Plug-In Electric Vehicles: Economic Impacts and Employment Growth

PRELIMINARY FINAL REPORT

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EXECUTIVE SUMMARY

Many studies over the past decade have estimated the economic benefits of plug-in electric vehicles (PEVs). These studies typically examine future market penetration scenarios where PEVs displace conventional petroleum-fueled vehicles. Significant macroeconomic benefits can occur from this petroleum displacement. This report provides a review of these studies and presents details on the macroeconomic impacts of electric vehicles, with emphasis on light-duty vehicles (LDVs).

In summary, the narrative from the literature proceeds as follows:

1. *Plug-in electric vehicles (PEVs) reduce petroleum consumption and lower fuel costs, putting money back into drivers' pockets and household budgets*. Households spend up to 25% of their budgets on transportation, much of which is due to gasoline and other petroleum fuel costs. Compared to conventional vehicles, fuel cost savings for PEV drivers are estimated at hundreds to thousands of dollars per vehicle annually. When drivers save money on fuel costs, this leaves more in household budgets to be spent on everything from food to furnishings, haircuts to healthcare, and vacation to education—allowing for necessities and improved quality of life.

2. *The injection of petroleum fuel savings towards other goods and services in the local economy creates new jobs and boosts economic output (typically measured as gross domestic product, or GDP)*. The difference in employment and economic output per dollar spent in other sectors can generate 16 times as many jobs per dollar spent compared to the petroleum sector. Household savings can add up to substantial region-wide savings. Total fuel savings due to large-scale PEV use have been estimated at the national, state, and regional level. Depending upon market penetration assumptions, use of PEVs leads to fuel savings that range from hundreds of millions of dollars to billions of dollars depending on the geographic scope (e.g., local, state-wide, national). These fuel cost savings can be used by consumers to purchase other goods and services in local and regional economies.

3. *Shifts in spending due to PEV use generates economic activity and job production through incremental increases in vehicle costs, and increased demand in the sectors producing vehicles, vehicle components, and charging infrastructure*. Many studies have estimated total cost of ownership of PEVs to be lower than that of conventional vehicles, meaning that even with increased vehicle costs, drivers and households are still left with more money in their pockets and budgets to spend elsewhere in the

economy. A dollar spent on automobile manufacturing (and in sectors anticipated to produce PEV components) generates far more jobs than a dollar spent on petroleum fuel.

When accounting for the increased incremental costs of PEVs, a recent nationwide study estimates that, over the 2015 to 2040 period, large-scale PEV use is anticipated to increase economic output by up to $20 billion annually, generate a net of up to 147,000 jobs, and save households hundreds of dollars per year in lower fuel costs (billions of dollars collectively).

4. *Large-scale PEV use has the potential to reduce electricity rates to all electric utility customers.* Increased use of PEVs will increase utility revenues. Utilities in the U.S. typically operate far below the peak capacity of power generation equipment and infrastructure (i.e. power plants and transmission systems), so electricity rates per kWh are typically higher than they could be if the available capacity were not underused. Large-scale use of PEVs—particularly if charged at off-peak times—could increase electricity revenue relative to infrastructure capacity, potentially leading to reduced rates for all electric utility customers. For example, a recent set of analyses evaluating future scenarios of PEV market penetration in the Northeast states estimated the net value of these potential electricity rate savings at ~$4 to $24 billion per state by 2050. Net combined benefits in the five states studied could total over $200 billion by 2050, $155 billion of which would accrue to utility customers and PEV owners in the form of savings on utility bills and fuel costs.

5. *Additional economic benefits of large-scale PEV use include mitigating negative economic losses due to oil price shocks; generating additional revenue for vehicle owners through vehicle-to-grid systems; providing power quality and stabilization services; reducing pollution and its associated private and social costs; and facilitating integration of alternative and distributed energy sources*. Although these benefits are not as well quantified in the literature at a macroeconomic scale, they are real and expected to be significant under a future transportation system that includes a large population of PEVs.

Some governance bodies have implemented policies aimed at incentivizing PEV use. Although oftentimes these policies are driven by environmental or energy security goals, the literature has demonstrated that such policies also make smart economics. State-level policies aimed at incentivizing PEV use have been estimated to increase economic output by tens of millions of dollars per state. Conversely, the elimination of such policies has been estimated to result in the loss of billions of dollars in economic output and thousands of jobs. The same is true at the national level. For example, one study evaluated a suite of policies to incentivize PEVs and estimated an overall employment impact of approximately two million new jobs by 2020.

This report provides greater detail on key studies now informing the debate on the macroeconomic benefits of PEV use in the US. In summary, this literature paints a picture that is highly positive. The transition from petroleum fuel to electricity in the transportation sector will undoubtedly lead to economic activity and job growth, and such benefits should be part of any assessment that evaluates the costs and benefits of policies aimed at incentivizing PEV use.

1 BACKGROUND AND INTRODUCTION

1.1 PETROLEUM FUEL AND LOCAL AND REGIONAL ECONOMIES

American households typically spend 20% of their budgets on transportation, with households in vehicle-dependent areas tending to spend up to 25% [1]. Gasoline fuel is one of the largest transportation expenses for families and businesses. In 2016, over 143 billion gallons of gasoline were consumed in the U.S., at a cost of over $300 billion.

Money spent on gasoline and other petroleum fuel tends to leave local and regional economies. According to U.S. Energy Information Administration (EIA) estimates, about 80% of petroleum expenditures immediately leave the local economy [2, 3]. Even with the increased petroleum production seen in the U.S. over the past few years, the nation still imports about 10 million barrels of oil per day from about 70 countries [4]. To put this quantity in perspective, U.S. gasoline consumption is 9.3 million barrels per day [5][1]. Much of the money spent on petroleum "leaks" out to petroleum-producing nations abroad [1]. At the local or regional level, this effect is even more pronounced, as petroleum is produced and refined outside of these regions, and refined products are transported in by outside companies. In Ohio, for instance, an estimated 84% of gasoline expenditures leave the state [6], and the level of petroleum production in Arizona meets only 0.1% of state petroleum demand [7].

An average household spends between $2,000-$2,500 per year on gasoline for transportation, or just under 5% of annual household budgets [1, 8]. This is money that cannot be spent on other goods and services, from food to furnishings, vacation to education, haircuts to healthcare. Money saved on petroleum fuel, therefore, can be redirected to these and other non-petroleum sectors in local and regional economies, generating output and jobs. Due to imports and also the nature of the petroleum industry, few jobs are generated for every dollar spent on petroleum fuel—especially when compared to the jobs that could be generated if spent on other goods and services. In California, it is estimated that 16 times the number of jobs are generated for every dollar spent in non-petroleum sectors, compared to spending that dollar on oil and gas [6].

Figure 1. Relative Job Intensity of Sectors in the California Economy, per Dollar Spent [9]

[1] In addition to gasoline, petroleum products consumed in the United States include diesel and jet fuel, and heating oil, among others; total U.S. daily petroleum consumption averaged about 19.7 million barrels per day in 2016.

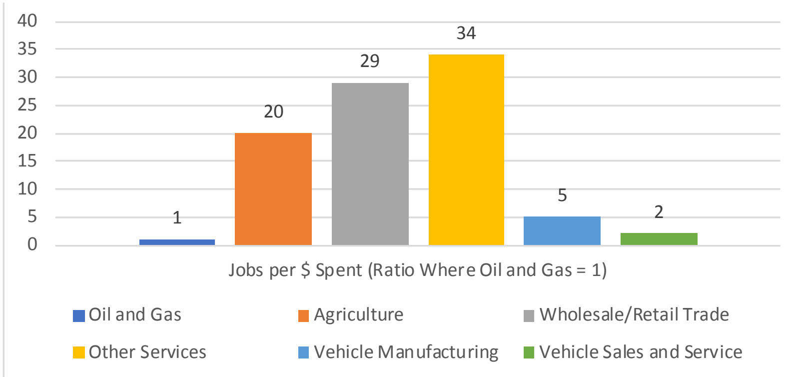


Figure 1 shows that the number of jobs supported per dollar spent can vary considerably depending on the economic sector, with agriculture, wholesale/retail, and general services demonstrating much higher relative job intensity compared to the oil and gas sectors.

1.1 PLUG-IN ELECTRIC VEHICLES, FUEL COST SAVINGS, AND THE ECONOMY

Plug-in electric vehicles (PEVs) are powered by electricity. In contrast to petroleum, the vast majority of electricity consumed in the United States is produced domestically [1]. Additionally, PEVs are far more efficient—so PEV fuel costs are only 1/4 to 1/2 that of conventional internal combustion engine vehicles (ICEVs). Fuel cost savings can add up to thousands of dollars annually for a typical household [10]. In addition, PEVs have fewer moving parts compared to ICEVs, so on average, maintenance costs are expected to be lower as well [11-13]—decreasing total cost of operation further, and augmenting household savings.

These savings can be spent by households on any number of goods or services that provide necessities, enrichment, or improved quality of life. For instance, a recent analysis estimated that in Florida, households using PEVs would save a net $1,700 per year on fuel and maintenance, most of which would be spent on food, household furnishings, clothing, and entertainment [14, 15].

This household spending can increase output and employment in these and other sectors. For example, the above-mentioned Florida study estimated that a PEV-owning household would increase spending for food by ~$770 annually compared to an ICEV-owning household [14, 15]. That collective spending would increase demand in the sectors that feed us—from markets, to restaurants, to farms. Employment would be generated in these businesses, and the employees would then spend their earnings in the local economy on a number of other goods and services in the local economy. In this way, household fuel cost savings can "multiply" through the local economy, generating growth in economic output and jobs.

In addition to concerns of petroleum expenses leaking out of the local economy, oil prices are volatile. When oil price spikes occur, the consequences on national and regional economies can be disastrous, as households have even less disposable income to spend on other goods and services. Large-scale use of PEVs may mitigate the effects of oil price shocks due to the improved efficiencies of PEVs and the greater stability of electricity markets. Additionally, the widespread use of PEVs may actually decrease electricity costs for all electric utility customers; provide power quality services to the electric utility sector; and generate environmental benefits that reduce societal costs due to pollution from petroleum-fueled vehicles, to name a few.

This report explores the literature related to these topics. We focus on the transition to PEVs in the U.S. light-duty vehicle (LDV) transportation sector, and the macroeconomic impacts associated with the displacement of petroleum fuel with electricity in this sector.[2] The report is structured consistent with the typical analytical flow of these types of studies. Section 2 of the report discusses the petroleum displacement and fuel cost savings associated with PEV market penetration. Section 3 then explores the macroeconomic impacts of these fuels savings, with further refinement by geographic scope (e.g., local, state, national). Section 4 discusses macroeconomic elements associated with capital cost expenditures for PEVs, and Sections 5 and 6 present emerging research related to the impact of PEVs on utility costs and other ancillary benefits, respectively. Section 7 introduces the policy aspects of this discussion by presenting policy analysis literature to inform policymaking. Finally, Section 8 concludes the report.

2 Petroleum Displacement and Fuel Cost Savings

Petroleum displacement is beneficial for most local and regional economies, as the vast majority of expenditures spent on petroleum "leaks" out of local economies, transferring wealth out of the pockets of community residents. The leakage of petroleum expenditures outside a local economy creates one of the key economic benefits of electric vehicles: reducing the use of petroleum allows households and businesses to reduce fuel expenditures, which can then be spent in other sectors of the economy.

Lidicker et al. (2010) examined the economics of electric vehicles in various regions of the United States, including California, several states in the Northeast and Midwest, Hawaii, Colorado, Texas, and Florida. To estimate annual fuel savings, the study used fuel prices from the highly volatile periods of July 2008, January 2009, and July 2009; when gasoline prices ranged between a high of $4.54/gallon in Sacramento in July 2008 and a low of $1.73/gallon in Boston in January 2009. The study found that PEVs typically save hundreds of dollars in annual fuel costs, ranging from $100 to $1,800 per vehicle; the highest fuel cost savings were found in the Midwest [10].

A series of studies of the Southwest U.S. estimated potential petroleum displacement from PEV use in Arizona, Nevada, New Mexico, and parts of Utah, assuming two electric vehicle market penetration scenarios: (1) an EIA baseline scenario, and (2) a PEV-scenario, where PEVs comprised 5% of the on-road fleet by 2030 (8% by 2035 for Utah). The studies estimated average annual fuel savings per PEV vehicle, combined fuel cost savings for the entire state for the years 2020 and 2030, and job creation potential in 2030 or 2035 [7, 16-18]. Fuel savings for plug-in hybrid electric vehicles (PHEVs) ranged from $350 to $1,000 per year, while savings for battery electric vehicles (BEV) reached $650 to $1,500. In aggregate, the estimated savings realized by PEV drivers result in combined statewide annual fuel cost savings of $10 to $144 million by 2020 and $46 to $490 million by 2030, for each state.

[2] Although we touch upon some of the ancillary economic benefits of PEVs – such as those mentioned previously – the literature is relatively light on these topics when viewed through a macroeconomic lens.

Several additional studies took a similar approach to estimate fuel savings per vehicle, per household, and/or per region; as these studies also incorporate input-output analysis to estimate macroeconomic impacts of these fuel savings, the findings are presented in the following section.

Table 1. Results from analyses estimating fuel savings impacts of PEV market penetration in the Southwest US.

Region	Annual Fuel Savings Per Vehicle		Statewide Annual Fuel Cost Savings ($M)			
			2020		2030	
	PHEV	BEV	EIA Scenario	5% by 2030 Scenario	EIA Scenario	5% by 2030 Scenario
Arizona	$700 - $1,000	$1,000 - $1,450	$16 - $21	$106 - $144	$75 - $104	$350 - $490
Nevada	$600 - $900	$1,000 - $1,300	$5 - $7	$10- $24	$18 - $24	$53 - $138
New Mexico	$850 - $1,200	$1,150 - $1,600	$7 - $9	$41 - $57	$33 - $138	$46 - $200
Utah[3]	$345	$646	$29	$43	N/A	N/A

3 Macroeconomic Impacts of Fuel Cost Savings

A number of studies over the past decade have estimated the macroeconomic benefits of PEVs. These studies typically examine future market penetration scenarios where PEVs displace conventional petroleum-fueled vehicles. Such studies, which have been conducted at the regional, state, and national level, have estimated the fuel cost savings associated with PEV use as well as the resulting macroeconomic impacts in terms of increased gross domestic product (GDP) and jobs. To estimate these impacts, many studies use an approach called input-output analysis, as described below.

3.1 Input-Output Methodology in a PEV Context

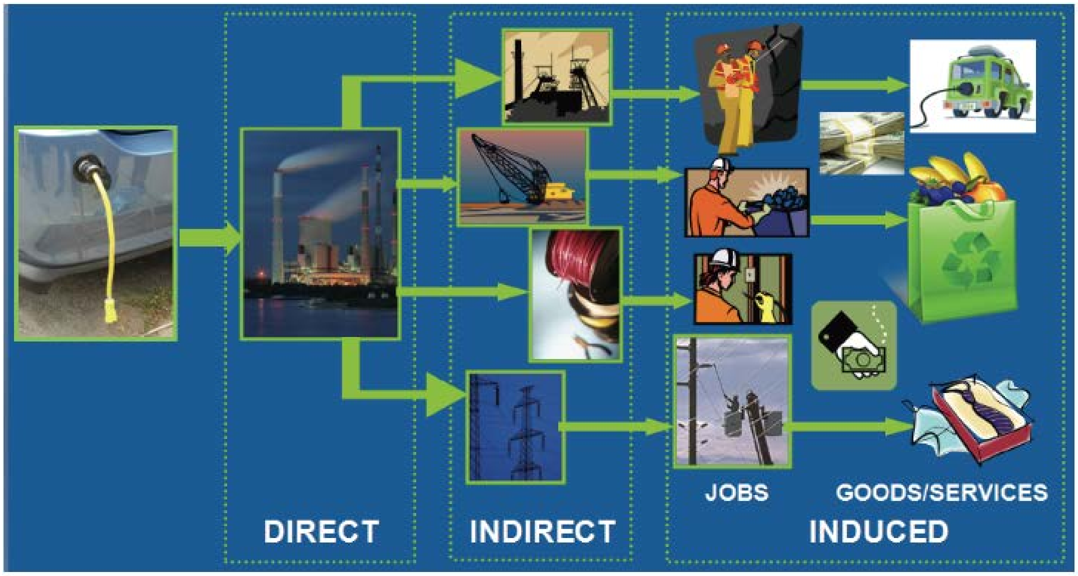
As region-wide fuel savings from PEVs are redirected to the purchase of other goods and services in other sectors of the economy, the new spending can create jobs and increase economic activity. Several studies have estimated the net impacts of shifts in spending from petroleum fuel to electricity as a transportation fuel—and the spending of these household savings in other sectors—using a method called *input-output analysis,* which models how dollars flow throughout the economy.

In such analyses, the direct impacts of shifts in spending from petroleum to electricity as a fuel are captured, as are the shifts of household expenditures due to the fuel cost savings mentioned in the previous section. Statistical data from national accounting systems—which capture production-consumption linkages in the economy—are used to estimate *indirect* and *induced* demand for additional goods, services, and jobs from other sectors in response to the direct shifts in demand (Figure 2).

For instance, increased demand for electricity will create *indirect* demand for fuel purchases at the power plant, which in turn trigger increased demand for other inputs such as natural-gas drilling services, fuel delivery, power-generation or fuel-extraction equipment, and related employment to fill those demands. The employees in these sectors will then use their earnings on any number of goods and services in the economy—from food, to clothing, to education—which will in turn increase demand for employment in these sectors. These latter effects are considered *induced* economic impacts. This section presents studies that have estimated the macroeconomic impacts of fuel shifting due large-scale PEV use at the regional, state, and national level.

[3] In Utah, the evaluated higher market-penetration scenario was 8% PEVs by 2035 (as opposed to 5% by 2030 in other states).

Figure 2. Example direct, indirect, and induced impacts of increased electricity demand in the transportation sector.



3.2 State- And Regional-Level Studies

3.2.1 Six Cities Study

In 2007, the Electric Power Research Institute (EPRI) commissioned a study to estimate the macroeconomic impacts of electrification of the light-duty fleet in six urban cities (and their surrounding counties) across the United States: Austin, Texas; Birmingham, Alabama; Cleveland Ohio; Kansas City, Missouri; Newark, New Jersey; and, Sacramento, California [19].

Exploring a 2030 scenario where 40% of all light-duty vehicles in these regions were PEVs, and 16-20% of miles driven were all-electric, Winebrake and Green (2007) estimated that gasoline consumption would be reduced by 160 to 290 million gallons per region annually (depending upon the region), and electric vehicle use would result in total regional fuel cost savings of $190 to $720 million annually [19]. Assuming then-current fuel prices (~$2.60 to $3.00/gallon, regionally—the case most representative of current 2016 fuel prices), the study estimated that the shifts in fuel expenditures would increase annual economic output by $110 million to $590 million per region while increasing employment by 380 to 3,730 job-years per region (Table 2) [19]. Results varied according to the economic structure and fuel prices within each region (e.g., Cleveland and Kansas City have a similar amount of gasoline displacement, but the employment impacts in these regions varies by more than 30%); however, in almost all cases[4], net economic output and employment impacts of fuel shifts were positive.

[4] The study estimated macroeconomic impacts for several fuel price cases; estimates reported here are for the 2007 fuel price case, which assumed fuel prices mirroring current (2016 average) fuel prices. The study also evaluated cases for 2004 fuel prices, and high and low oil price projections. Slightly negative economic impacts were estimated for the low oil price case (which assumed fuel prices far below those seen today and in recent years).

Table 2. Results from Winebrake and Green (2007), showing fuel demand shifts and estimated macroeconomic impacts of light duty vehicle PEV use in Six U.S. Cities.

Region	Fuel Demand Shifts (Year 2030)			Macroeconomic Impacts (2030) (Case II 2007 Fuel Price Range)	
	Gasoline & Diesel Displaced (M gal/year)	Increased Electricity Demand (GWh/year)	Household Fuel Cost Savings (Range) ($M/year)	Output $M/year	Employment Job-years
Cleveland	280	2,100	$330 – $680	$380 - $590	3,670 - 3,730
Austin	200	1,450	$200 – $430	$110 - $250	380 - 410
Birmingham	160	1,160	$190 – $370	$160 - $270	1,290 - 1,320
Kansas City	290	2,110	$370 – $720	$330 - $540	2,860 - 2,880
Newark	270	2,030	$310 – $650	$180 - $430	1,370 - 1,590
Sacramento	170	1,240	$250 – $460	$110 - $250	860 - 870

3.2.2 New York State

The New York State Energy Research and Development Authority (NYSERDA) (2011) used similar assumptions of electric vehicle market penetration as those in the 2007 EPRI study (40% of LDVs and ~17-22% of miles driven); however, electric vehicles were assumed to displace conventional vehicles in a back-casted, hypothetical scenario in 2008. Compared to a baseline scenario, the study estimated that this level of PEV use would have reduced demand for petroleum by 1.7 billion gallons per year and statewide petroleum spending by $4 to $10 billion (depending on fuel price assumptions). Reduced fuel spending would have resulted in net fuel cost savings (minus increased electricity demand) of $2 to $8 billion, or $540 to $1,050 in annual fuel cost savings per household [20]. The macroeconomic impacts of these shifts in spending were estimated to increase overall statewide economic output (gross state product, or GSP) by $4.4 to $10.7 billion and increase employment by 19,800 to 59,800 job-years. The vast majority (85% to 95%) of employment impacts were generated by increased consumer spending, demonstrating the importance of household spending in non-petroleum sectors of the economy [20].

3.2.3 California

California also compared two scenarios of PEV market penetration to baseline assumptions, and used input-output analysis to estimate the macroeconomic impacts of these scenarios. Assuming a scenario where PEVs comprise 15% of new vehicle market penetration by 2025, Roland-Holst (2012) estimated increased economic output (GSP) of nearly $5 billion, and net job growth of nearly 49,000 jobs. In a scenario where PEVs comprise 45% of the new vehicle market in 2030, the study estimated that, compared to the baseline scenario, GSP would increase by over $8 billion in 2030, and over 97,000 jobs would be created [9].

3.2.4 Ohio

Maves and Brenner (2012) reported results of an analysis of macroeconomic impacts of transportation electrification in Ohio, which estimated that the addition of 1,000 PEVs to Ohio's economy would result in net economic impacts of $1.3 million in increased economic output, $508,000 in additional wages, and 20 jobs [6]. It is important to note that the market penetration of PEVs in this study (1,000 vehicles) is quite low, and the scale of estimated economic impacts reflects this; all else equal, increased market penetration would lead to economic impacts of a greater scale.

3.2.5 Florida

Gaschel (2016) reported results of an analysis which examined the total and per-household savings associated with a shift to large-scale PEV use in Florida (~20,000 PEVs in 2016 and 60,000 in 2020, ramping up to 280,000 by 2025 and 780,000 by 2030). The study estimated ~$1,700 in household savings annually due to petroleum fuel and maintenance cost savings. The study also estimated to which non-petroleum sectors the savings would be redirected, finding that most would be spent on food ($770), clothing and services ($260), household expenses ($200), and entertainment ($200) [14, 15]. The net macroeconomic impacts of these PEV-induced spending shifts were estimated to result in increased economic activity of $31 million in 2016, increasing to nearly $1.5 billion in 2030. Additionally, nearly 230 jobs were estimated to be generated in 2016, increasing to 8,400 jobs by 2030; and, yielding an additional $7 million in wages in 2016, increasing to ~$300 million in 2030.

3.2.6 Southwest U.S. (AZ, NV, NM, UT)

Finally, a set of studies examining the impacts of PEV use in the Southwest U.S. (referenced in preceding section) estimated the job creation potential from PEV scenarios in 2030 for Arizona, Nevada, New Mexico, and Utah. Using a less rigorous methodology (as compared to input-output analysis), the studies estimated that 230 to 1,900 jobs could be generated per state, assuming 5% PEV market penetration in 2030 (8% by 2035 for Utah) [7, 16-18].

3.3 National-Level Studies

The state results are consistent with studies that were conducted on a national level. Winebrake and Green (2009) employed a method similar to the studies above to estimate the macroeconomic impacts of PEV-induced petroleum displacement nationally. Examining a future scenario where 40% of the U.S. light duty household market was comprised of PEVs (and ~20% of miles traveled were electric), the study estimated that large-scale PEV use would reduce gasoline demand by over 41 billion gallons per year, reduce household gasoline expenses by $118 billion, and save households $86 billion in fuel costs overall. These effects would lead to an increase in national economic output of $23 to $94 billion annually and creation of 162,000 to 863,000 jobs [21].

The Winebrake and Green (2009) findings were consistent with earlier national-level studies – the earliest being a 2002 U.S. DOE study that estimated that replacing only 1% of light-duty vehicles in the U.S. fleet with PEVs would reduce petroleum consumption by 24,000 barrels of oil per day—over 8.7 million barrels annually—and induce nearly $1.5 billion in economic activity, resulting in a net increase of over 14,000 jobs [22]. Winebrake (2003) examined the macroeconomic impacts of a 2025 scenario where 50% of all vehicles were PEVs, and estimated that this level of electric vehicle market penetration would reduce annual petroleum consumption by 1.5 billion barrels, increase GDP by $38 billion, and generate over 440,000 jobs [23]. Though not employing input-output analysis, Draper (2008) estimated that future wide-scale use of PEVs would reduce fuel and maintenance costs for PEV drivers by $80 billion, while net petroleum imports would decline by $20 billion, and the battery industry would grow by $120 billion [24].

More recently, Melaina et al. (2016) estimated macroeconomic benefits of large-scale PEV market penetration throughout the United States. Their results indicated fuel savings of hundreds of dollars per year per PEV and aggregate fuel cost savings of billions of dollars annually. These savings lead to billions of dollars in increased economic output, and employment growth of up to 140,000+ jobs [25]. Because this study also included a comprehensive assessment of vehicle capital costs, we present it in more detail in the following section. A summary of the estimated macroeconomic impacts in this and the preceding studies' findings are presented in Table 3.

Table 3. Summary of analyses estimating the macroeconomic impacts of PEV use in U.S. light duty vehicle sector.

Region	Source	Main Assumptions	GDP Impacts (Range)	Jobs (Range)
United States	EPRI Winebrake and Green 2009	40% of light-duty vehicles PEVs 16-20% of miles driven electric	$23B - $94B	162,000 - 863,000
	Winebrake 2003	50% of vehicles PEVs	$38B	440,000
	NREL Melaina et al. 2016	Several scenarios of PEV market penetration ranging between 12 million and 73 million PEVs by 2035 (see Table 4 for details)	$2B - $12B	100,000-150,000
	U.S. DOE 2002	1% of light-duty vehicles PEVs	$1.5B	14,000
States				
California	Roland-Holst 2012	PEVs 15% of on-road fleet by 2025	Near $5B	49,000
		PEVs 45% of on-road fleet by 2030	Near $8B	97,000
Florida	Gaschel 2016	20k PEVs in 2016; 60k in 2020; 280,000k in 2025; 780,000 in 2030	$31M - $1.49B	230 - 8,400
Ohio	Maves and Brenner 2012	Add 1,000 PEVs in Ohio	$1.3M	20
New York	NYSERDA 2011 Winebrake and Green	PEVs 40% of light duty vehicles 17-22% of miles driven electric in 2008	$4.4B to $10.7B	19,800 to 59,800
Arizona	Salisbury 2013 & 2014	PEVs 5% of on-road fleet by 2030	N/A	114 -713
Nevada				430 - 1,930
New Mexico				54 - 315
Utah	SWEEP 2017	PEVs 8% of on-road fleet by 2035		n/a
Regional				
Cleveland	EPRI Winebrake and Green 2007	40% of light-duty vehicles PEVs 16-20% of miles driven electric by 2030	$380 - $590	3,670 - 3,730
Austin			$110 - $250	380 - 410
Birmingham			$160 - $270	1,290 - 1,320
Kansas City			$330 - $540	2,860 - 2,880
Newark			$180 - $430	1,370 - 1,590
Sacramento			$110 - $250	860 - 870

4 ACCOUNTING FOR ELECTRIC VEHICLE CAPITAL COSTS

Studies from the previous sections calculate the macroeconomic impacts of shifting demand from petroleum to electricity as a transportation fuel; however, the increased upfront capital costs of PEVs are not captured or included in much of the modeling work. This is a potentially important consideration, as much of the economic impacts seen in these studies results from the redirecting of fuel cost savings to other sectors in the economy. If PEV owners, therefore, do not see a *net savings* in vehicle operating costs, we may not see the expected benefits in terms of economic output and employment.

Many studies have found that due to their lower fuel costs and lower service and maintenance costs, PEVs are expected to have a lower total cost of ownership in comparison to ICEVs [11, 12, 26-29]. Accounting for increased capital costs, even present day PEVs have lower total costs of ownership compared to ICEVs, and battery and production costs are expected to decrease significantly even further in future (e.g., modeled battery-production costs have declined by 73% since 2009), such that purchase prices of PEVs may equal that of ICEVs by 2022 [1, 11, 30].

As with fuel savings, vehicle owners' savings on total vehicle expenditures can be directed toward other goods and services in the economy, and may result in increased economic output and employment. But until recently a key question remained—what are the *overall* macroeconomic impacts of these shifts in spending? In a 2016 study sought to inform this question the National Renewable Energy Laboratory (NREL) examining: "To what degree might PEVs benefit the U.S. economy over the long term...after PEVs have been adopted on a large scale, nationwide, and within mainstream consumer households?" [25]

The study used input-output analysis in a similar approach to the studies outlined previously. However, it built upon earlier efforts by examining the question at a national scale, while also conducting focused analysis of the nine census regions of the United States (shown in Table 4). The model also included changes in costs and related shifts of spending due to PEV incremental costs and PEV charging infrastructure costs. A number of future PEV market penetration scenarios were examined, and are shown in Table 4.

Large-scale PEV market penetration is estimated to result in net private benefits of ~$250 to $340 per vehicle (PEV owners' fuel savings minus vehicle incremental cost and charging infrastructure costs), resulting in total private benefits of $3 to $27 billion in 2035, nationwide. The macroeconomic impacts of net household savings were estimated to result in increased employment on average of tens of thousands of jobs (up to 100,000-150,000 jobs/year); and increased GDP of $2-$12 billion annually [25].

Table 4. Results from the Melaina et al. (2016), showing estimated macroeconomic impacts of national PEV market penetration in the U.S. light-duty sector.

Scenarios	Year 2035					Avg. Annual Macroeconomic Impacts, 2015-2040			
	PEV Market Penetration Assumption (# by 2035)	Gasoline Use (Million Gallons)	% Reduction in Gasoline Use	Private Benefits ($/year/ PEV)	Total Private Benefits ($B/year)	Household Income ($M/year, $2013)	Jobs	GDP ($B/year)	Output ($million/year)
Niche	12 Million	66,506	23%	$273	$3.3	$3,855	110,000	$5.6	(619)
Breakthrough	24 Million	64,665	25%	$269	$6.6	$3,707	99,000	$5.8	1,723
Aggressive	73 Million	57,471	34%	$255	$18.6	$3,016	52,000	$6.6	11,003
High Cost	69 Million	55,949	35%	n/a	n/a	$176	(30,000)	$2.5	11,994
Low Cost	79 Million	58,750	32%	$344	$27.3	$5,104	109,000	$9.9	11,201
High Oil	92 Million	51,948	40%	n/a	n/a	$6,990	147,000	$12.5	20,196
Low Oil	66 Million	59,824	31%	n/a	n/a	$1,046	1,000	$3.7	8,444
Baseline	0	86,735	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Estimates of benefits stated above (and shown in Table 4) are *net economic benefits*, accounting for additional costs to PEV owners. In fact, **in nearly all scenarios the private benefits of fuel savings tend to more than offset the expenses of vehicle incremental costs and charger costs to PEV owners, generating substantial macroeconomic benefits on a national scale**. This is in part due to the substantial macroeconomic impacts of petroleum fuel displacement, but also due to the economic and employment intensity of automobile and component manufacturing and sales, compared to petroleum. As shown in Figure 1 earlier, in California, vehicle manufacturing is estimated to generate ~5 times the employment per dollar spent compared to the petroleum sector, while vehicle sales and service sectors are associated with twice the number of jobs per dollar spent [9].

There are also social benefits associated with PEV use. NREL estimated for each census region the total social benefits of large-scale PEV use, which included private benefits of cost savings plus public benefits of reduced greenhouse gas emissions (GHGs), and the societal value of reduced petroleum consumption. The net private and social benefits were estimated to be positive and substantial for all examined regions, as shown in Table 5. Overall, the study estimated, for Aggressive and Low-Cost Scenarios, net social benefits totaling $260 to over $500 per vehicle, per year (depending upon region); $1.1 to $7.3 billion total social benefits per region per year; and, total national social benefits of $26.5 to $34.3 billion.

Table 5. Results of the Melaina et al. (2016) study estimating, by census region, private and social benefits of future large-scale PEV market penetration in the light duty vehicle sector (per vehicle and total net benefit).

Census Region Examined	Total Private and Social Net Benefit per PEV ($/year)	Total Regional Private and Social Net Benefit ($Billion/year)
South Atlantic	$379 - $449	$5.7- $7.3
East North Central	$327 - $397	$3.9 - $5.2
Pacific	$375 - $447	$3.7 -$4.9
West South Central	$407 - $477	$3.7 - $4.7
Middle Atlantic	$262 - $330	$2.3 - $3.2
West North Central	$445 - $509	$2.3 - $2.9
East South Central	$434 - $503	$2.0 - $2.5
Mountain	$345 - $417	$1.7 - $2.2
New England	$305 - $368	$1.1 - $1.4
National Total	**$362 - $431**	**$26.5 - $34.3**

5 Electric Utility Customer Rate Savings

Another economic benefit of large-scale PEV use is the potential to reduce electric utility rates to all electricity customers in response to increased revenue by utilities per unit of generation capacity. Infrastructure required to generate electricity (such as power plants and transmission systems) is sized in a way to meet the peak electricity demands on the system, meaning that available capacity is often underused. The capacity utilization, or “load factor,” is only ~60% on average, which leads to higher costs per kilowatt-hour (kWh) of electricity sold and purchased than would be possible at higher load factor [31]. Large-scale use of PEVs—particularly if charged at off-peak times—can increase utility revenue relative to infrastructure capacity, potentially leading to reduced rates for all electric utility customers [31, 32].

A very recent set of analyses (2016 – 2017) by M.J. Bradley & Associates, LLC (MJB&A) estimated the economic impacts of large-scale transportation electrification in the Northeast states of Connecticut, Maryland, Massachusetts, New York, and Pennsylvania [33-38]. Future scenarios of large-scale PEV penetration in the light-duty vehicle sector were developed, and the costs and benefits of each were estimated (in the years 2030 to 2050). Examined scenarios included:

- The 8-state ZEV (zero-emission vehicle) scenario, which has the goal of 3 million ZEVs by 2025, and where 7-11% of vehicles were PEVs by 2030, and 17-25% were PEVs by 2050; and,
- The 80 by 50 scenario (80% reduction in GHGs by 2050), where ~25% of on-road vehicles were PEVs in 2030, and 80-90% of vehicles were PEVs by 2050.

Like earlier work, the MJB&A analyses estimated the fuel savings benefits to PEV owners and GHG emissions reductions. However, the analyses also examined economic benefits including reduced rates for utility customers. In order to estimate these benefits, the studies developed two scenarios: one in which PEV owners plug in their vehicles to charge immediately upon returning home or arriving at work; and one in which incentives or price signals are used to encourage off-peak charging. Off-peak charging is preferable from a cost standpoint as it costs utilities more to provide peak load generation, and it also costs utilities less in terms of infrastructure upgrades.

Table 6. Results from MJB&A (2016-2017) analyses showing estimated cumulative benefits to light-duty vehicle PEV owners and electric utility customers in five Northeast States [33-38].

State	Cumulative Statewide Benefits by 2050	
	Reduced Vehicle Operating Costs ($billion)	Reduced Electric Bills ($billion)
Massachusetts	$16.8	$7.8
New York	$34.1	$24.3
Connecticut	$9.4	$3.6
Maryland	$21.6	$4.5
Pennsylvania	$23.1	$9.6

The studies estimated that, by 2050, net cumulative benefits for all five Northeast states could total over $200 billion. Of this amount, $155 billion would accrue to utility customers and PEV owners in the form of savings on utility bills and fuel costs (Table 6). The economic benefits were estimated to surpass $3,900 per person in the examined region. The estimated net present value per PEV of these benefits ranged from ~$200 per vehicle per year in 2030 to $500 per vehicle per year in 2050 [33].

Additionally, a 2014 study examined whether utility customers would be better off due to large-scale PEV use in California—that is, would revenues to utilities offset the increased costs for necessary infrastructure and capacity investments? Estimating utility net revenues given two scenarios of PEV-charging electricity rates (time of use and tiered), the study found that in both cases, net utility revenues increased (that is, revenues from PEV use exceeded any additional costs to the utility due to PEV use) [31, 39]. If some or all of the additional revenue were passed onto utility customers, it would result in electricity rate savings for all electric utility customers.

6 Ancillary Benefits of Large-Scale PEV Use

Research has indicated many additional potential benefits of large-scale PEV use. For instance, several analyses have also suggested that macroeconomic impacts of improved efficiency and/or electrification of medium- and heavy-duty vehicles in the United States, would have significant economic benefits [39-43]; given the unique and varied characteristics of that sector, however, a detailed discussion of these findings is outside the scope of this document. Here we discuss two main potential ancillary benefits of large-scale light-duty PEV use: mitigating economic impacts of oil price shocks, and integration of renewable, distributed energy resources.

6.1.1 Mitigating Economic Impacts of Oil Price Shocks with PEVs

In addition to the macroeconomic effects associated with petroleum dollars leaking out of the economy, the volatility of global oil markets creates additional economic burdens. When oil prices spike, the negative economic consequences can be significant. With most goods and services, a sharp increase in price leads to a decreased demand; however, in the case of gasoline, short term price elasticities of demand are relatively inelastic (people still need to drive to work and home, and go to the grocery store and doctor). As reported by the U.S. Department of Energy, a 25 to 50 percent increase in the price of gasoline reduces gasoline consumption by only 1 percent [1]. Therefore, even more money drains out of household budgets into fueling vehicles, leaving less to be spent in the local, regional, and national economies.

Oil price spikes have preceded, and have been linked to, many economic downturns in recent U.S. history, including the Great Recession of 2008. Much literature exists on the macroeconomic impacts associated with oil price volatility [1, 44-49]. A review of that literature is beyond the scope of this work; however, that literature demonstrates that oil consumption is linked to macroeconomic costs (which have been estimated at ~$4-5 per barrel of oil consumed), and that reducing petroleum consumption could help minimize these costs [1].

Use of higher efficiency vehicles can mitigate these effects. For example, if the fuel economy of the U.S. LDV fleet in 2008 had achieved the 2025 CAFE standard of ~48 MPG, American drivers would have saved over $200 billion in gasoline expenditures—equivalent to over 1% of GDP at the time, and an amount roughly equivalent to the decline in GDP seen in the 4th quarter of 2008. A recent U.S. Department of Energy report quoted Michael Levi of the Council on Foreign Relations as stating, “a fifty-dollar price swing [in the price of oil] is only half as bad if you’re using half as much oil” [1]; oil price swings are even less of a problem if your vehicle isn’t using any oil. In this way, large-scale use of PEVs has even more potential to mitigate oil price shocks, as PEVs are powered by electricity.

Research indicates that movement to PEVs would help reduce the economic burdens associated with oil dependence. A study conducted by Keybridge Research, LLC and the University of Maryland for the Electrification Coalition examined the effects of a hypothetical oil price shock, where an oil price spike (similar to that of 2008) occurs in the year 2025. The study compared the anticipated macroeconomic effects of a base case to an "EV Policy Case," (where 14 million PEVs were projected to be on the road by 2020—123 million by 2030), finding that PEVs could mitigate about 1/3 of GDP and job losses from an oil price shock. In particular, the examined suite of policies (and resulting PEV market penetration) would in the first year alone prevent the loss of $213 billion in GDP (1% of GDP); 1.6% of disposable income ($253 billion); and 1.4 million jobs [50]. Assuming that the price shock happened in 2025, and prices returned to base levels by 2030, the EV Policy Case was estimated to prevent the cumulative loss of $505 billion in GDP and $758 billion in disposable income [50].

6.1.2 Renewable Energy Integration and Distribution

Through a system called vehicle-to-grid, or vehicle-grid-integration (VGI), PEVs could connect to and communicate with the electricity grid (or distributed energy sources) to optimize charging times, and improve the overall efficiency and affordability of the electricity system. Additional beneficial aspects of VGI are providing power quality services to the grid, and the ability to sell power from the vehicle to the grid on demand, potentially generating revenue for PEV owners [51,52]. These and other key aspects of VGI may allow PEVs to facilitate the integration of clean, U.S.-generated and distributed renewable energy sources into the United States electricity system. PEVs, for instance, can potentially provide energy storage and stabilizing services for intermittent renewable energy sources, thus decreasing the overall cost of renewable energy and improving its utility [53, 54].

Renewable energy is associated with more jobs per unit of energy compared to fossil fuel energy sources, and large-scale use of renewable energy throughout the U.S. is expected to generate hundreds of thousands to millions of jobs in the future [55]. Extraordinary growth is happening in these sectors now. In 2015, wind and photovoltaic (PV) solar accounted for two-thirds of all new electricity-generation capacity installed in the United States [30]. Installed wind power has tripled since 2008, and wind power manufacturing jobs tripled in the period 2007 to 2011 alone (to 30,000 jobs) [30, 56]. Jobs in wind power manufacturing, construction, and operations recently reached 90,000—with a total economic value of $2 billion [30]. The solar energy sector employed 220,000 people in 2015, and manufacturing of photovoltaic components alone contributed economic value of $1 billion [30].

The costs of renewable energy have declined dramatically in recent years (i.e., 41%, 64%, and 54% reduction since 2008, for land-based wind, utility-scale solar PV, and distributed solar PV, respectively), and are expected to continue to decline in the future [30]; installed capacity and use of renewable energy are projected to increase accordingly. The cost of production of PEVs has also declined dramatically, and is projected to continue to do so (as noted earlier, battery production cost projections have declined 73% since 2009), while use of PEVs has the potential to increase dramatically as well [30].

The concurrent interest in, growth, and cost reductions of renewable energy and PEVs, along with the potential symbiotic relationship between these sectors, presents a significant opportunity for both of these sectors. PEVs can facilitate renewable energy integration into the electricity system by addressing key technical limitations of, barriers or challenges associated with renewable energy, thus indirectly generating employment and economic activity in these sectors. And renewable energy—particularly distributed--allows additional energy security for PEV owners, while potentially providing innovative and integrated systems such as solar PV in parking lots [57]. PEVs can further reduce relative costs to owners of distributed renewable energy systems, while renewable energy systems can reduce fuel cost outlays for PEV owners. For instance, a recent analysis indicated that a solar PV system in Florida used to charge a PEV would have a payback of 16 years (when considering electricity purchases avoided), but when accounting for gasoline fuel cost savings, the payback period would be 6 years [11].

Employment is not simply a matter of quantity, it is also one of quality. Jobs designated as “green jobs”—which include employment related to renewable energy and electric vehicles—are typically of a higher quality than non-green jobs. Green jobs tend to require greater interpersonal skills and use of cognitive skills, involve higher levels of education and on-the-job training, and are less routine compared to non-green jobs [58].

Electric vehicles have the potential to provide distributed storage and power quality benefits for a renewable energy grid. These potential services have only begun to be evaluated in a comprehensive way in the literature [for example, Noel, et al. (2017)] [59]. However, great potential appears to exist in this area, especially given the massive growth in the renewable energy sector in recent years [8], and the value in managing that power growth [30]. Moreover, PEV battery reuse [60] presents a viable option for energy storage, to better integrate intermittent wind and solar power into the grid and reduce the overall cost of wind and solar energy production [61].

7 Policy Analysis and Macroeconomic Impacts

7.1 Background

A wide range of studies demonstrate the potential macroeconomic benefits of PEVs in our transportation sector. A remaining question is whether government policies can be effective at encouraging PEV adoption in a way that will result in net economic benefits—especially when compared to potential government expenditures in other areas. This section of the report presents recent research that suggests that the net macroeconomic impacts of PEV-promoting incentives and policies can be substantial.

7.2 State-level Policies

A series of recent analyses estimated the macroeconomic impacts of PEV-incentivizing policies by examining the impacts of either *eliminating* an *existing policy* or *introducing an incentive* into a state [62-65]. These analyses evaluated the shifts in consumer spending and government spending associated with PEV policy decisions. For example, Wescott, et al. (2015) estimates the economic impact to the Georgia state economy assuming the Zero-Emission Vehicle Tax Credit was canceled, leading to reduced purchases of PEVs in the state. On the consumer side, they found that the cancellation of this credit would increase petroleum expenditures by $9 million in the first year alone, and by $714 million over a 16-year period; increase spending on maintenance reaching a cumulative $33 million after 5 years, and over $200 million over a 16-year period; and reduce consumer expenditures on other goods and services in the economy by $40 million in the first year and $614 million over a 16-year period [63]. However, on the government side, the State of Georgia would increase its revenue (due to the cancelation of the tax credit) by approximately $233 million over 16 years and could spend those funds on government projects. Accounting for both consumer spending and government spending effects, Wescott, et al. (2015) found net negative economic impacts of ~$250 million (over a 16-year period) associated with a cancelation of the Zero-Emission Vehicle Tax Credit, as shown in Table 7.

Table 7. Estimated cumulative impacts of eliminating (Georgia and Washington) or introducing (North Carolina and Oregon) PEV-incentivizing policies [62-65].

	Cumulative Impact of Eliminating PEV Policy ($Millions)						Cumulative Impact of Introducing PEV Policy ($Millions)					
	Georgia			Washington			North Carolina			Oregon		
Consumer Spending Shift	1 Year	5 Years	16 Years	1 Year	5 Years	16 Years	1 Year	5 Years	16 Years	1 Year	5 Years	16 Years
Motor Vehicle Spending	-$73	-$389	-$389	-$10	-$94	-$94	$39	$206	$206	$21	$109	$109
Electricity Spending	-$4	-$60	-$261	$0	-$11	-$46	$1	$20	$91	$1	$14	$59
Gasoline Spending	$9	$155	$714	$1	$40	$191	-$3	-$50	-$233	-$3	-$46	-$212
Maintenance Spending	$0	$33	$208	$0	$8	$51	$0	-$13	-$83	$0	-$9	-$55
Replacement Spending	-$3	-$46	-$213	$0	-$11	-$52	$1	$14	$67	$1	$10	$45
Other Consumer Spending	-$40	-$247	-$614	-$2	-$35	-$153	$3	$28	$157	$8	$59	$191
Net Change in Spending	-$111	-$555	-$555	-$11	-$103	-$103	$41	$205	$205	$28	$137	$137
Change in Other Government Spending	$47	$233	$233	$4	$34	$34	-$12	-$62	-$72	-$11	-$57	-$57
Change in Real GDP (2009 $)	-$16	-$107	-$252	-$2	-$25	-$68	$7	$37	$52	$6	$38	$83

Table 7 shows the results of other studies using similar methods to estimate the impacts of introducing policies to encourage PEVs in other states. For example, in North Carolina, the net effect on GDP of introducing a PEV Tax credit is estimated to be $7 million in the first year, or $52 million over 16 years [62]; in Oregon, the net effect on GDP of introducing a PEV Rebate is estimated to be $6 million in the first year, or $83 million over 16 years [65]; and in Washington State, the net effect of eliminating the Alternative Fuel Tax Exemption on GDP would be a reduction in GDP of $2 million in the first year, $68 million in reduced GDP over the 16-year period [64].

Similarly, a 2014 analysis estimated the macroeconomic impacts of cancelling California's Clean Vehicle Rebate program, finding that though the state government would save $800 million on outlays for the rebates, there would be a decline of $2 billion in state GDP, a reduction in 8,000 jobs, and, a decrease in government tax revenue by $87 million [66].

7.3 Macroeconomic Impacts of National Policies

At the national level, a 2010 study estimated the macroeconomic impacts of a potential suite of national policies intended to address barriers to the adoption of PEVs. The analyzed policy suite was developed in an earlier Electrification Roadmap companion document [67], and involved:

- Incentives for the purchase of PEVs in targeted regions;
- Incentives for installing charging infrastructure in targeted regions;
- Incentives for utility upgrades necessary to support large-scale deployment of PEVs;
- Incentives for U.S. production and purchase of PEV batteries; and,
- Support for automakers to modify automotive production facilities for PEV production.

The policy suite was projected to result in an *EV Policy Case* where: 50,000 to 100,000 PEVs were on the road in 6 to 8 cities by 2013, and 400,000 to 500,000 PEVs were on the road city in 2018—expanding to 14 million PEVs on the road by 2020 and 123 million PEVs on the road by 2030. By 2040, 75% of on-road vehicles would be PEVs. Compared to a Base Case scenario, the study estimated that the EV Policy Case would save 40 billion gallons of fuel by 2025; reduce petroleum imports by 12 billion barrels over the study period; result in increased combined household disposable income for the entire study period by *$5.6 trillion;* and increase employment by 1.9 million jobs in 2030 [50]. The study also estimated the anticipated *increase* in federal revenues due to shifts in economic activity, finding that compared to the base case scenario, in the EV Policy Case federal revenues would increase by $336 billion over the examined period.

8 Conclusion

Petroleum consumption presents a drain on local and regional economies, diverting financial resources of households and businesses away from other necessary or beneficial goods and services produced in local and regional economies. Reducing petroleum use in transportation can result in potentially large economic benefits to regions, when fuel cost savings are spent in other non-petroleum sectors of the economy, encouraging growth in everything from hospitality to health care to home repair.

Dozens of studies focusing on regions throughout the United States have demonstrated the potential beneficial economic impacts of large-scale PEV use. This is primarily due to effects of petroleum fuel displacement: PEVs save several hundreds of dollars in fuel costs per vehicle, per year. Combined, widespread use of PEVs could reduce gasoline expenditures by tens of billions of dollars annually nationwide, saving up to billions of dollars per state, and hundreds of millions of dollars per city.

The estimated macroeconomic impacts of shifts in spending due to PEVs include increased economic output (GDP) of up to tens of billions of dollars per year nationwide, and generation of tens of thousands to upwards of 1 million jobs. Even accounting for increased vehicle costs, the net effect of large-scale PEV use is increased economic activity and employment; this is due to fuel cost savings more than offsetting vehicle capital costs, in addition to the relative labor intensity of automotive manufacturing compared to petroleum production.

Additional economic benefits of PEVs include potential reduction in electric utility rates for all customers, and mitigation of economic losses due to oil price shocks. The resulting relative increase in household income from these savings may also be redirected to other goods and services, boosting regional economies.

Electric vehicles can also serve to integrate clean, U.S.-generated renewable energy sources, potentially serving as energy storage and stabilizing the intermittent energy source, thus decreasing the overall cost of renewable energy, improving its utility, and generating high quality "green jobs."

Lastly, policy analyses of have estimated that policies to incentivize PEVs increase economic activity and employment—even when accounting for the necessary government outlays and macroeconomic impacts if those government resources were used elsewhere.

There are a number of tools available to policy-makers, communities, and stakeholders to encourage the realization of potential macroeconomic benefits. A 2016 review of the literature found that research has indicated statistically significant influences of numerous PEV-promoting policies—ranging from rebates and tax credits, to emissions testing and high-occupancy vehicle (HOV) lane exemptions, to charging availability and preferential electricity rates [68]. Research has indicated that even comparatively low-cost strategies such as informing potential vehicle buyers of the lower total cost of operation of PEVs (as opposed to simply disclosing fuel-cost savings) will increase preference for PEVs over conventional vehicles [69]. As the findings reported in this document repeatedly suggest, as vehicle ownership costs in a region decline, and fuel and other cost savings are spent through the economy, increased economic activity and employment in the region may be expected just down the road.

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