Zero-Emission Cargo-Handling Equipment Feasibility Assessment

AECOM

November 21, 2019

TABLE OF CONTENTS

FIGURES

ACRONYMS

CARB	California Air Resources Board
CHE	Cargo-Handling Equipment
CORE	Clean Off-Road Equipment Voucher Incentive Project
CO_2	Carbon Dioxide
DAC	Disadvantaged Community
DPM	Diesel Particulate Matter
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
IAM	International Association of Machinists and Aerospace Workers Union
ILWU	International Longshore and Warehouse Union
kWh	Kilowatt-Hour
kV	Kilovolt
LCFS	Low Carbon Fuel Standard
MTO	Marine Terminal Operator
NOx	Nitrogen Oxides
NZE	Near-Zero-Emissions
OEM	Original Equipment Manufacturer
OICT	Oakland International Container Terminal
PG&E	Pacific Gas and Electric Company
PM_{10}	Particulate matter less than 10 micrometers in diameter
RPS	Renewables Portfolio Standard
RTG	Rubber-Tired Gantry
SB	Senate Bill
STS	Ship to Shore
TEU	Twenty-Foot Equivalent Units
ZANZEFF	Zero- and Near-Zero-Emissions Freight Facilities
ZE	Zero-Emissions

OBJECTIVES

The zero-emission CHE feasibility assessment has the following objectives:

- Identify near-term (2019-2023) commercially available equipment for a high-level (planning level) analysis of costs needed to transform current container handling equipment (CHE) using petroleum-based fuels at the Seaport to near-zero-emissions[1] and zero-emissions (NZE and ZE) goods movement.
- Estimate timing of initial efforts for each land-side equipment type based on cost, incentive funding, charging patterns, and other relevant factors.

Rather than estimate the capital costs to replace the entire inventory of land-side equipment at the Port of Oakland (Port), this report analyses capital and operating costs of battery-electric yard tractors and hybrid rubber-tired gantry (RTG) cranes that have achieved or are nearing commercial availability. This analysis is intended to demonstrate the potential capital and operating costs associated with these more widely available near-term NZE and ZE equipment technologies compared to traditional pure petroleum-fueled equipment, and how costs may trend over time.

EXECUTIVE SUMMARY

Key planning assumptions for this study include:

- No change will occur in status quo Seaport operations (i.e., operations remain primarily manual, in contrast to automated operations, which are not used at the Port).
- No equipment is discarded before the end of its typical life span (no *stranded assets*).
- Costs of electric vehicles decline over time due to falling battery costs and increasing production scale.
- Existing voucher programs remain in place indefinitely.
- No infrastructure costs are included (equipment costs only, not including charging equipment).

This report focuses on the analysis of the near-term equipment technologies with sufficiently developed commercial availability to allow for cost analysis, which primarily are electric yard tractors and hybrid lift equipment. Intermediate-term technologies that do not yet have substantial cost information available are discussed qualitatively, including electric top-picks. Overall results show that voucher programs to offset higher ZE and NZE equipment purchase prices (in contrast to conventional diesel equipment) will

---

[1] Near-zero equipment as defined in this report includes certified low nitrogen oxide (NOx) engines and hybrid engines.

be critical to facilitating their adoption, particularly in the near-term, while vehicle purchase costs remain much higher than those of traditional petroleum-based equipment. Hybrid lift RTG cranes are commercially available and may save 40% in fuel compared to a conventional diesel lift. Hybrid side-picks have also been developed by CVS Ferrari but do not yet have any US dealers.

SEAPORT AIR QUALITY 2020 AND BEYOND PLAN

The *Seaport Air Quality 2020 and Beyond Plan* includes three phases: Near-Term (2019-2023), Intermediate-Term (2023-2030), and Long-Term (2030-2050). The Seaport is moving forward in the context of anticipated new CARB regulations, currently under development, that are expected to have a substantial effect on the plan going forward (see the following section, Regulatory Setting).

Due to regulatory uncertainty and limited availability of current ZE equipment, an overall cost to convert all landside equipment to ZE has not been predicted in this study, as there is insufficient information available to develop a meaningful cost estimate or timeframe.

Overall equipment replacement costs were not analyzed in detail, as this was also not expected to yield a meaningful result due to a variety of technical, commercial, and regulatory uncertainties. For example, the Seaport has 386 pieces of diesel-powered CHE on-site. If Tier 4 diesel replacements were ordered tomorrow, the total replacement cost would be on the order of $125 million, plus tax and freight. If terminal operators instead ordered whatever demonstration ZE equipment is available today, it would amount to perhaps $350 million plus tax and freight (about three times higher). This is not a feasible or reasonable cost for operators, so this analysis focused instead on individual case studies for the equipment most likely to be feasible within the next 5 years. Although the Seaport awaits new regulations that will drive investment in zero-emissions equipment, investment in large amounts of new equipment (either clean diesel or ZE models), given the stranded assets concern (i.e., getting rid of equipment that still has some useful life remaining), are not expected. Furthermore, while demonstration equipment models are available for purchase in small quantities, current ZE equipment vendors do not have the production capability to replace petroleum-powered equipment serving the Seaport with ZE models.

Infrastructure costs, such as transmission system upgrades and electric vehicle charging stations, are also not included in this report.

REGULATORY SETTING

CARB regulates mobile sources of emissions. The relevant regulation is the Mobile Cargo-Handling Equipment Regulation (CHE Regulation) at Ports and Intermodal Rail Yards, amended in October 2012.The CHE Regulation requires new equipment to have either a Tier 4 Final off-road engine or a model year 2010 or newer on-road engine. Yard tractors were required to be fully compliant with the CHE Regulation by December 31, 2017, and other types of yard equipment (top-picks, RTG cranes, etc.) were required to be fully compliant by December 31, 2013. In March 2017 the CARB Governing Board directed CARB staff to develop new regulations for CHE that will require up to 100% ZE equipment by 2030. New CHE regulations may be adopted as soon as 2022, with implementation starting as early as 2026.

The feasibility of the proposed 2030 ZE regulations will depend heavily on how the rule is structured and how stranded assets are treated. A rule that requires all equipment in operation to be fully ZE by 2030 is unlikely to be feasible, as this will require terminal operators to get rid of substantial quantities of equipment with some useful life remaining. However, if the rule is structured such that all new purchases from 2030 onward are required to be ZE, the feasibility of meeting this schedule will improve, although the schedule may still present substantial technical challenges. See Figure 1: CHE Technology Maturity Status, later in the report, for a summary of the technical and commercial status of various ZE and NZE equipment types.

INCENTIVE FUNDING

The most readily accessible incentive funding beginning in 2020 will be CARB's Clean Off-Road Equipment Voucher Incentive Project (CORE) administered by CALSTART on a first-come-first-serve basis. The program will likely provide incentives up to 80% of the capital cost differential between diesel and NZE/ZE equipment. Yard tractors can be purchased via CORE with voucher up to $180,000, plus an additional 10% ($18,000) for operations within a Disadvantaged Community (DAC). Currently, several off-dock City of Oakland and Port of Oakland tenants operate electric yard tractors at the former Oakland Army Base. These existing electric yard tractors were purchased through the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), a similar program to CORE that is out of money; future incentives will be received through CORE.

Yard tractors operating within marine terminals must be designed to support heavier loads than those that have been purchased for off-dock use. Yard tractors suitable for serving vessels at a marine terminal (on-dock) are in the demonstration phase.

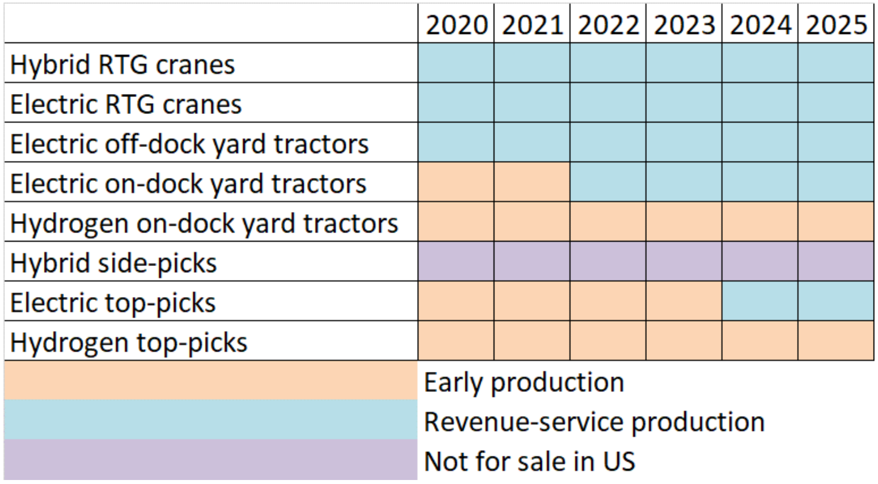
EQUIPMENT AND VEHICLE TECHNOLOGIES CONSIDERED

This analysis considered five types of CHE: on-dock yard tractors, off-dock yard tractors, RTG cranes, top-picks, and side-picks.

Advanced technologies to replace conventional equipment vary considerably in their current state of development. Current options for replacement include hybrid NZE equipment, alternative fuel engines that allow NZE operation (e.g., natural gas engines using renewable natural gas), battery-electric vehicles, hydrogen fuel cell vehicles, and terminal equipment that can be connected to the electricity grid through cables or bus bars. For example, hybrid RTG cranes, which use a battery with a small engine for repowering when energy recovery is insufficient to keep the battery charged, are part of the regular offering list from multiple large equipment vendors (e.g., Kalmar, Kone, and Paceco). On the other end of the spectrum, battery-electric top-picks are a few years away from early production. Furthermore, there are potential issues associated with the electrical vehicle charging equipment, including city electrical permit and inspector safety certification requirements, standardization of electric plug design between manufacturers, and the technological advancement of master controllers (power management) to charge vehicles sequentially and reduce peak demand.

Figure 1: CHE and Truck Technology Maturity Status shows a conceptual view of the availability of each type of equipment analyzed in this report. Although early production indicates prototypes exist and individual units may be available for purchase and testing by interested parties, large-scale production and purchases are not available. These early units will also generally be effectively custom-made as ordered and thus have much higher purchase costs and lead times than fully commercially available vehicles, as full commercial production requires much more robust manufacturing infrastructure and speed of delivery. Revenue-service production means vehicles are fully commercially available, and fleets of vehicles can be purchased as needed from equipment manufacturers. Except for battery hybrid RTG cranes and side-picks, all of these refer to fully electric vehicles. Other technologies, such as a hydrogen fuel cell top-pick and a hydrogen on-dock yard tractor are in the demonstration phase and have not yet reached early commercialization. Only a single prototype of each of the two hydrogen equipment types has been produced, so these have not been analyzed in detail. No OEM has announced plans to commercialize any type of hydrogen fuel cell CHE, so these are unlikely to be widely available in the near-term.

Figure 1: CHE Technology Maturity Status



	2020	2021	2022	2023	2024	2025
Hybrid RTG cranes	🟦	🟦	🟦	🟦	🟦	🟦
Electric RTG cranes	🟦	🟦	🟦	🟦	🟦	🟦
Electric off-dock yard tractors	🟦	🟦	🟦	🟦	🟦	🟦
Electric on-dock yard tractors	🟧	🟧	🟦	🟦	🟦	🟦
Hydrogen on-dock yard tractors	🟧	🟧	🟧	🟧	🟧	🟧
Hybrid side-picks	🟪	🟪	🟪	🟪	🟪	🟪
Electric top-picks	🟧	🟧	🟧	🟧	🟦	🟦
Hydrogen top-picks	🟧	🟧	🟧	🟧	🟧	🟧

🟧	Early production
🟦	Revenue-service production
🟪	Not for sale in US

Off-dock yard tractors offer the most detailed data, as there are four worldwide manufacturers (Orange EV, BYD, Kalmar, and Terberg) with battery-electric models as of late 2019. Most units are lighter-specification machines suitable for off-dock use only, not for heavier marine terminal applications, which comprise 90% of the Port's yard tractor fleet. A comprehensive cost analysis of these machines shows that they may save money compared to diesel today, and cost savings likely improve over time, as the price of electric vehicles is expected to drop due to decreases in battery prices and increasing production economies of scale. High capital costs, however, are a barrier to widespread adoption, and the availability of CORE vouchers to offset the higher purchase price of electric yard tractors is critical and will remain critical to users' widespread adoption.

Although the overall amount of electric power needed for CHE charging will be low in the near term compared to the current power used at the Port due to the relatively small number of units that will be deployed, the peak power delivery capacity required for charging on busy days may become substantial in the intermediate term. This can potentially be mitigated by pairing chargers with a battery buffer to limit the draw on the electric grid. Any such buffer (or other energy storage system) can be charged during off-peak hours, with the energy stored used to charge electric equipment during peak hours to avoid charging directly from the grid during peak hours. This can both reduce energy costs and spread out peak charging loads but would increase infrastructure costs related to implementing battery-electric equipment.

Hurdles to initial adoption of battery-electric on-dock yard tractors include operator concerns about either battery range or maximum allowed cargo-handling weight (ability to move up to 170,000 pounds) and uncertainty about the role of ILWU (International Longshore and Warehouse Union) and IAM (International Association of Machinists and Aerospace Workers Union) labor in plugging and unplugging vehicles. As these issues are better understood, on-dock electric yard tractors may become a more appealing option in the intermediate term.

This assessment focuses on battery-electric yard tractors as the most appealing zero-emissions CHE at marine terminals because the state of battery-electric yard tractor development is advanced enough to allow a preliminary cost analysis. Other options exist, including hydrogen fuel cell vehicles or internal combustion vehicles using alternative and renewable fuels, but these vehicles have downsides in terms of current development status, cost, fuel availability, local emissions, or upstream emissions compared to battery-electric vehicles. An ongoing effort to increase renewable power to the California electric grid may eventually allow electric equipment to be paired with zero-emissions electricity for true zero-emissions operations. Regardless of if or when the California electric grid becomes 100% renewable, the fraction of renewable power is expected to increase every year for the foreseeable future.

CONTAINER TERMINAL OPERATIONS

Five primary types of CHE are used at the Seaport to handle containers within the marine terminals and at off-dock facilities:

- Ship-to-shore (STS) cranes
- RTG cranes
- Top-picks
- Side-picks
- Yard tractors (on-dock and off-dock)

Figure 2: Import Container Move Schematic Example shows a schematic of how this equipment is used for a typical import container move (i.e., taking a container from a ship to the marine terminal to a drayage truck). For imports, an STS crane removes the container from the vessel and places it on a yard tractor. A top-pick moves the container from the yard tractor to the stacked containers in the yard. When a drayage truck is ready to receive a container, an RTG crane moves the container from the stack onto the truck. When a container is brought to a marine terminal for loading onto a ship (an *export move*) only top-picks are used. The top-pick moves the container from the drayage truck to the stack, and then from the stack to a yard tractor. The yard tractor then brings the container to the STS crane for loading onto the vessel. This practice is why top- and side-picks are far more numerous than RTG cranes at U.S. West Coast container terminals, and why commercial availability of ZE top-pick models is crucial to transitioning the U.S. West Coast to fully zero-emission terminal operations.

Figure 2: Import Container Move Schematic Example

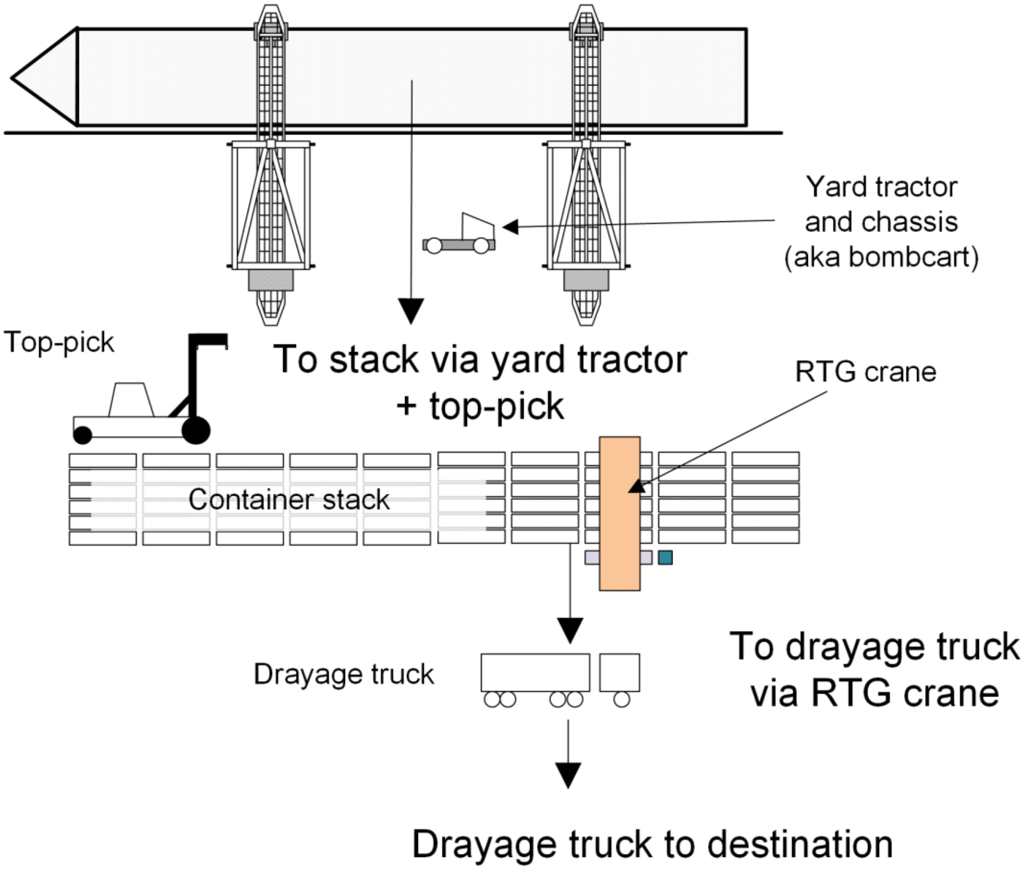


Figure 3 shows example images of top-picks and RTG cranes.

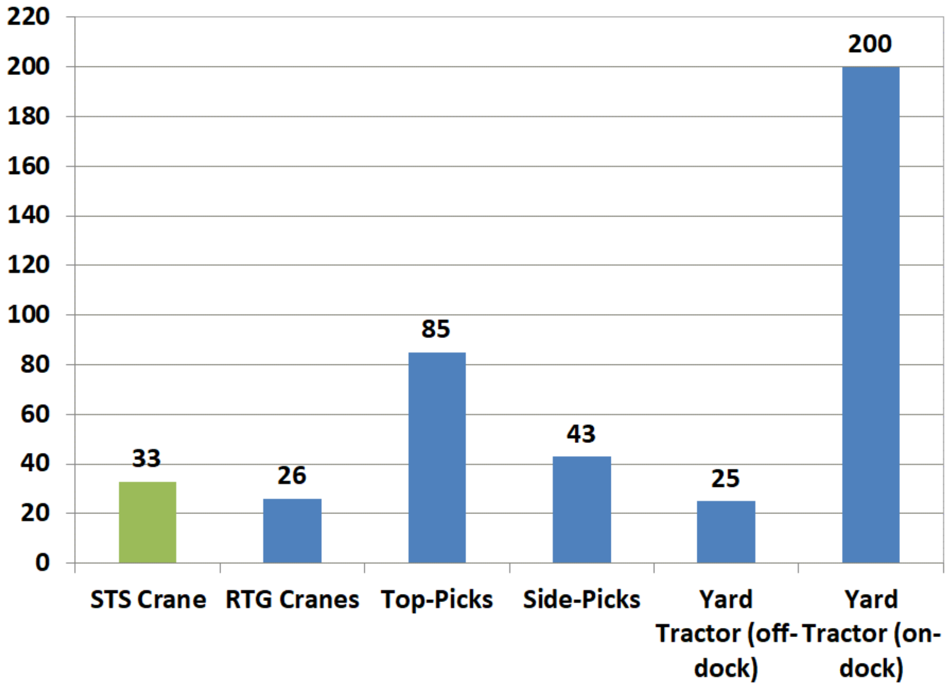
Figure 3: Top-Pick (left) and RTG Cranes (right)

Note:

Source: Diane Heinze, Port of Oakland. 2019.

Figure 4 shows the inventory of each piece of CHE at the Port.

Figure 4: Port-Wide CHE Equipment Inventory



Source: Diane Heinze, Port of Oakland. 2019.

CURRENT STATE OF ZERO-EMISSIONS VEHICLE TECHNOLOGY

The STS cranes in Oakland are powered by electricity delivered via high-voltage cables. All the STS cranes are 100% electric and no batteries are involved with their operation.

Although approximately 25% of the global fleet of RTG cranes also runs on electric power delivered by cable or bus bar, this type of landside infrastructure is incompatible with the standard stevedoring practice on the U.S. West Coast, which is to use top-picks to place import containers into a stack and RTG cranes to extract containers for drayage trucks (see Figure 2: Import Container Move Schematic Example). For this reason, hybrid-electric RTG cranes appear to be the most appealing option to reduce emissions from this class of CHE in the near to intermediate term. Hybrid RTG cranes are currently available from multiple equipment vendors (e.g., Mi-Jack, Kalmar, Kone, and Paceco). SSA Terminals, which operates Oakland International Container Terminal (OICT) and Matson Terminal, is in the process of replacing 13 1,000-horsepower engines with 142-horsepower engines via the hybrid-electric RTG project.

As described above, and as Figure 4: Port-Wide Cargo-Handling Equipment Inventory shows, top-picks are a much more common CHE than RTG cranes in Oakland. At present, there are no commercially available battery-electric or hydrogen top-picks. A few electric top-picks have been developed as custom conversions for demonstration purposes, as has one hydrogen unit, but the cost of these machines will probably not indicate what original equipment manufacturers (OEMs) will charge customers in the future. Fully battery-electric top-picks are under development. Hybrid-electric side-picks exist but are only suitable for lighter applications (empty containers) and no models are available for sale in the US market. No hybrid top-picks are available. Development of fully battery-electric top-picks is driven largely by interest in transitioning to full zero-emissions operations in California. Therefore, developing a fully electric top-pick is of greater interest than the interim step of hybridizing. Because hybrid top-picks are not currently commercially available or under development, hybrid top-picks costs were not analyzed in detail.

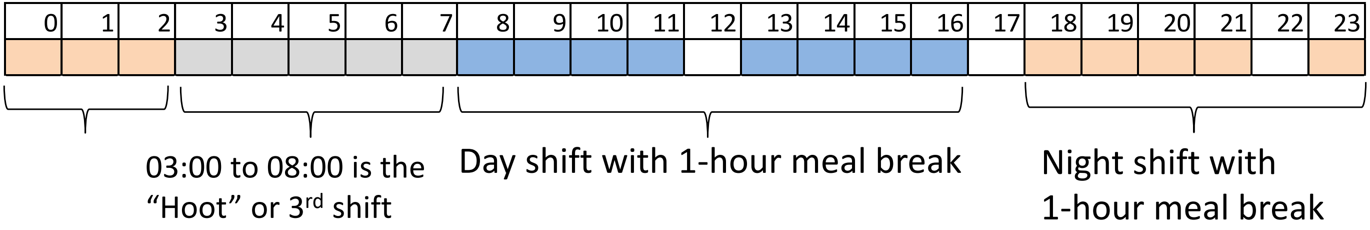
There are indications that fully electric top-picks will be available in the intermediate term (2023-2030). Through a variety of grant funding sources, the Port of Long Beach plans to test five electric top-picks at three separate facilities in the near term. In addition, the Kalmar website states:

> "Kalmar announced that our full offering will be available as electrically powered versions by 2021. Why have we taken such a leap with our entire product portfolio? Because the industry demand is there, and it's growing much faster than anyone could have anticipated only a few years ago" (Kalmar Global 2018).

As previously mentioned, operating hours per charge and labor rules regarding plugging in equipment are major issues limiting the enthusiasm of marine terminal operators for battery-electric yard tractors.

Figure 5 shows the standard working hours for the ILWU, the union responsible for stevedoring operations (loading and unloading of ships) on all U.S. West Coast marine terminals (IAM also operates at OICT and Matson Terminal but is not directly involved in stevedoring).

Figure 5: ILWU Work Hours

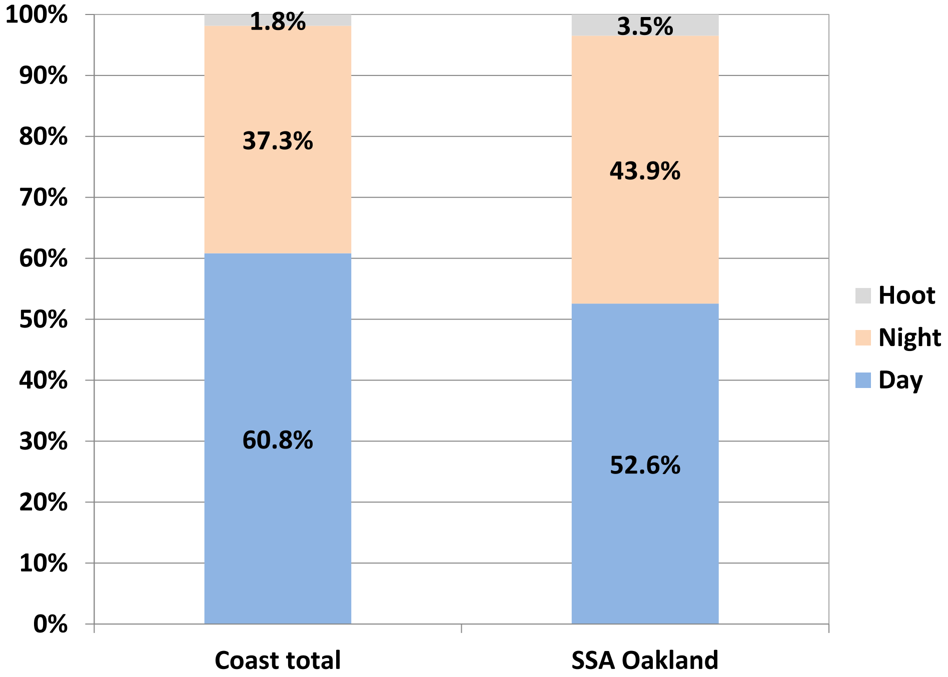


Note:

Source: Andrews 2018, Bauer 2018, & Gagnon 2018.

Figure 6 shows a breakdown of the total shifts worked in 2017 at the terminals on the entire U.S. West Coast versus the total shifts worked at OICT in Oakland, showing that hoot shifts are worked occasionally, but vessel operations are dominated by day and night shift activity.

Figure 6: Shifts Worked in 2017 at OICT versus U.S. West Coast Container Terminals



Notes:

OICT = Oakland International Container Terminal
SSA = SSA Terminals

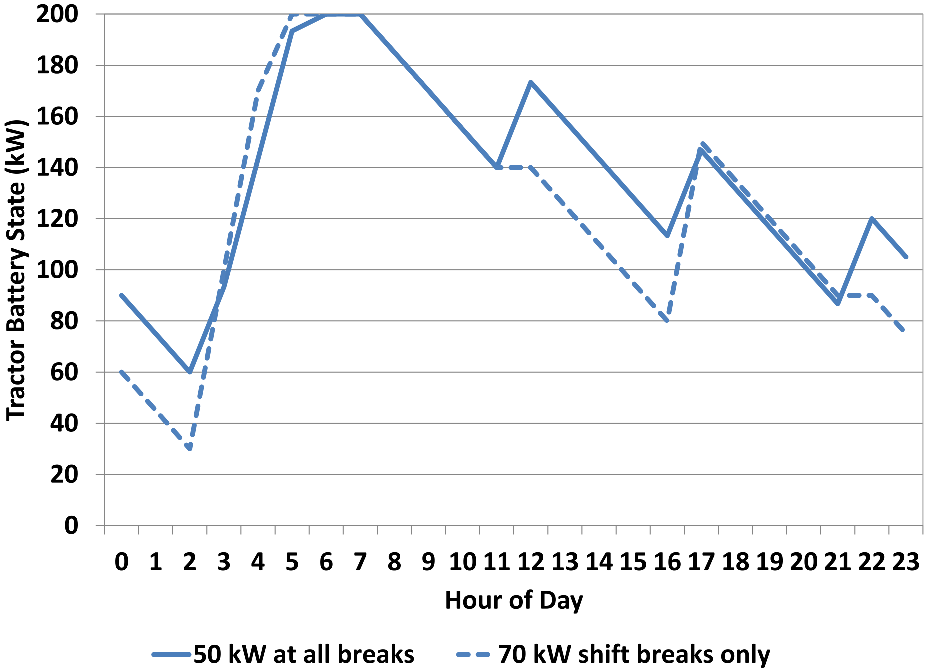
Sources: *Pacific Maritime Association 2017 Annual Report* (PMA 2018)*;* Susan Ransom, Customer Support Manager, SSA Terminals, and Jim Rice, General Manager of OICT, SSA Terminals, email to Port of Oakland staff, October 16, 2018.

The primary opportunity for electric vehicle charging is the 5-hour *hoot* shift between 3:00 a.m. and 8:00 a.m. An ideal equipment specification for the Oakland market would have a battery large enough to last 20 operating hours. If a marine terminal yard tractor uses perhaps 15 kilowatt-hours (kWh) per hour, roughly three times more than a non-Port yard tractor (conversation between Port staff and Bill Aboudi, owner of AB Trucking, 2018), a battery of about 220 kW would be sufficient if the vehicle could be charged between the day and night shift breaks. This is approximately equal to the maximum battery sizes currently offered from manufacturers. There are days when all three shifts are worked—this analysis considers an average day, recognizing that in reality, electric yard tractor charging solutions may sometimes need to accommodate the maximum three-shift usage scenario. The two-shift scenario is based on being able to fully recharge tractors overnight during the third (hoot) shift.

Figure 7 shows two potential battery use and recharge patterns during a two-shift workday for a nominal 200 kWh battery. A 200-kWh battery was selected as a value near the top-end of current electric on-dock yard tractor models for sale. For 16 hours of work at 15 kWh per hour, an electric yard tractor will require a total of 240 kWh per day if required for a full two shifts. With a 200-kWh battery size, this means some recharging over an hour-long shift, and lunch breaks may be required during peak operating conditions.

Both cases in Figure 7 assume the battery drains at a rate of 15 kWh per hour of operation, and any hour break would result in a net 40 minutes of actual recharge time. The solid bar shows a recharge rate of 50 kW over each shift break, meal break, and the hoot shift. The dashed line shows a recharge rate of 70 kW during shift breaks and the hoot shift only. Meal breaks are excluded due to uncertainty about whether vehicles can effectively be recharged during meal breaks; this uncertainty is based the fact that in current operations, yard tractors may not be parked in locations with charging stations over meal breaks. Either pattern shows that electric yard tractors have the potential to operate through a typical two-shift workday, with recharging as needed over shift changes and/or breaks.

Figure 7: Yard Tractor Battery State during a Two-Shift Workday



ELECTRICAL SYSTEM STATUS

UTILITY OPERATIONS AND TERRITORY

The Port of Oakland has been serving as a municipal utility since 1985, at a portion of the Seaport and the Oakland International Airport. The TraPac Terminal, the Ben E. Nutter Terminal, the Outer Harbor Terminal, Matson Terminal, and Howard Terminal all have Pacific Gas and Electric Company (PG&E) as their utility. The main Port utility customers include tenants at the former Oakland Army Base, OICT, Cool Port, and BNSF Railway. In addition, shore power (cold ironing) is also served by the Port utility, with the exception of Matson Terminal.

The Port and PG&E are on target to meet the requirements of the Renewable Portfolio Standards (RPS) and California legislative mandates, such as the recently passed Senate Bill 100 (SB 100), which updates the RPS requirements to 60% eligible renewable by 2030 and 100% carbon-free electric supply to end-use customers by 2045.

CARGO-HANDLING EQUIPMENT COST AND EMISSIONS ANALYSIS

AECOM analyzed the two cost recovery scenarios presented below for equipment types that have early commercial advanced technology replacement options. Evaluations are also included for drayage trucks and renewable diesel as a replacement fuel. This analysis includes equipment only, not infrastructure.

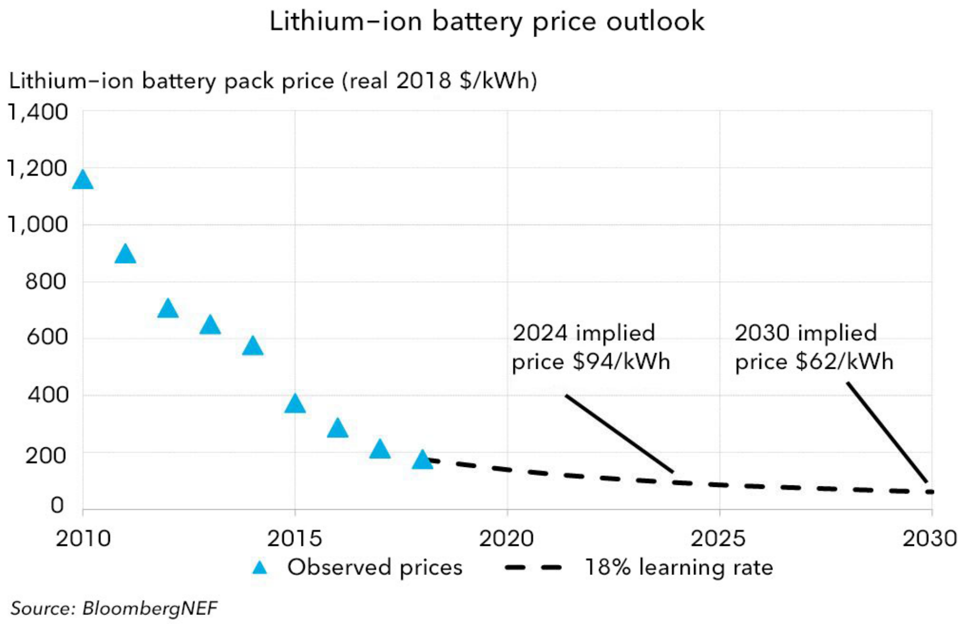
ELECTRIC VERSUS DIESEL YARD TRACTORS (ON- AND OFF-DOCK)

In the near to intermediate term, electric vehicles will cost more to buy than diesel equivalents but will likely save on maintenance and fuel costs. Subsidy programs in California can defray most of the difference in the purchase price between diesel and electric vehicles. Previously, the HVIP program had $78 million in funds for this purpose from California's cap-and-trade revenue, and the program’s stated goal was to reduce the purchase cost difference in zero-emissions and conventional equipment by 80%. A similar program, CORE, will be available in 2020.

An electric yard tractor may cost more than double what a comparable new diesel yard tractor costs in 2019 This is due to the relatively high cost of batteries and the very low production volume that increases the design and manufacturing cost per unit. In addition to the higher upfront costs, these yard tractors have a longer delivery time than their diesel counterparts and are not available from the lot. However, it is expected that the price of the lithium-ion batteries powering the electric yard tractors will continue to decline for the foreseeable future.

Figure 8 is a chart of the future predicted price of lithium-ion batteries, generated by Bloomberg New Energy Finance.

Figure 8: Predicted Lithium-Ion Battery Price



Notes:
kWh = kilowatt-hour
Li-ion = lithium-ion
Source: BloombergNEF 2018.

According to Figure 8 above, a 200-kWh battery that costs $40,000 or more in 2019 may cost as little as $12,400 (in 2018 dollars) in 2030. This trend, along with increasing scales of commercial production over time, will drive down the prices and price premium of electric yard tractors versus diesel machines over time.

As an example of this, consider the comparison of costs in 2019 versus 2025 for off-dock yard tractors. A new diesel yard tractor will cost $115,000 (in 2019 dollars) for both years. With 12% tax and fees included, a new diesel yard tractor will cost approximately $129,000 to purchase. A new off-dock electric yard tractor currently costs about $274,000 including tax but the purchase price can be reduced 80% with a CORE voucher. Accounting for a voucher value of 80% of the additional cost for electric versus diesel, this yields a voucher of $104,000 in 2019, for a net retail price of $170,000.

By 2025, the retail price of an off-dock electric yard tractor may decline to approximately $208,000 including tax due to lower battery costs and commercialization scale. The rebates available will decline along with the difference in price between diesel and electric, so the 2025 voucher is expected to be

$56,000, for a net price of $154,000, which is about $24,000 higher than a diesel yard tractor. Whether CORE vouchers will be available after 2023 is unknown, and this may have a substantial impact on cost trends; without them, the 2025 example case will cost equipment buyers $71,000 more per yard tractor.

Electric yard tractors will generate savings in both maintenance and energy compared with diesel yard tractors, based on preliminary operating data from existing in-use electric yard tractors as well as current diesel fuel and electricity costs. However, these on-dock tractors are likely to incur some operating cost for the labor to plug and unplug the vehicles, as drivers of electric yard tractors are not likely to plug and unplug their own vehicles. Alternatively, some operators have expressed a preference for an automated mode of charging such as inductive charging; this is under development.

Beginning in January 2019, additional electric yard tractor savings may be realized from Low Carbon Fuel Standard (LCFS) credits. Depending on the sale price of the LCFS credits, and the costs to administer the LCFS program and monetize LCFS credits, LCFS credits could be used to offset the cost of electric yard tractors.

The following assumptions were used to derive operating expense savings for electric yard tractors, with differences for on- versus off-dock units noted:

- Operating hours per year: 1,600 hours per year on-dock vs. 1,000 hours per year off-dock, both growing at 1.2% per year
- Diesel tractor maintenance cost: $30/operating hour on-dock; $25/operating hour off-dock
- Electric tractor maintenance cost is 2/3 of diesel maintenance ($20/hour on-dock vs. $17 off-dock)
- 2.5 gallons of diesel burned at $3.50 cost per gallon = $8.75 per hour fuel cost
- Electricity consumption & costs, including LCFS credits:
  - LCFS credits generate around $0.16/kWh at $125/credit. After about 20% broker fees, this reduces electricity costs by about $0.13/kWh
  - Electricity costs are about $0.15/kWh; after LCSF credits this is $0.02/kWh
  - On-dock: 15 kW used at a mean rate of $0.02/ kWh = $0.33/hour cost
  - Off-dock: 10 kW used at a mean rate of $0.02/ kWh = $0.22/hour cost

Figure 9 shows a comparison of the total annual cost of an on-dock electric versus a diesel yard tractor based on 2018 values, while Figure 10 shows this comparison for off-dock electric tractors. With CORE vouchers, the all-in annual cost to purchase and operate an electric vehicle may already be less than that of a diesel yard tractor, considering vehicle costs only. However, infrastructure costs are not included and will add to the total cost of owning and operating an electric yard tractor. It should also be noted that this cost estimate assumes relatively problem-free operations.

Figure 9: Annualized <u>On-Dock</u> Yard Tractor Cost Comparison (2019)

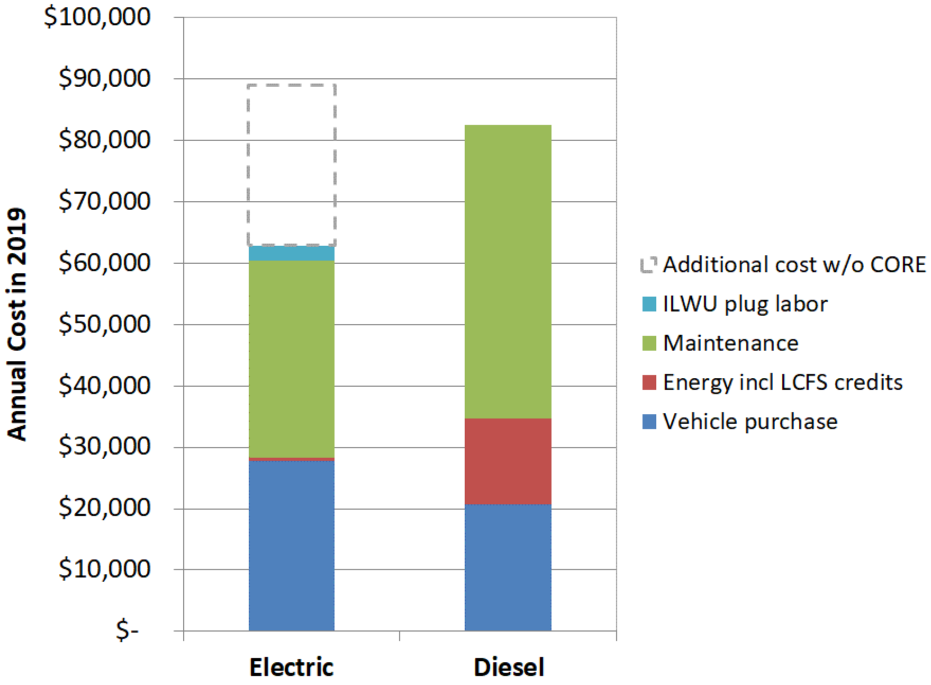
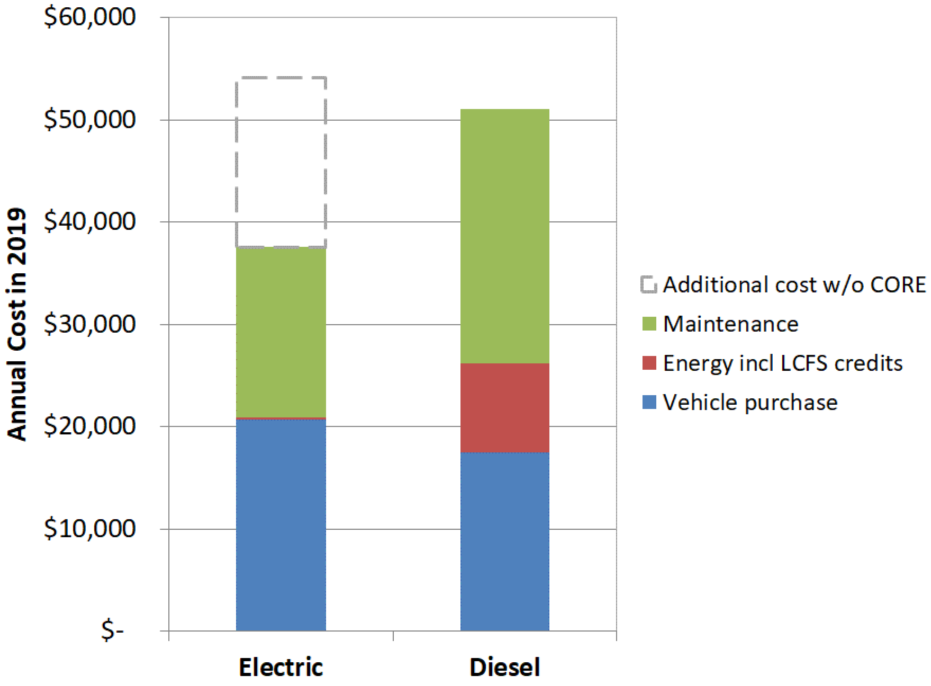


Figure 10: Annualized <u>Off-Dock</u> Yard Tractor Cost Comparison (2019)

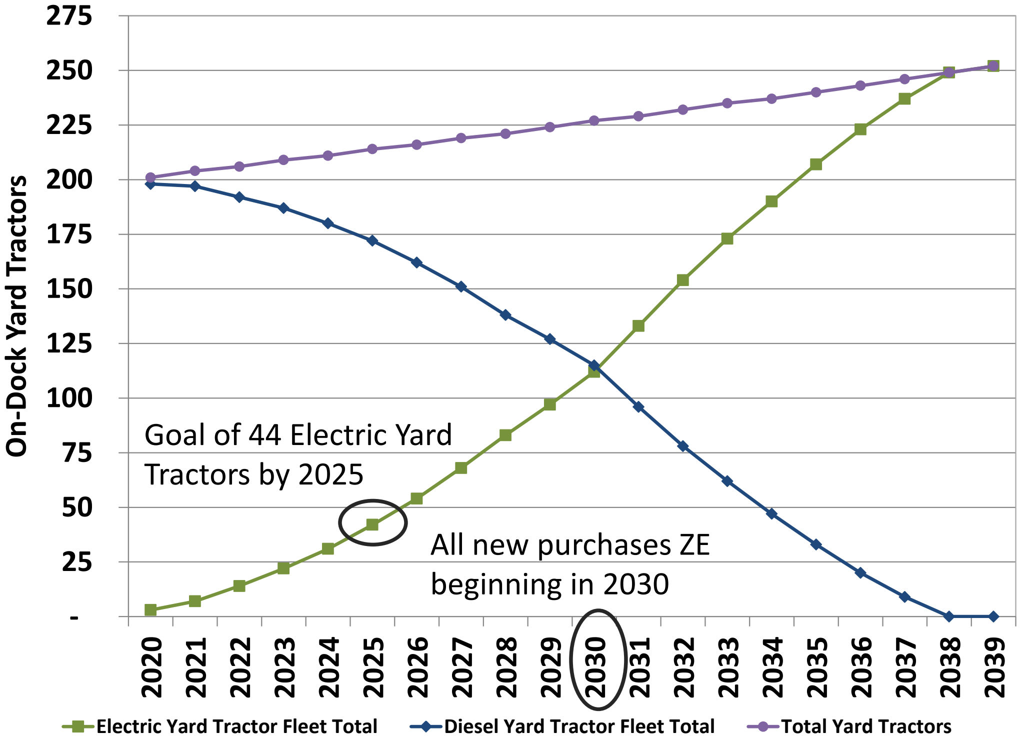


On a purely financial basis, electric yard tractors seem appealing at present with subsidies, and this equipment will get more appealing over time. Despite this, it is difficult to predict the rate at which operators will adopt this equipment. Operators are concerned about the lack of real-world data in marine terminals regarding battery range, load capacity, and durability (how long the vehicle will actually last), as well as the uncertainty regarding plug in and unplug labor protocols and the availability of parts and repair service. For businesses that typically purchase used equipment, the higher capital expenses may be more of a deterrent, even if the operating expenses are lower, and current equipment may not be fully amortized yet. Smaller operators may not be able to afford the equipment and/or banks may be unwilling to provide financing for equipment that does not have a proven track record.

The makeup of the overall fleet of vehicles at the Port will change gradually because a typical diesel on-dock yard tractor has a useful life of approximately 8 years, according to interviews with each of the marine terminal operators. It is unlikely that operators will replace equipment before the end of its useful life, so it is assumed that one-eighth of the Port fleet of 200 yard tractors will be replaced each year on average.

Figure 11 shows the assumed electric (versus diesel or gasoline) yard tractor fleet sizes at the Port over the next 20 years. This analysis assumed that beginning in 2030, all new yard tractors purchased will be electric. Prior to that, the fraction of electric yard tractors bought ranges from about 10% to 60%. New purchases to accommodate volume growth are also included, and a larger total yard tractor fleet size is therefore expected in 2039 rather than 2020.

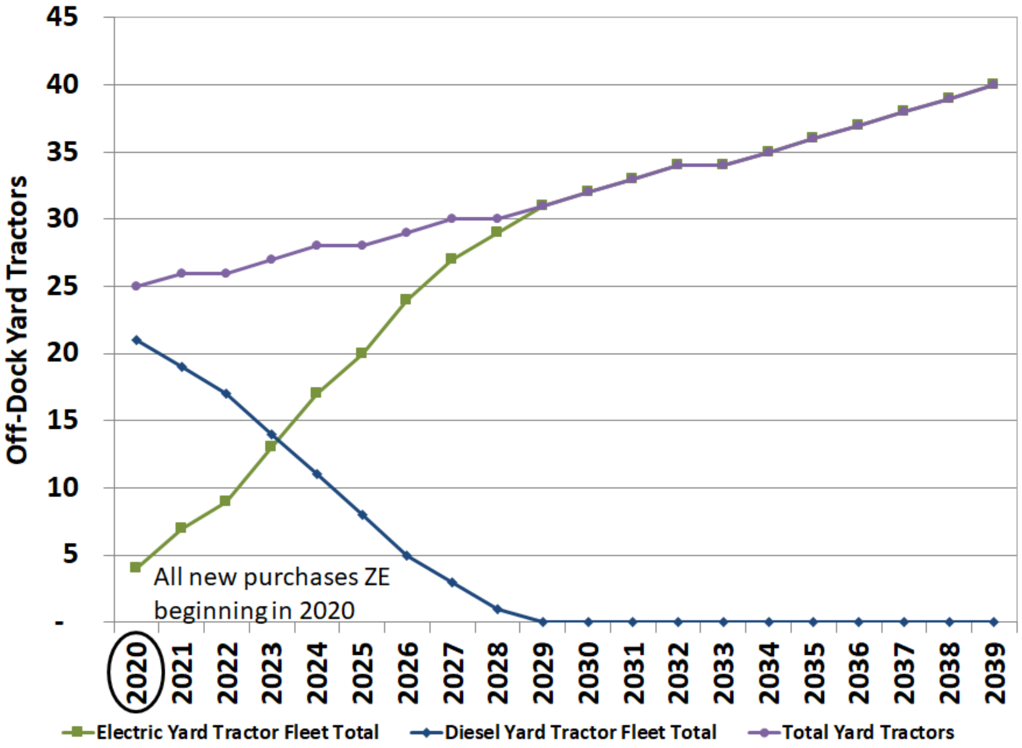
Figure 11: Assumed Fraction of On-Dock Yard Tractors Using Electric Power versus Petroleum Fuels



Note: The goal of 44 electric on-dock yard tractors by 2025 was approved by the Board of Port Commissioners in June 2019

Based on the goal of having all new off-dock yard tractors purchased as electric beginning in 2020, and the small existing off-dock tractor fleet size (25 total), the feasible timeframe to convert all existing petroleum based off-dock tractors to electric could be sooner than on-dock tractors, as shown in Figure 12.

Figure 12: Assumed Fraction of Off-Dock Yard Tractors Using Electric Power versus Petroleum Fuels



ELECTRIC TOP-PICKS

Electric top-picks are a potentially promising new technology under development that could lead to substantial CHE-related emissions reductions, if proven feasible. After yard tractors, top-picks are the most common type of on-terminal container handling equipment at the Port, and they contributed 45% of diesel particulate matter (DPM) from cargo-handling equipment in 2017 (Ramboll 2018: Table 4-3).

Although the feasibility of electric top-picks is not yet established, there is a pending demonstration projects in the near term:

- SSA Marine at Port of Long Beach Pier J will be testing two battery-electric top-picks, and the demonstration phase is expected to be complete in 2020.

HYBRID VERSUS PURE DIESEL EQUIPMENT

RTG Cranes

AECOM developed a cost analysis for hybrid RTG cranes, which is presented below. Hybrid RTG cranes (as opposed to fully electric cranes) were included because they are both commercially available and compatible with existing operations at the Seaport.

Note that RTG cranes are a very different type of equipment than the yard tractors analyzed in previous sections (see the example in Figure 3). RTG cranes lift containers out of stacks and place them onto yard tractors, resulting in very high-power loads and thus requiring a grid-connected system for fully electric operations (typically a cable-reel or bus bar). Although fully electric RTG cranes are also available worldwide, they are not compatible with the U.S. West Coast practice of placing imports coming off a vessel into stacks with a top-pick and retrieving them with an RTG crane (see the previous section, Background: Container Terminal Operations).

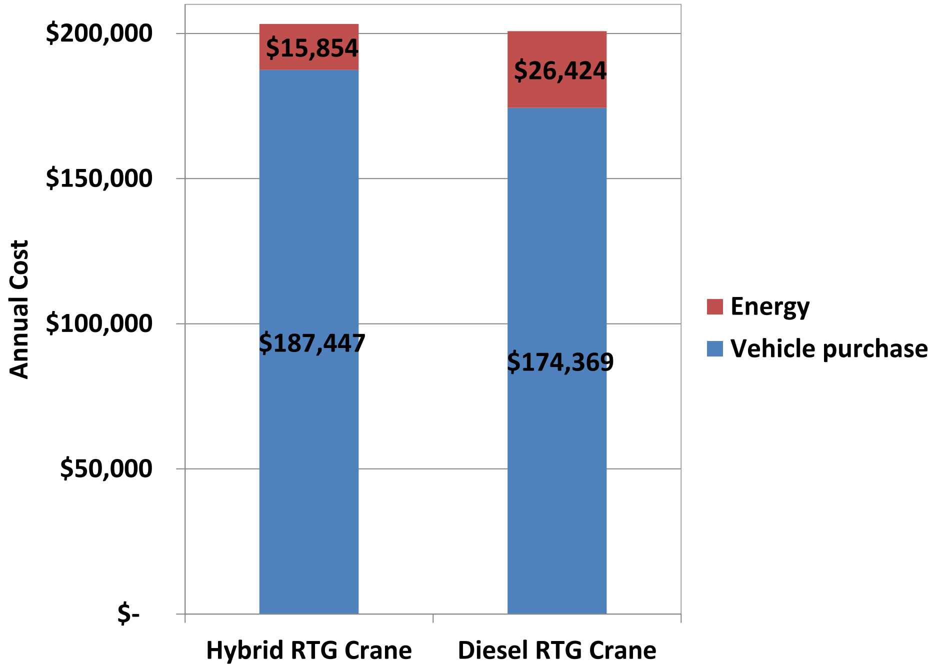
Key assumptions used to analyze the cost of hybrid versus pure diesel RTG cranes were:

- A new hybrid RTG crane costs $150,000 more than a pure diesel RTG crane ($2.15 million versus $2.00 million, respectively).
- Both diesel and hybrid RTG cranes have a 20-year machine life.
- Diesel RTG cranes burn on average 6 gallons of diesel per operating hour.
- Hybrid RTG cranes reduce fuel consumption by 40% (to 3.6 gallons per hour).
- The cost per gallon of diesel and associated diesel exhaust fluid is $3.50.
- The mean current RTG crane utilization is 1,200 hours per year.
- There is no difference in annual hybrid versus pure diesel maintenance costs.

Note this analysis is based on purchasing new hybrid RTG cranes, not retrofitting existing equipment, as the latter is a much more costly tactic, at roughly $500,000 per retrofit. Retrofits would only be feasible if supported by grant funding, as was done by SSA Terminals at OICT, but additional grant funding for hybridizing may not be available. Hybridizing RTG cranes through regular ongoing equipment replacement schedules would take on the order of two decades to complete, as some of the remaining 13 pure diesel RTG cranes at the Seaport are relatively new and will likely not be replaced for many years. The typical life of an RTG crane is about 20 years, more than twice the average life of a yard tractor.

Figure 13 compares total annualized RTG crane purchase and fuel costs for hybrid versus pure diesel machines, at 1,200 operating hours per year. The chart shows little difference in annual cost between the two cases. Note that RTG cranes at the Seaport are currently operated at a fairly low level of utilization, which limits the potential cost savings that can be generated by reduced hourly fuel usage. Over time as volumes are expected to increase, additional savings with hybrid RTG cranes may be recouped through increased utilization and thus more annual fuel savings. Figure 13 does not include newly available LCFS credits, which can potentially be used to offset hybrid equipment costs.

Figure 13: Cost Comparison of Hybrid versus Pure Diesel RTG Cranes



Note:
RTG = rubber-tired gantry
Source: Port of Oakland 2019. Final Seaport Air Quality 2020 and Beyond Plan, Appendix F. June.

Other Hybrid Lift Equipment

Other commercially available hybrid lift equipment includes reach stackers from Kone cranes and side-picks manufactured by CVS Ferrari. Reach stackers are similar to top-picks with rotation and multiple row-stacking capability, while side-picks lift only empty containers. Reach stackers are not used in regular operation at any Seaport container terminal, so hybrid reach stackers were not analyzed as part of this study. While a hybrid side-pick model exists, CVS Ferrari does not sell these in the U.S. and only one unit is in operation in Europe. No hybrid top-picks (which have heavier duty cycles than side-picks, as they handle loaded containers) are currently commercially available.

Due to the expected regulatory push toward requiring ZE equipment in California, several tests of fully electric top-picks, supported by grant funding, are planned in the state in the near-term. There has been comparatively little interest in development of hybrid top-picks, as hybrid models may not meet the ZE regulations that are under development. Hybrids top-picks and side-picks may also be less financially appealing, as they will not generate the same level of operating expense savings to offset increased purchase costs as fully electric models.

REFERENCES

American Association of Port Authorities. 2018. Available at: https://www.aapa-ports.org/unifying/content.aspx?ItemNumber=21048#Statistics

Andrews, Michael. Terminal Manager, Everport Terminal Services. September 14, 2018. In-person interview with AECOM and Port of Oakland.

Bauer, Brian. Vice President, Operations, TraPac. September 4, 2018. In-person interview with AECOM and Port of Oakland.

BloombergNEF. 2018. New Energy Outlook (NEO). Bloomberg New Energy Finance. June. Available at: https://about.bnef.com/new-energy-outlook/.

Gagnon, Paul. Vice President, SSA Terminals. August 29, 2018. In-person interview with AECOM and Port of Oakland. October 2, 2018. Conversation with Port staff.

Kalmar Global. 2018. “Are you ready to be fully electric by 2021?” May 22. Available at: https://www.kalmarglobal.com/ news--insights/2018/20180522_are-you-ready-to-be-fully-electric-by-2021/.

Mitchell, Alexander. California Air Resources Board (CARB). Personal communication with Susanne von Rosenberg. 2018.

Mongelluzzo, Bill. 2018. “Gates Open for Imports.” *Journal of Commerce*, October.

Pacific Maritime Association. 2018. *2017 Annual Report*. Available at: http://www.pmanet.org/annual-report.

Piellisch, Rich. 2018. “Oakland and Renewable Diesel: ‘Not a Single Downside’.” *NGT News*, March. Available at: https://ngtnews.com/oakland-and-renewable-diesel-not-a-single-downside.

Port of Oakland Staff and Bill Aboudi, owner of AB Trucking. 2018. Conversation between Port staff and Bill Aboudi.

Port of Oakland Seaport Air Quality 2020 and Beyond Plan. June 2019. Available at: https://www.portofoakland.com/community/environmental-stewardship/maritime-air-quality-improvement-plan/

Port of Long Beach. May 2019. *Charging Ahead: The Port Community Electric Vehicle Blueprint*. Available at: http://www.polb.com/civica/filebank/blobdload.asp?BlobID=15071

Ramboll. 2018. *Port of Oakland 2017 Seaport Air Emissions Inventory Final Report*. August. Available at: http://www.portofoakland.com/files/PDF/Port_Oakland_2017_Emissions_Inventory.pdf.

Ransom, Susan, Customer Support Manager, SSA Terminals, and Jim Rice, General Manager of OICT, SSA Terminals. October 16, 2018. Email to Port staff.

San Pedro Bay Ports (SPBP). September 2019. *Clean Air Action Plan Final 2018 Feasibility Assessment for Cargo-Handling Equipment.* Available at: https://cleanairactionplan.org/documents/final-cargo-handling-equipment-che-feasibility-assessment.pdf/

Taylor. 2018. Zero-Emission Container Handler Preliminary Industrial Lift Truck Specification Sheet. September.

The Tioga Group, Inc. (Tioga). 2016. Port of Oakland Truck Parking Report.