AN ASSESSMENT OF MACROECONOMIC IMPACTS OF MEDIUM- AND HEAVY-DUTY ELECTRIC TRANSPORTATION TECHNOLOGIES IN THE UNITED STATES

Achieving Employment and Output Gains through Petroleum Displacement, Fuel Cost Savings, and Increased Demand for Related Industries

James J. Winebrake, PhD
Erin H. Green
Edward W. Carr, PhD

Energy and Environmental Research Associates, LLC
11 April 2018

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Acknowledgements

This research was supported through funding from the California Electric Transportation Coalition (CalETC). We are grateful to Eileen Tutt, Executive Director of CalETC, for her support throughout the project. We are also grateful to other reviewers for their expert advice and comments, including members of the CalETC Advisory Board.

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Executive Summary

An ongoing movement is afoot towards the electrification of transportation in the United States. Electrification is gaining momentum and has expanded from the light-duty passenger vehicle market to other technologies in medium- and heavy-duty vehicle (M/HDV) markets. These technologies have the potential to deliver large economic benefits to adopters, primarily due to fuel cost savings.

But the economic benefits do not end with the technology adopters. There are macroeconomic effects that also occur as users move from petroleum imports to domestic electricity; as fuel savings are passed along to customers and investors; and as capital investments occur in the local economy.

Very little research has been done on the macroeconomic impacts associated with a shift from diesel fuel to electricity in the M/HDV sector. This report attempts to fill that gap. The report provides an assessment of the macroeconomic impacts of electrification of transportation-related medium- and heavy-duty technologies with a focus on four technologies: (1) Electric Forklifts; (2) Truck Stop Electrification; (3) Shore Power; and (4) Electric Transit Buses. The analysis integrates technology characterizations, energy price forecasts, and future market penetration scenarios with input-output analysis methodologies to identify the potential macroeconomic impacts of technology adoption. We perform a US-wide analysis for all technologies; and a region-wide analysis for select state/technology combinations, which are: (1) Texas/Electric Forklifts; (2) Ohio/Truck Stop Electrification; (3) Florida/Shore Power; and (4) New York City/Electric Transit Buses. This geographic scope allows readers to understand the scale of impacts not only at the national level, but also at a more regional level.

The results we obtain validate our hypothesis that electrification of these technologies can provide significant economic benefits to the nation and to a region. For example, our mid-level market penetration scenarios for the four examined technologies (combined) lead to increases in employment by 238,600 jobs[1] by 2030, and increases in economic output by $44.7 billion. Results by technology type for 2030 under our mid-level market penetration scenario are as follows:

- Electric Forklifts could displace over 1.8 billion gallons of petroleum fuel per year, at net fuel cost savings[2] of $2.4 billion per year, resulting in increased economic output of $3.5 billion and the creation of 17,900 new jobs. Cumulative macroeconomic impacts for the period 2015-2030 are estimated at increased employment of up to 156,000 job-years and increased economic output of $36.4 billion.

- Truck Stop Electrification (TSE) could displace 192 million gallons of petroleum fuel per year, at net fuel cost savings of over $650 million per year, resulting in increased output of $560 million and the creation of 9,000 new jobs. Cumulative macroeconomic impacts are estimated at increased employment of up to 36,300 job-years, and increased economic output of $2.3 billion.

- Shore Power could displace nearly 945 million gallons of petroleum fuel per year, at net fuel cost savings of over $740 million per year, resulting in increased output of up to $4.2 billion and increased employment reaching up to 14,600 new jobs. Cumulative macroeconomic impacts are estimated at increased employment of up to 88,200 job-years, and increased economic output of $26 billion.

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[1] Consistent with these types of analysis, the term “jobs” represents a “job-year” – or one person employed for one year. When reporting annual results, we use the term “jobs”, while we use “job-years” when reporting cumulative results.

[2] Net fuel cost savings refer to savings on petroleum expenditures, accounting for increased electricity expenditures.

- Electric Buses could displace over 50 million gallons of petroleum fuel per year, at net fuel cost savings of $35 million per year, resulting in increased output of $340 million and the creation of 820 new jobs. Cumulative macroeconomic impacts are estimated at increased employment of up to 6,800 job-years, and increased economic output of $2.4 billion.

Estimated reductions in petroleum fuel expenditures for all evaluated technologies (2015 – 2030) are shown in Figure ES 1, and Table ES 1; estimated macroeconomic impacts for all evaluated technologies, cumulative to year 2030 are shown in Table ES 2.

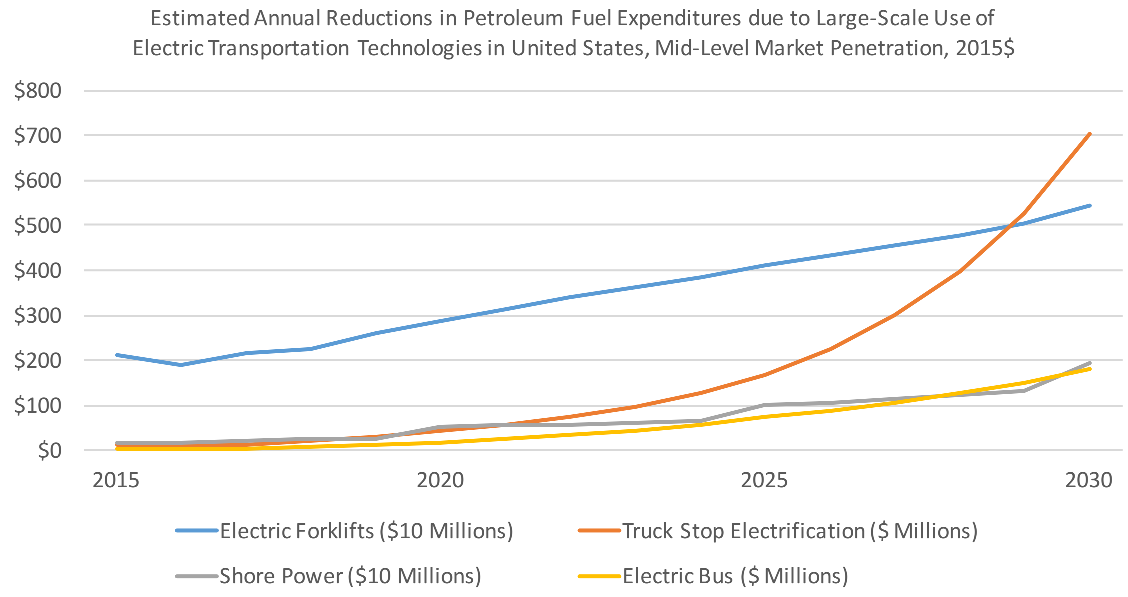

Figure ES 1. Estimated Savings on Petroleum Fuel Expenditures in the U.S. due to Large-Scale Market Penetration of Evaluated Electric Transportation Technologies

Table ES1. Estimated Reductions in Petroleum Fuel Expenditures due to Large-Scale Use of Studied Technologies in the United States, Mid-Level Market Penetration Scenarios, Millions $2015

	Electric Forklifts ($M)	Truck Stop Electrification ($M)	Shore Power ($M)	Electric Buses ($M)	Total ($M)
2020	**$2,890**	**$40**	**$510**	**$20**	**$3,460**
2025	**$4,090**	**$170**	**$990**	**$75**	**$5,330**
2030	**$5,445**	**$700**	**$1,930**	**$180**	**$8,260**

Table ES2. Estimated Macroeconomic Impacts Due to Large-Scale Use of Studied Technologies in the United States, Mid-Level Market Penetration Scenarios, Case I Impacts, Millions $2015

	Electric Forklifts	Truck Stop Electrification	Shore Power	Electric Buses	Total
Employment (Jobs)					
2030	**17,900**	**9,000**	**6,900 - 14,600**	**820**	**34,620 – 42,320**
Cumulative (2015-2030)	**156,000**	**36,300**	**39,500 – 88,200**	**6,800**	**238,600 – 287,300**
Output (Millions, 2015$)					
2030	**$3,500**	**$560**	**$990 - $4,200**	**$340**	**$5,390 - $8,600**
Cumulative (2015-2030)	**$36,400**	**$2,300**	**$6,000 - $26,200**	**$2,400**	**$44,700 - $64,900**

Our results for the regional economic assessments are also significantly positive. For each of these assessments, we use region-specific market penetration scenarios, energy prices, and the structural characteristics of each regional economy. The mid-level market penetration scenario results by 2030 are as follows:

- Electric Forklifts in Texas could displace over 180 million gallons of petroleum fuel per year, at net fuel cost savings of $260 million per year, resulting in increased output of $70 million and creation of 1,000 new jobs in the state. Cumulative macroeconomic impacts for Texas (2015-2030) are 8,400 job-years and increased output of $660 million.

- Truck Stop Electrification (TSE) in Ohio could displace nearly 7 million gallons of petroleum fuel per year, at net fuel savings of nearly $23 million per year, resulting in increased output of $20 million and creation of 350 new jobs in the state. Cumulative macroeconomic impacts for Ohio (2015-2030) are 1,300 job-years and increased output of $75 million.

- Shore Power in Florida could displace 69.3 million gallons of petroleum fuel per year, at net fuel cost savings of $140 million per year, resulting in increased output of up to $560 million and creation of up to 1,960 jobs in the state. Cumulative macroeconomic impacts for Florida (2015-2030) are increased employment of up to 10,500 job-years and increased output of up to $3.1 billion.

- Electric Buses in New York City could displace 4 million gallons of petroleum fuel per year, at net fuel cost savings of $4 million per year, resulting in increased output of $17 million and creation of 30 new jobs in the city. Cumulative macroeconomic impacts for New York City (2015-2030) are increased employment of up to 290 job-years and increased output of $130 million.

These results indicate that decision makers must give serious consideration to accelerating the adoption of these types of electric technologies. The displacement of petroleum by electricity (and the resulting fuel savings that gets reinvested in the US economy), can have significant, positive macroeconomic benefits. These results apply not only to the nation, but also to states and regions that invest in these technologies.

1 Introduction

1.1 Benefits of Electrification

There is ongoing interest in the electrification of transportation in the United States. Electrification is now gaining momentum and has expanded from the light-duty passenger vehicle market to other technologies and vehicles in medium- and heavy-duty vehicle (M/HDV) markets.

The initial push towards electrification was largely driven by environmental concerns. The environmental consequences of a petroleum-fueled transportation system, including negative health effects resulting from pollutant emissions and global climate change due to greenhouse gases (GHGs), are increasingly visible. Electric vehicles reduce tailpipe emissions to zero, and typically (and sometimes drastically) reduce total emissions of GHGs and other pollutants.

A potentially large benefit of transportation electrification that is less prevalent in policy discussions is economic. Electric vehicles and technologies are highly efficient, typically consuming only one-half to one-quarter the energy of their petroleum-powered counterparts (on a per-mile or per-hour basis). Therefore, electricity is far less expensive than petroleum as a transportation fuel. Annual fuel cost savings of electric vehicles and equipment can be significant, depending on technology characteristics and usage.

Unlike money spent on foreign petroleum, which leaves the economy, fuel cost savings are reinvested *in* the economy through the purchase of other goods and services. In this way, fuel savings due to electrification can cycle and multiply through the economy, increasing overall economic activity and generating new jobs. The funneling of petroleum expenditures outside of the economy is even more of a concern in localities or regions with no petroleum industry. In such cases, nearly all petroleum expenditures leave the region. Thus, economic benefits of electric vehicles and technology accrue not only to individual drivers and private owners (*micro*economic impacts), but to the economy as a whole (*macro*economic impacts).

1.2 Quantification of Economic Benefits of Electrification

Various studies have sought to estimate the potential future macroeconomic impacts of electric vehicle use in the United States (US) using a method called input-output (I/O) analysis (described in further detail below). At the regional or state level, studies have estimated that macroeconomic impacts of displacing petroleum fuel with electricity may increase economic activity in a region by millions to billions of dollars annually. At the national level, researchers estimate that hundreds of thousands of jobs and billions of dollars in economic output can result from transportation electrification [1-10].

However, these studies have focused on the light-duty vehicle (LDV) or passenger vehicle market. There is opportunity for transportation electrification in the medium- and heavy-duty vehicle (M/HDV) market as well, including forklifts; buses; truck stop electrification (TSE); shore power (ships using electricity to power auxiliary engines while at port); trucks; passenger rail; cargo-handling equipment at ports; and airport ground support equipment, to name a few.

Recent studies have demonstrated the cost-effectiveness of electric M/HDV vehicles and technologies, as compared to petroleum-powered counterparts, and have found annual net savings to owners of thousands of dollars per vehicle or technology [11, 12]. One study used I/O to estimate the national macroeconomic impacts of large-scale *efficiency* measures in M/HDV trucks, and estimated that by 2030, annual increased employment of 124,000 jobs, and increased economic output of $10.4 billion would result [13]. However, no published study has estimated the potential macroeconomic impacts of large-scale M/HDV electrification in the US.

1.3 Purpose and Approach

The purpose of this research is to estimate macroeconomic impacts of M/HDV electrification at the national, state, and local scale, for a range of vehicles and technologies. As M/HDV markets, uses, owners, equipment, and payment structures are unique compared to the LDV sector, this work will broaden the understanding of the potential range of macroeconomic impacts of transportation electrification.

In addition to estimating macroeconomic impacts for a new sector, this work seeks to advance the understanding of the *total* economic impacts of electric vehicles and technologies. Most studies using I/O to estimate economic impacts of electric transportation have focused on the impacts of displacing petroleum with electricity, but have neglected to estimate macroeconomic impacts of changes in other important components of the total cost of operation of vehicles (e.g. capital equipment, chargers, or maintenance expenditures). These are potentially important considerations. For example, a 2016 National Renewable Energy Laboratory (NREL) study accounted for incremental vehicle costs and home charger costs of light duty vehicle electrification, and estimated, on average over the 2015 to 2040 period, net positive economic impacts of 52,000 jobs and $6.6 billion in increased GDP per year [9]. This work is the first to incorporate many of the costs of M/HDV vehicle and equipment ownership in its analysis.

1.4 Report Structure

The structure of this report is as follows. In Chapter 2, we present the study methodology. Chapters 3-6 provides analysis of each electric technology we evaluated – both at a national level and a regional level. Those chapters include details regarding data sources, market penetration assumptions, and results. Chapter 7 concludes the report and provides policy insights and research limitations.

2 Methodology

2.1 Selection of Technologies and Regions for Evaluation

This research provides an assessment of four different electric technologies in the M/HDV sector. We used the following selection criteria to identify the technologies:

- Potential scale of market penetration, near- and longer-term;
- Characteristics of potential markets, sectors, and applications making them particularly suited for electrification (or trends indicating movement in that direction);
- Technical or practical feasibility (for technology and for macroeconomic analysis);
- Availability of appropriate data inputs;
- Confidence in, or robustness of, available data;
- Trends in sectors using the technologies; and,
- Relative confidence in future projections in a sector.

In conducting research around these criteria, we reviewed numerous reports, papers, databases, and models from academic, government, and non-governmental sources. Sources included, for instance, peer-reviewed journal articles; the California Air Resources Board (ARB); the Electric Power Research Institute (EPRI); National Academies of Science; Transportation Research Board; university research centers and research papers; Port Authorities; U.S. Department of Transportation; U.S. Environmental Protection Agency; U.S. Department of Energy's Energy Information Administration, Alternative Fuels Data Center, and National Renewable Energy Laboratory (NREL); National Transit Database; industry groups and individual firms; and, NGOs such as Union of Concerned Scientists. Consultant reports were also reviewed, in particular recent work examining the cost effectiveness of M/HDV PEV/T technologies by ICF International and Energy+Environmental Economics [11, 12].

Based on this review and an iterative process in initial stages of analysis, we selected the following technologies to evaluate: (1) Forklifts; (2) Truck Stop Electrification (TSE); (3) Shore Power (ships using electricity to power auxiliary engines while at port); and, (4) Buses. For each of these technologies, we develop market penetration scenarios for the US, and conduct macroeconomic analysis of impacts at a national scale.

The national scale, however, can sometimes camouflage distinctions in anticipated impacts in specific regions, due to variations in energy prices, fuel mix, and economic structure, among others. Therefore, the selection process also focused on the *geographic scope* for macroeconomic analysis. This process included identifying, assessing, and comparing such regional variables as electricity fuel mix, energy prices, transportation markets, economic structure, regulations and incentives, and levels of petroleum dependence, among others. We collected literature and data related to these elements and compiled these data in order to "rank" states with respect to their relevance for the analysis, and for technology electrification.

We included in our geographic selection process a number of criteria, including: an efficiency score developed by Onat et al. (2017) [14], which identified states that are particularly suited for widespread adoption of electric vehicles and technology, and are environmentally and economically suited to do so. We also identified: (1) regions containing the busiest ports (for shore power); (2) regions with significant long-haul trucking activity; (3) regions with large public transit bus systems; and, (4) regions with high commercial and industrial economic activity and projected growth in these areas (for forklifts). Based on these criteria, the following regions (and technology pairings) were selected for the analysis:

- **Electric Forklifts:** (1) United States; (2) Texas
- **Truck Strop Electrification:** (1) United States; (2) Ohio
- **Shore Power:** (1) United States; (2) Florida
- **Electric Buses:** (1) United States; (2) New York City

2.2 Scenario Development

We constructed market penetration scenarios for each technology for the time period of 2015 to 2030. We then used these scenarios to estimate energy use and costs based on technical parameters, expected usage of the technologies, fuel costs, capital costs, O&M costs, etc. We compare these scenarios to a baseline scenario assuming zero market penetration of the technology. Figure 1 depicts the scenario development process. Outputs from this process lead into the next phase, macroeconomic input-output (I/O) analysis.

For each technology, unless explained otherwise, we evaluate three market penetration scenarios. They are:

1) **Low Market Penetration Scenario** Current levels of market penetration (or, depending on technology examined, current growth trends) are assumed to continue through 2030. We use the *Low Oil Price* forecast from the Energy Information Administration (EIA) Annual Energy Outlook (AEO). In general, due to relatively inexpensive petroleum fuel, these scenarios represent “worst-case” macroeconomic impacts of electrification.

2) **High Market Penetration (or Aggressive Scenario)** High levels of market penetration are assumed. These scenarios do not represent the upper limit in terms of electrification of the technology, but represent the higher range of realistic expectations, given the current and anticipated market, policy environment, and anticipated levels of technology turnover. We use the *High Oil Price* EIA AEO energy price forecast for this scenario.

3) **Mid-Level Market Penetration (or Reference Case)** In these scenarios, market penetration of electric vehicles and technologies are midway between the *Low* and *High Market Penetration* scenarios. These scenarios may be considered a reasonable “middle-of-the-road” for estimating potential macroeconomic impacts of electrification. We use EIA AEO *Reference Case* energy price forecasts for these scenarios.

Together the assumptions in these scenarios are used to estimate shifts in energy consumption and other key expenditures (i.e. vehicle costs) associated with each scenario, which are then employed as inputs in the next phase—modeling macroeconomic impacts.

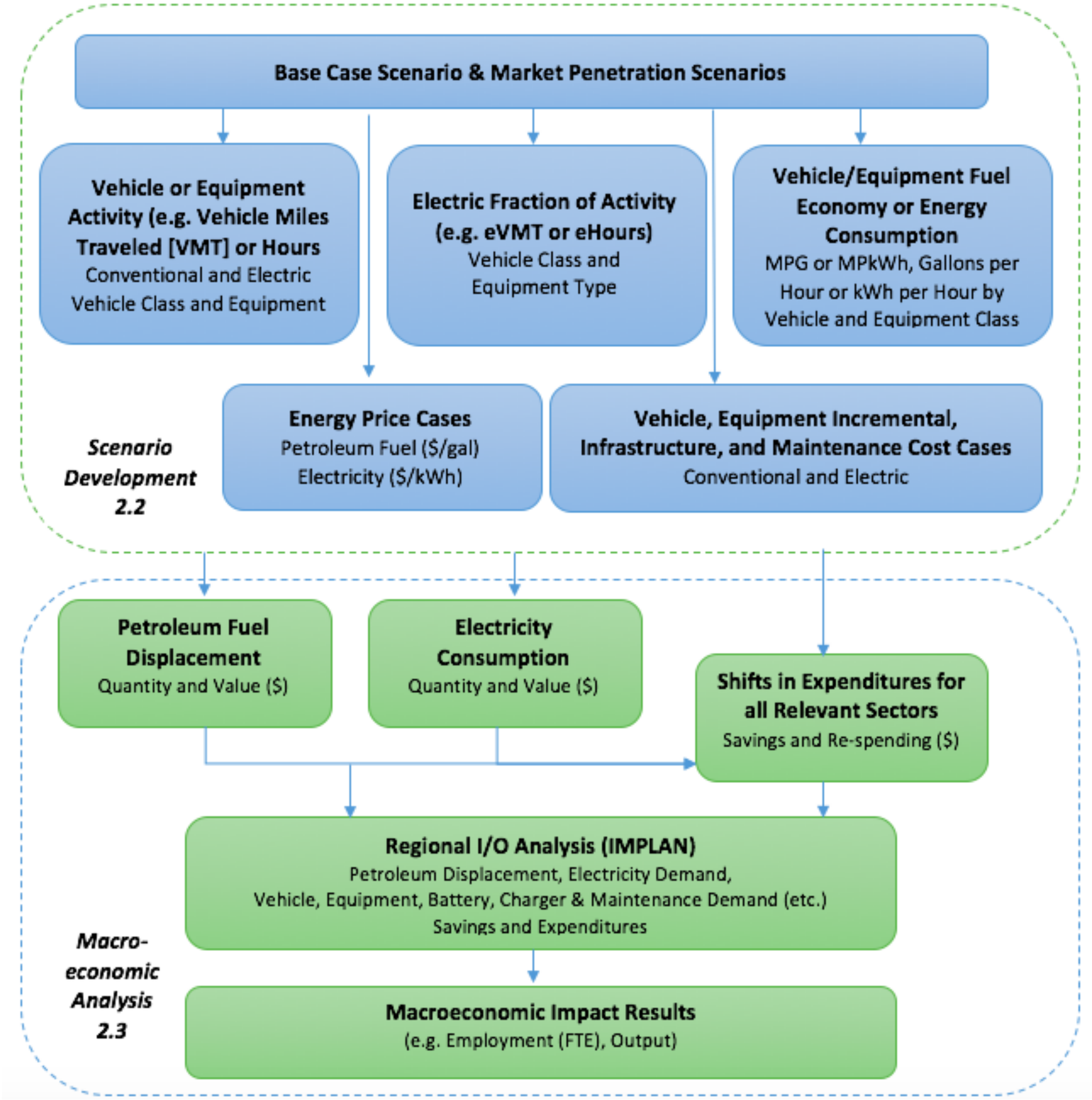

Figure 1. Steps Involved in Scenario Development and Macroeconomic Analysis

2.3 Macroeconomic Analysis

2.3.1 Estimating Shifts in Energy Consumption and Other Expenditures

We use scenario assumptions to estimate shifts in demand for energy and equipment in physical units (i.e. kWh/year for electricity; gallons of gasoline or diesel equivalent for petroleum fuel; units for vehicles, equipment, or chargers). Detailed assumptions vary by technology and are described in each specific section. For each technology and scenario, we estimate annual shifts in electricity and petroleum consumption for 2015-2030 and convert these to net fuel cost savings. Where available, we also estimate the following:

- Vehicles, equipment, batteries, chargers, and other capital equipment expenditures;

- Operations and maintenance costs;
- Installation costs; and,
- Hourly usage (for usage charges or fees).

Annual shifts in demand (i.e. kWh; gallons; new vehicles) are then translated to shifts in expenditures in these sectors (e.g. $ millions/year) for compatibility with I/O analysis. To estimate aggregate expenditures, energy prices and forecasts from EIA are used; capital, maintenance, other costs are compiled from various sources including: technology cost-effectiveness assessments; NGO, and government reports and datasets; existing cost models, and, industry sources.

2.3.2 Input-Output Analysis

Input-output (I/O) analysis allows us to estimate macroeconomic impacts (such as employment and GDP) resulting from shifts in economic activity within a regional or national economy. Relying on statistical data from the US national accounting system, I/O analysis captures the many production-consumption linkages within the economy.

For instance, the production of electricity involves fuel purchases, equipment purchases, labor purchases, and maintenance services. Input-output analysis allows one to assess the changes in demand for these production inputs due to a change in demand for the final product. I/O analyses are valuable not only because they capture the *direct* impacts of such shifts (for example, in a shift in customer demand for electricity), but also because I/O evaluates the indirect and induced effects of these direct impacts. Figure 2 depicts examples of direct, indirect, and induced effects of electricity production.

In this work, we apply a “regional input-output” (RIO) approach, which allows us to track the economic impacts from shifts in economic activity within a regional economy. In this study, “regions” include the United States, Texas, Ohio, Florida, and New York City. For each selected region, we examine the region- wide economic impacts based on the market penetration scenarios and cases for selected technologies.

We use IMPLAN (IMpact Analysis for PLANning) for our analysis, relying on the most recently available economic structural matrices and data files (representing the year 2015) to construct our model. From our RIO analysis, we estimate the following:

- ***Output,*** which is measured in $/year and represents the value of economic activity in the region (by industry and in total); and,
- ***Employment,*** which is measured in jobs (when referring to a single year) or job-years (when referring to cumulative effects). Employment includes wage and salary employees, and self-employed jobs.

For each of these categories, we quantify the total (direct, indirect, and induced) output and employment impacts associated each shift, for the years 2025, 2030, and cumulative (2015-2030) impacts. The net impacts of all shifts indicate the potential macroeconomic impact of large-scale electric MD-HDV vehicle or technology use.

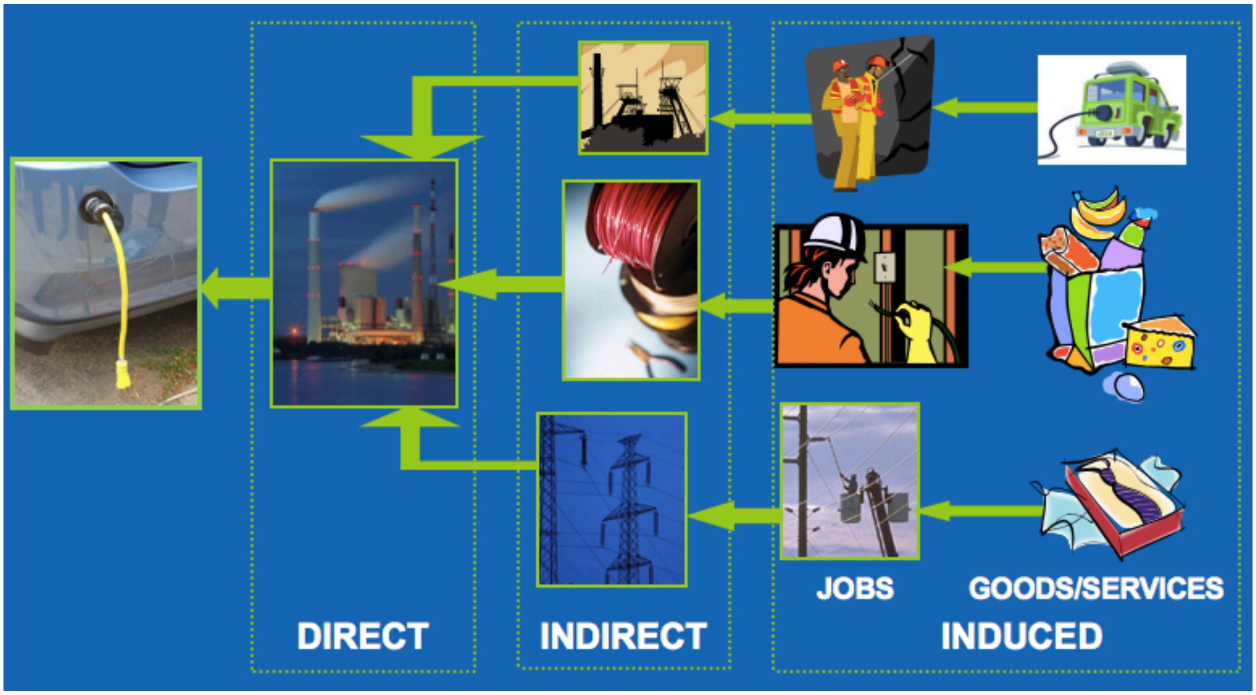

Figure 2. Example Direct, Indirect, and Induced Economic Effects Due to Increased Electricity Consumption in Transportation

3 Macroeconomic Impacts of Electric Forklifts: An Assessment for the United States and Texas

Summary of Chapter Findings

- Under our Mid-level Market Penetration scenario, compared to a baseline scenario of zero market penetration, electric forklifts will displace over 1.8 billion gallons of petroleum fuel per year in the United States by 2030, at net fuel cost savings of $2.4 billion per year. This will result in increased output of $3.5 billion and increased employment of 17,900 new jobs. Cumulative macroeconomic impacts for the period 2015-2030 are estimated at increased employment of up to 156,000 job-years, and increased economic output of $36.4 billion.

- Under our Mid-level Market Penetration scenario, electric forklifts will displace over 180 million gallons of petroleum fuel per year in Texas by 2030, at net fuel cost savings of $260 million per year, resulting in increased output of $70 million and creation of 1,000 new jobs in the state. Cumulative macroeconomic impacts for Texas (2015-2030) are 8,400 job-years and increased output of $660 million.

3.1 Chapter Overview

In this chapter, we develop future market penetration scenarios for electric forklifts in the United States (US) and Texas. We use these scenarios to evaluate the macroeconomic impacts of this use. We first describe the electric forklift scenario assumptions. We then present results specific to the United States. Finally, we present assumptions and results specific to Texas.

3.2 Scenario Development

Three scenarios were evaluated for electric forklifts for the time period 2015-2030: Low, Mid-Level, and High Market Penetration. We evaluate each scenario using a range of energy prices,[3] capital costs, charger costs, and battery costs. The scenarios are described below. Figure 3 shows the population of electric forklifts in the United States, by class, for each scenario.

- Low Market Penetration Scenario
  In the Low Market Penetration Scenario, we use projected forklift sales based on *ITA Market Intelligence* report data, which reports forklift sales by year over time [11, 12]. Historic annual growth rates were used to project forklift populations by fuel type and class through 2030. Market penetration assumptions are shown in Figure 3. We use energy price forecasts from EIA's AEO *Low Oil Price* case. We assume forklift capital costs, charger costs, and battery costs to be on the low end of the range of estimates.

- High Market Penetration Scenario
  In the High Market Penetration Scenario, we assume that 60% of Class 1 & 2 forklifts are electric by 2020, with 80% market penetration by 2030, equating to nearly 1 million electric forklifts by 2030,

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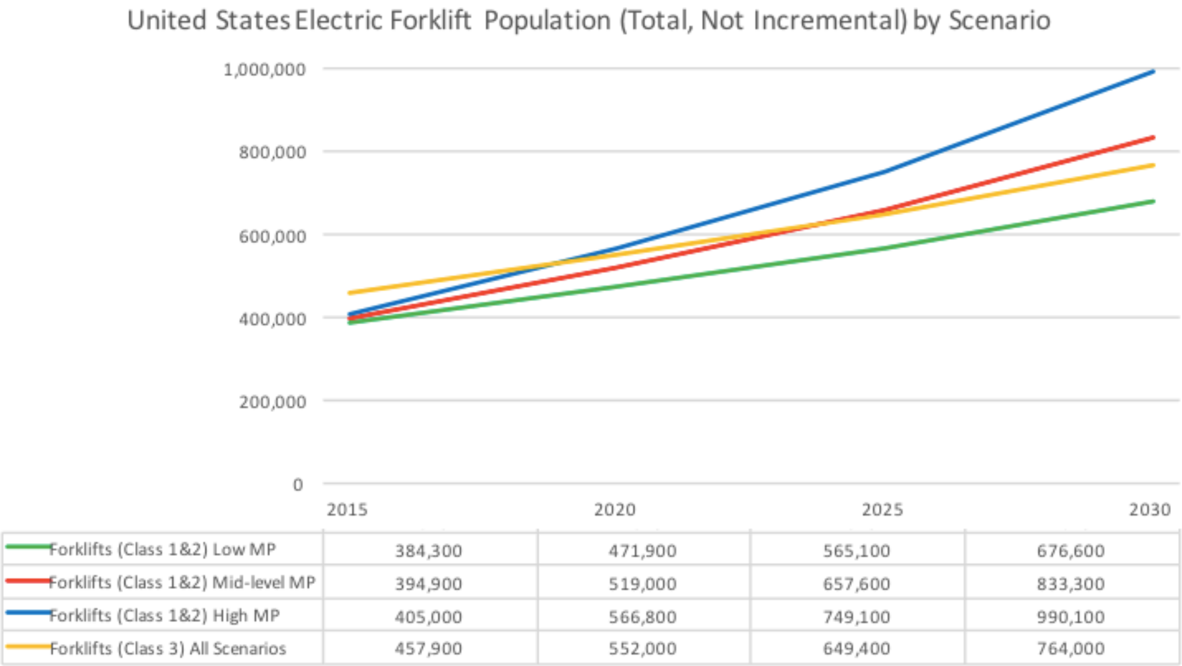
[3] Energy prices include commercial electricity prices, industrial electricity prices, diesel, and gasoline.

compared to ~400,000 in 2015. We use energy price forecasts from EIA’s AEO *High Oil Price* case. We assume forklift capital costs, charger costs, and battery costs, are assumed to be on the high end of the range of estimates.

- Mid-Level Market Penetration Scenario:
  In the Mid-Level Market Penetration Scenario, market penetration falls between that of Low and High Market Penetration Scenarios, as shown in Figure 3, with Class 1&2 market penetration increasing from ~400,000 electric forklifts in 2015 to ~830,000 in 2030. We use energy price forecasts EIA’s AEO *Reference Case* projections. We assume forklift capital costs, charger costs, and battery costs in the mid-range of low and high estimates.



	2015	2020	2025	2030
🟩 Forklifts (Class 1&2) Low MP	384,300	471,900	565,100	676,600
🟥 Forklifts (Class 1&2) Mid-level MP	394,900	519,000	657,600	833,300
🟦 Forklifts (Class 1&2) High MP	405,000	566,800	749,100	990,100
🟨 Forklifts (Class 3) All Scenarios	457,900	552,000	649,400	764,000

Figure 3. U.S. Electric Forklift Market Penetration by Scenario (Total Population), 2015-2030

3.3 Macroeconomic Impacts for the United States

3.3.1 Shifts in Expenditures: United States

3.3.1.1 Electricity Demand and Costs

Several important economic shifts occur when electric forklifts increase their market penetration. For example, electric forklifts and related charging will increase electricity consumption, and thus demand for electricity generation, transmission, and distribution. We calculate aggregate electricity consumption (million kWh) for each market penetration scenario assuming that forklifts are used 3,150 hours per year, with 8,000-pound electric forklifts consuming ~18,300 kWh per year, and 19,800 pound forklifts consuming ~52,000 kWh annually[4]. Estimated projected electricity demand for each scenario, as compared to a baseline of zero electric forklifts, is shown in Figure 4.

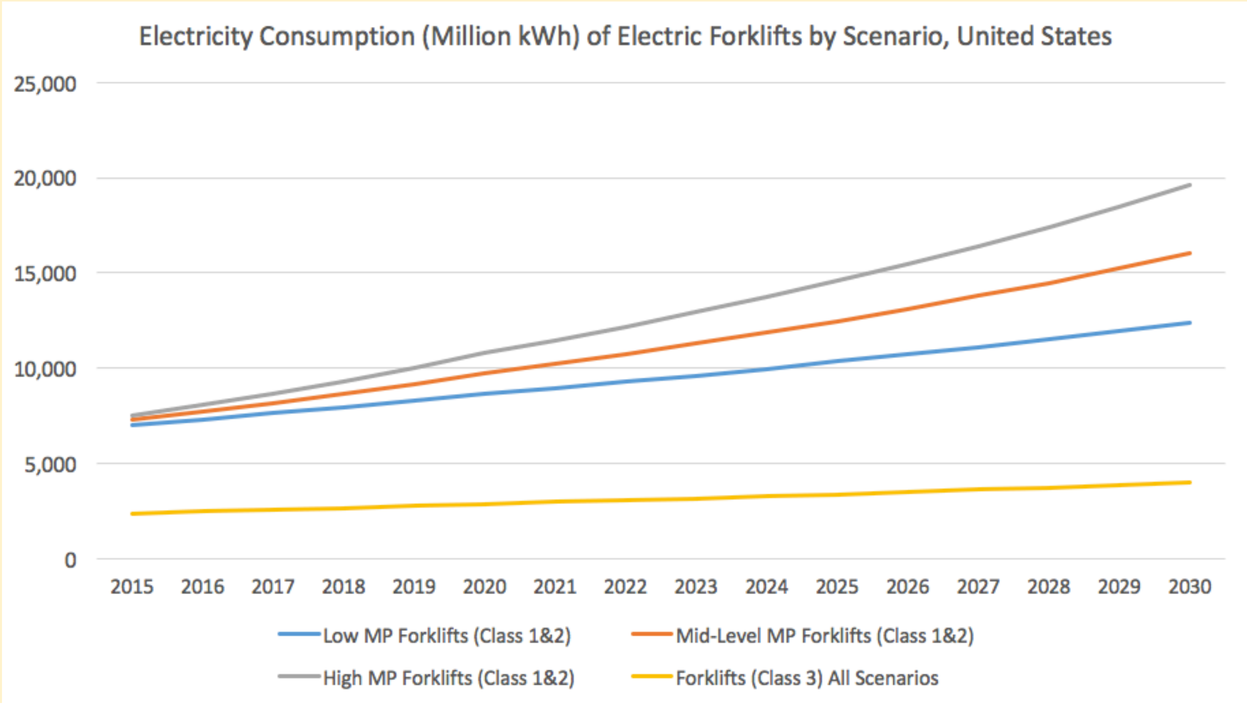


Figure 4. Aggregate Annual Electricity Consumption of Electric Forklifts by Scenario, United States, 2015-2030

Electricity expenditures are estimated for each market penetration scenario, and are based on the following assumptions:

- Electricity rates ($/kWh) and projected price changes from EIA Annual Energy Outlook 2017 (EIA AEO) are used to estimate electricity prices, by sector (commercial and industrial), for each year 2015-2030. Electricity prices are adjusted to $2015.
- Baseline electricity prices for the Mid-Level Market Penetration Scenario and High Market Penetration scenarios are derived from the EIA AEO *Reference Case* and *High Oil Price Case*, respectively. In these scenarios, electricity rates assume demand charges and differences in rates for regular and fast charging. We assume that regular charging comprises 72.5% of charging, and fast charging comprises 27.5%, and using those estimates, we calculate a weighted electricity rate. The overall average electricity rate per kWh with demand charges is estimated to be approximately 57%[5] higher than the baseline electricity rate for each sector. In certain utility markets, of course, demand charges will exceed this level, while demand charges are entirely absent in other utility markets[6][15]. Average weighted electricity price assumptions for each scenario are shown in Figure 5.
- We assume 50% of forklift electricity use is consumed in commercial applications; and 50% is consumed in industrial applications.

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[4] Energy consumption estimates for forklifts—both aggregate and unit-scale—are derived from recent (2014-2016) analyses of cost-effectiveness of electric forklifts by ICF. Market penetration estimates in that study (conducted for California) were scaled to the United States.

[5] In these cases, regular charge rates are assumed to be ~29% higher than baseline rates, and fast charge rates are assumed to be ~129% higher than baseline rates.

[6] Demand charges are present in approximately half of U.S. electricity markets as reported by EIA's Utility Rate Database (https://openei.org/wiki/Utility_Rate_Database) and NREL; demand charges reported in the NREL's database of maximum demand charges for industrial and commercial customers vary from $0 to $90/kW.

- In the Low Market Penetration scenario, baseline electricity prices are derived from the EIA AEO Low Oil Price case, and no demand charges are assumed.

We use aggregate annual electricity consumption and electricity prices to estimate aggregate electricity expenditures for each scenario and year, as compared to a baseline assuming zero market penetration of electric forklifts. Estimated aggregate electricity expenditures for each scenario are shown in Figure 8.

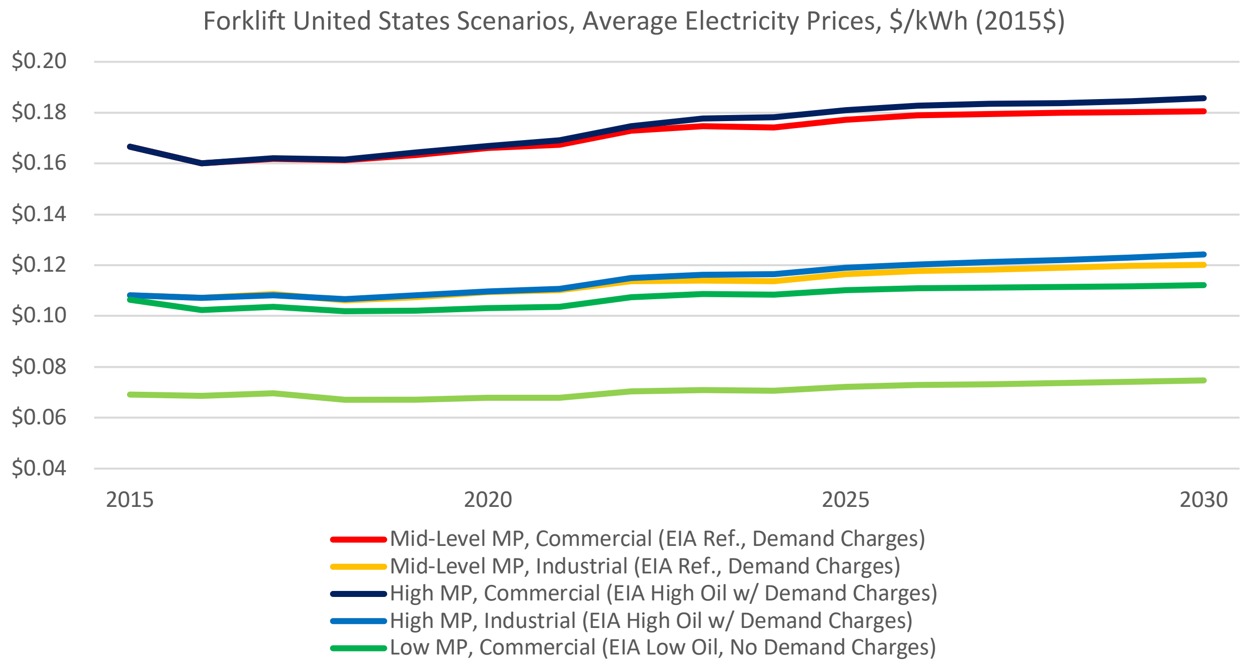

Figure 5. Average Weighted Electricity Prices for Evaluated Electric Forklift Scenarios, United States 2015-2030

3.3.1.2 Petroleum Demand and Savings

The market penetration of electric forklifts will decrease consumption of petroleum fuel. Changes in aggregate petroleum consumption (million gallons) for each market penetration scenario assume that 8,000-pound electric forklifts displace gasoline- or propane-powered forklifts (120 HP or less) consuming 2,360 gallons of fuel per year, and 19,800-pound electric forklifts displace diesel-powered (120-175 HP) forklifts consuming 3,480 gallons of fuel (diesel) per year[7]. Petroleum displacement (millions of gallons of gasoline equivalent (GGE)) estimates for each scenario is shown in Figure 6. Petroleum fuel price assumptions for each scenario and fuel type are shown in Figure 7.

We calculate avoided petroleum expenditures for each scenario using fuel prices from EIA AEO 2017. Fuel prices for commercial and industrial distillate are used to calculate a weighted average assuming 50% commercial, 50% industrial fuel use. The Mid-Level Market Penetration scenario assumes *Reference* case projections; the High Market Penetration scenario assumes *High Oil Price* case projections; and the Low Market Penetration scenario assumes *Low Oil Price* case projections. In addition, we use gasoline prices as a proxy for propane prices. Lastly, annual aggregate petroleum expenditures are calculated assuming that 80.8% of the petroleum fuel displaced is gasoline or propane, and the remainder (19.2%) is diesel.[8]

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[7] Aggregate net petroleum displacement estimates are derived based on estimates reported in ICF (2016). Detailed assumptions not reported here are available in those reports.

[8] Based on underlying assumptions in ICF analysis, that 86.1% of forklifts displace gasoline and propane, and 13.9% displace diesel, and adjusted to reflect relative average fuel consumption for gasoline vs. diesel-powered forklifts.

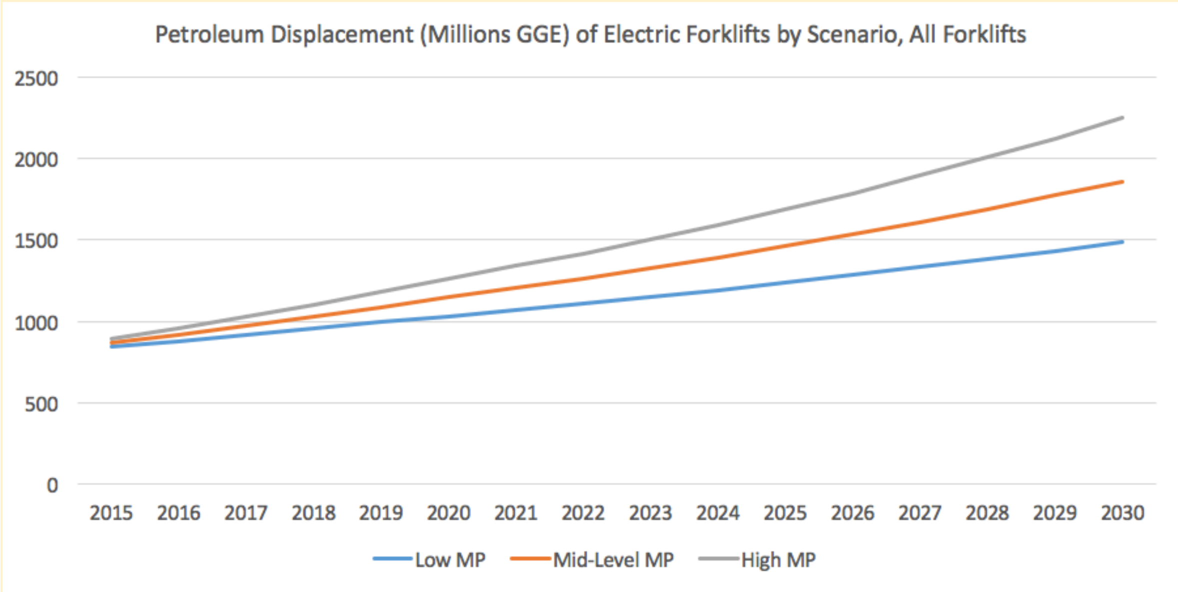


Figure 6. Aggregate Annual Petroleum Displacement due to Electric Forklifts by Scenario, United States, 2015-2030

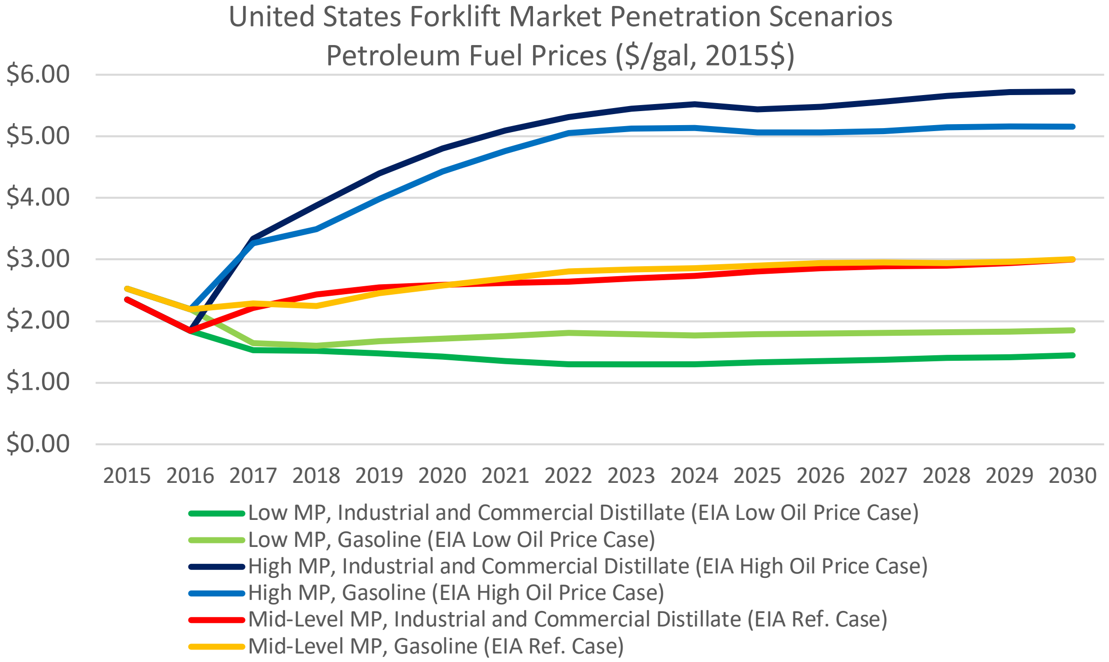


Figure 7. Average Petroleum Fuel Prices for Evaluated Electric Forklift Scenarios, United States 2015-2030

3.3.1.3 Net Fuel Cost Spending Shifts

We estimate aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to electric forklift market penetration in the US for each scenario. Figure 8 shows estimated shifts in expenditures for the Mid-Level Market Penetration scenario (in millions 2015$), compared to a baseline assuming zero market penetration of electric forklifts.

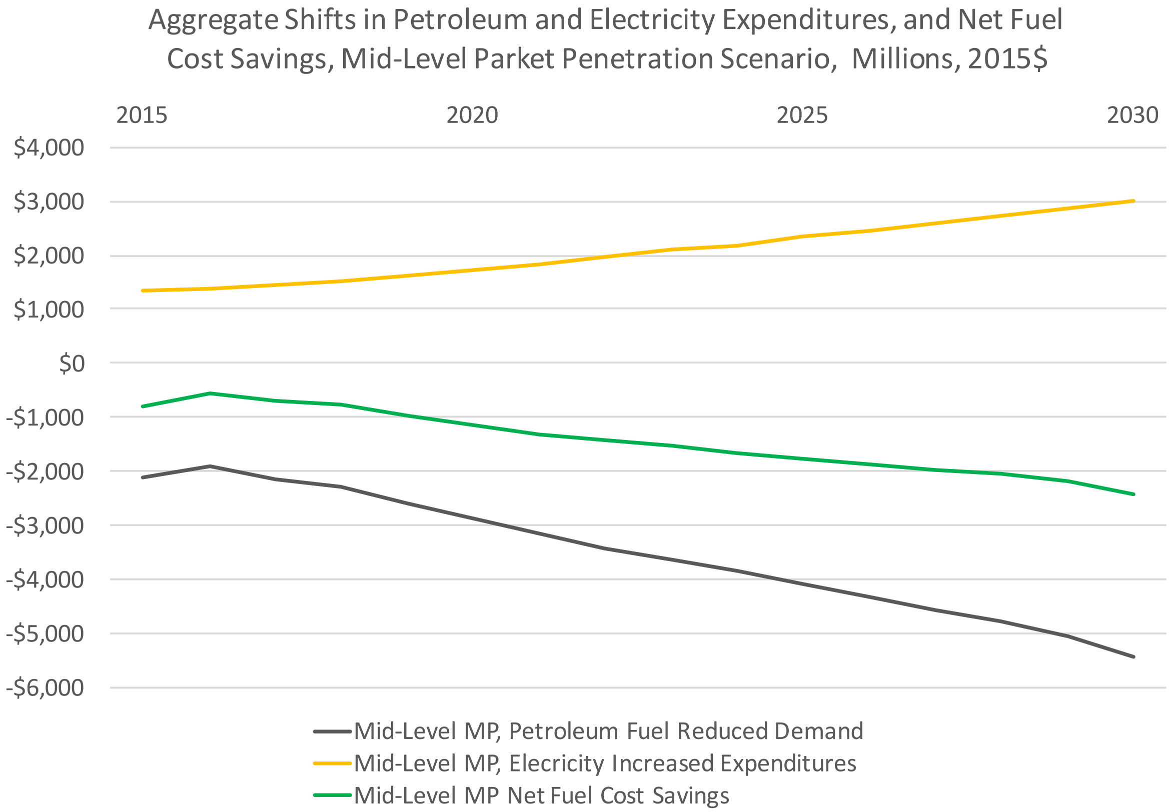


Figure 8. Aggregate Annual Shifts in Electricity and Petroleum Demand, and Net Fuel Cost Savings due to Electric Forklift Market Penetration in the United States, 2015-2030

3.3.1.4 Shifts in Expenditures in Other Forklift-Related Sectors

A shift from conventional to electric forklifts will affect demand for goods and services in many other sectors, including forklift and battery manufacturing, chargers, maintenance, and indirect or induced economic activity in response to operational cost savings. Here we present the approach and assumptions used to estimate these shifts. Unless otherwise noted, capital and maintenance costs are reported in 2015$, and were estimated using a methodology presented in previous work [11, 12].

3.3.1.4.1 Incremental Costs and Forklift Manufacturing

Electric forklifts have higher upfront capital costs compared to conventional forklifts, and so increased market penetration of electric forklifts will require increased expenditures on forklifts. Total electric forklift incremental costs (including batteries) are assumed to range from $12,350 to $27,500 for 8,000 lb. forklifts, and $33,560 for 19,800 lb. forklifts. Assumed battery costs per forklift (discussed below) were subtracted from total forklift incremental costs to estimate non-battery incremental costs. For Low and Mid-Level Market Penetration scenarios, initial incremental costs (in 2015$) are estimated to decline by approximately 10% by 2020, and 25% by 2030. Incremental costs are assumed to stay constant (in 2015$) in the High Market Penetration scenario. For this analysis, we assumed that non-battery incremental costs increased demand in the forklift manufacturing sector. Estimated net shifts in capital expenditures for the Mid-Level Market Penetration scenario are shown in Figure 9.

3.3.1.4.2 Incremental Costs and Battery Manufacturing

Batteries make up a significant share of the incremental cost of electric forklifts. Increased market penetration of electric forklifts will increase capital costs for firms purchasing forklifts, and will also increase demand for battery production. Estimated aggregate shifts in expenditures on forklift batteries are based on assumptions of battery costs per electric forklift ranging from $9,850 to $14,280, with the operating life of batteries (8.4 to 8.9 years) assumed to equal the lifetime of electric forklifts. For Low and Mid-Level Market Penetration scenarios, incremental costs (in 2015$) are estimated to decline by approximately 40% by 2020, and decline by 60% by 2030, based on projections for future battery costs in electric transportation [11, 16, 17]. Incremental costs are assumed to stay constant (in 2015$) in the High Market Penetration scenario. We attribute aggregate increased forklift battery expenditures to the battery manufacturing for I/O analysis. Net estimated shifts in expenditures on electric forklift batteries for the Mid-Level Market Penetration scenario are shown in Figure 9.

3.3.1.4.3 Forklift Chargers

Chargers are another capital equipment cost associated with switching from conventional to electric forklifts. Aggregate shifts in expenditures for chargers were estimated assuming capital costs for chargers ranging from $3,500 to $5,000 for regular chargers on the low end, to $10,000 to $15,000 for fast chargers on the high end, with a lifetime of 14 years per charger. Estimates of annual aggregate expenditures on chargers are translated to increased demand in the battery charger manufacturing sector.

3.3.1.4.4 Maintenance Costs

Due to the relative lack of moving parts and mechanical components, electric forklifts require less maintenance than conventional, petroleum-powered alternatives. Annual costs are estimated to be approximately $900 less for electric forklifts, compared to conventional counterparts (for all evaluated forklift classes, sizes, and fuel types). This difference in annual maintenance costs is assumed to be constant across the forklift lifetime. We allocate these savings to forklift owners and operators, and we reduce demand for commercial and industrial machinery and equipment repair and maintenance sector for each year.

3.3.1.5 Net Operational Cost Savings

Electric forklifts tend to have lower cost of ownership compared to conventional petroleum-powered alternatives [11, 12]. We estimated these annual cost savings as follows, as compared to a baseline scenario with zero market penetration of electric forklifts:

$$\$S_y = \Delta\$E_y + \Delta\$P_y + \Delta\$I_y + \Delta\$C_y + \Delta\$M_y$$

where: y = year; $E = electricity expenditures; $P = petroleum expenditures; $I = incremental cost expenditures; $C = charger expenditures; and $M = maintenance cost expenditures.

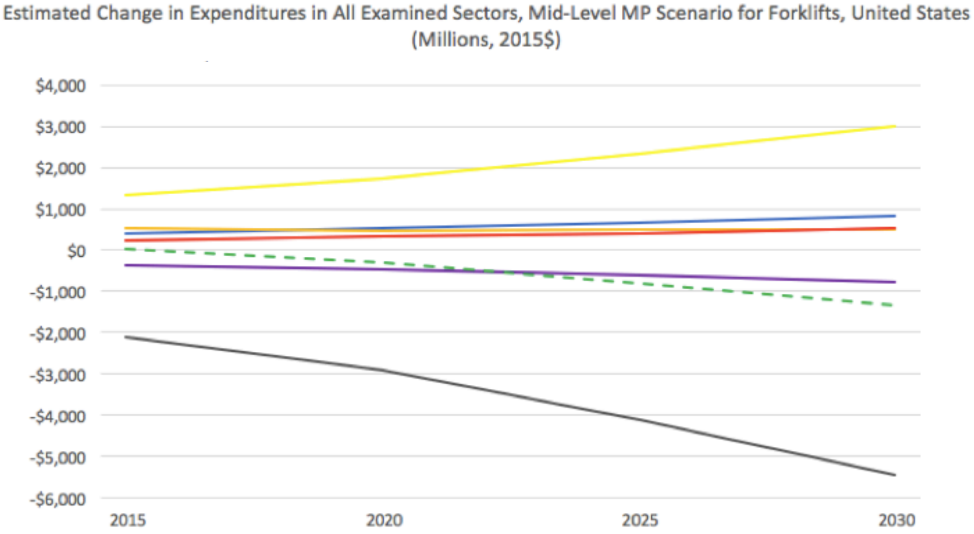
There is uncertainty in terms of how and where operational cost savings will be allocated, and therefore which sectors of the economy will benefit. Net operational savings may be used in a number of ways, including being retained and reinvested by industries using forklifts, being passed on to shareholders, being passed onto customers in the form of reduced prices, or any combination of these, which could vary within and between years. To estimate a range of potential economic impacts of forklift operational cost savings, we examine two cases:

- Case I: Savings to Households (HH)
  The first case assumes that any operational cost savings are passed on to customers. Case I assumes that companies using forklifts pass their savings onto customers to remain competitive, and these reduced costs are ultimately realized by households in the form of lower prices on goods. The net savings to household are assumed to be spent on other goods and services in the economy based on existing household spending patterns.

- Case II: Savings to Industries Using Forklifts (Business Surplus—BS):
  The second case assumes that operational cost savings are retained--and then spent--by the firms and industries using forklifts. Case II also assumes that these industries spend the savings using the typical spending patterns associated with increased demand and activity of their sector. Forklifts are used in many industrial and commercial applications, ranging from construction to warehousing to manufacturing to retail. In this case, we assign savings to the representative sectors (shown in Table 1). These results represent net impacts compared to a hypothetical baseline scenario of zero electric forklifts, in which all existing or projected forklifts are powered by petroleum fuel.

Estimated employment and output impacts reported in Table 2 and Table 3 include not only changes in activity in the sectors assumed to see direct shifts in demand (i.e. sectors shown in Table 1), but also indirect impacts (changes in employment and output in sectors providing necessary goods and services to an examined sector experiencing a direct shift in demand—for instance, the industries providing components to battery manufacturing would see indirect increases in demand), and induced impacts (economic activity in response to employees spending their earnings throughout the economy). Induced impacts here are particularly important in the context of Case I, where forklift operational cost savings are assumed to accrue to households, as households are assumed to spend these savings on goods and services throughout the economy. Details on direct, indirect, and induced economic impacts –for forklifts, and for each following technology and scenario—are available in the Appendix.

Figure 9 shows the estimated monetized shifts in demand for each sector and year, for the Mid-Level Market Penetration Scenario. Similar details for the Low and High-Market Penetration scenarios are available in the Appendix. Estimated shifts in demand are reported in $2015.



— Reduced Petroleum Fuel Demand	-$2,116	-$2,890	-$4,091	-$5,445
— Increased Electricity Demand	$1,332	$1,741	$2,332	$3,009
— Increased Forklift Incremental Cost (Other)	$405	$525	$657	$823
— Increased Forklift Incremental Cost (Battery)	$535	$476	$491	$510
— Increased Expenditures, Chargers	$249	$327	$415	$526
— Reduced Maintenance Demand	-$358	-$470	-$596	-$755
– – Net Operational Cost/Savings (Negative = Net Savings)	$47	-$291	-$792	-$1,332

Figure 9. Aggregate Annual Shifts in Expenditures due to U.S. Electric Forklift Market Penetration, 2015-2030

3.3.2 Macroeconomic Impacts of Electric Forklifts in the United States

We estimate the macroeconomic impacts of the shifts described above using the IMPLAN input-output analysis program with US datasets. The estimated shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors. Table 1 shows the categories for shifts in expenditures, and the associated sector in IMPLAN where shifts in demand are assigned. Impacts include total cumulative changes in employment (in job-years) and output ($ million) for the time period 2015-2030 for each scenario and case, shown in Table 2. We also estimate impacts for the years 2025 and 2030, as shown in Table 3. Estimated cumulative employment and output impacts by sector for the top ten sectors are available in the Appendix.

Employment impacts for the Mid-Level Market Penetration scenario are estimated to reach up to 25,000 jobs by 2030, for a cumulative impact of increased employment of 156,000 to 200,000 job-years for the entire period of 2015-2030. National economic output is expected to increase under this scenario by $3.5-$4.2 billion per year in 2030, for cumulative impacts of $36-$41 billion in the years 2015 through 2030. These results represent net impacts compared to a hypothetical baseline scenario of zero electric forklifts, in which all existing or projected forklifts are powered by petroleum fuel.

Estimated employment and output impacts reported in Tables 2 and 3 include not only changes in activity in the sectors assumed to see *direct* shifts in demand (i.e. sectors shown in Table 1), but also *indirect* impacts (changes in employment and output in sectors providing necessary goods and services to an examined sector experiencing a direct shift in demand—for instance, the industries providing components to battery manufacturing would see indirect increases in demand), and *induced* impacts (economic activity in response to employees spending their earnings throughout the economy). Induced impacts here are particularly important in the context of Case I, where forklift operational cost savings are assumed to accrue to households, as households are assumed to spend these savings on goods and services throughout the economy. Details on direct, indirect, and induced economic impacts –for forklifts, and for each following technology and scenario—are available in the Appendix.

Table 1. Estimated Shifts in Expenditures due to Electric Forklifts, and Associated Sector for Input-Output Analysis

Shift in Expenditures	Assigned Sector
Electricity	Electric Power Transmission and Distribution
Petroleum Fuel	Petroleum Refineries
Forklift Incremental Costs (non-battery)	Industrial Truck, Trailer, and Stacker Manufacturing
Forklift Battery Costs	Battery Manufacturing
Forklift Chargers	All other Miscellaneous Electrical Equipment and Component Manufacturing
Maintenance Costs	Commercial and Industrial Machinery and Equipment Repair and Maintenance
Net Operational Costs: Case I (Savings to Households—HH)	Households
Net Operational Costs: Case II (Savings to Business—BS)	Warehousing and Storage; Building Material and Garden Equipment and Supplies; Food and Beverage; and, Paper Mills

Table 2. Estimated Macroeconomic Impacts of Electric Forklifts in United States, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

United States Forklifts	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	12,800	17,000	5,800	9,100	38,700	54,800
Year 2030	17,900	25,000	7,700	12,700	52,900	76,400
Cumulative	**156,000**	**200,000**	**87,100**	**138,800**	**469,200**	**650,700**
Output (Millions, 2015$)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	$2,800	$3,200	$1,300	$1,600	$4,700	$6,400
Year 2030	$3,500	$4,200	$1,500	$2,100	$6,300	$8,800
Cumulative	**$36,400**	**$41,000**	**$17,400**	**$22,900**	**$60,000**	**$79,300**

3.4 Macroeconomic Impacts for Texas

3.4.1 Texas Market Penetration Scenarios

For the Texas analysis, the assumptions behind the market penetration scenarios are nearly identical to those used in the US analysis, and include estimates for Low-, Mid-Level, and High Market Penetration. Forklift population estimates are scaled based on Texas' share of the US population[9], as reported or projected by the US Census, for years 2015 through 2030. Figure 10 shows the assumed population of electric forklifts in Texas, by class, for each scenario. In the Mid-Level Market Penetration scenario, the Class 1 & 2 electric forklift population is projected to reach ~46,000 by 2020, and ~81,000 by 2030. Additional assumptions specific to Texas are described below.

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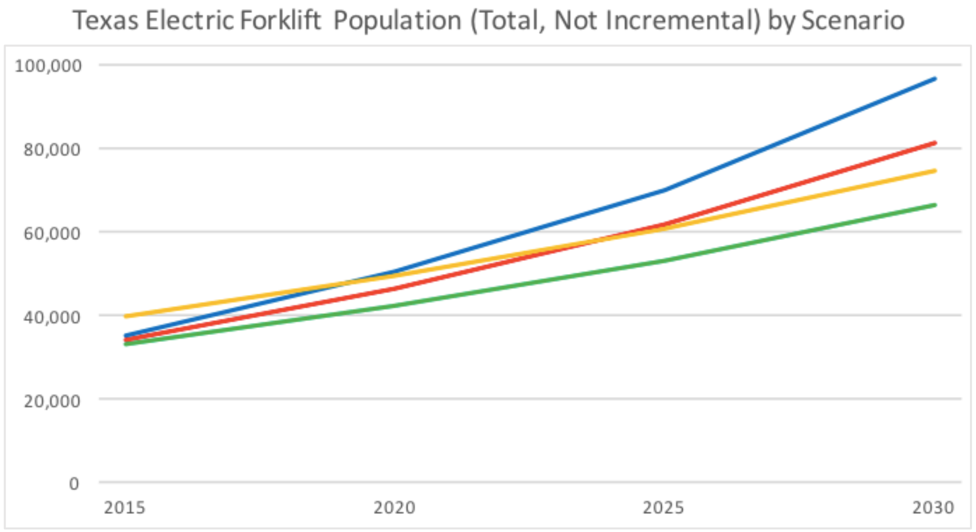
[9] As geographic-specific data on forklift numbers and use are largely unavailable, resident population numbers have been used to estimate state-level forklift populations in other analyses, such as ICF (see references).



🟩 Forklifts (Class 1&2) Low MP	33,100	42,100	52,700	66,000
🟥 Forklifts (Class 1&2) Mid-level MP	34,100	46,300	61,400	81,200
🟦 Forklifts (Class 1&2) High MP	34,900	50,600	69,900	96,500
🟨 Forklifts (Class 3) All Scenarios	39,500	49,200	60,600	74,500

Figure 10. Texas Electric Forklift Market Penetration by Scenario (Total Population, not Incremental), 2015-2030

3.4.2 Shifts in Expenditures: Texas

3.4.2.1 Electricity Demand and Costs

Using the electricity use assumptions in the preceding section, we estimate electricity demand for each Texas scenario and year. These estimates are shown in Figure 11. Electricity price assumptions are specific to Texas or the EIA South Central region, where appropriate, and are shown in Figure 12; aggregate electricity expenditures as compared to a zero baseline are shown in Figure 15.

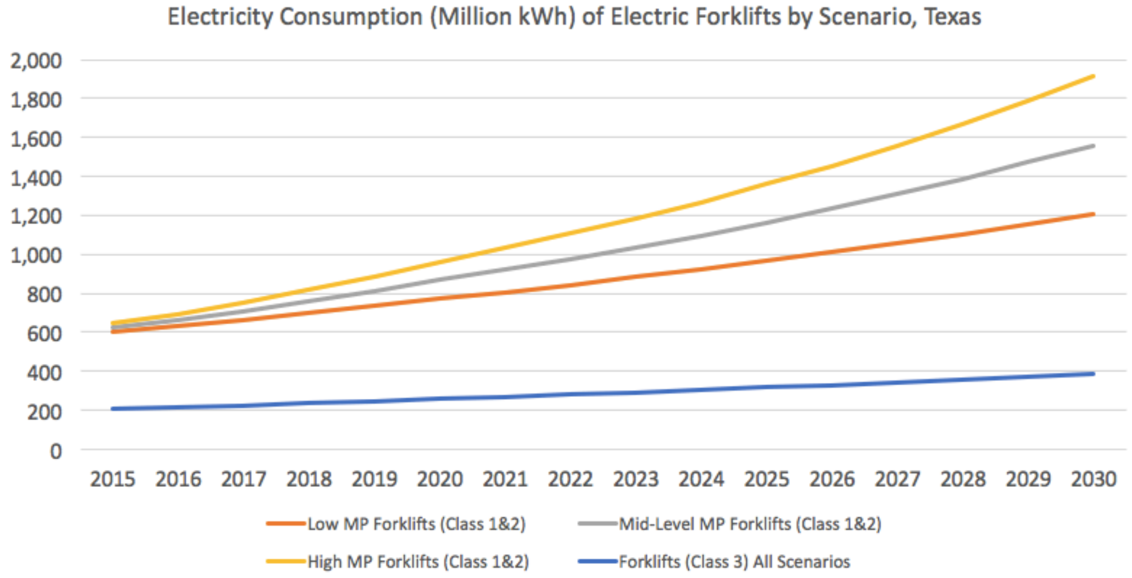


Figure 11. Aggregate Annual Electricity Consumption of Electric Forklifts by Scenario, Texas, 2015-2030

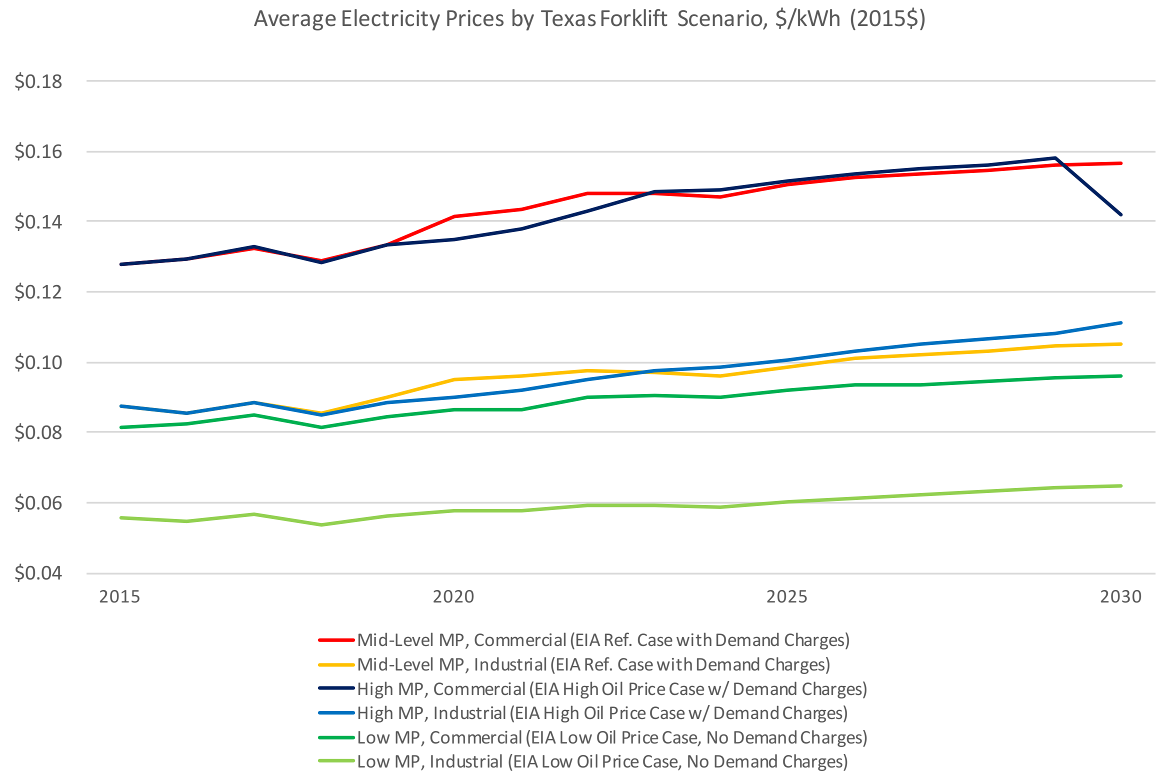


Figure 12. Average Weighted Electricity Prices for Evaluated Electric Forklift Scenarios, Texas 2015-2030

3.4.2.2 Petroleum Demand and Savings

Using forklift fuel use and displacement assumptions outlined above, we estimate petroleum displacement for each Texas scenario. Estimated annual petroleum displacement (millions GGE) for each Texas scenario is shown in Figure 13. Avoided petroleum expenditures are calculated using the assumptions described in the preceding section, with the exception that fuel prices from U.S. DOE EIA and projections from EIA AEO use prices specific to Texas or the EIA South Central region. Petroleum fuel price assumptions are shown in Figure 14.

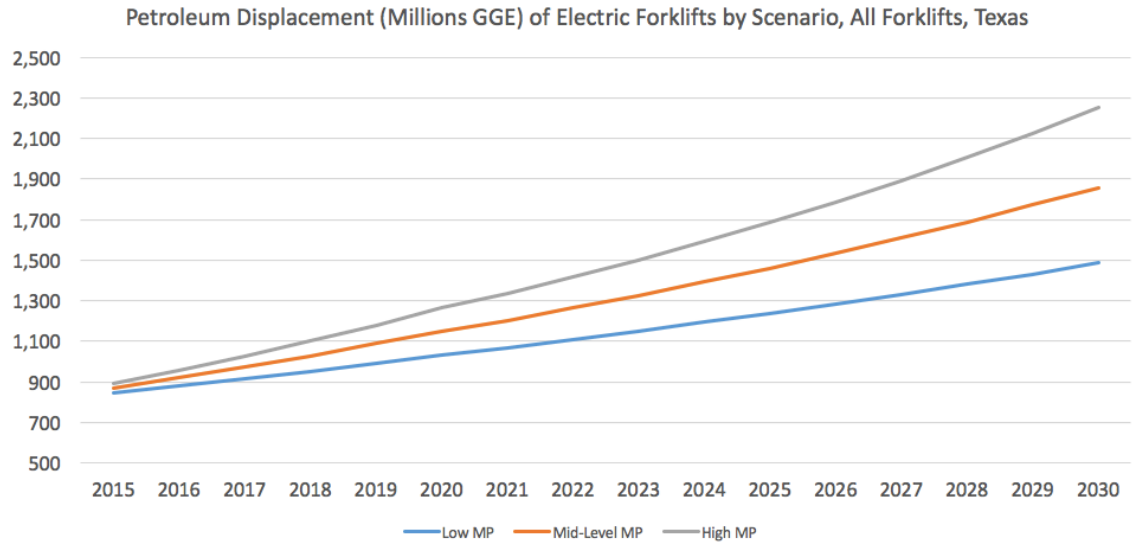


Figure 13. Aggregate Annual Petroleum Displacement due to Electric Forklifts by Scenario, Texas, 2015-2030

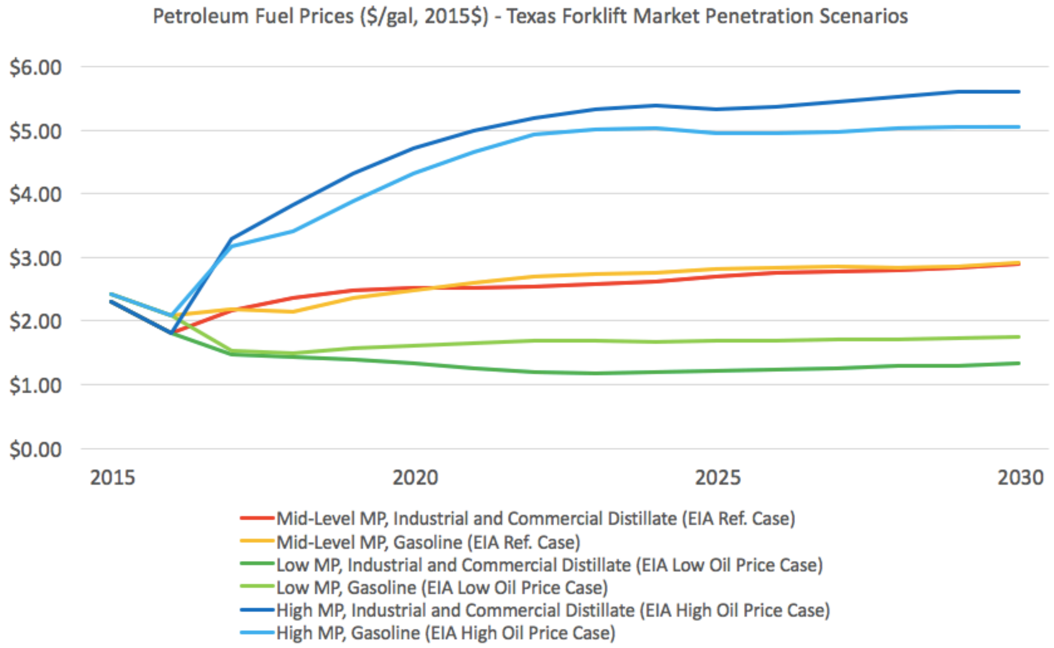


Figure 14. Average Petroleum Fuel Prices for Evaluated Electric Forklift Scenarios, Texas 2015-2030

3.4.2.3 Aggregate Spending Shifts

Aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to electric forklift market penetration in Texas are estimated for each scenario and year, 2015-2030. Figure 15 shows estimated shifts in expenditures (in millions 2015$) for the Mid-Level Market Penetration Scenario.

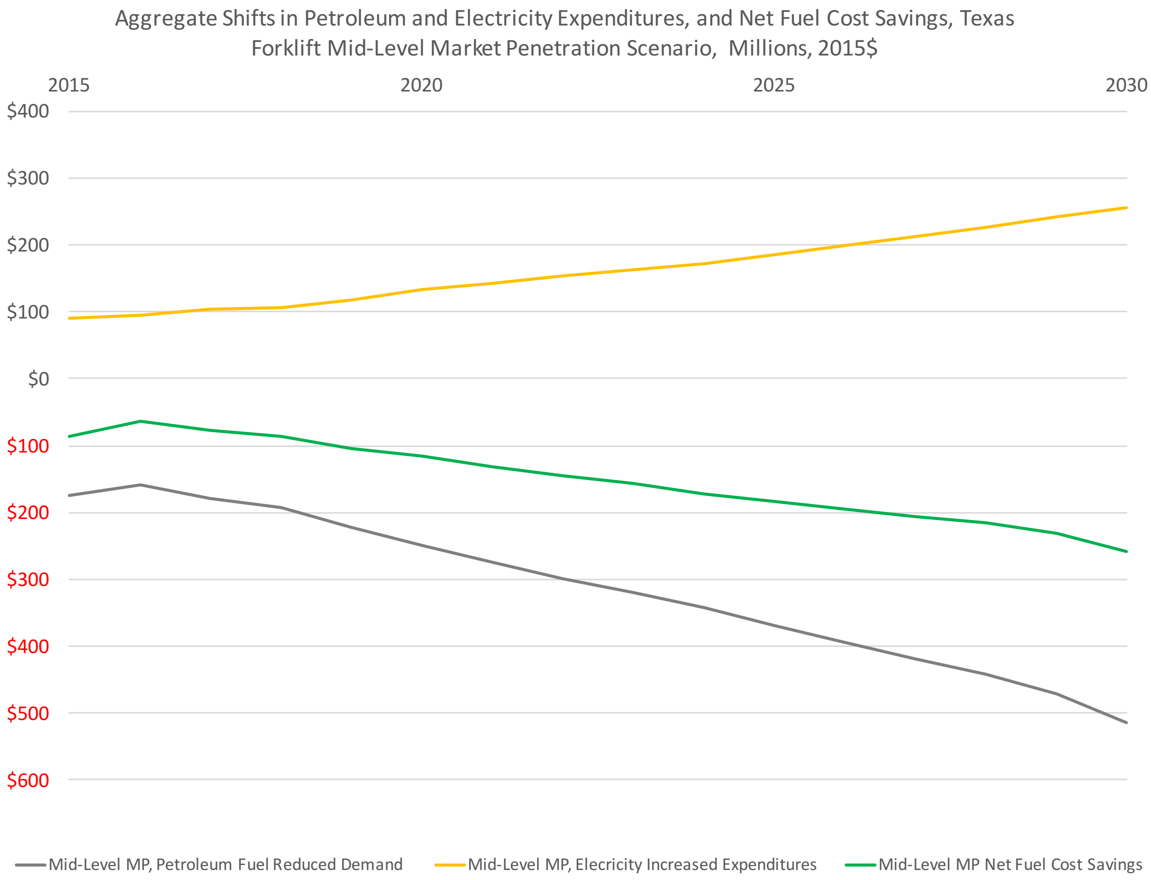


Figure 15. Aggregate Annual Shifts in Electricity and Petroleum Demand, and Net Fuel Cost Savings due to Electric Forklift Market Penetration in Texas, 2015-2030

3.4.2.4 Shifts in Expenditures in Other Forklift-Related Sectors

As described in greater detail in the preceding section, a shift from conventional to electric forklifts will involve changes in expenditures for many sectors, including forklift and battery manufacturing, chargers, maintenance, and indirect or induced economic activity in response to operational cost savings. The approach and assumptions used to estimate these shifts in spending in Texas are nearly identical to those used in the US analysis above, unless otherwise noted (e.g. energy price assumptions).

Figure 16 shows the estimated monetized shifts in demand for each sector and year, for the Texas Mid-Level Market Penetration scenario. Similar details for the Low- and High-Market penetration scenarios are available in the Appendix. Estimated shifts in demand are reported in $2015.

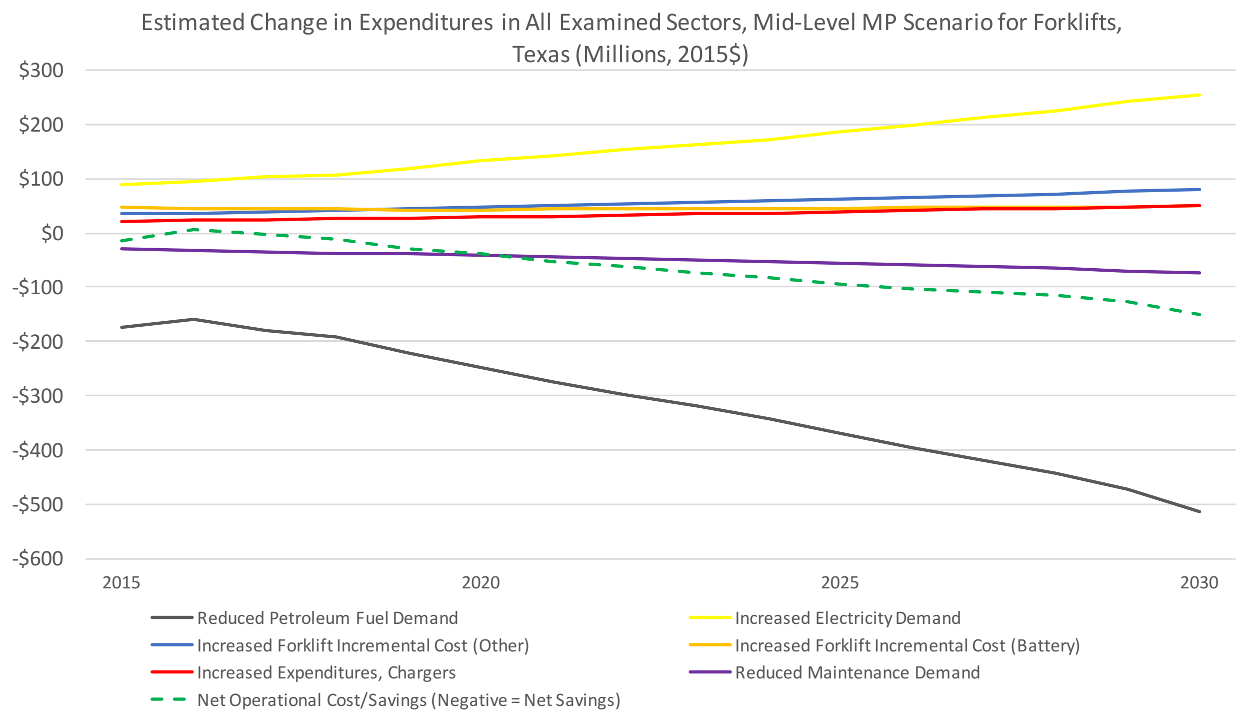


Figure 16. Estimate Aggregate Shifts in Expenditures due to Electric Forklift Market Penetration in Texas, 2015-2030

3.4.3 Macroeconomic Impacts: Texas

The macroeconomic impacts for Texas were estimated using the IMPLAN input-output analysis program, with datasets extracted for the State of Texas. The estimated shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors, as shown in Table 1 (in the preceding section). Macroeconomic impacts include total cumulative changes in employment (in job-years) and output ($ million), for the time period 2015-2030, for each scenario and case. Estimated impacts for the individual years 2025 and 2030 are also reported here. Estimated cumulative employment and output impacts by sector, for the top ten sectors, are available in the Appendix, as are estimates of cumulative direct, indirect, and induced employment and output impacts.

Employment impacts in Texas for the Mid-Level Market Penetration scenario are estimated to reach up to 1,800 jobs by 2030, for a cumulative impact of increased employment of 8,400 to 14,200 job-years for the entire period of 2015-2030. Mid-level market penetration of electric forklifts is estimated to increase state-wide economic output by $70-$170 million per year in 2030, with cumulative impacts of $660 million to $1.36 billion in increased economic output estimated for the entire period (2015-2030).

Table 3. Estimated Macroeconomic Impacts of Electric Forklifts in Texas, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

Texas Forklifts	Mid-Level Market Penetration		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	700	1,200	300	600	2,300	4,000
Year 2030	1,000	1,800	400	900	3,400	6,000
Cumulative	**8,400**	**14,200**	**4,400**	**9,800**	**28,300**	**47,500**
Output (Millions, 2015$)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	$60	$120	$20	$60	$30	$230
Year 2030	$70	$170	$20	$80	$40	$340
Cumulative	**$660**	**$1,360**	**$120**	**$780**	**$310**	**$2,600**

3.5 Chapter Conclusion

The results indicate that large-scale market penetration of electric forklifts in the United States and Texas, and resulting petroleum fuel displacement, fuel cost savings, and shifts in related industries, have the potential to produce substantial and positive macroeconomic benefits in the form of tens of thousands of jobs and billions of dollars of increased output by 2030.

4 Macroeconomic Impacts of Truck Stop Electrification: An Assessment for the United States and Ohio

Summary of Chapter Findings

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, truck stop electrification (TSE) in the United States will displace approximately 190 million gallons of petroleum fuel per year, at net fuel cost savings of $650 million per year. This, combined with other modeled economic shifts, will result in increased output of $560 million and increased employment of 9,000 jobs. Cumulatively, over 36,000 job-years of employment and $2.3 billion in increased economic activity is expected between 2015-2030.

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, truck stop electrification (TSE) in Ohio will displace nearly 7 million gallons of petroleum fuel per year, at net fuel savings of nearly $23 million per year. This will result in increased output of $20 million per year and increased employment of 350 jobs. Cumulatively, approximately 1,300 job-years of employment and $75 million in increased economic activity is expected between 2015 and 2030.

4.1 Chapter Overview

Long-haul trucking involves federally-mandated rest periods for drivers. During these rest periods the majority of operators opt to remain in their truck cabins, often idling the vehicle's engine so as not to lose the heating, cooling, or other power services that idling allows. Idling consumes a great deal of diesel fuel, especially in comparison to the relatively meager energy requirements of services provided in the cabin.

On average, idling consumes ~0.8 gallons of diesel fuel per hour, or 8 gallons over a ten-hour rest period [18]. This can add up to a substantial cost to truck drivers, owners, and operators. At $3.00 per gallon of diesel, $24 of diesel fuel could be consumed in one rest period; with an estimated 1,800 hours of annual idling during rest periods per long-haul truck, over $4,300 of fuel could be consumed idling per truck each year. In total, truck idling is estimated to consume about *1 billion* gallons of fuel annually, at a total cost of about *$3 billion* per year[18].

Truck stop electrification (TSE) technologies provide power to the truck cabin, allowing drivers to continue to use necessary energy services in their cabins without idling. In this analysis, we examine two types of TSE technologies: (1) plug-in APUs/Shorepower; and, (2) IdleAir. With plug-in APUs/Shorepower, the truck driver plugs into a parking stall to power onboard systems such as heaters, air conditioners, or accessories (such as coffee makers). IdleAir is standalone and provides power, heating and air conditioning through a vent-like system attached to the truck window, and does not require drivers to acquire additional equipment to operate.[10]

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[10] Shorepower (plug-in APU) and IdleAir TSE currently comprise over 90% of TSE spaces in the U.S. (2,630 out of 2,903 total). The relative market shares of Shorepower (53%) and IdleAir (37.6%) are assumed to remain constant throughout the examined

Both technologies are available to truck operators at designated parking spaces at truck stops and travel centers, and are made available for an hourly fee, which is substantially less than the equivalent cost of fuel used during idling. Large-scale use of TSE has potential in terms of fuel cost savings to trucking firms and related macroeconomic impacts of these fuel cost savings. In this chapter, we evaluate these macroeconomic impacts for future market penetration scenarios for two regions: (1) United States, and (2) Ohio. We first describe the TSE scenario assumptions, which apply to both regions. Next, we present the scenario assumptions and results specific to the United States. Finally, we present the assumptions and results specific to the Ohio analysis.

4.2 Scenario Development

We evaluate three scenarios for the time period 2015-2030: Low, Mid-Level, and High Market Penetration. In order to capture a range of potential economic impacts, we explore a variety of energy prices, capital equipment costs, and other variables. Descriptions of the scenarios are as follows:

- Low Market Penetration Scenario
  In this scenario, we assume market penetration rates consistent with a recent analysis of cost-effectiveness of electric vehicles and technologies [11, 12]. For the TSE Low Market Penetration scenario, we assume that the current number of TSE spaces (2,630) remains constant through 2030, though the use of these (capacity factor) increases from 28% in 2015 to 50% in 2020, and 60% in 2030. The number of TSE spaces is based on the number of electrified parking spaces identified in the U.S. Department of Energy's Alternative Fuels Data Center in 2017 [19]. Energy prices for this scenario are derived from EIA AEO projections using the *Low Oil Price* case. We assume capital costs and vehicle equipment costs to be on the low end of the range of estimates.

- High Market Penetration
  In this scenario, we assume 30% of truck parking spaces are electrified in 2020, and 50% in 2030, for a total of over 100,000 electrified spaces by 2030. The average capacity factor of spaces is assumed to increase to 67% in 2020 and 75% in 2030. Energy prices for this scenario are derived using EIA AEO *High Oil Price* case projections. We assume capital costs and vehicle equipment costs to be on the high end of the range of estimates.

- Mid-Level Market Penetration Scenario
  In this scenario, we assume market penetration falls halfway between that of the Low and High Market Penetration scenarios, as shown in Figure 17, with the number of TSE spaces exceeding 52,000 by 2030. Energy prices for this scenario are derived from EIA AEO *Reference Case* projections. We assume capital costs and vehicle equipment costs to be in the mid-range of low and high estimates.

Figure 17 shows the population of TSE spaces in the US for each scenario.

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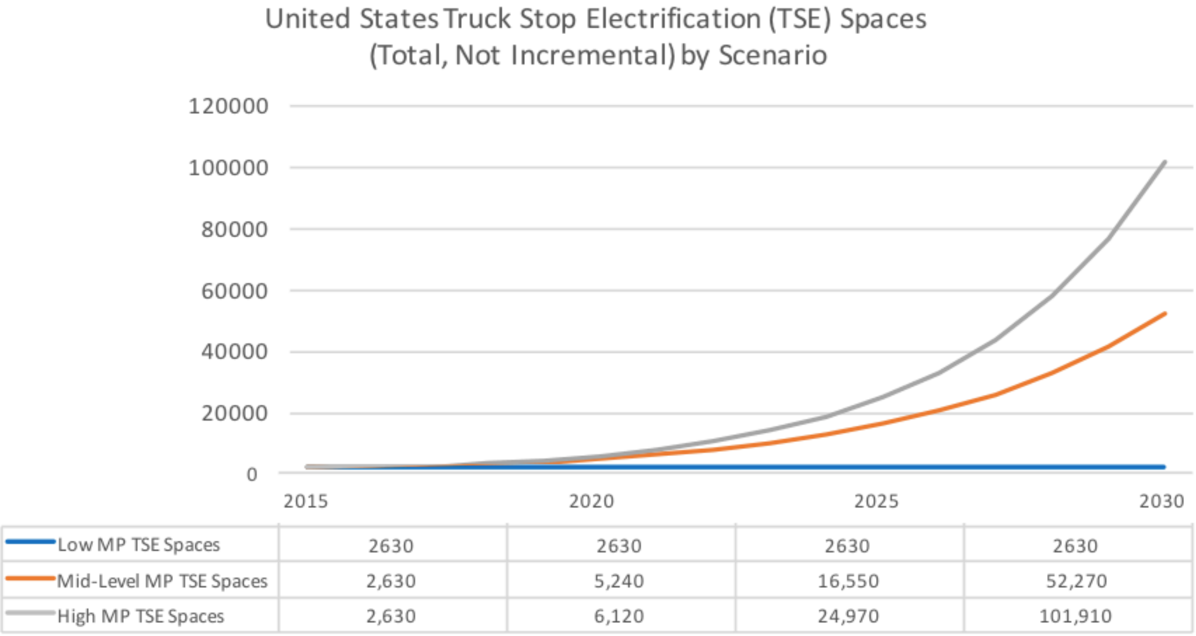
period. Total non-electrified spaces are based on total available truck parking spaces in the U.S., as reported in AllStays, an online database of facilities for truckers.



	2015	2020	2025	2030
Low MP TSE Spaces	2630	2630	2630	2630
Mid-Level MP TSE Spaces	2,630	5,240	16,550	52,270
High MP TSE Spaces	2,630	6,120	24,970	101,910

Figure 17. U.S. TSE Market Penetration by Scenario (Total Electrified Parking Spaces), 2015-2030

4.3 Macroeconomic Impacts for the United States

4.3.1 Shifts in Expenditures: United States

4.3.1.1 Electricity Demand and Costs

Shifts in energy consumption in the electricity and petroleum markets occur under conditions of TSE market penetration. For example, large-scale market penetration of TSE will increase electricity consumption and demand for electricity generation, transmission, and distribution. Aggregate electricity consumption (million kWh) for each scenario is based on the assumption that TSE consumes 1.39 kWh per space per hour, with each space used ~2,450 to ~6,570 hours per year (depending upon scenario and year).[11] Estimated projected electricity demands for each scenario, as compared to a zero baseline TSE scenario, are shown in Figure 18.

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[11] Energy consumption estimates for TSE spaces are based on recent (2014-2016) analyses of cost-effectiveness of TSE in California (2016).

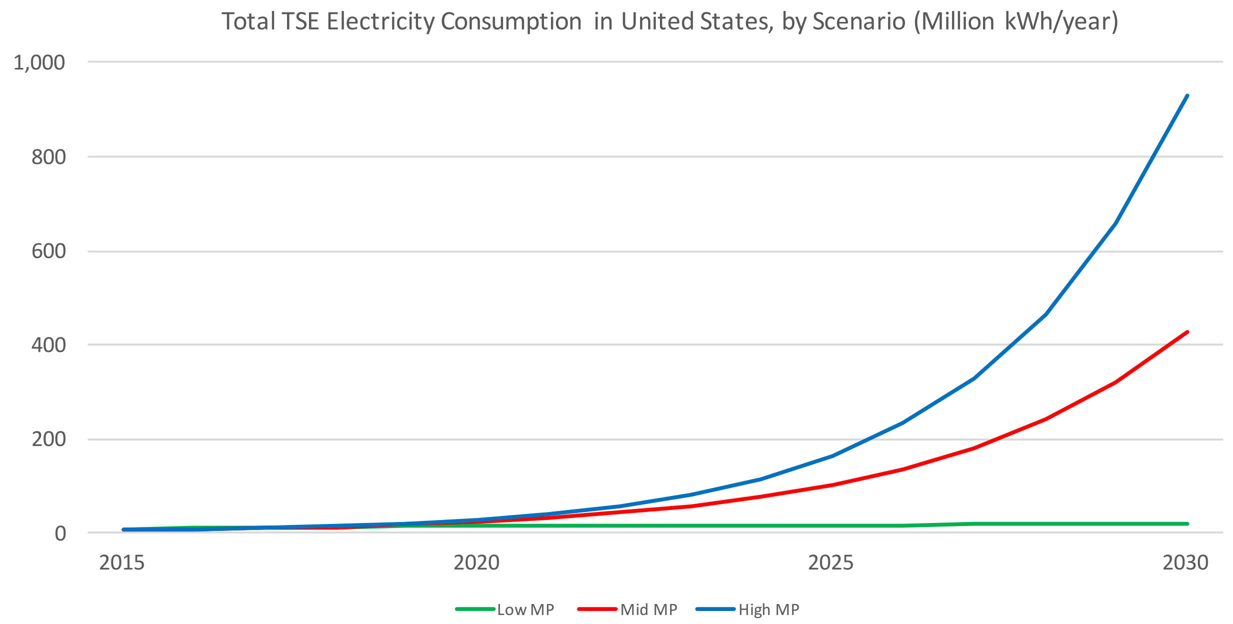

Figure 18. Aggregate Annual Electricity Consumption of TSE by Scenario, United States, 2015-2030

We estimate electricity expenditures for each scenario based on the following assumptions:

- Electricity rates ($/kWh) from US DOE EIA and projected price changes from EIA AEO 2017 are used to estimate US average electricity prices for 2015-2030. Electricity prices are adjusted to $2015.
- Baseline electricity prices for the Mid-Level, Low, and High Market Penetration scenarios are derived from the EIA AEO *Reference Case*, *Low Oil Price Case*, and *High Oil Price Case*, respectively.

Electricity price estimates are shown in Figure 19. We use these prices, along with aggregate annual electricity consumption estimates, to calculate aggregate electricity expenditures for each scenario and year, compared to a baseline assuming zero market penetration of TSE. Estimated aggregate electricity expenditures for each scenario are shown in Figure 22.

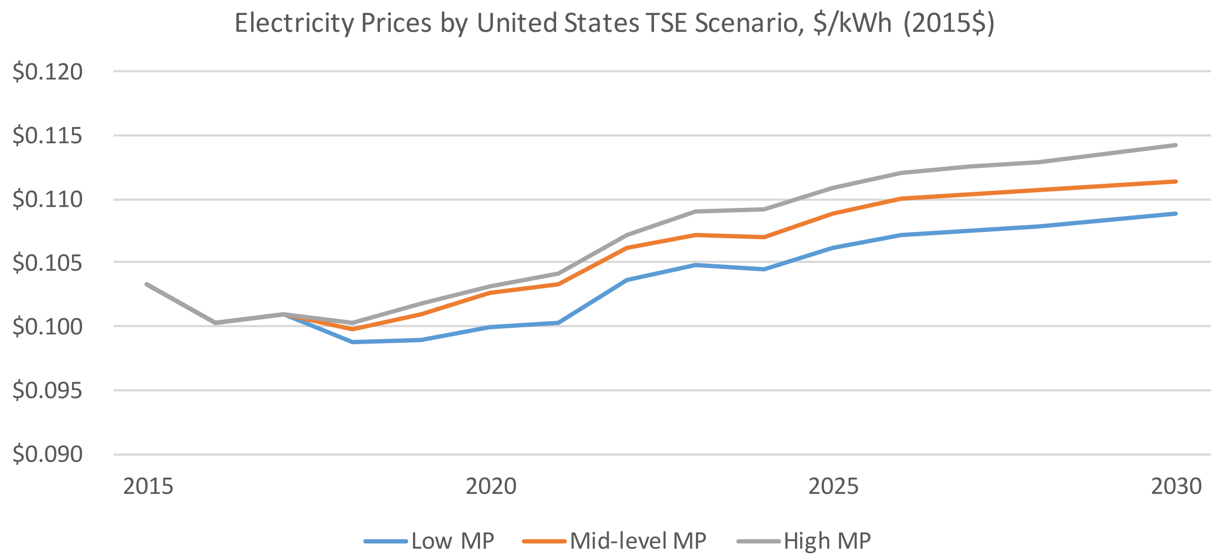

Figure 19. Average Annual Electricity Prices for Evaluated TSE Scenarios, United States 2015-2030

4.3.1.2 Petroleum Demand and Savings

Market penetration of TSE will decrease consumption of petroleum fuel. To estimate changes in aggregate petroleum consumption (million gallons) for each scenario, we assume that TSE displaces the use of fuel in two main categories. The first is replacing straight idling by trucks, which would otherwise consume 0.8 gallons of diesel fuel per hour [20]. The second is displacing the use of on-board auxiliary power units (APUs), which are assumed to consume 0.35 gallons of diesel fuel per hour [20]. In all scenarios, we assume that the market penetration of APUs is 9% through 2020, increasing exponentially to 30% in 2020 and 40% in 2030. Each TSE space is assumed to be used ~2,450 to ~6,570 hours per year, depending upon the scenario (details are available in the Appendix). Petroleum displacement (millions of gallons of diesel equivalent) is estimated for each scenario and year compared to a baseline assuming zero use of TSE; estimates are shown in Figure 20.

We use fuel price projections from EIA AEO 2017 to estimate on-road diesel prices for each year, 2015-2030 (2015$). For the Mid-Level Market Penetration scenario, we assume EIA AEO *Reference Case* projections; for the High Market Penetration scenario we assume *High Oil Price Case* projections; and, for the Low Market Penetration scenario we assume *Low Oil Price Case* projections. Diesel fuel price assumptions for each scenario and fuel type are shown in Figure 21.

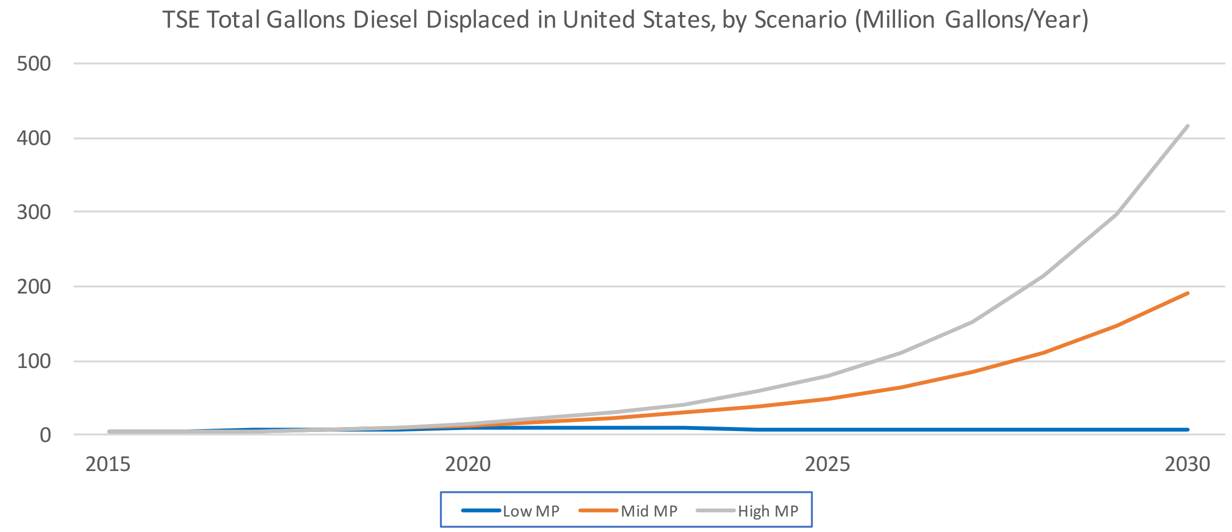

Figure 20. Aggregate Annual Diesel Displacement due to TSE by Scenario, United States, 2015-2030

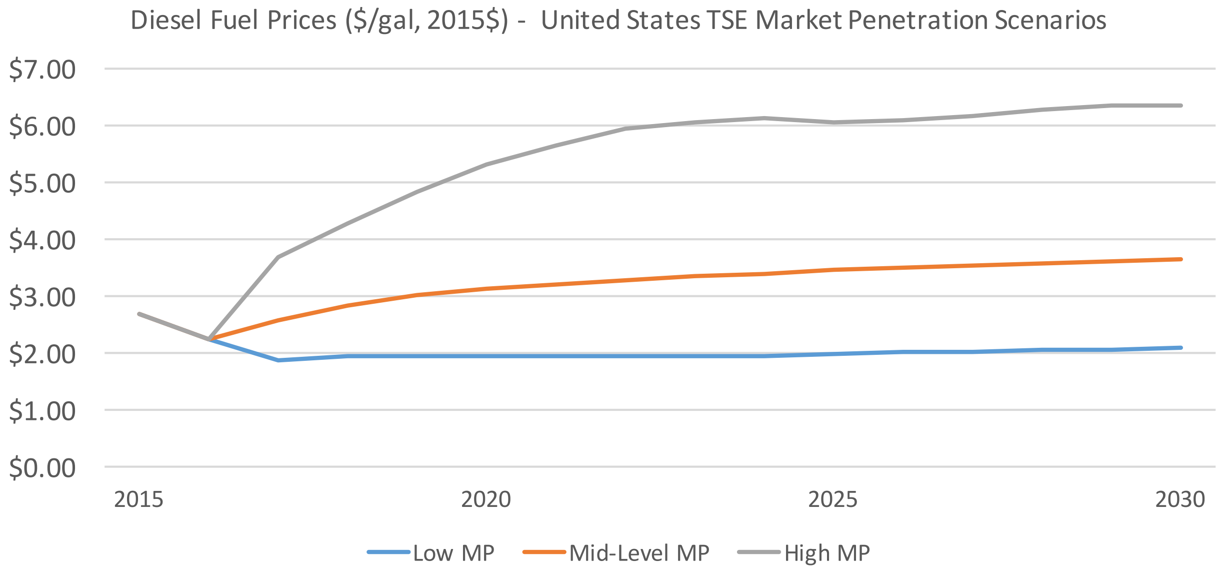

Figure 21. Annual Diesel Fuel Prices for Evaluated TSE Scenarios, United States 2015-2030

4.3.1.3 Aggregate Fuel Spending Shifts

We estimate aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to TSE use in the US for each scenario. Figure 22 shows estimated shifts in fuel expenditures (in millions 2015$) for the Mid-Level Market Penetration scenario.

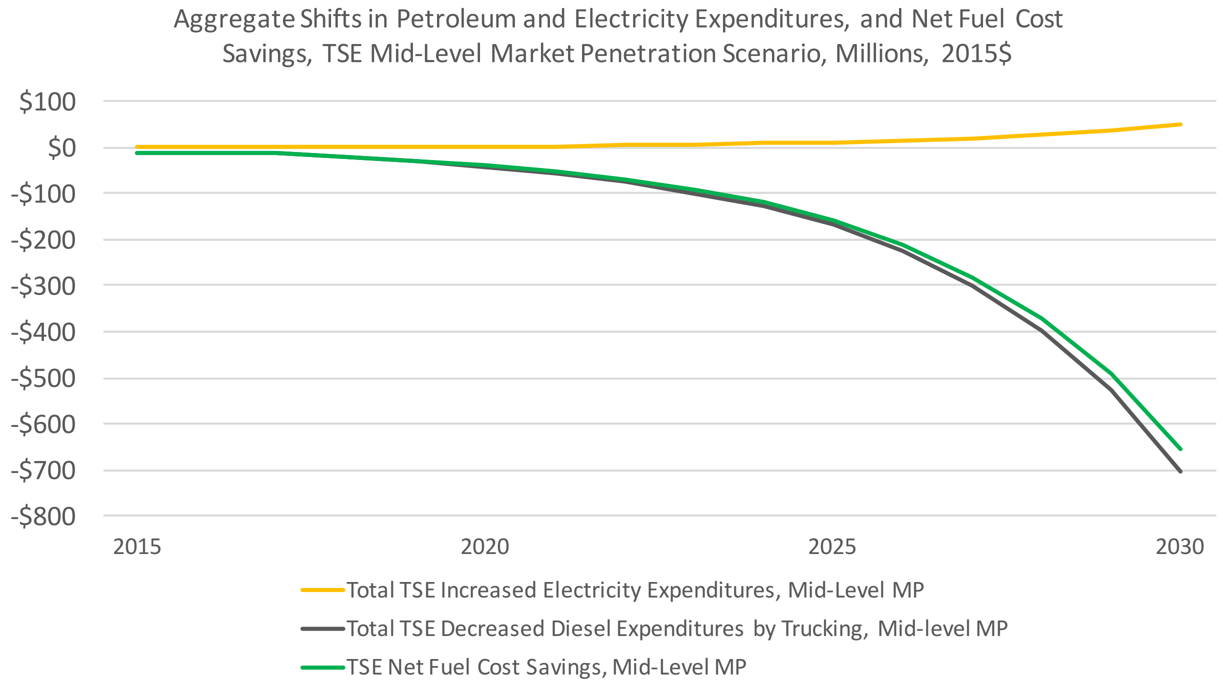

Figure 22. Aggregate Annual Shifts in Electricity and Petroleum Demand, and Net Fuel Cost Savings due to TSE Market Penetration in the United States, Mid-Level MP Scenario, 2015-2030

4.3.1.4 Shifts in Expenditures in Other TSE-Related Sectors

A shift away from truck idling to TSE will involve shifts in demand for other goods and services, including vehicle-side equipment, installation services, and maintenance services. Here we present the approach and assumptions used to estimate these shifts. Capital and maintenance costs are reported in 2015$, and are based on published reports [11, 12], and personal communication with TSE firms[12].

4.3.1.4.1 TSE Facility Costs

The establishment of TSE facilities involves a number of costs, including equipment and installation costs, and often construction including trenching and digging for power lines. We assume that capital costs range between $52,000 to $120,000 per facility for Plug-in APU/Shorepower-type TSE (annualized cost of $4,800 to $10,900), and $300,000 to $600,000 for IdleAir-type TSE (annualized cost of $24,000 to $48,000). We use these costs to model increased demand for related sectors, including construction of power and communication structures, electrical equipment, and TSE firm sectors. Net estimated shifts in expenditures on TSE facility costs for the Mid-Level Market Penetration scenario are shown in Figure 23.

4.3.1.4.2 Vehicle Maintenance Costs

Idling results in unnecessary wear-and-tear on trucks, which eventually results in the need for maintenance and repairs. The use of TSE can reduce truck maintenance expenditures by trucking firms and owner-operators, lowering operating costs. On average, one hour of idling results in approximately $0.15 in maintenance costs [21]. To estimate aggregate savings on maintenance expenditures by trucking firms, this hourly average maintenance cost of idling is multiplied by the number of hours TSE is used by trucks in any given year. We assume constant hourly maintenance cost savings across the study period (adjusted to 2015$), and we calculated these as aggregate savings to trucking firms. Aggregate savings on maintenance costs are then translated to reduced demand in the automotive repair and maintenance sector.

4.3.1.4.3 Vehicle Equipment Costs

In some cases, truck owners and operators purchase equipment and accessories on the vehicle side for use with plug-in APU/Shorepower type TSE. These costs are estimated at approximately $11,900 to $21,600 per truck stop (TSE facility) or $680 to $1,244 per year. We estimate aggregate expenditures on vehicle equipment using these assumptions and apply these expenditures to increased demand for the motor vehicle parts sector.

4.3.1.4.4 Hourly Service Fees / Revenue for TSE Firms and Truck Stops

Truck owners and operators are typically charged an hourly fee to use TSE services. The fee can vary to a large degree based on the technology and services provided (for instance, some TSE services also provide wireless internet or TV/video services). We assume hourly fees of $1.00 per hour for Plug-in APU/Shorepower-type TSE, and $1.69 per hour for IdleAir-type spaces; the revenue is assumed to be split equally between the TSE firm and the hosting site (travel center or truck stop)[13]. Hourly fees are also used to estimate net costs due to TSE use. Fee revenue, less expenses (e.g. capital, facility maintenance), is then applied to shifts in demand for equivalent sectors of the economy, as identified by firm NAICS codes (details in Table 4).

4.3.1.4.5 Facility Maintenance

According to a recent analysis of TSE cost-effectiveness, IdleAir-type TSE facilities require approximately $105,000 in labor costs per facility [11, 12]. We assume this cost applies to all IdleAir-type facilities each year,

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[12] Personal communications with executives from Shorepower and IdleAir via email and telephone.

[13] Based on industry websites, communication with TSE firms, and U.S. DOE AFDC.

to estimate aggregate annual maintenance expenditures. These facility maintenance costs are applied to the commercial and industrial machinery and equipment repair and maintenance sector.

4.3.1.5 Net Operational Cost Savings

Truck stop electrification results in an overall operational cost savings for truck owners and operators, compared to idling. Net annual aggregate operational cost savings for trucking firms were estimated as follows, as compared to a baseline scenario with zero market penetration of TSE:

$$\$S_y = \Delta\$P_y + \Delta\$V_y + \Delta\$F_y + \Delta\$M_y$$

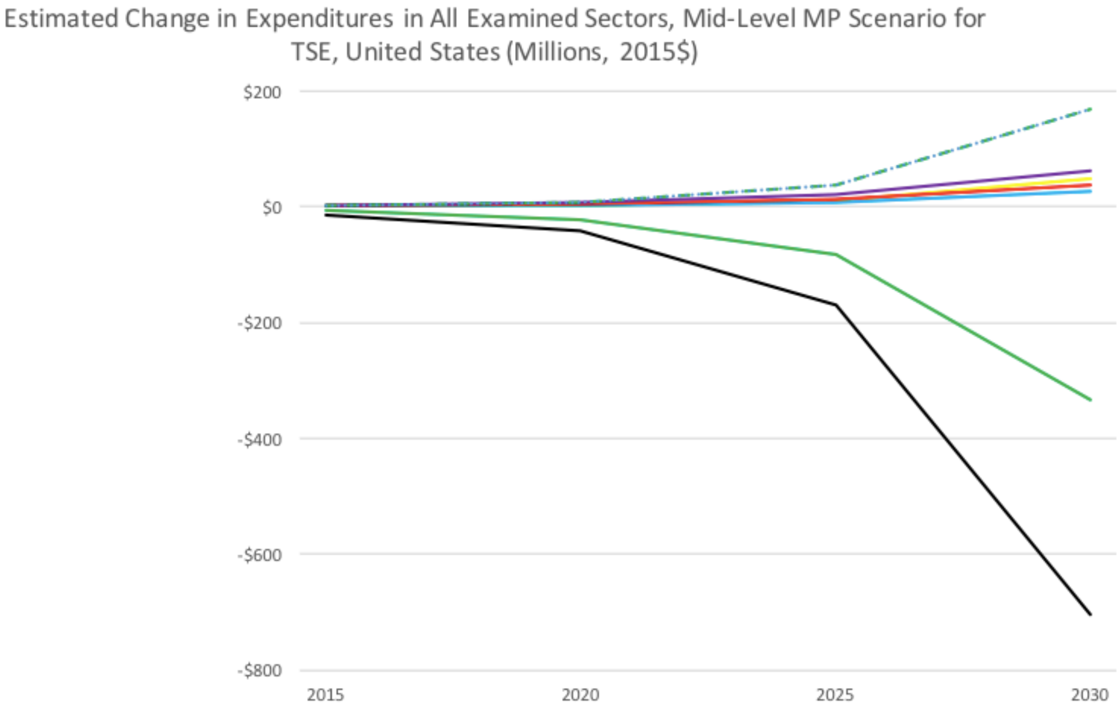
where: y = evaluated year; $S = net savings; $P = petroleum expenditures; $V = vehicle equipment expenditures; $F = TSE hourly fees; and $M = maintenance cost expenditures.

There is uncertainty regarding how cost savings will be allocated and which economic sectors will benefit. Net savings may be used in a number of ways, including being retained by trucking firms, passed on to shareholders, being passed onto customers in the form of reduced prices, or any combination of these. To estimate a range of potential economic impacts of TSE operational cost savings, we examine two cases.

- Case I: Savings to Households (HH)
  The first case assumes that any cost savings are passed on to customers. This case assumes that trucking firms using TSE pass their savings to customers to remain competitive, and these reduced costs are realized by households in the form of lower prices on transported goods. The net savings to households are assumed to be spent on other goods and services in the economy based on existing household spending patterns by income bracket.

- Case II: Savings to Trucking Firms (Business Surplus—BS)
  The second case assumes that operational cost savings are retained—and then spent—by trucking firms. In this case, we allocate savings to the truck transportation sector, and we assume that these savings follow typical spending patterns in that sector.

Figure 23 shows the estimated monetized shifts in demand for each sector and year, for the Mid-Level MP scenario. Estimated shifts in demand are reported in $2015.



	2015	2020	2025	2030
Reduced Petroleum Fuel Demand	-$13.3	-$41.0	-$168.6	-$704.2
Increased Electricity Demand	$0.9	$2.5	$11.0	$47.9
Reduced Truck Maintenance Demand	$0.9	$2.4	$7.7	$27.8
Net Operational Cost Savings in Expenditures by Trucking Sector ($Million/Year)	-$5.8	-$21.0	-$81.9	-$333.0
TSE Facility Maintenance	$1.9	$3.8	$12.0	$37.9
Total TSE Facility Capital Costs	$1.2	$7.2	$20.3	$61.6
Net Revenue TSE Firms ($M/yr)	$3.6	$7.5	$36.8	$168.0
Net Revenue to Truck Stops/Fuel Stations ($/yr)	$3.6	$7.5	$36.8	$168.0

Figure 23. Aggregate Annual Shifts in Expenditures due to U.S. TSE Market Penetration, 2015-2030

4.3.2 Macroeconomic Impacts: United States

We estimate the macroeconomic impacts of the above demand shifts using the IMPLAN input-output analysis program with US datasets. The estimated shifts in expenditures, by scenario and year, were applied as demand changes in IMPLAN sectors. Table 4 shows the categories for shifts in TSE-related expenditures and the associated sector to which shifts in demand are assigned.

Macroeconomic impacts estimated here include cumulative changes in employment (in job-years) and output ($ million) for the time period 2015-2030 for each scenario and case. We also report impacts for the years 2025 and 2030. Estimated cumulative employment and output impacts for the top ten sectors are available in the Appendix.

Employment impacts for the Mid-Level Market Penetration scenario are estimated to reach up to 10,200 jobs by 2030, for a cumulative impact of increased employment of 36,000-41,000 job-years for the entire period of 2015-2030. National economic output is expected to increase by $560-$810 million/year in 2030, with a cumulative impact between $2.3-$3.3 billion in increased economic output.

Table 4. Estimated Shifts in Expenditures due to TSE in the United States, and Sector for Input-Output Analysis

Shift in Expenditures	Assigned Sector
Electricity	Electric Power Transmission and Distribution
Petroleum Fuel	Petroleum Refineries
TSE Facility Capital Costs	Construction of Power and Communication Structures, Electrical Equipment, TSE Firm Sectors
TSE Facility Maintenance Costs	Commercial and Industrial Machinery and Equipment Repair and Maintenance
Vehicle Equipment Costs	Automotive Parts
Vehicle Maintenance Costs	Automotive Repair and Maintenance
TSE Service Hourly Fee	TSE Firm Sectors; Gasoline Stores
Net Operational Costs: Case I (Savings to Households—HH)	Households, by Income Bracket
Net Operational Costs: Case II (Savings to Business—BS)	Truck Transportation

Table 5. Estimated Macroeconomic Impacts of Truck Stop Electrification (TSE) in the United States, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

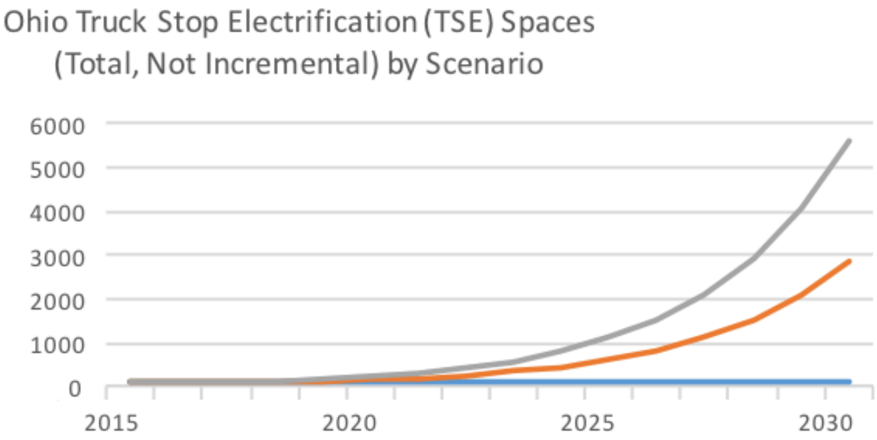
United States TSE	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Jobs)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	2,200	2,500	290	300	6,600	7,400
Year 2030	9,000	10,200	310	310	36,100	40,000
Cumulative	**36,300**	**41,200**	**4,300**	**4,500**	**124,700**	**343,000**
Output (Millions, 2015$)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	$140	$200	$20	$20	$400	$600
Year 2030	$560	$810	$20	$20	$2,100	$2,900
Cumulative	**$2,300**	**$3,300**	**$270**	**$300**	**$7,300**	**$9,100**

4.4 Macroeconomic Impacts for Ohio

4.4.1 Ohio Market Penetration Scenarios

We conducted a more focused analysis on the impact of TSE in Ohio. Ohio is a relative hub in the nation for trucking activity, and hosts one of the largest state populations of truck parking spaces (over 11,000) in the nation. For the Ohio analysis, the assumptions behind the market penetration scenarios are nearly identical to those used in the US analysis, and include estimates for Low-, Mid-Level, and High Market Penetration. The number of TSE facilities and spaces are based on the number of electrified parking spaces in Ohio as reported by the U.S. DOE AFDC, and the number of truck stops and non-electrified truck parking spaces as reported in Allstays, an online database for truckers [19, 22].

Figure 24 shows the population of TSE spaces in Ohio for each scenario. In the Mid-Level Market Penetration scenario, the total number of TSE spaces is projected to reach ~600 by 2025, and over 2,800 by 2030. The Low Market Penetration scenario assumes only 84 electrified spaces in 2030, while nearly 5,600 TSE spaces in 2030 are projected for the High Market Penetration scenario.



Low MP TSE Spaces	84	84	84	84
Mid-Level MP TSE Spaces	84	150	600	2,840
High MP TSE Spaces	84	220	1,110	5,590

Figure 24. Ohio TSE Market Penetration by Scenario (Total Population, not Incremental), 2015-2030

4.4.2 Shifts in Expenditures: Ohio

4.4.2.1 Electricity Demand and Costs

Using the TSE energy use assumptions outlined above, we calculate electricity demands for each Ohio scenario compared to a baseline of zero TSE. Electricity consumption estimates for Ohio TSE scenarios are shown Figure 25. Electricity price assumptions are specific to Ohio by scenario, sector, and type for each year; average weighted electricity price assumptions for each scenario are shown in Figure 26. Finally, aggregate annual electricity consumption of TSE and electricity prices are used to estimate aggregate electricity expenditures for each scenario and year compared to a baseline assuming zero market penetration of TSE. Estimated aggregate electricity expenditures for each Ohio TSE scenario are shown below in Figure 29.

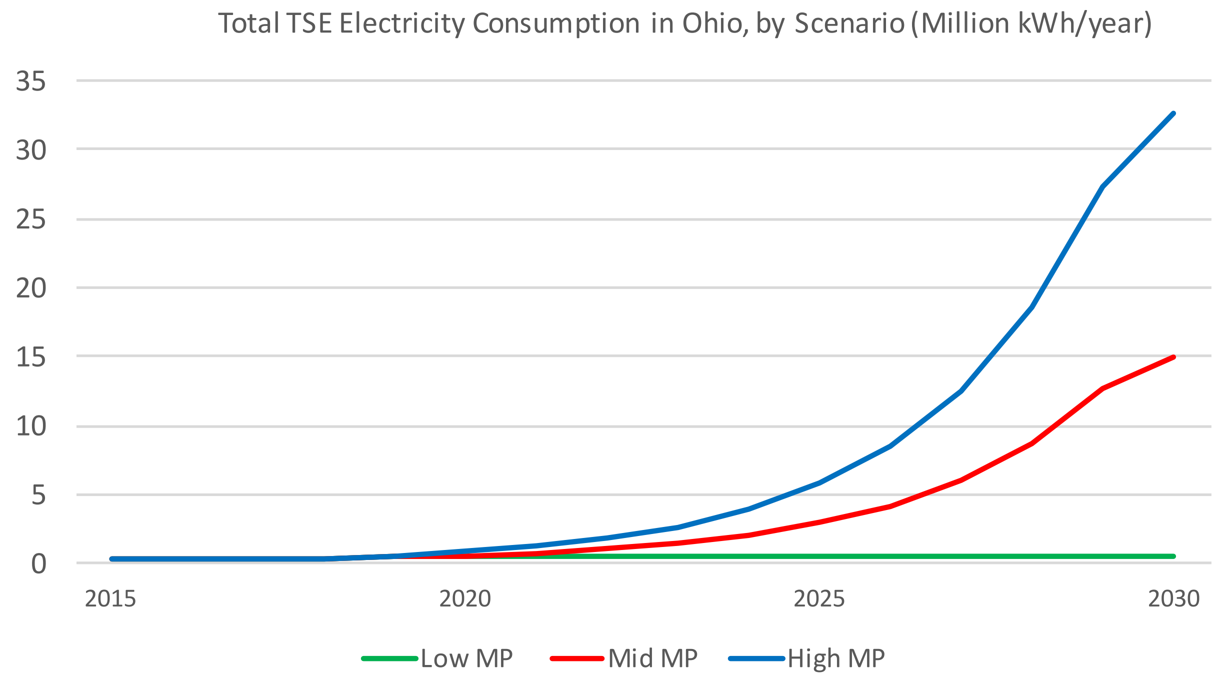


Figure 25. Aggregate Annual Electricity Consumption of TSE by Scenario, Ohio, 2015-2030

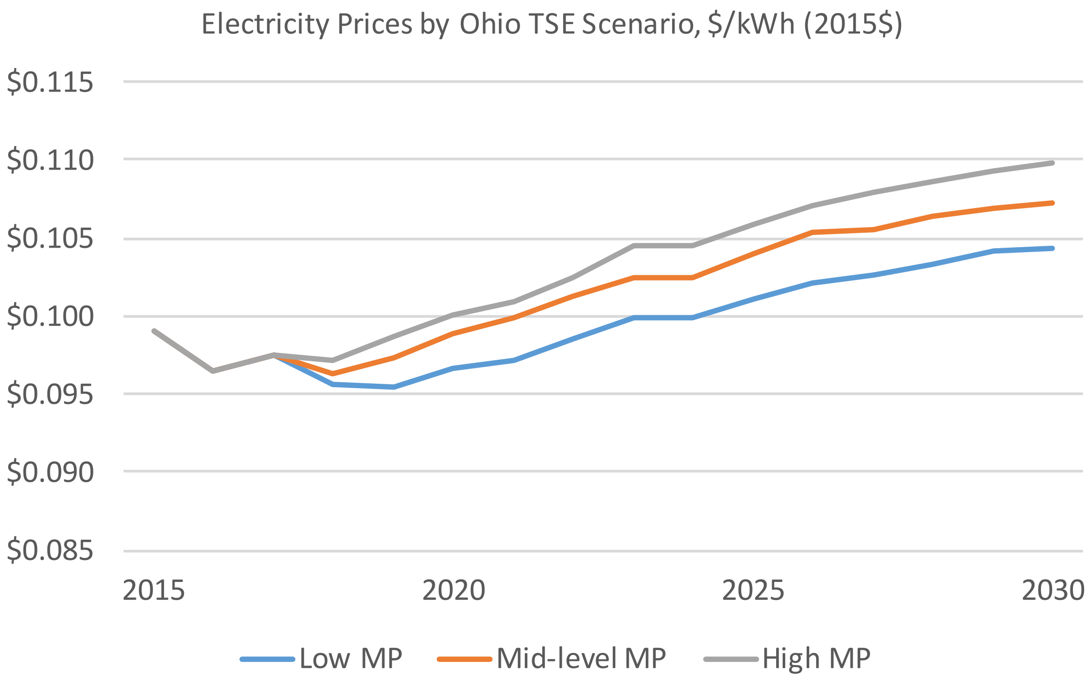


Figure 26: Average Annual Electricity Prices for Evaluated TSE Scenarios, Ohio 2015-2030

4.4.2.2 Petroleum Demand and Savings

Using the idling fuel consumption and TSE fuel displacement assumptions outlined in the preceding section, we calculated diesel fuel displacement for each Ohio scenario. Annual aggregate petroleum displacement estimates for each Ohio scenario are shown in Figure 27. Avoided petroleum expenditures are calculated using the assumptions described above, with the exception that fuel prices from U.S. DOE EIA and projections from EIA AEO are specific to Ohio or the EIA East North Central region. Diesel fuel price assumptions for Ohio are shown in Figure 28.

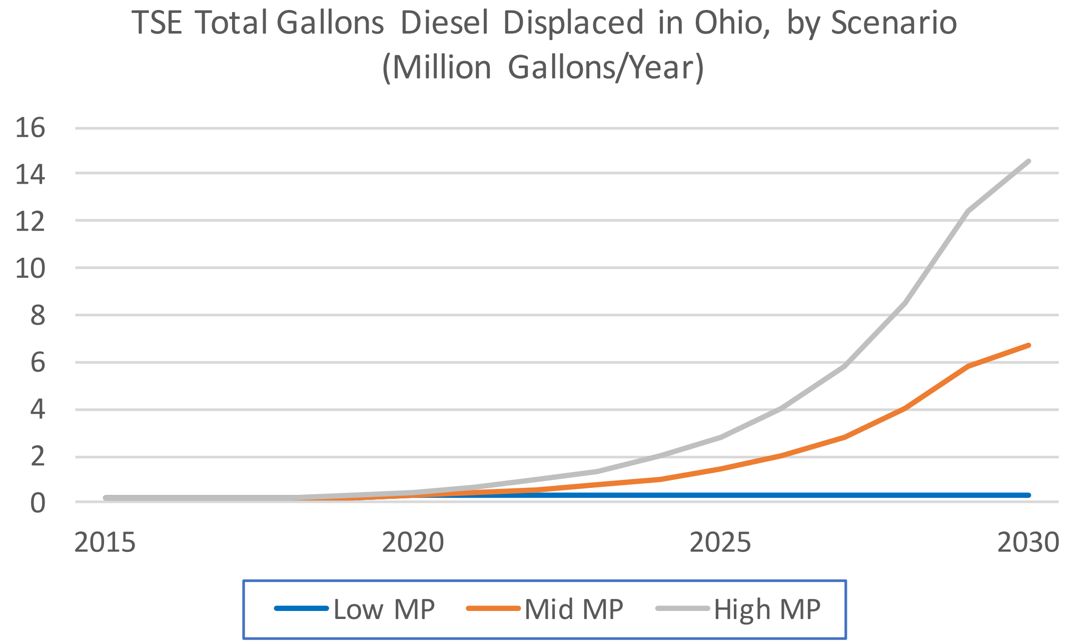


Figure 27. Aggregate Annual Petroleum Displacement due to TSE in Ohio, by Scenario, 2015-2030

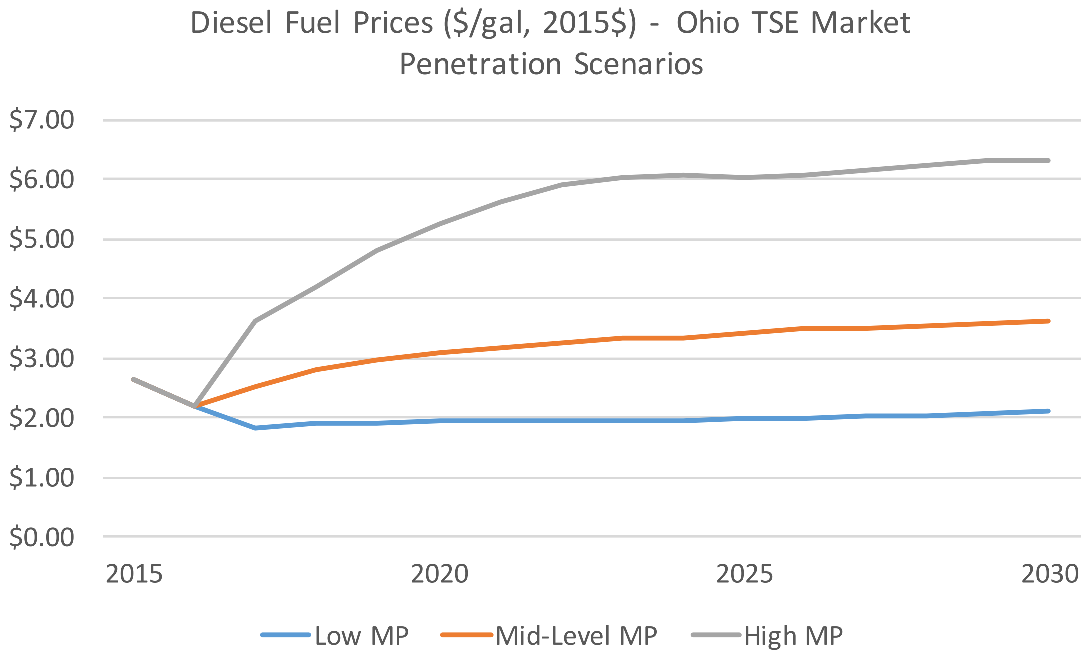


Figure 28. Average Diesel Prices for Evaluated TSE Scenarios, Ohio 2015-2030

4.4.2.3 Aggregate Spending Shifts

We estimate aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to large-scale TSE market penetration in Ohio for each scenario and year, 2015-2030. Figure 29 shows shifts in expenditures (in thousands, 2015$) for the Mid-level Market Penetration scenario, as compared to a baseline assuming zero market penetration of TSE.

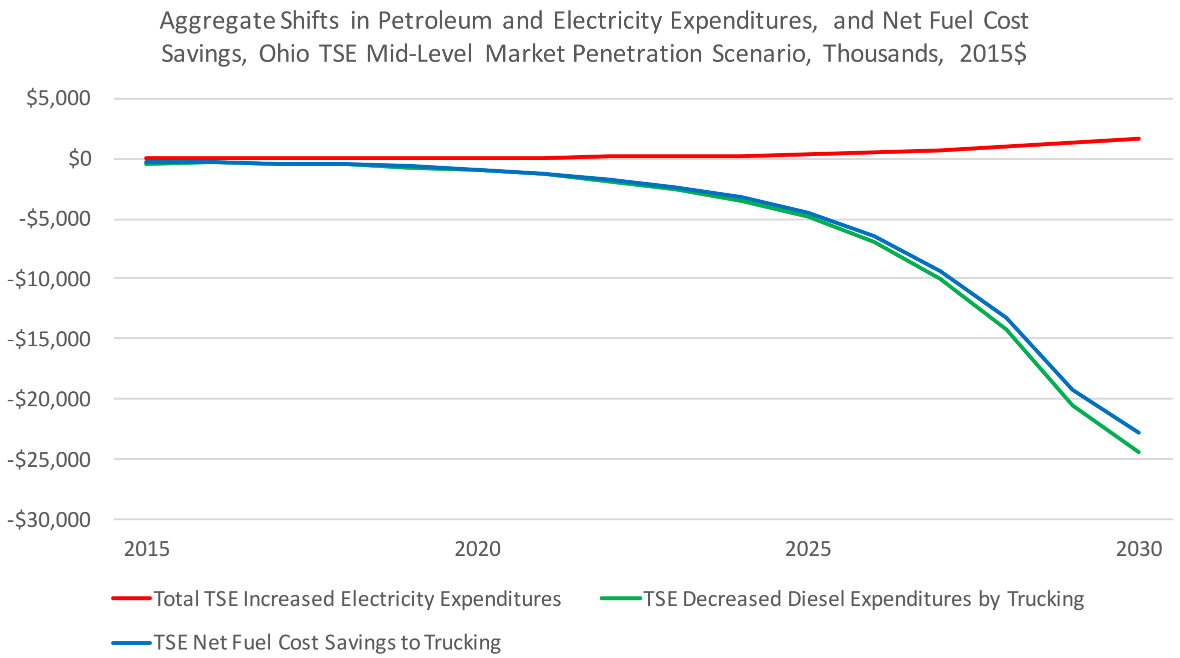
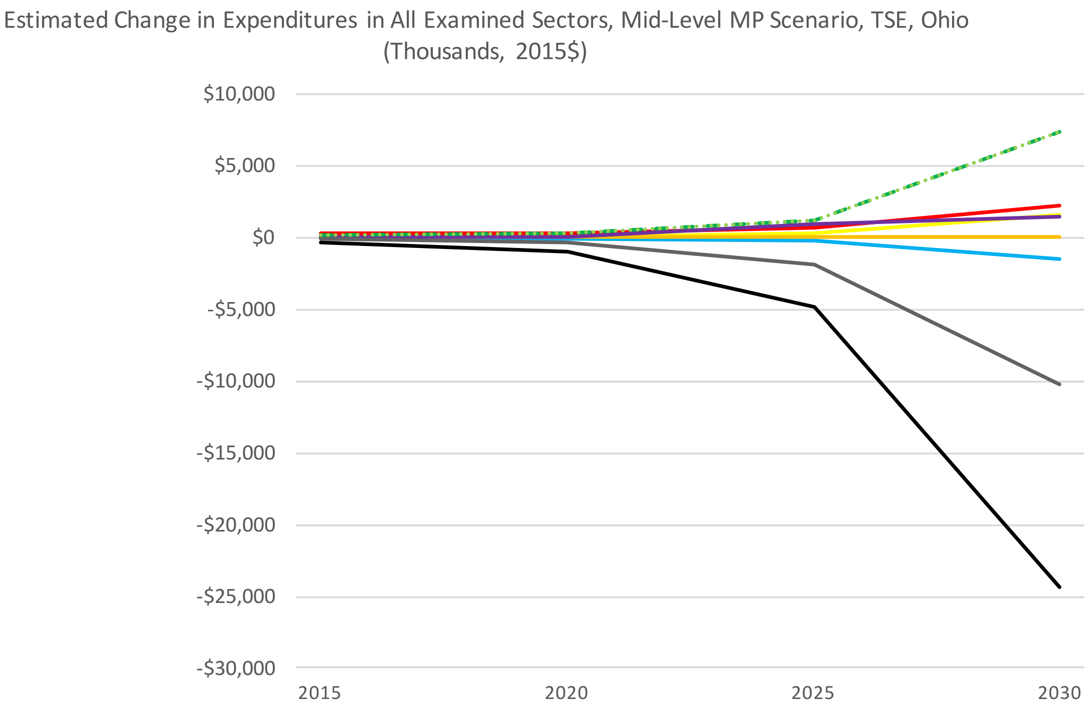


Figure 29. Shifts in Electricity and Petroleum Expenditures, and Net Fuel Cost Savings due to TSE Market Penetration in Ohio, 2015-2030

4.4.2.4 Shifts in Expenditures in Other TSE-Related Sectors

As described in greater detail above, a shift to TSE will involve changes in demand across many sectors of the economy. We apply a nearly identical approach to estimate the impact of shifting spending patterns in Ohio as we did for the US analysis, with some exceptions (e.g. energy price assumptions). Figure 30 shows the estimated monetized shifts in demand for each sector and year for the Ohio TSE Mid-Level Market Penetration scenario. Estimated shifts in demand are reported in $2015.



	2015			
Reduced Petroleum Fuel Expenditures	-$413	-$997	-$4,850	-$24,399
Increased Electricity Expenditures	$28	$59	$307	$1,616
Reduced Truck Maintenance Expenditures	-$28	-$69	-$277	-$1,510
Vehicle Equipment Expenditures	$1	$2	$7	$31
TSE Facility Maintenance Expenditures	$315	$315	$707	$2,187
Total TSE Facility Capital Cost Expenditures	$0	$50	$903	$1,403
Net Revenue TSE Firms	$95	$245	$1,127	$7,347
Net Revenue to Truck Stops/Fuel Stations	$95	$245	$1,127	$7,347
Operational Cost Savings in Expenditures by Trucking Sector (Negative = Savings)	-$133	-$428	-$1,951	-$10,187

Figure 30. Estimate Aggregate Shifts in Expenditures due to TSE Market Penetration in Ohio, 2015-2030

4.4.3 Macroeconomic Impacts: Ohio

We estimate the macroeconomic impacts of these shifts using IMPLAN with datasets representing the State of Ohio. The shifts in expenditures by scenario and year were applied to various IMPLAN sectors, as shown in Table 1 (in the TSE United States section). Estimated macroeconomic impacts include total cumulative changes in employment (in job-years) and output ($ million) for the time period 2015-2030 for each scenario and case, as shown in Table 6. Estimated impacts for the individual years 2025 and 2030 are also reported here. Estimated cumulative employment and output impacts by sector for the top ten sectors are available in the Appendix.

As shown below, Ohio employment impacts for the Mid-Level Market Penetration scenario are estimated to reach up to 390 jobs by 2030, for a cumulative impact of increased employment of 1,300 -1,500 job-years for 2015-2030. We estimate an increase in economic output in Ohio due to TSE of $20-$30 million/year in 2030, with cumulative impacts between $75 and $105 million.

Table 6. Estimated Macroeconomic Impacts of Truck Stop Electrification (TSE) in Ohio, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

Ohio TSE	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	70	75	12	13	180	230
Year 2030	350	390	14	14	1,000	1,250
Cumulative	**1,300**	**1,500**	**190**	**190**	**3,700**	**20,000**
Output (Millions, 2015$)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	BS	HH	BS	HH	BS
Year 2025	$5	$6	$1	$1	$10	$20
Year 2030	$20	$30	$1	$1	$40	$90
Cumulative	**$75**	**$105**	**$15**	**$15**	**$170**	**$320**

4.5 Chapter Conclusion

The results indicate that large-scale market penetration of truck stop electrification (TSE) in the United States and Ohio, and resulting petroleum fuel displacement, fuel cost savings, and shifts in related industries, have the potential to produce substantial and positive macroeconomic benefits, in the form of thousands of jobs and hundreds of millions of dollars of increased output by 2030.

5 Macroeconomic Impacts of Shore Power: An Assessment for the United States and Florida

Summary of Chapter Findings

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, shore power in the United States will displace nearly 945 million gallons of petroleum fuel per year at net fuel cost savings of over $740 million per year. This will result in increased output of up to $4.2 billion and increased employment of up to 14,600 jobs. Cumulatively, increased employment of up to 88,200 job-years and up to $26 billion in increased economic activity are expected between 2015-2030.

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, shore power in Florida will displace 69.3 million gallons of petroleum fuel per year at net fuel cost savings of $140 million per year. This will result in increased output of up to $560 million and increased employment of up to 1,960 jobs. Cumulatively, 10,500 job-years of employment and $3.1 billion in increased economic activity are expected (2015-2030).

5.1 Chapter Overview

The use of shore power (also called cold-ironing or Alternative Maritime/Marine Power) [14] is growing in the US. Shore power allows vessels to turn off their auxiliary engines while at dock and plug their shipboard systems into the local electricity grid. Shore power is used in at least nine US ports on the east and west coasts, with the majority in California, which spearheaded shore power development in the US. In this chapter, we evaluate the macroeconomic impacts of future market penetration of shore power in the US and the State of Florida.

5.2 Scenario Development

The California Code of Regulations requires a reduction in vessel auxiliary emissions via the *Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port*[15] (sometimes called the "At-Berth Regulation"). This regulation, enforced by the California Air Resources Board (CARB), is intended to reduce particulate matter (PM) emissions from ship auxiliary engines while at berth in California ports. The program is the most comprehensive in the country, and California leads all other states in the number of ports with shore power.

The At-Berth Regulation affects container vessels, passenger vessels, and refrigerated cargo vessels. Cruise vessels began commercially using shore power in 2001 in Alaska. CARB approved the At-Berth Regulation in 2007, and it optionally went into effect on 1 January 2010. As of 1 January 2014 all companies with fleets affected by the regulation were required to meet at least 50% compliance, either by using shore power, or an equivalent emissions reduction technology. As of 1 January 2017 compliance rates of 70% were required, and these rates will increase to 80% compliance on 1 January 2020. We use these compliance rates as a basis for developing our scenarios for the US and Florida, as outlined below.

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[14] We note that "shore power", or cold-ironing, is not the same technology/firm as "Shorepower", a truck stop electrification technology and firm highlighted in the previous chapter.

[15] Section 93118.3, title 17, chapter 1, subchapter 7.5, California Code of Regulations (CCR).

We develop scenarios for 25 ports throughout the US, as described in Vaishnav et al. (2016)[23]. The ports we include are listed below.[16] Taken together, the 25 ports in this study accounted for 45% of the annual vessel calls in 2015.

- Port Canaveral (FL)
- Port of Houston (TX)
- Port of Tacoma (WA)
- Port of Miami (FL)
- Port of Galveston (TX)
- Port Everglades (FL)
- Port of Baltimore (MD)
- Port of Newark (NJ)
- Port of Seattle (WA)
- Port of San Diego (CA)
- Port of Long Beach (CA)
- Port of Los Angeles (CA)
- Port Hueneme (CA)
- Port of Corpus Christi (FL)
- Port of New Orleans (LA)
- Port of New York (NY)
- Port of Tampa (FL)
- Port of Boston (MA)
- Port of Charleston (SC)
- Port of Bar Harbor (ME)
- Port of Jacksonville (FL)
- Port of Key West (FL)
- Port of San Francisco (CA)
- Port of Oakland (CA)
- Port of Richmond (CA)

To construct our scenarios, we developed activity projections for each port for three vessel categories: container ships, passenger (cruise) ships, and refrigerated cargo vessels. These activity projections are based on US Army Corps Entrances and Clearances data from 1997-2015, which contain a total of 781,000 port calls at the 25 ports in our study. We apply regression and forecasting techniques to identify trends in the number of vessels of each type calling at each of our 25 study ports, and project the number of calls and vessel sizes out to 2030.

Using compliance percentages from the At-Berth Regulation for California Ports, we developed three scenarios for each port: (1) Mid-Level Market Penetration; (2) High Market Penetration; and, (3) Low Market Penetration.[17] Based on data on vessel tonnage (which is linearly related to installed auxiliary power), we estimate the annual energy consumption used in auxiliary systems by vessel. Using those data, we can calculate the amount of electricity (kWh) required for various levels of shore power market penetration – as well as petroleum energy offsets. Scenario descriptions are described below and summarized in Table 7.

- Mid-Level Market Penetration Scenario
  This scenario assumes that California ports meet the At-Berth Regulations for California, and non-California ports would reach 50% of that level by 2030, which follows roughly the same timeline from the first commercial deployment of shore power in 2001 to the first mandatory compliance in California in 2014. Energy prices are assumed to follow the EIA AEO *Reference Case* in this scenario.

- Low Market Penetration Scenario
  This scenario assumes that California ports meet the At-Berth Regulations for California, and non-California ports reach market penetration 60% lower than the Mid-Level scenario. Energy prices are assumed to follow the EIA AEO *Low Oil Price Case* in this scenario.

- High Market Penetration Scenario

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[16] We omit the Port of Yerbabuena Island, as the harbor primarily serves US Coast Guard and recreational vessels, resulting in a total of 25 ports.

[17] The scenario projections for California ports follow the At-Berth Regulation timetable, and are the same across the Mid-Level, Low, and High Market Penetration scenarios.

This scenario assumes that California ports meet the At-Berth Regulations for California, and non-California ports reach market penetration 60% higher than the Mid-Level scenario (i.e., equivalent to 2020 shore power compliance rates in California). Energy prices are assumed to follow the EIA AEO *Low Oil Price Case* in this scenario.

Table 7. Shore Power Market Penetration Scenario Assumptions

Scenario	2015	2020	2025	2030
Mid-Level Market Penetration	California: 50% Rest of Country: 5%	California: 80% Rest of Country: 20%	California: 80% Rest of Country: 35%	California: 80% Rest of Country: 50%
Low Market Penetration	California: 50% Rest of Country: 5%	California: 80% Rest of Country: 10%	California: 80% Rest of Country: 15%	California: 80% Rest of Country: 20%
High Market Penetration	California: 50% Rest of Country: 5%	California: 80% Rest of Country: 25%	California: 80% Rest of Country: 50%	California: 80% Rest of Country: 80%

5.3 Macroeconomic Impacts for the United States

5.3.1 Shifts in Expenditures: United States

5.3.1.1 Electricity Demand and Costs

Several important economic shifts occur when shore power begins to displace power generation from petroleum fuel on-board ships. Due to the highly individual nature of shore power equipment to the specific port at which it is used, the capital costs of shore power are too uncertain to properly incorporate in this work. Therefore, we focus on the macroeconomic impacts of the displacement of petroleum fuel by electricity.[18] Aggregate electricity consumption (million kWh) for each scenario by year (compared to zero shore power use), is shown in Figure 31.

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[18] Future work at the individual port-level could include capital cost impacts specific to the individual port.

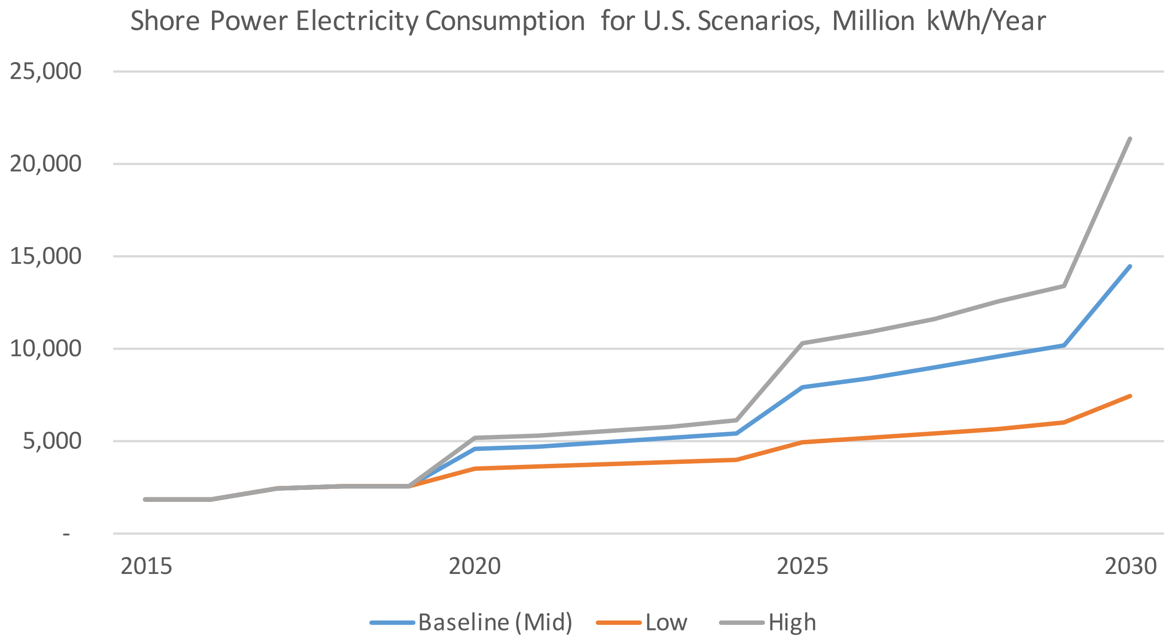

Figure 31. Aggregate Annual Electricity Consumption of Shore Power by Scenario, United States, 2015-2030

Based on these demand profiles, we estimate electricity expenditures for each shore power scenario. We use electricity rates ($/kWh) and projected price changes from EIA AEO 2017 to forecast US average electricity prices for each year 2015-2030 adjusted to 2015$. The prices for the Mid-Level, Low, and High Market Penetration scenarios are derived from the EIA AEO *Reference Case*, *Low Oil Price Case*, and *High Oil Price Case*, respectively. This allows maximum "bounding" of our results. Electricity prices for each scenario by year are shown in Figure 32. These prices, along with aggregate annual electricity consumption, are used to estimate aggregate electricity expenditures for each scenario, shown in Figure 35 (along with shifts in petroleum fuel expenditures).

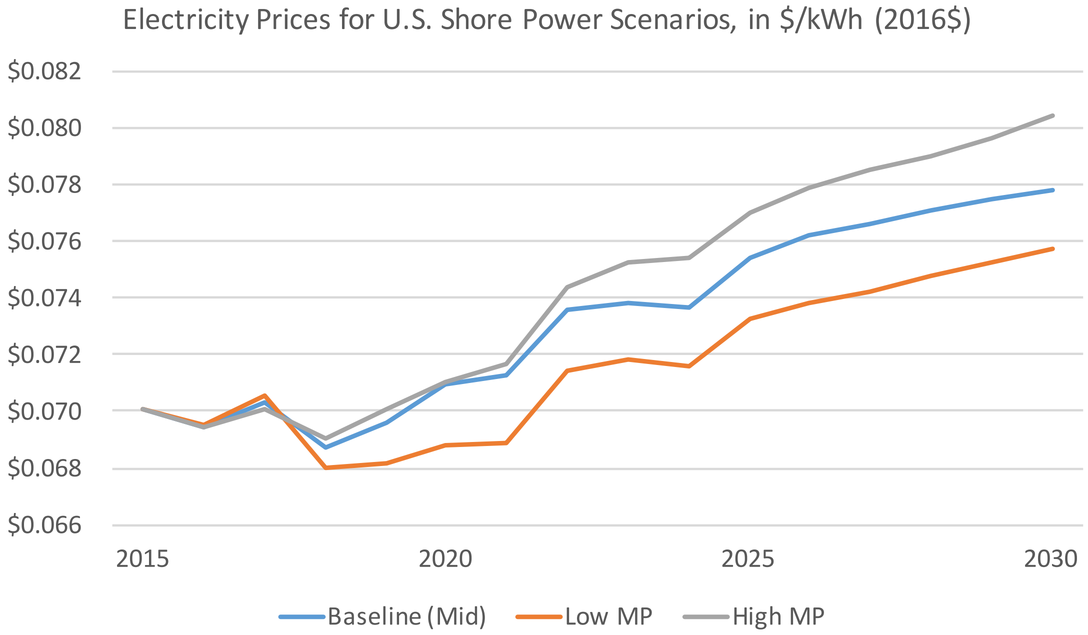

Figure 32. Average Annual Electricity Prices for Evaluated Shore Power Scenarios, United States 2015-2030

5.3.1.2 Petroleum Demand and Savings

Large-scale compliance and use of shore power will decrease consumption of petroleum fuel, specifically marine gas oil (MGO), which is typically used to power marine vessel auxiliary engines. We estimate changes in aggregate MGO consumption for each shore power scenario, based on the installed auxiliary power capacity of vessels by port. Petroleum displacement (in metric tonnes of MGO) for each scenario is shown in Figure 33.[19] Fuel prices assumptions for each scenario are shown in Figure 34. We convert these data to fuel cost savings for each scenario as shown in Figure 35 (along with shifts in electricity fuel expenditures).

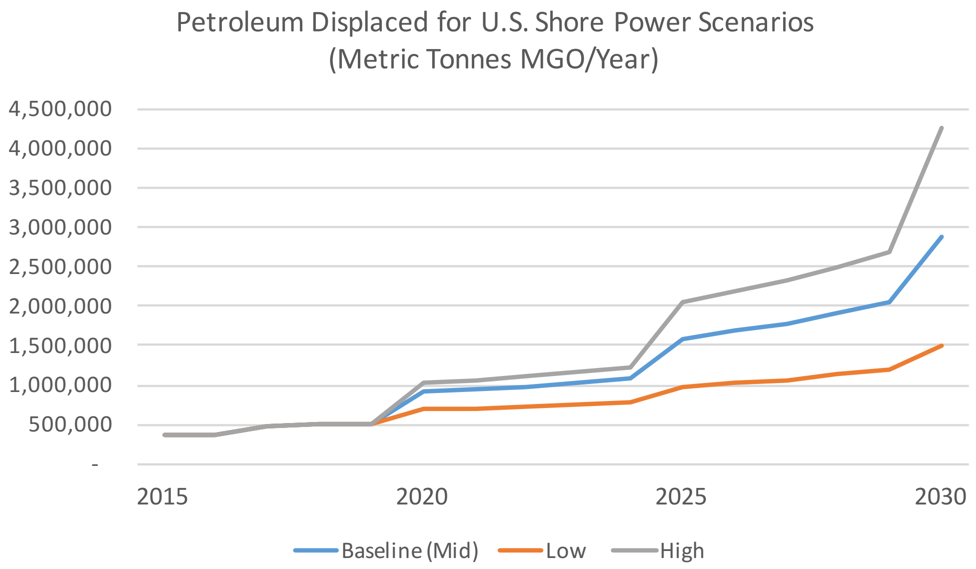

Figure 33. Aggregate Annual Petroleum (MGO) Displacement in the United States due to Shore Power by Scenario, 2015-2030

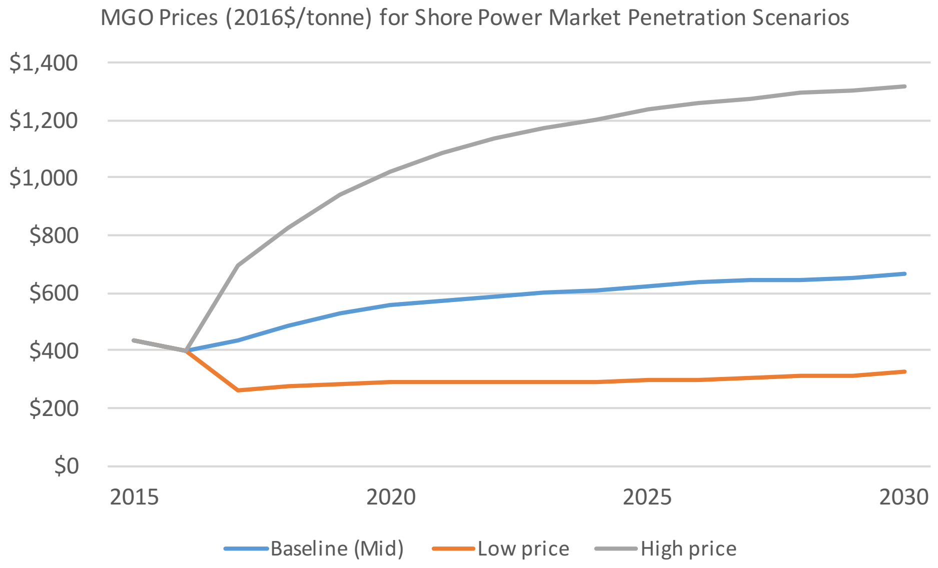

Figure 34. MGO Fuel Prices for Evaluated Shore Power Scenarios, United States 2015-2030

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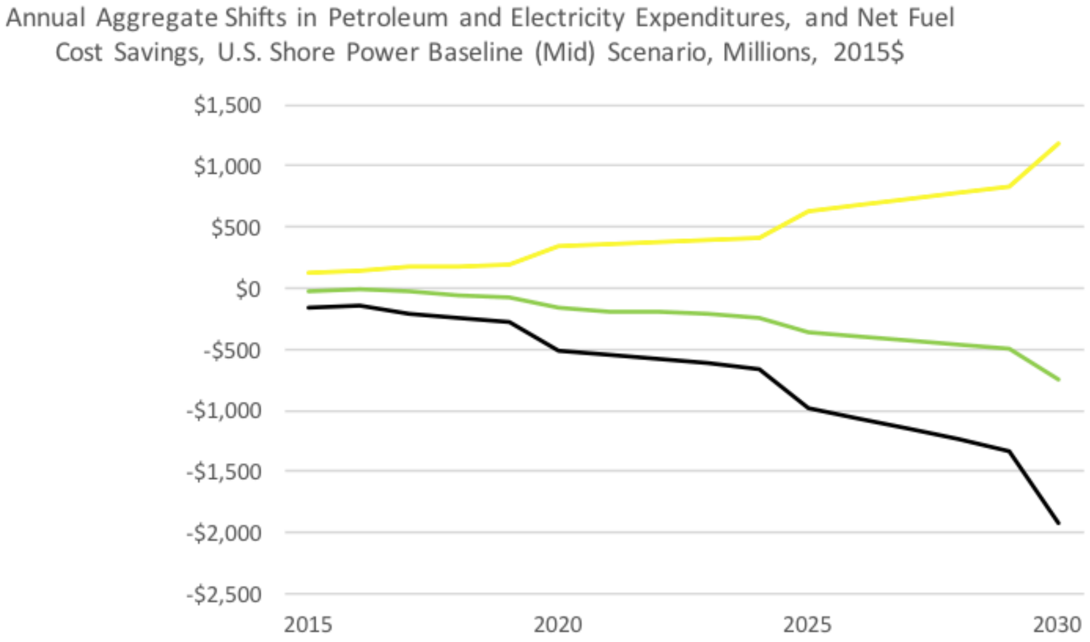
[19] Fuel consumption in the marine sector is typically reported in metric tonnes. We stay consistent to that in this report; however, we translate these volumes to gallons of petroleum in our summaries for ease of comparison with the other technologies we evaluate.

5.3.1.3 Aggregate Spending Shifts

Aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to shore power use in the US are estimated for each scenario. Figure 35 shows shifts in fuel expenditures (in millions 2015$) for the Mid-Level Market Penetration scenario.



	2015	2020	2025	2030
Electricity Expenditures	$134	$344	$634	$1,185
Decreased Petroleum Expenditures	-$158	-$509	-$990	-$1,926
Net Fuel Cost Savings (Negative = Savings)	-$24	-$165	-$356	-$741

Figure 35. Aggregate Annual Shifts in Electricity and Petroleum Demand, and Net Fuel Cost Savings due to Shore Power use in the United States, Baseline Mid-Level MP Scenario, 2015-2030

5.3.1.4 Directing Net Fuel Cost Savings

The use of shore power results in an overall fuel cost savings for shippers, compared to using auxiliary engines powered by MGO. There is uncertainty in terms of how and where these cost savings will be allocated, and therefore which sectors of the economy will benefit. Net fuel cost savings by shippers may be used in a number of ways, including being reinvested by U.S.-owned vessels and shippers, passed on to customers in the form of reduced freight rates, realized by foreign-owned vessels and shippers, or any combination of these. To estimate a range of potential economic impacts of shore power fuel cost savings, we examined three cases shown below.

- Case I: Surplus to Households (HH)
  The first case assumes that any fuel cost savings are passed on to customers. This case assumes that shippers pass their savings onto customers in the form of reduced freight rates (or ticket rates, etc.), which reduces prices of goods sold. The net savings to households are assumed to be spent on other goods and services in the economy based on existing household spending patterns by income bracket.

- Case II: Surplus to Shippers (SH)
  The second case assumes that operational cost savings are retained by shippers and spent in the US. In this case, savings are allocated to the shipping (water transportation) sector, and it is assumed that the spending of these savings results in the typical spending patterns associated with increased activity in this sector (i.e. this assumes that water transportation activity would expand, and/or shippers would buy more of the goods and services that they are currently purchasing based on existing spending patterns).

- Case III: Surplus to Non-U.S. Shipping (NS)
  The third case assumes that operational cost savings are realized by non-US vessels and shipping companies, who upon leaving port, do not spend any of the fuel cost savings in the US, nor pass along such savings to US customers in any way. Thus, fuel savings are assumed to leave the US economy entirely. This case may be seen as a worst-case scenario in terms of macroeconomic impacts of shore power fuel displacement.

Shore power is unique in terms of estimating macroeconomic impacts of petroleum displacement, as the vast majority of vessels docking at US ports do not purchase fuel from the US. If vessels purchase fuel from a US source, then any reductions in fuel use would have a negative effect on the US economy. These negative effects may be offset by electricity purchases, or not, depending on other assumptions discussed in this chapter. However, if vessels purchase fuel from a foreign source, then any reduction in fuel use would not have a negative impact on the US economy, and the shore power purchases would represent a positive shift in spending from a foreign entity (for fuel) to a US entity (for electricity).

To examine a range of potential macroeconomic impacts for shore power, we evaluate the above three cases with two main bounding assumptions: in the first set of analyses, we assume that all vessels are purchasing displaced MGO from a non-US source; in the second we assume that all vessels are purchasing displaced MGO from a US source. The assumption of foreign purchases of MGO is more likely to reflect reality, as more than 90% of all fuel used in international shipping is purchased outside the US[20]. US ports have arrived from ports of US origin; we report results of analyses assuming US purchased-fuel as a lower bound, conservative estimate of macroeconomic impacts.

5.3.2 Macroeconomic Impacts: United States

We estimate the macroeconomic impacts of the above economic shifts using IMPLAN with US datasets. The estimated shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors. Table 8 shows the categories for related expenditures, and the associated sector in IMPLAN to which shifts in demand are applied.

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[20] From Third International Maritime Organization Greenhouse Gas (IMO GHG) report, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf, Figure 5.

Table 8. Estimated Shifts in Expenditures due to Shore Power use in the United States, and Sector for Input-Output Analysis

Shift in Expenditures	Assigned Sector
Electricity	Electric Power Transmission and Distribution
Petroleum Fuel	Petroleum Refineries[21]
Net Operational Costs: Case I (Surplus to Households—HH)	Households
Net Operational Costs: Case II (Surplus to Shippers—SH)	Water Transportation
Net Operational Costs: Case III (Non-US Surplus—NS)	None

Macroeconomic impacts estimated here include total cumulative changes in employment (in job-years) and output ($ million) for the time period 2015-2030 for each scenario and case (Table 9). For the Mid-Level Market Penetration scenario, we also estimate and report annual impacts for the years 2025 and 2030 (Table 10). Cumulative employment and output impacts by sector for the top ten sectors are available in the Appendix, as are estimates of direct, indirect and induced economic impacts.

Employment impacts for the Mid-Level Market Penetration scenario are estimated to reach up to 14,600 jobs by 2030, for a cumulative impact of increased employment of 88,200 job-years for the entire period of 2015-2030. We estimate that fuel shifts due to use of shore power could increase national economic output by up to $4.6 billion per year in the 2030, with cumulative impacts of $26 billion in increased economic output.

Estimated macroeconomic impacts for shore power are high compared to other evaluated technologies in the cases where displaced fuel is purchased outside of the US. However, the shore power analyses do not incorporate capital equipment or infrastructure costs, and reflect economic impacts due to f*uel switching and fuel cost savings only*. Incorporating infrastructure costs would reduce net operational cost savings to shipping firms, and macroeconomic benefits would be lower (although, the industries producing shore power equipment and infrastructure would see increased output and employment (along with concomitant direct, indirect, and induced macroeconomic effects

In the cases where shore power displaces US petroleum and cost saving are spent outside the US, the macroeconomic impacts can be negative. Thus, to maximize US macroeconomic benefits of shore power, ports may charge other fees to capture some proportion of fuel savings from at-berth vessels, and reinvest those fees back into the US economy, which would lead to similar output as our HH cases.

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[21] See discussion above regarding this assumption; where we assume that displaced MGO has been purchased outside of the US, we do not model any shift in demand for the petroleum sector.

Table 9. Estimated Macroeconomic Impacts of Shore Power Petroleum Displacement in the United States, Cumulative (2015-2030) Impacts for all Evaluated Scenarios and Cases

	Mid-Level Market Penetration Scenario			**Low Market Penetration Scenario**			**High Market Penetration Scenario**		
100% of Displaced Petroleum Fuel Purchased Outside of United States, Cumulative Impacts									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Employment (Job-Years)	88,210	78,450	40,670	35,800	34,110	27,730	215,000	178,980	39,590
Output	$26,230	$28,570	$18,350	$13,850	$14,230	$12,510	$46,950	$55,580	$17,860
100% of Displaced Petroleum Fuel Purchased within United States, Cumulative Impacts									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Employment (Job-Years)	39,540	29,790	-8,000	19,100	17,400	11,020	121,740	85,720	-53,680
Output	$6,030	$8,370	-$1,860	$6,910	$7,300	$5,570	$8,240	$16,870	-$20,860

Table 10. Estimated Macroeconomic Impacts of Baseline (Mid) Scenario Shore Power Petroleum Displacement in the United States, Years 2025 and 2030.

Year		**Household (HH) Surplus**	**Shippers (SH) Surplus**	**Non-U.S. Surplus (NS)**
100% of Petroleum Fuel Purchased Outside of United States, Cumulative Impacts				
2025	Employment (Jobs)	7,580	6,720	3,410
	Output (Millions, 2015$)	$2,230	$2,430	$1,540
2030	Employment	14,600	12,850	6,180
	Output	$4,180	$4,590	$2,790
100% of Petroleum Fuel Purchased within United States, Cumulative Impacts				
2025	Employment	3,500	2,640	-670
	Output	$540	$740	-$160
2030	Employment	6,900	5,160	-1,520
	Output	$990	$1,400	-$410

5.4 Macroeconomic Impacts for Florida

5.4.1 Florida Market Penetration Scenarios

In this section, we present the results of an analysis examining the potential macroeconomic impacts of fuel displacement due to shore power compliance and use in Florida. Scenarios for the Florida portion of the analysis use the same assumptions as those in the United States analysis, with the exception that the region of focus is Florida, with its unique economic characteristics. In this section, we develop scenarios for the following Florida ports:

- Port Canaveral
- Port of Miami
- Port Everglades
- Port of Key West
- Port of Tampa
- Port of Jacksonville

5.4.2 Shifts in Expenditures: Florida

5.4.2.1 Electricity Demand and Costs

Using the electricity use assumptions outlined in the preceding section, we estimated projected electricity demand for all Florida shore power scenarios. These estimates are shown in Figure 36. Electricity price assumptions for each market penetration scenario (based on EIA AEO price projections, as outlined above) are shown in Figure 37; and aggregate electricity expenditures for each scenario and year, as compared to a zero baseline are shown in Figure 40.

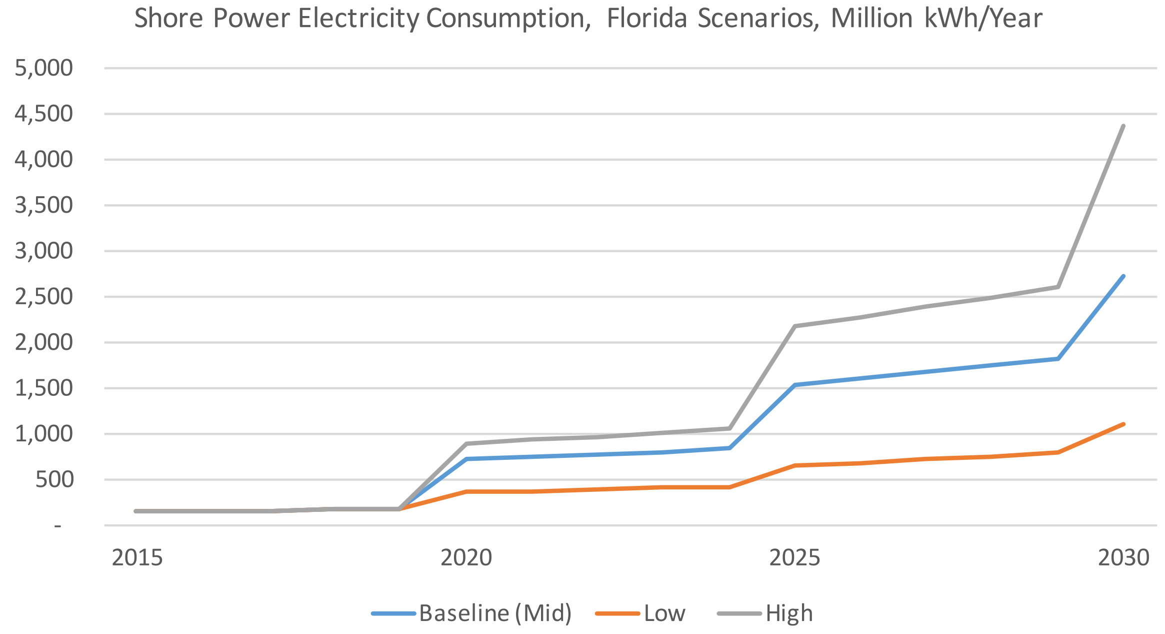


Figure 36. Annual Aggregate Electricity Consumption of Shore Power in Florida by Scenario, 2015-2030

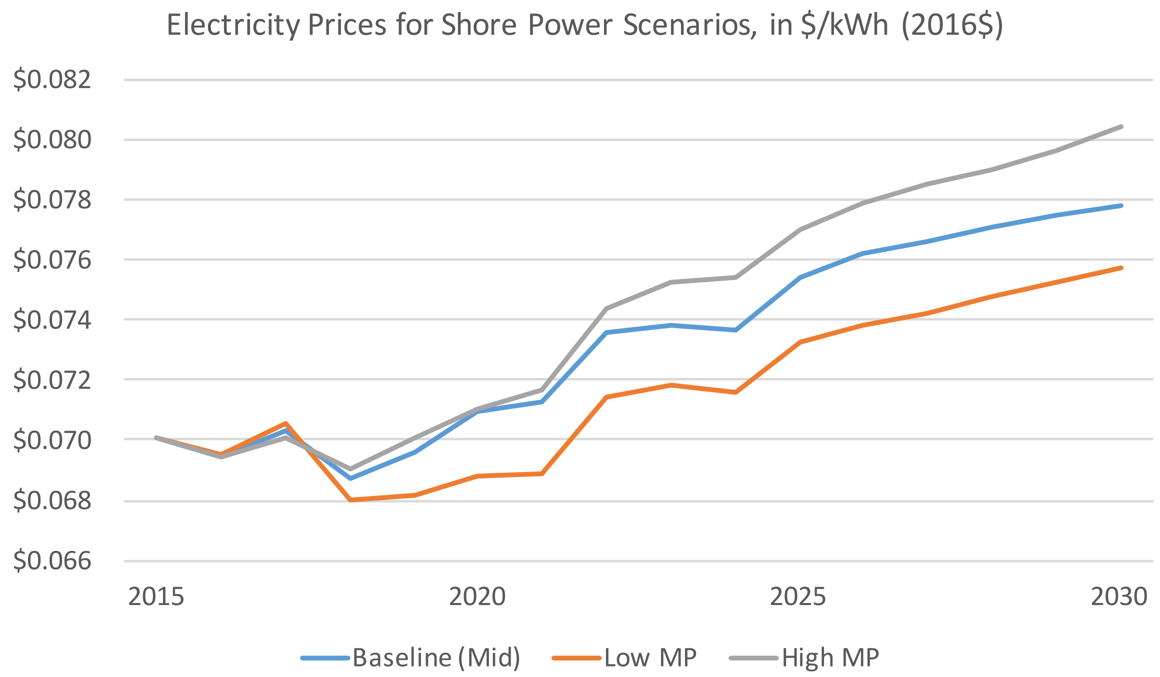


Figure 37. Average Weighted Electricity Prices for Evaluated Florida Shore Power Scenarios, 2015-2030

5.4.2.2 Petroleum Demand and Savings

Using the petroleum fuel displacement assumptions outlined in the preceding section, MGO fuel displacement was calculated for all Florida shore power scenarios. Annual aggregate petroleum displacement estimates are shown in Figure 38. Avoided petroleum expenditures are calculated using U.S. DOE EIA price projections, as described in the preceding section. Fuel price assumptions for each scenario are shown in Figure 39.

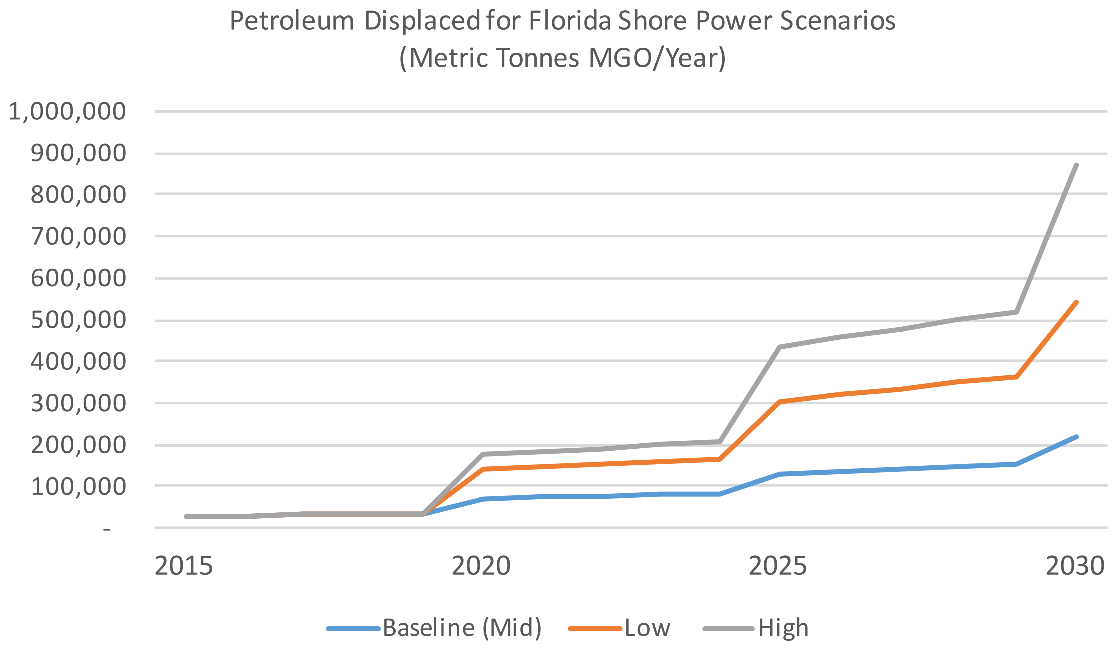


Figure 38. Aggregate Annual Petroleum Displacement due to Shore Power use in Florida, by Scenario, 2015-2030

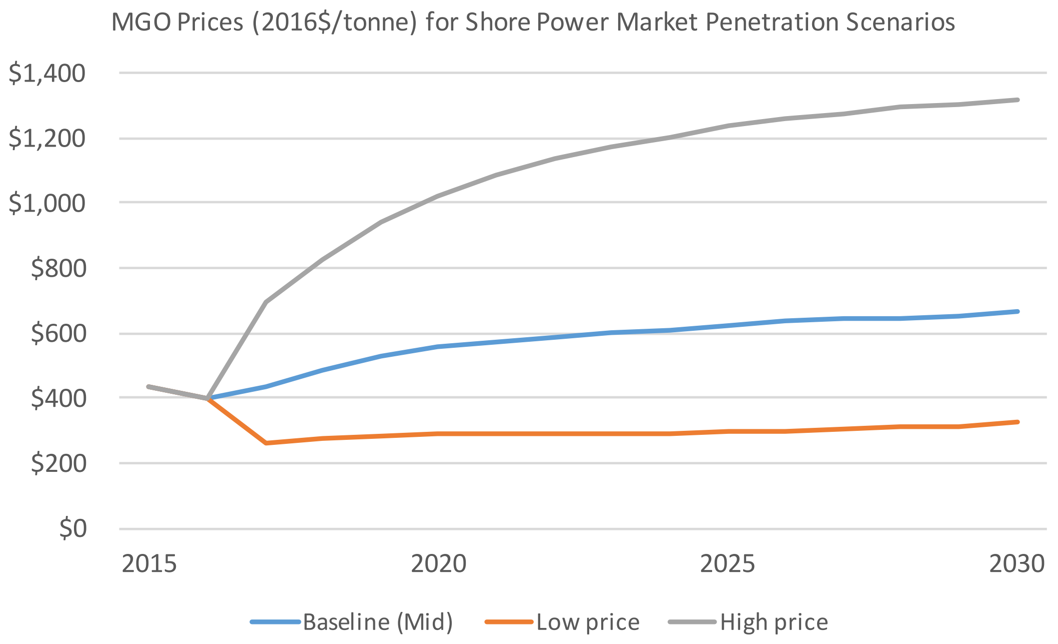
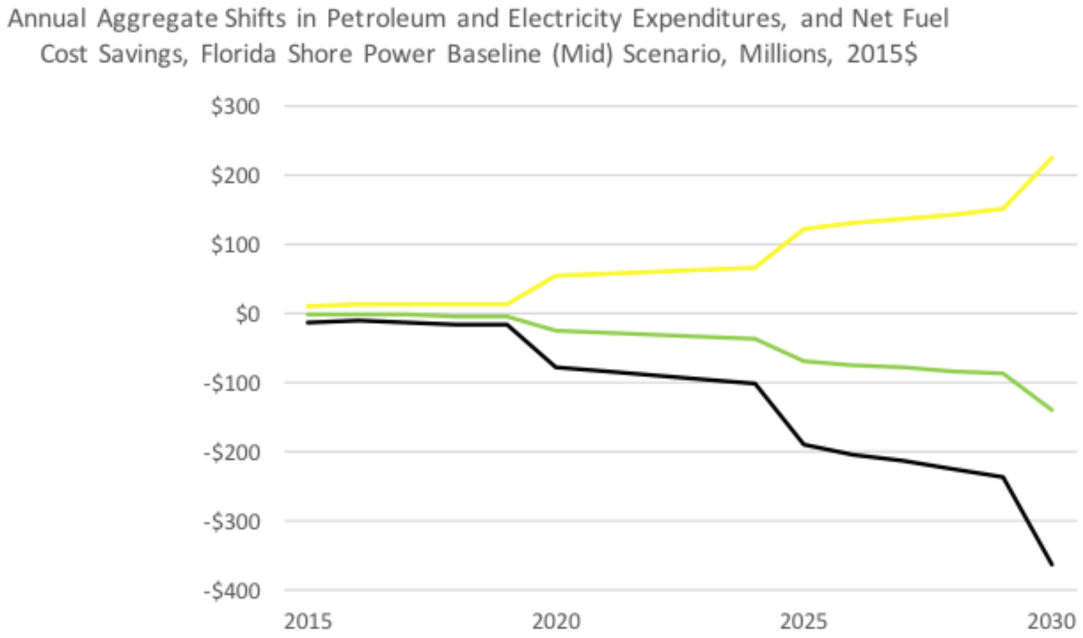


Figure 39. Average MGO Prices for Evaluated Florida Shore Power Scenarios, 2015-2030

5.4.2.3 Net Fuel Cost Savings

Aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to large-scale compliance and use of shore power in Florida are estimated for each evaluated scenario and year, 2015-2030. Figure 40 shows estimated shifts in expenditures (in millions 2015$) for the Mid-Level Market Penetration scenario.



Electricity Expenditures	$11	$53	$122	$225
Decreased Petroleum Expenditures	-$13	-$79	-$191	-$365
Net Fuel Cost Savings (Negative = Savings)	-$2	-$26	-$69	-$140

Figure 40. Shifts in Electricity and Petroleum Expenditures, and Net Fuel Cost Savings due to Shore Power use in Florida, 2015-2030

5.4.3 Macroeconomic Impacts: Florida

We estimated the macroeconomic impacts of these shifts were estimated using IMPLAN, with datasets extracted for the State of Florida. The estimated shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors, as shown above in Table 8, and as described in the preceding section. Macroeconomic impacts estimated include total cumulative changes in employment (in job-years) and output ($ million) over time (2015-2030) for each scenario and case (Table 11). For the Mid-Level Market Penetration scenario, we also estimate impacts for the years 2025 and 2030 (Table 12). Cumulative employment and output impacts for the top ten sectors are available in the Appendix, as are estimates of direct, indirect, and induced employment and output impacts.

Where displaced petroleum fuel MGO is assumed to be purchased from outside of the United States and where petroleum fuel cost savings are assumed to be spent within the United States, use of shore power in Florida under Mid-Level Market Penetration scenario could lead to 1,960 new jobs by 2030, with a cumulative impact of increased employment of up to 10,500 job-years for 2015-2030. Fuel shifts in this scenario could increase state-wide economic output by up to $560 million/year in 2030, for cumulative impacts of over $3 billion. Where displaced petroleum fuel is assumed to be purchased from Florida[22], and where petroleum fuel cost savings are assumed to be spent outside of the US, economic impacts are negative.

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[22] Florida accounts for approximately 7-9% of United States residual fuel and distillate fuel sales by volume.

Table 11. Estimated Macroeconomic Impacts of Shore Power Petroleum Displacement in Florida, Cumulative (2015-2030) Impacts for all Evaluated Scenarios and Cases

	Mid-Level Market Penetration Scenario			**Low Market Penetration Scenario**			**High Market Penetration Scenario**		
100% of Displaced Petroleum Fuel Purchased Outside of Florida, Cumulative Impacts									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Employment (Job-Years)	10,500	8,500	3,890	490	910	1,860	28,200	20,790	3,780
Output	$3,110	$3,450	$2,200	$860	$790	$1,050	$5,490	$6,750	$2,130
100% of Displaced Petroleum Fuel Purchased within Florida (Original Runs), Cumulative Impacts									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Employment (Job-Years)	2,230	230	-4,380	-1,450	-1,040	-80	12,120	4,720	-12,300
Output	$470	$810	-$440	$240	$170	$430	$360	$1,620	-$3,000

Table 12. Estimated Macroeconomic Impacts of Baseline (Mid) Scenario Shore Power Petroleum Displacement in Florida, Years 2025 and 2030.

Year		**Household (HH) Surplus**	**Shippers (SH) Surplus**	**Non-U.S. Surplus (NS)**
100% of Displaced Petroleum Fuel Purchased Outside of United States, Cumulative Impacts				
2025	Employment (Jobs)	1,030	830	380
	Output (Millions, 2015$)	$300	$340	$210
2030	Employment	1,960	1,570	680
	Output	$560	$620	$380
100% of Displaced Petroleum Fuel Purchased within United States, Cumulative Impacts				
2025	Employment	230	30	-420
	Output	$50	$80	-$40
2030	Employment	480	90	-810
	Output	$90	$150	-$90

5.5 Chapter Conclusion

The results indicate that large-scale adoption of shore power in the United States and Florida has the potential to result in macroeconomic benefits of tens of thousands of jobs and billions of dollars of increased output. The size of these impacts depends on two key factors: (1) where vessels currently purchase MGO fuel; and (2) what shippers do with fuel cost savings. For the first issue, economic impacts were more positive when fuel was assumed to be purchased outside of the US. Therefore, there may be a strategic economic advantage to emphasize shore power at US ports where a larger share of port calls are from foreign vessels that typically purchase fuel outside the US. For the second issue, the greatest benefits occur when shippers either pass along savings to consumers or purchase goods and services from the domestic market themselves. Few benefits occur when shippers take their fuel cost savings and spend them outside the US.

6 Macroeconomic Impacts of Electric Buses: An Assessment for the United States and New York City

Summary of Chapter Findings

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, electric transit buses will displace over 50 million gallons of petroleum fuel per year at net savings of $35 million per year. This will result in increased output of $340 million and increased employment of 820 jobs. Cumulatively, approximately 6,800 job-years of employment, and $2.4 billion in increased economic activity are expected between 2015-2030.

- Under our Mid-Level Market Penetration scenario, we estimate that by 2030, electric transit buses in New York City will displace 4 million gallons of petroleum fuel per year at net savings of $4 million per year. This will result in increased output of $17 million and increased employment of 30 jobs. Cumulatively, approximately 290 job-years of employment and $130 million in increased economic activity are expected between 2015-2030.

6.1 Chapter Overview

The use of electric transit buses is growing in many metropolitan areas throughout the US. Although investment in electric buses is usually justified on environmental grounds, there are some potential economic advantages to the shift from petroleum to electricity in the transit bus sector. In this chapter, we develop future market penetration scenarios for electric (EV) buses in the US and New York City. We use these scenarios to evaluate the macroeconomic impacts of this use. We first describe the electric bus scenario assumptions. We then present results specific to the United States. Finally, we present assumptions and results for New York City.

6.2 Scenario Development

We evaluate three scenarios for EV buses for the time period 2015-2030: Low, Mid-Level, and High Market Penetration. In order to capture a range of potential economic impacts, we evaluate each scenario using a range of energy prices, capital equipment costs, and other variables relevant for macroeconomic analysis. The scenarios are described as below, with Figure 41 showing the population of EV buses in the US for each scenario.

- Low Market Penetration Scenario
  The Low Market Penetration scenario for EV buses was based on the existing population of EV buses in the US, as reported in the Federal Transit Administration's National Transit Database, for the year 2015[23] [24]. Only 40-ft EV buses are included in the analysis due to data availability. The Low Market Penetration scenario assumes that this level of EV bus use (41 buses) continues through 2030. Buses

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[23] The most recent year for which data were available.

are assumed to be replaced at the end of a 14 year-lifetime [25, 26]. All buses, conventional and EV, are assumed to average 40,000 vehicle-miles traveled (VMT) per year, per CARB cost and data assumptions used their EV Bus Cost Model [25]. Energy prices for this scenario are derived from EIA AEO projections, using the *Low Oil Price* case.

- High Market Penetration Scenario:
  In the High Market Penetration scenario, we assume that 5% of the national 40-ft bus fleet is battery electric by 2020, 20% by 2025, and 50% by 2030. As shown in Figure 41, this equates to nearly 5,000 40-ft EV buses in 2025, and over 12,400 EV buses (collectively driving nearly 500 million VMT) by 2030. Buses are replaced near the end of the average 14-year lifetime, based on vehicle age as reported in the National Transit Database [24]. Energy prices for this scenario are derived from EIA AEO projections, using the *High Oil Price* case.

- Mid-Level Market Penetration Scenario:
  In this scenario, market penetration falls halfway between that of Low and High Market Penetration scenarios, with EV buses comprising 2.5% of the 40-ft bus fleet in 2020, 10% in 2025, and 25% of the fleet in 2030. As shown in Figure 41, this equates to nearly 2,500 EV buses in 2025, and over 6,200 EV buses collectively driving nearly 250 million miles) by 2030. Energy prices for this scenario are derived from EIA AEO *Reference Case* forecasts.

In all three scenarios, the total nationwide population of buses (~24,850), and average annual VMT per bus are assumed to remain constant over the 2015-2030 period, in alignment with flat trends in bus transit in recent years [24, 27]. Figure 41 shows the population of EV buses in the US for each scenario during the 2015-2030 period, while Figure 42 shows the estimate annual aggregate VMT of EV buses.

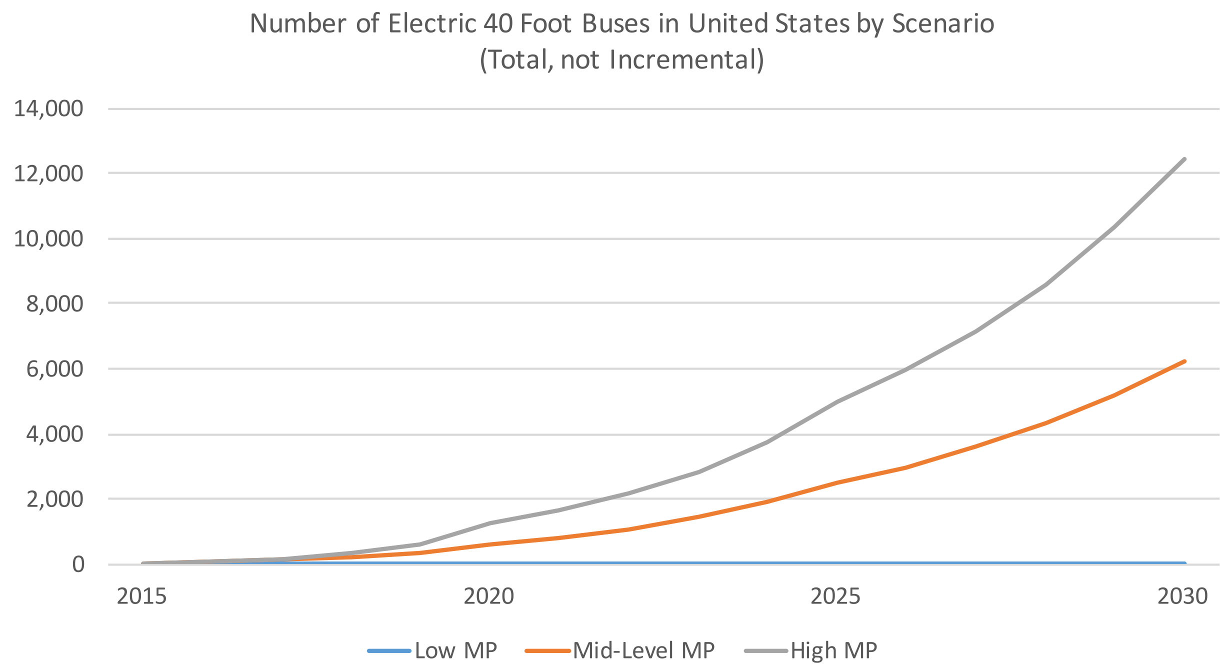

Figure 41. U.S. Electric Bus Market Penetration by Scenario (Total Number of EV Buses), 2015-2030

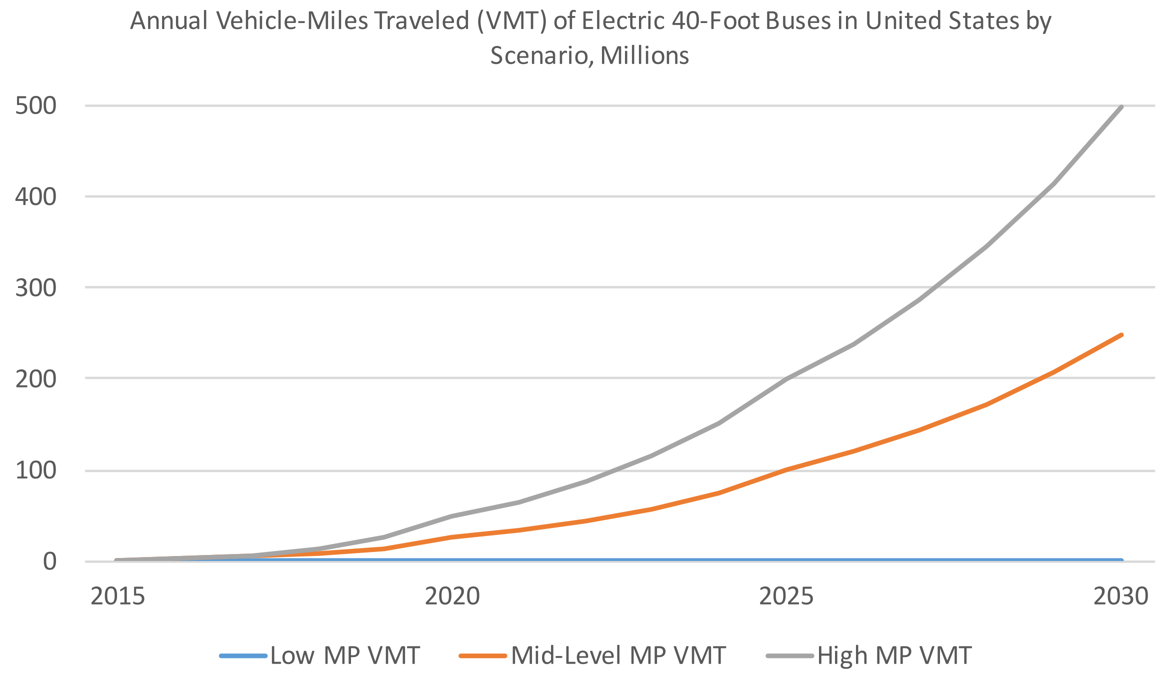

Figure 42. U.S. Electric Bus Vehicle-Miles Traveled (VMT) by Scenario 2015-2030

6.3 Macroeconomic Impacts for the United States

6.3.1 Shifts in Expenditures: United States

6.3.1.1 Electricity Demand and Costs

Large-scale market penetration of EV buses will increase electricity consumption, and thus demand for electricity generation, transmission, and distribution. Aggregate electricity consumption (million kWh) for each market penetration scenario and year assumes that EV buses on average consume 2.08 kWh per mile in 2015, improving 1 - 2% per year to 1.66 kWh/mile by 2030[24] [25]. We also assume 85% charger system efficiency (i.e. 15% losses). Estimated projected electricity demands for each scenario, as compared to a baseline of zero EV buses, are shown in Figure 43.

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[24] This assumes that the current average efficiency of EV buses (as assumed in the California Air Resources Board EV Bus Cost Data and Sources (https://arb.ca.gov/msprog/ict/meeting/mt170626/170626costdatasources.xlsx) improves in line with efficiency improvements of diesel buses, as explained in the petroleum displacement section.

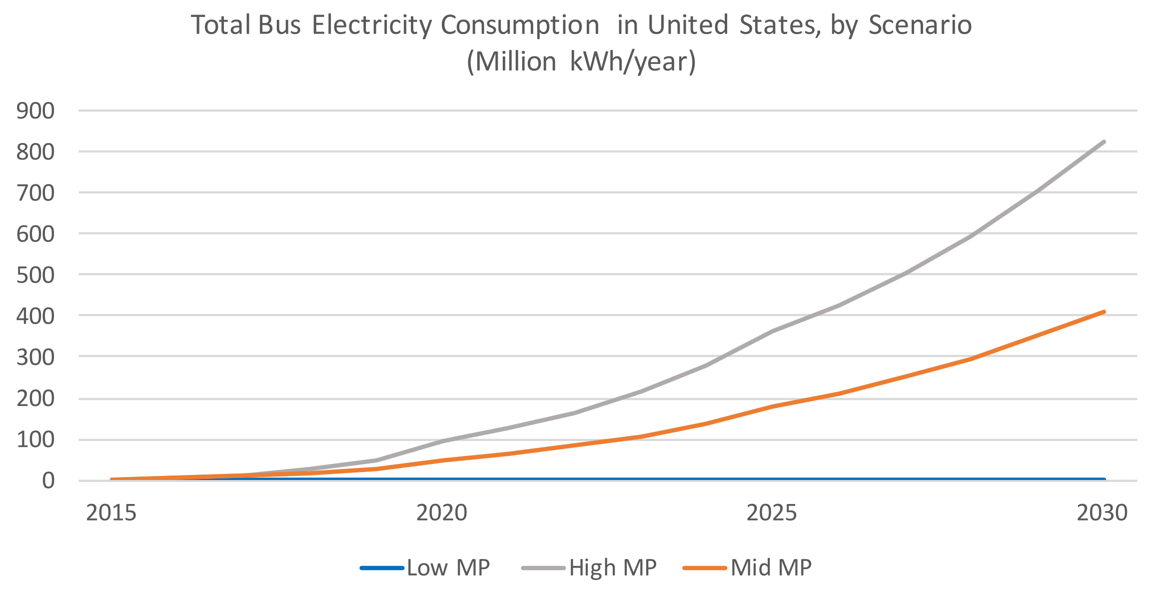

Figure 43. Aggregate Annual Electricity Consumption of EV Buses by Scenario, United States, 2015-2030

We calculate electricity expenditures for each scenario based on the following assumptions:

- Electricity rates for electricity used in transportation ($/kWh) from U.S. DOE EIA, and projected price changes from EIA AEO 2017 are used to estimate U. average electricity prices for each year 2015-2030 [28, 29]. Electricity prices are adjusted to $2015.
- Baseline electricity prices for the Mid-Level, Low, and High Market Penetration Scenarios are derived from the EIA AEO *Reference Case*, *Low Oil Price* case, and *High Oil Price* case, respectively.
- The Mid-Level and High Market Penetration scenarios assume the presence of demand charges which result in electricity rates approximately 266% those of baseline electricity prices, based on EV bus demand and usage charges reported by UCS and CARB [25, 30].

Electricity prices for each scenario and year are shown in Figure 44.

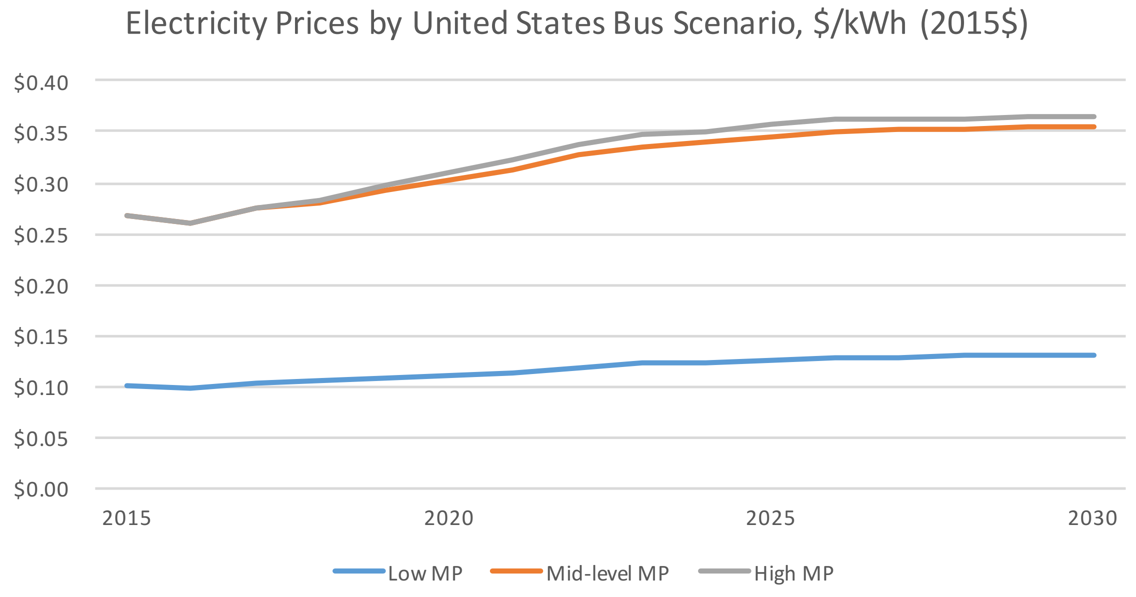

Figure 44. Average Annual Electricity Prices for Evaluated EV Bus Scenarios, United States 2015-2030

We use aggregate annual electricity consumption and electricity prices to estimate aggregate electricity expenditures for each scenario and year. Estimated aggregate electricity expenditures for each scenario are shown in Figure 47 (with shifts in petroleum fuel expenditures).

6.3.1.2 Petroleum Demand and Savings

Market penetration of EV buses will decrease consumption of petroleum fuel. Changes in aggregate petroleum consumption (million gallons) for each market penetration scenario assume that EV buses displace conventional diesel buses. We assume that displaced diesel buses have an average fuel efficiency of ~3.8 miles per gallon (MPG) in 2015, which improves 1-2% per year until 2030, until reaching ~4.7 MPG in 2030[25]. Average VMT of displaced diesel buses is assumed to be identical to that of EV buses (40,000 annually). We estimate petroleum displacement (millions of gallons) for each scenario and year compared to a baseline of zero use of EV buses; our results are shown in Figure 45. We calculate avoided petroleum expenditures for each scenario using EIA AEO 2017 price projections for transportation diesel fuel for each year, 2015-2030 [29]. Diesel fuel price assumptions for each scenario are shown in Figure 46.

6.3.1.3 Aggregate Fuel Spending Shifts

We estimate aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to EV bus market penetration in the US for each scenario between 2015-2030. Figure 47 shows shifts in fuel expenditures (in millions 2015$) for the Mid-Level Market Penetration scenario, compared to our baseline.

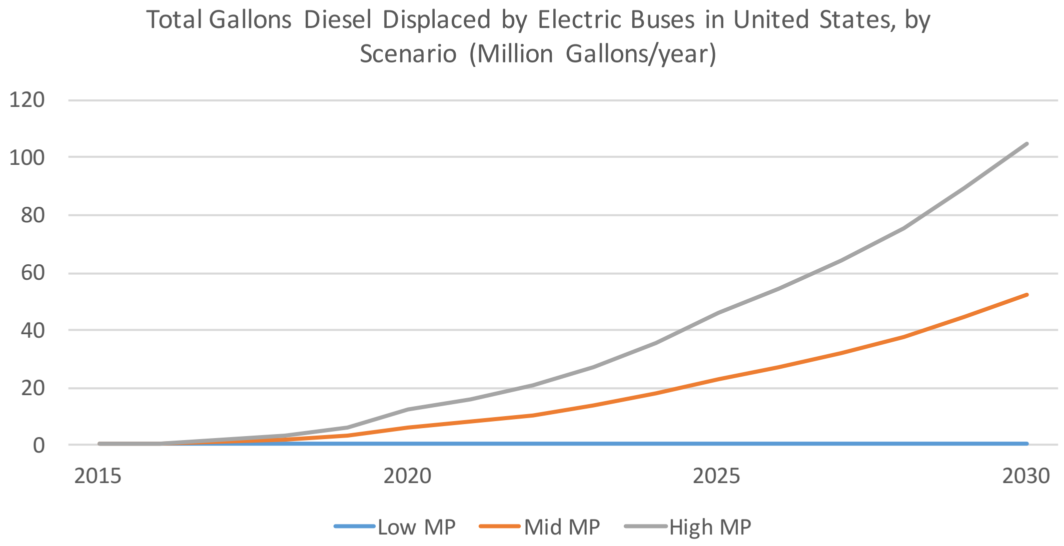

Figure 45. Aggregate Annual Diesel Displacement due to EV Buses by Scenario, United States, 2015-2030

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[25] Initial fuel economy of diesel buses is based on estimates from CARB (3.86 MPG) and Federal Transit Administration (3.66 MPG). Efficiency of on-road diesel buses is assumed to improve at the same rate as projected efficiency improvements of on-road HDV trucks, as projected in EIA Annual Energy Outlook 2017.

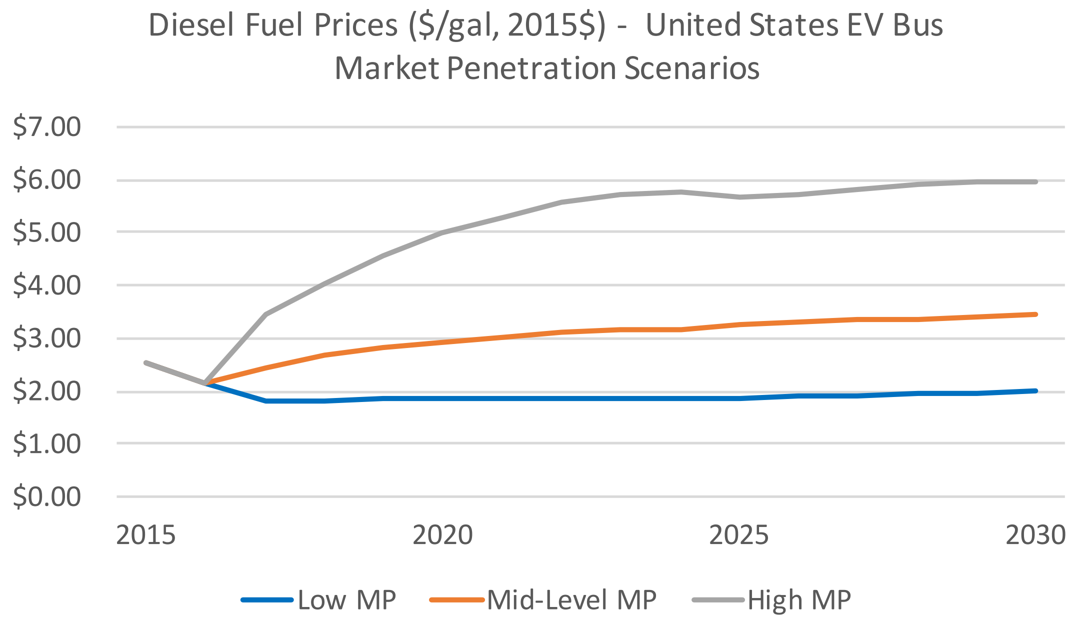


Figure 46. Annual Diesel Fuel Prices for Evaluated EV Bus Scenarios, United States 2015-2030

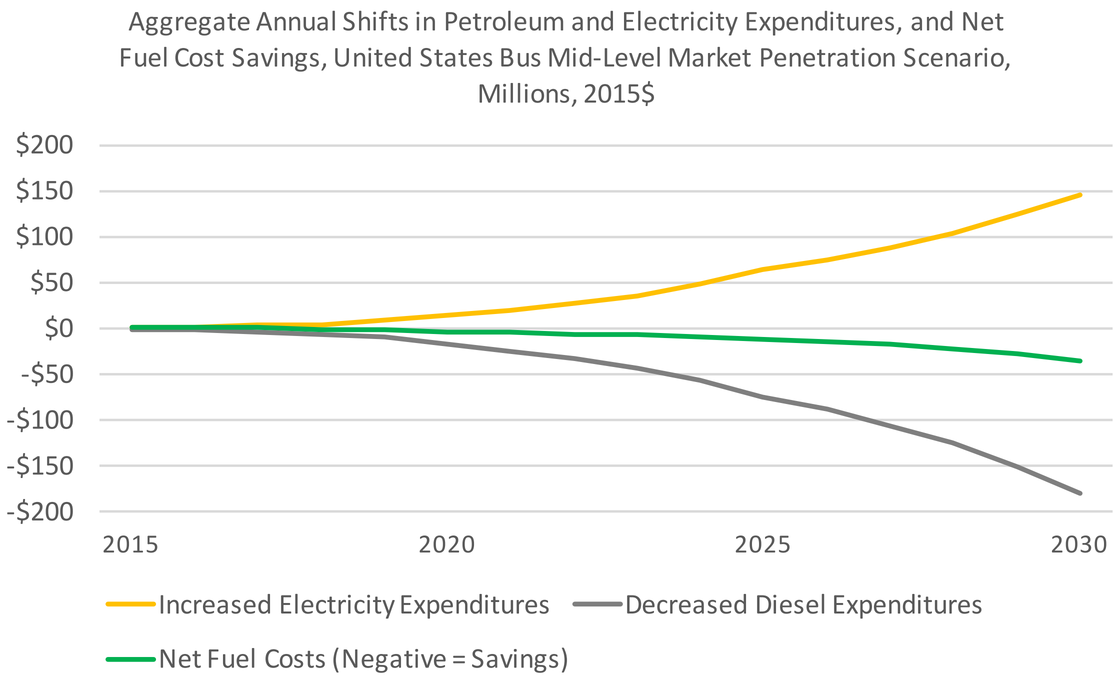


Figure 47. Aggregate Annual Shifts in Electricity and Petroleum Demand, and Net Fuel Cost Savings due to EV Bus Market Penetration in the United States, Mid-Level MP Scenario, 2015-2030

6.3.1.4 Shifts in Expenditures in Other EV Bus-Related Sectors

A shift towards EV buses will involve direct changes in demand for other sectors, including bus manufacturing, batteries, chargers, and maintenance. Here we present the approach and assumptions used to estimate these shifts. Capital and maintenance costs are reported in 2015$, and unless otherwise reported are based on data from ICF [11, 12] and the California Air Resources Board [25].

6.3.1.4.1 Incremental Costs and Bus Manufacturing

Electric buses have higher upfront capital costs compared to conventional diesel buses, and so increased market penetration of EV buses will result in increased capital expenditures. In this analysis, EV bus incremental costs (cost above that of diesel buses) are assumed to range from $145,000 to $332,000 in 2015 and are assumed to decline gradually to $40,700 to $176,500 by 2030 [11, 12, 25]. In all scenarios, we assume incremental costs to be an average of low and high capital cost estimates, given the mix in EV bus technologies, both current and anticipated. Non-battery incremental costs were assumed to increase demand in the “heavy duty truck manufacturing” sector. Net estimated shifts in expenditures on EV bus manufacturing for the Mid-Level Market Penetration scenario are shown in Figure 48 (following discussion of all shifts).

6.3.1.4.2 Incremental Costs and Battery Manufacturing

Batteries tend make up the majority of the incremental cost of EV buses. Increased market penetration of EV buses will increase capital expenditures for transit agencies and will also increase demand for battery production. Estimated aggregate shifts in expenditures on EV bus batteries are based on the assumption that 86% of EV bus incremental costs are due to batteries (this portion was derived using the current estimate of EV battery costs of $900 per kW, and current incremental costs for a range of EV bus battery sizes and costs, as estimated by ICF and CARB [11, 12, 25]). Aggregate increased EV bus battery expenditures are translated to increased demand in the battery manufacturing sector. Net estimated shifts in expenditures on EV bus batteries for the Mid-Level Market Penetration scenario are shown in Figure 48.

6.3.1.4.3 EV Bus Chargers

Chargers present another capital cost associated with switching from diesel to EV buses. Aggregate shifts in expenditures for chargers were estimated assuming capital costs for chargers ranging from $50,000 for slow chargers in 2015 on the low end (declining to ~$30,700 by 2030), to $350,000 for an on-route fast charger in 2015 on the high end (declining to $214,800 by 2030). For fast chargers, there are assumed to be 6 buses per charger; one charger per bus is assumed for slow chargers. Chargers are expected to have an average lifetime of 20 years. As with incremental and battery costs, EV bus charger costs are assumed to be midway between high and low cost estimates, assuming a range of technologies among the fleets of EV buses. Estimates of annual aggregate expenditures on chargers are translated to increased demand in the battery charger manufacturing sector.

6.3.1.4.4 Bus Maintenance Costs

Due to the relative lack of moving parts, EV buses typically require less maintenance than their diesel counterparts. According to CARB, EV buses can save up to $0.19 per mile due to reduced maintenance costs [25, 31]. To estimate aggregate savings on maintenance expenditures by transit agencies, the $0.19 per-mile maintenance savings estimate is multiplied by aggregate EV bus VMT in any given year. Maintenance cost savings are assumed to be constant across the examined time period (adjusted to 2015$), and are calculated as aggregate savings to transit agencies. Aggregate savings on maintenance costs are then translated to reduced demand in the automotive repair and maintenance sector.

6.3.1.4.5 Charger O&M Costs

Chargers require maintenance expenditures as well. Maintenance on slow (depot) chargers is estimated at $500 per year, while maintenance for fast on-route chargers is estimated at $13,000 per year [25]. These costs are multiplied by the total number of chargers per year, to estimate aggregate expenditures on charger O &M. Aggregate expenditures are translated to increased demand for commercial and industrial machinery and equipment repair and maintenance sectors of the economy.

6.3.1.4.6 Charger Installation Costs

Charger installation is yet another cost associated with a shift to EV bus use. Installation costs for EV bus chargers are estimated at \$50,000 per customer, with 5 buses per installation assumed for slow chargers, and 6 buses per installation assumed for fast chargers [11, 12]. We multiply these costs by the total number of chargers per year to estimate aggregate expenditures on charger installation. Aggregate expenditures are then translated to increased demand for commercial and industrial machinery and equipment repair and maintenance sectors of the economy.

6.3.1.5 Federal Government Spending

A large portion of transit capital equipment expenditures (typically 80%) is paid by the Federal government, through the Bus and Facilities Infrastructure Investment Program [32]. Additionally, the Low or No Emission Competitive program provides funds to state and local governments for the purchase or lease of zero-emission and low-emission transit buses (including EV buses) and supporting facilities; and \$55 million per year is available until fiscal year 2020 for these expenditures under the FAST Act [33]. This analysis assumes that 80% of all incremental cost and equipment costs (e.g. chargers) are paid for by the Federal government. The aggregate amount of federal expenditures on EV buses and infrastructure in a given year is then assumed to be deducted from federal investment based on existing spending patterns.

6.3.1.6 Net Operational Cost Savings

The use of EV buses results in an overall operational cost savings for transit agencies, compared to diesel bus counterparts. Net annual aggregate cost savings for transit agencies were estimated as follows, as compared to a baseline scenario with zero market penetration of EV buses:

$$\$S_y = \Delta\$E_y + \Delta\$P_y + \Delta\$V_y + \Delta\$C_y + \Delta\$M_y$$

where: y = year; \$S = net savings; \$E = electricity expenditures; \$P = petroleum expenditures; \$V = vehicle equipment expenditures; \$C = charger expenses, and \$M = maintenance savings.

To calculate the transit agencies' capital equipment and infrastructure expenditures each year, the transit agency's share of the capital cost (20%) is assumed to be financed over a 12-year period, at 3.75% interest.

There is uncertainty in terms of how and where transit agency operational cost savings will be allocated, and therefore which sectors of the economy will benefit. Net operational savings may be used in a number of ways, including being retained by and reinvested by transit agencies, being passed on to passengers in the form of reduced rates, or a combination of these. To estimate a range of potential economic impacts of EV bus use, we examined two cases:

- Case I: Savings to Households (HH)

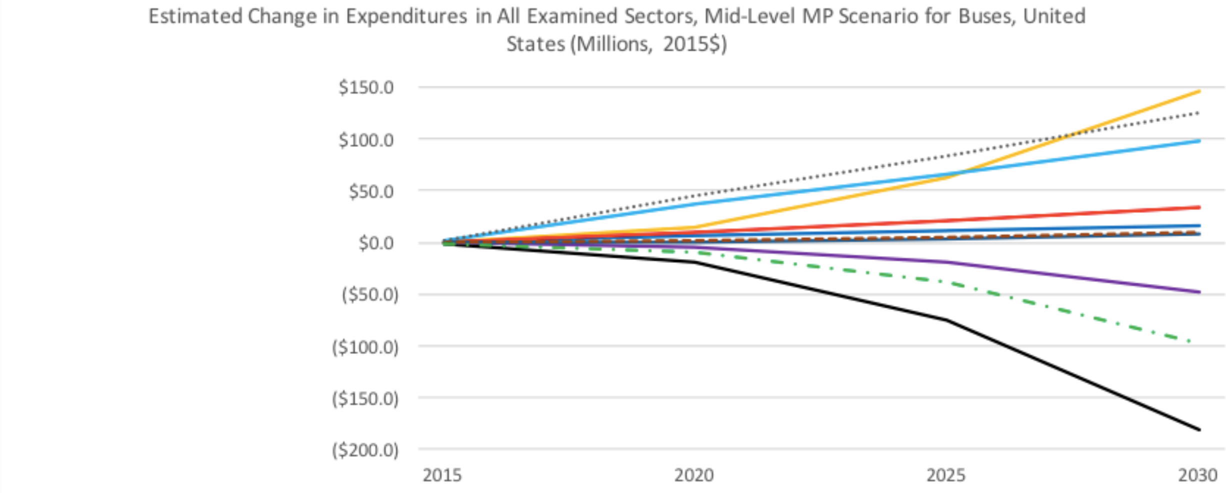
  The first case assumes that any operational cost savings are passed on to transit customers. This case assumes that transit agencies pass their savings onto passengers, and these reduced costs are ultimately realized in the form of lower prices for transit services. The net savings to households are assumed to be spent on other goods and services in the economy based on existing household spending patterns by income bracket.

- Case II: Savings to Transit Agencies (Transit Surplus—TS)

  The second case assumes that operational cost savings are retained—and then spent—by transit agencies or their associated local governments. In this case, savings are allocated to the State &

Local government sector (i.e. this assumes that State and Local government activity would buy more of the goods and services that they are currently purchasing based on existing spending patterns).

Figure 48 shows the estimated shifts in demand for each sector and year for the US Mid-Level Market Penetration scenario. Similar details for the Low- and High-Market penetration scenarios are available in the Appendix.



	2015	2020	2025	2030
Decreased Petroleum Expenditures	($1.1)	($18.3)	($75.2)	($180.8)
Increased Electricity Expenditures	$0.9	$14.8	$62.6	$145.8
Bus Incremental Cost Expenditures (Non-Battery)	$0.2	$6.0	$10.8	$15.8
Bus Battery Incremental Cost Expenditures	$1.4	$36.8	$66.1	$97.2
Charger Expenditures	$0.4	$10.3	$21.4	$34.6
Decreased Bus Maintenance Expenditures	($0.3)	($4.7)	($18.9)	($47.2)
Charger O&M Expenditures	$0.1	$0.8	$3.3	$8.3
Charger Installation Expenditures	$0.2	$2.4	$5.5	$9.5
Federal Government Expenditures on EV Buses and Equipment	$1.9	$44.4	$83.0	$125.7
Net Operational Cost Savings to Transit Agencies (Negative = Savings)	($0.7)	($9.2)	($37.7)	($98.2)

Figure 48. Aggregate Annual Shifts in Expenditures due to U.S.EV Bus Market Penetration, 2015-2030

6.3.2 Macroeconomic Impacts: United States

We used IMPLAN to calculate the macroeconomic impacts of all abovementioned shifts with US datasets. The estimated shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors. Table 13 shows the categories for shifts in EV bus-related expenditures, and the associated sector in IMPLAN where shifts in demand are assigned.

Macroeconomic impacts estimated here include total cumulative changes in employment (in job-years) and output ($ million), for the time period 2015-2030 for each scenario and case shown in Table 14. We also report annual impacts for the years 2025 and 2030. Estimated cumulative employment and output impacts by sector, for the top ten sectors, are available in the Appendix.

Table 13. Estimated Shifts in Expenditures due to EV Buses in the United States, and Sector for Input-Output Analysis

Shift in Expenditures	Assigned Sector
Electricity	Electric Power Transmission and Distribution
Petroleum Fuel	Petroleum Refineries
Vehicle Incremental Costs	Heavy Duty Truck Manufacturing
Bus Maintenance Costs	Automotive Repair and Maintenance
Batteries	Battery Manufacturing
Chargers	All other Miscellaneous Electrical Equipment and Component Manufacturing
Charger Maintenance & Charger Installation	Commercial and Industrial Machinery and Equipment Repair and Maintenance
Federal Government Spending	Federal Government Investment
Net Operational Costs: Case I (Savings to Households—HH)	Households
Net Operational Costs: Case II (Savings to Transit Agencies—TS)	Transit / Local & State Government (Non-education)

Table 14. Estimated Macroeconomic Impacts of EV Buses in the United States, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

United States Bus	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	TS	HH	TS	HH	TS
Year 2025	**730**	**250**	**-6**	**-4**	**990**	**1,620**
Year 2030	**820**	**670**	**-6**	**-2**	**550**	**4,030**
Cumulative	**6,800**	**NA**	**-10**	**NA**	**7,800**	**NA**
Output (Millions, 2015$)						
	Case I	Case II	Case I	Case II	Case I	Case II
	HH	TS	HH	TS	HH	TS
Year 2025	**$240**	**$140**	**-$1**	**-$1**	**$290**	**$380**
Year 2030	**$340**	**$280**	**-$1**	**$0**	**$220**	**$830**
Cumulative	**$2,400**	**NA**	**$5**	**NA**	**$2,400**	**NA**

6.4 Macroeconomic Impacts for New York City

6.4.1 New York City Market Penetration Scenarios

In this section, we present the results of an analysis examining the potential impact of large-scale electric (EV) bus use in New York City. New York City's Metropolitan Transportation Authority (MTA) is the largest public transit bus fleet in the United States, with approximately 5,700 buses serving the greater New York region. For the New York City (NYC) analysis, the assumptions behind the market penetration scenarios differ slightly those used in the United States analysis. Though we include estimates for Mid-Level, and High Market Penetration, we do not evaluate a Low Market Penetration scenario, as the current (2017) EV bus population is too small to conduct a meaningful analysis.

The Mid- and High Market Penetration Scenarios generally follow those of the United States EV Bus Scenarios: 10% market penetration assumed in 2025 and 25% market penetration in 2030 for the Mid-Level Market Penetration Scenario, 20% market penetration assumed in 2025, and 50% market penetration in 2030 for the High Market Penetration Scenario[26].

Similar to the United States analysis, the projected number of buses are based on the number of 40-foot diesel buses in MTA's fleet, as reported in the National Transit Database (2,633 buses reported for 2015, the most recent year for which data are available). An additional 180 diesel buses are added to the fleet in 2018, as per reports of MTA adding 180 buses to Brooklyn routes [34, 35]. EV buses are assumed to replace diesel buses when diesel buses have reached the end of their lifetime, using vehicle age as reported by the National Transit Database [24].

Vehicle-miles traveled (VMT) by NYC buses is estimated to be 27,000 VMT per year, as per average estimates of NYC bus VMT as reported in the National Transit Database [24].

Figure 49 shows the assumed population of EV Buses in New York City for each evaluated scenario. As shown in the figure, in the Mid-Level Market Penetration scenario, the EV bus population is projected to reach ~280 by 2025, and ~700 EV buses by 2030. The High Market Penetration scenario assumes ~560 buses by 2025, and ~1,400 EV buses by 2030. Figure 50 shows the assumed VMT of EV Buses in New York City for each evaluated scenario, showing by 2030 an estimated 19 million VMT for the Mid-level Market Penetration scenario, and an estimated 38 million VMT for the High Market Penetration scenario.

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[26] In both of these scenarios, the number of EV buses upon early market penetration (2018 to 2020) is based on reported plans for use of EV buses by MTA, where 10 buses will be used in a pilot, with plans for 70 buses by 2020, assuming the pilot works out as expected http://www.mta.info/news/2018/01/08/mta-testing-10-new-all-electric-buses-reduce-emissions-modernize-public-transit.

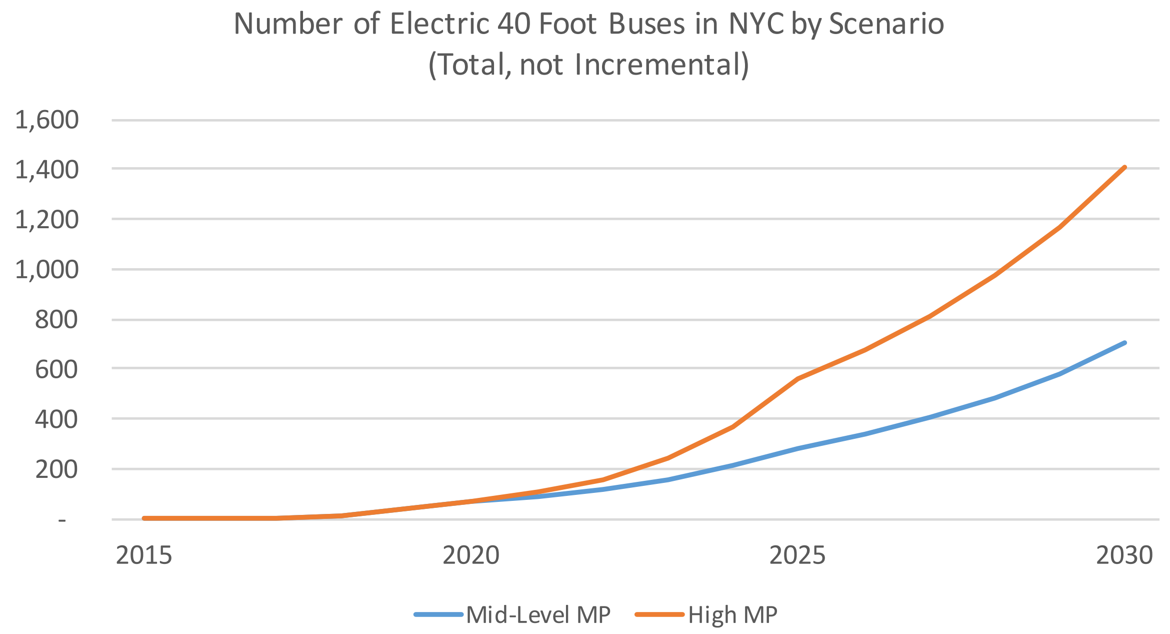


Figure 49. NYC EV Bus Market Penetration by Scenario (Total Population, not Incremental), 2015-2030

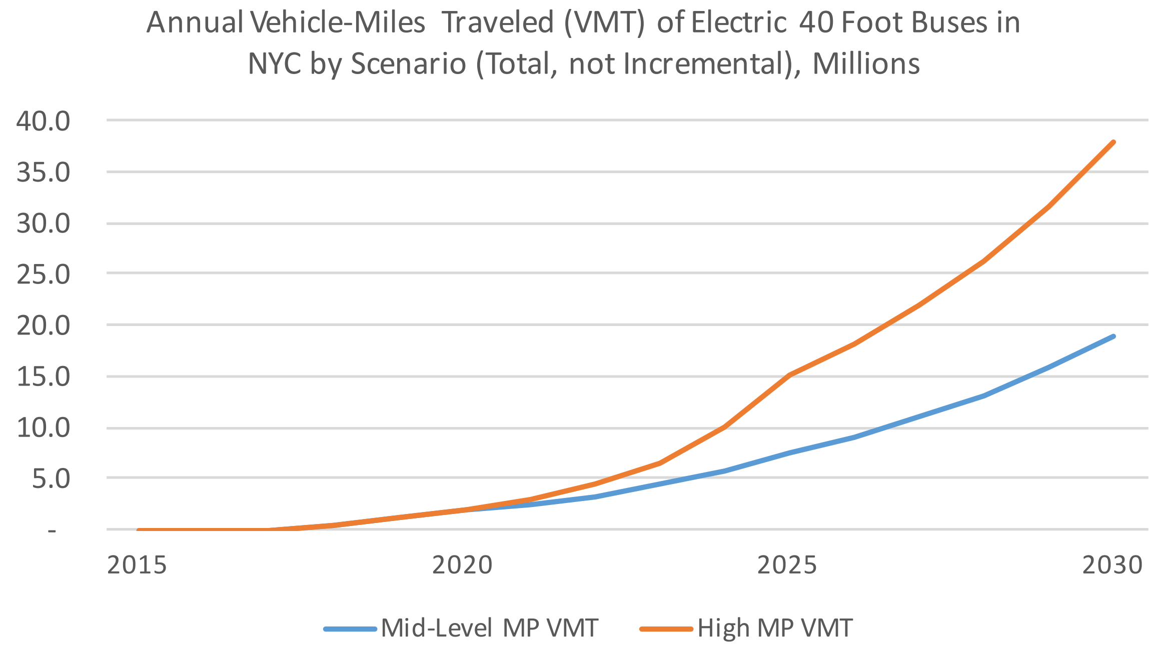


Figure 50. NYC EV Bus Vehicle Miles Traveled (VMT) by Scenario 2015-2030

6.4.2 Shifts in Expenditures: New York City

6.4.2.1 Electricity Demand and Costs

Using the EV bus energy use assumptions outlined in the preceding section, we estimated electricity demands for NYC. These estimates are shown in Figure 51. Electricity price assumptions are specific to New York or the EIA Middle Atlantic region, where appropriate, and are shown in Figure 52 [36]. Aggregate electricity expenditures for each scenario and year, as compared to a zero baseline are shown below in Figure 55.

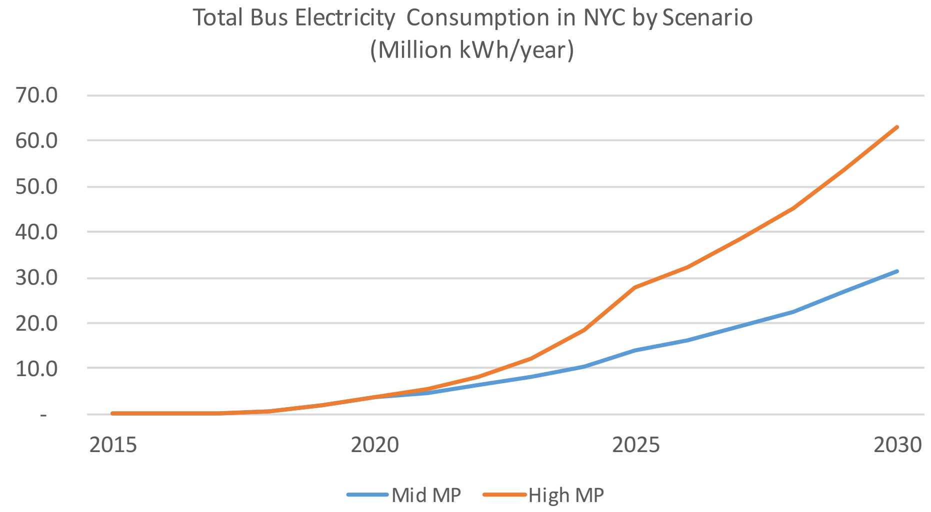


Figure 51. Aggregate Annual Electricity Consumption of EV Buses by NYC Scenario, 2015-2030

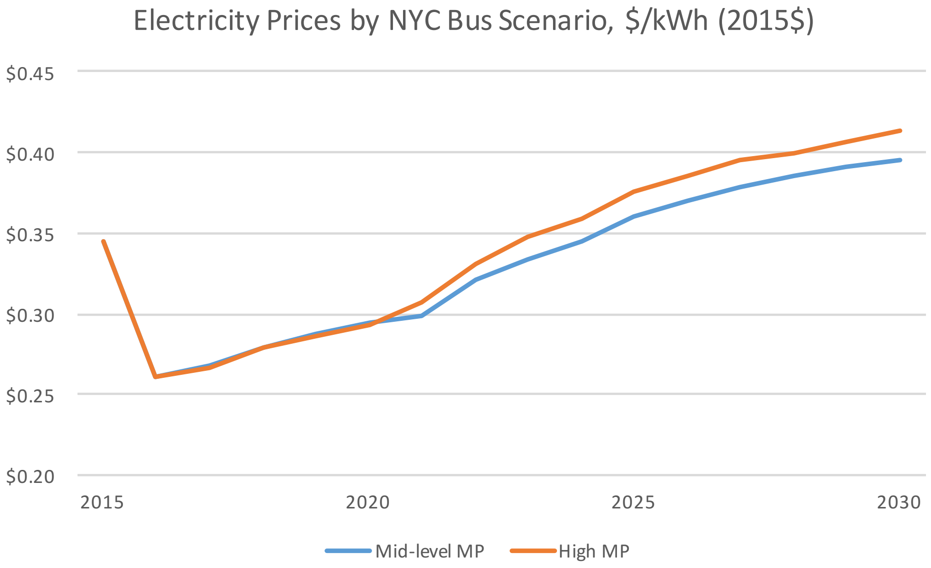


Figure 52. Average Electricity Prices for Evaluated NYC EV Bus Scenarios, 2015-2030

6.4.2.2 Petroleum Demand and Savings

Using the EV bus fuel displacement assumptions outlined in the preceding section, estimated diesel fuel displacement for both NYC EV bus scenarios were calculated. Estimated annual aggregate petroleum displacement (Million gallons) for both NYC scenarios is shown in

Figure 53. We calculate avoided petroleum expenditures using the assumptions described in the preceding section, with the exception that fuel prices from US DOE EIA and projections from EIA AEO use prices specific to New York or the EIA Middle Atlantic region. Diesel fuel price assumptions for New York for each scenario are shown in Figure 54. Aggregate electricity expenditures for each scenario and year, as compared to a zero baseline are shown below in Figure 55.

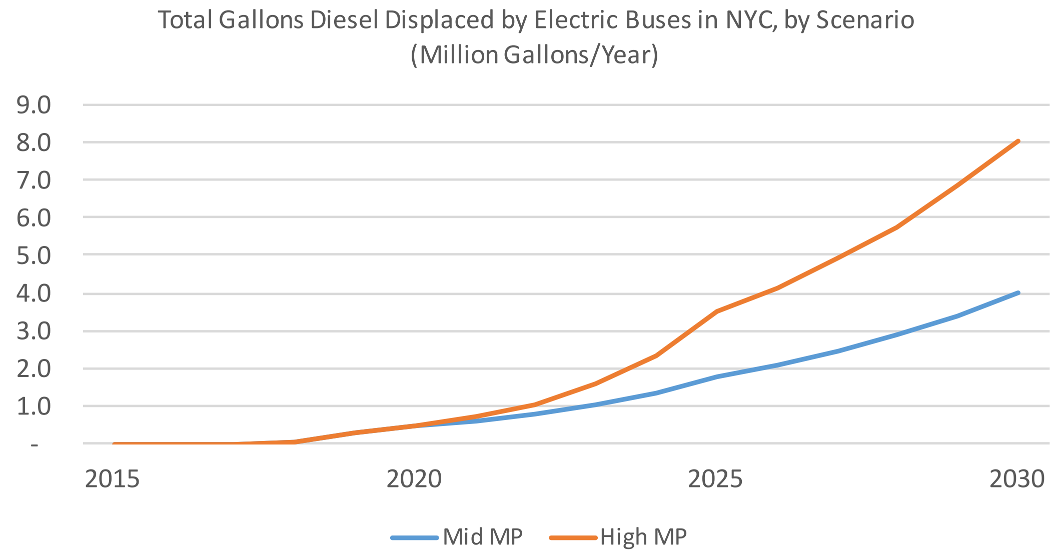


Figure 53. Aggregate Annual Petroleum Displacement due to EV Buses in New York City, by Scenario, 2015-2030

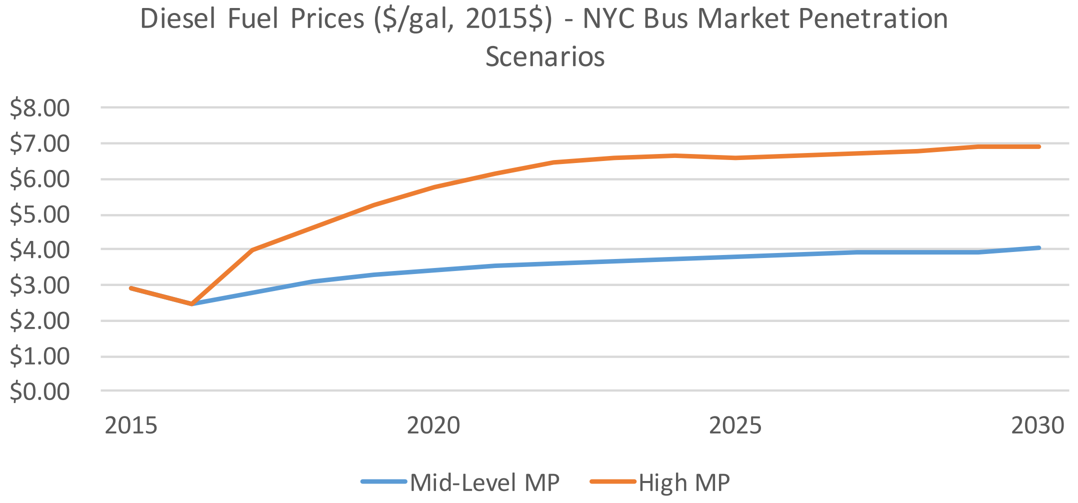


Figure 54. Average Diesel Prices for Evaluated NYC EV Bus Scenarios, 2015-2030

6.4.2.3 Aggregate Fuel Spending Shifts

Aggregate shifts in electricity expenditures, petroleum displacement, and net fuel cost savings due to large-scale EV bus market penetration in NYC are estimated for each scenario for 2015-2030. Figure 55 shows shifts in expenditures (in millions 2015$) for the Mid-level Market Penetration Scenario.

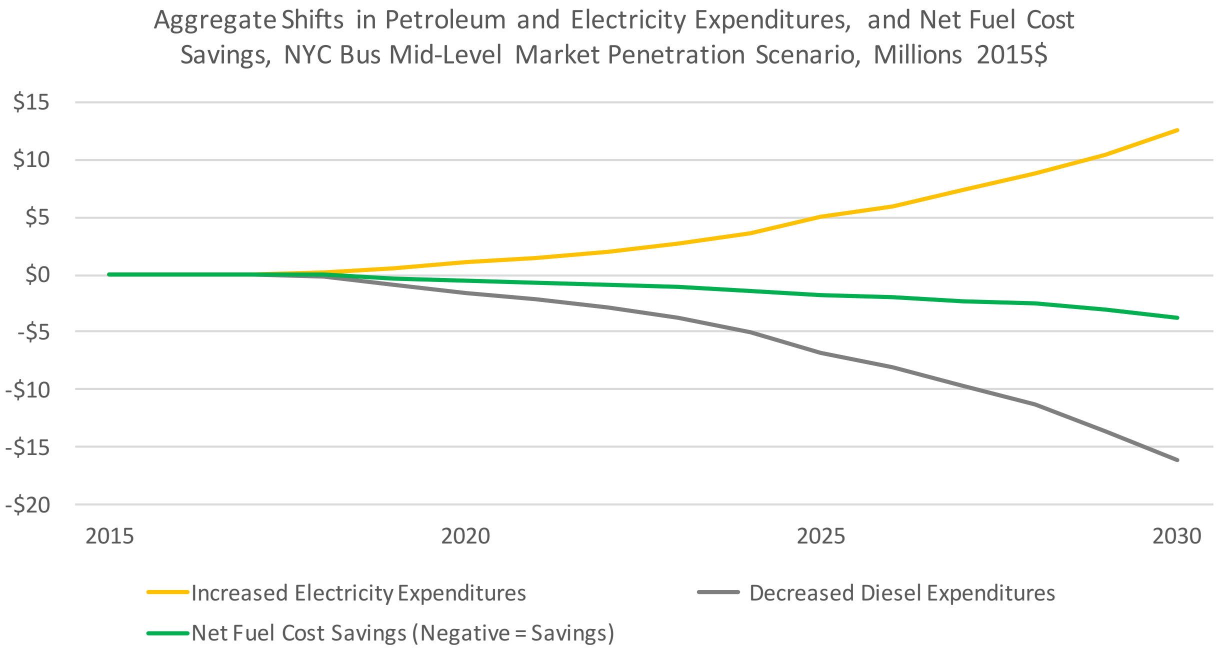
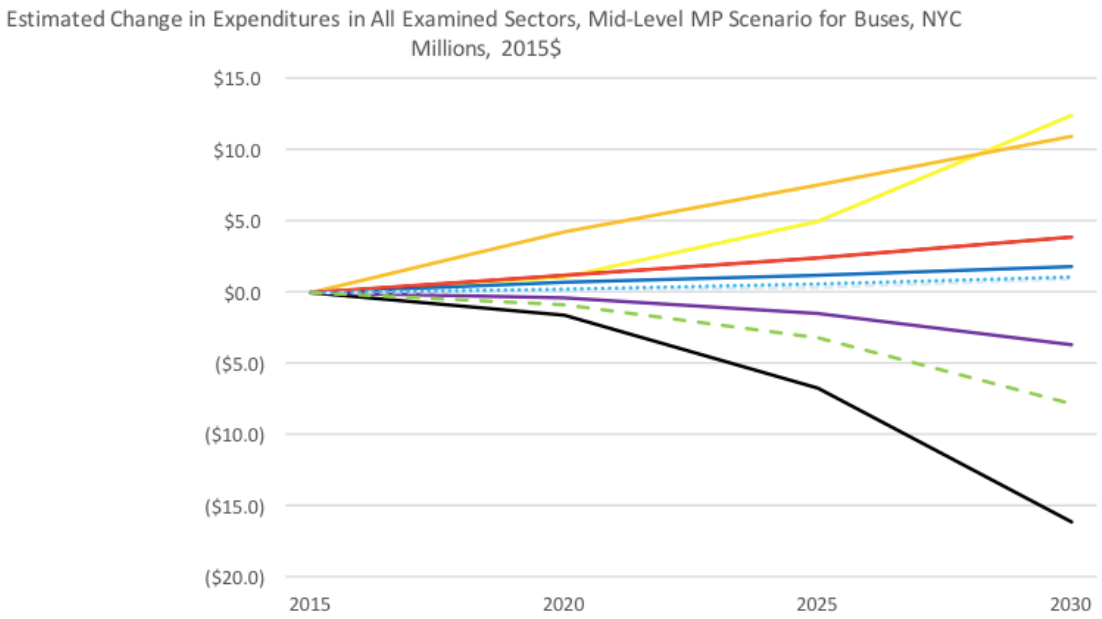


Figure 55. Shifts in Electricity and Petroleum Expenditures, and Net Fuel Cost Savings due to EV Bus Market Penetration in New York City, 2015-2030

6.4.2.4 Shifts in Expenditures in Other EV Bus-Related Sectors

A shift to EV buses will involve changes in expenditures across many sectors, as mentioned above. The approach and assumptions used to estimate these shifts in spending in NYC are identical to those used in the US analysis, with the exception of energy price assumptions and federal government spending.

For Federal government spending, we assume that 80% of all incremental vehicle costs and equipment costs (e.g. chargers) are paid by the Federal government. In the US analysis we adjusted Federal government investment in other sectors to account for the increased expenditures on EV buses and infrastructure. However, this analysis is more localized, and it cannot be reasonably assumed that increased spending on EV buses in NYC will influence Federal investment within the area to a similar degree. Therefore, in the NYC analysis, we do not adjust for changes in Federal government activity elsewhere. Figure 56 shows the estimated monetized shifts in demand for each sector and year, for the NYC EV Bus Mid-Level Market Penetration scenario. Estimated shifts in demand are reported in $2015.



	2015	2020	2025	2030
Decreased Petroleum Expenditures	$0.0	($1.6)	($6.7)	($16.2)
Increased Electricity Expenditures	$0.0	$1.1	$5.0	$12.5
Bus Incremental Cost Expenditures (Non-Battery)	$0.0	$0.7	$1.2	$1.8
Bus Battery Incremental Cost Expenditures	$0.0	$4.2	$7.5	$11.0
Charger Expenditures	$0.0	$1.2	$2.4	$3.9
Decreased Bus Maintenance Expenditures	$0.0	($0.4)	($1.4)	($3.6)
Charger O&M Expenditures	$0.0	$0.1	$0.4	$0.9
Charger Installation Expenditures	$0.0	$0.3	$0.6	$1.1
Net Operational Cost Savings to Transit Agencies (Negative = Savings)	$0.0	($0.8)	($3.2)	($7.8)

Figure 56. Estimate Aggregate Shifts in Expenditures due to EV Bus Market Penetration in NYC, 2015-2030

6.4.3 Macroeconomic Impacts: New York City

The macroeconomic impacts of the above economic shifts were estimated using the IMPLAN input-output analysis program, with datasets for the five-county New York City region served by the New York Metropolitan Transit Agency (MTA). The shifts in expenditures, by scenario and year, were translated into related shifts in demand in IMPLAN sectors as shown in Table 13 (in the preceding section).

Estimated macroeconomic impacts include total cumulative changes in employment (job-years) and output ($ million) for 2015-2030 for each scenario and case. Estimated impacts for the individual years 2025 and 2030 are also reported here. Employment impacts for the Mid-Level Market Penetration scenario are estimated to reach up to 80 jobs by 2030, for a cumulative impact of increased employment of 290 job-years for 2015-2030. The Mid-Level Market Penetration scenario also generates an increase in economic output in New York City by $17 to $27 million/year in 2030, for cumulative impacts of $130 million in increased economic output.

Table 15. Estimated Macroeconomic Impacts of EV Buses in NYC, showing impacts for years 2025, 2030, and Cumulative impacts (2015-2030)

EV Buses NYC	**Mid-Level Market Penetration**		**High Market Penetration**	
Employment (Job-years)				
	Case I HH	Case II TS	Case I HH	Case II TS
Year 2025	30	50	90	190
Year 2030	30	80	30	260
Cumulative	**290**	**NA**	**410**	**NA**
Output (Millions, 2015$)				
	Case I HH	Case II TS	Case I HH	Case II TS
Year 2025	$13	$17	$31	$50
Year 2030	$17	$27	$16	$61
Cumulative	**$130**	**NA**	**$160**	**NA**

6.5 Chapter Conclusion

The results from this chapter indicate that large-scale adoption of electric transit buses in the US and New York City can result in large petroleum fuel displacement, fuel cost savings, and demand in related industries. These impacts have the potential to create macroeconomic benefits of hundreds of jobs and hundreds of millions of dollars of increased output by 2030.

7 Conclusion: Implications and Limitations

7.1 Summary of Findings

This work presents the most comprehensive analyses to date of the potential macroeconomic impacts of large-scale electrification of medium- and heavy-duty transportation technologies. The research has demonstrated that the potential macroeconomic impacts of electrification of medium- and heavy-duty vehicles and transportation technologies in the US are substantial and positive. Given our Mid-Level Market Penetration scenarios, we estimate that market penetration of the evaluated technologies (Electric Forklifts, Truck Stop Electrification, Shore Power, and Electric Transit Buses) could collectively increase employment by over 34,000 jobs and increase economic output by nearly $5.4 billion per year by 2030. The cumulative macroeconomic impacts of these technologies for the years 2015 through 2030 are estimated at nearly *240,000 job-years* and nearly *$45 billion* in increased economic output.

We have also estimated potential macroeconomic impacts of electrification at the state and regional scale, and have found that regional impacts are also generally positive. Electrification of these technologies can create hundreds to thousands of jobs by 2030 and increased economic activity in the tens of millions of dollars. Overall, these results indicate that large-scale adoption of these electrified technologies will result in positive macroeconomic impacts.

7.2 Limitations

It goes without saying that these types of analyses include high potential uncertainty due to the nature of the data, forecasts projections, and models used. To begin, future projections used in scenarios are just that—projections, not predictions. All of the key variables in this analysis, including energy consumption of technologies and vehicles, energy prices, and capital equipment costs, are estimates. These scenarios are not intended to demonstrate what the future *will* look like with electric transportation technologies, but rather to illustrate the potential scale of macroeconomic impacts if large-scale market penetration of these technologies were to occur. For this reason, we have tried to include a variety of scenarios to help frame the overall set of possibilities that the future may hold.

Another limitation is the use of input-output modeling for longer-term economic analysis. Input-output analysis relies on actual (empirical) production functions as measured in our *current* economic structure. If the structure of our economy changes drastically during the time period of analysis, the outputs from I/O modeling are not as robust. In addition, I/O modeling necessarily requires the aggregation of some sectors of the economy (as discussed throughout this report). Because of this aggregation, some level of specificity in the results is lost. But despite these limitations, I/O analysis is the best modeling framework for capturing the direct, indirect, and induced economic effects due to changing macroeconomic spending patterns.

7.3 Implications and Future Directions

It has become all too common that policy decisions related to incentivizing electric transportation technologies rely only on (1) the direct *micro*economic costs to the private owner or operator; or, (2) the societal benefits due to reductions in greenhouse gas or criteria pollutant emissions. The expected societal *macro*economic impacts of electric transportation technology are not typically considered. For instance, a recent economic analysis of shore power use in the US found that in many cases, the costs of shore power to private owners exceeded their gains from fuel savings. In the same study, the societal benefits of shore power in terms of improved health and reduced greenhouse gas pollution was found to exceed the private costs [23]. Understanding and Incorporating the potentially substantial *macroeconomic* benefits of fuel displacement due to shore power might point toward shore power as beneficial both environmentally *and* economically and might provide further impetus for public incentives to encourage adoption.

This type of information may be used by policy makers to better anticipate the potential impacts of electrification in their regions and may be useful to understand whether it is beneficial to incentivize and otherwise support these types of technologies. Future work may involve in-depth analysis of additional technologies, or exploration in regions where policies or incentives to encourage adoption of electrification are under consideration.

8 Appendix

8.1 Top Ten Sectors for Increased Output and Employment by Scenario

The tables included in this section provide the top ten impacted sectors for increased output and employment for each of the technologies studies in this report. We include the results for the Mid-Level Market Penetration scenarios.

Table A1. Top Ten Sectors for Increased Output and Employment, United States. Forklifts Mid-Level Scenario, HH and BS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$32,350	Electric Power Transmission and Distribution	22,280
Electric Power Generation - Fossil Fuel	$13,260	All Other Miscellaneous Electrical Equipment and Component Manufacturing	20,760
Storage Battery Manufacturing	$7,690	Storage Battery Manufacturing	19,240
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$5,810	Electricity and Signal Testing Instruments Manufacturing	12,180
Electricity and Signal Testing Instruments Manufacturing	$5,060	Industrial Truck, Trailer, And Stacker Manufacturing	10,970
Industrial Truck, Trailer, And Stacker Manufacturing	$4,720	Electric Power Generation - Fossil Fuel	8,350
Electric Power Generation - Nuclear	$3,950	Wholesale Trade	7,850
Coal Mining	$2,860	Full-Service Restaurants	6,820
Wholesale Trade	$2,030	Real Estate	6,030
Owner-Occupied Dwellings	$1,290	Hospitals	4,990
Business Surplus Case (BS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$32,460	Retail - Food and Beverage Stores	31,220
Electric Power Generation - Fossil Fuel	$13,310	Electric Power Transmission and Distribution	22,360
Storage Battery Manufacturing	$7,690	Warehousing and Storage	21,980
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$5,810	Retail - Building Material and Garden Equipment and Supplies Stores	20,830
Electricity and Signal Testing Instruments Manufacturing	$5,060	All Other Miscellaneous Electrical Equipment and Component Manufacturing	20,760
Industrial Truck, Trailer, And Stacker Manufacturing	$4,730	Storage Battery Manufacturing	19,240
Electric Power Generation - Nuclear	$3,970	Electricity and Signal Testing Instruments Manufacturing	12,180
Coal Mining	$2,900	Industrial Truck, Trailer, And Stacker Manufacturing	10,990
Warehousing and Storage	$2,300	Electric Power Generation - Fossil Fuel	8,380
Retail - Food and Beverage Stores	$2,140	Wholesale Trade	7,590

Table A2. Top Ten Sectors for Increased Output and Employment, Texas. Forklifts Mid-Level Scenario, HH and BS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$2,520	All Other Miscellaneous Electrical Equipment and Component Manufacturing	2,000
Storage Battery Manufacturing	$700	Storage Battery Manufacturing	1,870
Electric Power Generation - Fossil Fuel	$690	Electric Power Transmission and Distribution	1,700
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$530	Electricity and Signal Testing Instruments Manufacturing	1,190
Electricity and Signal Testing Instruments Manufacturing	$440	Industrial Truck, Trailer, And Stacker Manufacturing	960
Industrial Truck, Trailer, And Stacker Manufacturing	$430	Full-Service Restaurants	430
Electric Power Generation - Wind	$260	Wholesale Trade	420
Wholesale Trade	$120	Electric Power Generation - Fossil Fuel	410
Electric Power Generation - Nuclear	$110	Real Estate	410
Local Government Electric Utilities	$90	Limited-Service Restaurants	330

Business Surplus Case (BS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$2,540	Retail - Food and Beverage Stores	3,640
Storage Battery Manufacturing	$700	Retail - Building Material and Garden Equipment and Supplies Stores	2,510
Electric Power Generation - Fossil Fuel	$690	Warehousing and Storage	2,470
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$530	All Other Miscellaneous Electrical Equipment and Component Manufacturing	2,000
Electricity and Signal Testing Instruments Manufacturing	$440	Storage Battery Manufacturing	1,870
Industrial Truck, Trailer, And Stacker Manufacturing	$430	Electric Power Transmission and Distribution	1,710
Warehousing and Storage	$280	Electricity and Signal Testing Instruments Manufacturing	1,190
Retail - Food and Beverage Stores	$260	Industrial Truck, Trailer, And Stacker Manufacturing	960
Retail - Building Material and Garden Equipment and Supplies Stores	$260	Real Estate	440
Electric Power Generation - Wind	$260	Electric Power Generation - Fossil Fuel	410

Table A3. Top Ten Sectors for Increased Output and Employment, United States. TSE Mid-Level Scenario, HH and TS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Retail - Gasoline Stores	$650	Retail - Gasoline Stores	9,870
Automotive Repair and Maintenance, Except Car Washes	$530	Automotive Repair and Maintenance, Except Car Washes	5,400
Real Estate	$300	Real Estate	1,440
Electric Power Transmission and Distribution	$230	Commercial and Industrial Machinery and Equipment Repair and Maintenance	1,120
Owner-Occupied Dwellings	$230	Construction of New Power and Communication Structures	1,110
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$170	Full-Service Restaurants	880
Construction of New Power and Communication Structures	$150	Hospitals	850
Wholesale Trade	$150	Limited-Service Restaurants	780
Hospitals	$130	Wholesale Trade	560
Electric Power Generation - Fossil Fuel	$100	Retail - General Merchandise Stores	520
Transit Surplus Case (TS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Truck Transportation	$1,310	Retail - Gasoline Stores	9,830
Retail - Gasoline Stores	$650	Truck Transportation	7,810
Automotive Repair and Maintenance, Except Car Washes	$520	Automotive Repair and Maintenance, Except Car Washes	5,330
Real Estate	$250	Real Estate	1,200
Electric Power Transmission and Distribution	$220	Commercial and Industrial Machinery and Equipment Repair and Maintenance	1,120
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$170	Construction of New Power and Communication Structures	1,110
Construction of New Power and Communication Structures	$150	Couriers and Messengers	800
Wholesale Trade	$150	Employment Services	670
Owner-Occupied Dwellings	$150	Full-Service Restaurants	610
Insurance Carriers	$110	Wholesale Trade	590

Table A4. Top Ten Sectors for Increased Output and Employment, Ohio. TSE Mid-Level Scenario, HH and TS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Retail - Gasoline Stores	$20	Retail - Gasoline Stores	410
Automotive Repair and Maintenance, Except Car Washes	$20	Automotive Repair and Maintenance, Except Car Washes	200
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$10	Commercial and Industrial Machinery and Equipment Repair and Maintenance	80
Real Estate	$10	Construction of New Power and Communication Structures	50
Owner-Occupied Dwellings	$10	Real Estate	40
Electric Power Transmission and Distribution	$10	Hospitals	30
Construction of New Power and Communication Structures	$10	Full-Service Restaurants	30
Hospitals	$0	Limited-Service Restaurants	30
Wholesale Trade	$0	Retail - General Merchandise Stores	20
Insurance Carriers	$0	Nursing and Community Care Facilities	20

Transit Surplus Case (TS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Truck Transportation	$40	Retail - Gasoline Stores	410
Retail - Gasoline Stores	$20	Truck Transportation	210
Automotive Repair and Maintenance, Except Car Washes	$20	Automotive Repair and Maintenance, Except Car Washes	200
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$10	Commercial and Industrial Machinery and Equipment Repair and Maintenance	80
Real Estate	$10	Construction of New Power and Communication Structures	50
Electric Power Transmission and Distribution	$10	Real Estate	30
Construction of New Power and Communication Structures	$10	Couriers and Messengers	20
Owner-Occupied Dwellings	$10	Full-Service Restaurants	20
Wholesale Trade	$0	Limited-Service Restaurants	20
Insurance Carriers	$0	Employment Services	20

Table A5. Top Ten Sectors for Increased Output and Employment, United States. Shore Power Mid-Level Scenario, 100% Displaced Fuel Purchased Outside of US, HH, SH, and NS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$7,389	Electric Power Transmission and Distribution	5,090
Electric Power Generation - Fossil Fuel	$3,031	Real Estate	3,470
Electric Power Generation - Nuclear	$903	Full-Service Restaurants	3,270
Owner-Occupied Dwellings	$804	Hospitals	2,880
Real Estate	$725	Limited-Service Restaurants	2,710
Coal Mining	$651	Wholesale Trade	2,330
Wholesale Trade	$603	Electric Power Generation - Fossil Fuel	1,910
Extraction of Natural Gas and Crude Petroleum	$465	Extraction of Natural Gas and Crude Petroleum	1,890
Hospitals	$446	Employment Services	1,810
Monetary Authorities and Depository Credit Intermediation	$314	Retail - General Merchandise Stores	1,740
Shippers Surplus Case (SH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$7,359	Electric Power Transmission and Distribution	5,070
Water Transportation	$3,782	Water Transportation	4,530
Electric Power Generation - Fossil Fuel	$3,017	Real Estate	2,650
Electric Power Generation - Nuclear	$899	Wholesale Trade	2,530
Wholesale Trade	$656	Extraction of Natural Gas and Crude Petroleum	2,320
Coal Mining	$649	Scenic and Sightseeing Transportation and Support Activities for Transportation	2,290
Petroleum Refineries	$599	Full-Service Restaurants	2,150
Extraction of Natural Gas and Crude Petroleum	$570	Electric Power Generation - Fossil Fuel	1,900
Real Estate	$553	Employment Services	1,860
Owner-Occupied Dwellings	$479	Limited-Service Restaurants	1,640
Non-U.S. Shipping Surplus Case (NS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**

Electric Power Transmission and Distribution	$7,274	Electric Power Transmission and Distribution	5,010
Electric Power Generation - Fossil Fuel	$2,979	Electric Power Generation - Fossil Fuel	1,880
Electric Power Generation - Nuclear	$888	Extraction of Natural Gas and Crude Petroleum	1,740
Coal Mining	$637	Full-Service Restaurants	1,300
Extraction of Natural Gas and Crude Petroleum	$428	Real Estate	1,130
Owner-Occupied Dwellings	$270	Wholesale Trade	970
Wholesale Trade	$251	Employment Services	930
Local Government Electric Utilities	$248	Limited-Service Restaurants	910
Real Estate	$236	Electric Power Generation - Nuclear	890
Electric Power Generation - Wind	$223	Hospitals	830

Table A6. Top Ten Sectors for Increased Output and Employment, United States. Shore Power Mid-Level Scenario, 100% Displaced Fuel Purchased within US HH, SH, and NS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$7,300	Electric Power Transmission and Distribution	5,030
Electric Power Generation - Fossil Fuel	$2,990	Real Estate	2,210
Electric Power Generation - Nuclear	$890	Full-Service Restaurants	2,070
Coal Mining	$630	Electric Power Generation - Fossil Fuel	1,880
Owner-Occupied Dwellings	$460	Hospitals	1,860
Real Estate	$460	Limited-Service Restaurants	1,570
Hospitals	$290	Employment Services	1,130
Local Government Electric Utilities	$250	Nursing and Community Care Facilities	1,130
Electric Power Generation - Wind	$220	Retail - General Merchandise Stores	1,070
Monetary Authorities and Depository Credit Intermediation	$200	Retail - Food and Beverage Stores	1,020
Shippers Surplus Case (SH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$7,270	Electric Power Transmission and Distribution	5,010

Water Transportation	$3,770	Water Transportation	4,520
Electric Power Generation - Fossil Fuel	$2,980	Scenic and Sightseeing Transportation and Support Activities for Transportation	2,120
Electric Power Generation - Nuclear	$890	Electric Power Generation - Fossil Fuel	1,880
Coal Mining	$630	Real Estate	1,380
Scenic and Sightseeing Transportation and Support Activities for Transportation	$360	Employment Services	1,180
Real Estate	$290	Waste Management and Remediation Services	1,040
Local Government Electric Utilities	$250	Full-Service Restaurants	950
Wholesale Trade	$230	Couriers and Messengers	940
Electric Power Generation - Wind	$220	Electric Power Generation - Nuclear	890
Non-U.S. Shipping Surplus Case (NS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$7,190	Electric Power Transmission and Distribution	4,950
Electric Power Generation - Fossil Fuel	$2,940	Electric Power Generation - Fossil Fuel	1,850
Electric Power Generation - Nuclear	$880	Electric Power Generation - Nuclear	880
Coal Mining	$620	Coal Mining	740
Local Government Electric Utilities	$240	Marketing Research and All Other Miscellaneous Professional, Scientific, And Technical Services	490
Electric Power Generation - Wind	$220	Local Government Electric Utilities	380
Electric Power Generation - Hydroelectric	$110	Scenic and Sightseeing Transportation and Support Activities for Transportation	330
Other Basic Inorganic Chemical Manufacturing	$90	Employment Services	250
Electric Power Generation - Biomass	$70	Electric Power Generation - Hydroelectric	140
Rail Transportation	$60	Commercial Logging	140

Table A7. Top Ten Sectors for Increased Output and Employment, Florida. Shore Power Mid-Level Scenario, 100% Displaced Fuel Purchased Outside of US, HH, SH, and NS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,208	Electric Power Transmission and Distribution	760
Electric Power Generation - Fossil Fuel	$533	Real Estate	630
Owner-Occupied Dwellings	$102	Extraction of Natural Gas and Crude Petroleum	410
Real Estate	$98	Full-Service Restaurants	400
Electric Power Generation - Nuclear	$63	Hospitals	380
Wholesale Trade	$58	Limited-Service Restaurants	330
Hospitals	$56	Electric Power Generation - Fossil Fuel	310
Local Government Electric Utilities	$47	Nursing and Community Care Facilities	240
Insurance Carriers	$34	Retail - General Merchandise Stores	240
offices of Physicians	$32	Retail - Food and Beverage Stores	230
Shippers Surplus Case (SH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,203	Electric Power Transmission and Distribution	750
Water Transportation	$650	Water Transportation	710
Electric Power Generation - Fossil Fuel	$531	Extraction of Natural Gas and Crude Petroleum	420
Wholesale Trade	$66	Real Estate	400
Electric Power Generation - Nuclear	$63	Scenic and Sightseeing Transportation and Support Activities for Transportation	360
Real Estate	$63	Electric Power Generation - Fossil Fuel	310
Scenic and Sightseeing Transportation and Support Activities for Transportation	$58	Wholesale Trade	260
Local Government Electric Utilities	$46	Full-Service Restaurants	210
Owner-Occupied Dwellings	$45	Employment Services	180

Extraction of Natural Gas and Crude Petroleum	$32	Couriers and Messengers	180
Non-U.S. Shipping Surplus Case (NS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,195	Electric Power Transmission and Distribution	750
Electric Power Generation - Fossil Fuel	$526	Extraction of Natural Gas and Crude Petroleum	400
Electric Power Generation - Nuclear	$63	Electric Power Generation - Fossil Fuel	300
Local Government Electric Utilities	$44	Real Estate	130
Extraction of Natural Gas and Crude Petroleum	$31	Full-Service Restaurants	110
Owner-Occupied Dwellings	$22	Marketing Research and All Other Miscellaneous Professional, Scientific, and Technical Services	90
Real Estate	$20	Maintenance and Repair Construction of Nonresidential Structures	80
Wholesale Trade	$16	Employment Services	80
Maintenance and Repair Construction of Nonresidential Structures	$13	Limited-Service Restaurants	70
Extraction of Natural Gas Liquids	$10	Hospitals	70

Table A8. Top Ten Sectors for Increased Output and Employment, Florida. Shore Power Mid-Level Scenario, 100% Displaced Fuel Purchased within US, HH, SH, and NS Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,200	Electric Power Transmission and Distribution	750
Electric Power Generation - Fossil Fuel	$530	Real Estate	470
Owner-Occupied Dwellings	$80	Full-Service Restaurants	310
Real Estate	$70	Hospitals	310
Electric Power Generation - Nuclear	$60	Electric Power Generation - Fossil Fuel	300
Hospitals	$50	Limited-Service Restaurants	250
Local Government Electric Utilities	$40	Nursing and Community Care Facilities	210
Offices of Physicians	$20	Retail - General Merchandise Stores	190

Insurance Carriers	$20	Retail - Food and Beverage Stores	190
Limited-Service Restaurants	$20	Offices of Physicians	180
Shippers Surplus Case (SH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,190	Electric Power Transmission and Distribution	750
Water Transportation	$650	Water Transportation	710
Electric Power Generation - Fossil Fuel	$530	Scenic and Sightseeing Transportation and Support Activities for Transportation	340
Electric Power Generation - Nuclear	$60	Electric Power Generation - Fossil Fuel	300
Scenic and Sightseeing Transportation and Support Activities for Transportation	$50	Real Estate	250
Local Government Electric Utilities	$40	Couriers and Messengers	150
Real Estate	$40	Waste Management and Remediation Services	130
Waste Management and Remediation Services	$30	Employment Services	120
Owner-Occupied Dwellings	$20	Full-Service Restaurants	110
Insurance Carriers	$20	Marketing Research and All Other Miscellaneous	80
Non-U.S. Shipping Surplus Case (NS)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$1,190	Electric Power Transmission and Distribution	740
Electric Power Generation - Fossil Fuel	$520	Electric Power Generation - Fossil Fuel	300
Electric Power Generation - Nuclear	$60	Local Government Electric Utilities	60
Local Government Electric Utilities	$40	Electric Power Generation - Nuclear	60
Electric Power Generation - Wind	$10	Marketing Research and All Other Miscellaneous Professional, Scientific, And Technical Services	50
Scenic and Sightseeing Transportation and Support Activities for Transportation	$10	Scenic and Sightseeing Transportation and Support Activities for Transportation	30
Marketing Research and All Other Miscellaneous Professional, Scientific, And	$0	Full-Service Restaurants	20

Technical Services			
Electric Power Generation - All Other	$0	Employment Services	10
Coal Mining	$0	Electric Power Generation - Solar	10
Rail Transportation	$0	Rail Transportation	10

Table 9. Top Ten Sectors for Increased Output and Employment, United States. EV Bus Mid-Level Scenario, HH Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Electric Power Transmission and Distribution	$740	Storage Battery Manufacturing	1,610
Storage Battery Manufacturing	$640	All Other Miscellaneous Electrical Equipment and Component Manufacturing	750
Electric Power Generation - Fossil Fuel	$310	Commercial and Industrial Machinery and Equipment Repair and Maintenance	600
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$210	Electric Power Transmission and Distribution	510
Heavy Duty Truck Manufacturing	$140	Wholesale Trade	420
Wholesale Trade	$110	Full-Service Restaurants	200
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$90	Electric Power Generation - Fossil Fuel	190
Electric Power Generation - Nuclear	$90	Employment Services	160
Coal Mining	$70	Limited-Service Restaurants	150
Owner-Occupied Dwellings	$40	Management of Companies and Enterprises	150

Table A10. Top Ten Sectors for Increased Output and Employment, New York City. EV Bus Mid-Level Scenario, HH Cases, Cumulative Impacts (2015-2030)

Household Surplus Case (HH)			
Output (Millions, 2015$)		**Employment (Jobs)**	
Description	**Total**	**Description**	**Total**
Storage Battery Manufacturing	$70	Storage Battery Manufacturing	180
Electric Power Transmission and Distribution	$60	All Other Miscellaneous Electrical Equipment and Component Manufacturing	90
All Other Miscellaneous Electrical Equipment and Component Manufacturing	$20	Commercial and Industrial Machinery and Equipment Repair and Maintenance	50
Heavy Duty Truck Manufacturing	$20	Electric Power Transmission and Distribution	40
Commercial and Industrial Machinery and Equipment Repair and Maintenance	$10	Wholesale Trade	20
Wholesale Trade	$10	Heavy Duty Truck Manufacturing	20
Electric Power Generation - Fossil Fuel	$0	Management of Companies and Enterprises	10
Management of Companies and Enterprises	$0	Full-Service Restaurants	10
Owner-Occupied Dwellings	$0	Marketing Research and All Other Miscellaneous Professional, Scientific, And Technical Services	0

Lessors of Nonfinancial Intangible Assets	$0	Limited-Service Restaurants	0

8.2 Direct, Indirect, and Induced Output and Employment Impacts by Technology and Scenario

Table A11. Estimated Macroeconomic Impacts of Electric Forklifts in United States, showing Direct, Indirect, and Induced effects (2015-2030)

United States Forklifts	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
Effect	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	23,250	93,250	-8,100	75,250	70,700	361,550
Indirect	18,400	45,750	-4,000	28,700	-2,750	110,900
Induced	114,350	60,850	99,250	34,900	401,200	178,250
Output (Millions, 2015$)						
	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	($3,650)	$4,150	($7,300)	$2,100	($23,900)	$8,650
Indirect	$21,050	$26,750	$8,200	$15,000	$17,300	$41,050
Induced	$19,000	$10,100	$16,500	$5,800	$66,650	$29,600

Table A12. Estimated Macroeconomic Impacts of Electric Forklifts in Texas, showing Direct, Indirect, and Induced effects (2015-2030)

Texas Forklifts	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
Effect	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	2,500	11,100	-400	7,700	7,250	35,800
Indirect	-750	1,900	-1,100	1,450	-2,900	5,900
Induced	6,600	1,150	5,850	650	24,000	5,700
Output (Millions, 2015$)						
	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	($650)	$400	($800)	$200	$2,600	$800
Indirect	$300	$80	$50	$500	$600	$1,000
Induced	$1,000	$200	$850	$100	$3,500	$850

Table A13. Estimated Macroeconomic Impacts of Truck Stop Electrification (TSE) in the United States, showing Direct, Indirect, and Induced effects (2015-2030)

United States TSE	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
Effect	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	17,000	24,600	2,700	2,950	63,600	293,200
Indirect	-600	5,000	150	350	-1,050	-1,050
Induced	19,850	11,700	1,500	1,200	62,200	50,900
Output (Millions, 2015$)						
	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	($700)	$600	$15	$60	$1,900	$1,800
Indirect	($350)	$800	$10	$50	($1,100)	($1,100)
Induced	$3,300	$1,950	$250	$200	$10,300	$8,450

Table A14. Estimated Macroeconomic Impacts of Truck Stop Electrification (TSE) in Ohio, showing Direct, Indirect, and Induced effects (2015-2030)

Ohio TSE	Mid-Level Market Penetration (Reference Case)		Low Market Penetration		High Market Penetration	
Employment (Job-years)						
Effect	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	750	950	125	130	1,500	18,200
Indirect	50	150	10	15	-13	-13
Induced	550	350	50	50	2,250	1,850
Output (Millions, 2015$)						
	Case I HH	Case II BS	Case I HH	Case II BS	Case I HH	Case II BS
Direct	($10)	$25	$4	$5	($140)	$65
Indirect	$10	$30	$2	$3	$1	$1
Induced	$75	$50	$7	$6	$310	$255

Table A15. Estimated Macroeconomic Impacts of Shore Power Petroleum Displacement in the United States, showing Direct, Indirect, and Induced effects (2015-2030) for all Evaluated Scenarios and Cases

	Baseline (Mid) Compliance Scenario			**Low Compliance Scenario**			**High Compliance Scenario**		
Employment (Job-years)									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Direct	3,210	7,730	3,210	2,780	3,540	2,780	1,490	18,140	1,490
Indirect	(6,070)	11,140	(6,070)	2,990	5,890	2,990	(25,770)	37,720	-25,770
Induced	42,400	10,920	(5,140)	13,330	7,960	5,250	146,020	29,860	-29,390
Output (Millions, 2015$)									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Direct	($2,960)	$810	($2,960)	$1,420	$2,050	$1,420	($12,450)	$1,450	($12,450)
Indirect	$1,940	$5,740	$1,940	$3,280	$3,920	$3,280	($3,560)	$10,460	($3,560)
Induced	$7,040	$1,820	($840)	$2,210	$1,320	$870	$24,250	$4,960	($4,850)

Table A16. Estimated Macroeconomic Impacts of Shore Power Petroleum Displacement in Florida, showing Direct, Indirect, and Induced effects (2015-2030) for all Evaluated Scenarios and Cases

	Baseline (Mid) Compliance Scenario			**Low Compliance Scenario**			**High Compliance Scenario**		
Employment (Job-years)									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Direct	360	1,060	350	260	120	260	(30)	2,580	(30)
Indirect	(4,620)	(2,290)	(4,620)	(700)	(1,180)	(700)	(10,540)	(1,930)	(10,540)
Induced	6,500	1,450	(110)	(1,020)	30	350	22,700	4,060	(1,720)
Output (Millions, 2015$)									
	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS	Case I HH	Case II SH	Case III NS
Direct	($500)	$140	($500)	$170	$40	$170	($2,140)	$260	($2,140)
Indirect	$80	$460	$80	$210	$130	$210	($620)	$800	($620)
Induced	$890	$200	($15)	($140)	$4	$50	$3,120	$560	($240)

Table A17. Estimated Macroeconomic Impacts of EV Buses in the United States, showing Direct, Indirect, and Induced impacts (2015-2030)

United States Bus	Mid-Level Market Penetration (Reference Case)	Low Market Penetration	High Market Penetration
Employment (Job-years)			
Effect	HH		
Direct	1,150	-17	2,100
Indirect	2,500	7	2,500
Induced	3,100	0	3,150
Output (Millions, 2015$)			
	HH		
Direct	$800	-$200	$350
Indirect	$1,100	$5,450	$1,500
Induced	$500	$24,900	$500

Table A18. Estimated Macroeconomic Impacts of EV Buses in NYC, showing Direct, Indirect, and Induced impacts (2015-2030)

EV Buses NYC	Mid-Level Market Penetration (Reference Case)	High Market Penetration
Employment (Job-years)		
Effect	HH	
Direct	200	400
Indirect	20	-70
Induced	65	90
Output (Millions, 2015$)		
	HH	
Direct	$95	$110
Indirect	$25	$40
Induced	$10	$15

8.3 Truck Stop Electrification Hours Used per Space

Table A19 shows the average annual number of hours used per TSE space for each scenario.

Table A19. Average Hours Used per TSE Space, for Each United States TSE Scenario, 2015-2030

Year	Low MP Scenario	Mid-Level MP	High MP
2015	2452.8	2452.8	2452.8
2016	2754.4	2601.0	2619.3
2017	3093.0	2758.1	2797.2
2018	3473.4	2924.8	2987.1
2019	3900.4	3101.5	3189.8
2020	4380.0	3288.8	3406.4
2021	4460.6	3487.5	3637.7
2022	4542.7	3698.3	3884.6
2023	4626.2	3921.7	4148.4
2024	4711.4	4158.6	4430.0
2025	4798.0	4409.9	4730.8
2026	4886.3	4676.3	5051.9
2027	4976.2	4958.8	5394.9
2028	5067.8	5258.4	5761.2
2029	5161.0	5576.1	6152.3
2030	5256.0	5913.0	6570.0

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