Implementation of Action 6 of the California Sustainable Freight Action Plan (CSFAP) Phase 3: Tracking Economic Competitiveness

Final Report Part 3: Economic Impacts of Electrification of Cargo Handling Equipment at POLA/POLB

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A Research Report from the Pacific Southwest Region University Transportation Center

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16. Abstract
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The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

Dan Wei and Genevieve Giuliano conducted this research Implementation of Action 6 of CSFAP Phase 3 Tracking Economic Competitiveness. Part 3: Economic Impacts of Electrification of Cargo Handling Equipment at POLA/POLB, at Price School of Public Policy, University of Southern California. The research took place from May 2019 to December 2021 and was funded by a grant from the California Department of Transportation (Caltrans) in the amount of $299,500. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

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Abstract

Electrification of cargo handling equipment (CHE) is identified as one of the major strategies for reducing emissions from port operations, as part of the efforts under the San Pedro Bay Clean Air Action Plan (CAAP). In this study, we analyze the macroeconomic impacts of the electrification of CHE at Port of Los Angeles and Port of Long Beach between 2020 and 2045. A state-of-the-art macroeconometric model, the Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI+) Model, is applied to analyze both the aggregate impacts on the California state economy and the implications to the transportation sector. The primary input data to the REMI Model are the estimates of the direct costs and savings associated with the transition to electric CHE. The results indicate that increased equipment and infrastructure cost of transition to zero-emission (ZE) CHE can result in losses of jobs and economic output. Moreover, gross output in the port-related sector and aggregate transportation sector in CA decreases, while gross output in these sectors in rest of U.S. increases, indicating some port related business can be shifted out of California. However, the impacts remain small in percentage terms because of the size of the state economy. We also perform several sensitivity analyses to examine how the macroeconomic impact results would change in response to changes in key assumptions, including funding sources, cost pass-through potentials, equipment costs, battery technology development, among others.

Executive Summary

California's transportation system contributes significantly to the state economic growth, as well as its GHG and criteria pollutant emissions. California has been leading the nation, and in many aspects the world, in the regulation of heavy-duty vehicles and equipment in the goods movement sector. Major and unprecedented emission reductions have already been achieved as a result of these regulations. Mobile cargo handling equipment (CHE) includes any motorized vehicles at seaports and intermodal rail yards that are used to lift or move cargos or to perform routine activities of maintenance and repairs. The California Air Resources Board (CARB) is assessing near-zero or zero-emission (NZE/ZE) technologies for mobile CHEs at ports, intending to implement new regulations by 2026 to transition these emissions sources to NZE/ZE operations. The goal is to achieve most of the emission reductions target before 2031.

The San Pedro Bay Clean Air Action Plan (CAAP), initiated in 2006 by the Ports of Los Angeles and Long Beach (POLA/POLB), outlines strategies to mitigate emissions from cargo movement in the port complex. Transitioning fossil fuel-powered CHE to zero-emission has been identified as a key strategy, with a target for ports to have an emission-free CHE fleet by 2030.

This study focuses on analyzing the economic impacts of electrifying the entire CHE fleet at POLA and POLB over 25 years (2020-2045). The analysis assumes replacement of current fossil-fueled equipment with zero-emission electric CHE at the end of their useful life. Depending on the remaining life of the fleet and the useful life of the new equipment, most of the equipment will have two or three replacements during this study horizon. The evaluation includes equipment capital costs (e.g., equipment purchase, battery replacement, and charger costs), operation and maintenance expenditures, and infrastructure capital costs within the port complex.

The analytical framework utilizes the results of the micro-level analysis of the direct incremental costs (such as increased capital investment cost and infrastructure cost) or savings (such as savings in fuel expenditures or operation and maintenance costs) associated with the CHE electrification transitions as the inputs to the REMI PI+ macro-econometric model. Figure ES1 presents the integrated analytical framework of the study.

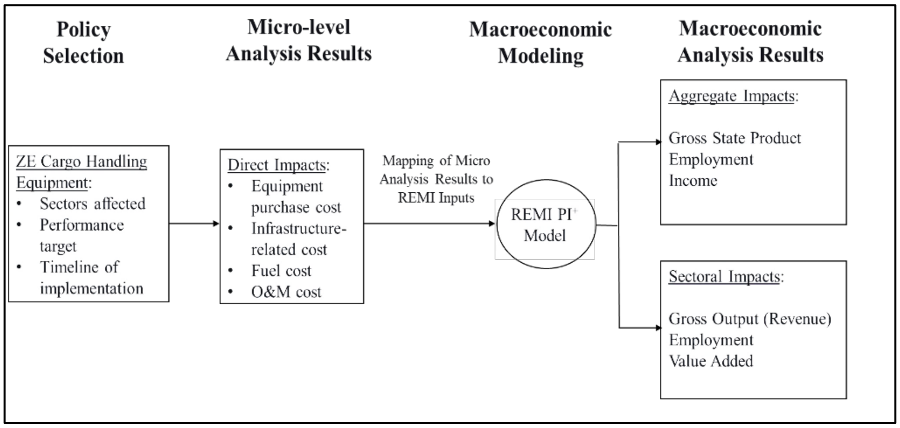

Figure ES-1. Analytical Framework of Economic Impact Analysis of CHE Electrification

Table ES-1 summarizes the estimated direct costs (or cost savings) for the transition to electric CHE at POLA and POLB comparing to the baseline condition (i.e., baseline operation and turnover of conventional CHE) between 2020 and 2045. The total incremental costs are estimated to be $6.9 billion in net present value (NPV). The incremental costs incurred by equipment purchases and battery replacements account for over 70% of the total increased cost. Charger and electrical/civil infrastructure costs account for another 25% of the total. Fuel cost savings are small because of the high demand charges on electricity.

Table ES-1. Summary of Total Costs of Transition to ZE CHE at POLA/POLB (2020-2045) (in million 2019$)

Category	Simple Total	NPV
Electric CHE Equipment Costs	3,910	3,029
Battery Replacement Costs	2,722	1,886
Electric CHE Charger Costs	755	606
Electrical Infrastructure Upgrade Costs	269	229
Civil Infrastructure Costs	1,102	940
Changes in Fuel Costs	-35	-36
Changes in Maintenance Costs	169	232
Total	**8,893**	**6,886**

The macroeconomic modeling results (summarized in Table ES-2) indicate that the increased equipment and infrastructure cost of transition to ZE CHE can result in losses of jobs and economic output. The total employment impacts are estimated to be 96,771 thousand job-years losses between 2020 and 2045. This translates to average annual employment losses of 3,721 job-years. The NPV of the GSP, gross output, and personal income losses over the entire study period are estimated to be $7.24 billion, $13.00 billion, and $8.78 billion, respectively. Although some of these impacts are relatively large in terms of absolute levels, they remain small in percentage terms because of the size of the state economy. A decomposition of the total impacts indicates that the increased capital cost of the port sector results in the highest negative impacts on the economy.

Table ES-2. Macroeconomic Impacts of Electrification of CHE at POLA/POLB

Variable	Units	NPV (or Total Job-Year Jobs)
Total Employment	Job-year	-96,771
GSP	B 2018$	-7.24
Output	B 2018$	-13.00
Personal Income	B 2018$	-8.78
Price Index	2012=100	

We also perform several sensitivity analyses to examine how the results would change in response to changes in key assumptions. These analyses indicate the important benefit of government incentive programs to lower the high up-front capital cost burden of CHE electrification on the regulated sector and to reduce the negative macroeconomic impacts. When the ports can only partially pass their increased costs to downstream businesses and end users, the negative impacts on the economy as a whole are estimated to be smaller because of the reduced negative supply-chain (or multiplier) effects. However, output losses in the port-related sector are the highest in this case. In all the scenarios, gross output in the port-related sector and the aggregate transportation sector in California decreases, while gross output in these sectors in rest of U.S. increases, indicating California is losing businesses to other regions when the capital and operating costs of the ports increase.

Finally, the primary goal of transitioning cargo handling equipment to zero-emissions is to mitigate criteria and GHG emissions at California's ports and protect public health. A thorough evaluation of this transition should consider not only its economic impacts but also environmental and public health benefits, along with potential co-benefits such as improved productivity and enhanced energy security by reducing dependence on energy imports.

1. Introduction

Assembly Bill (AB) 32, The California Global Warming Solutions Act of 2006 (Statutes of 2006, Chapter 488), which was signed into law in 2006, established a comprehensive program to combat global warming and mitigate greenhouse gas emissions from all sources in California. California's climate change strategy is based on the principle that economic prosperity and environmental sustainability should be inextricably integrated. To achieve this overarching goal, the Climate Change Scoping Plan and The First Update to the Climate Change Scoping Plan were developed to solidify California's commitment to reducing and reversing the adverse effects of climate change to our environment, our communities, and on our economy. Accordingly, a collection of actions and initiatives that integrate climate thinking and sustainability programming while growing the economy have been identified and developed by the state.

California's transportation system contributes significantly to the state economic growth and its GHG and criteria pollutant emissions. California has been leading the nation, and in many aspects the world, in the regulation of heavy-duty vehicles and equipment in the goods movement sector. Major and unprecedented emission reductions have already been achieved as a result of these regulations. California's freight industry is vital because of its significant contribution to international trade and domestic commerce. It is also responsible for a large share of total transportation sector emissions within the state. The California Sustainable Freight Action Plan (CSFAP) was initiated by Governor Brown in 2016 to provide a high-level vision for the state to transition to a more efficient, environmentally friendly, and economically competitive freight transport system. The Action Plan calls for the State agencies to develop specific policies, regulations, investment programs to facilitate the state freight sector to adopt clean and zero emission technologies, improve efficiency, and enhance economic competitiveness.

The transition to a clean energy future provides a great opportunity to foster economic growth through the attraction and creation of new businesses and industries to capture additional efficiencies and productivity gains while dramatically reducing GHG emissions. Major co-benefits to businesses of GHG emission reductions include saving energy costs, lowering maintenance costs, improving productivity, increasing competitiveness, and making companies less vulnerable to energy price fluctuations. On the other hand, technology and infrastructure changes to further cut emissions come at a cost. To achieve this movement, it is important that an economic analysis on the costs and benefits associated with State climate actions is conducted.

The need for developing enhanced methods and tools to assess various impacts, including economic impacts, of state climate actions and strategies was discussed as part of the Scoping Plan Update. In order to determine the true impacts of regulatory actions on California's industries and businesses, more data are needed and more analysis are required to evaluate the potential economic impacts in a macroeconomic range. According to Senate Bill 617, state agencies need to conduct a Standardized Regulatory Impacts Assessment (SRIA) when a proposed regulation is expected to result in economic impacts exceeding $50 million. The economic impacts of several major freight-related regulations have been evaluated by CARB, such as the Heavy-Duty Vehicle Inspection Program, Advanced Clean Trucks Regulation, and Ocean-Going Vessels at Berth Measures. However, more studies are needed to examine the potential economic impacts of a broader set of initiatives, policies, and regulations under the CSFAP.

Providing specific evaluation on the impacts to individual industries or technologies are also important. Assessing the cost of each regulatory measure on businesses can lead to important modifications of specific State actions and programs. This in turn will inform the success of programs in meeting California's long-term emission targets and in ensuring that the economic costs of State actions are not overly burdensome to specific business sectors.

The second part of the California Sustainable Freight Action Plan (CSFAP) economic competitiveness provisions requires assessment of the economic impacts of the Action Plan on the freight sector. In this project, we use the Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI+) Model to analyze the economic impacts of one prioritized Action Plan policy/regulation – electrification of cargo handling equipment.

2. Regulation of Mobile cargo Handling Equipment

2.1. CARB Regulations on Cargo Handling Equipment

Mobile cargo handling equipment (CHE) includes any motorized vehicle that operate at seaports and intermodal rail yards to handle cargo or to perform routine maintenance and repair activities. The existing Mobile CHE Regulation by California Air Resource Board (CARB) was originally adopted in 2005 and took into effect in 2006. The primary goal of this regulation is to reduce toxic and criteria emissions from mobile CHE and to reduce the harms of the emission pollutions to public health. The regulation called for the establishment of best available emission control technology for new and existing CHE fleet to help the ports meet certain emissions standard. According to CARB, the goal of the 2006 CHE regulation was fully achieved by the end of 2017 (CARB, 2021).

In order to further reduce emissions at the ports, CARB Staff is conducting assessment on the availability and performance of near-zero or zero-emission technologies to be used as alternatives to all combustion-powered cargo handling equipment. The plan is to amend the regulations of the existing CHE and other freight regulations for commercial harbor craft and drayage trucks to support the transition of these emissions sources to zero- or near-zero operations.

CARB is going to propose the timeline and schedule to adopt the new equipment and construct or upgrade the supporting facility infrastructure at the ports. It is anticipated that the new regulations and rules on CHE will start taking effect in 2026. The goal is to achieve the majority of the emission reductions target before 2031. The new proposed regulation will apply to all mobile equipment at seaports and intermodal rail yards. Equipment powered by diesel, gasoline, natural gas, and propane-fueled will all be subject to the new requirements (CARB, 2021).

2.2. Zero-emission Cargo Handling Equipment Strategy in POLA/POLB Clean Air Action Plan

The San Pedro Bay Clean Air Action Plan (CAAP) was created and approved by Port of Los Angeles and Port of Long Beach (POLA/POLB) in 2006. The Plan provides overall strategies to dramatically mitigate emissions of various types of air pollutants from cargo movement in and surrounding the Port complex. The CAAP has been updated periodically, with the latest updated version of the CAAP released in 2017. Since the 2006 adoption of the original CAAP, more than 85% of diesel particulate matter emissions from mobile sources at the ports have been reduced (POLA/POLB, 2021).

As one of the sources contributing a large share of pollution at the ports, the CAAP has identified the transition of fossil fuel powered CHE to zero-emission CHE as one of the major strategies to reduce emissions from port operations. The CAAP has set the target for the ports to transition to emission free CHE fleet by 2030. Various strategies that would facilitate this transition process have been outlined in the 2017 CAAP Update (POLA/POLB, 2017):

- Starting from 2019, the terminal operators are requested to submit an equipment inventory and 10-year equipment procurement schedule plan to the ports. These plans need to be periodically updated in order to keep a continuous forecasts of the equipment turnover schedule for the folloing 10 years. The ports will use these plans as the basis to work with the terminal operators to make sure that the replacement of the equipment is aligned with the anticipated useful life of the equipment.

- Starting from 2018, the ports need to provide progress reports to evaluate the current status of equipment technologies deployed in the terminals and the availability of supporting infrastructure, conduct feasibility assessment of the available NZE and ZE technology, and identify potential operational and financial challenges of electrification of terminal equipment. The feasibility assessment report is required to be updated every 3 years.

- Various strategies to incentivize the adoption of the NZE/ZE equipment are also identified in the 2017 CAAP Update: 1) in collaboration with the utilities and manufacturers of advanced CHE equipment, the Ports will formulate plans for port-wide infrastructure construction and upgrade to support the transition to NZE/ZE terminal equipment; 2) the Ports will pursue grants and funding offered by federal, state, and local government agencies to facilitate demonstration and testing of new equipment technologies; 3) the Ports will work with terminal operators and equipment manufacturers to pursue other funding sources to accelerate the deployment of NZE/ZE CHE in the terminals.

2.3. Scope of the CHE Electrification Case Study

In this study, we analyze the economic impacts associated with the CHE electrification at Port of Los Angeles and Port of Long Beach, focusing on a time horizon of 25 years between 2020 and 2045. We assume that the current fossil-fueled equipment will be replaced by zero emission electric CHE when it reaches the end of useful life. Depending on the remaining life of the fleet and the useful life of the new equipment, most of the equipment will be replaced for two or three times during this study horizon. The evaluation of the costs associated with this electrification transition is confined within the port complex, including both the equipment capital costs (e.g., equipment purchase, battery replacement, and charger costs) and O&M and fuel expenditures of the equipment, as well as infrastructure capital costs to upgrade or build the suitable fueling/charging and other supporting infrastructure to accommodate the deployment electric CHE.

We note that this study does not include the followings in the analysis:

- It does not assume future possible transitions to automation operation mode in additional terminals. In other words, we assume that the port operations do not change other than the shift to electric equipment.

- The analysis is confined within the boundary of the ports. Any costs for updating the grid transmission capacity to accommodate the increased load at the ports are not analyzed. It is assumed that adequate electricity resources can be supplied to the ports.
- The implications of the increased load demand of electricity to the resilience of port operation are not analyzed: the impacts of possible increased number of power interruptions and the costs associated with preparation and coping strategies such as setting aside backup systems are not included.

3. Methodology

3.1. Overall Analytical Framework

The impact analysis adopts the analytical framework (see Figure 1) we developed in previous economic impact studies of climate and energy policies, including transportation-related policies (Rose and Wei, 2012; Wei and Rose, 2014; Lawrence et al., 2017; Wei et al., 2017; Rose and Wei, 2019). It starts with the establishment of the policy scenario(s) to be evaluated, followed by the estimation of the micro-level impacts of the policy on the regulated industries (or entities). The micro-level analysis results in terms of both direct incremental costs (such as increased capital investment cost and infrastructure cost) or savings (such as savings in fuel expenditures or operation and maintenance costs) associated with the implementation of the policy are used as the inputs in the REMI macroeconomic model to analyze the aggregate and sectoral impacts of the policy on the state economy.

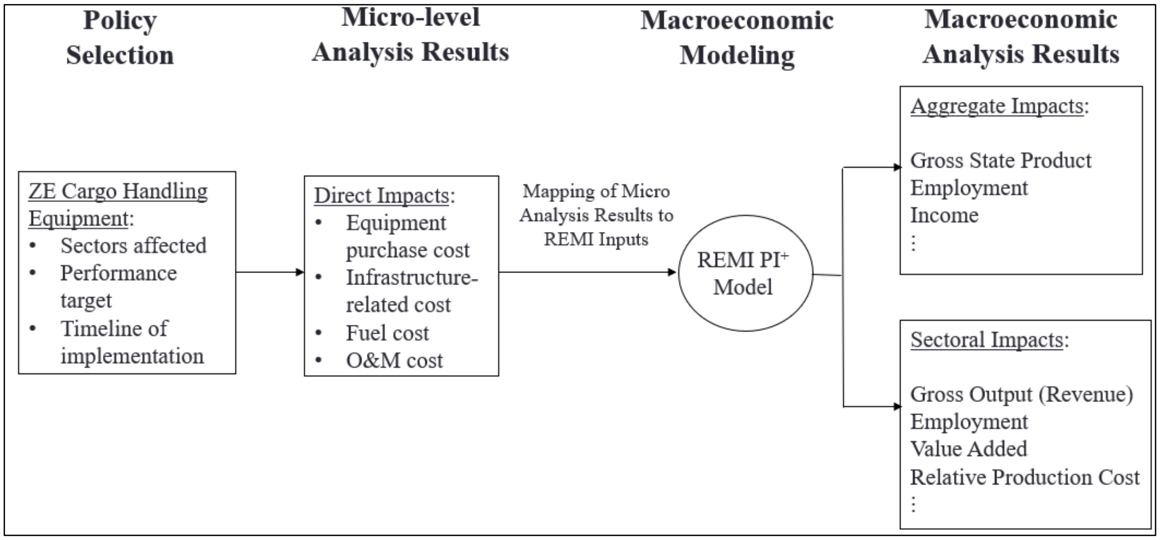

Figure 1. Analytical Framework of Economic Impact Analysis of CHE Electrification

3.2. REMI PI+ Model

The REMI PI+ Model was selected to evaluate the macroeconomic impacts (including gross state product, employment, and personal income) of the CHE electrification at the ports. It is the most widely used macroeconometric model to analyze the economic impact of energy and climate policies in the U.S. The REMI Model has evolved over the course of more than 30 years of refinement (see, e.g., Treyz, 1993). It is a packaged program, but is built with a combination of national and region-specific data. In addition to the widespread use in the academic community, government agencies in practically every state in the U.S. have used a REMI Model for a variety of purposes. In California, the REMI Model is used by Department of Finance, California Air Resources Board, the South Coast Air Quality Management District, Southern California Association of Governments, Association of Bay Area Governments, and many other government and regional planning agencies to analyze the economic impacts of proposed regulations and regional development policies and initiatives (REMI, 2020).

As a macroeconometric forecasting model, the REMI model covers the entire economy based on macroeconomic aggregate relationships such as consumption and investment. REMI differs somewhat in that it includes some key relationships, such as exports, in a bottom-up approach that allows evaluation of specific sector-based policy options. In fact, it makes use of the finely-grained sectoring detail of an input-output (I-O) model, i.e., it divides the economy into 160 sectors, and thereby depicts important distinctions among them.

The REMI model is able to analyze the quantity interactions between sectors (ordinary multiplier effects) but with refinements for price changes not found in I-O models. That is, the Model incorporates the responses of producers and consumers to price signals and the changes in other market and regulatory conditions, and captures the substitution effects and other price-quantity interactions. The REMI Model also brings into play features of labor and capital markets, as well as trade with other states or countries, including changes in competitiveness. The labor market in the REMI model is linked to a demographic module of population migration. It also includes input substitution between labor and other factors of production, market supply and demand, wage rate determination, and economic geography considerations of labor accessibility of individual industries.

The econometric feature of the REMI Model refers to the fact that the model is based on inferential statistical estimation of key parameters based on pooled time series and cross-regional (panel) data. This gives the Model an additional capability of being able to extrapolate the future course of the economy, a capability that most other types of economic impact models usually lack. A more detail description of the REMI Model is presented in Appendix D.

The version of the REMI Model used in this study includes two geographical regions: California and rest of U.S. The model divides the whole economy into 160 sectors and is established based on U.S. and California historical data through 2018.

4. Estimation of Direct Costs/Cost-Savings of Electrification of CHE

4.1. Inventory of the Cargo Handling Equipment

Data on the existing cargo handling operational equipment, including the equipment types, engine types, and counts are gathered from the Air Emissions Inventory reports of POLA/POLB (POLA, 2020; POLB, 2020). Table 1 and Table 2 present a summary of the inventory. In total, there are over 3,400 units of equipment in use to handle cargo movement at the marine terminals at the ports, among which yard tractors accounts for nearly 50% of the fleet, followed by forklifts and top handlers.

Table 1. POLA CHE Inventory by Equipment Type and Engine Type

Type	Electric	LNG	Propane	Gasoline	Diesel	Total
Forklift	8		356	7	115	486
Wharf Crane	81					81
RTG Crane					101	101
Side Pick					15	15
Top Handler					213	213
Yard Tractor		17	178		789	984
Other	51		1	5	148	205
Total	**140**	**17**	**535**	**12**	**1,381**	**2,085**

Table 2. POLB CHE Inventory by Equipment Type and Engine Type

Type	Electric	LNG	Propane	Gasoline	Diesel	Total
Forklift	9		104	24	106	243
RTG Crane					59	59
Side Handler					8	8
Top Handler					182	182
Yard Tractor			2	92	547	641
Sweeper	1		7		8	16
Other	187		6	2	47	242
Total	**197**	**0**	**119**	**118**	**957**	**1,391**

In addition to the data on the counts of CHE by equipment and engine type, the Air Emissions Inventory reports also provide the information on the minimum, maximum, and average model year of the equipment. Tables 3 and 4 summary the average model year for the major types of fossil fuel powered CHE used at the ports.

Table 3. Average Model Year for Fossil Fueled CHE at POLA

CHE	LNG	Propane	Gasoline	Diesel
Forklift		2000	2011	2010
Wharf Crane				
RTG Crane				2008
Side Pick				2013
Top Handler				2011
Yard Tractor	2010	2007		2011

Table 4. Average Model Year for Fossil Fueled CHE at POLB

CHE	Propane	Gasoline	Diesel
Forklift	2005	2012	2010
RTG Crane			2006
Side Handler			2004
Top Handler			2010
Yard Tractor	2009	2012	2012
Sweeper	2005		2011

4.2. Capital Expenditures of Transitioning to ZE CHE

4.2.1. Equipment Cost

We gathered data on the unit cost of conventional CHE and the costs associated with the purchases of new near zero emission (NZE) or zero emission (ZE) equipment from various sources. These data are presented in Table 5. The gray highlighted entries represent the unit cost data we use in this study. These highlighted data represent the most recent equipment cost estimates that are available.

The equipment life span for the various types of CHE are as follows (Moffatt and Nichol, 2015; EnSafe Inc., 2017; POLA/POLB, 2017):

- Yard Tractor: 8 years
- RTG Crane: 15 years
- Top Handler: 15 years
- Side Pick: 15 years
- Forklift: 10 years

Table 5. Comparison of Diesel, NZE and Electric CHE Unit Costs

CHE Type	M&N (2015)		CAAP (2017)			2019 Feasibility Report		
	Diesel	Electric	Diesel	NZE	Electric	Diesel	NZE	Electric
Yard Tractor (Hostler)	100,000	200,000	125,000	162,500	275,000	100,000	150,000	320,000
RTG Crane	1,200,000	1,800,000	1,300,000	1,820,000	2,500,000	1,200,000	1,350,000	1,800,000
Side Pick	600,000	1,800,000 (price of eRTG)	450,000	640,500	1,700,000			
Forklift			40,000	40,000[1]	45,000			
Top Handler			560,000	784,000	1,700,000			

Sources: Moffatt and Nichol (2015); EnSafe Inc. (2017); Tetra Tech. (2019); EPRI (2021).

[1] We assume the gas and LPG fueled forklifts have a similar price as diesel fueled forklifts (EPRI, 2021; AFS, 2021).

In this analysis, we assume that the electric CHE has the same life span as their conventional equipment counterparts. Based on the unit cost, average model year of the existing fleet, and life span of each type of the equipment, the upfront investment costs associated with the purchases of electric CHE for the initial transition and for future replacement cycles at POLA/POLB are calculated in Table 6. Depending on the remaining life of the current equipment, the purchasing costs of the new equipment will not be incurred at the same time. In addition, since the study period is from 2020 to 2045, most of the equipment will be replaced for two or three times during this planning horizon. In the last two rows of Table 6, the simple sum of the incremental equipment capital costs of the electric CHE and the net present value (NPV) (assuming a 3% discount rate) of the costs over the entire study period are presented.

Two major assumptions are adopted in the calculations:

- Replacement ratio: the current technology for manned electric CHE does not have the operation capacity to allow for a 1:1 replacement. Based on recent minimum performance demonstrations at the port, the goal of 16-hour operating time between recharging has not been achieved yet. For example, most of the tested electric top handlers need two charges to operate 16 hours. Moffatt and Nichol (2015) also noted that the current technology of battery powered yard tractors can only operate one shift per charge. In such cases, an entire second fleet would be needed when the first fleet enters into the charging shift. Therefore, in our analysis, we assume a 2:1 replacement ratio between battery powered electric CHE and their conventional counterpart for the first replacement. For subsequent replacements over the study horizon, we assume that future potential batter technology development would enable longer operating time, and thus by the time of the second replacement cycle for each individual type of CHE, a 1:1 replacement ratio will become possible.

- Trajectory of capital cost of the electric CHE in the future: Although the price of ZE heavy-duty trucks is projected to decrease by almost 30% between now and 2030, since the market for CHE is much smaller, it provides no opportunity for economies of scale. No available studies have forecast similar price declines of electric CHE as of ZE heavy-duty trucks. In this analysis, we assume that the price of the various types of electric CHE will remain at the levels shown in the gray-highlighted entries in Table 5 (in real dollar terms) over the analysis period.[1]

In the Base Case analysis, in order to perform a fair comparison, we only focus on the cost differentials associated with the replacement of current CHE fleet with electric CHE. The analysis does not assume future possible transition to automation operation model in additional terminals at the ports. In addition, we assume that the throughput capacity of the terminals would remain the same with the transition to ZE CHE. Therefore, except for the second fleet of electric CHE that are needed in the first replacement period to accommodate the time for charging (as described above), there is no need to increase the number of CHE or the ship to shore cranes (STS) to handle increased throughput capacity as the scenarios analyzed assuming eRTG operation mode or high density mode in the Moffatt and Nichol Report (2015).

Table 6 presents the equipment replacement costs for five-year periods over the study period. Appendix Table C1 presents the year-by-year cost estimates. The total incremental equipment costs comparing to the baseline condition are estimated to be $3.0 billion in net present value (NPV) using a 3% discount rate.

Table 6. ZE CHE Equipment Replacement Costs (Incremental Costs Compared to Baseline Technology) by 5-Year Intervals (in millions 2019$)

	Yard Tractor (Hostler)	RTG Crane	Side Pick	Top Handler	Forklift	Total
2020-2025	909.2	104.6	23.6	516.9	35.6	1,589.9
2026-2030	360.1	0.0	44.3	604.9	2.9	1,012.2
2031-2035	0.0	0.0	10.0	0.0	0.6	10.6
2036-2040	360.1	104.6	0.0	207.5	2.9	675.2
2040-2045	360.1	0.0	18.8	242.8	0.6	622.3
Simple Total	**1,989.5**	**209.3**	**96.6**	**1,572.1**	**42.7**	**3,910.2**
NPV Total	**1,548.6**	**156.1**	**72.3**	**1,213.5**	**38.2**	**3,028.6**

4.2.2. Battery Replacement Cost

There are many factors affecting the lifespan of the batteries used in electric CHE. Major factors include battery type, intensity of usage, and maintenance. Based on current technology, the battery for the electric CHE is unlikely to last the entire useful life of the equipment itself. Some of the equipment that has relatively shorter useful life, no battery replacement may be needed, while for the types of equipment that has a relatively long useful life, two battery replacements during the life span of the equipment might be needed. Because of the uncertainty of the speed of battery technology development in the future decades, in this analysis, we assume that all battery-electric equipment will require one battery replacement for each equipment useful life. We further assume that the cost of the new battery is about two-thirds the cost of the equipment. Table 7 presents the estimated costs of

[1] By using the same equipment price in real dollar terms over time, it takes into consideration an expected price inflation rate of about 1.5% to 2% annually.

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battery replacement for five-year periods. Note that the numbers for RTG are all zero in Table 7 since the grid-electric RTG cranes will receive electricity through their direct connection to the power grid (using the busbar or the cable reel system), thus they do not need to be equipped with battery systems to store electricity. Appendix Table C2 presents the year-by-year cost estimates.

Table 7. Battery Replacement Costs by 5-Year Intervals (in millions 2019$)

	Yard Tractor (Hostler)	RTG Crane	Side Pick	Top Handler	Forklift	Total
2020-2025	735.8	0.0	0.0	0.0	35.2	771.0
2026-2030	0.0	0.0	18.2	414.6	7.7	440.5
2031-2035	367.9	0.0	0.0	485.2	17.6	870.7
2036-2040	367.9	0.0	34.2	0.0	3.9	405.9
2040-2045	0.0	0.0	9.1	207.3	17.6	234.0
Simple Total	**1,471.6**	**0.0**	**61.5**	**1,107.1**	**82.0**	**2,722.2**
NPV Total	**1,083.0**	**0.0**	**39.1**	**707.1**	**56.4**	**1,885.6**

4.2.3. Infrastructure Costs

4.2.3.1. Cost of Chargers

The first type of infrastructure costs we consider in the analysis is the cost of the charging systems. According to the 2018 Feasibility Assessment Report for CHE (Tetra Tech., 2019), the costs of the charger for the battery-powered yard tractors are estimated at $100,000. In addition, the associated infrastructure installation costs are estimated at $50,000. It is also assumed that each electric yard tractor would need one charger.

For Top Handlers, the cost of the chargers with different charging options are obtained from a manufacturer quote through our contact at Pacific Merchant Shipping Association (PMSA). In the calculation below, we use an average of the costs of three charging options (which is $187,400). These estimates do not include infrastructure/installation costs. We therefore assume that the infrastructure installation cost is about 50% of the charger cost as in the case of electric yard tractor.

For electric side picks, the charger cost is assumed to be the same as the top handlers. For forklifts, the charger cost is estimated to be $38,488, based on energy consumption ratio compared to yard tractors. Again, a 50% charging infrastructure installation cost is assumed for both side picks and forklifts.

One factor we take into consideration is that the service life of the charging system is likely to extend beyond the useful life of the electric CHE. We adopt the same assumption used in the 2018 Feasibility Assessment Report that the charger service can be extended to two useful lives of the CHE.

Table 8 summarizes the estimated costs of chargers for various types of CHE for five-year periods. Appendix Table C3 presents the year-by-year cost estimates. The total cost of chargers is estimated to be $0.66 billion in net present value (NPV) using a 3% discount rate.

Table 8. Electric CHE Charger Costs by 5-Year Period (in million 2019$)

	Yard Tractor (Hostler)	RTG Crane	Side Pick	Top Handler	Forklift	Total
2020-2025	268.1	0.0	2.2	51.2	67.8	389.4
2026-2030	0.0	0.0	4.2	59.9	0.0	64.1
2031-2035	0.0	0.0	0.0	0.0	0.0	0.0
2036-2040	268.1	0.0	0.0	0.0	27.8	295.9
2040-2045	0.0	0.0	0.0	0.0	6.1	6.1
Simple Total	**536.3**	**0.0**	**6.5**	**111.0**	**101.7**	**755.5**
NPV Total	**422.5**	**0.0**	**5.4**	**95.5**	**82.2**	**605.7**

4.2.3.2. Electrical Infrastructure Upgrade Costs

The report on the preliminary cost estimates of selected CAAP strategies (EnSafe Inc., 2017) provides the estimates on the costs of bringing additional electrical power down to the terminals that are needed to support the electrification requirements of the 2017 CAAP. Appendix Table C4 and Table C5 present these estimates for individual terminals at POLA and POLB, respectively. However, one thing to note is that these electric infrastructure costs pertain to several CAAP strategies, including not only electrification of cargo-handling equipment, but also electric infrastructure and shore power system to support electric heavy-duty vehicles and ocean-going vessels. The total estimated electric infrastructure costs are $319 million for POLA and $219 for POLB. In the analysis, we assume that half of these electrical infrastructure upgrade costs are attributable to the transition to electric CHE, and these costs are distributed evenly between 2020 and 2030, with the end year being the target year specified in the POLA/POLB Clean Air Action Plan to transition to a zero-emission CHE fleet.

4.2.3.3. Civil Infrastructure Costs

According to the Moffatt & Nichol (2015) report, in addition to the costs associated with the standard electrical infrastructure upgrade, there are also civil infrastructure costs for terminal redevelopment to accommodate the operation of the electric cargo movement equipment. Some examples of the civil infrastructure costs include the costs for new RTG runways, cable turnover pits, and above grade electrical bus bars (i.e., items that are not installed by the electrical contractors, and thus are not included in the electrical infrastructure costs identified above). The average civil infrastructure costs are estimated to be $350,000 per gross acre. For an approximately 3,149 gross acres of the San Pedro Bay terminals, the total civil infrastructure costs are estimated to be about $1.1 billion. Again, we assume that the civil infrastructure costs are distributed evenly between 2020 and 2030.

4.3. Operation and Maintenance Costs

In addition to the incremental capital expenditures on the purchase of electric CHE and the batteries for mid-useful life replacement, and the capital investment cost on the infrastructure system to support the operation of the electric equipment, transition to the fleet of electric CHE will also result in changes in fuel and maintenance costs comparing to the use of conventional CHE.

4.3.1. Fuel Cost

For both yard tractors and RTG cranes, we collected data on fuel price, fuel economy, and operation hours of the CHE using different engine types from the 2018 Feasibility Assessment Report for CHE (Tetra Tech., 2019). The basic data are presented in Table 9 for yard tractors and in Table 10 for RTG cranes. The electricity price is calculated based on the tariff rates under different demand charge structures between SCE and LADWP. Under the Charge Ready Program, SCE offers the EV rates that eliminate demand charges (but increase energy charges to offset part of the losses to the utility provider) in response to SB-350 to support electrification in the transportation sector (Tetra Tech., 2019). The tariff rates of LADWP include demand charges for peak-time uses. Because the special EV rate will phase out after 2024, we also collected the data on SCE non-EV rate, which is a more traditional rate structure that includes demand charges. In the Base Case analysis, we use the SCE EV rates for years before 2024. The electricity cost calculated as the average of the SCE non-EV rate and the LADWP rate is used in the rest of the study period. In the last column of Table 9 and Table 10, the total fuel cost per unit of yard tractor and RTG crane is calculated. Comparing the Battery Electric yard tractor and the diesel yard tractor, the cost-saving of fuel consumption is estimated to be $8,027 per yard tractor per year before 2024, and $1,205 after 2024. The corresponding annual fuel cost savings of replacing a diesel RTG crane with a ZE Grid Electric RTG crane is estimated to be $32,634 before 2024, and $30,353 after 2024.

Table 9. Fuel Cost Assumptions of Yard Tractors

Yard Tractor by Engine Type	Fuel Price ($/DGE)	Activity (hr/yr)	Fuel Economy (DGE/hr)	Fuel Cost $/yr
Baseline Diesel	3.27	1,662	2.5	13,587
NZ LNG ICE	2.52	1,662	2.78	11,643
ZE Battery Electric (util 2024)	6.69	1,662	0.5	5,559
ZE Battery Electric (after 2024)	14.90*	1,662	0.5	12,382

* This is calculated as the average tariff rate of the LADWP and SCE non-EV rates.
Source: calculated based on data from Tetra Tech. (2019)

Table 10. Fuel Cost Assumptions of RTG Cranes

RTG Cranes by Engine Type	Fuel Price ($/DGE)	Activity (hr/yr)	Fuel Economy (DGE/hr)	Fuel Cost $/yr
Baseline Diesel	3.27	2,102	9.5	65,299
NZE Diesel Hybrid	3.27	2,102	5.7	39,179
ZE Grid Electric (until 2024)	$4.44	2,102	3.5	32,634
ZE Grid Electric (after 2024)	4.75*	2,102	3.5	30,353

* This is calculated as the average tariff rate of the LADWP and SCE non-EV rates.
Source: calculated based on data from Tetra Tech. (2019)

For forklifts, we use the forklift cost comparison tool provided by Electric Power Research Institute (EPRI, 2021). This tool provides the comparison of lifecycle costs for electric, propane, and diesel forklifts. With the assumptions of diesel price of $3.3/gal and propane price of $2.2/gal (FirstEnergy, 2021; Tetra Tech, 2019), we estimate that the energy savings obtained from replacing a diesel or propane fueled forklift with an electric forklift is about $6,926 per year before 2024 and $3,767 after 2024.

Tables 11 and 12 present the fuel cost estimates for diesel and battery-electric top handlers and side picks, respectively. The data on average operation activity level and fuel economy of the equipment are obtained from manufacturer data and our communication with port experts (Kalmar, 2018; Greenport, 2019; DC Velocity, 2019). We again use the SCE EV rate util 2024 and the average of the SCE non-EVE and LADWP tariff rates for the rest of the study period. The results indicate that the estimated average annual fuel cost of the battery-electric top handler and side pick is $9,928 and $4,621 lower than their diesel counterparts before 2024, but is $23,154 and $10,776 higher after 2024.

Table 11. Fuel Cost Assumptions of Top Handlers

Top Handlers by Engine Type	Fuel Price ($/DGE)	Activity (hr/yr)	Fuel Economy (DGE/hr)	Fuel Cost $/yr
Baseline Diesel	3.27	2,400	4.7	36,886
Electric Top Handler (before 2024)	6.69	2,400	1.68	26,957
Electric Top Handler (after 2024)	14.90	2,400	1.68	60,039

Table 12. Fuel Cost Assumptions of Side Picks

FELs by Engine Type	Fuel Price ($/DGE)	Activity (hr/yr)	Fuel Economy (DGE/hr)	Fuel Cost $/yr
Baseline Diesel	3.27	1,500	3.5	17,168
Electric Side Pick (before 2024)	6.69	1,500	1.25	12,547
Electric Side Pick (after 2024)	14.90	1,500	1.25	27,944

Next, based on the inventory of CHE fleet, the replacement schedules of the equipment over the course of the study period, and the fuel cost changes per unit of equipment, the annual fuel cost changes of deploying the electric CHE at POLA/POLB are calculated and presented in Table 13 for five-year periods. We assume there is an average 3% annual fuel cost increase for each type of fuel (EIA, 2021). Appendix Table C6 presents the year-by-year cost estimates. The changes in fuel costs of the transition to electric CHE over the 25-year study period are estimated to be a cost saving of $35.7 million in net present value (NPV) using a 3% discount rate.

Table 13. Changes in Fuel Costs of Transition to ZE CHE by 5-Year Periods (in millions 2019$)

	Yard Tractor (Hostler)	RTG Crane	Side Pick	Top Handler	Forklift	Total
2020-2025	-9.0	-20.1	0.0	2.6	-23.2	-49.7
2026-2030	-8.9	-30.8	1.2	58.0	-16.6	2.9
2031-2035	-10.3	-35.7	1.8	67.2	-19.7	3.4
2036-2040	-11.9	-41.4	2.1	77.9	-22.9	3.9
2040-2045	-13.8	-48.0	2.4	90.3	-26.5	4.5
Simple Total	**-53.8**	**-175.9**	**7.6**	**296.0**	**-108.9**	**-35.0**
NPV Total	**-35.2**	**-111.9**	**4.5**	**179.6**	**-72.7**	**-35.7**

4.3.2. Maintenance Costs

The maintenance costs of the baseline CHE are collected from M&N (2015) and Tetra Tech. (2019) (see Tables 14 and 15). It is assumed that the maintenance costs of battery-electric yard tractors would be 30% lower than the maintenance costs needed for the diesel baseline equipment. This assumption is adopted following a recent study by Port of Oakland on the technology development of CHE (Port of Oakland, 2018). For RTG cranes, based on the M&N (2015) report, the maintenance costs of grid-connected RTG cranes are expected to be 25% lower compared to the baseline diesel RTG cranes. The maintenance costs can be further reduced to 40% lower than the baseline technology if automated stacking crane (ASC) are adopted by the ports.

Table 14. Maintenance Cost Assumptions of Yard Tractors

Yard Tractor by Engine Type	Maintenance Per Hour ($)	Activity (hr/yr)	Maintenance Per Year ($)
Baseline Diesel	24.07	1,662	40,004
NZ LNG ICE	24.07	1,662	40,004
ZE Battery Electric	16.85	1,662	28,005

Source: calculated based on data from Tetra Tech. (2019)

Table 15. Maintenance Cost Assumptions of RTG Cranes

RTG by Engine Type	Maintenance Per Hour ($)	Activity (hr/yr)	Maintenance Per Year ($)
Baseline Diesel	40.44	2,102	85,005
NZE Diesel Hybrid	40.44	2,102	85,005
ZE Grid Electric	30.33	2,102	63,754

Source: calculated based on data from Tetra Tech. (2019)

According to M&N (2015), the maintenance costs of conventional top handles and side picks are $90,000/yr/unit and the costs for standard forklifts are $25,000/yr/unit, respectively. We assume that the maintenance costs of battery-electric side picks, top handlers, and forklifts are on average 25% lower than the costs of the diesel baseline equipment.

The changes in annual maintenance cost associated with the electrification of the CHE at POLA/POLB are calculated and presented in Table 16 for five-year periods (year-by-year results are presented in Appendix Table C7). The total maintenance costs are expected to increase in the earlier years of the study period because the second fleet is needed in the first replacement cycle. Cost savings in maintenance can be achieved starting from the second replacement cycle for each individual type of CHE when a one-to-one replacement ratio between the conventional and electric CHE becomes feasible with the potential battery technology development.

Table 16. Changes in Maintenance Costs of Transition to ZE CHE by 5-Year Period (in millions 2019$)

	Yard Tractor (Hostler)	RTG Crane	Side Pick	Top Handler	Forklift	Total
2020-2025	156.0	25.4	2.2	32.8	46.3	262.7
2026-2030	-6.5	34.0	3.8	88.9	33.6	153.8
2031-2035	-97.5	34.0	4.6	88.9	-14.0	16.0
2036-2040	-97.5	-4.1	2.5	39.7	-22.3	-81.7
2040-2045	-97.5	-17.0	-0.6	-44.4	-22.3	-181.7
Simple Total	**-142.9**	**72.3**	**12.5**	**205.8**	**21.4**	**169.1**
NPV Total	**-29.1**	**60.4**	**9.1**	**156.9**	**35.1**	**232.4**

4.4. Total Cost Estimates

Table 17 summarizes all the direct costs (or cost savings) we estimated in the previous sub-sections for the transition to electric CHE at POLA and POLB comparing to the baseline condition (i.e., baseline operation and turnover of conventional CHE) between 2020 and 2045. The total incremental costs are estimated to be $8.9 billion as a simple sum of the annual costs over the study period, or $6.9 billion in net present value (NPV).[2] The incremental costs incurred by equipment purchases and battery replacements account for over 70% of the total increased cost. Charger and electrical/civil infrastructure costs account for 25% of the total. Fuel cost savings are small because of the high demand charges on electricity. In Figure 2, the estimated incremental costs (savings) by cost category of

[2] The incremental costs associated with the converting to all electric CHE estimated in this study ($8.9 billion) are lower than the costs estimated in the 2015 Moffatt & Nichol Report, which indicated an increased cost of $16 billion compared to the conventional technology. There are several reasons to explain the difference. First, the M&N Report analyzed a longer planning horizon (from 2015 to 2045), and thus modeled more equipment replacement cycles. For example, there are four replacements of yard tractors and three replacements of RTG cranes during the study period of the M&N Report, comparing to three replacements of yard tractors and two replacements of RTG cranes in our analysis. Second, the M&N study assumed the shifting from the existing mode of terminal operation to eRTG operation mode, which can support increased throughput capacity of the terminals. As a result, existing ship to shore (STS) cranes need to be renovated or replaced to increase their height and outreach to accommodate larger ships, and additional new STS cranes need to be purchased to meet the requirement under the eRTG operation mode. Third, at the time of the M&N study, no feasible electric Front End Loader (FEL) (including top handlers and side picks) solution was available. Therefore, the study assumed that all the FELs will be replaced by eRTG cranes. The costs of eRTG cranes are slightly higher than the costs of electric top handlers and side picks presented in the EnSafe Inc. (2017) Report that we use in this study. Fourth, the M&N study assumed that the equipment cost increases at a 5% annual inflation rate, which is much higher than the 1.5-2% rate applied in this study.

the CHE electrification are presented for the 5-year time periods. Large amounts of upfront capital investment costs will be required in the first 10 years of the study period primarily because a second fleet of the electric equipment is needed to replace the conventional equipment in the first replacement cycle and all the supporting electrical infrastructure needs to be completed in this time frame. Battery costs account for a higher proportion of the total costs in later years as battery replacements occur several years following the purchase of the electric equipment.

Table 17. Summary of Total Costs of Transition to ZE CHE at POLA/POLB (2020-2045) (in million 2019$)

Category	Simple Total	NPV
Electric CHE Equipment Costs	3,910	3,029
Battery Replacement Costs	2,722	1,886
Electric CHE Charger Costs	755	606
Electrical Infrastructure Upgrade Costs	269	229
Civil Infrastructure Costs	1,102	940
Changes in Fuel Costs	-35	-36
Changes in Maintenance Costs	169	232
Total	**8,893**	**6,886**

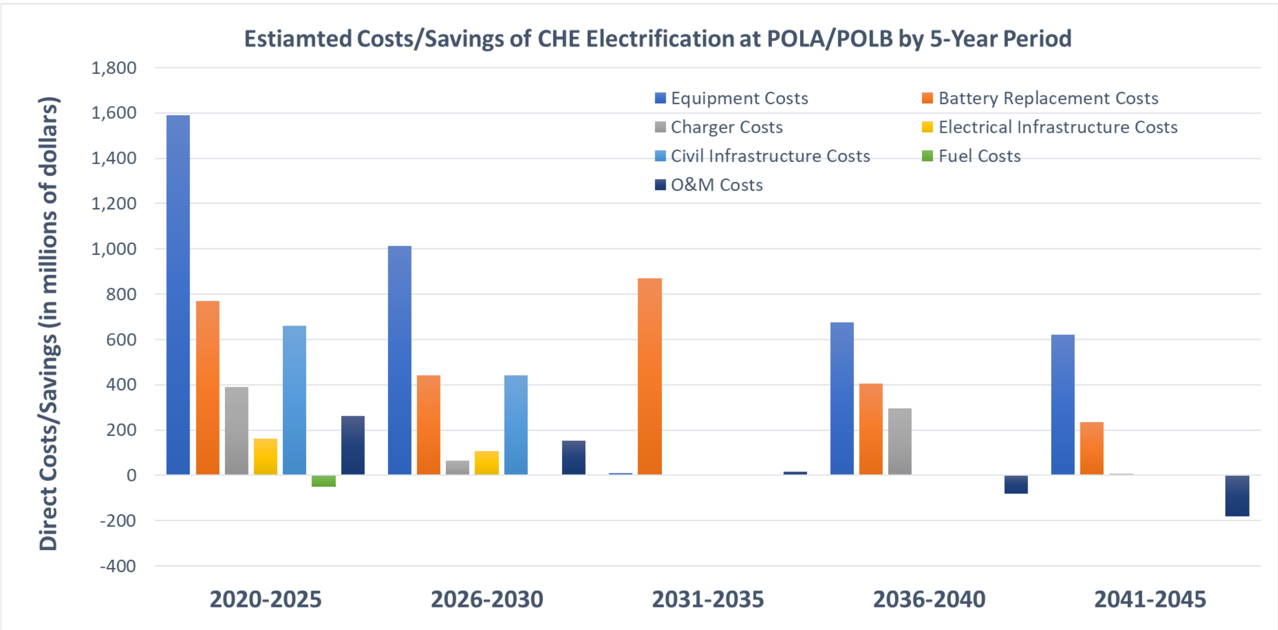

Figure 2. Estimated Costs/Savings of CHE Electrification at POLA/POLB by 5-Year Period (in millions 2019$)

5. Macroeconomic Impact Analysis Results

5.1. Application of the REMI Model

Before undertaking the economic simulations in the REMI Model, the direct impact data are prepared for utilization in the model. This step involves the selection of appropriate variables and determination of the proper economic sectors in REMI to simulate the policy's changes. Table 18 illustrates how the direct costs and savings of the CHE electrification are translated into REMI economic variable inputs.

In Table 18, the second column shows the micro analysis results for different types of direct impacts (or "drivers") of the CHE electrification. The third column presents the corresponding economic variables in the REMI PI+ Model and indicates their position within the Model (i.e., in which one of the five major model blocks in REMI described in Appendix D that the policy variables can be found). The direct impacts are also categorized in terms of whether they are expected to generate positive or negative impacts on the economy in the last column.

Table 18. Linkages between Direct Costs/Savings of Electrification of CHE at POLA/POLB and REMI Simulation Inputs

Linkage	Direct Costs/Savings of Electrification of CHE	Policy Variable Selection in REMI	Positive or Negative Stimulus to the Economy
1	Capital Investment – CHE purchase	Output and Demand Block →Exogenous Final Demand (amount) for Other General Purpose Machinery Mfg sector → Increase	Positive
2	Capital Investment – Battery Replacement	Output and Demand Block →Exogenous Final Demand (amount) for Other Electrical Equipment and Component Mfg sector → Increase	Positive
3	Capital Investment – Chargers	Output and Demand Block →Exogenous Final Demand (amount) for Other Electrical Equipment and Component Mfg sector → Increase	Positive
4	Capital Investment – Electric Infrastructure	Output and Demand Block →Exogenous Final Demand (amount) for Electric Power Generation, Transmission and Distribution; Construction; Electrical Equipment Mfg; Other Electrical Equipment and Component Mfg; Motor Vehicle Mfg sectors →Increase	Positive
5	Capital Investment – Civil Infrastructure	Output and Demand Block →Exogenous Final Demand (amount) for Construction; Cement and Concrete Product Mfg; Architectural and Structural Metals Mfg; Electrical Equipment Mfg; Other Electrical Equipment and Component Mfg sectors → Increase	Positive
6	Changes in Fuel Cost	Compensation, Prices, and Costs Block →Production Cost (amount) of Scenic and Sightseeing Transportation and Support Activities for Transportation sector →Decrease/Increase	Positive (for fuel cost savings)

Linkage	Direct Costs/Savings of Electrification of CHE	Policy Variable Selection in REMI	Positive or Negative Stimulus to the Economy
7	Increase Demand of Electricity	Output and Demand Block →Exogenous Final Demand (amount) for Electric Power Generation, Transmission and Distribution sector → Increase	Positive
8	Changes in Maintenance Cost of CHE	Compensation, Prices, and Costs Block →Production Cost (amount) of Scenic and Sightseeing Transportation and Support Activities for Transportation sector →Increase/Decrease	Negative (for increased cost)
9	Increased Capital Cost of the Ports	Compensation, Prices, and Costs Block →Capital Cost (amount) of Scenic and Sightseeing Transportation and Support Activities for Transportation sector →Increase	Negative
10	Decreased Demand of Diesel	Output and Demand Block →Exogenous Final Demand (amount) for Petroleum and Coal Products Mfg sector→Decrease	Negative

5.2. Base Case Analysis Results

5.2.1 Aggregate Economic Impacts

The aggregate economic impacts of the electrification of CHE at POLA/POLB are presented in Table 19 for the five 5-year time periods between 2020 and 2045 for the following indicators: employment, gross state product (GSP), output (sale revenues), personal income, and price index (the year-by-year simulation results are presented in Appendix E). The Net Present Value (NPV) computed by adopting a 3% rate of discount over the entire study period is also presented for GSP, output, and personal income impacts in the last column. The first partition of Table 19 presents the impacts in levels and the second partition presents the impacts in terms of percentage changes with respect to the baseline levels.

Table 19. Aggregate Macroeconomic Impacts of Electrification of CHE at POLA/POLB

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,081	-4,767	-2,819	-2,930	-1,540	-96,771
GSP	B 2018$	-0.57	-0.47	-0.30	-0.32	-0.16	-7.24
Output	B 2018$	-0.99	-0.85	-0.57	-0.59	-0.33	-13.00
Personal Income	B 2018$	-0.65	-0.56	-0.36	-0.42	-0.27	-8.78
Price Index	2012=100	0.010	0.006	0.002	0.005	0.003	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.024%	-0.019%	-0.011%	-0.011%	-0.006%	
GSP	B 2018$	-0.019%	-0.014%	-0.008%	-0.008%	-0.004%	
Output	B 2018$	-0.019%	-0.015%	-0.010%	-0.009%	-0.005%	
Personal Income	B 2018$	-0.025%	-0.020%	-0.011%	-0.012%	-0.007%	
Price Index	2012=100	0.008%	0.005%	0.001%	0.003%	0.001%	

Major highlights of the simulation results include:

- The NPV of the GSP losses over the entire planning period are estimated to be $7.24 billion. The impacts vary over time, with the greatest GSP losses occur in the earlier periods, in which the first replacement of various types of diesel CHE by electric CHE take place. The higher negative impacts on GSP in earlier years also stems from the assumption that a second fleet of the electric CHE is needed to operate the same level of cargo handling activities because of the limitation on battery ranges.
- The average annual employment losses are estimated to be 3,722 job-years[3] over the entire study period. The largest employment losses also occur in the first two 5-year time periods. The total employment impacts are estimated to be 96,771 job-years losses between 2020 and 2045.
- The losses in gross output (or sale revenues) are estimated to be $13.00 billion in NPV.
- The net personal income losses are projected to be about $8.78 billion in NPV.
- The price index in the state is projected to increase by about 0.008% and 0.005% in the first two 5-year time periods because of the increased capital and production cost of the port sector, which in turn affect the delivered price of the freight transport sector, and subsequently the production cost of the downstream sectors depending on port services and the price of the goods and services produced by these downstream sectors.
- Although some of the aggregate impacts are relatively large in terms of absolute levels, they remain small in percentage terms because of the size of the state economy.[4]

5.2.2. Decomposition of Impacts

In order to obtain a better understanding on how the various economic factors affect the bottom-line aggregation impacts of the CHE electrification policy, we also perform a decomposition analysis of the results. The decomposition analysis can provide valuable insights to identify the major contributing factors to the aggregate impact of the policy.

Figures 3 and 4 present the decomposition of the employment and GSP impacts of the electrification of CHE at POLA/POLB, respectively. The bars with different colors represent impacts of individual stimulus or dampening effects. The black solid line indicates the total net impact. The results indicate that the increased capital cost of the port sector results in the highest negative impacts on the economy. The positive stimuli mainly come from the spending on equipment in the investment years and increased demand in construction associated with the building and installation of the supporting infrastructure of the electric CHE. The variation of the net impacts (black solid line) over time reflects the high and low investment years on equipment and battery, which stems from the combined effect of replacement cycles of various types of CHE. We also note that negative impacts caused by the increased capital costs to the ports are much larger in magnitude than the positive impacts stemming from the stimulus effects of the investment expenditures. One major reason is that a large proportion of the electric CHE is assumed to be purchased from manufacturers outside of the state. The default regional purchase coefficient, which is about 35%, of the General Purpose Machinery Manufacturing sector in the REMI

[3] One job-year refers to a worker working full time for one year. Results presented for a given year represent the jobs in place that year whether they are new jobs or carryovers from past years.

[4] In 2019, the GSP of California was $3.1 trillion and the total employment was over 18 million.

Model is used. This means that about two thirds of the equipment will be purchased from suppliers out of California. The spending on imports would not generate direct and indirect stimulus effect on employment and GSP of the state.

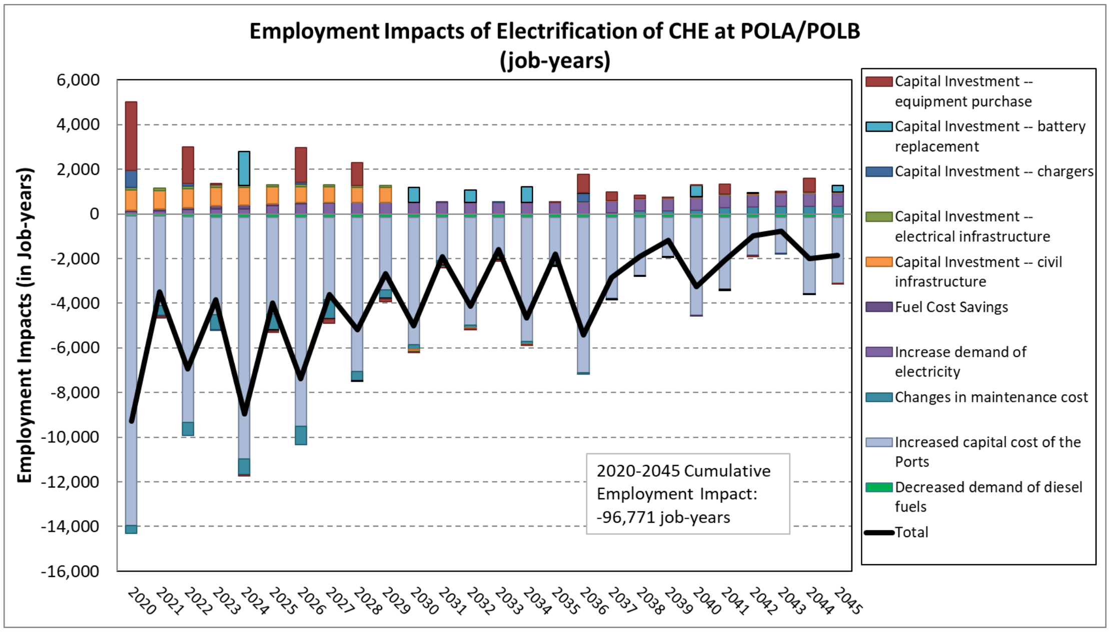

Figure 3. Decomposition of the Employment Impacts of CHE Electrification at POLA/POLB

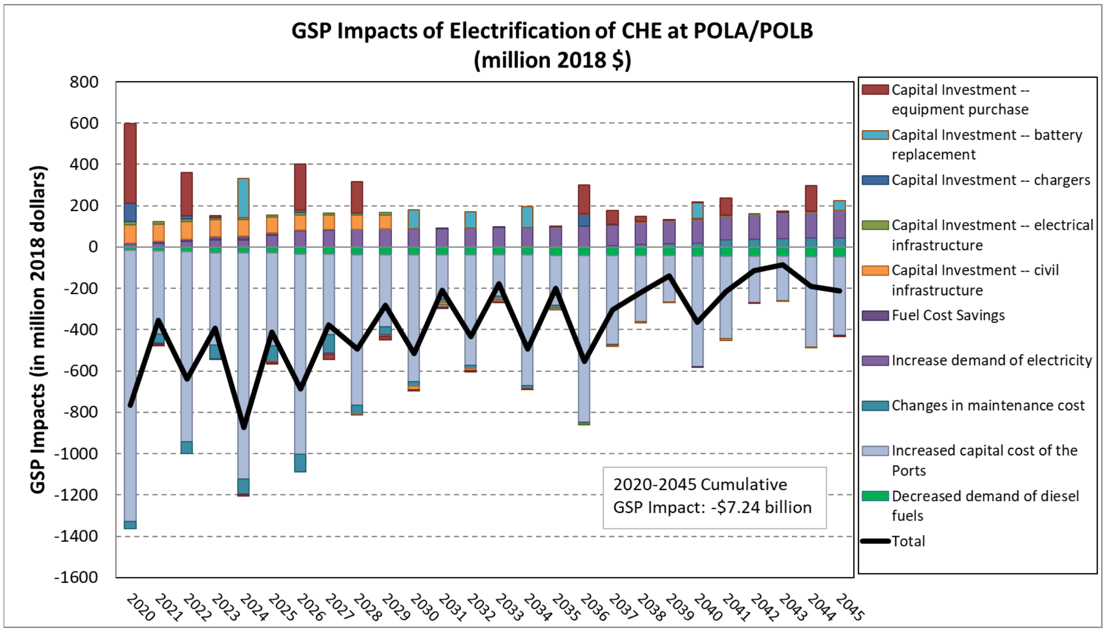

Figure 4. Decomposition of the GSP Impacts of CHE Electrification at POLA/POLB

5.2.3. Sectoral Impacts

In addition to the aggregate impacts on the state economy, we also analyze the employment impacts on a sectoral basis. To make the analysis and comparison manageable, we aggregate the 160 REMI sectors into 15 sectors, with key sectors, including the port-related sector and the manufacturing sectors of the cargo handling equipment, remain at their most disaggregated levels. The sectoral employment impacts over the entire study period are plotted in Figure 5. The port-related sector is the most negatively impacted one, with an average annual employment impacts of over 700 job-years. Other sectors that are estimated to experience relatively large employment losses include Wholesale Trade and Retail Trade, Other Transportation, and Other Services. Table 20 presents the employment impacts in 5-year periods of the top five negatively impacted sectors. The last column of the table presents the average annual impacts over the entire study period. The most positively affected sectors are those related to the manufacturing of the zero-emission cargo handling equipment and the Utilities sector (electricity providers) that is stimulated by the increased demand of electricity. Table 21 presents the employment impacts in 5-year periods of the top positively impacted sectors.

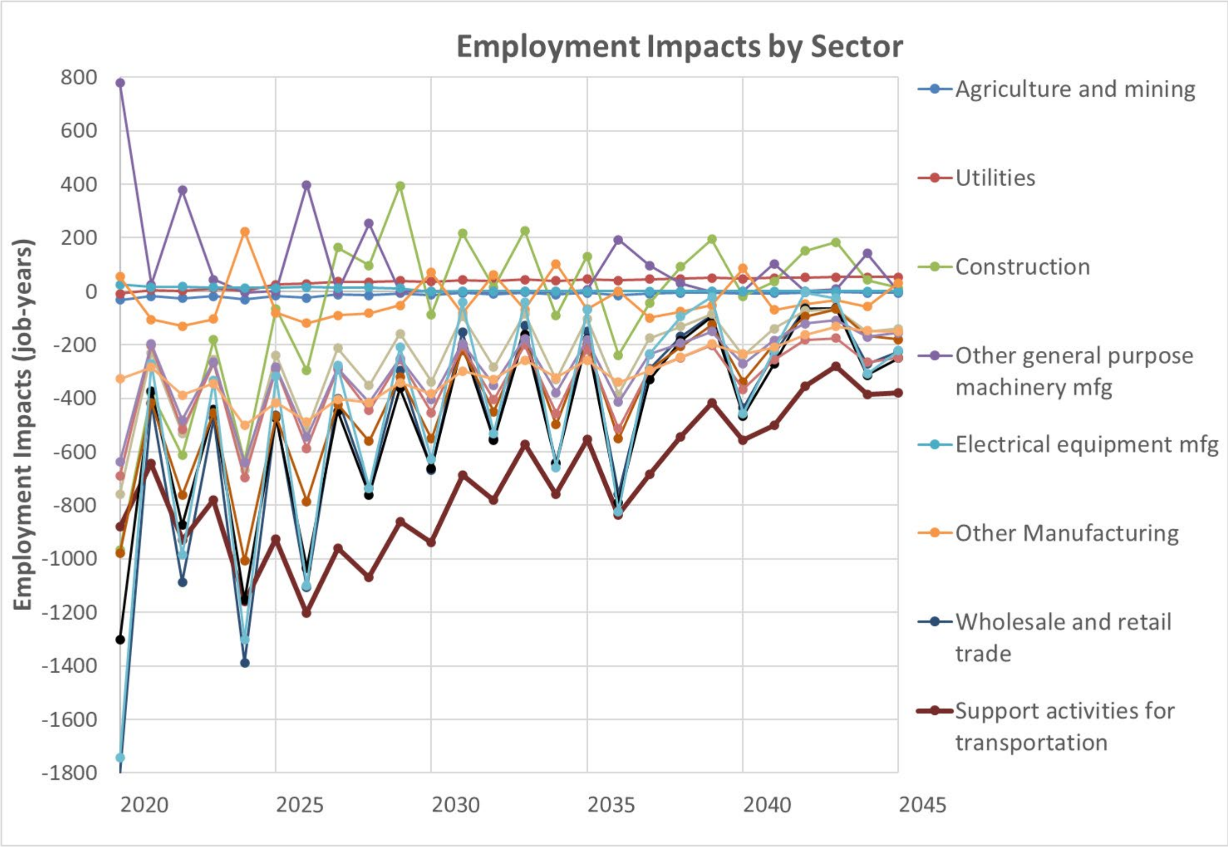

Figure 5. Employment Impacts by Sector

Table 20. Average Annual Employment Impacts of Top Negatively Impacted Sectors (job-years)

Sector	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	2020-2045
Support activities for transportation and sightseeing transportation	-887	-1006	-670	-607	-380	**-717**
Wholesale and retail trade	-940	-642	-325	-349	-171	**-503**
Other Transportation	-770	-653	-348	-373	-193	**-479**
Other services (except public administration)	-825	-590	-268	-326	-156	**-448**
Professional, scientific, and business services	-681	-528	-309	-303	-141	**-403**

Table 21. Average Annual Employment Impacts of Top Positively Impacted Sectors (job-years)

Sector	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	2020-2045
Other general purpose machinery manufacturing	204	129	1	64	51	**94**
Utilities	6	35	42	46	52	**35**
Electrical equipment manufacturing	16	11	0	0	0	**6**

5.3. Sensitivity Analysis

5.3.1. Sensitivity Analysis on Funding Sources and Cost Pass-through Assumption

The economic impacts of a regulation on both the state economy and the individual sectors that are directly subject to the regulation are affected by the assumptions on funding sources. Key assumptions need to be made include:

- What is the proportion of funding coming from in-state vs. out-of-state sources? The former can come through retained earnings or debt financing by the regulated sectors (ports in this case). It can also come from state government subsidies and incentive programs. The latter can come from federal transportation funding or out-of-state venture capital investment.
- For the portion of costs borne by the port and terminal operators, would they be translated to higher port service fees and subsequently be passed through onto consumers?
- For state incentive programs, would the funding result in offsetting effects as reduced government expenditures in other projects or programs or would it be compensated by increased taxes or fees in other areas?

In order to examine how changes in these assumptions would affect the impacts of CHE electrification on the state economy, as well as the implications to the transportation sector, we have performed the following sensitivity analyses with respect to funding sources and cost pass-through assumption.

Base Case: state incentive programs are assumed to cover about 10% of the equipment and infrastructure costs.[5] We further assume that this government funding will not offset any other state

[5] There are a few relevant incentive programs that electric CHE can be qualified. For example, the Clean Off Road Equipment Voucher Incentive Project (CORE) is designed to provide purchase incentives of cleaner off-road freight equipment. Since 2019, more than $40 million vouchers have been issued (California CORE, 2021). The Southern California Edison's Charge Ready Transportation Program provides up to $343 million to support the development

government expenditures. The remaining 90% of the costs will be borne by the ports. The default assumption in the REMI Model is that the increased costs of the ports will be automatically passed onto downstream customers through increased cost and thus delivered price of port services.

Sensitivity Case 1 (S1): In this sensitivity case, we assume that there is no state incentive funding. Therefore, 100% of the costs will be borne by the ports and then passed through onto downstream customers.
Sensitivity Case 2 (S2): Everything is same as in the Base Case. However, it is assumed that the 10% state government subsidy will be offset by a reduction in government spending in other similar areas.
Sensitivity Case 3 (S3): Everything is same as in the Base Case. However, it is assumed that the funding of the 10% state government subsidy will come from an increase in the gasoline tax.
Sensitivity Case 4 (S4): Everything is same as in the Base Case. However, it is assumed that the ports can only partially pass the increase costs onto downstream customers.

Table 22 presents the total impacts in terms of employment, GSP, and output over the entire study period for the various sensitivity cases on funding sources (more detailed results are presented in Appendix F). The results for the Base Case are also presented in the first row of the table for easy comparison. The results of S1 indicate that without any state government subsidy, the negative impacts on employment will be about 9% higher than in the Base Case. For the two scenarios in which we assume that the state government subsidy will be offset by a reduction in other government expenditures (S2) or an increase in gasoline tax (S3), the negative impacts on employment are estimated to be about 3% and 6% higher than in the Base Case, respectively. These analyses indicate that the establishment of government incentive programs to subsidize high up-front capital costs of the CHE electrification transition will improve the macroeconomic performance of this policy, even in the cases that the funding of these incentive programs need to be offset in other areas. Finally, when the ports can only partially pass their increased costs to downstream businesses and end users (S4), the negative impacts on the state economy as a whole are estimated to be smaller. This is because a greater proportion of the negative shock is absorbed by the port sector in this scenario, and thus results in reduced negative supply-chain (or multiplier) effects.

Table 22. Total Economic Impacts of Sensitivity Cases on Funding Sources (2020-2045)

Scenarios	Employment Impact (job-years)	GSP Impact (NPV in B $)	Output Impact (NPV in B $)
Base Case (gov't subsidy w/o offset; cost pass-through)	-96,771	-7.24	-13.00
S1. No Incentives	-105,565	-7.96	-14.30
S2. Gov't Subsidy w/ offset: reduced gov't spending in other similar areas	-99,757	-7.55	-13.55
S3. Gov't Subsidy w/ offset: increased gas tax	-102,746	-7.87	-14.14
S4. Partial cost pass-through by Ports (gov't subsidy w/o offset)	-86,583	-6.41	-11.75

of charging infrastructures by its customers, of which between 25% and 75% (or $86 million and $257 million) are available to ports and warehouses (CPUC, 2018). The Volkswagen Environmental Mitigation Trust allocates about $70 million funds to support Zero-Emission Freight and Marine Projects between 2019 and 2020 (VW Mitigation Trust, 2021).

5.3.2. Sensitivity Analysis on Other Key Factors

In the Base Case analysis, although we have used the data that are best available at the time of the study, there are uncertainties associated with several key factors affecting the total costs of the adoption of the electric CHE. In this sub-section, we run sensitivity analyses that take into considerations the possible ranges of various types of cost that formulate a lower-bound cost case and an upper-bound cost case. Specifically, we made lower- and upper-bound assumptions on the following set of variables: 1) equipment cost of electric CHE; 2) battery cost; 3) charger cost; 4) electrical and civil infrastructure cost; 5) replacement ratio between electric and conventional CHE; 6) cost of electricity. The assumptions on the ranges of equipment and infrastructure costs are primarily determined based on the cost data collected from various sources (Moffatt and Nichol, 2015; EnSafe Inc., 2017; Tetra Tech., 2019; EPRI, 2021), as well as communications with port experts (PMSA, 2021).

For the assumptions on the replacement ratio between the electric and conventional CHE, we assume a 2:1 ratio for the first replacement cycle and 1:1 ratio for any remaining cycles during the study period in the Base Case. Depending on the average model year of the current fleet and the designed useful life of the equipment, the second replacement cycle will take place in around 2030 (the exact year varies across different types of equipment). For the lower-bound cost case, we assume that the 1:1 replacement ratio can be achieved earlier in the study period in about Year 2025. Therefore, for any CHE, only one unit of electric equipment is needed to replace its conventional counterpart after 2025 even it represents the first replacement during the study period. For the upper-bound cost case, we assume that the 1:1 replacement ratio will be achieved later in the study period in about Year 2035. Therefore, the 2:1 ratio will apply to any replacement taking place before 2035 even it represents the second replacement of some equipment during the study period.

For the assumption on cost of electricity, in the lower-bound cost case, we use the special EV rate offered by SCE ($6.69/DGE) through Year 2024 and then assume the LADWP rate ($11.60/DGE, with demand charge accounting for about 60% of total cost) for rest of study period. In the upper-bound case, we use the SCE non-EV rate ($18.2/DGE, with demand charge accounting for about 85% of total cost) for the entire study period.

One thing to note is that we use the manufacturing useful life of the equipment in both the Base Case and the lower- and upper-bound cases. Although in practice some individual pieces of equipment might last longer than the designed (average) useful life (depending on the intensity of use and the maintenance cost spent on the equipment), there are also cases that the equipment is damaged or destroyed before they reach their designed useful life because of accidents and heavy uses. Also, the useful life of the equipment we use in the analysis is consistent with CARB required replacement schedule. Given these considerations, we assume that there is no variation in this parameter across the simulation cases.

Table 23. Assumptions of the Lower-Bound and Upper-Bound Cost Sensitivity Analysis

Variable	Lower-bound	Upper-bound
CHE equipment cost	10% lower than base case	10% higher than base case
Battery cost	10% lower than base case	10% higher than base case
Charger cost	10% lower than base case	10% higher than base case
Infrastructure cost	20% lower than base case	20% higher than base case
Replacement ratio between electric and diesel CHE	1:1 ratio for any replacement after 2025	1:1 ratio for any replacement after 2035
Cost of electricity	SCE EV rate util 2024; electricity rate with lower demand charge (account for about 60% of total electricity cost) after 2024	Electricity rate with higher demand charge (account for about 85% of total electricity cost) for the entire study period

The estimated costs associated with the electrification of CHE at POLA/POLB for both the Base Case and the lower-bound and upper-bound cases are presented in Table 24 by cost category. The NPV of the total incremental cost is estimated to be $5.0 billion in the lower-bound case, which is 27% lower than that in the Base Case. Although the equipment cost is assumed to be 10% lower in this case, the total incremental equipment replacement cost is estimated to be over 20% lower than in the Base Case. The result is a combined effect of the assumptions of lower unit equipment cost and a more rapid technological development of battery that enables earlier one to one replacement ratio between electric and conventional equipment. For the upper-bound case, the NPV of the total incremental cost is estimated to be $9.2 billion, which is 34% higher than in the Base Case. The most influential factor in this case is again the trajectory of battery development in the future. When it is assumed that the realization of a 1:1 replacement ratio will be delayed until after Year 2035 in the upper-bound case, the total incremental equipment replacement cost is estimated to be 30% higher than in the Base Case. Finally, the degree that the demand charge dominates total electricity costs would greatly affect the net changes in fuel cost of the electrification of CHE. When the demand charge is assumed to be increased from accounting for 60% of total electricity costs in the lower-bound case to 85% in the upper-bound case, the results change from a $300 million fuel cost savings to $257 million net increase in fuel cost.

The total macroeconomic impacts in terms of employment, GSP, and output over the entire study period for the lower- and upper-bound sensitivity cases are presented in Table 25. Again, the results for the Base Case are also presented in the first row of the table for easy comparison. The total employment impact is estimated to be 67,758 and 133,254 job-years losses in the lower-bound case and upper-bound case, which are 30% lower and 38% higher than in the Base Case, respectively. The NPV of GSP losses are estimated to be $5.19 billion in the lower-bound case and $9.76 billion in the upper-bound case.

Table 24. Total Incremental Costs of Transition to ZE CHE at POLA/POLB (2020-2045) (in millions of dollars)

	Base Case		Lower-Bound		Upper-Bound	
	Simple Total	NPV	Simple Total	NPV	Simple Total	NPV
Equipment Replacement Costs	3,910	3,029	2,998	2,320	5,128	3,952
Battery Replacement Costs	2,722	1,886	2,216	1,548	3,432	2,368
Charger Costs	755	606	680	545	831	666
Electrical Infrastructure Upgrade Costs	269	229	215	184	323	275
Civil Infrastructure Costs	1,102	940	882	752	1,323	1,128
Changes in Fuel Costs	-35	-36	-453	-300	414	257
Changes in Maintenance Costs	169	232	-215	-35	673	571
Total	**8,893**	**6,886**	**6,324**	**5,013**	**12,122**	**9,218**

Table 25. Total Economic Impacts of Lower-Bound and Upper-Bound Cost Sensitivity Cases (2020-2045)

Scenarios	Employment Impact (job-years)	GSP Impact (NPV in B $)	Output Impact (NPV in B $)
Base Case	-96,771	-7.24	-13.00
Lower-bound Cost Case	-67,758	-5.19	-9.41
Upper-bound Cost Case	-133,254	-9.76	-17.41

5.4. Impacts on Port and Transportation Sector in California

The sectoral impact analysis presented in Section 5.2.3 indicates that the port-related sector and the aggregate transportation sector are the most negatively impacted sectors under this policy. The NPV of gross output losses in the port-related sector in California is estimated to be $2.65 billion. To put this into context, the projected operating revenue for the 2021-22 fiscal year is $533.3 million of POLA and $413 million of POLB (DiMartino, 2021). Assuming a stream of operating revenue at this same level over 26 years, the NPV of total operating revenues of the two ports is about $17 billion. The output losses for the aggregate transportation sector are lightly over $4 billion. At the same time, the model results indicate that there is an inter-regional substitution of the economic activities in the port and aggregate transportation sector. Table 26 presents the gross output impacts for the port sector and transportation sector for California and Rest of the U.S. In all the scenarios, gross output in the port-related sector and the aggregate transportation sector in California decreases, while gross output in these sectors in Rest of U.S. increases, indicating California is losing businesses to other regions. In addition, although Scenario S4 (in which we assume the ports can only partially pass the increased cost to downstream customer) results in the smallest gross output losses economy-wide, output losses in the port-related sector are the highest in this scenario. The reason that the increased gross output in the aggregate transportation sector is slightly lower than the increased gross output in the port-related sector in Rest of U.S. is because a number of transportation sub-sectors are estimated to have small decreases in gross output in Rest of U.S.

Table 26. Gross Output Impacts of Port Sector and Transportation Sector for California and Rest of U.S. (in billion 2018$)

Scenario	Port Sector		Transportation Sector	
	CA	Rest of U.S.	CA	Rest of U.S.
Base Case	-2.65	2.06	-3.95	1.95
S1. No Incentives	-2.84	2.20	-4.23	2.08
S2. Gov't Subsidy + Reduced Gov't Spending Elsewhere	-2.65	2.06	-3.97	1.94
S3. Gov't Subsidy + Increased gas tax	-2.66	2.06	-4.02	1.96
S4. Partial cost pass-through by Port	-3.79	1.31	-4.76	1.29
Lower-bound Cost Case	-1.92	1.50	-2.86	1.41
Upper-bound Cost Case	-3.56	2.76	-5.30	2.62

6. Conclusion

California's transportation system plays a significant role to the state economic growth, but at the same time also contributes the largest share of the state GHG and criteria pollutant emissions. California has been leading the nation, and in many aspects the world, in the regulation of heavy-duty vehicles and equipment in the goods movement sector. California's freight industry is vital because of its significant contribution to international trade and domestic commerce. It is also responsible for a large share of total transportation sector emissions. The California Sustainable Freight Action Plan (CSFAP) was initiated in 2016 to provide a high-level vision for the state to transition to a more efficient, environmentally friendly, and economically competitive freight transport system. The transition to a clean energy future provides a great opportunity to foster economic growth, but at the same time, technology and infrastructure changes to further mitigate emissions come at a cost. Therefore, it is important that an economic analysis on the costs and benefits associated with State climate actions is conducted.

In this report, we analyze the macroeconomic impacts on the California State economy of the electrification of cargo handling equipment at Port of Los Angeles and Port of Long Beach between 2020 and 2045. The study compares the costs of equipment, infrastructure, fuel, and O&M expenditures of the deployment of electric CHE relative to baseline operation and turnover of conventional CHE. A state-of-the-art macroeconometric model, the Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI+) Model, is applied to analyze the macroeconomic impacts of this transition in terms of the impacts on employment, gross state product, output, and personal income. The primary input data to the REMI Model are the estimates of the direct costs and savings associated with the transition to electric CHE.

The micro-level analysis results indicate that the net incremental costs of the transition to zero emission electric CHE at POLA and POLB between 2020 and 2045 are about $6.9 billion in net present value, among which equipment purchase and battery replacement costs account for more than 70% of the total incremental costs. Charger and electrical and civil infrastructure costs account for another 25% of the total. Fuel cost savings are estimated to be small because of the high demand charges on electricity. A large proportion of the incremental costs will incur in the first 10 years of the study period because of the need to develop the supporting electrical infrastructure at the ports in the near term to facilitate the transition and operation of electric CHE. It is also because a second fleet of the electric equipment is needed to replace the conventional equipment before the development of the battery technology can enable a one-to-one substitution.

The macroeconomic modeling results indicate that the total employment impacts are estimated to be 96,771 thousand job-years losses between 2020 and 2045. This translates to average annual employment losses of 3,721 job-years. The NPV of the GSP, gross output, and personal income losses over the entire study period are estimated to be $7.24 billion, $13.00 billion, and $8.78 billion, respectively. Although some of the aggregate impacts are relatively large in terms of absolute levels, they remain small in percentage terms because of the size of the state economy. A decomposition of the total impacts indicates that the increased capital cost of the port sector results in the highest negative impacts on the economy. The positive stimuli mainly come from the spending on equipment in the investment years and increased demand in construction associated with the building and installation of the supporting infrastructure for the electric CHE. However, the negative impacts greatly exceed the positive impacts generated through the investment in the equipment manufacturing and construction sectors. Major sectors that are negatively impacted by the policy include port-related sector, other transportation, wholesale trade and retail trade. The most positively affected sectors include those relate to the manufacturing of the zero-emission cargo handling equipment and the utilities sector (electricity providers).

We also perform several sensitivity analyses to examine how the results would change in response to changes in key assumptions. These analyses indicate the important benefit of government incentive programs to lower the high up-front capital cost burden of CHE electrification on the regulated sector and to reduce the negative macroeconomic impacts of this policy. When the ports can only partially pass their increased costs to downstream businesses and end users, the negative impacts on the economy are estimated to be smaller because of the reduced negative supply-chain (or multiplier) effects. However, output losses in the port-related sector are the highest in this case. In all the scenarios, gross output in the port-related sector and the aggregate transportation sector in California decreases, while gross output in these sectors in rest of U.S. increases, indicating California is losing businesses to other regions when the capital and operating costs of the ports increase.

Finally, the primary goal of the zero-emissions transition of the cargo handling equipment is to reduce criteria and GHG emissions from operating the equipment at California's ports and to protect public health. Therefore, a comprehensive evaluation of the impacts of this transition should juxtapose the economic impacts of this transition along with the environmental and public health benefits of the regulation, as well as any co-benefits in terms of improving productivity and enhancing energy security by reducing reliance on energy imports.

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Data Management Plan

Products of Research

Data used in this research is drawn from several technical studies as noted in the text and reference list. The inventory of CHE was obtained from air emissions inventory reports from the ports of Los Angeles and Long Beach. Equipment costs and lifespan of CHE were obtained from consultant technical reports and the ports. Infrastructure costs were drawn from technical reports and interviews with port experts. Operating costs were based on current electricity pricing from the utility companies serving the port area, current diesel and LNG fuel prices, and fuel economy of electric and fossil fuel powered equipment from technical reports. Maintenance costs were drawn from technical reports. All data sources are documented in the text. Cited reports are in the reference list with links for access. The data were used to calculate the total direct costs of transition to zero emission CHE at the ports of Los Angeles and Long Beach for the period of 2020-2050. The direct costs were used as input to the REMI-PI+ model, which generated the macroeconomic impacts.

Data Format and Content

All the datasets are stored in Excel format.

Data Access and Sharing

All the data used in this research is presented in the final report text and appendices. Reports from which the data were drawn are included in the reference list with links to access.

Reuse and Redistribution

Data cited or produced in this research have no restrictions on reuse and redistribution

Appendix A. Summary of Major Assumptions adopted in the Analysis

Below we summarize the list of major assumptions adopted in the Base Case analysis. Sensitivity analyses on some of these assumptions are run. The assumptions of the sensitivity cases are summarized in detail in the main text.

1. Current equipment prices (in 2018 real dollars) are used for all replacement cycles. By using the same equipment price in real dollar terms over time, it effectively takes into consideration an expected annual price inflation rate of 1.5% to 2%.
2. Electric CHE has the same life span as its corresponding conventional CHE.
3. The manufacturing designed useful life of equipment is used for both the conventional CHE and the electric CHE.
4. A 2:1 replacement ratio between battery powered electric CHE and their conventional counterpart is assumed for the first replacement. For the subsequent replacements taking place in the remaining study horizon, we assume that future batter technology development would enable longer battery ranges, and thus a 1:1 replacement ratio can be achieved starting from the second replacement cycle for each individual type of CHE.
5. For all battery-electric equipment, one battery replacement during the useful life is assumed.
6. The battery costs about two thirds of the total equipment cost.
7. Charger service is assumed to be extended to two useful lives of CHE.
8. Per unit operation cost of conventional and electric equipment is assumed to be same.
9. For the cost of electricity, the special EV rate offered by SCE is used though 2024. The electricity cost calculated as the average of the SCE non-EV rate and the LADWP rate is used in the rest of the study period.
10. Maintenance cost is about 25% to 30% lower for electric CHE comparing to its diesel counterpart.
11. State incentive programs are assumed to cover ~10% of equipment and infrastructure costs; the remaining costs are assumed to be borne by the ports; the REMI Model assumes these increased costs will be passed onto downstream customers through increased cost of port services.
12. We use the default regional purchase coefficient of the relevant sector in the REMI Model to estimate the percentage of electric CHE that will be manufactured and supplied within the state. The in-state share is about 35%. This means about two thirds of the equipment will be purchased from suppliers out of California.

Appendix B. Implication of CHE Electrification at POLA/POLB on Resiliency of the Grid

In this study, the evaluation of the infrastructure costs is confined to the electrical infrastructure and the associated civil works that are needed to accommodate the increased demand of electricity of the battery-electric or grid-connected new CHE. The study does not analyze the extent to which this electrification transition would require increased capacity of the electrical power grid and the potential costs this might incur to the port authorities and utility providers.

In the CAAP 2018 Feasibility Assessment Report for CHE (Tetra Tech, 2019), although the increased load for electrifying the CHE that needs to be served by LADWP and SCE was not quantified, the study provided the following general assessment:

- Assuming the charging stall for an electric yard tractor is 150 KW, the ports would require 255 MW of charging infrastructure for the total of nearly 1,700 yard tractors.
- The grid-connected RTG crane needs 710 kW of power to operate. Therefore, 111 MW of electricity distribution infrastructure is required for the total of 156 RTG cranes.
- On an average busy day, a very large terminal can operate 180 yard tractors and 20 to 30 RTG cranes. This would result in a peak charging demand of 27 MW for the yard tractors and an additional power demand of 14 to 21 MW for the RTG cranes.
- Based on the UCLA Luskin Center 2013 Report "Moving Toward Resiliency", the peak demands in the largest terminals, such as the APM Terminal at POLA, are about 10 to 15 MW (Matulka et al., 2013). If we use the 2013 estimates, providing power for charging the yard tractors can double or triple the terminals electricity demand, while the power needed for grid-connected RTG cranes also represents a doubling of the existing power demand.

If we take into consideration the other types of CHE, such as top handlers and forklifts, the increase of power load in the port region for CHE electrification would be substantial. Another recent estimate by Port of Long Beach indicates that the full transition to electric marine terminals will quadruple the power demand of the port (Houston, 2019). However, although the additional loads needed in the port region are significant, the CAAP Feasibility Assessment Report for CHE did not anticipate that this increase will result in a significant impact on the system-wide capacity of LADWP and SCE. In 2017, the peak load is 23,508 MW of SCE and 6,502 of LADWP. The total peak power demand of electric yard tractors and RTG cranes (255 MW + 111 MW = 366 MW) only accounts for about 1 percent of the combined peak load in the SCE and LADWP service territories. Therefore, the report concluded that there may not be a need for the utility providers to invest in substantial system-wide upgrades or to secure additional generating resources to serve the increased demand (Tetra Tech, 2019).

Currently, POLA and POLB is developing microgrids that help enhance energy security and demand flexibility in the network. There are several demonstration microgrid projects deployed at the ports, with the goal to primarily enhance the resilience of electricity supply to control and command centers and other critical security facilities. In POLB, these installations include a 300 KW solar carport, a microgrid energy controls center, a 330 KW stationary battery energy storage system, and a 250 KW microgrid-extending mobile battery energy storage system (POLB, 2018).

There are still many questions need to be answered in future studies. Although the increased load for fully electrified ports only accounts for a very small portion of the total peak demand load in the SCE and LADWP territories, having the power supply capacity for the entire grid is not the same as having sufficient transmission power, and thus it is unclear what the impacts of consuming large amounts of power in a concentrated location are to the local transmission and distribution facilities. In addition, to what extent microgrids could substitute for losses from a grid disruption and the level of operations can be retained during such grid outage still needs to be analyzed.

Appendix C. Estimation of Equipment, Infrastructure, O&M, and Fuel Costs of CHE Electrification by Year

Table C1. Electric CHE Equipment Replacement Costs (Incremental Costs Compared to Baseline Technology) by Year at POLA/PLOB (in 2019$)

Year	Yard Tractor (Hostler)	RTG Crane	Front End Loader	Top Handler	Forklift	Total
2020	909,201,000	0	23,600,000	0	29,200,000	962,001,000
2021	0	38,586,000	0	0	0	38,586,000
2022	0	0	0	516,880,000	1,200,000	518,080,000
2023	0	66,054,000	0	0	0	66,054,000
2024	0	0	0	0	0	0
2025	0	0	0	0	5,200,000	5,200,000
2026	0	0	0	604,920,000	0	604,920,000
2027	0	0	0	0	0	0
2028	360,113,500	0	44,250,000	0	0	404,363,500
2029	0	0	0	0	0	0
2030	0	0	0	0	2,920,000	2,920,000
2031	0	0	0	0	0	0
2032	0	0	0	0	120,000	120,000
2033	0	0	0	0	0	0
2034	0	0	0	0	0	0
2035	0	0	10,000,000	0	520,000	10,520,000
2036	360,113,500	38,586,000	0	0	0	398,699,500
2037	0	0	0	207,480,000	0	207,480,000
2038	0	66,054,000	0	0	0	66,054,000
2039	0	0	0	0	0	0
2040	0	0	0	0	2,920,000	2,920,000
2041	0	0	0	242,820,000	0	242,820,000
2042	0	0	0	0	120,000	120,000
2043	0	0	18,750,000	0	0	18,750,000
2044	360,113,500	0	0	0	0	360,113,500
2045	0	0	0	0	520,000	520,000
Simple Total	**1,989,541,500**	**209,280,000**	**96,600,000**	**1,572,100,000**	**42,720,000**	**3,910,241,500**
NPV Total	**1,548,583,232**	**156,073,967**	**72,281,989**	**1,213,472,308**	**38,189,402**	**3,028,600,898**

Table C2. Electric CHE Battery Replacement Costs by Year at POLA/PLOB (in 2019$)

Year	Yard Tractor (Hostler)	RTG Crane	Front End Loader	Top Handler	Forklift	Total
2020	0		0	0	0	0
2021	0		0	0	0	0
2022	0		0	0	0	0
2023	0		0	0	0	0
2024	735,777,250		0	0	0	735,777,250
2025	0		0	0	35,215,200	35,215,200
2026	0		0	0	0	0
2027	0		0	0	1,447,200	1,447,200
2028	0		18,224,000	0	0	18,224,000
2029	0		0	0	0	0
2030	0		0	414,596,000	6,271,200	420,867,200
2031	0		0	0	0	0
2032	367,888,625		0	0	0	367,888,625
2033	0		0	0	0	0
2034	0		0	485,214,000	0	485,214,000
2035	0		0	0	17,607,600	17,607,600
2036	0		34,170,000	0	0	34,170,000
2037	0		0	0	723,600	723,600
2038	0		0	0	0	0
2039	0		0	0	0	0
2040	367,888,625		0	0	3,135,600	371,024,225
2041	0		0	0	0	0
2042	0		0	0	0	0
2043	0		9,112,000	0	0	9,112,000
2044	0		0	0	0	0
2045	0		0	207,298,000	17,607,600	224,905,600
Simple Total	**1,471,554,500**	**0**	**61,506,000**	**1,107,108,000**	**82,008,000**	**2,722,176,500**
NPV Total	**1,082,960,435**	**0**	**39,123,091**	**707,076,364**	**56,412,661**	**1,885,572,551**

Table C3. Electric CHE Charging Infrastructure Costs by Year at POLA/PLOB (in 2019$)

Year	Yard Tractor (Hostler)	RTG Crane	Front End Loader	Top Handler	Forklift	Total
2020	268,125,000	0	2,248,800	0	55,631,093	326,004,893
2021	0	0	0	0	0	0
2022	0	0	0	51,160,200	2,286,209	53,446,409
2023	0	0	0	0	0	0
2024	0	0	0	0	0	0
2025	0	0	0	0	9,906,907	9,906,907
2026	0	0	0	59,874,300	0	59,874,300
2027	0	0	0	0	0	0
2028	0	0	4,216,500	0	0	4,216,500
2029	0	0	0	0	0	0
2030	0	0	0	0	0	0
2031	0	0	0	0	0	0
2032	0	0	0	0	0	0
2033	0	0	0	0	0	0
2034	0	0	0	0	0	0
2035	0	0	0	0	0	0
2036	268,125,000	0	0	0	0	268,125,000
2037	0	0	0	0	0	0
2038	0	0	0	0	0	0
2039	0	0	0	0	0	0
2040	0	0	0	0	27,815,547	27,815,547
2041	0	0	0	0	0	0
2042	0	0	0	0	1,143,105	1,143,105
2043	0	0	0	0	0	0
2044	0	0	0	0	0	0
2045	0	0	0	0	4,953,453	4,953,453
Simple Total	**536,250,000**	**0**	**6,465,300**	**111,034,500**	**101,736,314**	**755,486,114**
NPV Total	**422,535,569**	**0**	**5,414,897**	**95,502,115**	**82,228,173**	**605,680,754**

Table C4. Estimate of Electrical Charging Infrastructure Upgrade Costs, Port of Los Angeles

Terminal	Terminal Utility Upgrade Cost
Berth 46 Port of Los Angeles	$1,000,000
Berths 54-55 SSA Pacific, Inc.	$1,000,000
Berths 91-93 World Cruise Center/Ports America Cruise Inc.	$1,000,000
Berth 95 Catalina Sea and Air Terminal	$1,000,000
Berths 100-109 China Shipping North America/WBCT	$40,000,000
Berths 118-120 Kinder Morgan Terminals	$1,000,000
Berths 121-131 Yang Ming Marine Transport/WBCT	$40,000,000
Berths 136-147 TraPac, Inc.	$20,000,000
Berths 148-151 Phillips 66	$1,000,000
Berth 154-155 Port of Los Angeles/Pasha Stevedoring & Terminals	$1,000,000
Berth 163 NuStar Energy L.P.	$1,000,000
Berth 164 Valero/Ultramar Inc.	$1,000,000
Berths 165-166 Rio Tinto Minerals	$1,000,000
Berths 167-169 Shell Oil Products	$1,000,000
Berths 174-181 Pasha Stevedoring & Terminals	$1,000,000
Berths 187-190 Vopak Terminals	$1,000,000
Berth 191 Vopak Terminals/California Portland Cement	$1,000,000
Berths 195-199 WWL Vehicle Services Americas	$1,000,000
Berths 206-209 Port of Los Angeles/Pasha Stevedoring & Terminals	$1,000,000
Berths 210-211 SA Recycling, LLC	$1,000,000
Berths 212-225 Yusen Terminals Inc.	$40,000,000
Berths 226-236 Everport Terminal Services/STS	$40,000,000
Berths 238-240C PBF Energy	$1,000,000
Berth 301 Millennium Maritime Inc.	$1,000,000
Berths 302-305 Eagle Marine Services, Ltd.	$40,000,000
Berths 401-404 APM Terminals Pacific	$40,000,000
Berths 405-406 California United Terminals	$40,000,000
Total	***$319,000,000***

Source: EnSafe Inc. (2017)

Table C5. Estimate of Electrical Charging Infrastructure Upgrade Costs, Port of Long Beach

Terminal	Terminal Utility Upgrade Cost
Pier T Berths 130-140 TTI	$40,000,000
Pier G Berths G226-G236 International Transportation Service	$40,000,000
Pier F Berths F6-10 Long Beach Container Terminal	$0
Pier D-F, Berths 22, 24, 26 Middle Harbor	$0
Pier J Berths J243-J247, J266-J270 Pacific Container Terminal	$40,000,000
Pier A Berths A88-A96 SSA Terminals	$40,000,000
Pier C Berths C60-C62 SSA Terminals	$40,000,000
Pier D Berth D46 G-P Gypsum	$1,000,000
Pier F Berth F211 Koch Carbon	$1,000,000
Pier G Berth G212-G215 Metro Ports	$1,000,000
Pier F Berth F208 Mitsubishi Cement	$1,000,000
Pier F Berth F210 Morton Salt	$1,000,000
Pier B Berths B82 National Gypsum	$1,000,000
Pier T Berth T118 SA Recycling, LLC	$1,000,000
Pier D Berths D32 CEMEX USA	$1,000,000
Pier F Berth F209 Chemoil Marine Terminal	$1,000,000
Pier B Berths B82, B83 Petro-Diamond/Toyota Logistics Services	$1,000,000
Pier B Berths B76-B80 Tesoro Logistics Operations LLS	$1,000,000
Pier B Berths B84-B87 Tesoro Logistics Operations LLS	$1,000,000
Pier T Berth T121 Tesoro Logistics Operations LLS	$1,000,000
Pier S Berth S101 Vopak Terminal Long Beach Inc.	$1,000,000
Pier F Berths F204 — F207 Crescent Terminal (SSA)	$1,000,000
Pier D Berths D50-D54 Crescent Warehouse Company	$1,000,000
Pier T Berth T122 Fremont Forest Products	$1,000,000
Standby Berth — Pier F Berth F201 Port of Long Beach	$1,000,000
Total	***$219,000,000***

Source: EnSafe Inc. (2017)

Table C6. Changes in Fuel Costs of Transition to Electric CHE by Year at POLA/PLOB

Year	Yard Tractor (Hostler)	RTG Crane	Front End Loader	Top Handler	Forklift	Total
2020	-1,396,360	0	-14,384	0	-3,706,525	-5,117,269
2021	-1,438,251	-1,790,820	-14,816	0	-3,817,721	-7,061,607
2022	-1,481,398	-1,899,881	-15,260	-745,913	-4,093,852	-8,236,304
2023	-1,525,840	-5,306,786	-15,718	-768,290	-4,216,667	-11,833,301
2024	-1,571,615	-5,465,989	-16,189	-791,339	-4,343,167	-12,188,300
2025	-1,618,764	-5,629,969	99,942	4,885,153	-3,018,757	-5,282,396
2026	-1,667,327	-5,798,868	102,940	10,920,463	-3,109,320	447,889
2027	-1,717,347	-5,972,834	106,028	11,248,077	-3,202,600	461,325
2028	-1,768,867	-6,152,019	313,976	11,585,520	-3,298,678	679,932
2029	-1,821,933	-6,336,580	323,395	11,933,085	-3,397,638	700,330
2030	-1,876,591	-6,526,677	333,097	12,291,078	-3,604,554	616,353
2031	-1,932,889	-6,722,478	343,090	12,659,810	-3,712,691	634,843
2032	-1,990,875	-6,924,152	353,383	13,039,605	-3,824,072	653,889
2033	-2,050,602	-7,131,876	363,984	13,430,793	-3,938,794	673,505
2034	-2,112,120	-7,345,833	374,904	13,833,716	-4,056,957	693,710
2035	-2,175,483	-7,566,208	386,151	14,248,728	-4,178,666	714,522
2036	-2,240,748	-7,793,194	397,735	14,676,190	-4,304,026	735,957
2037	-2,307,970	-8,026,990	409,667	15,116,475	-4,433,147	758,036
2038	-2,377,209	-8,267,799	421,958	15,569,970	-4,566,141	780,777
2039	-2,448,526	-8,515,833	434,616	16,037,069	-4,703,126	804,200
2040	-2,521,981	-8,771,308	447,655	16,518,181	-4,844,219	828,327
2041	-2,597,641	-9,034,448	461,084	17,013,726	-4,989,546	853,176
2042	-2,675,570	-9,305,481	474,917	17,524,138	-5,139,232	878,772
2043	-2,755,837	-9,584,646	489,164	18,049,862	-5,293,409	905,135
2044	-2,838,512	-9,872,185	503,839	18,591,358	-5,452,212	932,289
2045	-2,923,668	-10,168,350	518,955	19,149,099	-5,615,778	960,257
Simple Total	**-53,833,921**	**-175,911,205**	**7,584,114**	**296,016,555**	**-108,861,495**	**-35,005,952**
NPV Total	**-35,247,919**	**-111,871,921**	**4,512,730**	**179,630,114**	**-72,741,413**	**-35,718,409**

Table C7. Changes in Maintenance Costs of Transition to Electric CHE by Year at POLA/PLOB

Year	Yard Tractor (Hostler)	RTG Crane	Front End Loader	Top Handler	Forklift	Total
2020	26,008,223	0	360,000	0	7,300,000	33,668,223
2021	26,008,223	2,507,644	360,000	0	7,300,000	36,175,866
2022	26,008,223	2,507,644	360,000	8,190,000	7,600,000	44,665,866
2023	26,008,223	6,800,390	360,000	8,190,000	7,600,000	48,958,613
2024	26,008,223	6,800,390	360,000	8,190,000	7,600,000	48,958,613
2025	26,008,223	6,800,390	360,000	8,190,000	8,900,000	50,258,613
2026	26,008,223	6,800,390	360,000	17,775,000	8,900,000	59,843,613
2027	26,008,223	6,800,390	360,000	17,775,000	8,900,000	59,843,613
2028	-19,499,415	6,800,390	1,035,000	17,775,000	8,900,000	15,010,975
2029	-19,499,415	6,800,390	1,035,000	17,775,000	8,900,000	15,010,975
2030	-19,499,415	6,800,390	1,035,000	17,775,000	-2,050,000	4,060,975
2031	-19,499,415	6,800,390	1,035,000	17,775,000	-2,050,000	4,060,975
2032	-19,499,415	6,800,390	1,035,000	17,775,000	-2,500,000	3,610,975
2033	-19,499,415	6,800,390	1,035,000	17,775,000	-2,500,000	3,610,975
2034	-19,499,415	6,800,390	1,035,000	17,775,000	-2,500,000	3,610,975
2035	-19,499,415	6,800,390	495,000	17,775,000	-4,450,000	1,120,975
2036	-19,499,415	3,038,924	495,000	17,775,000	-4,450,000	-2,640,491
2037	-19,499,415	3,038,924	495,000	5,490,000	-4,450,000	-14,925,491
2038	-19,499,415	-3,400,195	495,000	5,490,000	-4,450,000	-21,364,610
2039	-19,499,415	-3,400,195	495,000	5,490,000	-4,450,000	-21,364,610
2040	-19,499,415	-3,400,195	495,000	5,490,000	-4,450,000	-21,364,610
2041	-19,499,415	-3,400,195	495,000	-8,887,500	-4,450,000	-35,742,110
2042	-19,499,415	-3,400,195	495,000	-8,887,500	-4,450,000	-35,742,110
2043	-19,499,415	-3,400,195	-517,500	-8,887,500	-4,450,000	-36,754,610
2044	-19,499,415	-3,400,195	-517,500	-8,887,500	-4,450,000	-36,754,610
2045	-19,499,415	-3,400,195	-517,500	-8,887,500	-4,450,000	-36,754,610
Simple Total	**-142,923,690**	**72,296,650**	**12,532,500**	**205,807,500**	**21,350,000**	**169,062,960**
NPV Total	**-29,138,362**	**60,446,803**	**9,106,080**	**156,899,741**	**35,084,387**	**232,398,650**

Table C8. Net Cost of CHE Electrification at POLA/POLB by Cost Category by Year (in million 2019$)

Year	Equipment Costs	Battery Replacement Costs	Charger Costs	Electrical Infrastructure	Civil Infrastructure	Fuel Costs	O&M Costs	Total
2020	962.0	0.0	326.0	26.9	110.2	-5.1	33.7	1,453.7
2021	38.6	0.0	0.0	26.9	110.2	-7.1	36.2	204.8
2022	518.1	0.0	53.4	26.9	110.2	-8.2	44.7	745.1
2023	66.1	0.0	0.0	26.9	110.2	-11.8	49.0	240.3
2024	0.0	735.8	0.0	26.9	110.2	-12.2	49.0	909.7
2025	5.2	35.2	9.9	26.9	110.2	-5.3	50.3	232.4
2026	604.9	0.0	59.9	26.9	110.2	0.4	59.8	862.2
2027	0.0	1.4	0.0	26.9	110.2	0.5	59.8	198.9
2028	404.4	18.2	4.2	26.9	110.2	0.7	15.0	579.6
2029	0.0	0.0	0.0	26.9	110.2	0.7	15.0	152.8
2030	2.9	420.9	0.0	0.0	0.0	0.6	4.1	428.5
2031	0.0	0.0	0.0	0.0	0.0	0.6	4.1	4.7
2032	0.1	367.9	0.0	0.0	0.0	0.7	3.6	372.3
2033	0.0	0.0	0.0	0.0	0.0	0.7	3.6	4.3
2034	0.0	485.2	0.0	0.0	0.0	0.7	3.6	489.5
2035	10.5	17.6	0.0	0.0	0.0	0.7	1.1	30.0
2036	398.7	34.2	268.1	0.0	0.0	0.7	-2.6	699.1
2037	207.5	0.7	0.0	0.0	0.0	0.8	-14.9	194.0
2038	66.1	0.0	0.0	0.0	0.0	0.8	-21.4	45.5
2039	0.0	0.0	0.0	0.0	0.0	0.8	-21.4	-20.6
2040	2.9	371.0	27.8	0.0	0.0	0.8	-21.4	381.2
2041	242.8	0.0	0.0	0.0	0.0	0.9	-35.7	207.9
2042	0.1	0.0	1.1	0.0	0.0	0.9	-35.7	-33.6
2043	18.8	9.1	0.0	0.0	0.0	0.9	-36.8	-8.0
2044	360.1	0.0	0.0	0.0	0.0	0.9	-36.8	324.3
2045	0.5	224.9	5.0	0.0	0.0	1.0	-36.8	194.6
Simple Total	**3,910.2**	**2,722.2**	**755.5**	**269.0**	**1,102.2**	**-35.0**	**169.1**	**8,893.1**
Discounted Total	**3,028.6**	**1,885.6**	**605.7**	**229.5**	**940.2**	**-35.7**	**232.4**	**6,886.2**

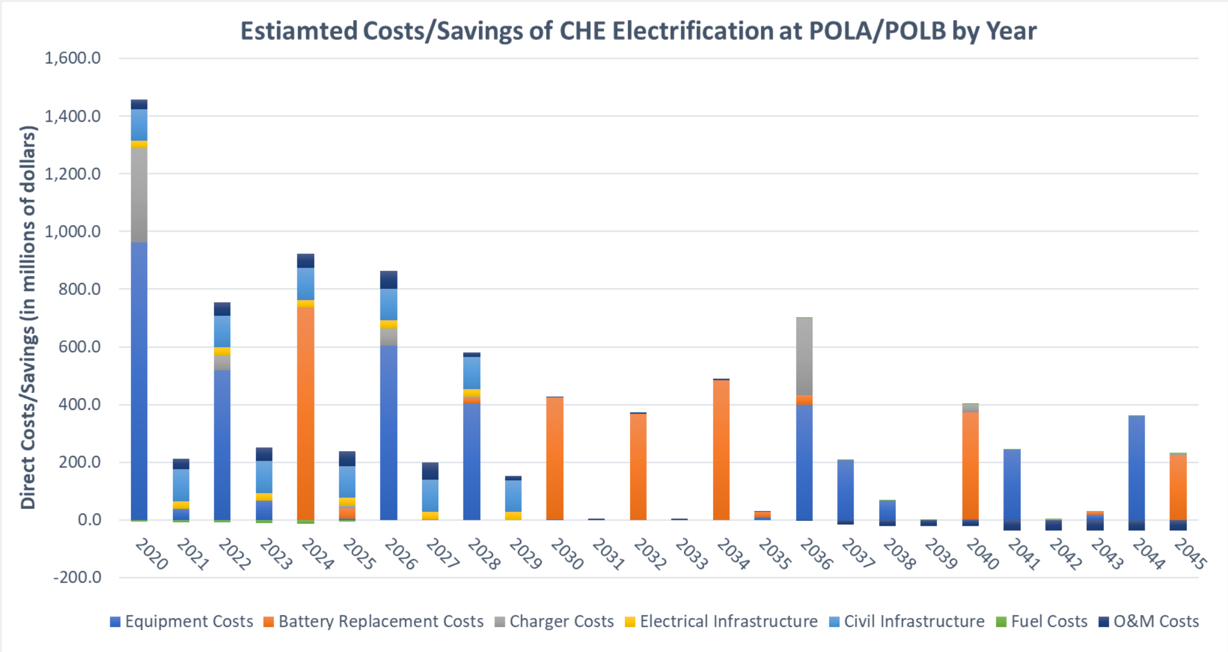

Figure C1. Estimated Costs/Savings of CHE Electrification at POLA/POLB by Year

Appendix D. Description of the REMI PI+ Model

REMI PI+ is a structural economic forecasting and policy analysis model. It integrates input-output, computable general equilibrium, econometric and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis and behavioral responses to wage, price, and other economic factors.

The REMI model consists of thousands of simultaneous equations with a structure that is relatively straightforward. The exact number of equations used varies depending on the extent of industry, demographic, demand, and other detail in the model. The overall structure of the model can be summarized in five major blocks: (1) Output and Demand, (2) Labor and Capital Demand, (3) Population and Labor Supply, (4) Compensation, Prices, and Costs, and (5) Market Shares. The blocks and their key interactions are shown in Figures D1 and D2.

The Output and Demand block includes output, demand, consumption, investment, government spending, import, product access, and export concepts. Output for each industry is determined by industry demand in a given region and its trade with the US market, and international imports and exports. For each industry, demand is determined by the amount of output, consumption, investment, and capital demand on that industry. Consumption depends on real disposable income per capita, relative prices, differential income elasticities and population. Input productivity depends on access to inputs because the larger the choice set of inputs, the more likely that the input with the specific characteristics required for the job will be formed. In the capital stock adjustment process, investment occurs to fill the difference between optimal and actual capital stock for residential, non-residential, and equipment investment. Government spending changes are determined by changes in the population.

The Labor and Capital Demand block includes the determination of labor productivity, labor intensity and the optimal capital stocks. Industry-specific labor productivity depends on the availability of workers with differentiated skills for the occupations used in each industry. The occupational labor supply and commuting costs determine firms' access to a specialized labor force.

Labor intensity is determined by the cost of labor relative to the other factor inputs, capital and fuel. Demand for capital is driven by the optimal capital stock equation for both non-residential capital and equipment. Optimal capital stock for each industry depends on the relative cost of labor and capital, and the employment weighted by capital use for each industry. Employment in private industries is determined by the value added and employment per unit of value added in each industry.

The Population and Labor Supply block includes detailed demographic information about the region. Population data is given for age and gender, with birth and survival rates for each group. The size and labor force participation rate of each group determines the labor supply. These participation rates respond to changes in employment relative to the potential labor force and to changes in the real after tax compensation rate. Migration includes retirement, military, international and economic migration. Economic migration is determined by the relative real after tax compensation rate, relative employment opportunity and consumer access to variety.

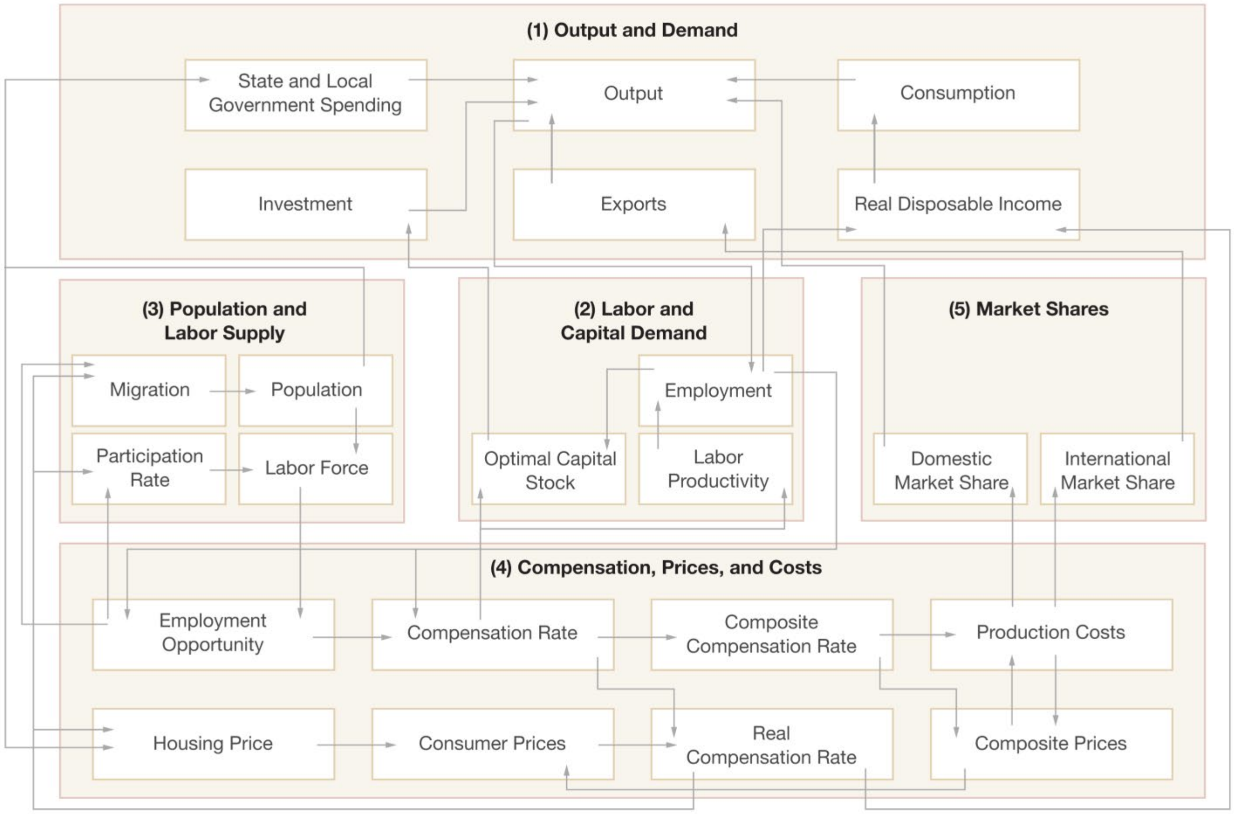

Figure D1. REMI Model Linkages (Excluding Economic Geography Linkages)
Source: REMI (2018).

The Compensation, Prices, and Costs block includes delivered prices, production costs, equipment cost, the consumption deflator, consumer prices, the price of housing, and the wage equation. Economic geography concepts account for the productivity and price effects of access to specialized labor, goods and services.

These prices measure the value of the industry output, taking into account the access to production locations. This access is important due to the specialization of production that takes place within each industry, and because transportation and transaction costs associated with distance are significant. Composite prices for each industry are then calculated based on the production costs of supplying regions, the effective distance to these regions, and the index of access to the variety of output in the industry relative to the access by other uses of the product.

The cost of production for each industry is determined by cost of labor, capital, fuel and intermediate inputs. Labor costs reflect a productivity adjustment to account for access to specialized labor, as well as underlying compensation rates. Capital costs include costs of non-residential structures and equipment, while fuel costs incorporate electricity, natural gas and residual fuels.

The consumption deflator converts industry prices to prices for consumption commodities. For potential migrants, the consumer price is additionally calculated to include housing prices. Housing price changes from their initial level depend on changes in income and population density. Regional employee compensation changes are due to changes in labor demand and supply conditions, and changes in the national compensation rate. Changes in employment opportunities relative to the labor force and occupational demand change determine compensation rates by industry.

The Market Shares equations measure the proportion of local and export markets that are captured by each industry. These depend on relative production costs, the estimated price elasticity of demand, and effective distance between the home region and each of the other regions. The change in share of a specific area in any region depends on changes in its delivered price and the quantity it produces compared with the same factors for competitors in that market. The share of local and external markets then drives the exports from and imports to the home economy.

As shown in Figure D2, the Labor and Capital Demand block includes labor intensity and productivity, as well as demand for labor and capital. Labor force participation rate and migration equations are in the Population and Labor Supply block. The Compensation, Prices, and Costs block includes composite prices, determinants of production costs, the consumption price deflator, housing prices, and the wage equations. The proportion of local, interregional and international markets captured by each region is included in the Market Shares block.

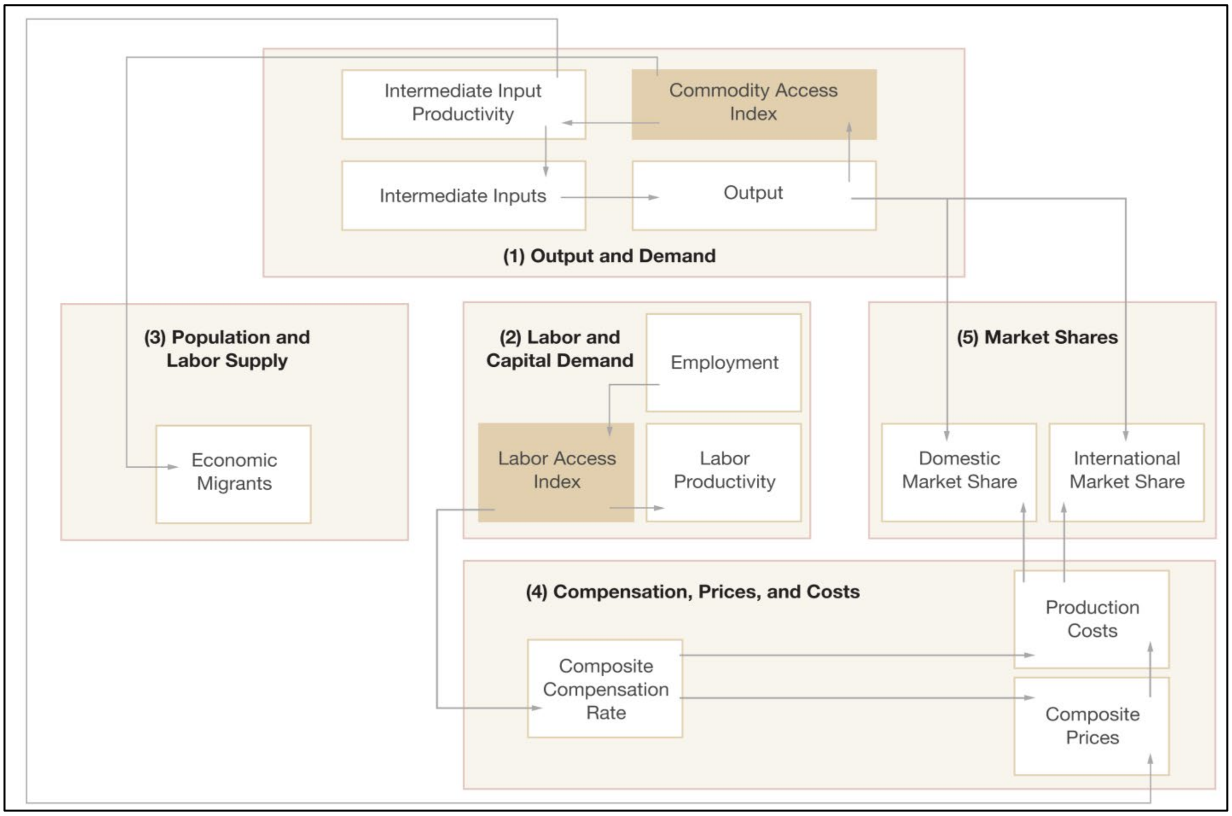

Figure D2. Economic Geography Linkages
Source: REMI (2018).

Appendix E. Additional REMI Simulation Results for the Base Case

Differences from Baseline Level

Variable	Units	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Total Employment	Job-year	-9,280	-3,491	-6,927	-3,848	-8,947	-3,995	-7,363	-3,594	-5,191	-2,668
Gross Domestic Product	B 2018$	-0.77	-0.35	-0.64	-0.39	-0.87	-0.41	-0.69	-0.38	-0.49	-0.28
Output (Sales Revenue)	B 2018$	-1.21	-0.65	-1.08	-0.72	-1.51	-0.77	-1.17	-0.72	-0.87	-0.55
Personal Income	B 2018$	-1.24	-0.23	-0.74	-0.32	-1.01	-0.34	-0.89	-0.34	-0.66	-0.30
Price Index	2012=100	0.034	-0.003	0.013	-0.001	0.018	-0.002	0.016	-0.002	0.010	-0.001

Variable	Units	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Total Employment	Job-year	-5,020	-1,919	-4,133	-1,603	-4,648	-1,794	-5,427	-2,841	-1,930	-1,194
Gross Domestic Product	B 2018$	-0.52	-0.21	-0.43	-0.18	-0.49	-0.20	-0.56	-0.30	-0.22	-0.14
Output (Sales Revenue)	B 2018$	-0.92	-0.43	-0.78	-0.37	-0.87	-0.41	-0.95	-0.57	-0.44	-0.30
Personal Income	B 2018$	-0.63	-0.19	-0.56	-0.18	-0.66	-0.20	-0.80	-0.34	-0.26	-0.18
Price Index	2012=100	0.009	-0.004	0.008	-0.003	0.012	-0.003	0.016	0.000	-0.001	-0.001

Variable	Units	2040	2041	2042	2043	2044	2045	NPV (or Total Person-Year Jobs)
Total Employment	Job-year	-3,259	-2,094	-971	-773	-2,003	-1,858	-96,771
Gross Domestic Product	B 2018$	-0.36	-0.22	-0.11	-0.09	-0.19	-0.21	-7.24
Output (Sales Revenue)	B 2018$	-0.66	-0.42	-0.26	-0.20	-0.36	-0.42	-13.00
Personal Income	B 2018$	-0.54	-0.32	-0.16	-0.16	-0.40	-0.34	-8.78
Price Index	2012=100	0.010	0.003	-0.002	0.000	0.008	0.004	

Percent Change from Baseline Level

Variable	Units	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Total Employment	Job-year	-0.038%	-0.014%	-0.027%	-0.015%	-0.035%	-0.016%	-0.029%	-0.014%	-0.021%	-0.011%
Gross Domestic Product	B 2018$	-0.027%	-0.012%	-0.021%	-0.013%	-0.028%	-0.013%	-0.021%	-0.012%	-0.015%	-0.008%
Output (Sales Revenue)	B 2018$	-0.025%	-0.013%	-0.021%	-0.014%	-0.029%	-0.014%	-0.022%	-0.013%	-0.016%	-0.010%
Personal Income	B 2018$	-0.049%	-0.009%	-0.029%	-0.012%	-0.039%	-0.013%	-0.033%	-0.012%	-0.023%	-0.010%
Price Index	2012=100	0.029%	-0.002%	0.011%	-0.001%	0.015%	-0.002%	0.012%	-0.001%	0.007%	-0.001%

Variable	Units	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Total Employment	Job-year	-0.020%	-0.008%	-0.016%	-0.006%	-0.018%	-0.007%	-0.021%	-0.011%	-0.007%	-0.005%
Gross Domestic Product	B 2018$	-0.015%	-0.006%	-0.012%	-0.005%	-0.014%	-0.005%	-0.015%	-0.008%	-0.006%	-0.004%
Output (Sales Revenue)	B 2018$	-0.016%	-0.007%	-0.013%	-0.006%	-0.015%	-0.007%	-0.015%	-0.009%	-0.007%	-0.005%
Personal Income	B 2018$	-0.022%	-0.006%	-0.018%	-0.006%	-0.021%	-0.006%	-0.024%	-0.010%	-0.007%	-0.005%
Price Index	2012=100	0.006%	-0.003%	0.006%	-0.002%	0.008%	-0.002%	0.010%	0.000%	-0.001%	-0.001%

Variable	Units	2040	2041	2042	2043	2044	2045
Total Employment	Job-year	-0.012%	-0.008%	-0.004%	-0.003%	-0.007%	-0.007%
Gross Domestic Product	B 2018$	-0.009%	-0.005%	-0.003%	-0.002%	-0.004%	-0.005%
Output (Sales Revenue)	B 2018$	-0.010%	-0.006%	-0.004%	-0.003%	-0.005%	-0.005%
Personal Income	B 2018$	-0.015%	-0.009%	-0.004%	-0.004%	-0.010%	-0.008%
Price Index	2012=100	0.006%	0.002%	-0.001%	0.000%	0.004%	0.002%

Appendix F. REMI Simulation Results for Sensitivity Cases

Table F1. Aggregate Macroeconomic Impacts of Sensitivity Case 1 (S1) – No Incentives

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,714	-5,278	-2,917	-3,146	-1,716	-105,565
GSP	B 2018$	-0.64	-0.53	-0.31	-0.34	-0.19	-7.96
Output	B 2018$	-1.10	-0.94	-0.59	-0.63	-0.37	-14.30
Personal Income	B 2018$	-0.71	-0.62	-0.37	-0.45	-0.30	-9.53
Price Index	2012=100	0.011	0.007	0.002	0.005	0.003	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.027%	-0.021%	-0.012%	-0.012%	-0.006%	
GSP	B 2018$	-0.021%	-0.016%	-0.009%	-0.009%	-0.004%	
Output	B 2018$	-0.022%	-0.017%	-0.010%	-0.010%	-0.005%	
Personal Income	B 2018$	-0.028%	-0.022%	-0.012%	-0.013%	-0.008%	
Price Index	2012=100	0.009%	0.005%	0.001%	0.003%	0.002%	

Table F2. Aggregate Macroeconomic Impacts of Sensitivity Case 2 (S2) – Government Subsidy Offset by Reduced Government Spending in Other Similar Areas

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,403	-4,934	-2,800	-2,964	-1,569	-99,757
GSP	B 2018$	-0.61	-0.49	-0.30	-0.32	-0.17	-7.55
Output	B 2018$	-1.05	-0.88	-0.57	-0.60	-0.34	-13.55
Personal Income	B 2018$	-0.67	-0.58	-0.36	-0.43	-0.28	-8.97
Price Index	2012=100	0.010	0.006	0.002	0.005	0.003	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.025%	-0.020%	-0.011%	-0.011%	-0.006%	
GSP	B 2018$	-0.021%	-0.015%	-0.008%	-0.008%	-0.004%	
Output	B 2018$	-0.021%	-0.016%	-0.009%	-0.009%	-0.005%	
Personal Income	B 2018$	-0.026%	-0.021%	-0.012%	-0.013%	-0.007%	
Price Index	2012=100	0.008%	0.004%	0.001%	0.003%	0.001%	

Table F3. Aggregate Macroeconomic Impacts of Sensitivity Case 2 (S2) – Government Subsidy Offset by Increased Gas Tax

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,656	-5,051	-2,806	-3,065	-1,640	-102,746
GSP	B 2018$	-0.64	-0.51	-0.30	-0.34	-0.18	-7.87
Output	B 2018$	-1.11	-0.92	-0.57	-0.62	-0.36	-14.14
Personal Income	B 2018$	-0.77	-0.66	-0.38	-0.48	-0.33	-10.20
Price Index	2012=100	0.014	0.009	0.003	0.006	0.004	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.027%	-0.020%	-0.011%	-0.012%	-0.006%	
GSP	B 2018$	-0.021%	-0.015%	-0.009%	-0.009%	-0.004%	
Output	B 2018$	-0.022%	-0.017%	-0.010%	-0.010%	-0.005%	
Personal Income	B 2018$	-0.030%	-0.023%	-0.012%	-0.014%	-0.008%	
Price Index	2012=100	0.011%	0.007%	0.002%	0.004%	0.003%	

Table F4. Aggregate Macroeconomic Impacts of Sensitivity Case 4 (S4) – Partial Cost Pass-through by Ports

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,170	-4,334	-2,201	-2,392	-985	-86,583
GSP	B 2018$	-0.58	-0.42	-0.23	-0.24	-0.09	-6.41
Output	B 2018$	-1.02	-0.77	-0.44	-0.47	-0.20	-11.75
Personal Income	B 2018$	-0.58	-0.46	-0.26	-0.31	-0.17	-7.15
Price Index	2012=100	0.006	0.003	0.000	0.002	0.001	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.025%	-0.017%	-0.009%	-0.009%	-0.004%	
GSP	B 2018$	-0.019%	-0.013%	-0.006%	-0.006%	-0.002%	
Output	B 2018$	-0.020%	-0.014%	-0.008%	-0.007%	-0.003%	
Personal Income	B 2018$	-0.023%	-0.016%	-0.009%	-0.009%	-0.004%	
Price Index	2012=100	0.005%	0.002%	0.000%	0.001%	0.000%	

Table F5. Aggregate Macroeconomic Impacts of Lower-Bound Cost Sensitivity Case

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-5,177	-3,009	-1,558	-1,858	-914	-67,758
GSP	B 2018$	-0.49	-0.30	-0.17	-0.20	-0.10	-5.19
Output	B 2018$	-0.85	-0.55	-0.34	-0.38	-0.21	-9.41
Personal Income	B 2018$	-0.55	-0.37	-0.20	-0.28	-0.17	-6.29
Price Index	2012=100	0.008	0.004	0.000	0.004	0.002	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.021%	-0.012%	-0.006%	-0.007%	-0.004%	
GSP	B 2018$	-0.016%	-0.009%	-0.005%	-0.005%	-0.002%	
Output	B 2018$	-0.017%	-0.010%	-0.006%	-0.006%	-0.003%	
Personal Income	B 2018$	-0.021%	-0.013%	-0.007%	-0.008%	-0.005%	
Price Index	2012=100	0.007%	0.003%	0.000%	0.002%	0.001%	

Table F6. Aggregate Macroeconomic Impacts of Upper-Bound Cost Sensitivity Case

Variable	Units	2020-2025	2026-2030	2031-2035	2036-2040	2041-2045	NPV (or Total Job-Year Jobs)
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	-6,844	-6,890	-5,192	-4,064	-2,292	-133,254
GSP	B 2018$	-0.64	-0.67	-0.56	-0.44	-0.25	-9.76
Output	B 2018$	-1.10	-1.19	-1.02	-0.81	-0.49	-17.41
Personal Income	B 2018$	-0.73	-0.81	-0.63	-0.59	-0.40	-11.89
Price Index	2012=100	0.012	0.010	0.004	0.006	0.004	
Percent Change from Baseline Level							
Total Employment	Job-year	-0.027%	-0.027%	-0.020%	-0.016%	-0.008%	
GSP	B 2018$	-0.021%	-0.020%	-0.016%	-0.011%	-0.006%	
Output	B 2018$	-0.021%	-0.022%	-0.017%	-0.013%	-0.007%	
Personal Income	B 2018$	-0.029%	-0.029%	-0.021%	-0.017%	-0.011%	
Price Index	2012=100	0.010%	0.008%	0.003%	0.003%	0.002%	