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TECHNICAL MEMORANDUM

To:	**John McLaurin, Pacific Merchant Shipping Association**
From:	**Kerry Simpson, PE**
Date:	**June, 2021**
Subject:	**Electrification of California Ports**
M&N Job No.:	**202025**

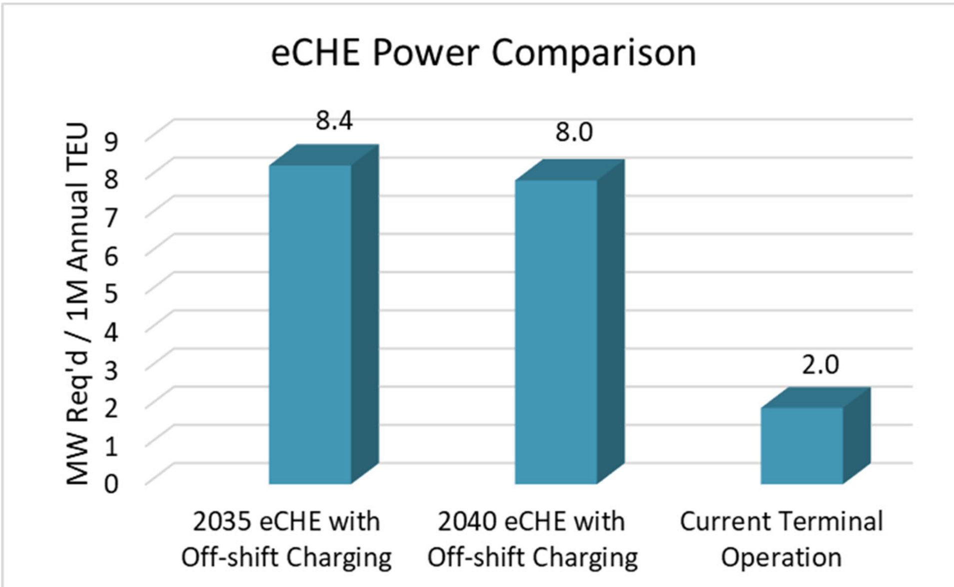
Executive Summary

This technical memorandum is provided to offer information related to select California ports' current and future impact on the State's energy grid. The study is limited to container and roll on/roll off (RoRo) marine terminals at the following California public ports: San Diego, Long Beach, Los Angeles, Hueneme, San Francisco, Oakland, and Richmond. The study does not address cruise, liquid and dry bulk, and break-bulk terminal electrification. The information provided within this technical memorandum is based on data collected from regional port partners, publicly available research, and Moffatt & Nichol (M&N) experience in the maritime sector.

Several challenges await California ports, terminals, and power suppliers in converting to all electric powered container and RoRo facilities, such as, but not limited to:

- Forecasted Power Demand: The marine cargo terminals are currently not fully dependent on regional power grid capacity. The combination of increased cargo demand and conversion to zero emissions cargo handling equipment (CHE) will likely result in the need for additional CHE, increase in electrical power required for CHE, and greater capacity of regional power supply.
- Equipment Mode of Operation: In the San Pedro Bay and Oakland port areas there are approximately 3,000 pieces of heavy-duty CHE; the majority still require conversion to be zero emissions capable. The most common container handling mode of operation in California uses the combination of rubber-tired gantry cranes (RTG), front end loaders (FEL – also known as a top pick), and yard tractors (UTR). CHE conversion status to electrically powered equipment is summarized as follows:
  - RTG is being tested via direct connection to the electrical grid.
  - Battery powered FEL is currently undergoing testing for use in container handling. Importantly, in the study regions, it is estimated that 75% of all container handling moves are performed by FEL equipment. Thus, the most widely (and cost efficient) utilized CHE is yet to be proven as a useable zero emissions CHE.
  - Battery powered yard tractors and charging equipment are being tested but not fully operational.
- Terminal Hours of Operation: The terminal principal contract work shifts (8 am-5 pm & 6 pm-3 am) at West Coast port operations overlap with both summer (10 am-8 pm) and winter (7 am-11 am & 5 pm-9 pm) peak grid demand hours. Thus, conversion to electric and battery-powered CHE will increase the burden on the electrical power grid during the peak hours.
- Truck Fleet: The port truck fleet discussed herein consists of a fleet of privately owned, over-the-road, diesel-fueled, Class 8 trucks that deliver to and from the container terminals. There are currently about 19,000 registered drayage trucks in the Los Angeles and Long Beach region, although these trucks are not dedicated to port drayage services and provide other Class 8 truck work in the region. Of the Class 8 trucks servicing the ports of Los Angeles and Long Beach, none are battery-powered, though there are several demonstration units in operation. Battery powered Class 8 trucks will require charging capability that is not currently available.

Future power requirements were developed in reference to year 2035 and 2040 based on study region forecasts, anticipated terminal mode of operation, estimated equipment use, and energy required to power equipment. Note that the potential for charging UTR on-shift or off-shift creates a range of power demand for the given categories. Electrification of all CHE will increase CHE on-terminal power demand from the current level of about 2 MW per 1M annual TEU at most terminals to about 8.4 and 8.0 MW per 1M annual TEU in 2035 and 2040, respectively, see below. Even though throughput increases from 2035 to 2040, eCHE power requirements decrease from 2035 to 2040 due to additional throughput in 2040 being attributed to high density terminal operational mode (see Figure 2 and Figure 3) that has a lower power requirement.



The total estimated power requirements also include anticipated terminal buildings, area lighting, reefer power, vessel shore power, and truck fleet power demands. Power requirements in 2035 and 2040 for the study regions are presented below. Note that the potential for charging UTR on-shift or off-shift creates a range of power demand for the given categories.

Study Regions	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
	Buildings & Area Lighting	51.1	51.1	51.1	51.1
	eCHE	169.4	230.9	203.7	244.0
	Reefer Power	89.0	89.0	98.5	98.5
	Shore Power*	73.9	73.9	78.7	78.7
	Drayage Trucking	125.6	125.6	137.0	137.0
	Totals	**509.1**	**570.6**	**569.0**	**609.4**

To put this power requirement into some perspective.

- 1 MW can power between 400 and 900 U.S. households. Using an average of 650 households per MW, the 2040 study region power demand of approximately 600 MW could power about 390,000 households, or a U.S. population of about 1.0 million.
- Total power demand from the port regions in 2035 and 2040 would require 50% and 53%, respectively, of one reactor at the Diablo Canyon Nuclear Power Generating Station, which is scheduled for shut down by 2025,

1.0 Introduction

Purpose

This technical memorandum is provided to offer information related to select California ports' current and future impact on the State's power grid. Consideration of power requirements includes container and roll on/roll off (RoRo) handling terminals and the highway trucking fleet required to support these facilities. The information provided within this technical memorandum is based on data collected from regional port partners, publicly available research, and M&N experience in the maritime sector.

Background

As part of emission reduction efforts, California is embarked on an effort to electrify transportation, including port operations. This trend is spurred by California Air Resource Board (CARB) rulemaking, ports of Los Angeles and Long Beach's Clean Air Action Plan (CAAP) program that includes 2030 requirements for zero emission container handling equipment (ZE CHE) operating in their terminals, and California Governor Newsom's executive order banning the sale of diesel and gasoline powered equipment starting in 2035. The result will be state-wide impacts for existing marine terminal operations and may lead to California requiring zero emission marine terminals that are electrical grid dependent.

There is concern associated with the potentially significant increased load demand on the California electrical grid, compounded by similar electrification of related transportation and manufacturing industries such as the trucks providing drayage services to California's ports.

In 2015, Moffatt & Nichol (M&N) prepared for the Pacific Merchant Shipping Association (PMSA) a "Sustainable Freight Strategy Impact Study" identifying, among other things, estimates of zero and near zero emission (ZE/NZE) mandate impacts to container terminals in Oakland, Los Angeles, and Long Beach. That study reviewed availability of zero emission marine terminal equipment, technology challenges for implementation, and capital and operating expense increases associated with the ZE/NZE conversions of marine container terminals.

After the 2015 study was released, there was considerable debate about the billions of dollars estimated for the conversion of equipment and infrastructure since, at that time, a very limited amount of terminal electrification of diesel-powered port equipment had occurred. Since 2015, a handful of conversion projects have been completed, including the near full-scale electrification of two port terminal facilities. Additionally, smaller scale demonstration projects have commenced where certain container handling equipment (CHE), including yard tractors and front-end loaders (FEL) have been converted to battery power, and RTGs that have been attached directly to power and tested at various marine terminals. These demonstration projects are ongoing, and data is beginning to emerge to inform future planning, including power requirements and energy use of electrified container handling equipment (eCHE).

In order to inform upcoming public policy decisions and future planning, PMSA retained M&N to evaluate the current landscape of eCHE to quantify power loads required at select California marine terminals to implement state-wide port terminal electrification. The findings are documented in this technical memorandum.

In general, the study efforts are limited to electrified equipment technology, power needs, and challenges within the ports and terminal boundaries that will be of interest to PMSA members, the carriers, terminal operators at select marine terminals, energy providers, supply chain partners, and public policy officials. The study is limited to container and RoRo marine terminals at the following California public ports: San Diego, Long Beach, Los Angeles, Hueneme, San Francisco, Oakland, and Richmond. The study does not address cruise, liquid and dry bulk, and break-bulk terminal electrification.

In addition to eCHE power requirements, the study will also consider the power requirements for shore-to-ship power at the container and RoRo berths, and power requirements for trucks that provide drayage services to the ports.

Glossary of Abbreviations

The abbreviations used in this technical memorandum are define in Table 1.

Table 1: Glossary of Abbreviations

Abbreviation	Term
AGV	Automated Guided Vehicle
ASC	Automated Stacking Crane
CAAP	Clean Air Action Plan
CAGR	Compound Annual Growth Rate
CARB	California Air Resources Board
CHE	Container Handling Equipment
CY	Container Yard
DC	Direct Current
eCHE	Electrified Container Handling Equipment
EV	Electric Vehicle
FEL	Front End Loader (Top or Side Pick)
IY	Intermodal (Rail) Yard
kW	Kilowatt
kWh	Kilowatt Hour
LALB	Los Angeles/Long Beach
LNG	Liquefied Natural Gas
M&N	Moffatt & Nichol
MHC	Mobile Harbor Crane
MHDET	Medium and Heavy-Duty Electric Trucks
Mvph	Moves Per Hour
MW	Megawatt
NCMT	National City Marine Terminal
OTR	Over the Road Drayage Truck
PMSA	Pacific Merchant Shipping Association
RMC	Rail-Mounted Cranes
RMG	Rail-Mounted Gantry Crane
RoRo	Roll On/Roll Off
RTG	Rubber-Tired Gantry Crane
RTG IM	RTG Serving Import Containers
RTG EX	RTG Serving Export Containers
STRADCY	Straddle Carrier that Serves CY
STRADSH	Strad Shuttle Carrier
STS	Ship-to-Shore
STS Dual	Dual Trolley Ship-to-Shore Crane
STS Single	Single Trolley Ship-to-Shore Crane
TEU	Twenty-Foot Equivalent Units

Abbreviation	Term
UTR / YT	Yard Tractor
UTRC	UTR that Remains Coupled to Chassis during Operation
UTRDC	UTR that is Decoupled from Chassis during Operation
ZE	Zero Emissions
ZE/NZE	Zero and Near Zero Emissions

Study Regions

The research and analysis documented in this technical memorandum is focused primarily on the major southern and northern California regions of international container and RoRo cargo handling, shown in Table 2.

While each port area and each cargo handling facility within a particular port area has their own unique energy needs, the intent of this effort is to identify conceptually the regional requirements for energy in the maritime sector.

Table 2: Study Regions

	Southern California	Northern California
Container Cargo	Port of Los Angeles	Port of Oakland
	Port of Long Beach	
	Port of San Diego	
	Port of Hueneme	
RoRo Cargo	Port of San Diego	Port of San Francisco
	Port of Hueneme	Port of Richmond

Study Milestones

The study primarily focused on power requirements for the milestone years of 2035 and 2040. The year 2035 is of interest as this is the culmination year of regulation to electrify transportation, including port operations in California. The year 2040 is of interest as this is the year the three major California ports will reach their container terminal throughput capacity based on the anticipated modes of container terminal operations on existing terminal boundaries in the three ports.

Terminal Equipment Focus

Container and RoRo operations in the study regions are anticipated to use a variety of eCHE and increase the use of shore power. Relative to electrical grid use, such equipment is either electrified, i.e., continuously connected to the grid, or battery powered requiring recharging from the grid. The terminal operational equipment included in this study falls into two primary categories: 1) ocean going cargo vessels and 2) landside equipment that moves cargo within the marine terminals. This technical memorandum will also consider the power required for trucks fleets to dray cargo to and from the ports. Proposed regulations spurring the conversion of highway truck fleets from diesel to battery powered will require a portion of the power grid capacity.

Vessels

In determining terminal power requirements, consideration is given to the shore-to-ship power used while vessels are at berth. Power consumed by vessels during this state is provided through at-berth electrical connections to a terminal's power source. Vessel power consumption varies based on vessel size and operational requirements of the vessel, such as refrigeration and/or ventilation, as shown in Table 3.

Table 3: Typical Vessel Power Requirements at Berth[1]

	Ship Capacity (TEU)	Power Requirement (kW)
Container Vessels	< 3,000	700
	3,001 – 5,000	1,000
	5,001 – 8,000	1,200
	8,001 – 10,000	1,400
	10,001 – 14,000	2,000
	> 14,000	2,500
RoRo Vessels	**Ship Capacity (Units)**	**Power Requirement (kW)**
	< 200	400
	201 – 750	800
	751 – 1,500	1,200
	1,501 – 1,600	1,500
	1,601 – 3,500	1,700
	3,501 – 6,000	2,000

Container Handling Equipment

The marine terminals considered in this study are limited to container and RoRo cargo handling terminals. The container terminals use a variety of CHE. Such equipment may currently be used in conjunction with a variety of fuel/power sources including direct connection to electrical grid, battery, diesel, diesel hybrid, propane, Liquefied Natural Gas (LNG), and gasoline. While some equipment type operational uses may be similar, power requirements may vary depending on technologies used. Table 4 provides fuel types and power variations for various heavy duty CHE types.

Table 4: Fuel Types and Power Variations for CHE Types

CHE Type	Demonstrated Fuel/Power Source	Power Variation Opportunity
STS Cranes	Direct electrical connection	
MHC	Diesel or direct electrical connection	
RTG Cranes	Diesel, hybrid	Direct electrical grid connection testing underway on the west coast
Straddle Carriers	Diesel, hybrid	Battery powered testing underway
Yard Tractors / UTR	Diesel	Battery powered testing underway
RMG	Direct electrical connection	
ASC	Direct electrical connection	
AGV	Battery or diesel powered	
FEL	Diesel	Battery powered testing underway

[1] 2019 Update to Inventory for Ocean-Going Vessels at Berth, CARB. At-Berth Emissions for Toyota Vessels in CY 2012 and Evaluation of Emissions Reduction Technologies, Starcrest Consulting Group, LLC. Information Portal, Technology Groups, Shore Power, Global Maritime Energy Efficiency Partnerships. Terminal Operator Interviews, M&N.

For the purposes of this study, since cargo rolls off and on to vessels under its own power, the only electrification consideration for RoRo terminals is shore power required for vessels while at berth. In addition, this study only considers heavy duty CHE operating on container terminals, as it represents the significant portion of the electrical power requirement for eCHE, while light and medium duty terminal equipment could be recharged during times of lower power requirements.

Regional Trucking

In addition to on-terminal power requirements of a marine terminal that are estimated based on vessel and equipment usage, there is a significant amount of power that will be required to service the California cargo carrying trucking fleet servicing the ports. The November 2020 study "Electrifying Freight: Pathways to Accelerating the Transition" provided by the Electrification Coalition's Freight Electrification Program, provides the following related information:

- Three out of four commercial trucks on the road today, and 98% of the largest Class 8 trucks, are powered by diesel.
- Charging a Class 8 truck with a 550-kWh battery and a driving efficiency of 0.45 miles per kWh from 20% to 80% would take 2.5-3.5 hours based on a 120kW direct current (DC) fast charge connection.
- Medium and heavy-duty electric trucks (MHDETs), especially Class 8 vehicles, are expected to have very high electrical demand requirements. The average light-duty electric vehicle (EV) consumes between 0.25 and 0.35 kWh per mile, while the average Class 8 electric truck at full load consumes between 2 and 2.5 kWh per mile, more than approximately eight times the energy consumption per mile.
- Class 8 electric trucks that travel 150 miles per day will likely need to charge around 300 kWh daily (based on 2 kWh per mile estimate at full load).
- Fleet power demand example: "a large fleet depot using 150 kW DC fast chargers to simultaneously charge 65 Class 8 electric trucks could demand over 9 MW of power."

2.0 Challenges

Forecasted Demand

It is important to understand the future power demand required since the marine cargo terminals are not currently fully electrified and dependent on regional power grid capacity. This study documents anticipated cargo demand to 2050. Table 5 depicts the assumed forecasted containerized and RoRo cargo demand growth, expressed in compound annual growth rate (CAGR), for the studied ports in California. The CAGR is based on historic forecasts for most studied ports. The CAGR containerized cargo for the southern California ports has been reduced to more conservative rates to reflect the following:

- Total container trade in the U.S. reached 47.9 million TEU in 2020, reaching record levels despite the COVID-led economic downturn. Growth was led by the sharp increase in demand for consumer and housing related products, driven by available income that otherwise had been spent on services.
    - Import growth is a continuation of a long-term trend which has seen import volumes leading U.S. trade. Over the past decade through 2020, import volumes have grown by an average 3.7% annually compared to a -1.1% for exports, through 2019 the average rates would have been 3.8% and -0.3% respectively. The disparity in growth rates has led to a surge in empty containers, which have grown by 6.0% annually.
- Consumer spending remains the leading contributor to overall economic activity. With much of the global manufacturing of these goods remaining in low-cost labor markets, the U.S. continues to be reliant on imports to meet demand.
- Export volumes remain challenged due to several factors, including slowing economic trends in Asia, Europe, and Latin America; a strong U.S. dollar; and China's reduction in waste import demand.
- The U.S. east and gulf coasts have gained share of overall trade at the expense of the west coast (in aggregate).
- Singular events such as the labor disruptions of 2014/2015, the opening of the expanded Panama Canal in 2016, and raising of the Bayonne Bridge in 2017 accelerated slower underlying shift trends to the U.S. east.
    - These slower trends reflect shifts in global production sources to Southeast and South Asia, increased use of the Suez Canal, demographics that favor the U.S. southeast, and broad capital improvement projects at many of the largest east and gulf coast gateways.
    - With these trends intact, continued shift to the east and gulf is expected.
- Total growth on the U.S. west coast is projected to increase by an average 2.4% annually over the coming decade (2021 to 2030), reflecting a return to trend growth in the post-pandemic world. This is, however, stronger than the previous 10-year period but remains below the 3.2% estimate for the U.S. as a whole. The forecast reflects the assumption that many of the slower, underlying trends which have supported a shift away from west coast ports remain intact, but that the singular events resulting in more incremental shifts will not be repeated (i.e., Panama Canal expansion, raising of Bayonne Bridge).
    - A risk from accelerated COVID-led relocation to the U.S. southeast, however, could lead to higher-than-expected growth trends in the U.S. southeast/gulf (at the expense of the west) in the near term.
- Los Angeles/Long Beach (LALB) is projected to grow by an average 2.4% annually and remain the dominant gateway for import cargo, retaining roughly 79% of the coast's import volume. The imbalance in trade continues to lead to a high volume of empty containers.

Table 5: Container and RoRo Anticipated CAGR for Port Areas

	Port Area	Cargo Forecast (CAGR)	Source
Containers	Port of Los Angeles	2.4%	San Pedro Bay Long-Term Unconstrained Cargo Forecast dated July 12, 2016 by Mercator International and Oxford Economics, and modified with M&N analysis[2]
	Port of Long Beach	2.4%	San Pedro Bay Long-Term Unconstrained Cargo Forecast dated July 12, 2016 by Mercator International and Oxford Economics, and modified with M&N analysis
	Port of San Diego	2.0%	Tenth Avenue Marine Terminal Redevelopment Plan 2015 and M&N analysis
	Port of Hueneme	2.0%	M&N analysis
	Port of Oakland	2.2%	2019-2050 Bay Area Seaport Forecast Revised Draft Final dated April 30, 2020 by The Tioga Group
RoRo	Port of San Diego	2.0%	National City Marine Terminal (NCMT) Optimization Study Final Report dated September 4, 2015 by Vickerman & Associates
	Port of Hueneme	2.8%	Comprehensive Annual Financial Report 2019 (2%-3%)
	Port of San Francisco	2.7%	2019-2050 Bay Area Seaport Forecast Revised Draft Final dated April 30, 2020 by The Tioga Group
	Port of Richmond	0.0%	Port RoRo Operations 2021
	San Pedro Bay	2.8%	San Pedro Bay Long-Term Unconstrained Cargo Forecast dated July 12, 2016 by Mercator International and Oxford Economics

The combination of increased cargo demand and conversion to eCHE will likely result in:

- Need for additional CHE.
- Increase in electrical power required for eCHE.
- Greater capacity of regional power supply.

Mode of Operation

Container handling terminals typically utilize a particular equipment mode of operation. In the study regions, container operations involve:

- Ship-to-shore (STS) cranes for loading and off-loading vessel containerized cargo.
    - Rail-mounted STS gantry cranes for loading and off-loading vessel containerized cargo are used by the vast majority of container terminals.
    - Mobile harbor cranes are used by a few terminals for loading and off-loading vessel containerized cargo (notably Port of Hueneme and Port of San Diego).
- Horizontal transportation for moving containers between the berth and container storage yard and/or intermodal rail yard (IY).
    - UTR with "bomb-cart" trailers are the primary mode of transportation to move containers between the berth and container storage yard and/or intermodal rail yard.
    - Some terminals use straddle shuttle carriers (STRADSH) or automated guided vehicles (AGVs).

[2] The San Pedro Bay Long-Term Unconstrained Cargo Forecast published a 4.8% CAGR. Subsequent analysis, by M&N, which included the recent economic downturn, modified the CAGR to 2.4%.

- Container storage and retrieval equipment (includes gate and empty container handling services).
    - A combination of RTG cranes and FEL – top pick/side pick is the most common method of storing and retrieving containers within the container storage yard, gate, and empty container service areas.
    - Some terminals use STRADCY or automated stacking cranes (ASCs) for storing and retrieving containers within the container storage yard, gate, and empty container service areas.
- IY container handling equipment.
    - FEL is currently the most common CHE used to load and unload rail cars.
    - Rail-mounted cranes (RMC).
    - RTGs.

The most common container handling mode of operation in the study regions uses a combination of RTG, FEL, and yard tractor. Additionally, it is estimated that 75% of all container handling moves are performed by FEL equipment. Currently, of the three most common CHE, only the RTG can be electrified via direct connection to the electrical grid but its electrification causes concerns regarding productivity limitations. Yard tractors and FELs would require battery power for electrification.

- Battery powered yard tractors and charging equipment is being tested, but is yet to be proved to be able to replace the diesel yard tractor at a 1 for 1 ratio due to limited operating durations and available recharge durations.
- Battery powered FEL is currently undergoing testing for use in container handling. Until the battery powered FEL is fully proven, consideration should be given to the understanding that one of the most widely (and cost efficient) utilized CHE (the FEL) is yet to be proven as a useable eCHE. The battery powered FEL is not anticipated to be able to replace the diesel FEL at a 1 for 1 ratio due to limited operating durations and available recharge durations.

To determine power needs under an all-ZE scenario, it is assumed that all CHE is either electrified via direct connection to the grid or battery powered. This study anticipates four typical terminal operating modes indicated in Table 6. These operating modes have been successfully implemented and are proven on marine terminals on the west coast.

Table 6: Terminal Operating Modes - Equipment and Annual Throughput

Typical Terminal Operational Modes	Equipment Use (CY & IY)	Assumed Annual Throughput (TEU/Gross Acre)
1. High density container storage with electrified ASC	ASC + AGV/STRADSH in CY RMG in IY	10,000
2. Medium density container storage with electrified RTGs and battery-powered FELs	RTG + FEL + YT in CY FEL in IY	7,000
3. Medium density container storage with battery-powered STRADCY	Strad in CY RMG in IY	5,500
4. Low density wheeled container storage with battery-powered YT	YT + FEL for CY Empty Stacks FEL in IY	3,500

Existing Power Use

In the San Pedro Bay and Oakland study regions there are nearly 3,000 pieces of heavy-duty CHE that move containers on a regular basis. Most of the CHE still require conversion to be ZE capable. The CHE quantities provided in Table 7 are approximations from data gathering efforts for the San Pedro Bay and Oakland study regions.

Table 7: CHE Quantities and Power Configuration Status

CHE	Approximate Quantity (San Pedro Bay & Oakland)	Power Configuration Status
STS Cranes	200	Currently electrified
RTG	200	Predominantly diesel or diesel hybrid (testing for grid connection)
FEL	500	Diesel powered (testing for battery power)
STRADCY	30	Diesel powered (testing for battery power)
RMG	25	Currently electrified
UTR/YT	2,000	Diesel powered (testing for battery power)

Terminal Operations

The typical first work shift at west coast ports is 8 hours, typically from 8 am to 5 pm, with a one-hour lunch break, per a west coast collective bargaining agreement. Most terminals require some second shift work for vessels, gate, and rail service. The second shift is typically 8 hours, from 6 pm to 3 am with a one-hour lunch break. The third shift is typically 5 hours, from 3 am to 8 am, but is seldom used for terminal work other than rail shunting and possibly for equipment maintenance.

Electrical grid peak demand hours when overall demand for electrical power is highest are typically:

- Summer, 10:00 am to 8:00 pm during weekdays
- Winter, 7:00 am to 11:00 am and 5:00 pm to 9:00 pm

Figure 1 illustrates the time relationship between terminal operating hours and peak grid power demand periods. Terminal operations overlap with both summer and winter peak grid demand hours. Conversion to electric and battery-powered CHE will increase the burden on the electrical power grid during the peak hours. In addition, the most opportune recharge periods for battery powered equipment are during shift breaks and the third shift when not used.

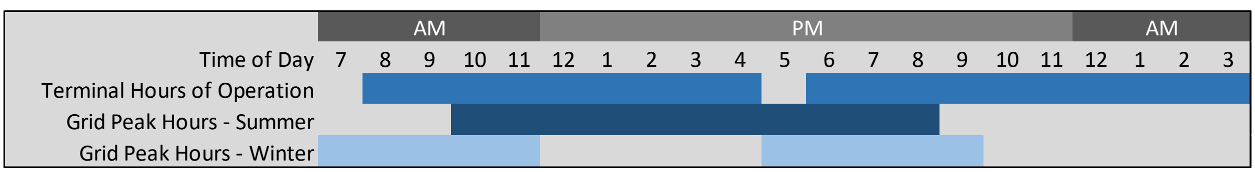


Figure 1: Terminal Operating Hours Compared to Peak Electrical Grid Hours

Equipment Technology

The following summarizes the state of conversion to battery powered and direct electrical connection for CHE considered as part of this study and their related challenges.

STS Cranes

STS cranes in the study regions are all powered through direct connection to the electrical grid. Advancements in technology such as dual trolley STS cranes (STS Dual), typically used in high-density terminal systems, require more power than the more common single trolley STS crane (STS Single).

RTG

RTG cranes in the study region are predominantly diesel powered or diesel-hybrid. Testing is currently underway for RTGs with direct connection to the electrical grid. RTGs with direct connection to the grid tend to have lower operational productivities than diesel powered or diesel-hybrid.

FEL

FEL type equipment is used predominantly in most container terminals. Testing is currently underway for battery powered FEL type equipment. Currently a battery powered FEL fleet has not replaced any of the terminal's diesel powered FEL fleet.

RMG

RMG cranes in the study regions are all powered through direct connection to the electrical grid.

Yard Tractors

Like FEL equipment for container stacking, the UTR is one of the most common CHE used in terminals for the horizontal transport of containers. Most UTRs are diesel powered. Testing is currently underway for battery-powered UTRs but they are not yet used in full operational conditions. Currently a battery powered UTR fleet has not replaced any of the terminal's diesel-powered UTR fleet.

Regional Truck Fleet

The regional truck fleet discussed herein consists of the fleet of privately owned, over-the-road, diesel-fueled, Class 8 trucks that provide services to dray containerized cargo to and from the container terminals. Some battery powered testing is underway, but only by a few manufacturers. There are currently about 19,000 registered drayage trucks in the LALB region, although these trucks are not dedicated to port drayage services and provide other Class 8 truck work in the region. None of the port registered drayage trucks are currently battery-powered commercialized Class 8 type vehicles, though there are several demonstration units in operation. Conversion to battery power for Class 8 trucks providing drayage services will require charging capability that is not currently available and would be connected to the power grid.

3.0 Future Power Requirements

Marine Terminals

The containerized and RoRo cargo handling terminals are primarily made up of five major energy using components that require electrical power via either direct connection to the power grid or batteries that are recharged from the grid.

1. Shore Power – Vessels at berth will have a direct connection to the power grid. While most study region container terminals are shore power equipped, most RoRo facilities are not. California Air Resources Board has developed regulations that require full compliance for container vessels in 2023 and RoRo vessels in 2025. Thus, additional power grid capacity will be required for shore power connection of the remaining container vessels that do not currently connect to shore power and all RoRo vessels in the study regions.
2. STS Cranes – All STS gantry cranes in the study regions have a direct connection to the power grid.
3. CHE – Electric powered ASC and RMG type equipment in the study regions have a direct connection to the power grid. RTGs are predominantly diesel powered with a small number currently undergoing testing with direct connection to the grid. Battery powered AGV and diesel-electric hybrid straddle carrier type equipment are in use at a very small number of container terminals in southern California. Battery powered UTR and FEL type equipment are still in testing phases.
4. Refrigerated Containers – California imports and exports a considerable amount of perishable food products in refrigerated containers. Refrigerated containers are connected to the grid while stored in the terminals. Those container terminals/ports that handle a high percentage of these or are refrigerated-cargo-based would have a higher power demand.
5. Ancillary Equipment and Infrastructure – Buildings, lighting, and other powered ancillary equipment and infrastructure requires direct connection to the power grid.

eCHE Power Requirements

The general methodology to estimate the total eCHE power requirements for the five California ports will include the following:

1. Develop typical terminal operating modes and quantify the CHE required at the berth, in the container yard (CY) and in the on-dock IY to support a unit 1M annual TEU throughput.
2. Estimate the power requirements for each of the grid-connected and battery-powered CHE.
3. Estimate the throughput potential for the typical operating modes on a per terminal gross acre basis.
4. Estimate the throughput forecast for each port.
5. Based on the terminal acreage at each port, apportion the typical operating modes to individual terminals to provide a total port throughput capacity that aligns with the regional forecast.
6. Calculate the quantity of CHE required to support the port throughput.
7. Estimate the total power (connected load) required to accommodate the corresponding CHE to support the port throughput.

The methodology application is presented in detail below.

Typical Terminal Operating Modes

The CHE associated with the four terminal operation modes presented in Table 6 and the percentage of terminal moves that are accommodated by the respective CHE in the terminal operating areas is presented in Table 8 through Table 11. These tables also provide the anticipated quantities of CHE required to support a unit of 1M annual TEU throughput achieved at a west coast container terminal. The CHE quantity estimates are based on the parameters indicated in Table 12, terminal operational hours in Table 13, and equipment productivities provided in Table 14.

Table 8: High-Density Operating Mode with ASC

Model Inputs	Wharf	Waterside		Landside Serving Gate	Landside Serving IY		On-dock IY
CHE Type	STS Dual	AGV	ASC	ASC	ASC	AGV	RMG
% moves per CHE	100%	100%	100%	100%	100%	100%	100%
# of CHE for 1M TEU	5	21	8	10	4	8	3

The high-density operating mode represents the highest degree of electrification and is similar to a fully automated terminal.

Table 9: Medium Density Operating Mode with RTG/FEL

Model Inputs	Wharf	Waterside		Landside Serving Gate		Landside Serving IY		On-dock IY
CHE Type	STS Single/ MHC	UTR	FEL	RTG	FEL	FEL	UTR	FEL
% moves per CHE	100%	100%	100%	50%	50%	100%	100%	100%
# of CHE for 1M TEU	5	36	5	7	4	2	10	2

The medium density operating mode with RTG/FEL represents continuance of the existing operational mode currently found at most west coast terminals relying on electrified versions of existing equipment to support a grounded container storage operation.

Table 10: Medium Density Operating Mode with STRAD

Model Inputs	Wharf	Waterside	Landside Serving Gate	Landside Serving IY	On-dock IY
CHE Type	STS Dual	STRADCY	STRADCY	Strad	RMG
% moves per CHE	100%	100%	100%	100%	100%
# of CHE for 1M TEU	5	14	14	6	3

Table 11: Low Density Operating Mode with Wheeled

Model Inputs	Wharf	Waterside		Landside Serving Gate	Landside Serving IY		On-dock IY
CHE Type	STS Single/ MHC	UTR	FEL	FEL	FEL	UTR	FEL
% moves per CHE	100%	100%	25%	25%	25%	100%	100%
# of CHE for 1M TEU	5	36	2	2	1	10	2

Table 12: Typical West Coast Container Terminal Throughput Parameters

Terminal Throughput Parameters	Value
TEU Factor (TEU/move)	1.8
Modal Splits	
Import Loads	50%
Import Empty	0%
Export Loads	25%
Export Empty	25%
Local	70%
On-dock IY	30%
Gate to Vessel Moves Factor	1.25
Throughput Daily Peaking Factor	1.30

Table 13: Terminal Operational Days and Hours

Terminal Operations	Wharf	Waterside Transport	Landside Serving Gate	Landside Serving IY	On-dock IY
Actual operating days per week	7	7	7	7	7
Operating hours per shift					
Typical 1st (Day) shift	8	8	8	6.5	6.5
Typical 2nd (Night) shift	8	8	8	6.5	6.5
Typical 3rd (Hoot) shift	0	0	0	0	0
Operating hours per day	16	16	16	13	13

eCHE Power Loads

eCHE is considered, depending upon its zone of operation, to be powered either through direct connection to the power grid or by rechargeable batteries on the eCHE.

The eCHE listed in Table 14 performs its operations in consistently defined paths and is, therefore, feasible to be continuously connected to the grid through cables or bus bars. The required grid electrical power is indicated as its average operating load and occurs during the terminal work shifts. This load is the average power utilized during a single operational cycle. The purpose of using the average load is to estimate the power load that would need to be available on the grid throughout the operation. It is not the peak load required during the operational eCHE cycle that is used to size the electrical infrastructure that supplies the eCHE. The purpose of the study is to determine the power requirement for a study region. It is considered highly unlikely that all the equipment operating in the port would be simultaneously drawing their respective peak operating loads, or, conversely, their minimum operating loads. By using the average operating load, it provides a realistic condition of required regional load, and is conservative as it assumes that all required eCHE is simultaneously operational and not at idle.

Table 14: Electrical Grid Powered eCHE Parameters

Equipment Type	Productivity (Mvph)	Average Operating Load (kW)	Power Source
Wharf			
STS Dual	30	700	Grid
STS Single	25	400	Grid
MHC	12	400	Grid
Waterside			
RTG	25.	80	Grid
ASC	17	100	Grid
Landside Gate			
RTG Import	8	80	Grid
RTG Export	20	80	Grid
ASC	12	100	Grid
Landside IY			
RTG	25	80	Grid
ASC	12	100	Grid
IY			
RTG	30	80	Grid
RMG	20	200	Grid

The CHE listed in Table 15 typically performs its operations in zones and moves throughout the terminal. Therefore, this eCHE is not suitable for direct connection and is assumed to be powered by rechargeable batteries. The power required during recharging of the batteries is considered its required power load. This study considered two alternative scenarios for the timing of equipment battery recharging:

1. on-shift charging, i.e., opportunity charging
2. off-shift charging

As automated CHE becomes more prevalent, automatic methods to recharge the battery-powered eCHE are under development and include plug-in, pantograph, and inductive solutions, as well as battery swapping. The idea being that the recharge solutions can be placed throughout the operational path and the eCHE briefly recharged during opportune moments (on-shift) without a dedicated lengthy down time to recharge the equipment. On-shift recharging does result in a decrease in eCHE productivity and, therefore, the eCHE fleet needs to be increased to compensate for the productivity decrease. For this study, the charge time has been increased by an estimated 25% to account for charger connect and disconnect durations. Based on this charge time, Table 15 provides charge time and resulting operating time for battery powered eCHE. A comparison of the two represents the percent of fleet that is unavailable during the opportunity charging and, therefore, the required percentage increase in fleet size to compensate and achieve the desired eCHE productivity. For example, an electrified straddle carrier has a charging time of 6.3 minutes, that subsequently allows the STRAD battery to operate for 55.2 minutes. So, for the 61.5-minute charge and operating cycle, the STRAD is charging 10% of the time. Therefore, to match the required STRAD fleet productivity, the fleet correspondingly needs to be increased by 10%. The increased number of UTRs and FELs to compensate for opportunity charging is indicated in Table 15. For on-shift opportunity charging, the power requirement is the charging unit load multiplied by the percentage of the fleet that is recharging. The on-shift charging power load is simultaneous and additive to the grid-connected eCHE load.

The other charging scenario considered is off-shift charging, where eCHE battery recharging occurs during terminal work shift breaks: the one hour between the first and second shift, and during the third shift. **Absent a breakthrough in battery technology, the current off-shift charging requirements for battery eCHE equipment will preclude operations during the third shift**. Off-shift charging is considered to occur when the grid-connected eCHE is idle. The power requirement of off-shift charging is the charging unit load multiplied by the fleet size. This is compared to the on-shift charging load and the larger of the two loads governs and is considered the total power requirement for the respective typical terminal operating mode for a unit 1M TEU throughput.

The FEL charge time during most shift breaks does not provide enough run time to last the subsequent shift. For that reason, the FEL is considered only to use on-shift charging, which will reduce equipment productivity and require increases to the FEL fleet.

Table 15: Electrified Battery Powered CHE Parameters

Equipment Type	Productivity (Mvph)	Power Source	Charging Unit Load (kW)	Charge Time (Hours)	Operating Time per Charge (Hours)	Reqd Fleet Increase for Opp Charging	Charge Method
Waterside							
UTR	3.5	Battery	200	1.3	10	11%	Off-shift/Opp
AGV	6	Battery	200	1.6	8.7	16%	Opp
STRADSH	11	Battery	400	0.105	0.92	10%	Opp
STRADCY	9	Battery	400	0.105	0.92	10%	Opp
FEL	25	Battery	400	2.5	10.7	19%	Opp
Landside Gate							
STRAD	8	Battery	400	0.105	0.92	10%	Opp
FEL	18	Battery	400	2.5	10.7	19%	Opp
Landside IY							
FEL	25	Battery	400	2.5	10.7	19%	Opp
UTRC	5	Battery	200	1.3	10	11%	Off-shift/Opp
UTRDC	8	Battery	200	1.3	10	11%	Off-shift/Opp
AGV	6	Battery	200	1.6	8.7	16%	Opp
STRAD	8	Battery	400	6.3	55	10%	Opp
IY							
FEL	30	Battery	400	2.5	10.7	19%	Opp

eCHE Power Unit Requirements

The resulting eCHE power load requirements for each operating mode with the quantities of eCHE indicated in Table 8 through Table 11 and corresponding to the charging scenarios presented above are provided in Table 16 for a unit 1M TEU annual throughput.

Table 16: eCHE Power Load Requirements for 1M TEU Annual Throughput

Terminal Operational Mode	Electrified CHE Power Load Requirement		
	On-Shift UTR Charging (MW)	Off-Shift UTR Charging (MW)	Governing Load per 1M TEU (MW)
High density container storage with electrified ASC	n/a	n/a	7.5
Medium density container storage with electrified RTG and FEL	5.4	9.2	9.2
Medium density container storage with electrified STRAD	n/a	n/a	6.1
Low density wheeled container storage with electrified UTRs	4.4	9.2	9.2

Port Throughput Growth Estimates & Assignment to Study Regions

The respective CAGR was assigned to each of four study regions and regional port container throughput was forecast to 2050, as presented in Table 17.

Table 17: Regional Port Forecast[3]

Study Region	San Diego	San Pedro Bay	Hueneme	Oakland
Growth	2.0%	2.4%	2.0%	2.2%
Year	**Annual Throughput (TEU)**			
2025	92,000	18,648,000	193,000	2,966,000
2030	102,000	20,996,000	213,000	3,307,000
2035	113,000	23,639,000	235,000	3,687,000
2040	125,000	26,615,000	259,000	4,111,000
2045	138,000	29,966,000	286,000	4,584,000
2050	152,000	33,739,000	316,000	5,111,000

Based on assumed throughput estimates per gross acre for the four terminal operating densities (see Table 6), future potential typical operating modes were assigned to the regional port terminals to align the throughput capacity for the study region with forecasted volumes. The typical terminal operating mode assumptions for the various study regions in 2035 and 2040 are presented in Figure 3Figure 2 through Figure 6.

[3] 2019-2050 Bay Area Seaport Forecast, The Tioga Group & Hackett Associates. National City Marine Terminal Optimization Study, Vickerman & Associates, LLC.

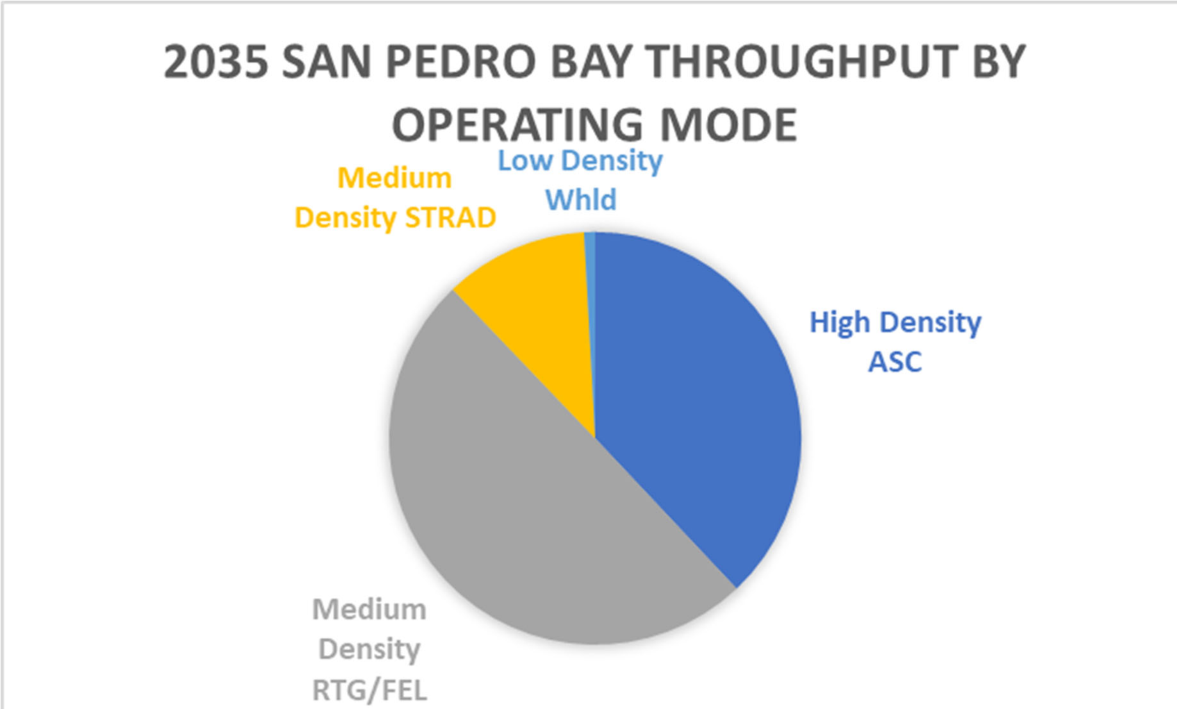


Figure 2: San Pedro Bay 2035 Container Throughput Distribution by Terminal Operating Mode

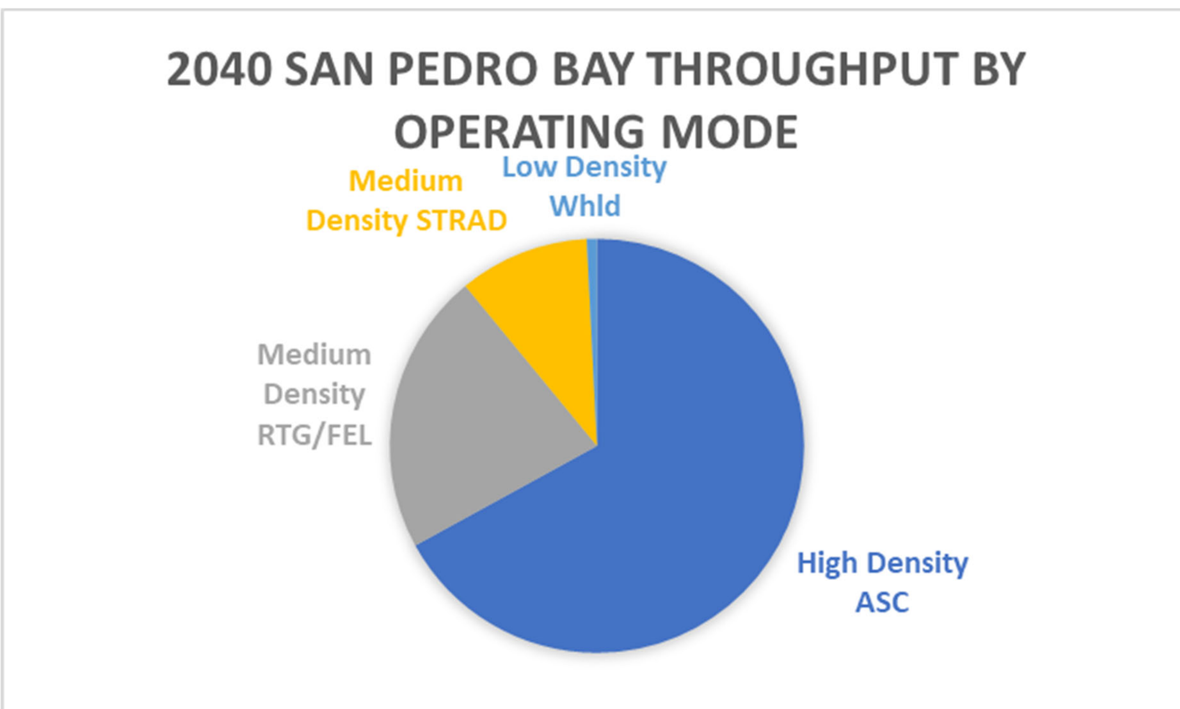


Figure 3: San Pedro Bay 2040 Container Throughput Distribution by Terminal Operating Mode

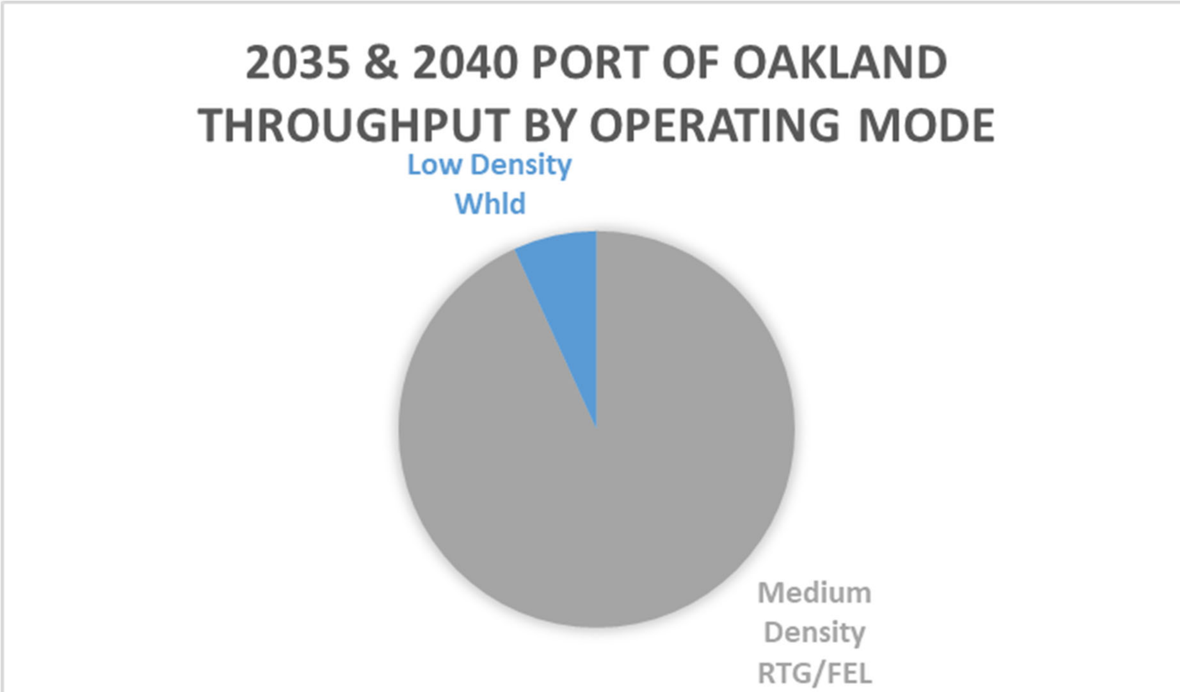


Figure 4: Port of Oakland 2035 & 2040 Container Throughput Distribution by Terminal Operating Mode

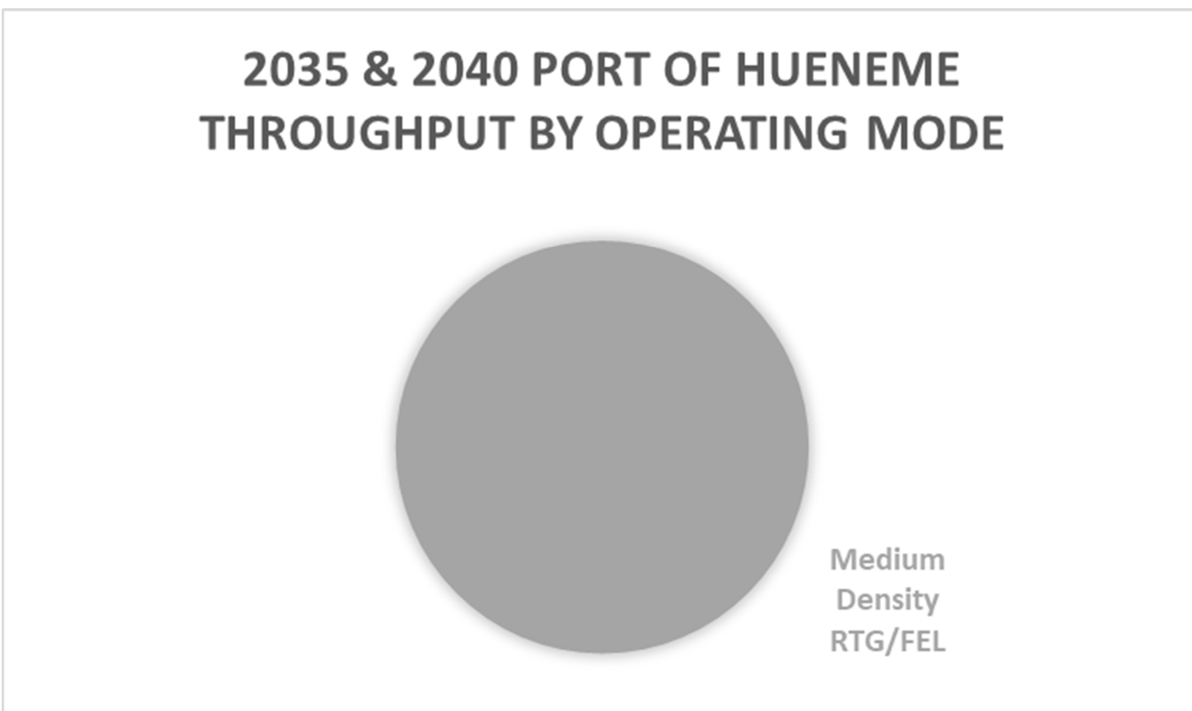


Figure 5: Port of Hueneme 2035 & 2040 Container Throughput Distribution by Terminal Operating Mode

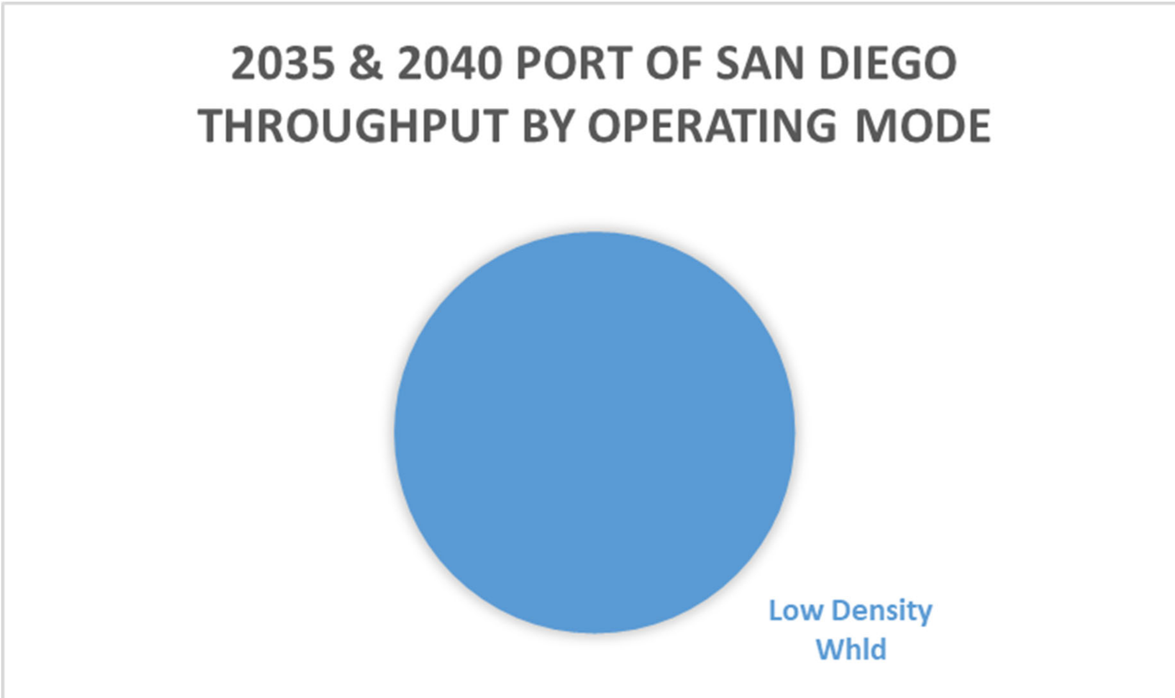


Figure 6: Port of San Diego 2035 & 2040 Container Throughput Distribution by Terminal Operating Mode

Port eCHE Power Requirements

The individual terminal power load requirement is estimated by multiplying its throughput by the eCHE unit power load requirement corresponding to its anticipated operating mode. The terminal's power load requirements are summed for each study region. Results indicate that the eCHE power requirement is closely tied to the charging strategy for electrified UTRs, i.e., off-shift or on-shift charging. Therefore, total power requirement results are provided for both off-shift and on-shift charging scenarios for each study region in Table 18.

Table 18: Total eCHE Power Load Required to Accommodate 2035 and 2040 Annual Container Throughput

Study Region	eCHE Power Load Requirement			
	2035		2040	
	On-Shift UTR Charging (MW)	Off-Shift UTR Charging (MW)	On-Shift UTR Charging (MW)	Off-Shift UTR Charging (MW)
Port of San Diego	0.5	1.0	0.6	1.2
San Pedro Bay	147.9	193.6	179.8	202.7
Port of Hueneme	1.3	2.2	1.4	2.4
Port of Oakland	19.7	34.1	21.9	37.7
Total	**169.4**	**230.9**	**203.7**	**244.0**

The off-shift hours available for charging mainly consist of the rarely used “hoot” shift (3 am-8 am); therefore, an opportunity exists for battery charging to occur outside of the electrical grid summer and winter peak demand hours presented above. However, this is also a period when solar power generation is unavailable. The future power rate schedules for off-peak demand hours and the incentives that renewable energy will provide to use off-peak demand have yet to be defined by the energy providers.

On-shift opportunity charging occurs, in part, during peak demand grid hours and requires additional eCHE to account for the loss in productivity during on-shift charging. Table 19 shows the percent increase in eCHE fleet size to accommodate on-shift opportunity charging and still provide the required equipment productivity.

Table 19: eCHE Fleet Size Increase for On-shift Opportunity Charging

eCHE	Fleet Size Increase
UTR	11%
STRAD	10%
AGV	16%
FEL	19%

Reefer Power Requirements

The power demand for plugged-in on-terminal refrigerated containers (reefers) was estimated using the following methodology:

- Estimate the reefer percentage of total container throughput for each study region.
- Using typical reefer container dwell times, calculate the average number of reefers stored within the terminals.
- Multiply the average reefer volume by an average 6kW to each plugged-in reefer container which accounts for cooling and idle periods.

The total reefer power requirement for each study region is provided in Table 20.

Table 20: Reefer Power Load Required to Accommodate 2035 and 2040 Annual Container Throughput

Study Region	Reefer % of Throughput	Reefer Power Requirement (MW)	
		2035	2040
Port of San Diego	95%	5.5	6.1
San Pedro Bay	4.5%	59.2	65.7
Port of Hueneme	90%	11.9	13.0
Port of Oakland	6%	12.4	13.7
	Total	**89.0**	**98.5**

Shore Power Requirements

Shore power was analyzed for both container and RoRo vessels in 2035 and 2040, see Table 21 and Table 22, respectively. The vessel analysis included the following considerations:

- Vessel size
- Vessel utilization factor
- Berth utilization based on throughput
- Power demand based on vessel size

Assumptions related to the shore power analysis are as follows:

- Vessel size matched to berth availability and anticipated cargo demand
- Weekly vessel services

Table 21: Estimated 2035 and 2040 Power Demand for Container Vessels

	Study Region	Shore Power Requirement (MW)	
		2035	2040
Containers	San Diego	0.7	0.7
	Los Angeles	21.8	24.4
	Long Beach	22.6	23.6
	Hueneme	1.0	1.0
	Oakland	7.8	9.0
	Total	**53.9**	**58.7**

Table 22: Estimated 2035 and 2040 Power Demand for RoRo Vessels

	Study Region	2035 and 2040 Shore Power Requirement (MW)
RoRo	San Diego	4.0
	San Francisco	4.0
	Richmond	2.0
	Hueneme	2.0
	San Pedro Bay	6.0
	Total	**18.0**

Terminal Ancillary Power Requirements

M&N estimated the power required in 2035 and 2040 for terminal buildings and high-mast area lighting using uniform ratios based on terminal acreage is provided in Table 23. High mast lighting power demand assumes LED light fixtures.

Table 23: Estimated 2035 and 2040 Power Demand for Terminal Ancillary Functions

	Study Region	2035 and 2040 Power Requirement (MW)
Buildings & Area Lighting	San Diego	2.4
	San Pedro Bay	35.7
	Hueneme	2.5
	Oakland	10.5
	Total	**51.1**

Regional Trucking Requirements

M&N estimated the power required to provide DC fast charging to a regional fleet of drayage trucks. The methodology is as follows:

- Using the cargo forecast for each study region, calculate the number of gate transactions (local containers) per year.
- Using an assumption of percentage of dual-transaction roundtrips (two containers per port visit), calculate the number of local truck roundtrips per year.
- Apply the parameters of a known battery-powered heavy duty (Class 8) truck, in this case the Kenworth T680E.
- Using assumptions of average trip distance and speed, calculate the number of charging cycles required.
- Apply the charger power requirements to calculate total power required in MW.
- Report the results for years 2020 (baseline as if ZE fleet existed), 2035, and 2040.

Truck trip volume and power calculation parameters used in the analysis are provided in Table 24 and Table 25.

Table 24: Regional Trucking Power Parameters

Parameter	Value
Percent local cargo	70%
TEU/container factor	1.8
Gate/vessel move ratio	1.25
Percent dual transaction local trips 2020	50%
Percent dual transaction local trips 2040	70%
Average miles per one-way trip	25
Average miles per roundtrip	50
Average kWh per truck mile	2.0
Average drayage days per week	5.5
Average travel miles per day per active truck	150
Average travel speed (mph)	30
Average travel hours per day, per truck	5
Number of fast charge cycles per day, per truck	1
Charger hours per day, per truck	2.64
Charging hours per day available	24
Charger inter-truck time (min)	15

Table 25: Kenworth Class 8 T680E Power Parameters

Parameter	Value
GVWR (lbs)	54K-82K
Battery Capacity (kWh)	396
Battery Range (miles)	150
DC fast charger capability (kWh)	120
DC fast charge average charge time (hrs) for 80%	2.64

The estimated power required to provide DC fast charging to a regional fleet of drayage truck are summarized in Table 26.

Table 26: Estimated Power Requirements to Provide DC Fast Charging for Drayage Trucks

Year	Port of San Diego	San Pedro Bay	Port of Hueneme	Port of Oakland	Total
Local Container Moves per Year					
2020	40,347	8,051,458	85,069	1,293,056	**9,469,931**
2035	54,931	11,491,181	114,236	1,792,292	**13,452,639**
2040	60,764	12,937,847	125,903	1,998,403	**15,122,917**
Regional Fleet Local Truck Roundtrips per Year					
2020	26,898	5,367,639	56,713	862,037	**6,313,287**
2035	33,291	6,964,352	69,234	1,086,237	**8,153,114**
2040	35,743	7,610,498	74,060	1,175,531	**8,895,833**
Regional Fleet Local Truck Miles per Year					
2020	1,344,907	268,381,944	2,835,648	43,101,852	**315,664,352**
2035	1,664,562	348,217,593	3,461,700	54,311,869	**407,655,724**
2040	1,787,173	380,524,918	3,703,023	58,776,552	**444,791,667**
Regional Fleet kWh/Day					
2020	9,405	1,876,797	19,830	301,412	**2,207,443**
2035	11,640	2,435,088	24,208	379,803	**2,850,739**
2040	12,498	2,661,013	25,895	411,025	**3,110,431**
Regional Fleet Fast Charger Operating Hours per Day					
2020	83	16,516	175	2,652	**19,425**
2035	102	21,429	213	3,342	**25,087**
2040	110	23,417	228	3,617	**27,372**
Regional Fleet Fast Chargers Required, 24-Hour Operation					
2020	4.0	689	8	111	**812**
2035	5.0	893	9	140	**1,047**
2040	5.0	976	10	151	**1,142**
Regional Fleet Fast Charger Power Required (MW)					
2020	0.48	83	1.0	13	**97.4**
2035	0.60	107	1.1	17	**125.6**
2040	0.60	117	1.2	18	**137.0**

Figure 7 presents regional port fleet roundtrips per year. The regional truck fleet fast charger power requirements are presented in Figure 8.

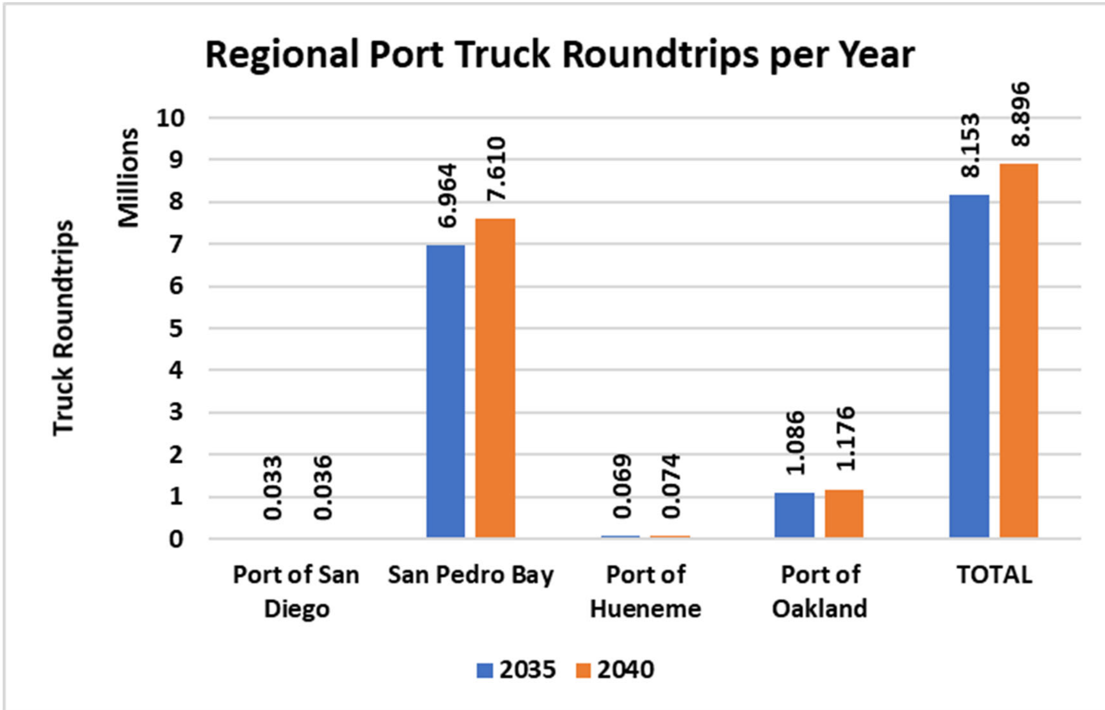


Figure 7: Regional Port Truck Roundtrips per Year

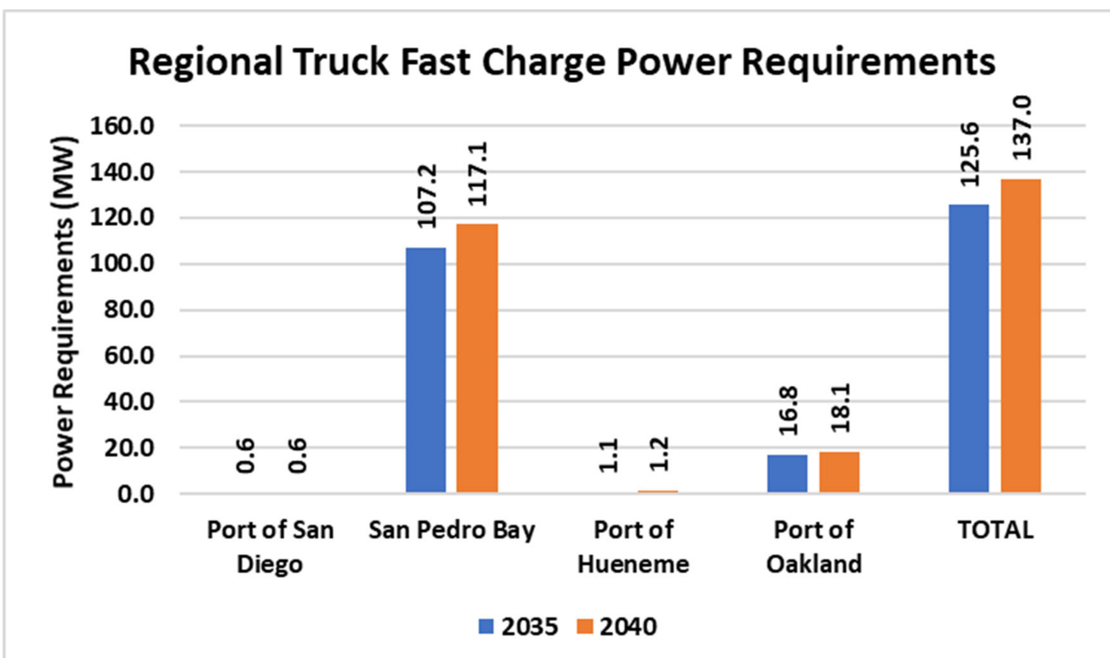


Figure 8: Regional Truck Fast Charging Power MW

4.0 Findings

The following results illustrate the power required in year 2035 and 2040 to support container terminal ancillary functions, eCHE, refrigerated container storage, shore power for container and RoRo vessels, and drayage trucking in the study regions. Note that the potential for charging UTR on-shift or off-shift creates a significant range of power demand for the eCHE component. The eCHE power requirements are related to the container terminal throughput for each study region. The relationship is also compared to the cargo forecast based on the CAGR used in the study to suggest a possible timing. As CARG is revised in the future, it will revise the expected timing of the throughput. The relationship presented between throughput and power requirements will remain the same with revised forecast CAGR.

Port of San Diego

The Port of San Diego will see an increase in power demand (see Table 27) based on:

- Capacity to accommodate anticipated growth in containers and autos.
- Conversion of diesel-powered CHE to electric grid or battery powered eCHE.
- Increase of reefer power capacity as demand increases, as the Tenth Avenue Marine Terminal is primarily a destination for refrigerated cargo.
- Shore power capability at auto RoRo terminal (NCMT).
- Conversion of regional diesel-powered drayage trucks to battery powered.

Table 27: 2035 and 2040 Power Demand – Port of San Diego

	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
Port of San Diego	Buildings & Area Lighting	2.5	2.5	2.5	2.5
	eCHE	0.49	1.03	0.55	1.16
	Reefer Power	5.5	5.5	6.1	6.1
	Shore Power*	4.7	4.7	4.7	4.7
	Drayage Trucking	0.6	0.6	0.6	0.6
	Totals	**13.7**	**14.2**	**14.4**	**15.0**

The Port of San Diego eCHE power load requirement and total power requirements, including shore power for both container and RoRo terminals, with respect to annual terminal throughput are indicated in Figure 9 and Figure 10, respectively, and associated with study throughput forecast.

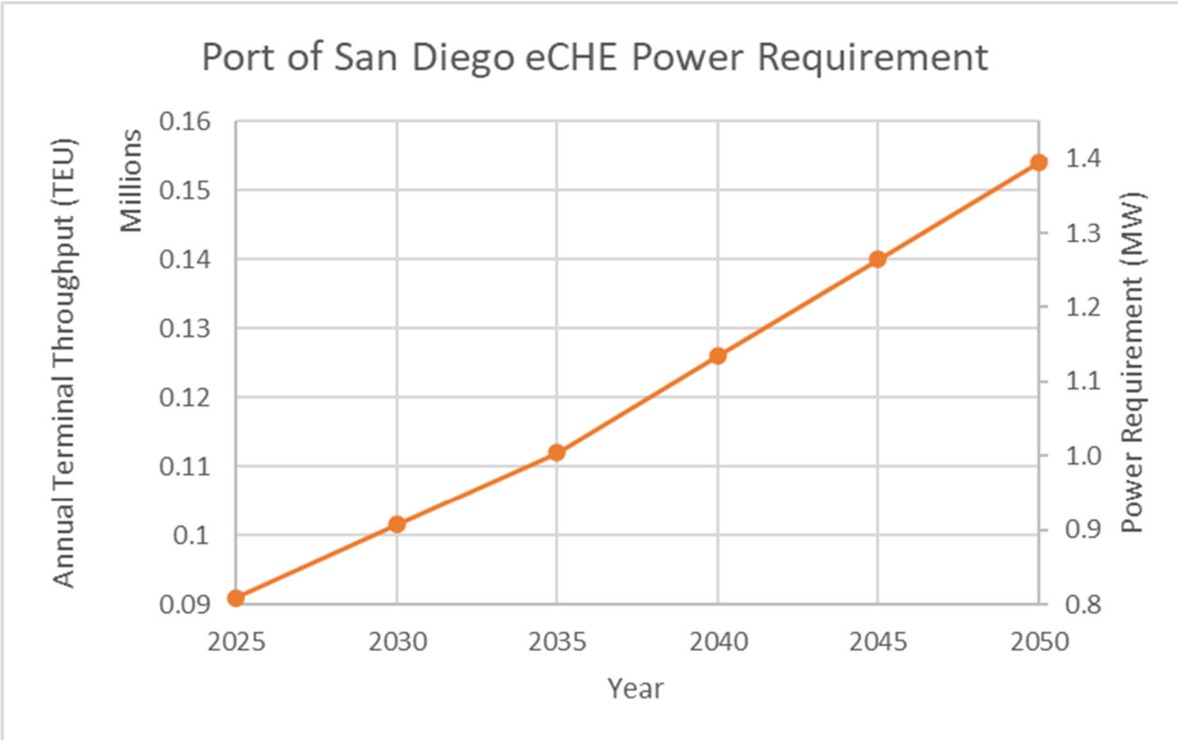


Figure 9: Port of San Diego eCHE Total Power Load Requirement

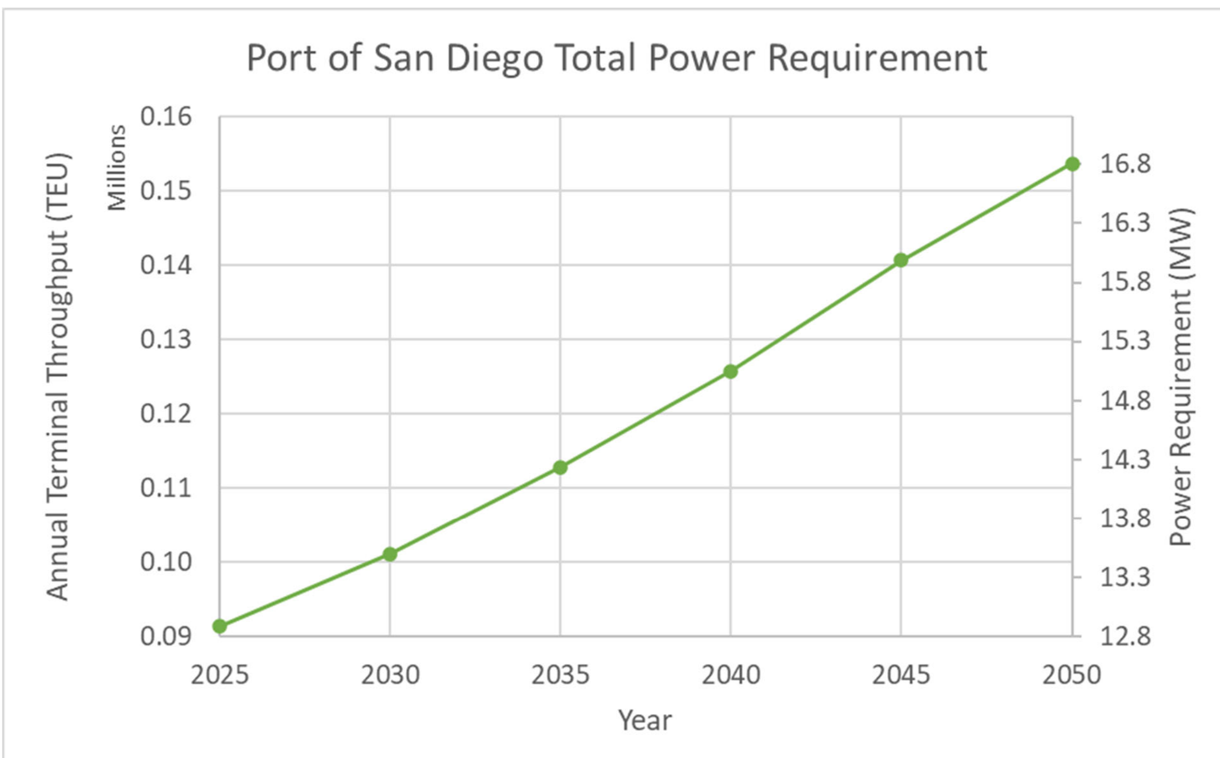


Figure 10: Port of San Diego Total Power Requirements

San Pedro Bay

The ports of San Pedro Bay will see an increase in power demand (see Table 28) based on:

- Capacity to accommodate anticipated growth in containers and autos.
- Conversion of diesel-powered CHE to electric grid or battery powered eCHE.
- Increase of reefer power capacity as demand increases.
- Shore power capability at auto RoRo terminals
- Conversion of diesel-powered drayage trucks to battery powered.

Table 28: 2035 and 2040 Power Demand – San Pedro Bay

	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
San Pedro Bay	Buildings & Area Lighting	35.7	35.7	35.7	35.7
	eCHE	147.9	193.6	179.8	202.7
	Reefer Power	59.2	59.2	65.7	65.7
	Shore Power*	50.4	50.4	54.0	54.0
	Drayage Trucking	107.2	107.2	117.1	117.1
	Totals	**400.4**	**446.1**	**452.3**	**475.2**

The San Pedro Bay ports' eCHE power load requirement and total power requirements, including shore power for both container and RoRo terminals, with respect to annual terminal throughput are indicated in Figure 11 and Figure 12, respectively, and associated with study throughput forecast.

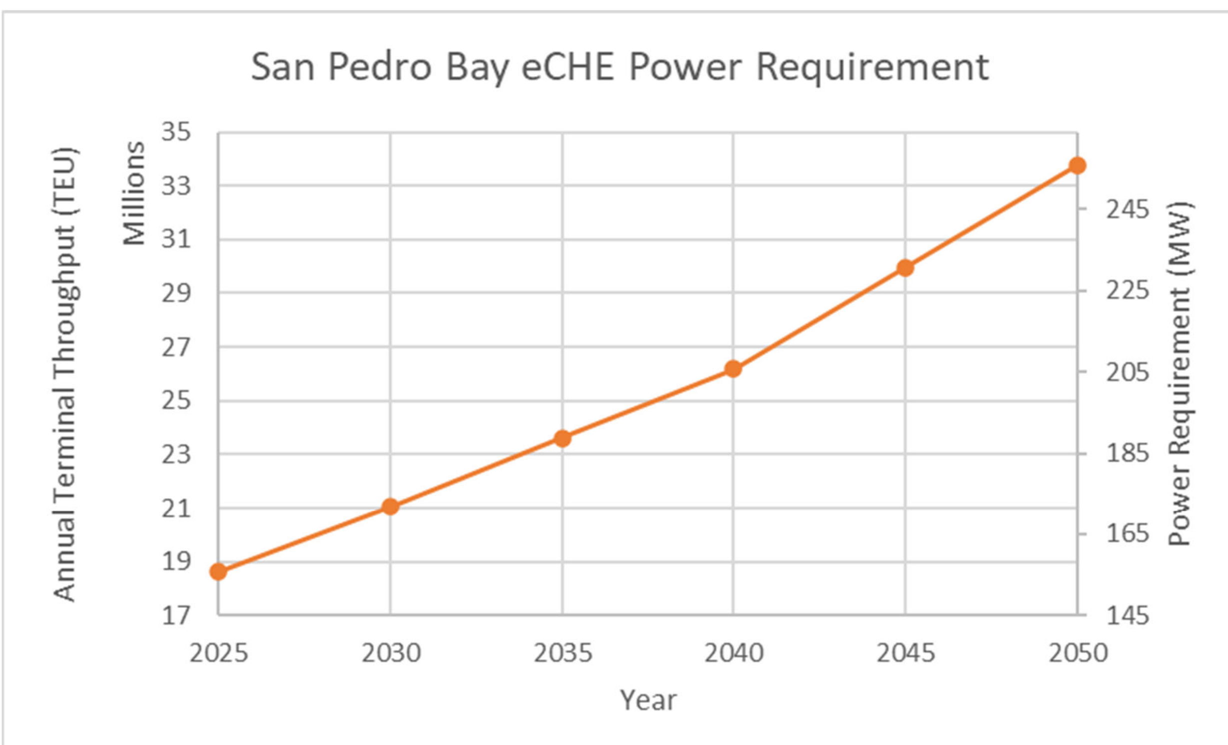


Figure 11: San Pedro Bay Ports eCHE Total Power Load Requirement

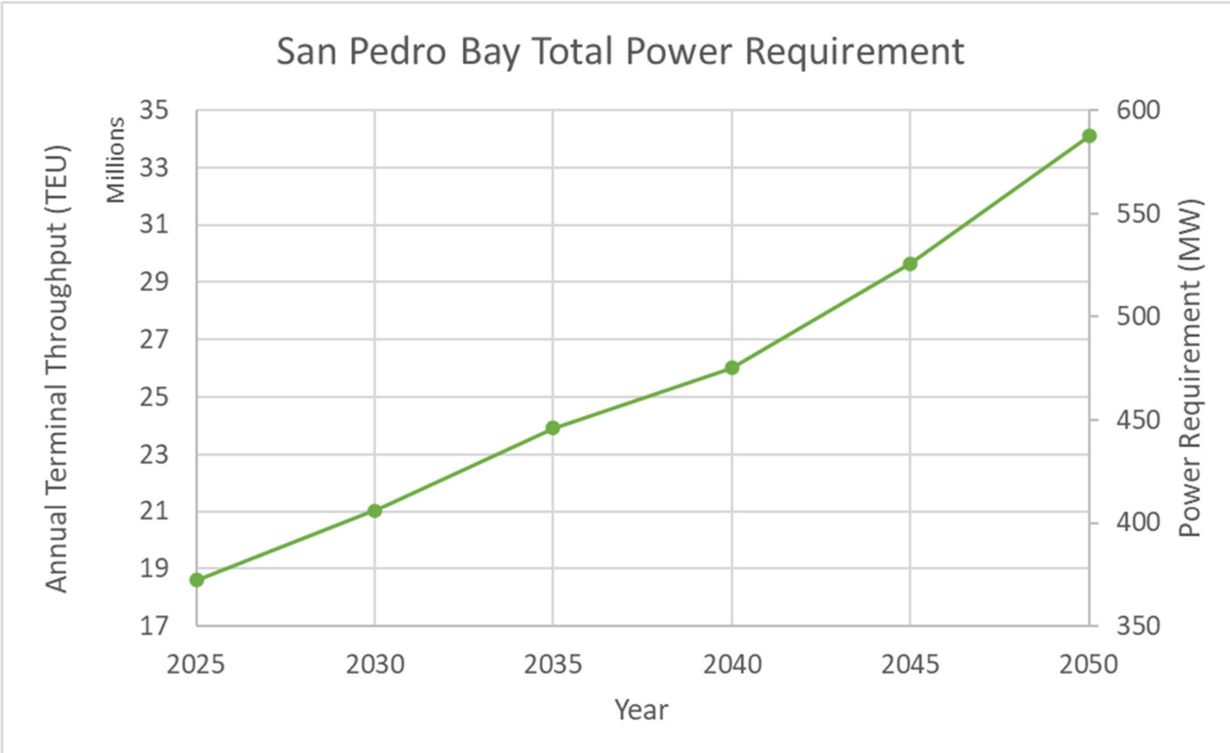


Figure 12: Port of San Pedro Bay Total Power Requirements

Port of Hueneme

The Port of Hueneme will see an increase in power demand (see Table 29) based on:

- Capacity to accommodate anticipated growth in containers and significant growth in autos.
- Conversion of diesel-powered CHE to electric grid or battery powered eCHE.
- Increase reefer power capacity as demand increases, as the Port of Hueneme is primarily a destination for refrigerated cargo.
- Shore power capability at auto RoRo terminal.
- Conversion of regional diesel-powered drayage trucks to battery powered.

Table 29: 2035 and 2040 Power Demand – Port of Hueneme

	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
Port of Hueneme	Buildings & Area Lighting	2.5	2.5	2.5	2.5
	eCHE	1.3	2.2	1.4	2.4
	Reefer Power	11.9	11.9	13.0	13.0
	Shore Power	5.0	5.0	5.0	5.0
	Drayage Trucking	1.1	1.1	1.2	1.2
	Totals	**21.8**	**22.7**	**23.0**	**24.0**

The Port of Hueneme eCHE power load requirement and total power requirements, including shore power for both container and RoRo terminals, with respect to annual terminal throughput are indicated in Figure 13 and Figure 14, respectively, and associated with study throughput forecast.

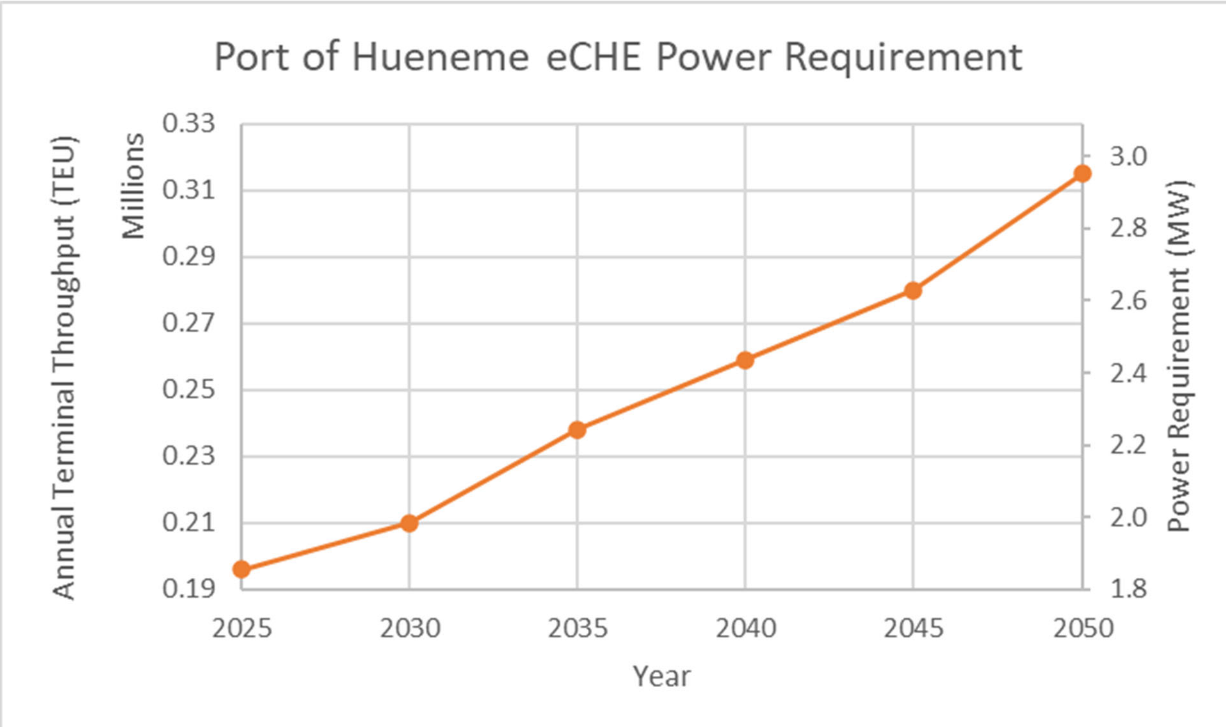


Figure 13: Port of Hueneme eCHE Total Power Load Requirement

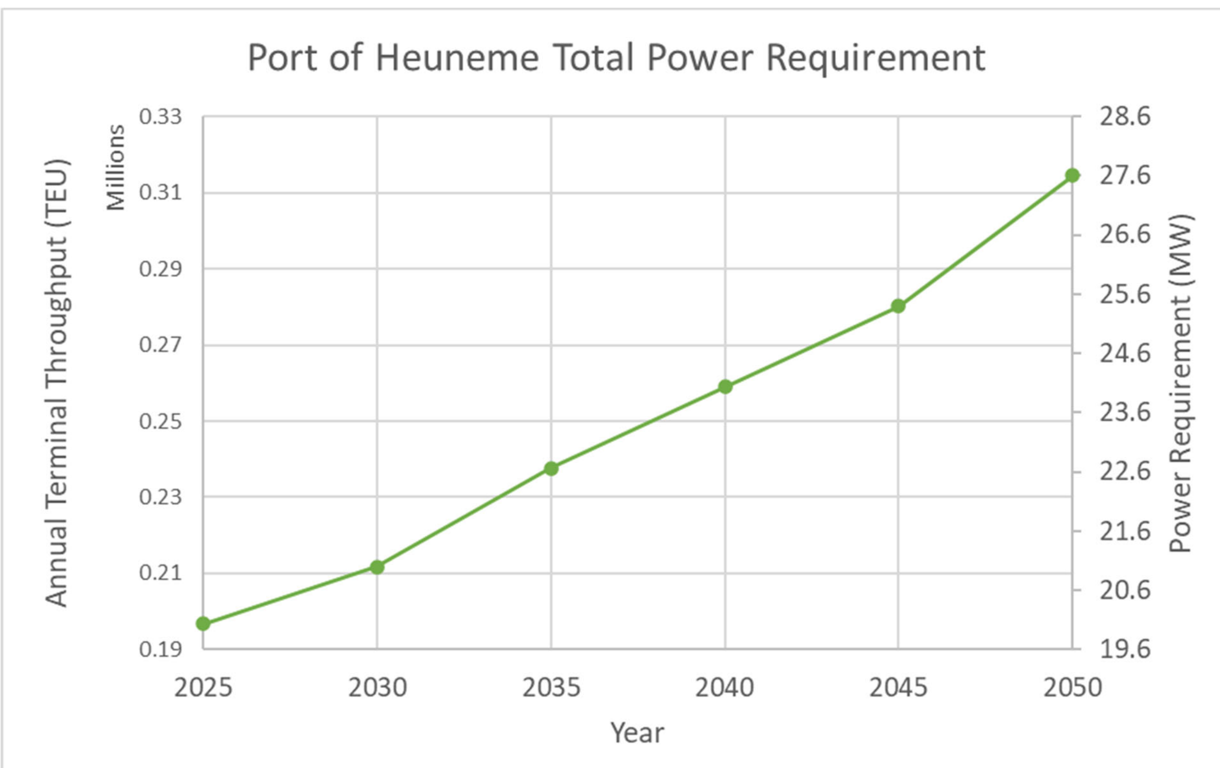


Figure 14: Port of Hueneme Total Power Requirements

Port of Oakland

The Port of Oakland will see an increase in power demand (see Table 30) based on:

- Capacity to accommodate anticipated growth in containers.
- Conversion of diesel-powered CHE to electric grid or battery powered eCHE.
- Increase reefer power capacity as demand increases.
- Shore power capability at some terminals.
- Conversion of regional diesel-powered drayage trucks to battery powered.

Table 30: 2035 and 2040 Power Demand – Port of Oakland

Port of Oakland	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
	Buildings & Area Lighting	10.5	10.5	10.5	10.5
	eCHE	19.7	34.1	21.9	37.7
	Reefer Power	12.4	12.4	13.7	13.7
	Shore Power*	7.8	7.8	9.0	9.0
	Drayage Trucking	16.8	16.8	18.1	18.1
	Totals	**67.2**	**81.6**	**73.2**	**89.1**

The Port of Oakland eCHE power load requirement and total power requirement with respect to annual terminal throughput are indicated in Figure 15 and Figure 16, respectively, and associated with study throughput forecast.

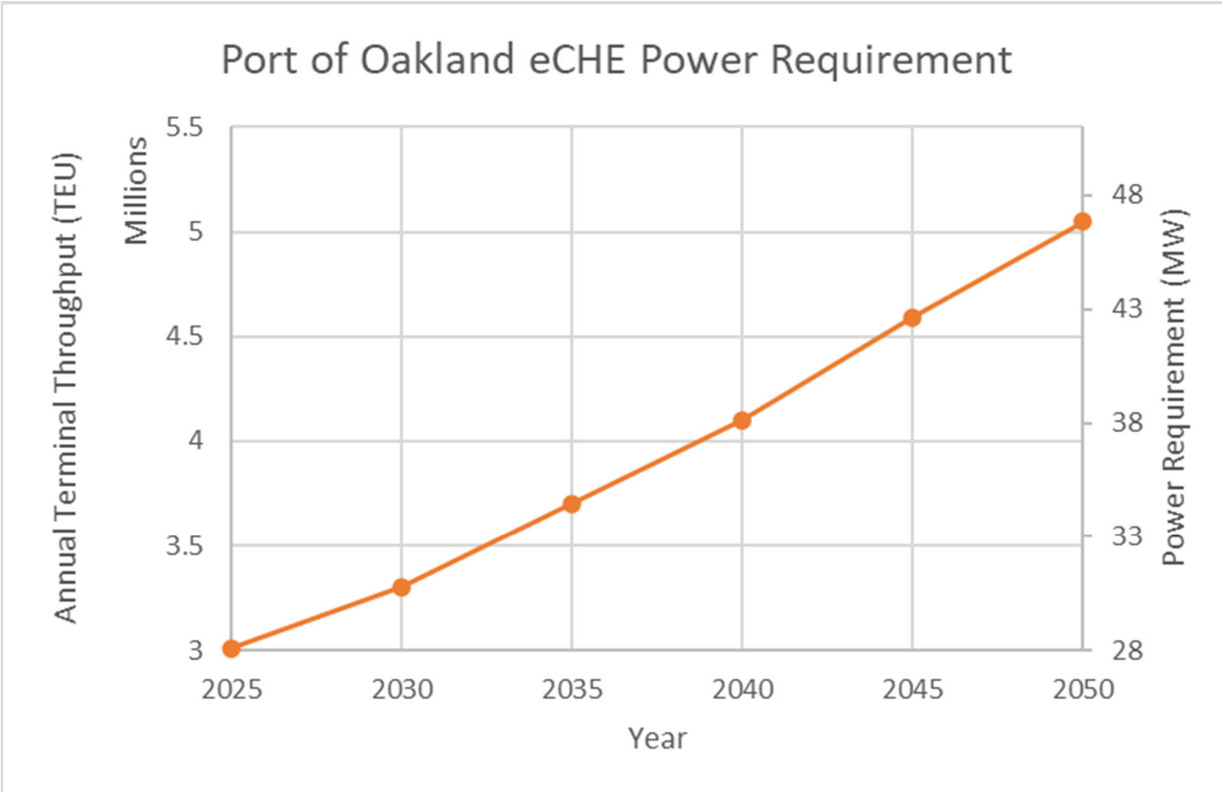


Figure 15: Port of Oakland eCHE Total Power Load Requirement

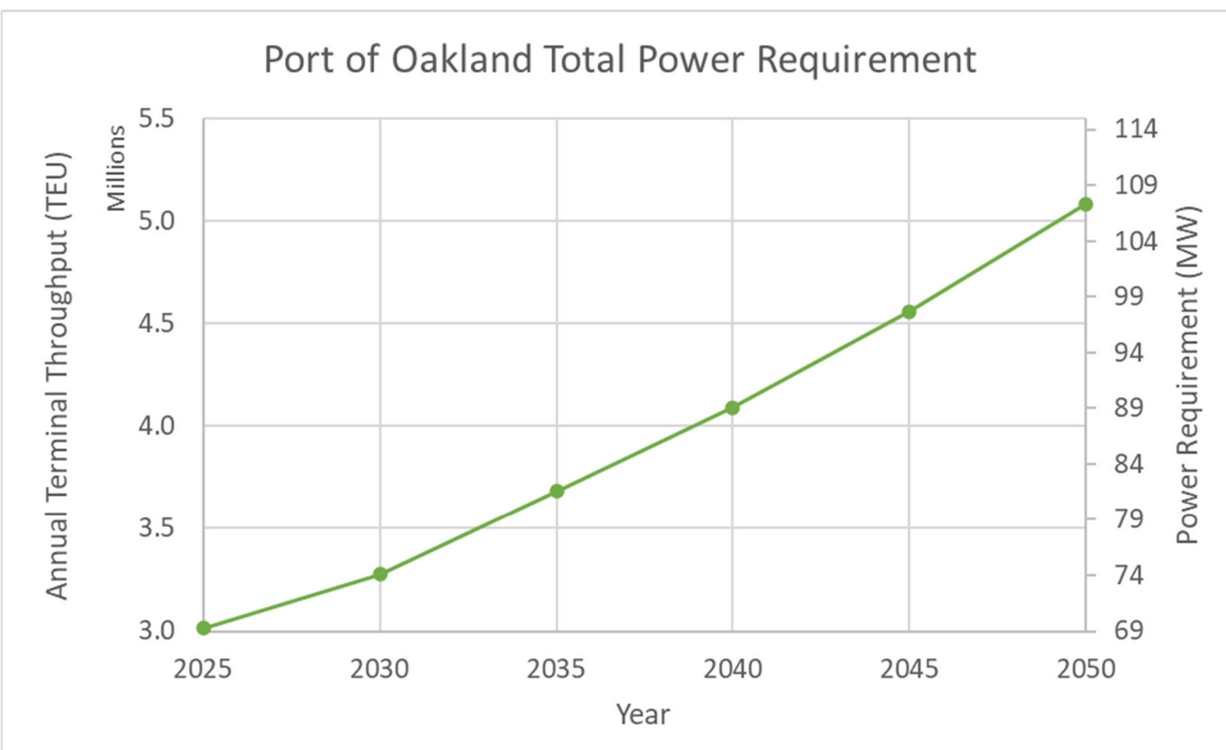


Figure 16: Port of Oakland Total Power Requirements

Study Regions Total Power Requirement

The total power requirements, including shore power for San Francisco and Richmond RoRo terminals, for the study regions in 2035 and 2040 are presented in Table 31 and Figure 17 and Figure 18, respectively.

Table 31: 2035 and 2040 Power Demand – All Study Regions

	Terminal Component	Required Power Demand (MW)			
		2035	2035	2040	2040
		On-Shift UTR Charging	Off-Shift UTR Charging	On-Shift UTR Charging	Off-Shift UTR Charging
All Study Regions	Buildings & Area Lighting	51.1	51.1	51.1	51.1
	eCHE	169.4	230.9	203.7	244.0
	Reefer Power	89.0	89.0	98.5	98.5
	Shore Power*	73.9	73.9	78.7	78.7
	Drayage Trucking	125.6	125.6	137.0	137.0
	Totals	**509.1**	**570.6**	**569.0**	**609.4**

* Includes RoRo terminal shore power at San Francisco and Richmond

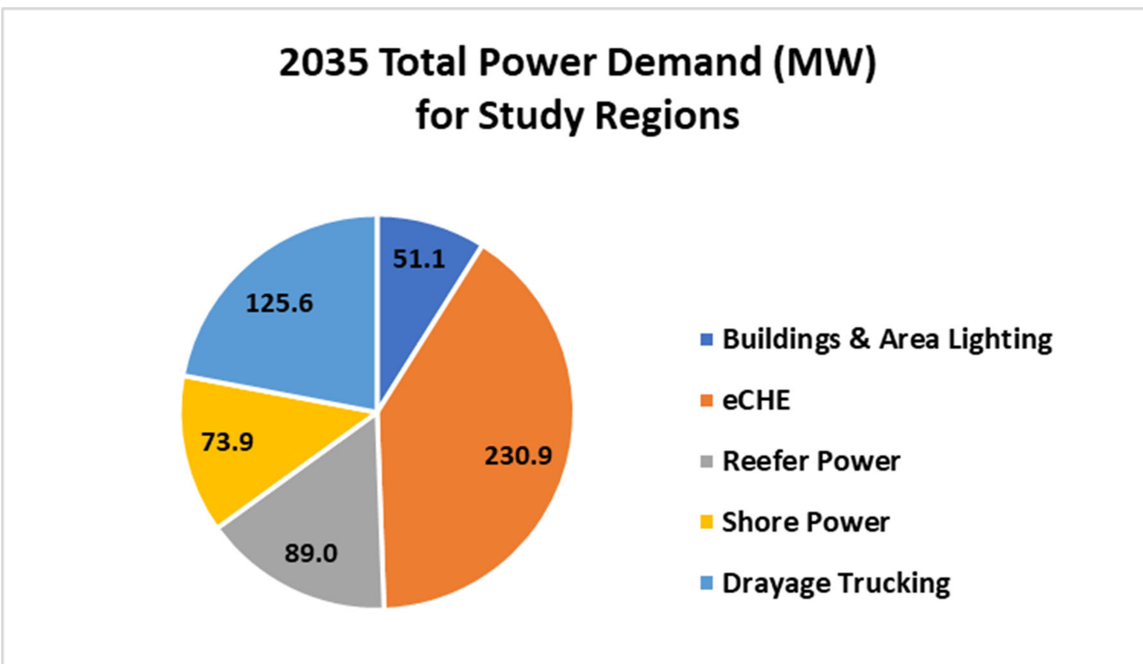


Figure 17: 2035 Total Power Demand for All Study Regions

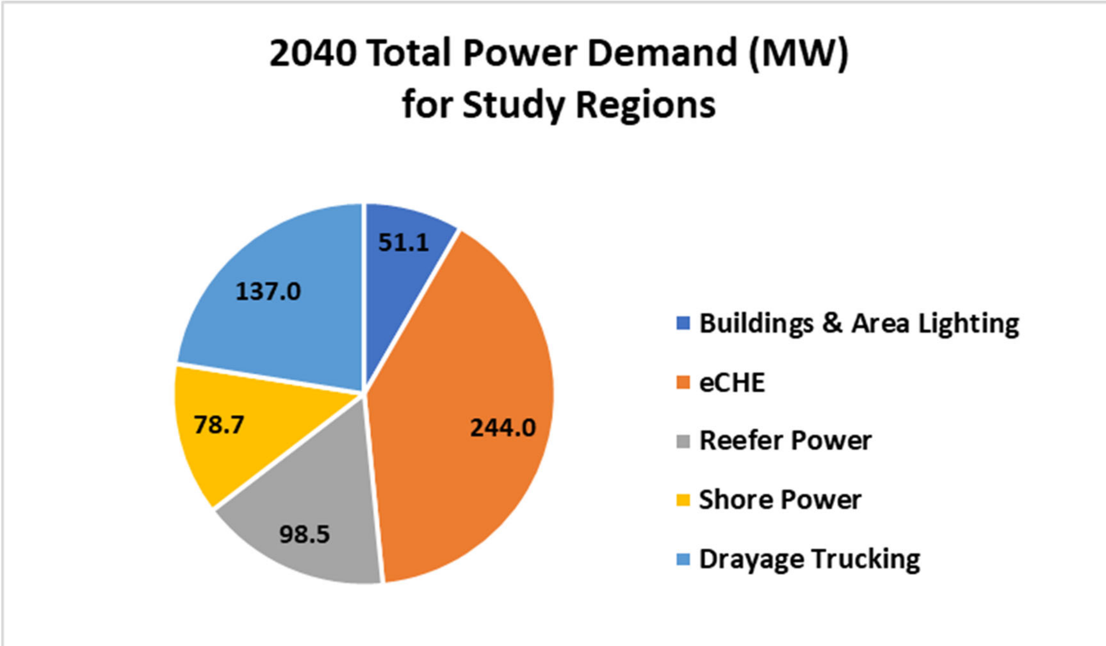


Figure 18: 2040 Total Power Demand for All Study Regions

To put this power requirement into some perspective.

- 1 MW can furnish power to between 400 and 900 U.S. households. Using an average of 650 households per MW, the 2040 study region power demand of ~600 MW could power about 390,000 households, or a population of about 1.0 million (in the U.S.).
- Total power demand from the port regions in 2035 and 2040 would require 50% and 53%, respectively, of one reactor at the Diablo Canyon Nuclear Power Generating Station, which is scheduled for shut down by 2025.

The total 2040 study region forecasted throughput of 31.1M TEU is about a 60% increase over of 2020 volumes (19.5M TEU).

- Electrification of all CHE will increase eCHE on-terminal power demand from the current level of about 2 MW per 1M annual TEU at most terminals to about 8.4 MW per 1M annual TEU in 2035 and 8.0 MW in 2040, see Figure 19. Even though throughput increases from 2035 to 2040, eCHE power requirements decrease from 2035 to 2040 due to additional throughput in 2040 being attributed to high density terminal operational mode (see Figure 2 and Figure 3) that has a lower power requirement.

- Charging electrified regional fleets of over-the-road trucks to serve the study region ports could add about 125.6 and 137.0 MW of power demand in 2035 and 2040, respectively. This represents about 22% of the 2035 and 2040 total power demand calculated herein.

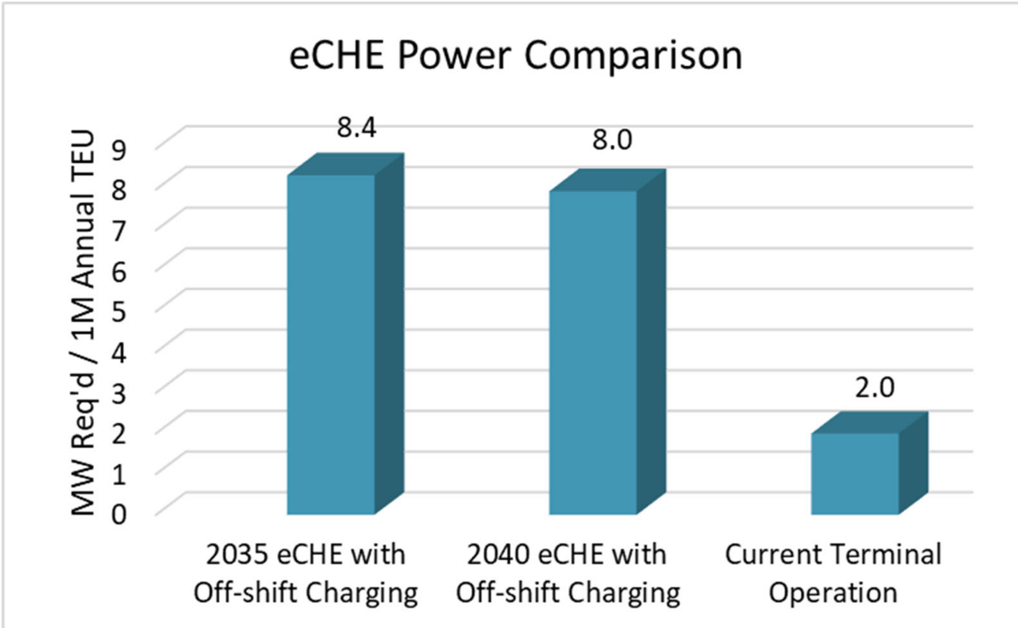


Figure 19: eCHE Power Comparison

5.0 Next Steps

The challenges presented in this study are container and RoRo marine terminal focused. Power demand on the California grid has its own unique challenges. The following discusses some of these challenges and related issues. The significant power demands identified in this study should be balanced with an awareness of the fragility and the fluidity of the goods movement supply chain relative to quality, cost, resiliency, and improvements. The consequences for not addressing the challenges could result in periodic shutdowns at the marine terminals or inability to continuously operate at daily capacity, resulting in breakdowns of the supply chain.

- Power quality
  - Power must be available during contractable terminal hours of operation
  - Sufficient real-time power must be available to support each region
  - Sufficient real-time power must be available to provide acceptable power regulation to avoid significant voltage dips and surges. Currently, marine terminal operations experience interruptions from periodic electrical shutdown of grid connected CHE that is caused by significant voltage dips and surges. The risk of occurrence and resulting impacts of electrical shutdown, is anticipated to increase as additional eCHE is connected to the grid and eCHE power demands increase.
  - Power supply must have capacity to meet the regional peak demand
  - Power requirements for the study regions need to be integrated with regional power requirements, including the anticipated increase of electric vehicles on the transportation network
- Power cost
  - Power requirements during labor shift breaks (off-shift charging) or during labor operations (on-shift opportunity charging) may overlap with regional peak power demand
  - Power rate schedules need to be defined to allow marine terminal operators to make informed business decisions with respect to the type, quantity, and power supply method of eCHE
- Resiliency
  - Power supply must have sufficient redundancy to be dependable enough to result in a near zero probability of blackouts and brownouts
  - Power supply must have sufficient redundancy to be able to rapidly recover from a natural or manmade disaster
  - Required power supply requires the development of power demand mitigation plans and adaption strategies
- Necessary distribution improvements
  - Power providers must plan and execute improvement needed to their infrastructure to meet regulatory compliance by their customers
  - Power providers need to understand customer planned improvements and their associated power needs to allow the providers to increase grid capacity in a timely manner
  - Critical and ancillary infrastructure needs to be identified, realized, funded, and maintained to meet the regulation timeline