists believe that the unstable economic conditions faced by the U.S. economy since 2015 are largely due to the economic repercussions of the 2015 oil disruption, as global market shares for many energy intensive products were lost when U.S. products could not compete with products from Europe, Southeast Asia, and India who made a transition away from petroleum prior to 2015.

This latest crisis has experts echoing an earlier call to diversify America's transportation sector by using "alternative fuel vehicles" and electric drive vehicles that operate on non-petroleum based fuels. This is reminiscent of the situation 25 years ago when government considered policies and incentives that would encourage the development of these types of vehicles.

However, despite annual introductions of "concept vehicles" that run on fuels such as hydrogen, auto manufacturers have yet to achieve any significant market penetration with alternative fuel or electric drive vehicles. EIA data indicate that these vehicles currently make up less than 2% of the vehicle market and are mostly relegated to fleet operations, although some experts have suggested that hydrogen fuel cell vehicles may be commercially available in five to ten years.

Progress towards alternative fuels and electric drive vehicles would also help the U.S. curb carbon dioxide ($CO_2$) and other greenhouse gas emissions, which many experts believe caused the current four-year drought in the Midwest, the Florida Coastal Disaster of 2018, and the devastating tidal intrusion of 2023 that flooded much of the Norfolk/Hampton Roads, VA area. EIA estimates that U.S. $CO_2$ emissions have increased from 5.5 Gigatonnes to 7.7 Gigatonnes over the past 25 years. Over 35% of those emissions are from transportation.

Although some politicians are once again calling for research and development, tax incentives and purchase mandates to encourage the use of alternative fuels, these policies have never gained political support in the past and are expected to languish in Congress again.

## 2. Americans Respond to Recent OPEC Decision by "Plugging-In"

WASHINGTON, June 1, 2025 –World oil prices rose once again yesterday as OPEC voted to curb production in efforts to achieve a $45 per barrel price. This is the third production decrease since December 2024, when prices were at $33 per barrel. Prices are expected to increase to $42 per barrel on the spot market today.

U.S. consumers have responded by avoiding gasoline purchases, where per gallon prices are expected to top $2.50/gallon in most areas. Instead, many Americans are "plugging-in" their vehicles and using battery power for most travel.

It is estimated that approximately 50% of Americans currently drive "electric drive vehicles," or EDVs, which combine either a gasoline or other internal combustion engine with an electric drive system. In addition to these "hybrid systems," EDVs also include all-battery power electric vehicles and fuel cell vehicles. EDVs currently on the market obtain fuel economies ranging from 55-75 MPG.

In addition, more than half of the EDVs in operation have "plug-in" or "grid-connection" capabilities. This option, which first became popular more than 15 years ago, allows drivers to charge on-board battery packs at home, work, or one of a growing number of public charging stations.

Vehicle battery packs come in various sizes and are identified by an "all electric range," or AER, designation. The AER corresponds to the number of miles the vehicle can travel using only the battery pack system. About half of the EDVs operating in the U.S. have an AER between 20-30 miles; approximately one quarter have AERs less than 20 miles, and about one quarter have AERs greater than 30 miles.

Although these ranges seem small, U.S. drivers have recognized that battery systems can serve most driving needs using all electric power. Most Americans only drive an average of 20 miles per day. Drivers often find themselves using all-electric power when convenient, during ozone alert days, and when it makes economic sense, as in the current situation. For example, a recent transportation survey by the Energy Information Administration (EIA) showed that instead of paying for the recent increases at the gasoline pump, EDV drivers have turned to using their battery systems more frequently, allowing them to avoid the economic impacts of the recent petroleum price shock.

Utilities have been able to cope with this new demand, since EDV charging occurs primarily at night during "off-peak" times, when capacity is available and costs are much less than during the day ("peak" times).

In addition, most of the plug-in EDVs include a "grid-feedback" feature that allows the vehicle to send power back to the grid when needed. In this way, vehicles connected to the grid during the day can help utilities meet peak demand and provide other services, such as spinning reserves, power quality management, or backup power.

In some cases, this latter service has proved very profitable for employees of industries where electricity reliability is critical. Instead of purchasing costly backup power systems, industries such as semi-conductor manufacturers and Internet information providers, are paying employees to plug their EDVs into the corporate backup power system.

The use of EDVs has led to a reduction in the demand for petroleum in the U.S. to 13 million barrels per day, down from 17 million barrels per day in 2000. This reduction occurred despite an increase of total miles traveled from 2.3 trillion miles in 2000 to 3.7 trillion miles today.

At an average world oil price of $33/barrel in 2024, this reduction accounts for a $48 billion decrease in the U.S. trade deficit.

The availability of EDVs has allowed the U.S. to avoid much of the economic turbulence faced by other nations. For example, OPEC price increases have negatively affected the growth of China and India, two of the largest consumers of petroleum in the world.

Populations in urban areas have also been indirectly rewarded with the recent OPEC production decreases. With more drivers using their AER feature, emissions from vehicles in urban areas have been reduced by 25%. In fact, many urban regions predict few, if any, ozone alert days this summer because of drivers' use of EDVs. In addition, EDVs have proven to be the most effective strategy in reducing greenhouse gases (GHG) and meeting the GHG reduction targets established in the International Global Warming Mitigation Treaty of 2012.

The incentives and technology development that led to today's high population of EDVs occurred over 20 years ago as Congress wrestled with issues associated with energy independence. Recognizing that the ubiquity and convenience of gasoline fuel would be hard to overcome, Congress instead supported the integration of electric drive systems into gasoline vehicles, which came to be known as "hybrid electric vehicles." Congress also developed policies and programs that encouraged the further advancement of plug-in systems, fuel cells, and other alternative fuels.

The EDV Development Act of 2005 helped bring about a plethora of battery technology breakthroughs and cost reductions. This allowed a significant transition to occur between 2010 and 2020, when EDVs started to incorporate lighter but more powerful battery pack systems that achieved AERs of 20-30 miles. This significantly reduced petroleum consumption and ameliorated the economic impacts associated with OPEC decision-making.

Now, with most EDV technology being manufactured in the U.S., auto companies and supporting industries have captured large vehicle and parts markets in Europe, Japan, and other parts of the world. Recent developments indicate that this market growth will continue for the foreseeable future.

**Figure 1. Overview of the Modeling Process.**

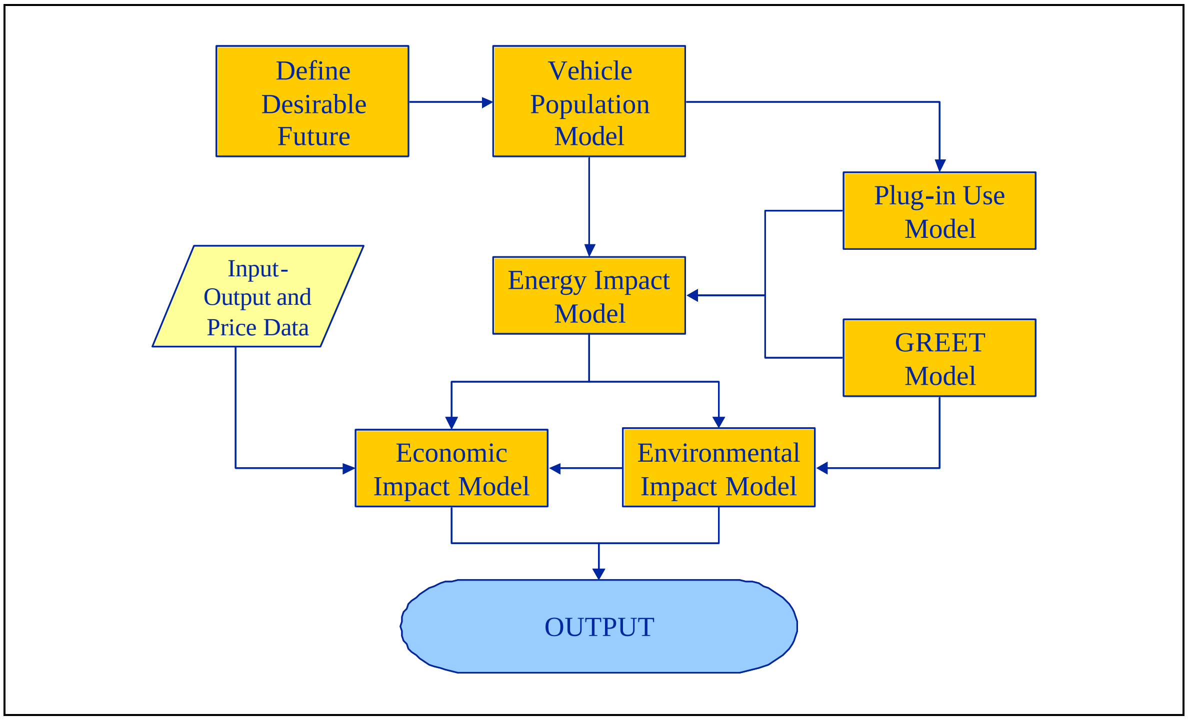


**Table 1. Macro-Level Data for Year 2025.**

| | 2000 | 2020 | 2025 |
|---|---|---|---|
| U.S. Population (millions) | 275.69 | 325.33 | 337.46 |
| US GDP (billion 1996 dollars) | 9223 | 16525 | 18239 |
| Vehicle Population (millions) | | | |
| Light-Duty Cars[1] | 124.5 | 134.0 | 136.4 |
| Light-Duty Trucks | 65.4 | 131.0 | 152.6 |
| Commercial Light Trucks[2] | 5.8 | 8.6 | 9.3 |
| Medium-Heavy Duty Vehicles[3] | 4.1 | 5.5 | 5.8 |
| Heavy-Heavy Duty Vehicles[4] | 4.5 | 7.5 | 8.2 |
| Vehicle Miles Traveled (billions) | | | |
| Light-Duty Cars | 1534.7 | 1835.7 | 1871.5 |
| Light-Duty Trucks | 805.6 | 1794.9 | 2093.4 |
| Commercial Light Trucks | 69.5 | 112.4 | 123.7 |
| Medium-Heavy Duty Vehicles | 49.7 | 73.8 | 78.3 |
| Heavy-Heavy Duty Vehicles | 164.6 | 286.4 | 318.8 |
| Fuel Efficiency (fleet average mpgge) | | | |
| Light-Duty Cars | 21.6 | 24.7 | 25.4 |
| Light-Duty Trucks | 17.1 | 18.2 | 18.4 |
| Commercial Light Trucks | 13.6 | 15.4 | 15.7 |
| Medium-Heavy Duty Vehicles | 8.2 | 8.5 | 8.6 |
| Heavy-Heavy Duty Vehicles | 5.5 | 6.0 | 6.3 |
| Energy Use (trillion BTU) | | | |
| Light-Duty Cars | 8641.2 | 9387.4 | 9490.1 |
| Light-Duty Trucks | 6304.8 | 11953.0 | 13777.0 |
| Commercial Light Trucks | 637.6 | 913.6 | 998.6 |
| Medium-Heavy Duty Vehicles | 758.0 | 1094.7 | 1154.6 |
| Heavy-Heavy Duty Vehicles | 3765.5 | 6004.4 | 6755.4 |
| U.S. Petroleum Production (MBD) | 9.03 | 9.95 | 10.20 |
| U.S. Petroleum Consumption (MBD) | 19.74 | 26.66 | 28.70 |
| Net Import (MBD) | 10.71 | 16.71 | 18.50 |
| World Oil Price (2000 $/barrel) | $27.72 | $24.68 | $24.58 |
| Total $CO_2$ (MMTC Eq)[6] | 1561.70 | 2087.77 | 2238.19 |
| OPEC Market Share[7] | 0.40 | 0.48 | 0.50 |

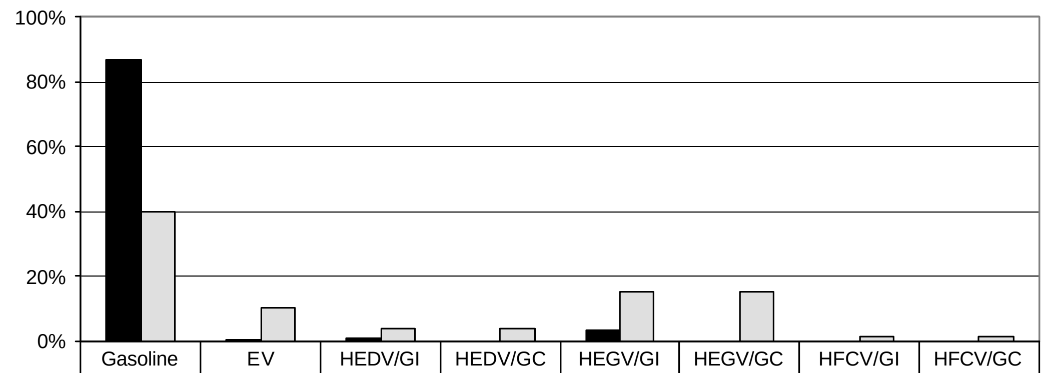
Source: Based on data from EIA's Annual Energy Outlook 2002. (Energy Information Administration 2001) Year 2000 and 2020 data taken direction from AEO tables; year 2025 data projected based on linear extrapolation of data from 2000-2020. [1]Light-Duty Cars and Light-Duty Trucks are those less than 8,500 Gross Vehicle Weight (GVW). [2]Commercial Light Trucks are those between 8500 and 10,000 GVW. [3]Medium-Heavy Duty Trucks are those 10,000-26,000 GVW. [4]Heavy-Heavy Duty Vehicles are those greater than 26,000 GVW. [5]MBD = million barrels per day. [6]Carbon dioxide ($CO_2$) emissions measured in million metric tons of carbon equivalent (MMTC Eq). [7]OPEC Market Share represents the total world oil supply provided by OPEC countries.

**Table 2. Actual and Projected Values for Light-Duty Cars and Trucks by Fuel Type (Millions of Vehicles).**

| | EIA 2000 (actual) | *AEO 2025* (projected) | *AEO 2025 (%)* | *EDV Future* | *EDV Future* (%) |
|---|---|---|---|---|---|
| Total LDV Stock | 189.85 | 289.00 | 100.0% | 289.00 | 100.0% |
| Gasoline | 184.62 | 250.68 | **86.74%** | 115.36 | **39.92%** |
| Diesel | 1.91 | 9.16 | 3.17% | 9.16 | 3.17% |
| M85 FFV | 0.05 | 0.51 | 0.18% | 0.51 | 0.18% |
| M85 | 0.00 | 0.00 | 0.00% | 0.00 | 0.00% |
| E85 FFV | 2.35 | 11.75 | 4.07% | 11.75 | 4.07% |
| E85 | 0.00 | 0.00 | 0.00% | 0.00 | 0.00% |
| CNG | 0.09 | 0.31 | 0.11% | 0.31 | 0.11% |
| CNG Bi-fuel | 0.33 | 2.76 | 0.96% | 2.76 | 0.96% |
| LPG | 0.07 | 0.31 | 0.11% | 0.31 | 0.11% |
| LPG Bi-fuel | 0.34 | 1.45 | 0.50% | 1.45 | 0.50% |
| EV | 0.01 | 0.56 | **0.20%** | 28.90 | **10.00%** |
| HEDV/GI | 0.01 | 2.35 | **0.81%** | 11.56 | **4.00%** |
| HEDV/GC | -- | -- | -- | 11.56 | **4.00%** |
| HEGV/GI | 0.08 | 9.09 | **3.15%** | 43.35 | **15.00%** |
| HEGV/GC | -- | -- | -- | 43.35 | **15.00%** |
| FCV-Gasoline | 0.00 | 0.06 | 0.02% | 0.00 | 0.0% |
| FCV-Methanol | 0.00 | 0.00 | 0.00% | 0.00 | 0.0% |
| HFCV/GI | 0.00 | 0.00 | **0.00%** | 4.34 | **1.5%** |
| HFCV/GC | -- | -- | -- | 4.34 | 1.5% |

Notes: M85 = 85% methanol, 15% gasoline blend; FFV = flex-fuel vehicle; E85 = 85% ethanol blend; CNG = compressed natural gas; LPG = liquid petroleum gas; EV = pure electric vehicle; HEDV = hybrid electric diesel vehicle (grid-connected (GC) and grid-independent (GI)); HEGV = hybrid electric gasoline vehicle (GI and GC); FCV = fuel cell vehicle; HFCV = hydrogen fuel cell vehicle (GI and GC). Note that AEO does not include GC vehicles in their most recent forecasts.

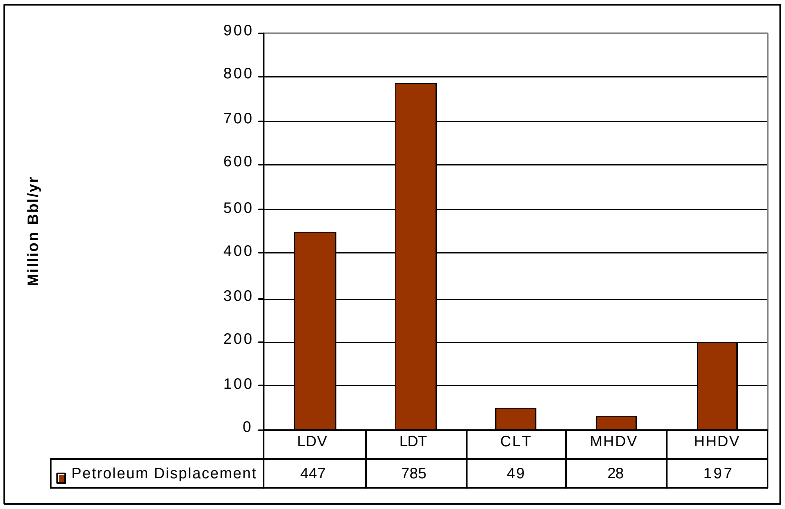
**Figure 2. Light-Duty Cars and Trucks: Population Comparison by Fuel Type for Two Scenarios for Year 2025 (percent).**




| | Gasoline | EV | HEDV/GI | HEDV/GC | HEGV/GI | HEGV/GC | HFCV/GI | HFCV/GC |
|---|---|---|---|---|---|---|---|---|
| AEO 2025 | 86.7% | 0.2% | 0.8% | 0.0% | 3.1% | 0.0% | 0.0% | 0.0% |
| EDV Future | 39.9% | 10.0% | 4.0% | 4.0% | 15.0% | 15.0% | 1.5% | 1.5% |

Notes: EV = 100% battery powered electric vehicle; HEDV/GI = hybrid electric diesel vehicle, grid independent; HEDV/GC = hybrid electric diesel vehicle, grid connected; HEGV/GI = hybrid electric gasoline vehicle, grid independent; HEGV/GC = hybrid electric gasoline vehicle, grid connected; HFCV/GI = hydrogen fuel cell vehicle, grid independent; HFCV/GC = hydrogen fuel cell vehicle, grid connected.

**Figure 3. Petroleum Displacement Due to *EDV Future* by Vehicle Class, 2025 (million barrels/yr)**




Notes: LDV = light-duty vehicles; LDT = light-duty trucks; CLT = commercial light trucks; MHDV = medium-heavy duty trucks; HHDV = heavy-heavy duty trucks.

**Figure 4. GDP Benefits Due to *EDV Future* for 2025 (Billion $/yr).**

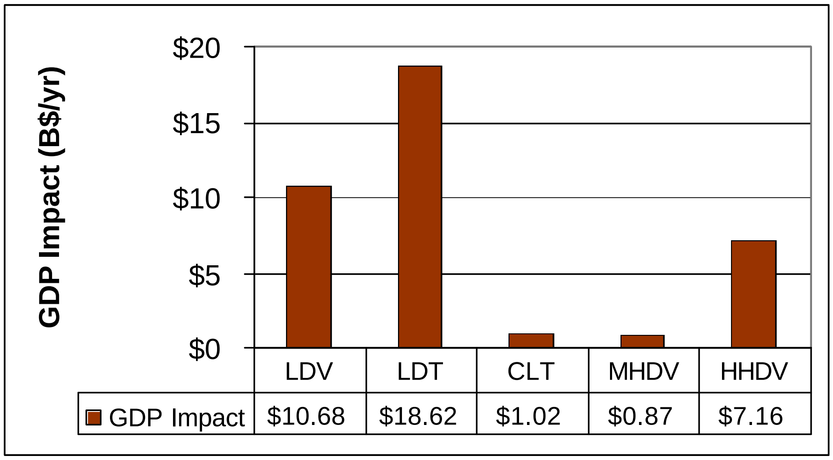


**Figure 5. Labor Impacts Due to *EDV Future* for 2025 (Jobs/yr).**

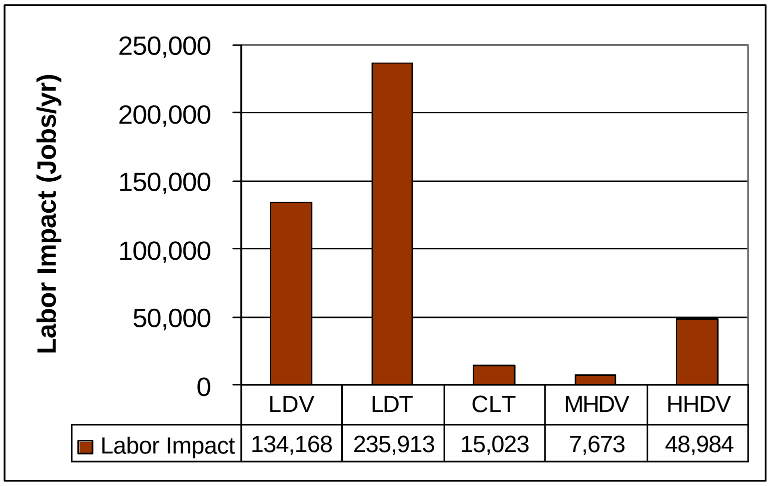
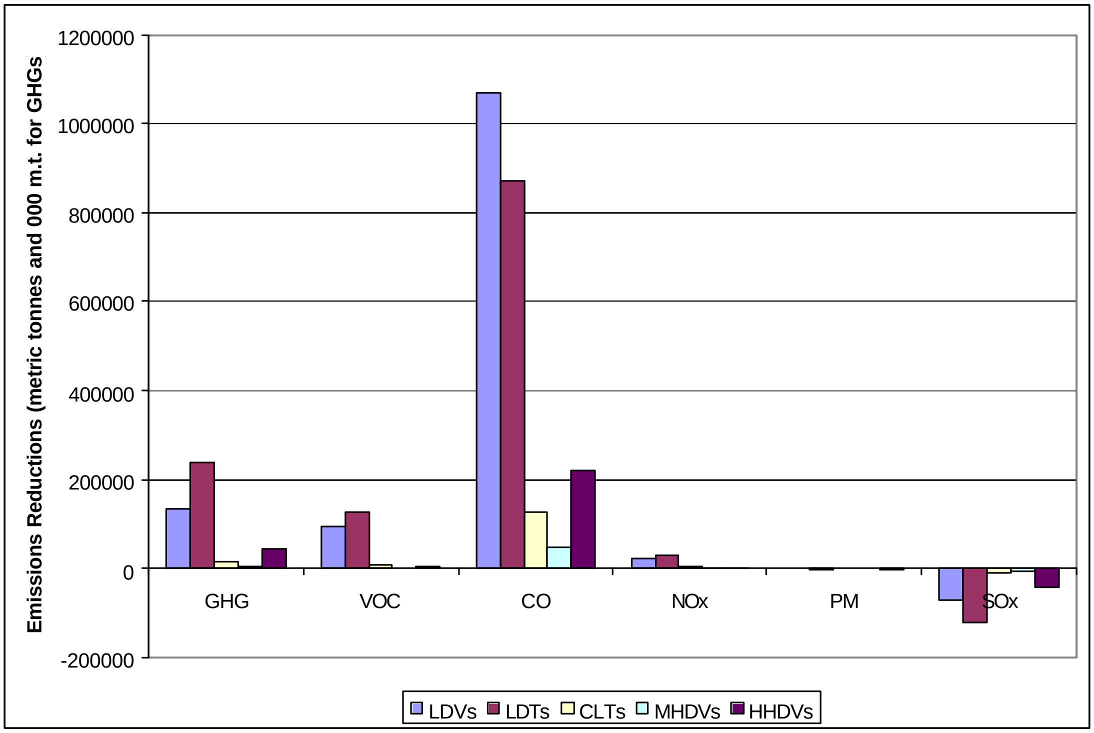


**Figure 6. Emissions Reductions Due to *EDV Future*, 2025 (metric tonnes/yr for all pollutants, *except* GHGs which are in thousand metric tonnes/yr).**




Notes: Figure 6 depicts emissions reductions and so positive values represent reductions v. the *AEO 2025* case. Also, note that GHG emissions reductions are in *thousand* metric tonnes per the Y-axis label.

**Table 3. Monetized Emissions Values and Total Impact of *EDV Future* for 2025.**

| Pollutant | $/ton | Total M$/yr (2002$) |
|---|---|---|
| CO | $ 360 | $ 924 |
| VOC | $ 3,660 | $ 935 |
| NOx | $ 3,300 | $ 224 |
| GHG | $ 15 | $ 7,255 |
| $SO_2$ | $ 180 | $ (49) |
| PM | $ 3,000 | $ (27) |
| **TOTAL** | | **$ 9,261** |

Notes: GHGs are based on emissions of $CO_2$, $CH_4$, and $N_2O$. These emissions are normalized to tons of "$CO_2$ equivalents" using accepted global warming potential values.

**Table 4. Summary Table of Macroeconomic Benefits of *EDV Future.***

| Macroeconomic Impact | Billion $/yr |
|---|---|
| Balance of trade | $ 26.3 |
| GDP Impact | $ 38.3 |
| Environmental Costs | $ 9.3 |
| Military Costs | $ 7.5 |
| Oil Disruption Costs | $ 7.5 |
| Labor | 440,000 jobs/yr |