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Cost benefit analysis of the federal tax credit for purchasing an electric vehicle

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COST BENEFIT ANALYSIS OF THE FEDERAL TAX CREDIT FOR PURCHASING AN ELECTRIC VEHICLE

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Contents

Abstract:

This paper will present the results of a cost-benefit analysis performed to determine the public benefits of the $7500 federal tax credit for purchasing an electric vehicle. A cost benefit ratio including air pollution, carbon dioxide emissions, and oil dependence as components was created and applied to every county in the continental United States. The results suggest that the current tax credit is too high since it does not create $7500 worth of public benefits using the benefits included in the analysis. Benefits vary regionally due to sources of electricity generation and existing air pollution levels with counties in the northeast and on the west coast generally seeing higher benefits from EV use. The largest component of the benefits is from reducing oil dependence while it was also found that EV use in some areas could actually increase air pollution and CO2 emissions. The cost-benefit analysis indicates that the government should consider lowering the tax credit and that air pollution and CO2 emissions from the electric power industry need to be addressed before widespread EV use occurs in much of the United States.

Introduction:

The 21st century will hold many challenges for American society. Climate change is one of the biggest and a major problem worldwide. In addition, U.S. worries about energy security have increased as the country becomes more reliant upon imported oil for transportation. Switching from internal combustion engine vehicles to electric vehicles (EVs) can be part of the solution to both of these problems. At present, electric vehicles are considerably more expensive than internal combustion engine vehicles (ICEV). To increase adoption, the federal government provides a $7500 tax credit to lower the cost to consumers. This thesis will examine the value to taxpayers of tax credits for electric vehicles in the United States.

Electric vehicles can be defined as any vehicle that uses an on board battery to power a motor. This paper will focus on personal vehicles so although trains and buses can be electric vehicles, they will not be discussed here. Fuel cell powered vehicles are also technically EVs; however this paper will limit the discussion to vehicles using traditional chemical batteries as they are currently available for purchase from major manufacturers.

Vehicle Types:

Electric vehicles come in three main varieties: hybrids, plug-in hybrids, and pure electric vehicles (TVA, 2011). Hybrids use batteries to improve fuel efficiency and some of them can run on battery power alone for very short distances at low speeds. However, hybrids need gasoline or some other fuel source to function in any meaningful way. The onboard batteries are charged through regenerative braking. A popular example of a hybrid is the Toyota Prius.

Plug-in hybrids still have an internal combustion engine, but can also be plugged into an external electricity source to charge their batteries. Plug-in hybrids can usually run for an extended distance on electric alone. Once the battery is depleted, the internal combustion engine takes over. Plug-in hybrids can also operate as a conventional hybrid to increase fuel economy once the initial charge is depleted. As of this writing, the only commercially available PHEVs are the Chevy Volt and Toyota Prius PHEV.

A pure EV is powered solely by its battery and typically has a longer all electric range than a plug-in hybrid. Once the battery is depleted, it must be recharged for the vehicle to continue operating. There are currently two family sized pure EVs available in the U.S., the Nissan Leaf and Ford Focus Electric.

Benefits of Electric Vehicles:

Electric vehicles offer an alternative to internal combustion engine vehicles and there are several reasons why a switch to EVs is attractive. Climate change has become one of society's major issues in the 21st century. Transportation, especially in the United States, is a major contributor to greenhouse gas (GHG) emissions accounting for 27% of U.S. emissions. (EPA, 2009). Replacing internal combustion engine vehicles with electric vehicles is one way to cut down on emissions as EVs do not produce any emissions directly (DOE, 2011). Some emissions will occur from the manufacturing process and the true emissions reduction from switching to EVs is partially dependent upon how the electricity powering them is generated. If power comes from solar, wind, hydro, or nuclear the GHG emissions from using an EV will be minimal. If the power comes from fossil fuels, there will still be GHG emissions associated with EV use. On a related note, EVs in battery-powered mode do not emit air pollutants of any kind and therefore do not contribute to smog in urban areas (DOE, 2011). Once again, the true benefit depends upon how the electricity is generated.

Environmental benefits aside, EVs also cut down on noise pollution (DOE, 2011). The benefit of this will be obvious to anyone who lives near a busy highway.

Electric vehicles can also improve total energy efficiency. Seventy-five percent of the energy stored in the battery makes it to the wheels, whereas internal combustion engine vehicles average only around 20% (DOE, 2011). This occurs because much of the energy stored in fossil fuels is lost as heat when they are burned. If electricity used to power EVs comes from a source like hydroelectric that does not produce waste heat, then there is a major efficiency benefit. Switching to EVs will improve energy security as well. The U.S. imports 51.4% of its oil, which makes it reliant upon potentially hostile nations for some of its energy (Smith, 2011). In 2011, the U.S. imported 39 million megawatt hours of electricity while consuming over 4 billion megawatt hours so imports make up less than 1% of the total (EIA, 2011). In addition, all imports come from Canada and Mexico, both of which are stable democratic allies of the U.S. (EIA, 2011).

Limitations of Electric Vehicles:

Electric vehicles are not perfect and several important problems are worth discussing. Electric vehicles have limited range, averaging 100-200 miles on a charge as opposed to internal combustion engine vehicles that average about 300 miles between fueling (DOE, 2011). The range limitation would not be a huge problem if EVs could be refueled as quickly as other vehicles. Unfortunately charging their batteries can take quite a while. DC fast charging technology exists and can charge the battery to 80% in half an hour however; it is expensive and can harm the battery (Advanced Energy, 2011). Level 1 charging which utilizes a standard wall outlet will take around 8 hours to charge the batteries (Advanced Energy, 2011). Level 2 charging can charge a battery in around 2-4 hours (Advanced Energy, 2011). Plug-in hybrids do not suffer from the same range problem since they can also run on gas, however this limits their environmental and energy security benefits.

Electric vehicles are fine for shorter journeys, but are not practical for long ones because of the recharging time. Owners of electric vehicles might have to own an internal combustion engine vehicle as well for longer trips. Cost is also an issue as the Chevy Volt, a plug-in hybrid, costs $31,000 for the base model after a tax credit of $7500 (Cheverolet). However, internal combustion engine cars similar to the Volt will cost around $16,000-$20,000 so there is still a hefty premium for EVs (Cheverolet).

This thesis will perform a cost benefit analysis to determine if the public benefits of EV use outweigh the $7500 cost of the tax credit. A benefit-cost ratio will be created and applied to every county in the continental U.S. to determine which counties see the greatest net benefit from EV use. Counties will be ranked by benefit and the factors influencing their ranking will be discussed. This paper will end with possible policy options and recommendations.

Literature Review:

This literature review will discuss the case for EVs from the consumer's perspective, the case for government support for EVs, and some ideas for improving the current tax credit system. From the consumer's perspective, EVs will be shown to be too expensive. The government on the other hand will want to encourage EV use due to the public benefits it creates in human health, the environment, and the economy. The last section will discuss the problems with giving a geographically uniform tax credit and linking the value of such a tax credit to battery capacity.

EVs from the consumer perspective:

A cost benefit analysis performed in 2006 determined that PHEVs were too expensive for consumers to justify purchasing (Markel & Simpson, Cost Benefit Analysis of Plug-in Hybrid Electric Vehicle Technology., 2006). The authors determined that battery prices had to fall substantially and the cost of gas had to rise substantially for PHEVs to be economically worthwhile to consumers. Over the long term, the authors projected that the incremental cost of EVs compared to conventional vehicles would be as high as $8,000 (Markel & Simpson, Cost Benefit Analysis of Plug-in Hybrid Electric Vehicle Technology., 2006). They projected that a PHEV with an electric range of 20 miles could reduce fuel consumption by as much as 45%. To do this, the frequency distribution of daily driving distances was used to determine how much of each daily drive could be done on battery power alone.

Several issues exist with this assessment. At the time of writing, there were not any PHEVs on the market yet so the authors had to use hypothetical vehicles. The authors also did not discount anything in their analysis. An assessment of the benefits to consumers of an actual PHEV can now be done since they have arrived on the market. Discounting should be done because it gives a better idea of what the consumer's willingness to pay for a vehicle should be.

Beyond that, EVs can provide benefits to their owners beyond cost savings. People concerned about their carbon footprint may place a high value on the ability of an EV to run without creating significant CO_2 emissions. Factors such as this would be different for each individual and thus difficult to include in a cost-benefit analysis from the consumer's perspective. Still, using only cost savings as a measure of value to the consumer it appears as if EVs will remain too expensive for some time to justify purchasing without some intervention to lower the cost.

Case for Government Support:

Environmental:

Electric vehicles produce social benefits in excess of those that accrue solely to the owner of the car. By reducing tailpipe air pollution emissions, the owner of the vehicle breathes cleaner air as does everyone around them. Lower CO_2 emissions will help slow the pace of global warming which benefits people worldwide. The link between air pollution from vehicles and negative health effects has long been known. One study found that areas of Los Angeles County, California that had higher concentrations of certain air pollutants experienced statistically significant increases in mortality from respiratory illnesses (Mahoney, 1976). The primary source of ozone, the most prominent of the air pollutants in the study is from vehicle emissions. Air pollution is thought to be responsible for up to 50,000 premature deaths in the U.S. each year and increased health costs of $150 billion (NOAA, 2012). It should also be noted that automobiles are not responsible for all of this as other major sources of air pollution include power stations and other industrial facilities.

Health effects from breathing in vehicle emissions are not the only problem associated with them. Vehicle emissions can contribute to acid rain as well as degraded water quality and damage to ecosystems. CO_2 emissions, although not a pollutant with direct human health or environmental effects, contribute to climate change through the greenhouse effect. The exact consequences of climate change are unknown, but the potential for incredibly costly damage exists. Tendencies towards stronger storms, more variable rainfall, and more frequent heat waves are some of the possible damaging effects. In the long term, coastal flooding due to glacial melting could displace hundreds of millions in some of the world's biggest cities (IPCC, 2007).

Motor vehicles have been recognized as the largest single contributor to climate change worldwide. Goddard Space Studies Institute classified economic sectors by their contribution to climate change instead of by each chemical species overall contribution. Although industrial processes and power stations generate large amounts of GHGs, they also produce large amounts of cooling agents including aerosols. The industrial sector may have actually had a net cooling effect due to the other pollutants it was producing. Because of the negative health effects of those pollutants, efforts to restrict their emission are underway which have the potential to accelerate climate change. For the near term, efforts to reduce motor vehicle emissions will have the most effect because motor vehicles do not emit large quantities of cooling agents in addition to their considerable emissions of GHGs (Unger, 2010).

Governments have many policy tools available to discourage the emission of pollutants and GHGs. One option is to increase the cost of emitting GHGs or air pollution through taxing consumption of fuel that causes the emissions. This allows consumers to save money by driving less, purchase a more efficient vehicle to do the same amount of driving using less fuel, or switch to a vehicle whose fuel is not subject to the tax. Government can also target the use of personal automobiles since they are the major source of emissions from transportation. One way to do this would be to introduce a congestion charge that discourages driving in city centers and encourages the use of alternative modes of transportation in and around the city center. Vehicle manufacturers can be nudged into selling cars that produce less pollution through research and development assistance or outright forced to do so by raising fuel economy standards. Another option and the subject of this thesis are tax credits. Tax credits are given to consumers to lower the cost of purchasing fuel efficient or alternative fuel vehicles thereby increasing consumption of them (Gorham, 2002).

National Security and the Economy:

National security is another possible reason for government to support the development of EVs. The United States imports 51.4% of its oil (EIA, 2011). While much of this oil comes from friendly nations such as Canada and Mexico, some is imported from unstable or potentially hostile areas. Furthermore, the price of oil is set in an international market so even if oil keeps flowing to the US, a price shock due to a war in the Middle East will still be felt here. A key piece of the U.S. economy is the transportation sector, which is largely dependent upon oil. In 2011, 93% of the U.S transportation sector relied on an oil derivative such as gasoline or diesel (EIA, 2012). Rapidly rising oil prices are thought to reduce GDP as consumers have difficulty dramatically changing their consumption in the short term (Greene & Hopson, 2010). People have difficulty adjusting to rapid price rises because their gasoline consumption is tied to their choice of vehicle or where they live. These changes can be made in the long term with proper planning. However people cannot move or purchase a new car if oil prices rise dramatically within a matter of weeks or even months.

Oil dependence may be partially responsible for the threat of terrorism against the U.S (Sandalow, 2008). American foreign policy has placed immense importance on keeping oil flowing from the Middle East. In the past, American support of unpopular regimes such as the Shah of Iran and military involvement in Iraq has caused resentment towards the U.S. that is used by terrorist organizations such as Al Qaeda to recruit members. Oil dependence also keeps prices high which supports nations whose interests are at odds with the U.S. such as Iran (Sandalow, 2008). Many of the casualties in the Iraq War resulted from fuel convoys coming under fire. If the military was not dependent on oil to power its vehicles, many of those casualties could have been avoided (Sandalow, 2008). Finally, there appears to be a link between oil wealth and autocracy in developing nations with Venezuela and Saudi Arabia being just two examples of many (Sandalow, 2008).

Oil dependence is an economic issue as well as a national security problem. The costs of maintaining military strength necessary to keep oil flowing are by no means the only costs of oil dependence. Oak Ridge National Laboratory researchers David Greene and Janet Hopson concluded that oil dependence consists of four factors: “noncompetitive world oil market influenced by the OPEC cartel, high levels of US imports, the importance of oil to the U.S. economy, and the lack of economical and readily available substitutes for oil.” Their estimation of the cost of oil dependence consists of three components: wealth transfer, dislocation losses, and loss of potential GDP (Greene & Hopson, 2010). Wealth transfer is the transfer of money out of the U.S. due to artificially inflated prices that result from a noncompetitive market. Dislocation losses are reductions in GDP due to oil price shocks. Loss of potential GDP occurs because the same amount of human and physical capital cannot produce as much due to higher prices for natural resource inputs. The numbers have increased dramatically since the late 1990’s, but as a percentage of GDP oil dependence was worse in 1980 (Greene & Hopson, 2010). For 2009, the authors estimated a wealth transfer of $138 billion, dislocation losses of $111 billion, and a loss of potential GDP of $45 billion. Adding these together, the total cost of oil dependence in 2009 was $294 billion (Greene & Hopson, 2010).

Adoption of EVs is one way to reduce oil dependence costs since EVs can be powered from any source of electricity, a commodity that the U.S. is not a large importer of. Around 1% of electricity is imported and all of that is from Canada and Mexico. Electricity prices are set in regional markets so an event on the other side of the globe will not necessarily affect them. Unlike in transportation fuel, oil makes up a tiny portion of U.S. power plant feed stock. Even plug-in hybrids, which still use gasoline for longer trips are expected to reduce annual fuel consumption by at least 50% for most people (Markel & Simpson, Cost Benefit Analysis of Plug0in Hybrid Electric Vehicle Technology, 2006). The PHEV used in this analysis reduces fuel consumption by two thirds. People in urban areas who don't drive very far each day will see larger relative decreases in fuel consumption than people in rural areas since a higher proportion of their daily driving can be done on the battery alone (Markel & Simpson, Cost Benefit Analysis of Plug0in Hybrid Electric Vehicle Technology, 2006). Transitioning to electric vehicles will lessen the shocks to the economy of a disruption to the global oil supply. As oil becomes less important, the Middle East will lose some of its strategic importance to the U.S., which will lessen the potential for costly military interventions in the future.

Future energy security is another reason for government support for the development and adoption of EVs. Aside from the risk that the oil supply to the U.S. could abruptly decrease due to a geopolitical event, oil reserves will eventually run out or become so costly to extract that production will stop. Forecasts of when this will occur vary wildly, but society will need a replacement for oil. The International Energy Agency estimated in 2008 that world demand through 2030 could be met by expanding production (IEA, 2008). The exact date of peak oil depends largely on future demand and the rate of new discoveries, but the IEA's assessment indicates that we are not yet in crisis and there is still time for an orderly transition. Natural gas is one possibility, but as a fossil fuel it will also run out eventually. Electric vehicles offer a permanent solution to the problem as they can be powered by energy sources that will never run out such as hydropower, wind, and solar.

Energy security is not the only economic justification for government support of alternative fuel vehicles. One of the major reasons given for government support of science and technology in general is maintaining economic competitiveness. Vannevar Bush's report *Science; the Endless Frontier* (1945) outlined his recommendations for U.S. science policy. If government supports the scientific community, it will deliver endless prosperity through the creation of new technologies and industries. The U.S. must maintain its support for science and technology or risk being overtaken by other nations. New technologies spawn new industries that can create thousands of jobs such as the rapid growth of the information technology industry over the last few decades.

Electric vehicles represent a new frontier in automotive technology and have the potential to replace a large proportion of internal combustion engine vehicles. If the U.S. wants to maintain the competitiveness of its large automobile industry, it must become a leader in new automotive technologies or risk losing a valuable new industry to overseas competition. The Obama Administration lists the potential for tens of thousands of new jobs as one of the primary reasons for its investment of $5 billion in electric vehicle technologies (DOE, 2010). A goal of the Recovery Act funding for EVs is to increase American production of EV batteries from 2% of the world total to 40% by 2015 indicating that the administration wants the U.S. to be a leader in EV technology (DOE, 2010).

The Japanese government has decided to support the development and adoption of EVs through its Ministry of International Trade and Industry (MITI) (Ahman, 2006). MITI was created to pick and support important industries in Japan. In the 1960's the chemical industry was singled out for support. As the economy grew, focus shifted to knowledge industries, energy security, and Japan's role in the international community (Ahman, 2006). Electric vehicles fit in nicely with a focus on knowledge industries and energy security, which is probably the reason MITI, began to support them.

Starting in the 1970's, MITI began a comprehensive support program that assisted with research and development, infrastructure investment, market support, and standardization (Ahman, 2006). Joint research projects between government and industry were funded as well as solely private projects. Much of the research done was to improve battery technology. MITI provided program funding with a long-term view with many projects having ten-year timelines. The ECO Station project aimed to install 2000 alternative fueling stations with around half of these being EV charging stations. In addition to funding installation, MITI also provided support for development of charging station technologies (Ahman, 2006).

MITI used several strategies for early market support. To increase private demand, financial incentives were provided for purchasing or leasing an EV. In 1996, the program was revised to cover 50% of the additional cost of an EV (Ahman, 2006). To provide early demand for EVs, the government started purchasing them for its own fleet aiming to replace all of its current vehicles with low emission vehicles (LEVS). Around 60% of the total fleet was expected to be hybrids, a type of EV (Ahman, 2006).

The Japanese policies initially met with mixed results. Targets for EV sales were not met and the industry struggled to get off the ground. Battery technology developed under MITI's support however eventually made it into hybrids of which Japanese companies such as Toyota and Honda are now recognized as leading manufacturers. MITI began its program of support for

EVs with the goals of economic development and energy security in mind. In some sense, it has been a success as it has assisted in creating new products such as the Toyota Prius as well as reducing average fuel consumption in the Japanese vehicle fleet (Ahman, 2006). Ahman notes that technologies that can address multiple policy goals such as EVs are more likely to see positive gains from government support (Ahman, 2006).

Both the Japanese and American policies take a comprehensive approach to supporting electric vehicles. Both provide funding for R&D as well as infrastructure installation and financial incentives for consumers to purchase EVs. The American policy also includes loan guarantees to component manufacturers, which will lower financing costs for new factories. The American policy mirrors the Japanese one in that it has multiple goals. The Obama Administration touts the job creation benefits of investing in EVs, but would also like to improve energy security and the environment. Development of the EV industry may have spillover benefits whose value is unknown. The Japanese policy is an example of a program that was not justifiable based on cost-benefit measures, but was continued because the Japanese government wanted to be a leader is such a sector in the future.

Making Tax Credits more effective:

The reasons listed above provide some justification for tax credits supporting the policy goal of increasing electric vehicle consumption through their reduction of negative externalities resulting from oil consumption as well as the more difficult to measure positive externalities from becoming a leader in a new industry. Markel and Simpson (2006) show that EVs are currently too expensive for a consumer to justify purchasing one based on its lower fueling cost. To support the market in its infancy and reap the public benefits of EV use, the government subsidizes the cost of EVs. Subsidies for electric vehicles are currently done through tax credits that are given to anyone who purchases an EV.   Tax credits are a commonly used tool by policymakers; however a few authors see room for improvement in the current tax credit for electric vehicles. There is limited money to spend on tax credits for electric vehicles and on all other forms of policy related to electric vehicles. The government should try to achieve the highest return possible on this money. Linking subsidy amount to battery capacity seems logical at first since cars that use less gas produce fewer emissions and other negative effects. However, there are diminishing returns to battery capacity since the average trip is not very long (Michalek, 2012). Spending triple the money on cars that do not achieve triple the benefit is wasteful if the number of cars that can be purchased under the tax credit is limited. Providing less money for each car might increase the number of EVs purchased under the tax credit (Michalek, 2012).

Under the current tax credit, the amount given for each vehicle of a certain model is the same regardless of where the car is used. Social benefits of EV ownership are not evenly distributed however (Skerlos & Winebrake, 2010). Localized emissions from EVs are nonexistent since the vehicle does not burn anything. However, EV use does result in some emissions depending upon where the electricity powering it comes from. Areas where the electricity is generated primarily from non-fossil fuel sources will see higher benefits from EV use than areas where electricity is generated from coal or natural gas. Congested cities with poor air quality such as Los Angeles will see higher benefits from reducing air pollution than sparsely populated rural areas (Skerlos & Winebrake, 2010).

The current tax credit is intended to increase the number of people who purchase EVs. While it likely has caused some people to purchase EVs, many people who received the credit might have bought the vehicles anyway. While it is not possible to ask everyone in the country whether they would purchase an EV without the tax credit, it is possible to give the tax credit to certain income groups (Skerlos & Winebrake, 2010). Instead of a $7500 credit given to everyone, a larger credit could be given to middle and lower income individuals while wealthy people who can afford the car without it would not receive one or at least receive a smaller amount. Discriminating by income is not a perfect system since some wealthy people might have purchased the car because of the tax credit or lower and middle-income people may have stretched to buy the car without the credit. If the goal is to make EVs more affordable to more people, then a tax credit based on income does a better job than simply giving the tax credit to everyone.

The idea of targeting subsidies to increase social benefits from the same amount of money may deliver, however it is still likely to be controversial. A main concern of government is equality and giving certain groups of people or certain regions a higher share of resources is inherently unequal. A policy that discriminates based on income or region will result in some backlash, especially from areas or groups that receive smaller shares of the funding.

Research Questions:

A number of questions emerge from the literature review. Existing research supports the idea that a subsidy of some kind is currently necessary to support the EV market. The current tax credit is necessarily high to induce early adoption, another fact supported by existing research. However, existing research is less clear on the public benefits from EV use. That they exist is not in question in this thesis, rather I am interested in determining if money spent on the tax credit is at least equal to the public benefits from EV use. This thesis will focus on answering the following questions:

1. Do the public benefits from a single tax credit outweigh the cost of providing it?
2. How much does the cost-benefit ratio for providing a tax credit vary by location?
   a. Which counties have the highest cost benefit ratio?
3. What is the largest component to the public benefits from the tax credit? (GHG reductions, air pollution reductions, or energy security).

Methodology:

This paper will discuss a cost-benefit analysis of the federal tax credit for purchasing an EV. The primary tool will be a cost benefit ratio that will be applied to every county in the continental U.S. The cost in this case is simply the value of the tax credit, which is $7500. Benefits consist of reductions in air pollution, GHG emissions, and reduced oil dependence. These three components were chosen because of their ability to be monetized. EV use has other benefits possibly including building capacity to become a leader in an emerging high tech sector. Technology developed for EVs could have spillover benefits in other sectors including renewable energy storage. Although these are certainly benefits, they may never be realized. For that reason, I chose to not to include them in the cost benefit ratio.

Reductions in air pollution can be counted as a public benefit due to associated decreases in related health problems or premature deaths. Reductions in GHG emissions can be considered a public benefit because of the reduced likelihood of harmful climate change. Climate change's public costs are numerous, ranging from increased drought frequency and stronger hurricanes to coastal flooding caused by sea level rises. The U.S. economy's reliance on oil has costs associated with it because oil is a globally traded commodity whose price is controlled by a cartel. Economically damaging rapid price changes have occurred in part because of the uncompetitive nature of the oil market. Each of the benefits must be monetized before applying the ratio. How they are monetized is described below.

This analysis is attempting to show the benefit of using EVs instead of internal combustion engines. To do so requires some assumptions to be made. The EVs and PHEVs on the market are for the most part compact cars or even smaller and it is assumed that potential EV consumers are choosing between an EV and a conventional compact car. In this way, the benefits of EVs will be judged in relation to the next best available alternative as opposed to a large SUV. Another assumption is that consumers have preferences for different brands. Some consumers may prefer American cars while others may prefer imports. Attributes in addition to fuel economy may also be important. To account for this an average fuel economy for compact cars made by major manufacturers can be used. To do this, it is assumed that the consumer is choosing between an EV and the most efficient compact car made by each manufacturer so the average will consist only of the most fuel-efficient models. This means that the Chevy Cruze Eco will be included in the average instead of the base model.

Internal Combustion Engine Models Considered for this Analysis	
Model	MPG
Ford Focus SFE	33
Hyundai Elantra	33
Kia Forte Eco	30
Honda Civic HF	33
Mazda 3 DI	33
Nissan Sentra	30
Toyota Corolla	29
VW Golf	26
Chevy Cruze Eco	31
Average Combined Fuel Economy	31

Figure 1: Table shows the combined fuel economy of all ICE cars included in the analysis

Assumptions about driving habits must also be made to estimate how much an EV will reduce fuel consumption. EVs and PHEVs cannot replace all internal combustion engine driving for the average American since they have limited range. Unless it is assumed that people will totally cut long trips, some proportion of annual miles driven will require an internal combustion engine.   A frequency distribution of trip lengths for the average drive from the Bureau of Transportation Statistics is used to determine the average number of miles driven on battery per trip and the average number of miles driven on an internal combustion engine. The data include both the total number of trips taken between each length interval and the total number of miles driven at each interval. These can be used to determine the average trip length within each interval. If the trip is within the all-electric range, all miles are driven electric. If the trip is greater than the range, the all-electric range is subtracted from the trip length to determine the miles driven using an internal combustion engine. The miles driven using electricity and the miles driven on gas at each trip length are then multiplied by the frequency of that trip length and summed across all intervals to determine the average number of miles driven on battery and gas per trip. Dividing the total number of trips taken by the number of vehicles reveals that the average vehicle takes 1191 trips per year. Multiplying this by the average number of miles driven on electric and gas leads to the assumption that the vehicles in question will be driven for a total of 11578.7 miles in a year. A PHEV with a battery only range of 30 miles will be driven around 9111 miles/year on electric and 2467 miles/year on gas. Such a PHEV allows the owner to drive the same number of miles while using about 1/3 as much gas as they would with an internal combustion engine vehicle. An EV with a range of 100 miles will allow the owner to drive around 10505 miles/year on electric and 1073 miles/year on gas. It was assumed that the actual range seen by drivers would be lower than the stated figure due to people not driving for optimal efficiency all the time. In the case of pure EVs, it was assumed that trips close to the maximum range would be taken with an internal combustion engine vehicle instead to avoid the risk of running out of charge before reaching the destination.

Gasoline consumption can now be determined by dividing the miles driven on gas by the mpg of the vehicle. The reduction in gasoline consumption due to EV use is the difference between the gasoline consumption of the internal combustion engine vehicle and the gasoline consumption of the PHEV or internal combustion engine vehicle necessary to make longer trips that a pure EV cannot make. Electricity consumption is determined by multiplying the reported kWh/mile by the number of miles driven on electricity.

After calculating the reduction in gasoline consumption from switching to an EV, the reduction in tailpipe emissions can be calculated from the amount of each emission produced by burning a gallon of gas and the reduction in gallons consumed. The following equation was used to determine the tailpipe emissions of each vehicle where P1 is the amount of a particular pollutant emitted per unit of gasoline, G is the number of gallons consumed, and P2 is the amount of a particular pollutant emitted by the vehicle.

$$P1\frac{Tons}{Gal} * G\frac{Gal}{Yr} = P2\frac{Tons}{Yr}$$

This calculation is straightforward for CO2 since burning a gallon of gasoline produces 19.4 lbs of CO2 (PG&E, 2012). For the criteria air pollutants, numbers were not readily available possibly due to there being multiple grades of gasoline and cars having differing levels of pollution control. An average can be calculated using BTS data on gallons consumed by light duty passenger vehicles and EPA data on air pollution emissions from light duty passenger vehicles. The resulting tons pollutant/gallon figure can be used in the above equation. The equation below was used to calculate the amount of each pollutant caused by consuming one gallon of gas where P_T is the total amount of each pollutant emitted in the U.S., G_T is the total amount of gasoline consumed in the U.S., and P1 is the amount of each pollutant emitted per unit of gasoline.

$$\frac{P_t\frac{Tons}{Yr}}{G_T\frac{Gal}{Yr}} = P1\frac{Tons}{Gal}$$

Unfortunately, this is not the full story as creating the electricity to power EVs also creates emissions. These emissions will vary by location depending upon how the electricity is generated. The EPA, through its eGRID program keeps track of lbs per MWh of CO2, SO2, and NOx at a number of different geographic levels including state level. The EPA also keeps track of PM 2.5, PM 10, and VOC emissions from electric generation at the state level. Using the MWh of electricity generated in those states reported on eGRID allows for the calculation of lbs/MWh for these pollutants as well. Using the assumed annual electricity consumption of an average EV allows for the calculation of the annual amount of each emission type due to EV use in each state. APEEP's valuations for criteria pollutants at the county level and the average suggested price for CO2 emissions are used to determine the value of the emissions caused by EV use. The equation below was used to determine the emissions of each pollutant resulting from increased electricity demand where P_E is the amount of each pollutant produced per unit of electricity, E_{EV} is the amount of electricity consumed by the vehicle, and P_{EV} is the amount of each pollutant emitted by EV use.

$$P_E \frac{lbs}{MWh} * \frac{1\ Ton}{2000\ lbs} * \frac{1\ MWh}{1000\ kWh} * E_{EV} \frac{kWh}{Yr} = P_{EV} \frac{Tons}{Yr}$$

Monetizing the emissions is the final step before applying the cost-benefit ratio. There are numerous studies placing valuations on both criteria air pollutants and CO2. For criteria air pollutants, the baseline analysis in this study will use the Air Pollution Emission Experiments and Policy Analysis Model (APEEP) valuations since they allow differentiation at the county level whereas most other models only examine a few locations (Muller & Mendelson, 2009). Differentiation at the county level allows for the benefits of EV use to be examined nationwide instead of only in a few major cities. There is significant variation in estimates for the cost of

CO_2 emissions ranging from emissions having a positive economic effect to a cost of $1500/ton. The average valuation is $43/ton, which will be used in the baseline analysis. Since there is so much variation, sensitivity analysis will be performed applying the ratio with higher valuations for CO_2 emissions. The annual benefit from each emissions reduction was calculated using the following equation where Q is the quantity of each emission reduced, V is the value for reducing one unit of each emission, and V_{EV} is the value of an emissions reduction for a vehicle.

$$Q\frac{Tons}{Yr} * V\frac{\$}{Ton} = V_{EV}\frac{\$}{Yr}$$

Emissions reductions are not the only possible benefit from replacing an internal combustion engine vehicle with EVs. EVs do not require gasoline and can therefore be powered from domestically sourced energy. Oil dependence has far-reaching consequences beyond emissions. Money is transferred out of the country and rising prices cause people to spend more on imported oil instead of elsewhere in the economy, reducing the output that could have been produced otherwise. Oak Ridge National Laboratory has estimated that the cost of oil dependence in 2009 was around $294 billion. The U.S. consumed 18.77 million barrels of oil per day for a total of 6.851 billion barrels of oil in 2009. Dividing oil dependence cost by the total number of barrels consumes gives an oil dependence cost of $42.90/barrel. Since a barrel of oil produces 42 gallons of gasoline and other products, the dependence cost per gallon comes out to be $1.03 (Texas Oil and Gas Association, 2012).

$$\frac{294\ Billion\frac{\$}{Yr}}{6.851\ Billion\frac{bbl}{Yr}} = 42.9\frac{\$}{bbl} = \$1.03\frac{\$}{Gal}$$

How long the cars are in use is another important factor to consider for the cost benefit ratio. Whether the annual benefit is received for two years or twenty will make a huge difference in the results. Since EVs have not been commercially available for a very long time, battery life is somewhat of an unknown. The only PHEV on the market at the time of this writing, the Chevy Volt, has an electric powertrain warranty of eight years so worries about maintenance would be no different from an internal combustion engine vehicle for the first eight years of ownership. Since there is no guarantee that the car will function after eight years, the baseline analysis will assume that the cars in question are operated for eight years and then disposed of. Obviously many cars are in use for much longer than eight years. The car belonging to the author of this paper is twelve years old. What happens if the car is in use for a longer period of time will be discussed in sensitivity analysis.

The results will be separated into three scenarios; a PHEV scenario and a pure EV scenario that include vehicles eligible for the $7500 tax credit and a scenario for the Toyota Prius PHEV which has a smaller battery and is only eligible for a $2500 tax credit. This is done because averaging the all-electric mileage across the two vehicle types would not accurately reflect the vehicles that are available today. PHEVs are meant to be complete replacements for conventional internal combustion engine vehicles since they do not suffer from a range limitation. To do this, manufacturers must sacrifice some all-electric range to include an internal combustion engine. Averaging the dramatically different ranges of the two vehicle types would result in a hypothetical vehicle that is not similar to any currently existing EV. The Prius PHEV is separated from the other two because it is eligible for a much smaller tax credit.

While manufacturers may want people to think that pure EVs are a complete replacement for internal combustion engine vehicles, their limited range means that the average driver will also need an internal combustion engine vehicle for longer trips. This does not mean that they would necessarily need to own two vehicles since most driving could be done using a pure EV. An internal combustion engine vehicle could be rented for longer trips. This analysis will assume that people who purchase EVs will choose to rent or own the most efficient internal combustion engine vehicles on the market. The average fuel economy used for the internal combustion engine portion of their driving will use the same average as the vehicles the consumer could have chosen instead of an EV.

The cost component of the benefit-cost ratio is paid upfront and therefore does not need to be discounted. The annual benefits however do need to be discounted since they accrue over the eight years that the car is being operated. A discount rate must be applied in situations where payment happens over a period of time or payment is received at a later date since money in the present is worth more than money in the future. This happens because money spent in the present could be spent in an innumerable number of ways. Any project must achieve a higher rate of return than the next best alternative. Whatever the rate of return is determines the discount rate. A private investor who can get a 10% return in the stock market would want any potential project to have a higher rate of return and thus this investor would choose a discount rate of 10% at which to evaluate potential projects. Governments are more limited in what they can spend their money on and thus often use lower discount rates. Public projects are often evaluated at discount rates of around 7%.

The cost benefit ratio will be analyzed using four different discount rates. A 0% discount rate will be applied to see if the tax credit is justifiable in a case where the government had no alternative investment opportunities. A 2% discount rate will be applied to investigate whether the tax credit is appealing if the only other alternative is to invest the money in very low risk vehicle such as a certificate of deposit (CD). A 7% discount rate will be applied since it is a typical government discount rate and tax credits are public spending. Finally, a 12% rate will be applied to investigate a situation where a private firm receives the benefits of EV use in exchange for incentivizing people to purchase them.

To discount the annual benefits of EV use, they will be treated as an annuity received in the same amount each year. The following formula can be used to discount the present value an annuity received for a set number of years where A is the value of the annuity, I is the discount rate, n is the number of years the annuity is received, and PV is the total present value of that annuity.

$$A * \frac{(1+i)^n - 1}{i(1+i)^n} = PV$$

Results:

The cost-benefit ratio was applied to every county in the continental United States using APEEP's valuations for criteria air pollution, an assumed value of $43/tonne for carbon dioxide emissions, and a value of $42/barrel for reduced oil dependence. Under these assumptions, there was significant variation among counties with the top county seeing 230% of the benefit of the bottom county under the PHEV scenario and 206% of the benefit of the bottom county under the pure EV scenario. However, none of them saw a cost benefit ratio greater than one indicating that the current federal tax credit of $7500 is too high to justify on the grounds of public benefit.

PHEV Scenario:

The fact that the benefits from EV use did not outweigh the cost of the tax credit does not mean that consumption of EVs is harmful. Every county in the study was better off from replacing one internal combustion engine vehicle with an electric vehicle. Most of the benefit in every case came from reducing oil dependence. With an annual oil dependence benefit of $317 and an average annual total benefit of $338, oil dependence on average contributes 94% of the benefits of switching to a PHEV. Even in Los Angeles County, which saw the highest benefit at $473 annually, oil dependence still makes up 67% of the total.

Top Ten Counties by Annual Benefit			Bottom Ten Counties by Annual Benefit		
County	State	Annual Benefit	County	State	Annual Benefit
Los Angeles County	CA	$ 473	District of Columbia	DC	$ 219
Bergen County	NJ	$ 455	Medina County	OH	$ 256
San Francisco County	CA	$ 453	Cuyahoga County	OH	$ 258
Hudson County	NJ	$ 449	Stark County	OH	$ 259
Contra Costa County	CA	$ 443	Summit County	OH	$ 263
Windham County	VT	$ 439	Marion County	IN	$ 263
Bennington County	VT	$ 438	Clark County	IN	$ 265
Windsor County	VT	$ 437	Portage County	OH	$ 265
Rutland County	VT	$ 437	St. Joseph County	IN	$ 268
Orange County	VT	$ 437	Morgan County	IN	$ 270

Figure 2: Table shows the top and bottom ten counties by annual benefit for the PHEV scenario

Interestingly, not all counties are better off in terms of emissions from switching an internal combustion engine vehicle for a PHEV. The benefit in terms of emissions reduction is defined as the value of the difference in criteria air pollutant and carbon dioxide emissions between the EV scenario and the internal combustion engine scenario. Of the 3109 counties included in this analysis, 2305 of them saw a benefit from emissions reduction, which means that nearly 26% of counties in the U.S. are worse off from an emissions standpoint if someone chooses to replace an internal combustion engine vehicle with a PHEV.

Looking only at carbon dioxide emissions, 2318 counties saw a reduction in emissions from switching to an EV, which means that over 25% of counties in the U.S., would see higher carbon dioxide emissions because of PHEV use. In some cases, emissions are dramatically higher with counties in North Dakota seeing nearly a 1 ton per car per year increase in carbon dioxide emissions. In some sense, the air pollution numbers are worse with only 1515 counties seeing a positive benefit from air pollution reduction, which means 51% of counties in the U.S. are worse off from a criteria air pollutant standpoint if someone purchases an EV instead of an internal combustion engine vehicle. This does not mean that EV use in these counties caused increases in all criteria air pollutant categories, only that the harm caused by emissions in an EV use scenario is higher than it would be in an internal combustion engine scenario. It should also be noted that most of the air pollution totals both positive and negative are quite small in magnitude so the overall effect either way is very minor.

The initial intent of this analysis was to discount the annual benefits using several different rates. This may seem unnecessary given that the tax credit does not create $7500 worth of public benefits anywhere. Applying discount rates still has useful policy implications since it provides a better indication of what taxpayers should be willing to pay to increase EV use. To that end, the annual benefit was still discounted at 2%, 7%, and 12%. It is not surprising that this does not help justify the current tax credit as discounting only reduces the value of the annual benefits. The data and spreadsheet used in this analysis can be found on a CD-ROM attached to this document or on the Wallace Library's website.

Top Ten States by Annual Benefit from CO2 Emissions Reduction		Bottom Ten States by Annual Benefit from CO2 Emissions Reduction	
Vermont	$ 116	District of Columbia	$ (40)
Idaho	$ 108	North Dakota	$ (33)
Washington	$ 95	Wyoming	$ (28)
Oregon	$ 90	Utah	$ (18)
California	$ 82	Indiana	$ (18)
New Jersey	$ 70	Kentucky	$ (16)
Maine	$ 69	Delaware	$ (13)
New Hampshire	$ 66	New Mexico	$ (8)
Connecticut	$ 65	West Virginia	$ (7)
New York	$ 63	Colorado	$ (6)

Figure 3: Table shows the top and bottom states by annual benefit from CO2 reduction in the PHEV scenario

Top Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions			Bottom Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions		
County	State	Annual Benefit	County	State	Annual Benefit
Los Angeles County	CA	$ 75	Medina County	OH	$ (64)
Bergen County	NJ	$ 68	Philadelphia County	PA	$ (63)
Hudson County	NJ	$ 62	Cuyahoga County	OH	$ (62)
San Francisco County	CA	$ 54	Stark County	OH	$ (61)
Essex County	NJ	$ 51	Baltimore city	MD	$ (59)
Contra Costa County	CA	$ 44	District of Columbia	DC	$ (58)
Union County	NJ	$ 40	Summit County	OH	$ (57)
Passaic County	NJ	$ 35	Portage County	OH	$ (55)
Nassau County	NY	$ 30	Montgomery County	MD	$ (55)
Middlesex County	NJ	$ 30	DeKalb County	GA	$ (53)

Figure 4: Table shows the top and bottom counties in annual benefit from air pollution reduction in the PHEV scenario

Summary of Total Benefits at Chosen Discount Rates									
Discount Rate	Mean Total Benefit	Net Benefit	B/C Ratio	Max Total Benefit	Net Benefit	B/C Ratio	Min Total Benefit	Net Benefit	B/C Ratio
0%	$ 2,707	$ (4,793)	0.36	$ 3,788	$ (3,712)	0.51	$ 1,756	$ (5,744)	0.23
2%	$ 2,479	$ (5,021)	0.33	$ 3,468	$ (4,032)	0.46	$ 1,608	$ (5,892)	0.21
7%	$ 2,021	$ (5,479)	0.27	$ 2,827	$ (4,673)	0.38	$ 1,310	$ (6,190)	0.17
12%	$ 2,021	$ (5,479)	0.27	$ 2,827	$ (4,673)	0.38	$ 1,310	$ (6,190)	0.17

Figure 5: Table shows maximum, minimum, and average total benefit and net benefit at chosen discount rates

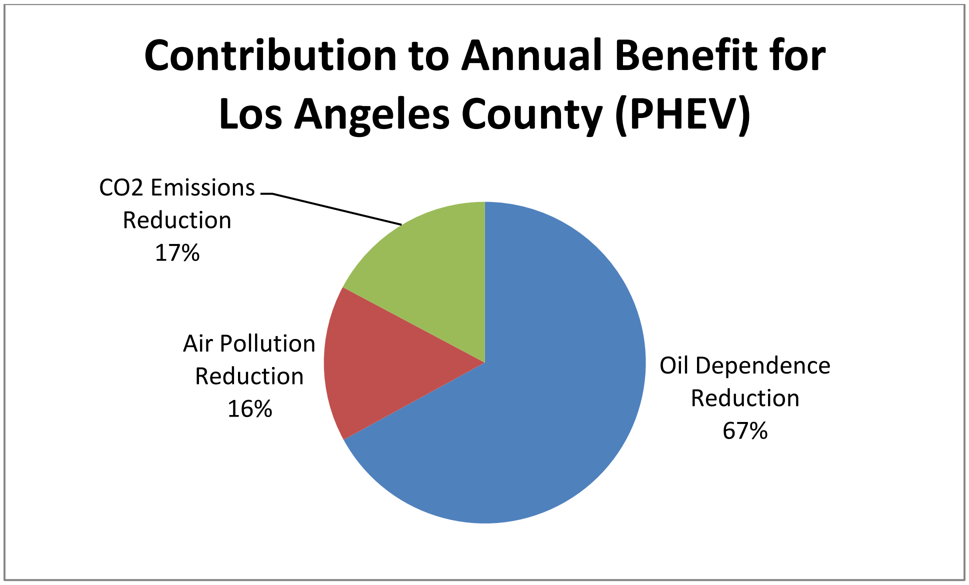

Figure 6: Chart shows the contribution of each variable to annual benefit from EV use

Pure EV Scenario:

The pure EV scenario ends up with a similar result to the PHEV scenario. The top and bottom counties are all the same and in the same order as are the top and bottom states. The values differ because less electricity and gasoline are consumed under this scenario. Since more miles are driven on electricity in the pure EV scenario, one would expect more electricity to be consumed. However since the pure EVs are more efficient than PHEVs and the number of all-electric miles is not dramatically higher, they actually use less electricity. The overall result of the tax credit not producing $7500 of benefits in any county is still true with pure EVs. Annual benefit increases under the pure EV scenario because the greater efficiency of the pure EVs allows them to produce fewer CO2 emissions than PHEVs, even in states that see higher emissions from EV use. The benefit from oil dependence reduction rises to $325. The top and bottom counties in benefit from criteria air pollution reduction do differ in the pure EV scenario. Queens County and Nassau County, both in New York, enter the top ten while the order among the bottom ten counties changes slightly. The top and bottom ten counties all see higher benefit from air pollution reduction although the bottom ten counties are all still worse off due to increased air pollution.

While overall benefits improved, there are still 553 counties that are worse off from an emissions standpoint due to EV use, which is around 18% of the total. Air pollution alone is a similar story with 1541 counties or around 49% of the total seeing worse air pollution under the pure EV scenario. Some states that saw slightly higher CO2 emissions under the PHEV scenario saw slightly lower emissions under the pure EV scenario, lowering the number of counties that see higher CO2 emissions to 409, which is still over 13% of the total.

Top Ten Counties by Annual Benefit			Bottom Ten Counties by Annual Benefit		
County	State	Annual Benefit	County	State	Annual Benefit
Los Angeles County	CA	$ 490	District of Columbia	DC	$ 238
Bergen County	NJ	$ 472	Medina County	OH	$ 273
San Francisco County	CA	$ 467	Cuyahoga County	OH	$ 275
Hudson County	NJ	$ 465	Stark County	OH	$ 276
Contra Costa County	CA	$ 457	Summit County	OH	$ 279
Essex County	NJ	$ 454	Marion County	IN	$ 279
Windham County	VT	$ 449	Clark County	IN	$ 281
Bennington County	VT	$ 449	Portage County	OH	$ 281
Windsor County	VT	$ 449	St. Joseph County	IN	$ 284
Rutland County	VT	$ 449	Morgan County	IN	$ 285

Figure 7: Table shows the top and bottom ten counties by annual benefit for the pure EV scenario

Top Ten States by Annual Benefit from CO2 Emissions Reduction		Bottom Ten States by Annual Benefit from CO2 Emissions Reduction	
Vermont	$ 120	District of Columbia	$ (32)
Idaho	$ 112	North Dakota	$ (25)
Washington	$ 100	Wyoming	$ (21)
Oregon	$ 95	Utah	$ (11)
California	$ 87	Indiana	$ (10)
New Jersey	$ 75	Kentucky	$ (9)
Maine	$ 74	Delaware	$ (6)
New Hampshire	$ 71	New Mexico	$ (1)
Connecticut	$ 70	West Virginia	$ (0)
New York	$ 68	Colorado	$ 1

Figure 8: Table shows the top and bottom states by annual benefit from CO2 reduction in the pure EV scenario.

Top Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions			Bottom Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions		
County	State	Annual Benefit	County	State	Annual Benefit
Los Angeles County	CA	$ 79	Philadelphia County	PA	$ (61)
Bergen County	NJ	$ 72	Medina County	OH	$ (61)
Hudson County	NJ	$ 65	Cuyahoga County	OH	$ (59)
San Francisco County	CA	$ 56	Stark County	OH	$ (58)
Essex County	NJ	$ 54	Baltimore city	MD	$ (57)
Contra Costa County	CA	$ 46	District of Columbia	DC	$ (55)
Union County	NJ	$ 43	Summit County	OH	$ (55)
Passaic County	NJ	$ 37	Portage County	OH	$ (53)
Nassau County	NY	$ 33	Montgomery County	MD	$ (52)
Queens County	NY	$ 32	DeKalb County	GA	$ (51)

Figure 9: Table shows the top and bottom counties in annual benefit from air pollution reduction in the pure EV scenario

Summary of Total Benefits at Chosen Discount Rates									
Discount Rate	Mean Total Benefit	Net Benefit	B/C Ratio	Max Total Benefit	Net Benefit	B/C Ratio	Min Total Benefit	Net Benefit	B/C Ratio
0%	$3,034	$ (4,466)	0.40	$4,213	$ (3,287)	0.56	$2,043	$(5,457)	0.27
2%	$2,778	$ (4,722)	0.37	$3,858	$ (3,642)	0.51	$1,871	$(5,629)	0.25
7%	$2,265	$ (5,235)	0.30	$3,145	$ (4,355)	0.42	$1,525	$(5,975)	0.20
12%	$1,884	$ (5,616)	0.25	$2,616	$ (4,884)	0.35	$1,269	$(6,231)	0.17

Figure 10: Table shows maximum, minimum, and average total benefit and net benefit at chosen discount rates

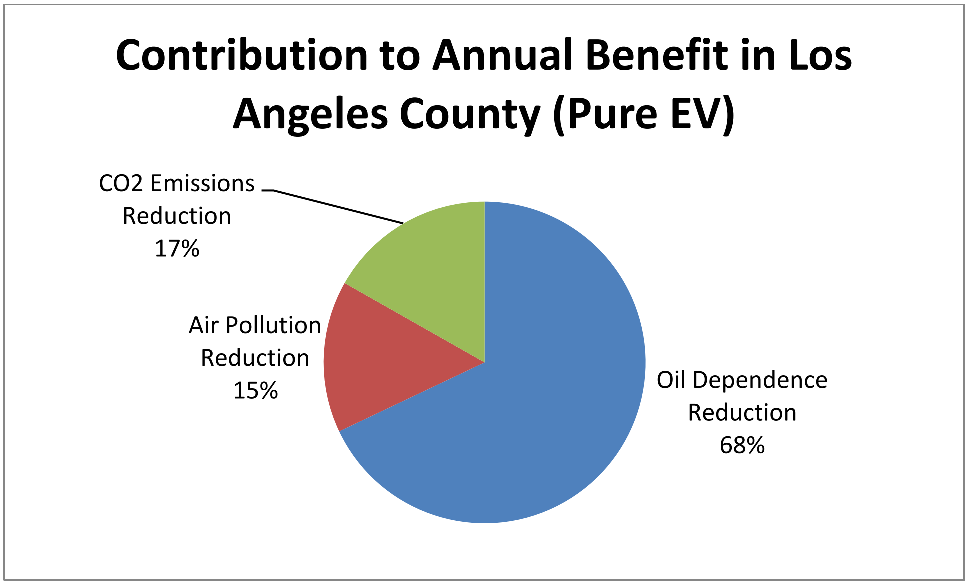

Figure 11: Chart shows the contribution of each variable to annual benefit from EV use

Prius PHEV Scenario:

The results for the Prius PHEV are somewhat different since it is only eligible for a smaller tax credit of $2500. Although the majority of counties still do not see positive net benefits after the cost of the tax credit is taken into account, many of them do. At a 0% discount rate 705 counties see positive net benefits while at a 2% discount rate 121 counties do, which is a great improvement over the first two scenarios. The average benefit cost ratio at .97 is also much higher than the first two scenarios. Overall, the maximum and average benefits from EV use are smaller than in either the PHEV or pure EV scenarios however; they only have to pay back $2500 instead of $7500 to see positive returns, which boosts the benefit-cost ratio.

The top and bottom counties under the Prius PHEV scenario are the same mix of counties as in the first two scenarios although in a slightly different order. The Prius PHEV sees fairly similar results to the other EVs considered in this analysis even though it has a much all-electric range (about 10 miles). This is most likely because many trips are less than 10 miles and the Prius PHEV has a much higher combined fuel economy when operating on gas only. The states that see the highest reduction in CO_2 emissions are the same as in the previous scenarios as are the states that see the lowest. Interestingly, there are no states that see higher CO_2 emissions because of EV use like there are in the PHEV and pure EV scenarios. The mix of counties at the top and bottom for criteria air pollutant reductions is also very similar with eight of both the top and bottom ten counties being the same as in the other two scenarios. Although no county sees higher CO_2 emissions in this scenario, 1204 counties (39%) are worse off from an air pollution standpoint.

Top Ten Counties by Annual Benefit			Bottom Ten Counties by Annual Benefit		
County	State	Annual Benefit	County	State	Annual Benefit
Los Angeles County	CA	$ 395	District of Columbia	DC	$ 252
Bergen County	NJ	$ 392	Medina County	OH	$ 265
Hudson County	NJ	$ 385	Stark County	OH	$ 266
San Francisco County	CA	$ 377	Cuyahoga County	OH	$ 266
Essex County	NJ	$ 375	Summit County	OH	$ 267
Contra Costa County	CA	$ 369	Marion County	IN	$ 268
Union County	NJ	$ 365	St. Joseph County	IN	$ 268
Queens County	NY	$ 364	Portage County	OH	$ 268
Passaic County	NJ	$ 360	Clark County	IN	$ 268
Kings County	NY	$ 360	Sioux County	ND	$ 269

Figure 12: Table shows the top and bottom ten counties by annual benefit for the Prius PHEV scenario

Top Ten States by Annual Benefit from CO2 Emissions Reduction		Bottom Ten States by Annual Benefit from CO2 Emissions Reduction	
Vermont	$ 94	District of Columbia	$ 14
Idaho	$ 90	North Dakota	$ 18
Washington	$ 84	Wyoming	$ 20
Oregon	$ 81	Utah	$ 25
California	$ 77	Indiana	$ 25
New Jersey	$ 71	Kentucky	$ 26
Maine	$ 70	Delaware	$ 28
New Hampshire	$ 69	New Mexico	$ 31
Connecticut	$ 68	West Virginia	$ 31
New York	$ 67	Colorado	$ 31

Figure 13: Table shows the top and bottom states by annual benefit from CO2 reduction in the Prius PHEV scenario

Top Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions			Bottom Ten Counties by Annual Benefit from Reduction in Criteria Pollutant Emissions		
County	State	Annual Benefit	County	State	Annual Benefit
Bergen County	NJ	$ 65	Philadelphia County	PA	$ (34)
Los Angeles County	CA	$ 62	Baltimore city	MD	$ (30)
Hudson County	NJ	$ 58	Delaware County	PA	$ (27)
Essex County	NJ	$ 49	Medina County	OH	$ (27)
San Francisco County	CA	$ 44	Stark County	OH	$ (26)
Queens County	NY	$ 41	Cuyahoga County	OH	$ (26)
Union County	NJ	$ 38	Summit County	OH	$ (25)
Kings County	NY	$ 36	Bucks County	PA	$ (24)
Contra Costa County	CA	$ 36	Portage County	OH	$ (24)
Nassau County	NY	$ 35	Montgomery County	MD	$ (22)

Figure 14: Table shows the top and bottom counties in annual benefit from air pollution reduction in the Prius PHEV scenario

Summary of Total Benefits at Chosen Discount Rates (Prius PHEV Scenario)									
Discount Rate	Mean Total Benefit	Net Benefit	B/C Ratio	Max Total Benefit	Net Benefit	B/C Ratio	Min Total Benefit	Net Benefit	B/C Ratio
0%	$ 2,431	$ (69)	1.0	$ 3,157	$ 657	1.3	$ 2,014	$ (486)	0.8
2%	$ 2,226	$ (274)	0.9	$ 2,891	$ 391	1.2	$ 1,844	$ (656)	0.7
7%	$ 1,815	$ (685)	0.7	$ 2,357	$ (143)	0.9	$ 1,503	$ (997)	0.6
12%	$ 1,510	$ (990)	0.6	$ 1,961	$ (539)	0.8	$ 1,251	$ (1,249)	0.5

Figure 15: Table shows maximum, minimum, and average total benefit and net benefit at chosen discount rates

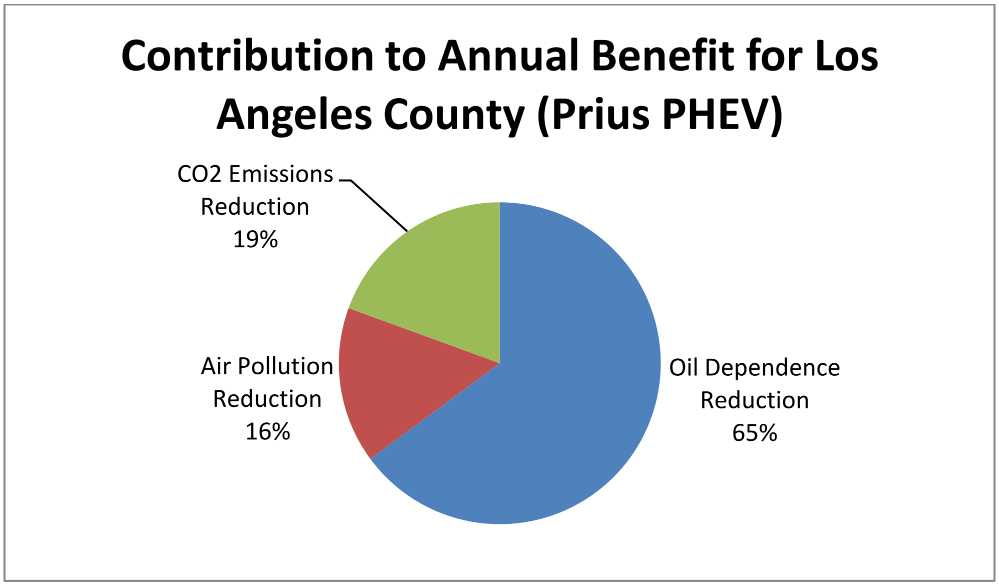

Figure 16: Chart shows the contribution of each variable to annual benefit from Prius PHEV use

Summary of Findings:

1. Every county is better off due to EV use
2. The benefits received even in the best county are too low to justify the current $7500 tax credit
3. The Prius PHEV, which only receives a $2500 tax credit, does produce enough public benefit in about 23% of counties to make up for the smaller tax credit.
4. The largest proportion of the benefits is from reduced oil dependence in all scenarios
5. Pure EV use results in higher benefits than PHEV use
6. More than a quarter of all counties will see higher CO2 emissions as a result of PHEV use while 20% of counties will see higher CO2 emissions as a result of pure EV use
7. Around half of all counties will see at least a slight increase in criteria air pollutants due to PHEV or pure EV use

Discussion:

This section will provide an explanation of the results shown in the previous section. Why certain counties and states performed the way they did will be explored here. There will also be sensitivity analysis to see how changing certain variable affects the results. This section will end with a discussion of possible policy options the government has to achieve its goals with respect to EV use.

Explanation of Results:

The areas with high and low public benefits from EV use are geographically clustered. Excluding the District of Columbia, the top and bottom ten counties are found in just five states. Densely populated counties in California and New Jersey make up the top six, four being in New Jersey and two being in California. The fact that this happened really is not that surprising. These areas receive higher benefits because changes in air pollution will have a higher effect here than they would in rural areas. Rural areas are likely to have lower air pollution to begin with since they have smaller populations and having fewer people means that fewer people will be exposed to pollution. A car driven in a rural county may only expose a few thousand people to its pollution compared to hundreds of thousands or even millions of people who might be exposed in urban counties.

Counties in New Jersey and California also benefitted from a relatively clean electricity supply. California produces less than 1% of electricity from coal while New Jersey produces around 19% (EPA, 2007). The non-combustion generation resources as a percent of total generation is another important indicator as it shows roughly the proportion of electricity that is generated without burning fossil fuels. In California it is 46.8% and in New Jersey it is 51.6% (EPA, 2007). Natural gas makes up most of the fossil fuel total for California and is the state's largest single source of electricity accounting for 46.7% of generation. While still a fossil fuel, natural gas is much cleaner than coal. Cleaner generation sources mean that the electricity needed to run EVs does not create as much air pollution or CO2 emissions. This means more of the tailpipe benefits remain.

The final four counties in the top ten are predominantly rural counties in Vermont. Unlike counties in New Jersey and California, Vermont counties see very little benefit from air pollution reductions since being rural in nature they don't have much of an air pollution problem. Vermont counties see much higher benefits from CO2 reductions than most other counties would. Again, this is due to how electricity is generated. There are not any coal-fired power plants in Vermont and fossil fuels in general play a very minor role. The non-combustion total for Vermont is 92.6% and nearly the entire combustion total is from biomass. Burning fossil fuels generates less than .25% of Vermont's electricity (EPA, 2007).

Excluding the District of Columbia, the bottom ten counties are all in Indiana and Ohio. The District of Columbia is somewhat of an outlier since it covers a small area and only has one power plant, which is not a fair representation of where its electricity comes from. The expectation prior to conducting this research was that sparsely populated rural counties would see the least benefit from EV use. This turned out not to be the case since many urban counties were actually worse off from an environmental perspective. None of the counties in the bottom ten could truly be considered rural since all are part of a metropolitan area. Morgan County, IN, the smallest of the bottom ten still has 68,000 people and is part of the Indianapolis metro area. Instead of receiving little benefit from air pollution reduction since it is not a problem, these counties have an air pollution problem that could be exacerbated by EV use.

Ohio and Indiana saw such poor results because of their electricity supply. Ohio gets 87% of its electricity from coal and 90% from combustion sources. Indiana gets 94% of its electricity from coal and 99% from combustion sources (EPA, 2007). A fossil fuel dependent generation mix that is particularly dependent upon coal seems to be a poor environment for adopting EVs. Seeing positive results does not require the use of predominantly renewable sources or nuclear power. Natural gas accounts for 98% of electricity generation in Rhode Island, which still sees an annual benefit from CO2 emissions of $48.07 (EPA, 2007).

It was not surprising that densely populated urban counties saw the highest benefit from reductions in criteria air pollution. Six of the counties in the top ten are also in the top ten for total benefit and the other four counties are all in the New York City metropolitan area. Much like New Jersey and California, New York has a relatively clean electricity supply getting 45% from non-combustion sources and only 13.7% from coal (EPA, 2007). Since coal seems to be the major source of criteria air pollutants from electricity generation, densely populated counties in states that don't rely on coal should see the highest benefit from reducing pollution.

As with CO2 emissions, the surprising result was that some counties were worse off from an air pollution standpoint because of EV use. Before conducting the analysis it was assumed that rural counties would see the lowest benefit, however the counties in the bottom ten are all in major metropolitan areas including Philadelphia, Baltimore, Cleveland, Washington DC, and Atlanta. Ohio's reliance on coal has already been discussed so the fact that half of the bottom ten counties for air pollution are in Ohio is not that surprising. Maryland contains two of the bottom ten counties, yet only relies on coal for 55% of its electricity, which is not particularly high by American standards. Pennsylvania also gets 55% of its electricity from coal while Georgia gets 63% (EPA, 2007).

Since Rhode Island gets 98% of its electricity from natural gas and still sees benefits from air pollution reduction, coal is again indicated as a major problem. The average coal plant releases 2249 lbs CO_2/MWh compared to only 1135 lbs/MWh for natural gas (EPA, 2007). For sulfur dioxide, the difference is much worse with the average coal plant emitting 13 lbs/MWh while the average natural gas plant emits only .1 lbs/MWh (EPA, 2007). The average coal plant also emits more than three times as much nitrous oxide as the average natural gas plant (EPA, 2007). While many states have much higher reliance on coal than Maryland and Pennsylvania, they also do not contain huge metropolitan areas that already have air pollution problems.

One of the most interesting findings from this analysis is that reducing oil dependence is a much larger portion of the total benefits from EV use than either the human health or environmental benefits of reducing air pollution and CO_2 emissions and in many cases, it is the only benefit derived from EV use. This is important since EVs are not the only way to reduce oil dependence. Natural gas vehicles, more fuel efficient gasoline powered vehicles, and conventional hybrids are all ways to achieve this goal focusing on personal transportation. Encouraging walking, biking, and use of public transportation are yet more solutions. In some areas discussed earlier EVs and PHEVs may achieve the best results in terms of emissions since at least theoretically they could produce zero CO_2 or air pollution while running on battery alone. However, EV technology is currently quite expensive and increasing adoption of cheaper technologies could probably be done at much lower cost to the public.

A recently completed master's thesis by RIT student Samir Nazir (2010) ranked counties in the United States by their overall potential for PHEV adoption. Although different metrics were used than in this thesis, the results have some interesting comparisons. While it is not all that surprising that the order of the rankings differs between Nazir's study and this one since they were not measured the same way, the overall theme of the results is quite similar. Nazir found that counties in California and the New York Metro Area presented the best opportunity for EV adoption, an almost identical result to the one in this analysis. Counties in Vermont, Idaho, and Washington scored well in both studies as well.

There are greater differences in results at the bottom of the rankings. Both studies found that rural counties in states reliant on fossil fuels for their electricity would see little benefit from EV use. As such, Wyoming and West Virginia are found near the bottom in both studies. The major difference seems to be in urban counties within states reliant on fossil fuels. In attempting to determine where the current tax credit produces net benefits, this analysis also indicated that some counties could be made worse off from an air pollution and CO2 emissions perspective. While population density is helpful in Nazir's study since it is used as a measure for market transformation, in this analysis its effect is accounted for in the value of reducing criteria air pollutants. This gives it a positive effect in areas where pollution is reduced the most and a negative effect in areas where more pollution is created because of EV use.

Sensitivity Analysis:

Even under the best circumstances within the initial assumptions, the current tax credit will not pay for itself. In Los Angeles County, California, the county with the greatest annual benefit, the total benefit after eight years under the PHEV scenario is $3788, which after the cost of the tax credit is accounted for, creates a net loss of $3717. For the public to recoup its $7500 investment, even without discounting the car would have to be in use for almost 16 years, which is nearly double the warranty on the battery.

Analysis of PHEV Payback Period for Los Angeles County (0% discount rate)			
Annual Benefit	$ 473		
EV Benefit after….		Net Benefit	Cost Benefit Ratio
8 years	$ 3,787	$ (3,713)	0.50
10 years	$ 4,734	$ (2,766)	0.63
12 years	$ 5,681	$ (1,819)	0.76
16 years	$ 7,575	$ 75	1.01
Payback Period			
15.8 years	$ 7,500	$ -	1.00

Figure 17: Table shows the PHEV payback period for Los Angeles County

In Los Angeles County, a pure EV achieves $527 of annual benefit, which results in $4213 after eight years. This is still not enough to pay for the $7500 tax credit and results in a net loss of $3287. Even with the higher annual benefit, a pure EV would have to be in use for more than 15 years, which is 87% longer than the warranty.

Analysis of Pure EV Payback Period for Los Angeles County (0% discount rate)			
Annual Benefit	$ 490		
EV Benefit after….		Net Benefit	Cost Benefit Ratio
8 years	$ 3,919	$ (3,581)	0.5
10 years	$ 4,898	$ (2,602)	0.7
12 years	$ 5,878	$ (1,622)	0.8
16 years	$ 7,837	$ 337	1.0
Payback Period			
15.3 years	$ 7,500	$ -	1.0

Figure 18: Table shows analysis of the pure EV payback period in Los Angeles County

The initial assumptions underlying this cost benefit analysis represent a fairly conservative estimate of the public benefits to EV use; however there is still room for sensitivity analysis to test the conclusion that the current tax credit is too high. Even without discounting the annual benefit from EV use would have to be $938/vehicle for the tax credit to be economically justifiable. This represents nearly double the benefit seen in Los Angeles County, which had the highest annual benefit of any county. There are several ways to test the sensitivity of the conclusion that the tax credit results in a net loss by changing the value of variables included in the cost benefit ratio including time the car is in use, the value of reducing one ton of CO2 emissions, and the value of reducing one ton of each criteria air pollutant.

Increased Vehicle Lifespan:

The car in question could conceivably be in use for longer than eight years. The initial assumption of eight years is fairly conservative since the warranty ensures that the electric components of the car will be in working order for at least eight years at no additional cost to the consumer. Increasing the number of years the car is in use will increase public benefit since benefit accrues over a greater number of years. A 25% increase in lifespan would keep it on the road for two additional years, making the annual benefit $3382 under the PHEV scenario, still resulting in a net loss of $4116. A 50% increase in lifespan would keep the car on the road for 12 years and create $4061 in public benefit, but would still result in a net loss of $3439. Even without discounting, the car would have to be in use for more than twenty-two years for the public to break even on the value of the tax credit. To put that in perspective, twenty-two years is nearly three times longer than the warranty for the battery. Therefore, the initial assumption that the car is in use for eight years does not seem to be the deciding factor in whether the tax credit is economically justifiable. Even under the pure EV scenario, the car would have to be in use for more than 21 years before benefits outweighed the cost of the tax credit.

Increased Cost of CO2:

The cost of CO2 emissions on the other hand could drastically change the results of this cost benefit analysis. While the average found in peer-reviewed estimates is $43/tonne, it has a standard deviation of $83 and estimates range from $0 to $1500 (IPCC, 2007). Exploring the affect of lower carbon prices is futile for the purpose of this analysis since the tax credit does not pay for itself at the initially assumed price in two of the scenarios. Doubling the cost per tonne of CO2 emissions to $86 falls within one standard deviation from the mean and under the PHEV scenario improves the maximum benefit to $555/year while the average benefit increases to $363/year. Under the pure EV scenario, average benefit increases to $383 and the maximum benefit increases to $576. While both scenarios are now significantly better than under the initial assumptions, they still fall far short of the $938 needed to break even under the most favorable circumstances.

A carbon price of exactly one standard deviation above the mean would be $126/ton. At this price, the average benefit is $386/year while the maximum benefit is $661/year under the PHEV scenario. Under the pure EV scenario the average rises to $411/year and the maximum rises to $681/year Again, these numbers are still too low to make the tax credit pay for itself in eight years, but combined with upward changes in other variables it is apparent that we are getting closer. In this case, if a PHEV were in use for twelve years at a 0% discount rate in the top county, the public would see a net total benefit of $433 after the tax credit was accounted for while a pure EV would result in $674 of net benefit. While this requires both a much higher carbon price and a greater vehicle lifespan, it is not out of the realm of possibility.

At the highest proposed CO2 price of $1500, the tax credit would easily pay for itself. In Los Angeles County, the benefits would exceed the costs in less than two years. The U.S. does not seem to be making its climate change policies based upon the worst-case scenario so the government building into its tax policy a $1500/ton price for CO2 emissions is unlikely. Although it is more than three standard deviations away from the mean, the $310/ton price suggested in the Stern Review (2006) is within the realm of possibilities. The Stern Review is a comprehensive assessment of the global consequences of climate change that is widely respected within the sustainability community. At $310/tonne, the highest benefit seen in any county under the PHEV scenario becomes $1157/year, which after eight years becomes $9254. At a 0% discount rate, this results in a net public benefit of $1754. While the average is still only $490, there are 136 counties over the $9378/year threshold needed to see net public benefits after eight years. Under the pure EV scenario, the average annual benefit rises to $543 while the maximum rises to $1195 and 191 counties see positive net benefits after eight years. This is still not enough to make the tax credit in its current format pay for itself since a majority of counties still do not see positive net benefits. The cost of CO2 emissions would have to rise to $1095 under the PHEV scenario and $864 under the pure EV scenario for the average annual benefit to reach a point where the tax credit breaks even at a 0% discount rate. Under the Prius PHEV scenario with its smaller tax credit, the average benefit after eight years is fairly close to $2500 with a B/C ratio of .97. The average county will see more than $2500 of benefit at all of the CO2 prices examined above the initial assumption of $43/ton. The maximum benefit after eight years is already greater than $2500 at the initial assumptions. Raising the CO2 price to $310 results in a B/C ratio of 3.0 which means the tax credit will see a 200% return on the initial investment.

PHEV Maximum Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 473	$ 3,788	$ (3,712)	0.5
$ 86	0.52	$ 555	$ 4,440	$ (3,060)	0.6
$ 126	2.00	$ 661	$ 5,290	$ (2,210)	0.7
$ 209	3.00	$ 885	$ 7,078	$ (422)	0.9
$ 310	3.22	$ 1,157	$ 9,254	$ 1,754	1.2

Figure 19: This table shows the highest benefit received among all counties at different CO2 costs without any discounting for the PHEV scenario

PHEV Average Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 338	$ 2,707	$ (4,793)	0.4
$ 86	0.52	$ 363	$ 2,903	$ (4,597)	0.4
$ 126	2.00	$ 386	$ 3,085	$ (4,415)	0.4
$ 209	3.00	$ 433	$ 3,463	$ (4,037)	0.5
$ 310	3.22	$ 490	$ 3,922	$ (3,578)	0.5

Figure 20: This table shows the average benefit received among all counties at different CO2 costs without any discounting for the PHEV scenario

Pure EV Maximum Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 489	$ 3,915	$ (3,585)	0.5
$ 86	0.52	$ 576	$ 4,611	$ (2,889)	0.6
$ 126	2.00	$ 681	$ 5,450	$ (2,050)	0.7
$ 209	3.00	$ 913	$ 7,304	$ (196)	1.0
$ 310	3.22	$ 1,195	$ 9,561	$ 2,061	1.3

Figure 21: This table shows the maximum benefit received among all counties at different CO2 costs without any discounting for the pure EV scenario

Pure EV Average Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 352	$ 2,819	$ (4,681)	0.4
$ 86	0.52	$ 383	$ 3,064	$ (4,436)	0.4
$ 126	2.00	$ 411	$ 3,292	$ (4,208)	0.4
$ 209	3.00	$ 471	$ 3,765	$ (3,735)	0.5
$ 310	3.22	$ 543	$ 4,341	$ (3,159)	0.6

Figure 22: This table shows the highest benefit received among all counties at different CO2 costs without any discounting for the pure EV scenario

Prius PHEV Maximum Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 473	$ 3,788	$ (3,712)	0.5
$ 86	0.52	$ 555	$ 4,440	$ (3,060)	0.6
$ 126	2.00	$ 661	$ 5,290	$ (2,210)	0.7
$ 209	3.00	$ 885	$ 7,078	$ (422)	0.9
$ 310	3.22	$ 1,157	$ 9,254	$ 1,754	1.2

Figure 23: This table shows the maximum benefit received among all counties at different CO2 costs without any discounting for the Prius PHEV scenario

Prius PHEV Average Net Benefit at Different CO2 Costs					
CO2 Cost/ton	St. Dev away from mean	Annual Benefit	Benefit after 8 Years	Net Benefit	B/C Ratio
$ 43	-	$ 338	$ 2,707	$ (4,793)	0.4
$ 86	0.52	$ 363	$ 2,903	$ (4,597)	0.4
$ 126	2.00	$ 386	$ 3,085	$ (4,415)	0.4
$ 209	3.00	$ 433	$ 3,463	$ (4,037)	0.5
$ 310	3.22	$ 490	$ 3,922	$ (3,578)	0.5

Figure 24: This table shows the average benefit received among all counties at different CO2 costs without any discounting for the Prius PHEV scenario

Another interesting development is that at higher CO2 prices, counties in Vermont and Idaho begin to see higher benefits than urban counties in California and New Jersey. Every county in both Vermont and Idaho sees over $1000/year in benefit with Windham County, VT seeing the highest benefit. This happens because CO2 becomes the largest component of the cost benefit ratio and Vermont and Idaho have by far the lowest emissions from electricity generation. It should also be noted that counties that were worse off from a CO2 emissions standpoint are even more so with higher valuations for CO2. Under the initial assumptions, counties in states that get most of their electricity from coal still saw an overall benefit from EV use because reducing oil dependence was always worth more than reducing emissions. The higher value for CO_2 in the Stern Review makes CO_2 emissions the largest contributor to the benefits so some counties that saw more CO_2 emissions due to EV use see most of the benefits from reduced oil dependence wiped out by higher emissions. While only one county is actually worse off due to PHEV use, 321 counties see lower benefits than the worst county under the initial assumptions. The situation is slightly better under the pure EV scenario with only 168 counties seeing lower benefit than the worst county under the initial assumptions.

Using the Stern Review's estimate of the cost of CO_2 emissions presents a compelling case for focusing the tax credit on certain regions. While under the initial assumptions there was fairly wide variation in benefits, changing the assumed cost of CO_2 emissions from $43 to $310 dramatically increases the difference between the top and bottom counties. Depending on the discount rate chosen, the counties that see the most benefit could actually receive a higher tax credit and still see net benefits. At the other end of the spectrum, it appears that EV use does not do much good in a fairly large part of the country. Consumers in these areas may not realize that their decision to purchase an EV will not be as helpful as they had thought. Instead of offering a tax credit for EVs in the bottom counties, the government could use a different mix of policies to achieve the same goals while at the same time creating a situation where EV use in these counties would eventually be beneficial.

Air Pollution Increase:

Although APEEP is the only existing model for air pollution costs covering all counties in the continental U.S., it is still possible to perform some sensitivity analysis with the air pollution numbers. A new version of APEEP is under development and although it has not been released yet, it appears that the valuations are in some cases an order of magnitude larger than in the original model. Without the actual numbers, it is impossible to know for sure how the results would change, however we can get an estimate by making the air pollution total component an order of magnitude larger. Under both scenarios, the average benefit drops while the maximum benefit rises substantially. A very small number of counties now see positive net benefits from the tax credit under the PHEV and EV scenarios while a much larger number of counties are actually worse off due to EV use.

Increasing the value of air pollution emissions by an order of magnitude has an enormous impact at the individual county level. Annual benefit in Los Angeles County in the PHEV scenario increases 142%, from $473 to $1143. At the other extreme, the minimum annual benefit decreases 245% from $219 to -$318. The EV scenario is a similar story with the maximum benefit increasing by 144% while the minimum benefit decreases by 215%. At the extremes then, increasing the valuation of air pollution emissions has a huge effect. However, there are 3109 counties in the sample, some of which are better off from an air pollution standpoint to varying degrees and some of which are worse off to varying degrees. This means that the average annual benefit is only 8% lower in the PHEV scenario and 9% lower in the EV scenario.

Carbon dioxide seems to have much higher leverage than air pollution in this analysis. At the individual county level air pollution can be important but over the total group of counties considered has a relatively small effect. None of the CO2 valuations considered were an order of magnitude larger than the initial assumptions yet at the highest valuation examined, the average benefit increased by 54%, much greater in magnitude than the 9% drop seen by changing the air pollution valuations. Looking back at the results, this make sense since about a third of counties were worse off due to CO2 emissions from power stations whereas around half of counties were worse off due to air pollution from power stations. Increasing the value attributed to each pollutant will not have as much of an effect on the average since the counties are almost evenly split between those that see more pollution and those that see less.

Possible Policy Options:

The results show that the $7500 federal tax credit is not justifiable based upon the reduction in air pollution, CO_2 emissions, and oil dependence. Air pollution and CO_2 emissions from cars are certainly big problems that have very real costs. As of 2010, there are 190,202,782 light passenger vehicles in the U.S., a number that has actually decreased slightly (RITA, 2010). At a cost to the government of $7500/vehicle, replacing all these cars with EVs would cost $1,427,000,000,000. Cars are a big source of pollution in aggregate, but an individual car does not produce very much pollution. Emissions and oil consumption from cars certainly need to come down, however giving $7500 to everyone who purchases an EV or PHEV is not a cost effective way to achieve this.

This is not to say that the government should eliminate tax credits for EVs entirely since a consumer's decision to purchase an EV produces public benefit in every county examined, the behavior is worth encouraging. Several possibilities exist here for changing the tax credit. The value of the tax credit should be lower if it is to provide net public benefits. Since there is a lot of variation in public benefit from EV use, the value of the tax credit could vary by location. Los Angeles County drivers should receive the largest tax credit since EV use in Los Angeles County provides the most public benefit. Unfortunately, this would mean that drivers in some cities such as Cleveland would receive a much lower tax credit. Such variation in the tax credit could be perceived as unfair, especially since there isn't a simple criteria that can be used to justify who gets the most money. Urban and rural cannot be the deciding factor since urban areas are found at both the top and bottom of the list. Air quality non-attainment cannot be used because EV use helps in some counties and hurts in others.

Discriminating based on location will be politically unappealing to both republicans and democrats. The counties that see the highest benefit from EV use are for the most part in states that lean democratic such as California, New Jersey, and Vermont. The counties that would receive the lowest tax credit are in battleground states like Ohio, Indiana, and Pennsylvania. Neither party will want to upset voters in battleground states by giving them a smaller share of federal money while republicans will not argue for higher tax credits in democratic leaning states. One way to avoid such a perception of unfairness would be to use the average public benefit from EV use to determine the value of the tax credit. Some counties would receive too much money while others would not receive enough, however they would even out overall. This solution still presents problems since the government would knowingly be providing an incentive to increase air pollution and CO_2 emissions in some areas.

Another possible solution is to provide a lower tax credit to all vehicles. As seen in the example of the Prius PHEV, EVs can produce enough public benefit to justify a still significant tax credit. If the amount were lowered to \$2500 for all EVs, many counties would see net public benefits. The average benefit from pure EV use after eight years is \$2818, high enough to justify a \$2500 tax credit. The story is the same for PHEV scenario with the average annual benefit after eight years being \$2707. Spending less on each vehicle allows the possibility of more people purchasing a vehicle under the tax credit program without increasing spending. It may also free up funding to spend elsewhere advancing the goal of increasing EV adoption and reducing the use of oil in transportation.

U.S. reliance on fossil fuels and coal in particular is a major barrier to realizing the full benefits of EV and PHEV use. Burning fossil fuels to generate electricity negates or even outweighs much of the benefit from replacing internal combustion engine vehicles with EVs in much of the country. For EVs to reach their full potential, the U.S. must generate its electricity from cleaner sources. Not only will this allow for greater reductions in emissions from transportation, but lower emissions from electricity generation as well. Widespread adoption of renewable energy and nuclear energy may not be economically feasible for some time. The U.S. should not wait years before addressing the environmental and public health problems created by the electric power industry. Fortunately, a cleaner option already exists in the form of natural gas. Since coal seems to be the major source of emissions from electricity generation, even simply replacing it with natural gas would be a large step in the right direction.

In the past, natural gas may not have been a viable replacement for coal since it was expensive and the U.S. had to rely on imports. Technological advances have allowed for the development of unconventional gas reserves, massively increasing the amount of domestic gas reserves. As of 2009, the US had estimated reserves of 2700 trillion cubic feet, which at the current rate of consumption of 24 trillion cubic feet/year would last for 112 years (EIA, 2012). Rapid development of newly available reserves has reduced the price of natural gas by 80% since 2008 (Mullaney, 2012), making it more competitive with coal from a price standpoint. Add in its lower CO_2 emissions and air pollution and natural gas is suddenly very attractive. Unlike solar and wind, natural gas is already priced competitively with coal and does not face problems with intermittency. Before the U.S. can rely on intermittent renewables for a large proportion of its electricity, cost effective storage technology needs to be developed so electricity is still available when the wind is calm or the sun isn't shining.

Natural gas vehicles would achieve the same oil dependence benefit since natural gas, like electricity, is cheap and domestically produced. A CNG powered Honda Civic costs around $26,000, much less than an EV. Congress allowed the tax credit for purchasing a CNG vehicle to expire in 2010. Since CNG vehicles are much closer to being competitively priced with conventional vehicles, a smaller tax credit could be effective at increasing adoption and therefore lowering oil dependence, CO2 emissions, and air pollution at a much lower cost to the public. Obviously, CNG vehicles still produce air pollution and CO2 and the U.S. will eventually run out of natural gas much like it is now doing with oil. A permanent solution is still necessary, but CNG vehicles are an option worth pursuing since they address our immediate problems at a much more affordable price. Waiting for EVs and hydrogen fuel cell vehicles to come down in price may simply take too long.

Several policy options are available for discouraging the use of fossil fuels and coal in particular by the electric power industry. A moratorium on the construction of new coal plants would send a clear signal to power companies that coal is not going to play a role in supplying future electricity demand. A moratorium would prevent the U.S. from becoming more reliant on coal, which is certainly a good thing; however it is not without its drawbacks. Preventing new coal plants does nothing to address the problems created by existing ones and moratoriums are seen as heavy handed by the public. A moratorium would single out coal while doing nothing to address other sources of CO2 and air pollution. Without a highly visible public health and environmental disaster like BP Deepwater Horizon to attribute to the coal industry, a moratorium could meet high public opposition.

Another possibility is to provide incentives for using natural gas instead of coal to generate electricity. One way to do this would be to provide low interest loans for converting existing coal fired power plants to natural gas. Existing plant owners may feel they have already sunk money into a coal plant and be unwilling to make another investment. The government could provide additional investment tax credits for converting coal to natural gas.

Stricter air pollution regulations and mine safety regulations would make coal use much more expensive. To comply with new regulations, power plant owners would have to install expensive pollution controls that would not be necessary if they burned natural gas instead. Mountain top removal mining could be banned or at least strongly discouraged. The process involves removing the areas of the mountain above the coal seam and filling nearby valleys with the debris so the coal can be accessed more cheaply than underground mining and is currently regulated by the EPA. However, the EPA notes that it causes water pollution and impacts forests. The EPA also notes that the cumulative environmental damage caused by mountain top removal is unknown (EPA, 2011). While stricter regulations would either decrease the amount of coal available or at least make it more expensive to extract, mountaintop removal mining is only one technique used so banning it may not have enough effect on its own.

Coal-fired power plants are one of the United States' largest sources of CO2 emissions, accounting for just over 27% of U.S. CO2 emissions or about as much as the entire transportation sector (EPA, 2011). Coal is easily the most carbon intensive major fuel source, accounting for 81% of emissions from electricity generation while generating only 45% of the electricity (EPA, 2011). As noted earlier, the states that emit more CO2 because of EV use rely heavily on coal. A cap and trade system has often been discussed as a method for reducing CO2 emissions. Such a system would issue permits for a certain amount of CO2 that each company is allowed to emit each year. The government would remove permits from the market each year, increasing the value of unused permits. Companies that found ways to reduce their emissions could then sell their permits to companies that needed to emit more.

Cap and trade is not a flawless strategy however. Setting the initial number of permits is important as setting it too low too quickly could force a heavy burden onto industry while giving too many permits would make them nearly worthless. The rate at which to take them out is also tricky since taking them out too quickly might not allow companies enough time to determine how best to reduce their emissions. Furthermore, a growing economy will require more of many things whose production causes carbon emissions. Even if a power company reduces their CO2 emissions per MWh by 20%, a 20% increase in demand for electricity from a growing population will negate that efficiency gain and require the company to buy more permits.

Cap and trade is not unworkable, however there is at least one much simpler solution; a tax on CO2 emissions. Numerous studies already exist placing a value on carbon emissions. While the results vary quite a bit, an average or median value could be used to determine the tax per ton of emissions. A tax would not cap emissions, which could be economically disastrous if it were set too low. A carbon tax would send a clear price signal to CO2 emitters and if properly set would provide an incentive for everyone to decrease their emissions. Taxes are appropriate in this situation since there is a negative externality from CO2 emissions in the form of climate change. Society would be better off if there were fewer CO2 emissions so clearly the market is not functioning as it should. The government can intervene in the market through either subsidizing beneficial behavior or penalizing bad behavior. While subsidies are justifiable for technologies that reduce CO2 emissions, a tax offers several advantages.

Pundits of all political persuasions complain about the government picking winners. Governments are not technology experts and may not support the optimal solution. A tax allows carbon emitters to pick a strategy to reduce their emissions that works best for them. In the case of power plant operators, some may decide to invest in emissions control technology or carbon capture and sequestration while others may invest in cleaner forms of generation technology. A carbon tax has the added benefit of addressing all CO_2 emissions with a single policy. CO_2 emissions from power plants, factories, cars, aircraft, and numerous other sources would all be subject to a tax. This allows individuals to decide how best to deal with their emissions. Some may decide to buy an EV while others may cut back on miles driven. Simply subsidizing EVs does not address the entire problem and comes off as the government saying that the solution to your CO_2 emissions is to buy an EV, even if you do not really want one.

I do not mean to say that subsidies are not desirable, only that they cannot be the sole solution to the problems of CO_2 emissions, air pollution, and oil dependence. Taxes on undesirable behavior can be used to subsidize desirable behavior, allowing for greater reductions in all three problem categories. Using a carbon tax to subsidize cleaner technologies will at least avoid the criticism of creating more public spending without a way to pay for it. Subsidies for "green" technologies will always appear as if the government picking winners to some people. For this reason, it is especially important that the government avoids lavishing money on a particular technology that it favors at the expense of other options. The point of a subsidy is to favor green options over those that make our pollution and CO_2 problems worse, not to also favor one green technology over another.

An efficiently designed subsidy program would ideally try to evaluate the benefits attainable from each technology and use this evaluation to determine the proper subsidy amount. Unfortunately, the government may be unwilling or unable to allocate the resources necessary to assess the thousands of options available accurately. Subsidies should be designed so that a technology is deemed competitive with the next worst option from an environmental standpoint. Natural gas should be favored over coal and oil while wind and solar should be favored over natural gas. If an exact determination of a technology's public benefit cannot be made, the government should at least try to ensure that the subsidy for that technology is not vastly in excess of the public benefit as is the case with the current EV tax credit. Not only does over subsidizing contribute to the perception of out of control public spending, it also means that money could have been spent somewhere else to better effect.

The benefit from the creation of a domestic market for EVs was not quantified for this analysis for several reasons. It would drastically expand the scope of the analysis since EV owners would have to be surveyed to determine how much of an impact, if any, the tax credit had on their decision to purchase an EV. Economics teaches us that as the price of a good drops, consumption of that good will increase. How much consumption increases depends upon the consumer's sensitivity to price changes. It is conceivable that some people who purchased EVs would have done so without the tax credit as either they place a high value on their environmental impact or they are early adopters of new technologies. As such, determining how much consumption would increase as a result of the tax credit is not as simple as it sounds since each individual's preferences are different.

Once the tax credit's impact on consumption has been determined, it would still be necessary to place a monetary value on the creation of an EV market for inclusion in the cost benefit ratio. Such a monetization would need to include the benefits from new manufacturing and engineering jobs both at the car companies as well as at their suppliers. Jobs would also be created in the service industry to supply the demand created by the new workers in the automotive industry. There would also be prestige associated with being a leader in a new high tech sector, bringing in skilled workers from around the world who want to work in the sector. Monetizing these benefits would be at best a very rough estimate and at worst a guess, especially for an industry that could be made obsolete by some future technological breakthrough. While the government would certainly like the EV tax credit to spur the creation of a thriving industry, the recommendations to follow will focus on the environmental and oil dependence benefits from EV use.

Limitations:

As with any analysis, this one is not perfect and there are several limitations worth discussing. The limitations are separated into an out-of scope section that deals with issues outside the scope of this paper and an in-scope section that deals with the limitations of the analysis itself.

Out-of-Scope Limitations:

This analysis intentionally limited the benefits garnered from the tax credit to reduced oil dependence, reduced air pollution, and reduced CO2 emissions. There are other possible benefits including the creation of a world class and self-sustaining EV manufacturing industry. A successful new industry has spillover benefits in the communities where it is based as well as in the economy as a whole. Quantify and monetizing these benefits however is not as straightforward as quantifying the benefits included in this analysis. In order to keep the scope manageable, they were left out.

Generally, the cost of any given technology will decrease over time. There is no reason to believe that EVs will be any different. The analysis presented in this thesis is concerned with EVs being purchased now. In five years, the technology could be dramatically cheaper or better than it is now. These developments would alter the conclusions of this analysis with EVs that do not require large subsidies or for which larger subsidies might be justified. The government could justify the current tax credit on the grounds of supporting an industry in its infancy that is expected to deliver competitive products in a few years time. It may not matter to the government that current EVs don't produce enough benefit to justify the tax credit as long as it supports the industry long enough to deliver products that don't need a tax credit for consumers to buy them. Japan's MITI did this with EV technology and ended up with a world-class hybrid industry that could one day lead to a pure EV industry as well.

The time of day at which EVs are charged is also an issue with this analysis. The numbers that were available for emissions per unit of electricity were an average over all electricity produced within the state. However, different times of day have different emissions profiles due to the generation resources that happen to be online. In some areas peak loads are met using natural gas power stations that only come online during peak times while baseload electricity is generated with hydroelectric or nuclear. Since home charging of EVs would be done primarily at night when baseload electricity is the primary source of electricity, that electricity consumption would have a much more favorable emissions profile. Conversely, some areas rely on coal for baseload electricity, which would result in a much worse emissions profile for nighttime charging.

This analysis looks at the use of an electric vehicle over several years and uses the current state of generation resources to assess its emissions reduction benefit. The mix of generation sources is likely to change somewhat over the eight years examined in this analysis; however the extent of that change is not predicted. Current policies and trends indicate a likely increase in renewables and natural gas at the expense of coal and possibly nuclear. Policies however are subject to the whims of politicians and can change substantially over eight years. Current trends could be made even stronger or possibly reversed.

In-Scope Limitations:

State level data for electricity production is not ideal since power consumed within a certain state may not have been produced there and different regions within a state may have different generation mixes. California, for example imports electricity from its neighbors, but the fuel mix for the imported electricity was not available. Imports in a worst-case scenario could all be from coal however, they could also be from cleaner sources like nuclear. In states that export electricity such as Alabama, an ideal dataset would breakdown how the electricity consumed within the state is generated and how the electricity exported is generated. Unfortunately, they are not and determining exact figures would likely be difficult since the electricity is sent into the grid which crosses state lines. Determining how each electron was generated for each county in the country is simply beyond the resources available for this analysis.

Metropolitan areas that cross state lines present another limitation for this method of analysis since in reality, the air quality in the entire metro area is probably quite similar and EV use on one side of the state line could have similar effects to EV use on the other. Unfortunately, using state level data for emissions from electricity generation assume that electricity consumed in the state is produced there possibly increasing the differences between counties on either side of the state line. One example of this is the Philadelphia metropolitan area that includes parts of Pennsylvania and New Jersey, states that have fairly different overall generation mixes. In reality, electricity consumed in the Philadelphia MSA is probably coming from both sides of the border. Even within a county, electricity could come from different sources. eGrid sub regions would have presented a better picture of how electricity is generated in a given area; however these are based on utility service boundaries instead of any state defined borders (Weber, 2010). Monetizing air pollution at the county level is already problematic since some counties contain large urban and rural areas, particularly out west. A monetization based on eGrid sub regions would be more problematic since some of them encompass several states.

This analysis probably overestimates the harm caused by increased pollution due to EV use in some areas. Due to the fact that the data does not specify which county a given electron comes from, it is necessary to assume that the air pollution caused by power plants is at a uniform level statewide. While this assumption may be fine for small states like Rhode Island, it is probably less so for a huge state such as Texas. Cuyahoga County, home of Cleveland, ranks in the bottom ten counties for annual benefit because Ohio is so reliant on fossil fuels for its electricity. Location of power plants within a state does not present a problem for CO2 emissions since they are not a local pollutant. The monetization is the same whether the electricity is produced in Cleveland or in a more rural Ohio county. It does not matter to the monetization that electricity consumed in Cleveland was produced in a more rural Ohio County. Criteria pollutants are different since their monetization depends upon where the pollution is encountered. Electricity consumed in Cleveland could come from within Cuyahoga County or from a rural area hundreds of miles away. Depending on weather conditions some of this pollution could still reach Cleveland since it is emitted from a smoke stack hundreds of feet off the ground, however it will not be as much as if the electricity came from within Cuyahoga County.

The assumption about driving habits in this analysis was that drivers would have the same driving habits no matter what vehicle they drove. This may not be the case in reality since there is some evidence that people who buy more fuel-efficient cars offset some of the fuel savings by driving more. The individual may drive more because driving is now less expensive which is good for the consumer, but reduces the social benefit seen from people buying more efficient vehicles.

This analysis uses the work of others to monetize the social benefit of EV use. The works that were chosen had an impact on the results. APEEP for instance was chosen because it monetized air pollution emissions at the county level. Different studies will come up with different values for each pollutant, which would affect both the magnitude of the benefits and each county's place in the rankings. Oil dependence is clearly a complicated problem to monetize and some people may look at the evidence and conclude that oil dependence is not a major problem. A different selection of studies could either minimize or dramatically increase the effect of one of the components of the benefit-cost ratio.

Air pollution models in general use political boundaries to assess the damage from air pollution. This may not be a problem for a small city of only a few square miles, but may not be as accurate over larger areas. County size is more of an issue in the western U.S. where a county such as San Bernardino County, California can have an area of thousands of square miles and a population of millions that is concentrated in a relatively small portion of the county. It seems likely that the air pollution damages are much less than stated in the rural parts of the county and much higher in the urban parts. Political boundaries will always be problematic for determining air pollution damages since they were never intended to be used for tracking sources of pollution and who is exposed to them.

Instead of using a top down average to determine the average emissions per gallon of gas for each pollutant, they could have been determined for each individual car and then averaged. Using this method would provide a more accurate estimate for the emissions from the internal combustion engine vehicles included in this analysis.

Recommendations:

Numerous policy options have already been discussed that could be supported by the results of this analysis. The policy options chosen will depend upon what the government's primary goals are. If the goal is to create a market for EVs, that substantially narrows the options available. Assuming that the money allocated to the EV tax credit is to be spent advancing the goals of reducing the environmental impact of transportation and reducing the economy's dependence on oil leaves a broader range of policy options available. The policy options recommended below will work within the broader set of goals while recognizing that this analysis did not include all possible benefits.

Automobiles are not the only way for people to get around, however land use and transit planning which could encourage walking, biking, and public transit use are done primarily at a local level so we will focus specifically on cars. Since the current tax credit seems to be too high**, the government should consider lowering it to the average benefit received over ten years at a 7% discount rate** ($3325 for PHEVs and $3698 for pure EVs). In much of the United States, EV use does produce reductions in air pollution and CO2 emissions that in turn produce monetary benefit, just not $7500 worth. Lowering the amount given per vehicle allows the government to achieve emissions reduction without overpaying. The 7% discount rate was chosen since the government could have spent the money on another project that produces public benefit. Assuming the car is in use for ten years allows for batteries that outlive their warranty as well as those that were replaced under warranty and may keep the car in operation longer than eight years. Again, the benefits examined in this analysis might not fully explain why the government is choosing to provide an EV tax credit. If their goal really is to support early adoption of EVs, the government should first determine what affect the $7500 amount has on EV demand and what the effect of reducing that amount would be.

Under the assumption that money allocated to the tax credit will be spent towards the same goals even if it is not needed, the remaining money and perhaps even more should be spent on research and development to make EVs cheaper. The high cost of the batteries is the primary driver for EV costs. Research should be focused on making the batteries cheaper by reducing the amount of precious metals required and improving manufacturing techniques. Research does not need to be done entirely, if at all, in government laboratories. Grants could be given to universities or private companies to study the subject. While car companies are already working making EVs cheaper, in a constrained economy they may not be able to spend as much on research and development as they would like.

Lack of charging infrastructure is another major inhibitor to the widespread adoption of EVs and PHEVs. The federal government already provides financial assistance for installing charging infrastructure and planning is heavily dependent upon local building codes, which may place the responsibility more on state and local governments. Availability of workplace charging is likely to be a major factor in a consumer's decision to purchase an EV**. The Federal government is the country's largest employer and could make workplace charging available to an enormous number of people simply by installing the necessary infrastructure at its own buildings.**

To recognize the full benefits of EV use, air pollution from power plants must come down. The biggest discrepancy between coal and natural gas is sulfur dioxide with coal plants emitting thousands of times more than the average natural gas plant. Since SO2 is one of the major criteria air pollutants, the government should tighten restrictions on how much SO2 it is permissible to release. Although the average emits 13 lbs SO2/MWh, some older plants are far worse. The AES Greenridge plant in Yates County, NY emits 32 lbs SO2/MWh that even in a rural area creates $15.7 million in environmental and public health damage each year (EPA, 2007). Meanwhile, the AES Somerset Plant in Niagara County, NY emits only 1.2 lbs SO2/MWh (EPA, 2007). While this is still worse than natural gas, it is much better than 32 lbs/MWh and even the national average of 13 lbs/MWh. These two plants both burn bituminous coal and are owned by the same company so the owner clearly has access to the required technology to reduce SO2 emissions. **The EPA should craft regulations that target the worst offenders, forcing them to either upgrade their facilities or close their plants.**

If the federal government is serious about creating a large market for EVs, it should ensure that cleaner supplies of electricity meet new electricity demand from EV users. Ideally, new demand should be met by wind, solar, or hydroelectricity. Although it has its own environmental drawbacks, nuclear power does not create air pollution or CO2 emissions and should also be considered. The results of the cost benefit analysis indicate that states that are reliant upon natural gas can still receive some environmental and health benefits from EV use so it should also remain a possibility. Coal should be avoided, at least until a better understanding of how the use of particular coal technologies affects social benefit from EV use. Building more coal plants to satisfy demand from EV consumers might solve the nation's energy security problem, but it could very well make air pollution worse and accelerate climate change. Solving one problem by exacerbating another seems counterproductive at best.

In addition to the air pollution and climate change problems associated with burning gasoline, there is evidence that suggests that the current gas tax at both the state and federal level does not cover the true cost of automobile use. Losses from accidents as well as wear and tear on roads are additional problems that current gas taxes do not fully cover. A gas tax that does not reflect the true cost of driving is a problem since it encourages people to drive too much by artificially reducing the cost. Each state sets its own gas tax which means a flat increase at the federal level would still result in differing total tax rates. As long as the average tax rate is high enough to cover the true cost of driving, this should not be a problem. A higher federal gas tax would address the goals of reducing CO2 emissions and air pollution since it would incentivize people to cut back on their driving or purchase more fuel efficient vehicles. Either way fewer gallons of gas will be consumed which will create less pollution with the added benefit of reducing oil imports. Every gallon conserved is a gallon that does not need to be imported. A higher gas tax will also raise revenue that could be spent further incentivizing people to cut back on their gasoline consumption such as funding subsidies for alternative fuel vehicles.

The federal government should reinstate its tax credit for purchasing natural gas vehicles. As previously discussed, natural gas vehicles achieve emissions benefits relative to internal combustion engine vehicles at a much lower marginal cost than PHEVs or EVs. Since natural gas prices have fallen so much, the tax credit could be even lower than it initially was and still provide the necessary incentive for consumers to make the switch. The government should also explore options for incentivizing the construction of natural gas fueling infrastructure. A major drawback to natural gas is that it must be shipped in pipelines that require large upfront capital investment. As part of any new infrastructure bill, the government should include financing assistance for natural gas infrastructure.

Summary of Recommendations:

1. Consider reducing subsidy to average amount
2. Increase R&D funding to reduce the cost of batteries
3. Install charging infrastructure at federal buildings
4. Tighten regulations on emissions from power plants
5. Meet new electricity demand from EVs with cleanest possible source
6. Increase the gasoline tax to both raise money for funding AFVs and incentivize consumers to reduce their gasoline consumption in the manner that suits them best.

Further Research:

In writing this thesis, numerous opportunities for future research have presented themselves. The limitations of this analysis have already been discussed and some of them could be overcome given enough time and resources. Further research can both expand upon this analysis as well as inform the study of other policy areas. One of the major limitations discussed earlier was the inability to track individual electrons from where they are consumed to their source. While this is probably impossible, a less ambitious survey of utilities regarding how and where they generate their electricity as well as whom they sell it to could provide a better idea of the regionally different social costs of electricity consumption. This has implications for EV policy as well as policy relating to energy efficiency in general.

The cost benefit analysis performed here is focused on the benefits created by one car in one place. A single car does not require a new power plant, however widespread adoption of EVs probably will. EVs will require ubiquitous charging infrastructure as well as increased transmission and generation capacity. If this is to be done, it will be important to know what ratio of generation sources is required for EV adoption to leave society better off than it was. If new demand is met with coal plants, society could be worse off than if it had never adopted EVs. Policymakers need to know how their decisions regarding EV and electric power policy interact as well as the consequences of ignoring such interaction.

The effectiveness of the tax credit at incentivizing people to purchase EVs is another area worthy of further research. It is still early so the people who have already purchased EVs may not be representative of those who will in the future so surveying them as to what factored into their decision to purchase an EV may not give a true assessment of how people consider price when purchasing a vehicle. A wider survey of car consumers could be used to indicate the price point at which most people would consider an EV. This will be useful to policymakers as it will shed light on what level of subsidy would be necessary to create a market for EVs.

A major part of the benefits from EV use is derived from reducing oil dependence. While this is indeed valuable, substituting electricity for oil could create a similar problem if the supply of electricity does not increase with demand. If EV adoption happens at a faster rate than new electricity generation can be brought online, a situation similar to what has happened with oil where prices rise rapidly is easy to imagine. Research needs to be conducted to determine how much new capacity is needed to keep prices from rising quickly enough to create shocks to the economy or if this is even a potential problem in the first place.

More research needs to be done assessing air pollution damages in certain geographic areas. A new system of boundaries more appropriate to assessing air pollution damage should be set, preferably based on air pollution concentrations rather than determining an average concentration in a pre-defined geographic area. This would give policy makers a better idea of which areas will see the greatest benefit from any policy intended to cut air pollution emissions.

Given than government policies will have a role in shaping the sources of electricity generation that will be used in the future, it would be interesting to predict what that mix of sources will be. Ideally, there would be several scenarios; one that looked at a continuation of current trends, one that looked at an acceleration of them, and one that looked at a reversal. This would allow for a better prediction of the benefits from EV use in the future given the views of the political party in charge at the time.

Conclusion:

Electric vehicles, in some form, will have to play a role in the United States' transportation sector in the future. The cost-benefit analysis performed for this thesis found that the current $7500 federal tax credit does not produce enough quantifiable public benefit to justify itself based on the benefits from reduced CO2 emissions, reduced air pollution emissions, and reduced oil dependence. This does not mean that government should not support the adoption of EVs merely that the current mix of policies does not quite match up to the current state of the EV industry. A lower tax credit would reduce waste while freeing up money to be spent on bringing the cost of EVs down and improving charging infrastructure.

EVs offer clear benefits over internal combustion engine vehicles including zero tailpipe emissions and no need to burn oil. EVs will remain attractive to policymakers from across the political spectrum since they can be supported by an environmental, public health, or energy security argument. Unfortunately, the potential benefits of EV use are held back by the state of the electric power industry in parts of the country. Almost a third of all counties in the U.S. see worse air pollution and CO2 emissions from EVs than they would with internal combustion engine vehicles, indicating electricity needs to come from cleaner sources for a widespread adoption of EVs to have its intended environmental effect. Cleaner electricity will reduce some of the regional disparity seen in the benefits of EV use. This thesis indicates that there is room for improvement in policies regarding electric vehicles. Hopefully, such changes will result in a cleaner transportation system that is less reliant on imported oil.

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