Ending America's Energy Insecurity: Why Electric Vehicles Should Drive the United States to Energy Independence

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ABSTRACT

The homeland/national security threat posed by the United States' dependence on foreign oil has been part of the American discourse for years; yet nothing has been done. No pragmatic, realistic step-by-step plan has been pursued to end this scourge on the American people. The solution can be found in the problem. Net imports of oil account for approximately 50 percent of the oil the United States consumes. Likewise, 50 percent of oil consumed in the United States is consumed as motor gasoline. If, overnight, the United States stopped using oil to power its unleaded gasoline driven vehicles, if overnight drivers switched to electric vehicles, then overnight the United States would become energy independent. Using historical data to establish the effect of gasoline price changes on consumer vehicle choice, a predictive model has been created showing the expected switch to electric vehicles if the price of gasoline increases and the cost of electric vehicles decreases. There is a cost to energy independence: two to five dollars per gallon of retail gasoline sold. If monies raised from the tax are used to lower the price of electric vehicles, build recharge infrastructure, and dampen the regressive nature of the tax, energy independence is a few short years away.

PROLOGUE

Tomorrow: On a beautiful October morning in North Carolina, you wake up and turn on the news. Iran has declared war on the west. They have mined the Straight of Hormuz and their naval commandos have attacked and sunk multiple oil tankers. You sip your cup of morning coffee, watching the world response and the talking heads analyzing the situation, and then you head to work. On your way to work you notice that every gas station has a line of cars. Reassuring yourself that your tank is full, you do a double take as you catch sight of the price of gasoline: overnight it has increased by a dollar a gallon.

Three days later you cannot put it off any longer, you need gasoline. Your heart sinks as you see the line, then it sinks even lower as you see the price. Gasoline is now double what it was four days ago. Sitting in line, waiting an hour for your turn at the pumps, you listen to the news and hear about the combat operations underway to clear the Straight of Hormuz and bring Iran to account. The CENTCOM Commander sounds optimistic, but he is noticeably vague about when he expects oil to flow freely again. As he describes all the bombing sorties and boat sweeps for mines, you glance at the line creeping forward and cannot help but think of all the gasoline the military must be using.

The news turns to the weather and that hurricane that had been headed to Florida. It has taken a sharp turn North and is now expected to make landfall in North Carolina, tomorrow. The governor speaks and you nearly choke on your chewing gum as he tells folks that they need to evacuate inland if they can, but not to count on finding gasoline on the road. He goes on to warn that communities need to support each other. The state will do what it can, but the governor is worried the National Guard will not have enough gasoline to conduct its usual post-hurricane rescue and clean up activities. You think longingly of the generator you bought last hurricane season, and the empty jerry cans you keep in the trunk for just such an emergency. Just as it's your turn at the gas pump, the lights are turned off as the station manager announces they are out of gasoline.

While this sounds like bad science fiction, these or similar events will happen at some point in the future if the United States does not shed its dependency on foreign energy.

INTRODUCTION

This article is focused on one thing: describing the most plausible, ready to implement and truly achievable method of enhancing our national and homeland security by ending America's dependence on foreign oil. This article provides the tools policy makers can use to bring about energy independence, it gives the electric vehicle (EV) and utilities industries an idea of the opportunities energy independence would provide to them, and it explains to the general public both the true nature of the threat posed by US energy dependence as well as a path for eliminating that threat.

The amount of oil imported by the United States is roughly equal to the amount of oil used in the United States for motor gasoline. A shift to EVs would end our dependence on foreign oil.

Dependence on foreign oil threatens US national and homeland security. This threat manifests itself in several ways: it places unhealthy restraints on US and allied nations' policy choices; it weakens the nation economically by adding to the trade deficit; it forces our military to protect vital oil trade routes; and it strengthens our enemies by providing funding for their adversarial activities.

Too often the term "energy independence" is used as a proxy for other interests, misdirecting the discussion away from the grave threat dependence on foreign oil poses to our nation's security. For example, environmentalists appropriate the moniker of security in their efforts to develop renewable energies, though we cannot yet harness the sun and wind in sufficient quantities to end our dependence on foreign oil.[1] The US oil lobby wraps their persuasion in the patriotic visage of energy independence in their efforts to expand domestic oil production, though we cannot drill our way to true energy independence. These movements are topics worthy of their own consideration, but by superficially attaching their agendas to America's energy insecurity they hyper politicize what should be an issue of near unanimous agreement: the need to end our nation's energy dependence. This politicization makes a meaningful and narrowly focused discourse on solving the security threat posed by energy dependence nearly impossible.

For purposes of this article, "dependence on foreign oil" is the situation where the domestic demand for oil exceeds the available domestic supply. When the domestic supply is insufficient, some domestic consumption of oil *must* be satisfied by sources that originate in locations other than the states, territories, and possessions of the United States.

The remainder of this article is organized into five sections. First is an examination of the scope and nature of US dependence on foreign oil, including an historical look at how fuel prices affect consumer vehicle purchases. Following that is an explanation of how those consumer choices can be influenced and mathematically predicted by changes in the price of gasoline and the price of EVs. The article then describes policy choices that would lead to energy independence. The final sections discuss critical secondary considerations and offer an analysis of potential unintended consequences from the recommended policy choices.

THE SCOPE, RAMIFICATIONS, AND INTERCONNECTEDNESS OF DEPENDENCE ON FOREIGN OIL

The 1973/1974 oil embargo provides historical precedence for foreign nations using oil as a lever to affect US national policy.[2] In 1973/1974, the United States imported approximately 28 percent of the oil that it consumed.[3] The embargo, sometimes referred to as "Energy Pearl Harbor Day,"[4] was sufficiently severe to serve as the catalyst for legislative action concerning the use of fuel. Gas shortages were significant enough that, along with a tripling of world oil prices, gasoline consumption in the United States actually decreased by 2 percent in response to the embargo.[5] The situation was so severe that naval oil reserves were tapped for emergency civilian supplies.[6]

The economic cost of dependence on foreign oil is staggering. The United States has an oil trade deficit of approximately $1,000,000,000 per day, larger than our trade deficit with China,[7] which in 2010 was approximately $748,000,000 per day.[8] Oil consumption represents 40 percent of America's energy needs, with 20 percent of the oil the United States consumes coming from the Persian Gulf Region.[9] The cost to the United States is compounded. Not only do we send one billion dollars out of our economy every day, but much of that same money is then used in a manner that directly threatens our security. Time and again, US military and national security leaders have warned of the substantial risk this outflow of capital poses to the security of the United States. For example, Vice Admiral Dennis McGinn has cautioned that the oil trade deficit, much of it enriching nations that wish us harm, is an unsustainable transfer of wealth that has us literally funding both sides of the conflict in the "war on terror."[10]Former national security adviser Robert McFarlane and former CIA director R. James Woolsey, have recently described our dependence on foreign oil as "the well from which our enemies draw their political strength and financial power: the strategic importance of oil, which provides the wherewithal for a generational war against us."[11]

The restraints oil dependency places on US foreign policy decisions are untenable. Hugo Chavez, president of Venezuela, has threatened to cut the supply of oil to the United States, not because of the threat of a US invasion, but as leverage to prevent Colombia from invading Venezuela.[12] Similarly, Russia has shown it may be willing to take military action to control the supply of oil flowing to the West. The invasion of Georgia may have been more about the Baku-Tbilisi-Ceyhan pipeline (a conduit of oil to the West owned by US and British energy firms) than about support of the separatists in South Ossetia.[13]

Similar threats have come from non-state actors like Osama bin Laden and Ayman al-Zawahiri, who have called for attacks on economic assets, especially energy sources.[14] In a tape aired by Al-Jazeera in February 2006, Zawahiri said, "I call on the mujahedeen to concentrate their attacks on Muslims' stolen oil, most of the revenues of which go to the enemies of Islam while most of what they leave is seized by the thieves who rule our countries."[15] The non-state threats are broader than just al Qaeda, with groups specifically attempting to wreak havoc in international markets.[16]

These attacks have real consequences, and the world oil market recognizes the risk posed by these attacks. In February of 2005, a failed al Qaeda attack on the Aramco facility in Abqaiq, Saudi Arabia, caused the price of oil on international markets to jump nearly two dollars per barrel.[17]

As significant as those threats are, perhaps the single greatest threat comes from Iran. Iran has expressed its intention privately and publicly, and possesses the ability to disrupt world oil supplies should it be attacked.[18] With tensions rising as the United States and other nations attempt to limit Iran's nuclear program, Iran's navy chief, Adm. Habibollah Sayyari, has said that closing the Persian Gulf choke point "is very easy for Iranian naval forces." It was the second such threat in as many days after Vice President Mohamed Reza Rahimi vowed to close the strait, cutting off oil exports, if the West imposes sanctions on Iran's oil shipments.[19]

These are not idle threats. If Iran retaliated and shut down the Strait of Hormuz, it would mean the temporary loss of more than 15 million barrels of oil a day.[20] Iran has built a military arsenal with this capability in mind. There are reports that Iran has purchased the SS-N-22 Moskit/ Sunburn anti-ship missile, designed to strike ships defended with the Aegis weapon control system.[21] Iran also has a large supply of anti-ship mines, including modern mines that remain stationary on the sea floor and fire a homing rocket when a ship passes overhead. In the deep waters in the Strait of Hormuz, such a weapon could destroy ships entering or exiting the Persian Gulf.[22] Furthermore, Iran's naval commandos are trained to attack shipping and offshore oil platforms.[23] Even with the United States' extensive military power, US intelligence estimates that Iran's military rearmament has given it the ability to shut off the flow of oil from the Persian Gulf temporarily.[24] Assessing the contemporary threat from the tensions over Iran's nuclear ambitions, General Martin Dempsey, chairman of the Joint Chiefs of Staff, reiterated that Iran has the capability to close the Strait of Hormuz.[25]

The looming Iranian threat to the oil supply places real restraints on US security policy choices. In considering an appropriate response to Iran's nuclear ambitions, US administration officials are wary of enacting sanctions on Iranian oil exports. Officials fear that it might drive up oil prices when the US and European economies are weak. As the United States and her allies consider the probable impacts, they are forced to conclude that in the end, they simply cannot predict what would happen.[26]

World oil supplies continue to be fungible. Though the United States imports much of its foreign oil from friendly nations like Canada and Mexico,[27] the entire world supply would be impacted by a significant disruption anywhere in the oil market.[28] Should any state or non-state actor temporarily interrupt the worldwide flow of oil, if the United States chooses to respond (for example to open the Strait of Hormuz), the government will be forced to make very difficult choices. "Reserve stores of petroleum and petroleum-based fuels would dwindle quickly – particularly during wartime operations – leaving the US military unable to obtain suitable alternative fuels and rendering it virtually immobile."[29] Therefore, it is not sufficient simply to be dependent on "friendly" nations for oil; it is critical that, when necessary, the United States can fully supply its own oil needs. This is discussed more fully below, in the consideration of secondary concerns.

There are also less obvious threats to homeland security from a reliance on foreign oil. If the military is demanding all available petroleum resources, fuel for fire, police, and ambulance services will be in short supply in the United States. Other, non-critical, demands for petroleum would be left completely unfulfilled (e.g., commuters, truckers, and the airline industry). Emergency services in the United States are delivered via fire trucks, ambulances, and police cars; all of those vehicles depend on access to gasoline or diesel fuel; therefore, delivery of emergency services in the United States depends on oil.

On August 14, 2003, over 9,300 square miles, covering eight states and portions of Canada lost electrical power with virtually no warning.[30] In New York City alone, emergency services responded to 91,000 911 calls during the outage. Even in their reduced capacity, emergency services were called on to perform more than thirty distinct tasks, inter alia: elevator rescue; subway rescue; fire suppression; hazard calls; traffic accidents; welfare checks at hospitals, senior citizen homes, day care centers, and prisons; providing power to critical care facilities; distributing water; opening emergency shelters for the elderly; and helping the elderly up and down stairs. The firefighters were able to perform these actions because they had fuel in their vehicles and because most of their 911 dispatch centers and many fire stations had emergency power.[31]

When Hurricanes Rita and Katrina made landfall oil and gasoline production was virtually halted as production facilities were evacuated and wells were closed. By September 1, at least one county in North Carolina was faced with 60 percent of its gas stations out of fuel.[32] Had the fuel shortages persisted or worsened, North Carolina would have been unable to provide the National Guard (which obtains its fuel through the state) with fuel for very long. The shortage occurred hundreds of miles from the storm. North Carolina was fortunate that it did not need to rely on the services of its National Guard during this crisis.

Imagine what might happen if an intentional disruption of the oil supply coincided with a widespread power outage or natural disaster. Imagine the National Guard, fire services, EMS, and law enforcement becoming essentially incapacitated.

US OIL IMPORTS AND OIL USES

The United States is the third largest producer of oil in the world.[33] For 2009, EIA data shows that the United States had net imports of 9.7 million barrels of crude oil per day.[34] The 9.7 million barrels of crude oil imported per day was from a total of 18.7 million barrels of crude oil used per day.[35] During the same year, 13.3 million barrels of oil were used per day for transportation purposes in the United States, with nine million barrels per day specifically used for motor gasoline.[36] The nine million barrels used every day for motor gasoline represented 48 percent of all US petroleum consumption.[37] The relative numbers have held fairly constant. In 2010, the United States consumed 19.1 million barrels of oil per day,[38] with nine million barrels per day used for motor gasoline.[39] In 2010, net imports accounted for 49 percent of US oil consumption.[40] Figure 1 below describes the uses of oil in greater detail.

Importantly, very little of the oil consumed in the United States (approximately 1.11 percent in 2009) is used for electricity production.[41] That means that adding nuclear or clean coal facilities, building wind farms, installing solar panel fields, etc., do little to foster energy independence. Those technologies do not replace oil combustion in a manner that can currently be utilized by most of the transportation sector.

By focusing on the single greatest use of oil – the nine million barrels that are used as motor gasoline every day – the solution emerges from the problem itself. Figure 2 below graphically illustrates the problem and in so doing, the genesis for a solution emerges.

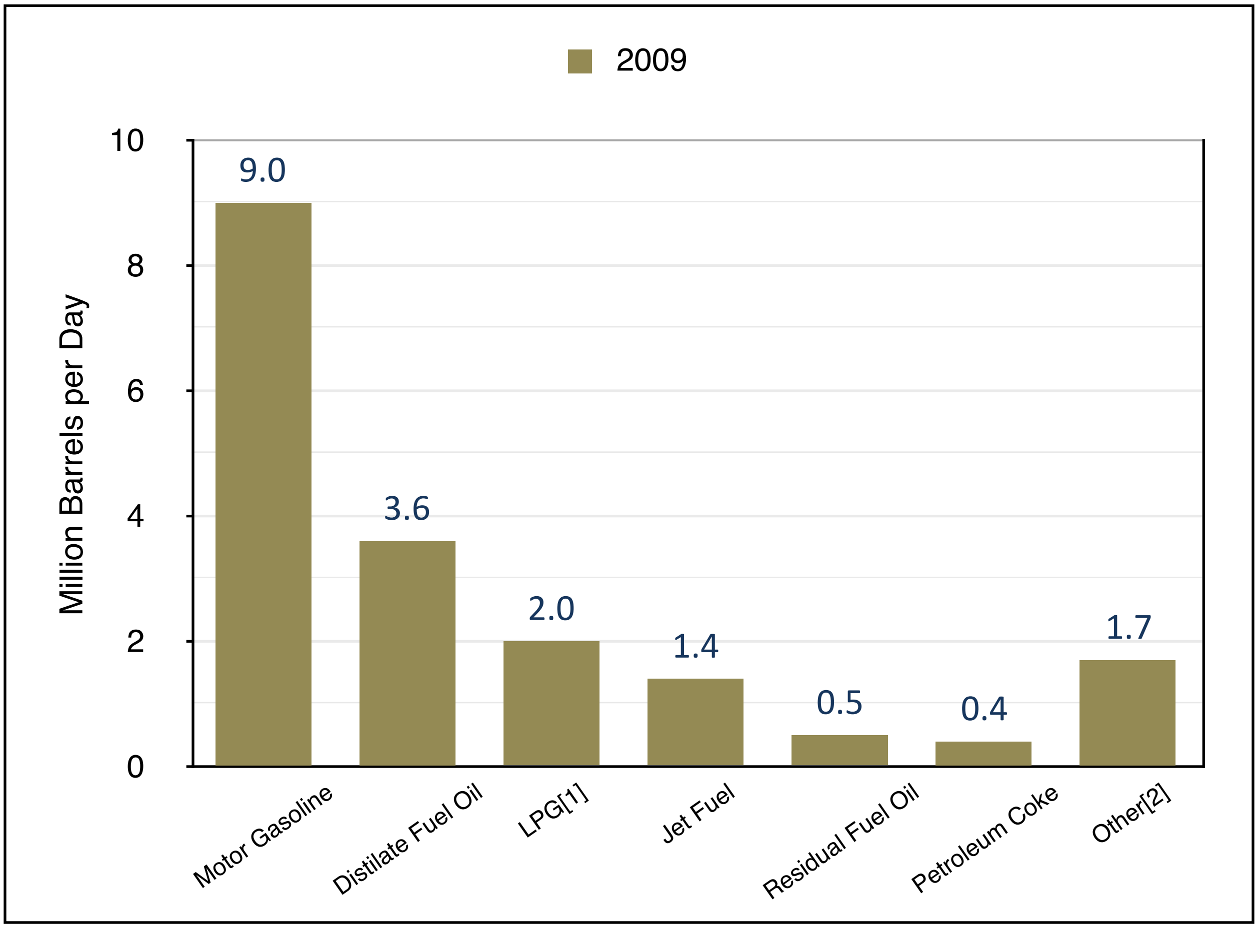

Figure 1. Uses of Oil [42]

1 Liquefied petroleum gases.

2 Asphalt and road oil, aviation gasoline, kerosene, lubricants, naphtha-type jet fuel, pentanes plus, petrochemical feedstocks, special naphthas, still gas (refinery gas), waxes, miscellaneous products, and crude oil burned as fuel.

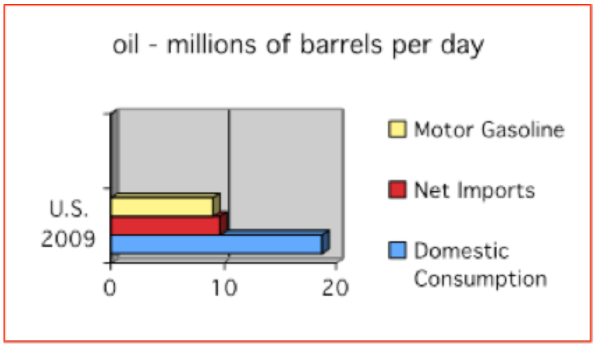

Figure 2. Oil Imports, Consumption and Amounts Used for Motor Gasoline[43]

If the United States stopped using gasoline to power its automobiles, it would essentially become energy independent overnight. While it may not be possible to transform literally overnight, it is possible to transition to EVs in a few short years, cease using motor gasoline, and thereby become energy independent in a few short years. Although the move to EVs is likely to occur slowly in response to market forces alone,[44] given the urgency of the security threat posed by dependence on foreign oil, market forces need to be stimulated to rapidly bring about the change.

Considerations Affecting the Adoption of an EV Fleet

Electric vehicle technology has advanced to the point of providing a driving experience in both range and performance that is comparable to that provided by internal combustion passenger vehicles. The high performance Tesla Roadster sports car is quite literally where the rubber meets the road. It is an EV capable of traveling 300 miles on a single charge.[45] The primary difficulty in providing mainstream vehicles of similar performance capability is the cost of EV batteries. Fortunately, EV battery prices are falling and falling quickly. One prediction is that a battery capable of powering a vehicle 100 miles, which cost $33,000 in 2011, will cost just $16,000 by the end of 2013.[46]

Analysis of historical fluctuations in gasoline prices demonstrates that with long-term price increases in the cost of gasoline, people will reduce their consumption of gasoline, at least partially, by moving to more fuel-efficient vehicles.[47] However, speeding up EV adoption depends on several factors, including: improving battery efficiencies and capacities to increase range; bringing the total cost of EV ownership in line with or below the total cost of gasoline powered vehicles; and increasing the pace of EV infrastructure development (e.g., recharge/refuel facilities).[48]

Gasoline Price and Vehicle Choice

Around the turn of the millennium, carbon tax and other policy discussions about global warming brought the question of gasoline elasticity into sharp focus. Rather than look just at traditional measures of elasticity, the literature evolved in an effort to account for income disparities, miles driven and, ultimately, vehicle choice. Gasoline demand and the demand for automobiles were modeled as a joint decision. By also accounting for income, it emerged that there was not a uniform elasticity measure, but rather elasticity varied across the income distribution.[49] Importantly, it was also determined that gasoline demand responds to changes in the price of gasoline in large part by modifying the fuel efficiency of the car fleet rather than through an adjustment of miles traveled.[50] An historic review, looking at the period from 2003 through 2007, determined that the 100 percent increase in gasoline prices over that time had induced motorists to adjust the types of vehicles they purchased.[51] One study determined that if gasoline price increases by 10 percent, the demand for SUVs will decrease by 13.7 percent and the demand for hybrid cars will increase by 9.1 percent.[52] The report specifically notes the potential policy advantages that tax increases on the price of gasoline have over increasing the federal corporate average fuel economy (CAFE) standards. That advantage stems from more direct alignment with market forces.[53]

A PREDICTIVE MODEL

Recognizing that changes in the price of gasoline will result in changes in the vehicles consumers purchase, a logical progression is to examine the possibility of predicting the extent of that change in purchasing behavior. In order to provide a rigorous basis for federal policies that would accelerate the nation's transition from gasoline internal combustion engines to a national fleet of EVs, it would be useful to develop a model to predict the effect various policy choices would have on EV adoption. The model developed here examines the basic costs of vehicle ownership as well as the more complex factors of vehicle choice. The methodology provides a model that should be reasonably accurate at lower volumes of sales, recognizing that given the overall complexities of the system, it cannot predict precise sales numbers. The model will also create a general methodology where any practitioner can incorporate additional factors, or utilize different assumptions, and have a grounded basis to predict the results flowing from those choices.

The model development is described in detail in Appendix 1. It relied on the theoretical framework developed by Jeihani and Sibdari.[54] Though they chose to calculate the relative probability of choosing one car over another, the model developed here solves for sales volume of a particular vehicle class. In all, three vehicle classes are included in the analysis: SUV, hybrid, and EV. Though the relationships established by hybrid data serve as reasonable proxies for EVs, because the influencing factors are somewhat different (e.g., the price of electricity can be expected to effect EV purchasing more than hybrids), EVs require their own equation. Historical data on both SUV and hybrid vehicle sales is used to determine coefficients whereby the mathematical equation most closely aligns with a graph of actual historical car purchase data.

The coefficients that multiply other terms are proportionality factors. That is, they measure the direction and strength of the effect of the term they multiply. By way of example, in Equation 1 below, the coefficient B multiplies household income. A change in household income is expected to cause a change in sales of a particular class of vehicles, but whether it causes more sales or less sales, and how much more or less, is captured by the coefficient B. There is one stand-alone coefficient. It is a catchall. There are certainly factors that influence the purchase of vehicles that are not included as factors contained in the equation. For example, an advertising campaign may impact vehicle sales but is not one of the factors analyzed using historical data. Some factors effecting sales could be determined while others are probably unknowable. The models in this article use the factors identified as relevant by Jeihani and Sibdari.

Where specific vehicle averages are necessary (for example, average sales price of the class of vehicle) a representative vehicle was chosen. The Ford Explorer represents the SUV class of vehicles, and the Toyota Prius represents the hybrid class of vehicles. The SUV was modeled to test the framework against a more traditional class of vehicles, one whose sales likely have a stronger correlation to the price of gasoline than other vehicle classes.

There is insufficient data for a meaningful historical analysis of EV sales, due to the low number of EV sales. Until sales are robust enough that it appears the modeling factors are measurably impacting total EV sales, a meaningful historical sales analysis, using the factors contained in this article, cannot be accomplished. Therefore, the coefficients derived for hybrid vehicles are used as a proxy in predicting EV sales, assuming the two are closely related. Those coefficients are then used in the model to predict future sales of EVs. Appendix 1 describes in detail how the formulas were derived. The equation for hybrid vehicle sales is:

$$\ln(S_{hy}) = A_{hy} + B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy} \tag{1}$$

The equation representing the sales figures of SUV vehicle sales is:

$$\ln(S_{SUV}) = A_{SUV} + B_{SUV}I + C_{SUV}U + D_{SUV}CPM_{SUV} + E_{SUV}P_{SUV} \quad (2)$$

The coefficients derived for the hybrid vehicle will be used as proxies for the EV sales volume model. It is reasonable to presume that factors influencing people's decision to purchase hybrid vehicles will similarly influence their decision to purchase EVs. As with hybrids, it is likely that the first consumers to purchase EVs do so for a myriad of concerns and motivations (e.g., environmental, status). As sales of hybrids grew, economic forces such as declining vehicle price and increase in gasoline price likely have become the dominant market drivers. The same is presumed to be true with EVs. Therefore, only one parameter from the hybrid model, Equation 1, was replaced. CPM_{hy} was replaced with PM_{EV}, which was derived using the representative cost of electricity per *kWhr* and the number of miles driven by the EV per *kWhr*. Accordingly, the model describing the sales volume of electric vehicles is represented by:

$$\ln(S_{EV}) = A_{hy} + (B_{hy} \times I) + (C_{hy} \times U) + (D_{hy} \times PM_{EV}) + (E_{hy} \times P_{EV}) \quad (3)$$

- A_{hy} = all consumer preferences and choice factors not specifically addressed elsewhere in the equation,
- S_{EV} = the sales volume of electric vehicles,
- B_{hy} = weight factor for societal annual income,
- I = societal average annual income,
- C_{hy} = weight factor for unemployment,
- U = total unemployment,
- D_{hy} = cost of locomotion factor,
- PM_{EV} = price per mile for locomotion,
- E_{hy} = weight factor for price of hybrid,
- P_{EV} = price of hybrid vehicle

Appendix 2 contains the historic data used to derive the constants, encompassing the years 1991 to 2010 for SUVs and 2000–2010 for hybrids, as well as a description of the process used to determine the coefficients. The resulting coefficients are contained in Table 1.

Note that D_{hy}, which represents the response of the hybrid vehicle sales figures to gas prices, is positive whereas D_{SUV} is negative. This is intuitively plausible and represents the expected fact that higher gas prices provide an incentive for the purchase of hybrid or electric vehicles whereas they provide a disincentive to the purchase (or ownership) of SUVs. At it most elemental, this is the basis for the government policy proposed below.

APPLICATION OF THE MODEL TO FORECAST SALES

At this point, the equations have been derived and the coefficients describing the direction and strength each factor has on the sales of a class of vehicles has been determined from fitting a mathematical curve to a graph of historical sales. Using the relationships captured by those coefficients, the models can now be applied to predict future sales by estimating the future value of the causal factors described in the equations (e.g., expectations of the future price of gasoline and of the future cost of the various classes of vehicles). It is therefore necessary to project the data into the future. Various government policy choices, (e.g., the gasoline excise tax per gallon and the rebate to the buyers of EVs) are parameters that can be adjusted by the user to achieve a desired result affecting the consumption of gasoline and the purchase of vehicle types.

Table 1. Coefficients of the Sales Volume Models (Equations 1 and 2) of Hybrid and SUV Vehicles as Derived by Fitting The Equations to Historical Sales Data (Appendix 2)

	A	*B*	*C*	*D*	*E*
Hybrid/electric	3.6	$2.16*10^{-4}$	$-1*10^{-13}$	31.1	$-1.66*10^{-4}$
SUV	13.36	$2.01*10^{-4}$	$-1.4*10^{-7}$	-10.8	$-1.97*10^{-4}$

Although the model was tested using a wide variety of parameters, those chosen were ultimately selected because they seemed to represent a good balance of the positive and negative effects of available policy choices and conservative assumptions about future economic conditions. The assumptions applied to the predictive model (Equation 3) to produce the predictive result can be found in Appendix 3.

Applying the policy (most notably a gasoline excise tax starting at $2 and rising to $5 per gallon of gasoline, and an EV purchase rebate of $15,000) and economic assumptions to Equation 3, provides the following projections of EV sales between 2011 and 2018 (Figure 3).

Figure 3 shows that EV sales will begin rising rapidly in a "hockey stick" manner once the policies choices listed above are introduced in 2012. A substantially higher gasoline price as well as a rebate of $15,000 to each EV buyer is expected to induce this "hockey stick" effect. The rebate is funded entirely from the revenue generated by the gasoline excise tax. (Note: policies that will lessen the regressive nature of this tax are discussed below.)

Table 2 shows the annual excise taxes predicted to be collected each year through 2018, the amounts to be distributed as rebates for EV purchases, and the remaining sums to be used to implement other EV adoption policies (e.g., refunds to low-income families and recharge infrastructure build out incentives). Note that until 2017, the incentive rebates represent less than 25 percent of the collected tax.

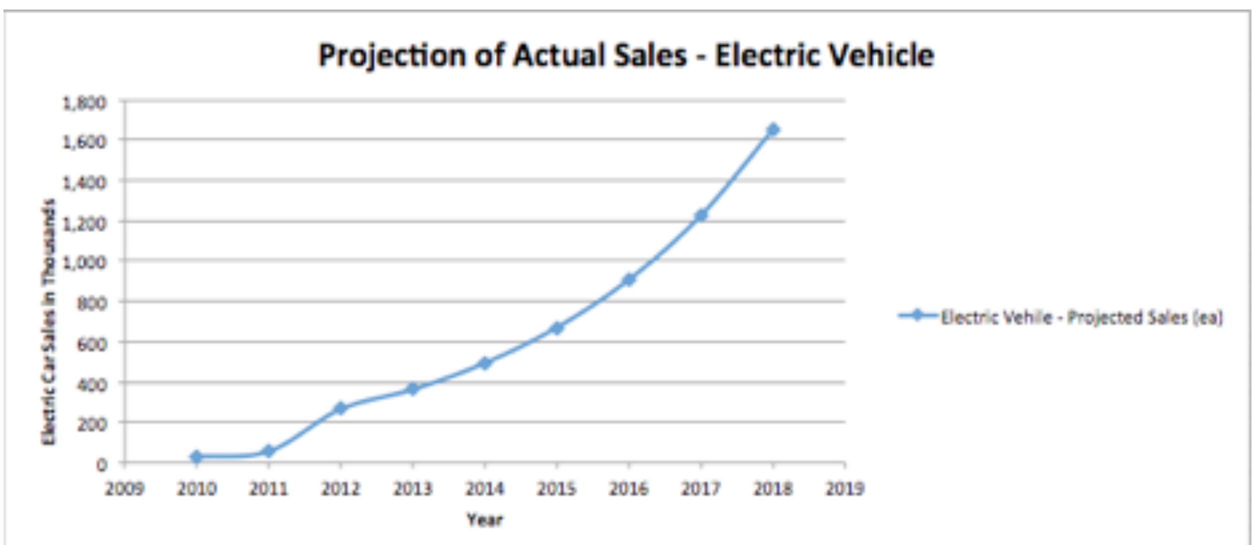

Figure 3. Predicted EV Sales for the Period 2011-2018 in Response to Taxation and Subsidy Policies as Projected by the Model

Table 1. Excise Tax Collected

Year	Total Gasoline Excise Tax Collected	Tax Used For EV Rebates	Gas Tax Net of EV Rebate
2012	$34,534,635,600	$3,982,118,284	$30,552,517,316
2013	$68,548,941,078	$5,438,617,192	$63,110,323,885
2014	$84,797,868,872	$7,405,192,521	$77,392,676,352
2015	$83,588,354,094	$10,054,056,083	$73,534,298,011
2016	$81,946,191,600	$13,613,986,738	$68,332,204,863
2017	$79,722,573,766	$18,388,609,526	$61,333,964,241
2018	$76,719,100,877	$24,780,556,145	$51,938,544,732

Any effort at predicting future behavior is a risky proposition. The mathematical equation used here is no different. Due to the dearth of data relating to EV sales, it was necessary to presume that the hybrid coefficients will translate to the EV model, it fails to reflect the bounded nature of the vehicle market, and it presumes that past linear relationships will be maintained into the future. All this is to say, the model is not intended to be provide an actual, exact number of EVs that will be purchased. The numbers themselves are less important than the trends, the general magnitude of the results, and the relationship of the factors to each other. Graphically, it is the bend in the hockey stick of Figure 3 that is important. The bend represents the rapid change that can be brought about if the policy levers discussed are utilized appropriately.

POLICY CHOICES

SUGGESTED COURSE OF ACTION

The modeling results demonstrate that it is possible to alter consumer behavior significantly in favor of EV purchases by using an excise tax to raise the price of gasoline and using those funds in part to bring down the cost of EVs. Each step in lowering the use of gasoline by automobiles is a step towards energy independence and greater national and homeland security. Therefore, in a program announced significantly ahead of time, the federal government should implement an excise tax on retail gasoline purchases. In order for elasticity to strengthen, consumers must have substitutes that are easy to switch to. That is, if there are not readily available alternative choices to driving a vehicle that uses gasoline, consumers will not be able to change their car purchase choices even if gasoline is extremely expensive. Therefore, a portion of the funds raised by the excise tax should go directly towards a tax credit or point of purchase credit for the purchase of EVs. The additional funds raised should be used to offset the effect of the tax on the lowest income segment in the population. That concern is addressed in more detail below. Additionally, it is important to use those funds as incentive to propel the creation of a recharging infrastructure in the United States. The ultimate goal is an all EV automobile market and the end of motor gasoline powered vehicles, without diminishment of the US driving experience, and without a switch to vehicles powered by other forms of oil (e.g., diesel). As stated previously, tax increases on the price of gasoline create a more direct alignment with market forces (as compared with CAFE standard increases).[55] The policy choices described herein accelerate market forces, but in the end, it is a policy reliant on market forces to drive the change to EVs. It is not recommended that government mandate that only EVs are sold, rather that with appropriate and limited pressure, the market will determine which and what type of vehicles are available for sale.

EXCISE TAX ON RETAIL GASOLINE PURCHASES

A tax on the sale of retail gasoline should be implemented. As was demonstrated by the model, an excise tax of between two and five dollars raises more funds than is required for rebates, even where the rebate is $15,000, double the historical rebate on new EV purchases. In order to allow consumers to prepare for the economic consequences of the excise tax, and with the goal of seeing change at the beginning of implementation, it is important that the policy be announced ahead of time. It takes one to two years of gasoline price increases before there are real shifts in purchase behaviors.[56]

Phasing in the tax serves two purposes. First, though announcing the increase ahead of time should allow for a more immediate response to the price increases, there are inevitably consumers who cannot or will not react immediately. A phase-in allows some of those consumers to adjust before the full tax is in place. Additionally, a phase-in would allow any unanticipated consequences to occur in a more controlled manner, diminishing their magnitude and allowing more time to respond appropriately.

Eventually, economies of scale should bring down the price of EVs so that they are sufficiently competitive without government rebates. According to the DOE, just the creation of battery manufacturing plants, spurred by Recovery Act matching funds, is lowering battery prices through economies of scale.[57] As demand increases and production rises to meet the demand, prices should fall allowing market forces to drive the price reductions.

RECHARGE INFRASTRUCTURE

If EVs are to be adopted nationwide, a well-designed and widely distributed network of charging stations is imperative.[58] A portion of the funds collected by the excise tax net of EV rebates should be used to assist in the creation of this infrastructure. The fourth column of Table 2 illustrates the additional monies that will be available to policymakers. A portion of those funds will also be required to offset the economic hardship the gasoline tax may create for low-income families. That issue is discussed in more detail below.

Range anxiety, a term described by Bostford and Szczepanek,[59] is a phenomenon not present with hybrid vehicles and, therefore, not captured by the coefficients developed from hybrid vehicle historical data. Range anxiety is particularly troublesome because it is more than a reflection of the ability of a driver to go from point A to point B. It reflects that a driver may choose not to try to go from point A to point B even when the EV is fully capable of traveling that distance. Bostford and Szczepanek describe range anxiety using an anecdote from the Tokyo Electric Power Company (TEPCO). In 2007, TEPCO introduced electric service vehicles and tracked employee usage of the vehicles over an 8 x 15 km service area. Initially, overnight charging was the only option. A few months into the program they realized that EV drivers were only covering a small portion of the service area. TEPCO responded by adding a fast charge station that could be used any time of the day. After its installation, EV drivers accessed the service area in a similar manner to conventional vehicle drivers. Most interestingly, the fast charger was rarely used.[60] The point is that the fast charger was not necessary to meet the actual needs of the EV, it was necessary to meet the psychological needs of the EV drivers. It was necessary to counter range anxiety. If range anxiety is not addressed, it may have a significant deleterious effect on the accuracy of the EV model.

There are various types of recharge facilities. The cost of the slow charge facilities is significantly cheaper than for fast charge. In fact, some EVs can slow charge without any change to a standard electrical outlet.[61] As shown in Figure 4, as the speed of the charge goes up, so does the required voltage/amperage output, which necessitates more expensive facilities.

Typical set of charging options developed for an EV.				
EVSE	Utility Service	Usage	Charge Power (kW)	Time to Charge
Level 1	110 V, 15 A	Opportunity	1.4	18 hours
Level 2	220 V, 15 A	Home	3.3	8 hours
Level 2	220 V, 30 A	Home/Public	6.6	4 hours
Level 3	480 V, 167 A	Public/Private	50-70	20-50 min

Figure 4. Recharge Levels and Time to Charge[62]

One estimate of the cost of recharging stations can be taken from a project underway in Portland, Oregon.[63] Oregon is using a two million dollar federal grant (stimulus money) to build forty-two "quick charge" stations along the I-5 corridor, ensuring no gap greater than fifty miles. That averages out to $47,619 federal dollars per station. These stations are designed to charge an EV battery to 80 percent capacity in a twenty to thirty minute period.[64]

A project funded in part by the US Department of Energy (DOE) provides an estimate for the cost of building slow charge stations. Given the total cost of $230 million (of federal money) to build 15,000 charging stations, each station costs approximately $15,333; however, that also includes 310 quick charging stations,[65] which are more expensive. Assuming the quick charging stations cost $47,619 each, the cost per station of the ordinary charging stations would be approximately $14,652 federal dollars.

Fortunately, recent stimulus funds have established the efficacy of dollar-for-dollar grants in establishing a recharge infrastructure. As described previously, with two million dollars of stimulus funds Oregon has created a recharge infrastructure covering all of Interstate 5 that runs through the state. It is not expected that funds will be required to incentivize all recharge stations. As EV sales increase, market forces may lead to the development of the infrastructure as well. Already some retail establishments have determined that it is in their interest to put in recharge parking spaces.[66] Nevertheless, especially given the concerns of range anxiety, to truly jump start US energy independence, significant investment should be put into creating a recharge infrastructure, fully funded by the retail gasoline excise tax.

NEW POWER STATIONS AND INFRASTRUCTURE

EVs use far more energy than may be obvious. Adding an EV to a neighborhood will increase the demand for electricity to the same or greater extent of adding a new house to the neighborhood. For example, the Tesla Roadster contains a 56 kWh battery.[67] By comparison, consumption by residential utility customers averaged 908 kWh per month,[68] meaning that the average house uses about 30 kWh per day versus the 56 kWh per day if a person fully drained the Tesla Roadster battery each day. The energy currently provided by gasoline will have to come from power stations. This means the United States will need not only additional stations but also additional transmission infrastructure, as the current infrastructure is not sufficient.[69]

Fortunately, power companies are largely financially successful.[70] If the regulatory obstacles are diminished, private industry should take over the building of generation and transmission capabilities to meet the demand created by EVs;[71] however, it takes time to build power stations and the transmission infrastructure to support it. If the regulatory obstacles are removed, and the government's plan to encourage EV adoption is transparent, unambiguous, communicated, and publicized one to two years before it goes into effect, that will allow market forces to begin responding so they are prepared to meet the rise in demand.

CRITICAL SECONDARY CONCERNS

PUBLIC SUPPORT FINANCIALLY

Will the US citizenry accept a substantial tax on the sale of gasoline? There is a historical basis to believe they might, if citizens accept the security implications that are alleviated by the tax. A parallel can be drawn to economic events during and after WWII. Between the purchase of government war bonds, and the substantial federal income tax paid by Americans, federal revenues were raised to never before seen amounts, "$98.3 billion by 1945, nearly half the war-swollen GDP."[72] Although the government's propaganda campaign centered on the ethical imperative to counter the Axis tyranny, combined with the self-interest realized by investing in war bonds, research has shown that the government missed the mark. The real reason citizens accepted the fiscal hardship was not for abstract ideals; rather it was the chance to help someone they could identify with. The idealized all-American GI, the boy next door, was who they were helping. By paying taxes and buying bonds, people saw themselves putting a gun and bullets directly in the hands of a GI. This allowed for a sort of indirect participation in the war itself.[73]

A similar view of the same social/psychological phenomena has been referred to as the post-tragedy opportunity bubble.[74] Breckenridge and Moghaddam look at the psychological similarities between the attacks of 9/11 and the attack on Pearl Harbor. They describe the fleeting moment of opportunity where the populace rallies around its leaders, trusts them more, and, because they are looking for a specific way to help, can be directed in a manner not usually possible.

In the first State of the Union Address after 9/11, President Bush called on Americans to give at least two years over the course of their lifetimes to the service of their neighbors and nation.[75] Unfortunately, that message did not resonate with Americans in a way likely to make them feel like part of the fight against those who attacked us. The success of fiscal participation during WWII turned on personalizing the response, allowing the citizenry to feel it was truly participating in defeating the great evil. The urgent desire to participate was given outlet in a contemporaneous ability to aid in the defeat of the enemy. The outlet was immediate and direct, not an ephemeral and vague channeling of that desire to some general purpose, at some undetermined time in the future.

In reviewing the post 9/11 response, Breckenridge and Moghaddam show that the government's failure to provide meaningful participation resulted in a failure to capture the public's long-term engagement and support. There was no mechanism for the citizenry to help defeat the great evil. Furthermore, the opportunity to harness the public sentiment is fleeting. Once the bubble pops, the opportunity is essentially lost.[76]

Taken together, these examples show an uphill, though not impossible, task of moving the citizenry of the United States to accept the sacrifice of a significant tax on gasoline. A simple and straightforward message needs to make the case that there is an ongoing and real evil threatening the nation, caused by dependence on foreign oil. In countering this threat, the link must be clear in the minds of the citizenry: money spent at the pump (in the form of an additional tax) is buying back the very guns and bombs that are killing Americans. Secondly, a personal and clear image must be established between the money paid and the lives saved. While paying the tax may not put a gun in the hands of a GI, it can be shown to take a gun out of the hands of the enemy. No more traumatic head injuries, no more amputees, no more sophisticated plots to attack America.

Currently the country may not be ready to view the threat of dependence on foreign oil in the same concrete terms as the bombing of Pearl Harbor or the events of 9/11. If that is the case, the government should nonetheless begin building the framework described herein. With so many enemies funded by oil sales, it is unfortunately only a matter of time before another tragic event disrupts the landscape of the United States. When that happens, leadership should be ready to ask for the participation of the citizenry, to ask for their shared sacrifice as a direct and meaningful way to participate in defeating those who seek to do us harm.

PUBLIC SUPPORT POLITICALLY

By using EVs as the mechanism to end energy dependence, this paper promotes a solution that both the political right (ending dependence on foreign oil) and the political left (environmental benefits of EVs) have vocally supported in the past. Though this article is solely focused on the detrimental effects energy dependence has on US security, proposing a solution that is agreeable to both sides of the political spectrum should ease adoption by the political system that must choose whether or not and how to implement the plan.

SOURCE OF ENERGY STORAGE MATERIALS

The current technology of choice for powering EVs is the lithium ion battery.[77] There are several problems with reliance on lithium for energy storage. First, there is disagreement with just how much economically available lithium there is in the world, with some experts saying supplies are quite limited,[78] and others saying there are ample supplies available.[79] More troubling for national and homeland security is the location of the largest known deposits of lithium. They are not in the United States. The Andes Mountains in South America, specifically the area where the borders of Chile, Bolivia, and Argentina meet, contain a large majority of the world's usable lithium,[80] with Bolivia containing the largest known deposits in the world.[81] Recent discoveries in Afghanistan suggest that it too may possess significant deposits of lithium. Additionally, current battery technology relies on magnets of a type that depends on rare earth metals like neodymium, 95 percent of which are produced in China.[82]

It defeats the goal of energy independence if the United States simply trades one energy dependency for another. "We know that Bolivia can become the Saudi Arabia of Lithium."[83] Policymakers must be mindful of this potential development, but it is still preferable to dependence on vehicles that derive locomotion through oil, and there are reasons to believe it is avoidable. In the first instance, unlike reliance on oil (where the resource is consumed with each trip) EVs consume locally produced electricity with each trip and additional lithium is only required when the battery is replaced or a new vehicle is purchased. To put this in perspective, consider the difference between events that squeeze the supply of oil and those that would squeeze the supply of lithium. A shutoff of oil has an almost immediate deleterious effect on transportation. A squeeze on the supply of lithium means that fewer new batteries can be produced. The batteries in existence will continue to function. Over a period of weeks or months a lessening in the efficiency of vehicles may be seen, but there will not be a fundamental disruption of the transportation sector.

There are also other potential sources of lithium. The Institute of Ocean Energy at Saga University in Japan has described the research being conducted by Japan and South Korea to enable harvesting of the 230 billion tons of lithium present in seawater.[84] Similarly, lithium may not be the one and only source of energy for EV batteries. The history of the EV battery shows a progression every few years to a different source material, from lead acid to nickel metal hydride and now to lithium-ion.[85] Development is constantly progressing on a variety of alternatives like aluminum air batteries. Some research has shown reason to believe that metal air batteries – where the cathode of the battery is air – could provide up to eleven times the energy density of the best lithium-ion batteries currently available.[86] Variety should be strongly encouraged, with appropriate nudges to help orient the market's focus towards resources available within the United States.[87]

WHY NOT NATURAL GAS?

Proponents of natural gas have touted it as the best alternate method of powering vehicles. There are a number of factors that make natural gas less appealing, at least at this point in time, than electric vehicles. First, to achieve equivalency to the range of today's gasoline powered vehicle, the natural gas must be in a liquefied form. The technical complications of using and widely distributing liquefied natural gas at refueling stations has roughly the same challenges as establishing a recharge infrastructure for electric vehicles. Except, of course, that home charging an electric vehicle overnight is no more complicated than plugging in a household dryer, so in effect a portion of the recharge infrastructure is already in place.

Second, using natural gas as the direct source to power vehicles locks the country into a single source replacement for oil. Though estimates suggest America's natural gas resources are quite large, it does not make sense to create an infrastructure that limits the country's flexibility, and not all estimates describe such robust stores.[88] What if estimates are wrong? What if the difficulty of extracting the natural gas proves greater than currently believed? What if the environmental affects are so ruinous that the country rejects some forms of extraction? What if we simply run out of this non-renewable source? Electric vehicles are a far more flexible option. The electricity to charge the batteries can come from any source of domestically supplied energy and still yield energy independence. If natural gas supplies are as bountiful and available as currently thought, natural gas could fuel the power plants that charge the electric vehicles. The great flexibility of the electric vehicle is that it can just as readily incorporate energy from coal, solar power, wind or any other source or combination of sources of energy.

FUNGIBLE NATURE OF THE OIL MARKET

Oil is part of a fungible world market.[89] That means that reducing oil to levels where the United States is capable of providing all its petroleum needs does not necessarily mean that the oil used in the United States will be 100 percent domestically produced. As it stands currently, the United States exports two million barrels of oil per day.[90] As US demand decreases with the roll out of EVs, the United States may begin to export more of its oil. As a fungible product, domestic oil prices will not necessarily be protected from the effects of international disruption of oil supplies. However, if the United States is capable of supplying its own oil requirements, then with proper planning it can ensure a relatively uninterrupted supply of oil regardless of international supply disruptions.

For example, in considering what first responders can do to offset the impact on their operational capabilities in the event of localized fuel shortages, it has been suggested that they should enter into firm contracts for fuel.[91] At present, firm contracts would not solve the problem for the country as a whole. If the world supply were disrupted, domestic sources could not fulfill the contracts, because there simply would not be enough fuel to go around. However, once energy independence is achieved, firm contracts with domestic suppliers could all be fulfilled. Those portions of the government or private sector that wish to hedge against supply disruptions could enter into futures contracts or other contractual arrangements to ensure a given supply at a given price.

UNINTENDED CONSEQUENCES

A REGRESSIVE EXCISE TAX

A tax is regressive when it causes lower-income families to pay a higher percentage of their income to the tax than higher-income families.[92] By adding a cost-per-gallon tax on gasoline, the financial effects would have a disproportionate impact on lower-income families. A simple way to lessen the impact would be in the form of a tax credit that is phased out over a particular income level. To avoid bureaucratic expenses, a national or regional average of both the price of gasoline and of the average gallons consumed can be used. The credit will not precisely match the expense incurred, but can be sufficiently harmonized to minimize the harm to lower-income families.

For example, in 2009, there were 8.8 million families living below the poverty line. For an idea of what that measures, for a family of four made up of two adults and two children the poverty line was $21,756.[93] For purposes of this example, assume that each of those families had one vehicle. As explained in Appendix 3, the average driver uses 490 gallons of gasoline a year. Assuming policymakers felt that all families below the poverty line should receive a rebate, then in a year where the gasoline excise tax was two dollars, 8.8 million families would receive a rebate of $980. That would be a total rebate to those families of $8.624 billion. If the rebate was phased out incrementally for families above the poverty line, even assuming another $8.624 billion was returned to those families, Table 2 shows that there would still be $13.3 billion left to use to promote recharge infrastructure growth ($30.55 billion left after EV rebates, minus $8.624 billion times two).

RISK OF INCREASING COST OF GOODS / INFLATION

Recent gasoline price increases have caused a corresponding increase in the cost of goods, and may diminish consumers' savings.[94] Rising gasoline prices can contribute to higher transportation costs, thereby raising expenses at all stages of production.[95] The course of action proposed herein minimizes that threat to an extent. In the first instance, the excise fee is only levied on motor fuel. This does not include diesel fuel, the form of oil used by the semi-trailer trucks that transport much of the goods across the nation. In 2009, in the United States, there was approximately 16,878,000 gallons of diesel fuel sold per day,[96] compared to approximately 49,798,000 gallons of retail unleaded gasoline sold per day.[97] Furthermore, the 49,798,000 gallons of retail gasoline subject to the excise tax is only about one sixth of the motor gasoline sales each day. The other categories of motor gasoline sold each day are DTW, rack, and bulk.[98] Therefore, governments and businesses that obtain their gasoline in bulk would not be subject to the excise tax under the implementation proposed herein. Since the price increase will not be on oil in general, but on a subset with less impact on commerce dependent on oil, the forces that would otherwise push the price of goods higher are diminished.

SIGNIFICANT DROP IN THE PRICE OF OIL

A switch from vehicles using motor gasoline to EVs may also be a victim of its own success. With sufficient numbers of EVs on the roads, the demand for gasoline will take a measurable decline. Should a significant number of other nations follow a similar course, the worldwide demand for gasoline may drop significantly, thereby reducing the price of oil. As the price of oil and therefore gasoline drops, the effect of the program may also decline. Determining an appropriate floor for the price of gasoline and automatically increasing the excise fee to maintain that floor could remedy this effect.

CONCLUSION

For forty years, every president of the United States has proclaimed the critical importance of energy independence. Time and again, the chains of foreign oil have shackled the decisions of American officials; yet, nothing has been done. No pragmatic, realistic step-by-step plan has been pursued to end this burden on the American people. America can break free of those artificially imposed restraints. There is a cost to achieving energy independence, and as shown herein, that cost is two to five dollars on each gallon of retail gasoline sold.

Two to five dollars per gallon of gasoline will bolster the nation's critical infrastructure by expanding and upgrading the production and transmission of electricity. Two to five dollars per gallon of gasoline will bring an end to funding the very terrorists we then spend billions trying to defeat. Two to five dollars per gallon of gasoline will bring an end to tortured national policy decisions and the otherwise nonsensical strategic military decisions. With conviction, determination, and selfless leadership – and two to five dollars per gallon of gasoline – the United States can achieve energy independence in a few short years.

ABOUT THE AUTHOR

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Appendix 1 – Premise and Development of the Model

PREMISE

The model developed by Jeihani and Sibdari provides the conceptual basis for development of a predictive model.[99] They utilize a binary vehicle choice model in order to provide a quantitative framework to assess the various factors that might influence consumer transition choices. In their work, the relative probability, *P,* of choosing one type of car, denoted by the subscript *e*, to another type of car, denoted by the subscript *c*, for any given household, *i*, is captured by the following formula:

$$\frac{P_{ie}}{P_{ic}} = \left(e^{A_e + B_e K_i + CL_e}\right) \Big/ \left(e^{A_c + B_c K_i + CL_c}\right) \tag{4}$$

Where ***A***, ***B***, and ***C*** are constants, ***K*** represents the characteristics of the buyer, and ***L*** represents the characteristics of the car. The constant ***A*** in Equation 4 can be related to the type of car that, in effect, represents a bias that a consumer might have towards a vehicle. For instance, range anxiety might well make a consumer wary of an EV and this may be captured in the constant ***A***, driving down the probability of choosing an electric car. Likewise, styling, or fuel economy might well have an influence, as could environmental considerations.

The constant ***B*** weights the characteristics of the buyer towards certain car types, while the constant ***C*** weights the vehicle characteristics.

The constant K_i captures household characteristics including both employment status and income while ***L*** captures the initial vehicle cost and the cost per mile for vehicle locomotion.

Though Jeihani and Sibdari used only one standalone constant, ***A***, one could imagine including a great many such constants in an attempt to capture a greater range of consumer biases. One could imagine developing an input to the car characteristics that would include a national defense cost per vehicle, where that cost reflects the investment made by the DoD to maintain shipping lanes, providing support to governments that are critical for oil imports, etc. Those costs would then appear as a price per vehicle, which could be denoted as a national defense cost, ***ND***, that is weighted by the fuel efficiency of a particular vehicle. Likewise, one could attempt to capture the economic costs of the oil trade deficit to the nation, the approximately one billion dollar daily deficit. Those costs could also appear as a price per vehicle and, denoted as a trade imbalance cost, ***TI***, would also be weighted by a vehicle's fuel efficiency.

Notably, Jeihani and Sibdari did not adjust for inflation when analyzing historical data they collected. Adjusting the historical data used herein was considered; however, the model is designed to reflect people's choices at a fixed point in time. When consumers go to purchase a vehicle they are considering what the price of gasoline currently is, what their income currently is, etc. They may also be considering what they expect the value of those items to be in the future, but they are concerned with absolute amounts. The model shows fixed choices from moment to moment. If high levels of inflation were anticipated going forward, that could influence consumer purchasing decisions in general (e.g., buy assets rather than hold onto money), but none of the purchase periods analyzed in this paper took place during periods where inflation was particularly high. From 1991 through 2010, no calendar year saw inflation greater than 4.2 percent.[100] In fact, adjusting for inflation would flatten the changes in the economic data. Rather than reflecting reality, it would actually skew the reality that the consumer faced at the time of their purchase decision.

DEVELOPMENT OF PREDICTIVE MODEL

Assuming a linear relationship between the change in the number of hybrid vehicles sold in any year, ΔShy, and any of the influencing parameters, as was the basis for the Jehani and Sibdari model, the number of hybrid vehicles sold in any year, S_{hy}, can be modeled and the model be used to project future sales. Future sales depends on many economic and perception factors. Among the national economic parameters the Jehani and Sibdari model included were: the median household income I, in the modeled year, the unemployment level U, and the price of gasoline G. For the vehicular economic parameters the model included the gas mileage, M_{hy}, as represented by the number of miles the vehicle can travel per gallon of gasoline and the hybrid vehicle price P_{hy}. Finally, all parameters associated with customer perception such as comfort, reliability, social appearance, environmental stewardship, etc. were lumped into a single coefficient A_{hy}. In essence, the coefficient represents the total combination of factors the consumer is considering that have not been specifically accounted for elsewhere in the equation.

One way to look at the effect of policy choices is by examining the fraction of new sales, $\Delta Sannual$, in any year relative to the total sales S_{annual}. This fraction is the *sales strain*, and is represented by:

$$\varepsilon_{sales} = \frac{\Delta S_{annual}}{S_{annual}} \tag{5}$$

A linear relationship between the sales strain and any influencing parameter is the simplest approach to modeling the sales figures. For example, the effect of household income, I, on the sales strain of hybrid vehicles when isolated from other parameters that influence sales, would be:

$$\frac{\Delta S^{I}_{hy}}{S_{hy}} = B_{hy} I \tag{6}$$

Where $\Delta SIhy$ is the change in the sales figures of hybrid vehicles due to the change in household income. As the overall sales figure S_{hy} increases so does the change in that figure due changes in any parameter such as I. The fundamental assumption in Equation (6) is that $\Delta SIhy$ varies linearly both with I and S_{hy}. The coefficient B_{hy} is a proportionality factor to be derived empirically using historic data.

Dependences similar to Equation 6 for the effects of U, CPM_{hy} and P_{hy} on the sales figures can be derived to provide $\Delta S^{U}{}_{hy}$, $\Delta S^{CPMhy}{}_{hy}$ and $\Delta S^{Phy}{}_{hy}$, which are the change in the sales figures when each of the representative parameters is isolated from the others. The proportionality coefficients to be assigned to these dependences are C_{hy}, D_{hy} and E_{hy} respectively. All three coefficients need to be determined empirically using historic data.

The combined effect of all these parameters on the annual sales figures of hybrid vehicles can be obtained by superposition or a simple addition:

$$\Delta S_{hy} = (B_{hy} I + C_{hy} U + D_{hy} CPM_{hy} + E_{hy} P_{hy}) S_{hy} \Delta t \tag{7}$$

Where Δt is the period over which sales occur. Since this model looks only at year-over-year sales, $\Delta t=1$ and can be dropped for simplicity from future derivations. Equation 7 can now be integrated for S_{hy}, then adding A_{hy}, the integration coefficient, which is described above, to provide:

$$S_{hy} = \exp(A_{hy} + B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy}) \quad (8)$$

Notably, this approach results in an exponential relationship between sales volume and income, unemployment, fuel costs and purchase price. Taking the natural log of this equation yields:

$$\ln(S_{hy}) = A_{hy} + B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy} \quad (1)$$

Note that Equation 1 is the immediate result of the integration of Equation 7. However, Equation 8 was shown first to show the relationship between this derivation and the model presented by Jehani and Sibdari. This expresses the relationship between the various parameters that are likely to influence the sales volume and the sales volume itself. Actual numerical values can be determined after obtaining the values of the coefficients $\boldsymbol{B_{hy}}$, $\boldsymbol{C_{hy}}$, $\boldsymbol{D_{hy}}$ and $\boldsymbol{E_{hy}}$, with an offset factor given by $\boldsymbol{A_{hy}}$. To derive the five empirical coefficients of Equation (1), one needs to obtain historical data concerning household income, unemployment, price of gasoline, gas mileage and car prices for at least five years. To the extent data is available, a similar equation can be derived for each vehicle model or model group.

In order to check the methodology against a more traditional vehicle class, a similar process was undertaken for the SUV class of vehicles. The equation representing the sales figures of SUV vehicles was derived similarly to Equation (1) to yield:

$$\ln(S_{SUV}) = A_{SUV} + B_{SUV}I + C_{SUV}U + D_{SUV}CPM_{SUV} + E_{SUV}P_{SUV} \quad (2)$$

Again, the coefficients A_{SUV}, B_{SUV}, C_{SUV}, D_{SUV}, and E_{SUV} are empirical coefficients. Similar to those of the hybrid vehicle, they are to be derived using at least five years of historical data.

Unlike SUVs and hybrid vehicles, the available historic data on the sales volume of EVs is inconsistent with extremely small numbers. Consequently, those figures were not considered reliable for the purpose of projecting future sales of EVs and the potential response to market-changing policies. Instead, the coefficients derived for the hybrid vehicle using historical data were retained as proxies for the EV sales volume model. It is reasonable to presume that factors influencing people's decision to purchase hybrid vehicles will similarly influence their decision to purchase EVs. As with hybrids, it is likely that the first consumers to purchase EVs do so for a myriad of concerns (e.g., environmental, status). As sales of hybrids grew, economic forces such as declining vehicle price and increase in gasoline would have become the dominant market drivers. The same is presumed to be true with EVs. Therefore, only one parameter from the hybrid model Equation 1 was replaced. CPM_{hy} was replaced with PM_{EV}, which was derived using the representative cost of electricity per *kWhr* and the number of miles driven by the EV per *kWhr*. Accordingly, the model describing the sales volume of electric vehicle is represented by:

$$\ln(S_{EV}) = A_{hy} + (B_{hy} \times I) + (C_{hy} \times U) + (D_{hy} \times PM_{EV}) + (E_{hy} \times P_{EV}) \quad (3)$$

As previously explained:

- $\boldsymbol{A_{hy}}$ = all consumer preferences and choice factors not specifically addressed elsewhere in the equation,
- $\boldsymbol{S_{EV}}$ = the sales volume of electric vehicles,
- $\boldsymbol{B_{hy}}$ = weight factor for societal annual income,
- $\boldsymbol{I}$ = societal average annual income,
- $\boldsymbol{C_{hy}}$ = weight factor for unemployment,
- $\boldsymbol{U}$ = total unemployment,

- D_{hy} = cost of locomotion factor,
- PM_{EV} = price per mile for locomotion,
- E_{hy} = weight factor for price of hybrid,
- P_{EV} = price of hybrid vehicle

Appendix 2 – Deriving the Constants with Historical Data

To derive the five empirical coefficients of Equation 1, A_{hy}. B_{hy}, C_{hy}, D_{hy} and E_{hy}, it is necessary to obtain historical data concerning household income, unemployment, price of gasoline, gas mileage, and car prices for at least five years. To the extent data is available, a similar equation can be derived for each vehicle model or model group. More than five years of data was available for each vehicle group. With only five years available, the five coefficients of each model (Equations 1 and 2) could be determined by solving five algebraic equations. With additional years available, the coefficients could be determined by fitting $ln(S_{hy})$ and $ln(S_{SUV})$, as determined by Equations 1 and 2 respectively, to the sales volumes as shown in Table 3, through adjustment of the coefficients of these equations until the overlap between the historic data and the analytic data is optimized.

Historical Data for SUVs and Hybrid Vehicles

Year	Income	Gas Price	SUV Sales	Hybrid Sales	Unemployment	SUV Price	Hybrid Price	Hybrid MPG	SUV MPG
	in US$ *1	$/gallon *2	*3	*4	*5	in US$ *6	in US$*7	*8	*9
‘91	30,126	1.10	1,095,000		8,628,000	15,747			16
‘92	30,636	1.09	1,003,000		9,613,000	16,692			16
‘93	31,241	1.07	1,311,000		8,940,000	17,550			17
‘94	32,264	1.07	1,623,000		7,996,000	18,860			16
‘95	34,076	1.10	1,816,000		7,404,000	22,305			16
‘96	35,492	1.19	1,890,000		7,236,000	21,170			16
‘97	37,005	1.19	2,450,000		6,739,000	21,485			16
‘98	38,885	1.02	2,581,000		6,210,000	21,560			16
‘99	40,696	1.12	2,831,000		5,880,000	22,070			16
’00	41,990	1.46	3,143,000	9,350	5,692,000	23,480	19,995	41	16
’01	42,228	1.38	3,450,000	20,282	6,801,000	25,210	19,995	41	17
’02	42,409	1.31	4,191,000	36,035	8,378,000	24,585	19,995	41	16
’03	43,318	1.52	4,118,000	47,600	8,774,000	26,285	19,995	41	15
’04	44,334	1.81	4,713,000	84,199	8,149,000	26,600	20,295	46	15
’05	46,326	2.24	4,084,000	209,711	7,591,000	27,165	21,275	46	16
’06	48,201	2.53	3,757,000	252,636	7,001,000	26,530	16,213*	46	16
’07	50,233	2.70	4,231,000	352,274	7,078,000	25,370	20,601*	46	16
’08	50,303	3.26	3,987,000	312,386	8,924,000	26,495	21,500	46	16
’09	49,777	2.36	2,296,000	290,271	14,265,000	28,470	22,000	46	16
’10	50,000	2.79	3,000,000	274,210	14,825,000	29,280	22,800	50	17

* Includes weighted average of rebate that was offered during some or all of the year.*10

*1 US Census Bureau, *Median Household Income by State: 1984 to 2009*, http://www.census.gov/hhes/www/income/data/historical/household/H08_2009.xls (only applicable to years 1991–2009. Year 2010 is an estimate).

*2 Jeihani and Sibdari, “The Impact of Gas Price Trends;” EIA, *Data I: All Grades Conventional EIA,* http://www.eia.gov/oog/ftparea/wogirs/xls/pswrgvwag.xls

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Figures 4 and 5 graphically represent the outcome of the optimal fit between the actual sales figures and the modeled figures. Optimization was achieved by minimization of the root mean square of the differences between actual and modeled figures. Table 1 shows the coefficients of the two models as derived through this analysis.

Figures 4 and 5 show that, after optimization of the coefficient, Equations 1 and 2 yielded generally good approximations of the actual sales data.

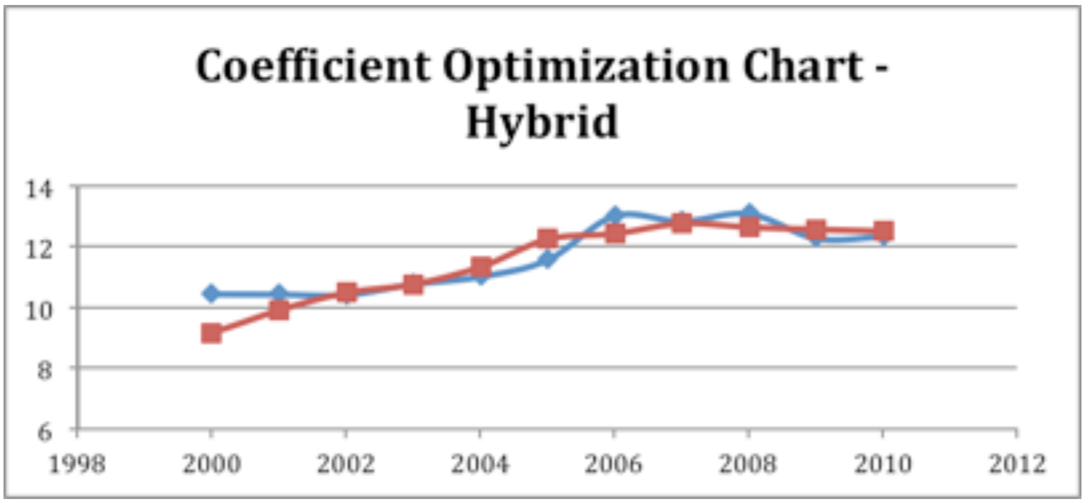

Figure 4. Comparison of the Variation of ln(Shy) with Year of Sale as Derived by Model (blue) with Historic Data (red)

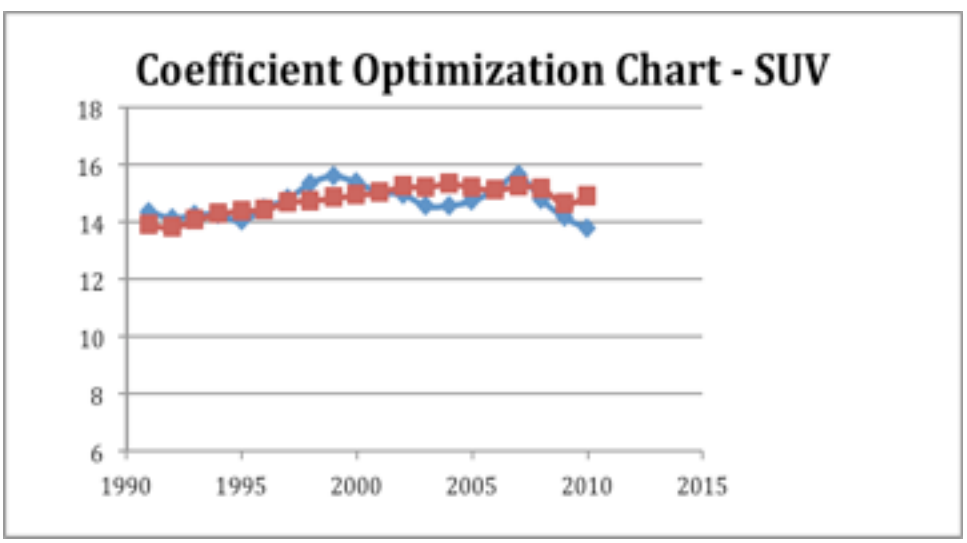

Figure 5. Comparison of the Variation of $ln(S_{SUV})$ with Year of Sale as Derived by Model (blue) with Historic Data (red)

Although the match between the actual and modeled sales volume is good, its application is limited. One should note that the two models (Equations 1 and 2) are independent of each other (i.e., as modeled, the sales of one group does not affect the sales of the other group (non-cannibalization)). Such independence is justified when the sales volume of hybrids or EVs is small relative to the total vehicle market; however, when the sales of one group overwhelm the market, the model must be reexamined. This failure of the model would occur at some point as the market responds so favorably to government policies that the use of internal combustion engines is almost completely abandoned in favor of EVs. Lacking a detailed analysis of the points of failure, it is assumed herein that the model should be used primarily as the predictor of trends (i.e., significant increase or decrease in the sales of certain vehicle groups, rather than the predictor of actual sales volumes).

Table 1. Coefficients of the Sales Volume Models (Eqns. 1 and 2) of Hybrid and SUV Vehicles as Derived by Fitting These Equations to Historical Sales Data

	A	***B***	***C***	***D***	***E***
Hybrid/electric	3.6	$2.16*10^{-4}$	$-1*10^{-13}$	31.1	$-1.66*10^{-4}$
SUV	13.36	$2.01*10^{-4}$	$-1.4*10^{-7}$	-10.8	$-1.97*10^{-4}$

Appendix 3 – Future Assumptions Used To Predict EV Sales

1. The gasoline excise tax is $2 per gallon in 2012, $4 the following year, and $5 in 2014 through 2018.

2. The EV price for 2011 uses the Manufacturer's Suggested Retail Price (MSRP) of the entry-level 2012 model year Nissan Leaf, $35,200 (Nissan) and a three percent annual decrease in price thereafter.[101] The expected MSRP does not include the government subsidy described below. This decrease is a conservative number considering the anticipated rapid change in volume, which will create economies of scale. However, this reflects a similar conservative determination made by Brooker, that the price of EV batteries will decrease by three percent per year.[102]

3. Though soon after publication of this work, actual 2011 sales volumes may be available for EVs, the 2011 sales volume used here was obtained from the predictive model. The 2010 EV sales were estimated as 10 percent of the hybrid vehicles sales volume of 274,210.[103]

4. The 2011 total sales cost of the EV reduces the MSRP described above by the $7,500 tax rebate that has historically been available for purchase of an all-electric vehicle. Beginning in 2012 and thereafter, the total cost of the EV begins with the MSRP price described above and reduces it by $15,000, the amount of tax rebate used for this particular predictive analysis.

5. Beginning in 2008 with an EV cost per mile of three cents,[104] the model assumes a three percent annual increase in the price per mile for the EV. This presumes the cost of electricity will increase with increased demand, though this could be offset if batteries become more efficient at recharging or otherwise become more efficient.

6. Gallons of gas sold per year begins with the actual gallons sold at retail in 2009, 18,176,124,000 gallons,[105] leaves the amount constant for 2010 and 2011, and assumes a five percent decrease in 2012, the first year a gasoline tax is imposed in this model. The five percent decrease assumes that imposition of the two-dollar tax will induce a decrease in the demand for gasoline. Each year beyond 2012, the decrease in gasoline sales is determined by multiplying the number of EVs sold the prior year by 490 gallons. The average driver drives 13,476 miles per year.[106] Current CAFE standards provide for an average vehicle gas mileage of 27.5 mpg.[107] Dividing average miles driven per year by average gas mileage provides an estimate of the gallons of gasoline used by each vehicle per year. Assuming that each EV sold the previous year will reduce sales of gasoline-powered vehicles by one that equates to 490 fewer gallons of gasoline sold in the current year for each EV sold the prior year. In fact, the decrease is likely higher due to drivers who purchase EVs throughout the year and other factors, but this is the estimate used in the model. A further benefit of this assumption is that it indirectly introduces a coupling between the sales volume of EVs and sales of other vehicles. It assumes that sales of EVs will cannibalize sales of all other vehicles; however, this is an incomplete and very partial coupling that does not overcome the weakness of the model as indicated above.

7. The unemployment factor begins in 2010 with the published total unemployment figure of 14,825,000,[108] and assumes a one percent reduction each year.

8. The income factor uses the 2009 median annual income of $49,777,[109] and assumes a one percent increase each year.

9. The base price of gasoline, prior to the introduction of the excise tax, begins with an average price of three dollars per gallon in 2011 and increases the price by five percent per year. That assumes that the world oil market will continue to see an increase in demand even as demand in the United States declines.

[1] Not to be confused with the environmental security scientific literature movement which looks at environmental problems like water shortages, climate change, and growing demand for other natural resources and examines how those environmental issues might affect national or world security. See for example Jeffery Boutwell, Thomas Homer-Dixon, and George Rathiens, "Environmental Change and Violent Conflict," *Warfare Ecology* (2011), http://dx.doi.org/10.1007/978-94-007-1214-0_3.

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