# Port of Oakland Seaport Air Quality 2020 and Beyond Plan: The Pathway to Zero Emissions

## Technical Memoranda for Quantitative Analyses to Support Evaluation and Prioritization of Screened Actions

PORT OF OAKLAND

May 2020

# Introduction

This report comprises four technical memos documenting the assumptions, methodology, and results of quantitative analyses used in the evaluation of Group 1 Screened Actions for the Port of Oakland Seaport Air Quality 2020 and Beyond Plan. The emissions analyses and accompanying memos were prepared by Ramboll. For details on how the actions were selected for quantitative analysis, please refer to the Memorandum: Evaluation and Prioritization of Screened Actions (April 2020), in particular the discussion on page 12 and summary in Table 1.

This report is organized as follows:

- Context for Emissions and Health Risk
- Memo on Locomotive Emissions Calculations for:
    - Clean Locomotive Program (Tier 4 Engines)
    - Electrical Switchers at OGRE and BNSF Yards
- Memo on Ocean-Going Vessel Emissions Calculations for:
    - Clean Ship Program (Tier 2 & 3 Engines)
- Memo on Tug Emissions Calculations for:
    - Tug Repower and Replacement
    - Tug Retrofit with Diesel Particulate Filters
    - Use of Renewable Diesel in Tugs
- Memo on Truck Emissions Calculations for:
    - Increased Double Cycling
    - Zero Emissions Trucks to Move Containers To/From Off-Dock Container Yards

The next section provides context for the emissions produced by Port-related activity, and the accompanying human health risk for Port workers and residents in the nearby community of West Oakland.

# Context for Emissions and Health Risk

This section provides background information about the emissions and health risk to West Oakland residents from sources related to Port activity. Data cited here are from the West Oakland Health Risk Assessment conducted by the Bay Area Air Quality Management District (BAAQMD) during development of the West Oakland Community Action Plan (WOCAP) in late 2019[1]. Sources addressed in the attached technical memos are highlighted yellow in the graphs below, to give the reader context on their magnitude and comparative impacts.

Figure 1 shows the modeled health impact (vertical axis) and diesel particulate matter (DPM) emissions (horizontal axis) of various sources operating near West Oakland in 2017. Sources higher up in the graph, such as non-Port trucks on the streets and highways, have the biggest health impact. Sources farther to the right in the graph, such as tugs and ships berthing and maneuvering, have the highest emissions. These waterborne sources, however, have lower health impacts than non-Port trucks because they occur farther away from the community.

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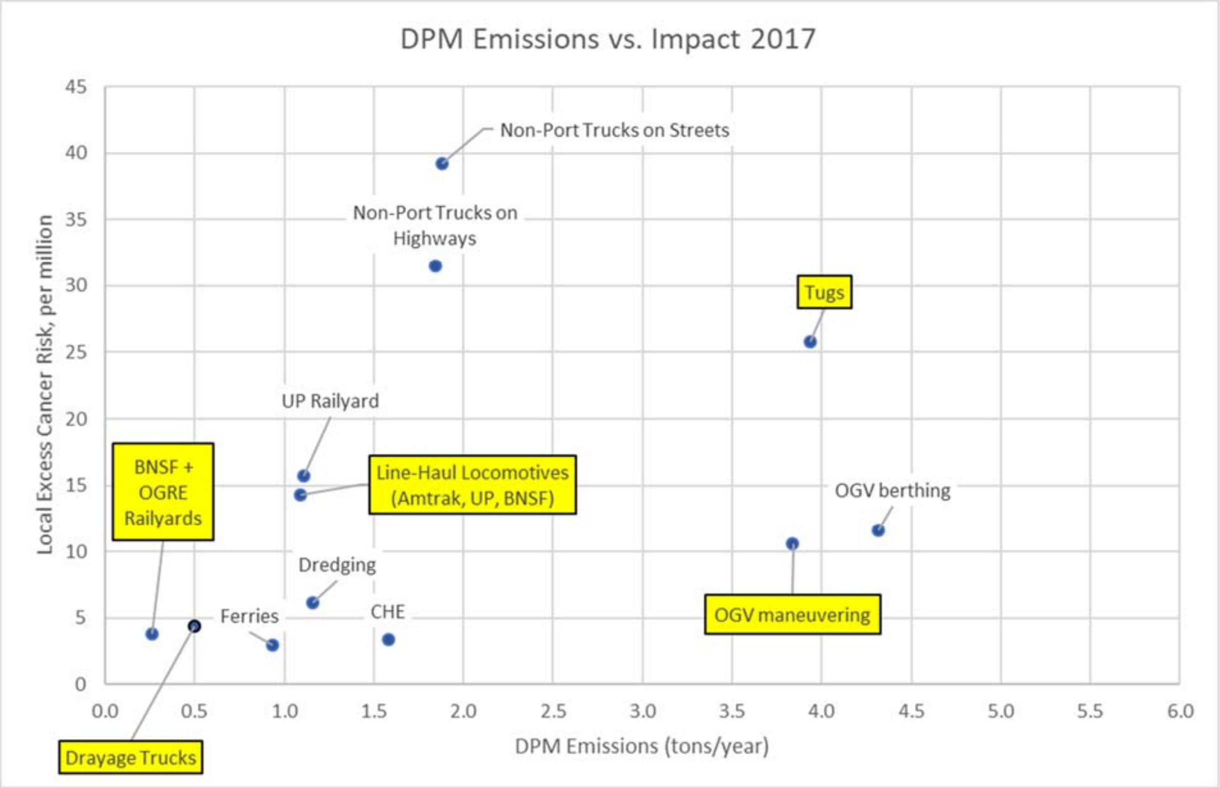
[1] "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October 2019.

*Figure 1: DPM Emissions vs. Impact in 2017*



Source: Port of Oakland using BAAQMD data from Public Record Request #2019-10-0109

Figure 1 shows that in 2017, the two sources with the least emissions and least health impact were the BNSF and OGRE railyards and drayage trucks. The drayage truck estimate includes drayage trucks driving on streets and highways, not just on terminals. Non-Port trucks are not subject to CARB's Drayage Truck Regulation, which is why their emissions are greater than trucks serving the Port. Non-Port trucks also tend to operate closer to and within the community more frequently than drayage trucks. As a result of their higher emissions and greater proximity to residences, the aggregate health impact of non-Port trucks is greater overall and on a per ton of emissions basis than that of drayage trucks.

Figure 2 shows the same graph for 2024, as forecasted by the BAAQMD as part of the same Health Risk Assessment done in 2019. Figure 2 shows the "Without WOCAP," or Business As Usual case, which represents the forecast without any of the WOCAP actions.[2] This can be used as a baseline forecast. Any of the reductions quantified in the four technical memos in this report would be on top of the reductions shown in Figure 2, which will be achieved by regulations and incentives already in place. The scale is the same on the two graphs, which helps the reader visualize the change in emissions and impact.

It is important to note that the BAAQMD assumed 5% year-over-year growth in the number of ship calls and the volume of cargo from 2017 to 2024. This is contrary to recent trends. The number of ship calls

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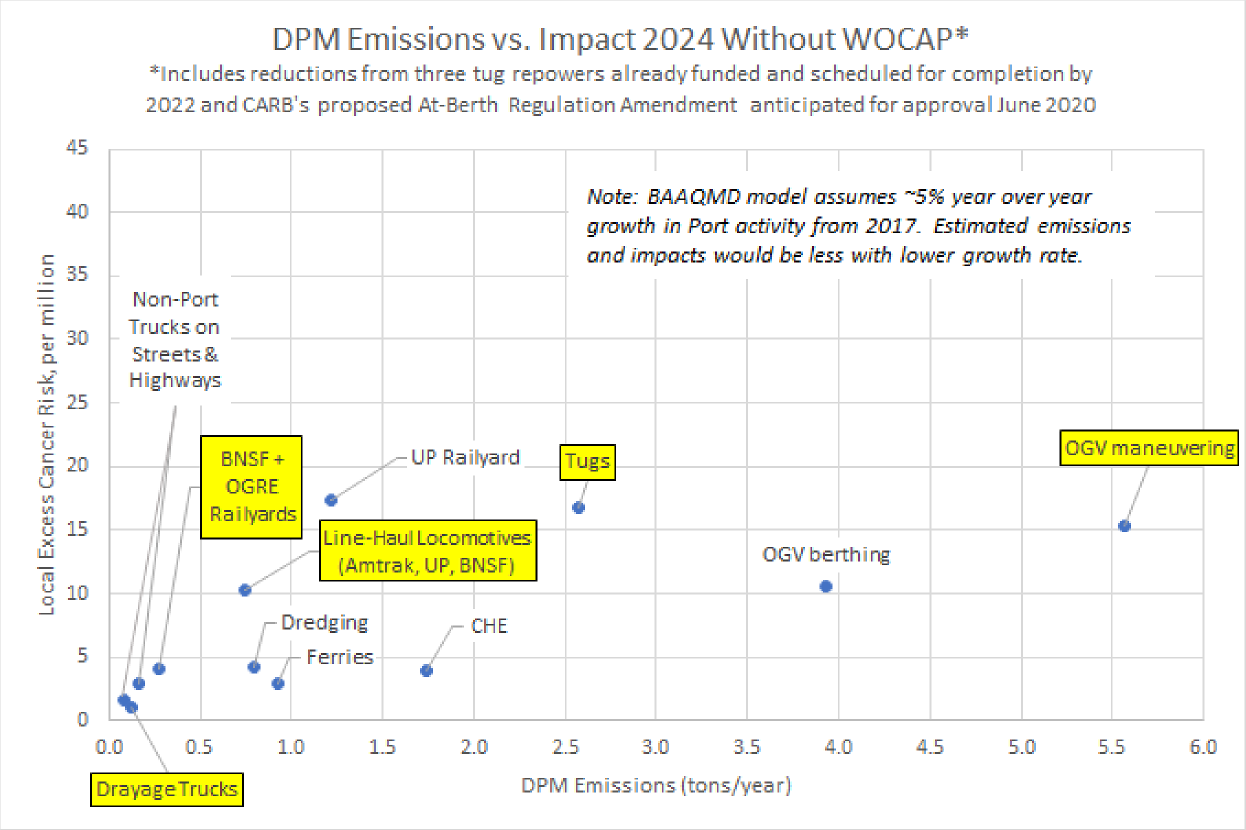
[2] Two actions which the BAAQMD considers part of the WOCAP are included in Figure 2. The BAAQMD incentivized three tug repowers which are scheduled for completion before 2022. The California Air Resources Board has proposed an amendment to its At-Berth Regulation which is expected to be approved in June 2020. These two actions are included in Figure 2 because of their relative certainty.

per year to the Port of Oakland has been decreasing since 2016 as ships get larger and carry more cargo per call. Furthermore, the Port's compounded annual growth rate between 2009 and 2019 was 2%. The global pandemic due to COVID-19 will almost certainly result in a further reduction in both ship calls and cargo, although the extent, duration, and recovery are not yet known. Therefore, the actual emissions and health impact for sources related to Port activity in 2024 are likely to be lower than shown in Figure 2.

*Figure 2: DPM Emissions vs. Impact in 2024 Without WOCAP*



Source: Port of Oakland using BAAQMD data from Public Record Request #2019-10-0109

This graph shows that the emissions and health risk from waterborne sources remain high (which would be the case even without the overestimate of emissions from waterborne sources due to the assumed and improbable 5% growth rate). This graph also shows that emissions and health impact from trucking decrease dramatically from 2017 to 2024 without the benefit of electrification; the emissions and health risk shown in the graph are associated with an essentially entirely diesel truck fleet, except for some demonstration projects. Due to CARB's Drayage Truck Regulation, trucks with model year 2009 and older engines will be banned from the Port at the end of 2022. CARB's Truck and Bus Regulation will ensure that emission controls for the non-drayage truck fleet "catch up" to the drayage truck fleet by the end of 2023.

The table below summarizes which of the highlighted sources are addressed by each technical memo. In some cases, only a subset of the highlighted sources are targeted by the strategies analyzed, as described in the Notes column.

| Technical Memo | Source highlighted in Figure 2 | Notes |
|---|---|---|
| Locomotives | Clean Locomotive Program: Line Haul Locomotives<br>Electrical Switchers: BNSF and OGRE Railyards | Clean Locomotive program would affect BNSF's share of emissions only, not Amtrak or UP. |
| Ocean-Going Vessels | OGV Maneuvering | Clean Ship Program for Tier 2 & 3 vessels would affect propulsion engines (used during maneuvering, but not while berthing). Higher Tier ship engines reduce NOx, not PM. |
| Tugs | Tugs | Tug repowers would affect tugs that are not already Tier 3 or 4. The analysis for installing filters is assumed to be in addition to Tier 4 repowers. The analysis for renewable diesel would affect all tugs in the baseline fleet, regardless of engine tier. |
| Trucks | Drayage Trucks | Truck studies such as double-cycling and using zero-emissions trucks for off-dock yards would affect a small subset of the drayage truck emissions. |

# MEMORANDUM

Date: **May 7, 2020**

To: **Tracy Fidell**

Cc: **Susanne von Rosenberg**

From: **Chris Lindhjem, Till Stoeckenius and Lit Chan**

Subject: **Line-Haul Locomotive Emissions Reductions**

## INTRODUCTION

This memorandum describes what effect increasing the fraction of Tier 4 line-haul locomotives arriving and departing the Port of Oakland (Port) leased railyards would have on emissions. Leased railyards at the Port are the Oakland International Gateway (OIG) operated by BNSF and the Outer Harbor Intermodal Terminal (OHIT) operated by Oakland Global Rail Enterprise (OGRE) and West Oakland Pacific Rail (WOPR) joint venture. This analysis forms a basis to analyze the impact that the West Oakland Community Action Plan (WOCAP)[1] strategy 64 might have:

> *"The Port of Oakland implements a Clean Locomotive Program to increase the number of U.S. EPA Tier 4 compliant locomotives used by the UP, BNSF, and OGRE railways to provide service in and out of the Port of Oakland."*

The UP railyard is not a Port tenant and is not located on Port property. Although it is mentioned in the WOCAP strategy, the UP yard is not included in this analysis. OGRE is a railroad servicing only local Oakland railyards and operates only switching locomotives.

While there is no federal requirement that railroads will upgrade their fleets, new locomotives will naturally turnover as the fleet ages. Therefore, we account for the normal turnover and estimate the benefit for accelerated turnover.

We also discuss here the feasibility of introducing electric switcher locomotives at the Port's railyards. This analysis forms a basis to analyze the impact that the WOCAP[2] strategy 65 (Screened Action 201) might have:

> *"The Port of Oakland studies the feasibility of using electric switcher locomotives at the two Port railyards."*

## LOCOMOTIVE FLEET CHARACTERIZATION

BNSF, which operates the OIG railyard, provided the line-haul locomotive fleet characterizations for calendar years 2015 and 2017. The engine certification tier level

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[1] WOCAP 2019. "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October.

[2] WOCAP 2019. "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October.

largely defines the model year groupings for the locomotives. The two-year (2015 to 2017) change in the fleet mix shown in Table 1 is indicative of the rate of fleet turnover to newer engines. Because Tier 0, 1, and 2 engines can be rebuilt to lower emissions, the original and rebuilt versions were grouped in the far-right column to better demonstrate the change in fleet mix.

**Table 1. Line-Haul Locomotive Fleet Turnover Estimates.**

| Tier | 2015 Fleet | 2017 Fleet | 2017 - 2015 | |
|---|---|---|---|---|
| | | | Difference | Change by Tier |
| N | 0.0% | 0.4% | 0.4% | 0.4% |
| 0 | 4.6% | 2.4% | -2.2% | -2.3% |
| 0+rebuild | 0.1% | 0.0% | -0.1% | |
| 1 | 3.9% | 2.7% | -1.1% | -6.7% |
| 1+rebuild | 33.4% | 27.8% | -5.6% | |
| 2 | 21.4% | 12.2% | -9.2% | 2.1% |
| 2+rebuild | 7.6% | 18.8% | 11.3% | |
| 3 | 27.9% | 31.8% | 3.8% | 3.8% |
| 4 | 1.2% | 3.9% | 2.7% | 2.7% |
| **Total Visits** | **1006** | **255** | | |

The future fleet turnover rate is uncertain because many business and technology factors affect the purchase of new and scrapping of older engines. For example, the United States Environmental Protection Agency (EPA) (2008)[3] estimated a 70-year life for switching engines and 40 years life for line-haul (though some line-haul locomotives transition to switching and short-line duty), which implies 1.4%/yr turnover to replace the fleet within 70 years. The California Air Resources Board (ARB) (2017)[4] estimated a 21-year life for line-haul locomotives, implying 4.8%/yr turnover. Both of these estimates assume no significant growth in the locomotive fleet. These values represent the range of normal turnover rates to newer (currently Tier 4) locomotives.

The normal turnover could be represented by the added fleet fraction of Tier 4 only, or the sum of the change in Tier 3+Tier 4, or the sum of change in Tier 2+Tier 3+Tier 4. Originally, the 2015 model year was the first year that Tier 4 locomotives were to be sold. However, as a result of delays in producing locomotives for market[5] and also perhaps either pre-buying of Tier 3 or reticence of the owner/operators to buy Tier 4 due to concerns about the technology or economic factors, the rate of turnover of Tier 4 locomotives may have been reduced. While the percent of Tier 2 locomotives (including rebuilds) increased from 2015 to 2017, it is unlikely that this increase represents turnover but rather is a result of some artificial, non-recurring aspect of the BNSF fleet demographic that encouraged Tier 2

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[3] EPA, 2008. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder," Assessment and Standards Division, Office of Transportation and Air Quality. EPA420-R-08-001, March 2008.

[4] ARB 2017. "2016 Line haul Locomotive Model & Update," October 2017. https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

[5] "*Since January 2015, U.S. EPA has allowed GE to sell Tier 3 credit locomotives (i.e., that meet U.S. EPA Tier 3 emissions levels) that can be offset by future orders of fully complying Tier 4 locomotives……EMD has publicly stated they will not produce full scale commercial production Tier 4 interstate line haul locomotives until at least late 2016 or early 2017.*" https://ww3.arb.ca.gov/msprog/tech/techreport/final_rail_tech_assessment_11282016.pdf

over older models. We believe that the [Tier 3 + Tier 4] turnover from 2015 to 2017 of 3.3% per year is a reasonable estimate of the normal fleet turnover.

Assuming a 3.3% turnover to Tier 4 with an equal across the board reduction in older models results in a summary of how the fleet might have changed from 2017 to 2020 and the forecasted fleet composition in 2023 shown in Table 2. The new Tier 4 fleet fraction would be matched by an equivalent reduction in Tier 0 and Tier 1 locomotives. We assumed that all remaining mandated rebuilds were completed by 2020. Over the next 7 years (from 2020 to 2027), Tier 1 would likely be reduced as more Tier 4 locomotives normally come into the fleet, and Tier 2 would be reduced after 2027.

**Table 2. Line-Haul Locomotive Fleet Normal Turnover Estimates.**

| Tier | 2017 Fleet | 2020 Fleet | 2023 Fleet | 2027 Fleet |
|---|---|---|---|---|
| N | 0.4% | 0.0% | 0.0% | 0.0% |
| 0 | 2.4% | 0.0% | 0.0% | 0.0% |
| 0+ rebuild | 0.0% | 0.0% | 0.0% | 0.0% |
| 1 | 2.7% | 0.0% | 0.0% | 0.0% |
| 1+ rebuild | 27.8% | 23.4% | 13.5% | 0.3% |
| 2 | 12.2% | 0.0% | 0.0% | 0.0% |
| 2+ rebuild | 18.8% | 31.0% | 31.0% | 31.0% |
| 3 | 31.8% | 31.8% | 31.8% | 31.8% |
| 4 | 3.9% | 13.8% | 23.7% | 36.9% |

## LINE-HAUL LOCOMOTIVE EMISSIONS

Locomotive emission factors are available from two sources: ARB and EPA.  This analysis relies on the ARB emission rates adjusted by EPA emission factors for newer locomotives for the reasons described below.

Locomotive emission estimates for line-haul and switching locomotives operating at the OIG railyard published in the Port of Oakland's Seaport Emission Inventories for 2005[6] and 2012[7] were based on emission rates (g/hr) by operating mode (also called notch setting). These emission rates were derived from emission test results published by ARB and Southwest Research Institute (SWRI) and were detailed in the Port of Oakland's Seaport Emission Inventory for 2005. The ARB/SWRI study results better reflect emissions for in-yard locomotive activity in contrast to travel between distant rail yards, which typically involves higher average operating loads. Emission rates by mode from the ARB/SWRI studies were only available for Tier 2 and earlier engine models and did not include the impact of rebuilds or newer engines.

Because the ARB emission rates are better for in-yard activity and do not include Tier 3 or higher locomotives, we relied on EPA[8] average emission factors to estimate the emission rates for newer locomotives.  We used ratios of the average EPA emission factors shown in Table 3) to determine the emission rate adjustments shown in Table 4. We multiplied the by-mode Tier 2 locomotive emissions by the Tier 3, Tier 4 and Tier 2+ rebuild adjustments

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[6] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

[7] https://www.portofoakland.com/files/pdf/environment/maqip_emissions_inventory.pdf

[8] EPA 2009. "Emission Factors for Locomotives," EPA-420-F-09-025 April 2009.

shown in Table 4. Similarly, the EPA's estimated benefit of Tier 1+ and Tier 0+ rebuilds were applied to Tier 1 and Tier 0 models respectively.

**Table 3. EPA[9] Line-Haul Locomotive Emission Factors (g/hp-hr)**

| Tier Level | HC | CO | NOx | PM |
|---|---|---|---|---|
| N | 0.48 | 1.28 | 13.00 | 0.32 |
| 0 | 0.48 | 1.28 | 8.60 | 0.32 |
| 0+ rebuild | 0.30 | 1.28 | 7.20 | 0.32 |
| 1 | 0.47 | 1.28 | 6.70 | 0.32 |
| 1+ rebuild | 0.29 | 1.28 | 6.70 | 0.20 |
| 2 | 0.26 | 1.28 | 4.95 | 0.18 |
| 2+ rebuild | 0.13 | 1.28 | 4.95 | 0.08 |
| 3 | 0.13 | 1.28 | 4.95 | 0.08 |
| 4 | 0.04 | 1.28 | 1.00 | 0.015 |

**Table 4. Line-Haul Locomotive Emission Rate Ratios**

| Tier Ratio | HC | NOx | PM |
|---|---|---|---|
| 0+ / 0 | 0.625 | 0.837 | 0.625 |
| 1+ / 1 | 0.617 | 1.000 | 0.625 |
| 2+ / 2 | 0.500 | 0.900 | 0.444 |
| 3 / 2 | 0.500 | 0.900 | 0.444 |
| 4 / 2 | 0.154 | 0.182 | 0.083 |

While using by-mode emission factors is the method used in the Port of Oakland's Seaport Emission Inventory, we used the EPA generic emission factors to gauge the relative (%) emission reduction expected with fleet turnover for purposes of evaluating the relative emission reduction resulting from turnover to Tier 4. Table 5 shows the average fleet emission factors that were estimated based on the EPA average emission factors by engine Tier level (from Table 3) combined with the fleet composition shown in Table 2.

**Table 5. Fleet Average Line-Haul Emission Factors (g/hp-hr) and Reductions (%)**

| Fleet Average | HC | CO | NOx | PM |
|---|---|---|---|---|
| 2017 Fleet | 0.21 | 1.28 | 5.45 | 0.136 |
| 2020 Fleet | 0.16 | 1.28 | 4.81 | 0.099 |
| 2023 Fleet (Accelerated turnover 2020 Fleet) | 0.13 | 1.28 | 4.25 | 0.081 |
| 2027 Fleet | 0.10 | 1.28 | 3.50 | 0.056 |
| **2020/2017 Emission Reduction** | **25%** | **0%** | **12%** | **27%** |
| **2023/2020 Emission Reduction** | **16%** | **0%** | **12%** | **18%** |
| **2027/2020 Emission Reduction** | **37%** | **0%** | **27%** | **43%** |

Table 5 also shows the emission reductions based on normal fleet turnover from 2017 to 2020, 2020 to 2023, and 2020 to 2027 in the last three rows of the table, respectively. The

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[9] EPA 2009. "Emission Factors for Locomotives," EPA-420-F-09-025 April 2009.

2017/2020 reduction shown in Table 5 represents the expected current year 2020 baseline emissions from normal turnover that incorporates eliminating all Tier 0 and Tier 1 engines, reduction of some Tier 1+ locomotives replaced with Tier 4 locomotives, and completed rebuilds of Tier 2 locomotives. The 2023/2020 emission reductions represent the emissions from 9.9% greater fleet fraction of Tier 4 locomotives as compared to 2020 with an equally lower fraction of Tier 1+ locomotives. This provides a sense for the level of emission reductions the accelerated fleet turnover would have provided in 2020 if the fleet characterization in 2020 was more like that expected for 2023.

Line-haul locomotive emissions at OIG reported in the 2017 Seaport Emission Inventory and projected emissions for 2020 and 2023 assuming a 9.9% increase in Tier 4 locomotives between 2017 and 2020, and 2020 and 2023 are shown in Table 6. The 2017 base case emissions are based on 2017 activity levels, including operational measures that reduced idling time.

**Table 6. OIG Line-Haul Emissions (tons/year)**

| Calendar Year | ROG | CO | NOx | PM10 (DPM) |
|---|---|---|---|---|
| 2017 | 0.025 | 0.054 | 0.400 | 0.007 |
| 2020 est. | 0.019 | 0.054 | 0.353 | 0.005 |
| 2023 est. | 0.016 | 0.054 | 0.312 | 0.004 |
| | | | | |
| Difference 2020 – 2023 | 0.003 | 0 | 0.041 | 0.001 |

The OIG emissions in the Seaport Emission Inventory were limited to the railyard boundary. Thus, the emission reductions between 2020 to 2023, as shown in Table 6, do not account for the full scope of locomotive activity that the Bay Area Air Quality Management District (BAAQMD) included in the community emission inventory in the WOCAP. Emission reductions from accelerated turn over to Tier 4 locomotives within the emissions domain used by the BAAQMD would therefore be greater than that shown in Table 6. The OIG trains arrive and depart via the northeast mainline that Union Pacific and passenger rail also use, as shown by the orange line in Figure 2-12 of the WOCAP (reproduced below). The BAAQMD included those emissions in its inventory under the Union Pacific, OHIT, and main rail line portions of its inventory. The distance along the mainline from the railyard to northern boundary where the mainline passes beneath I-580 is about 2 miles. However, the locomotive operating modes for travel along this segment are not known, so those emissions are not included in the analysis summarized in Table 6. Emission reductions for trains coming and leaving the OIG with a cleaner fleet would be realized along the mainline north of Oakland at least up to the BNSF yard in Richmond or possibly for other track segments within California.

Accelerating the fleet turnover to include the greater fraction of Tier 4 locomotives otherwise expected in 2023 by 2020 would result in the emission benefit shown in the last line of Table 6; NOx emissions would have been reduced by 0.041 tons, and PM emissions by 0.001 tons. Similar emission reductions in future years would be expected for accelerations of turnover by three years. For example, making the fleet composition in 2021 what it would otherwise not have looked like until 2024, and so on. This would be the case so long as enough Tier 1 locomotives remained to be turned over, which, under the normal rate of turnover, would occur in 2027 (or in 2024 assuming 3-year accelerated turnover occurs).

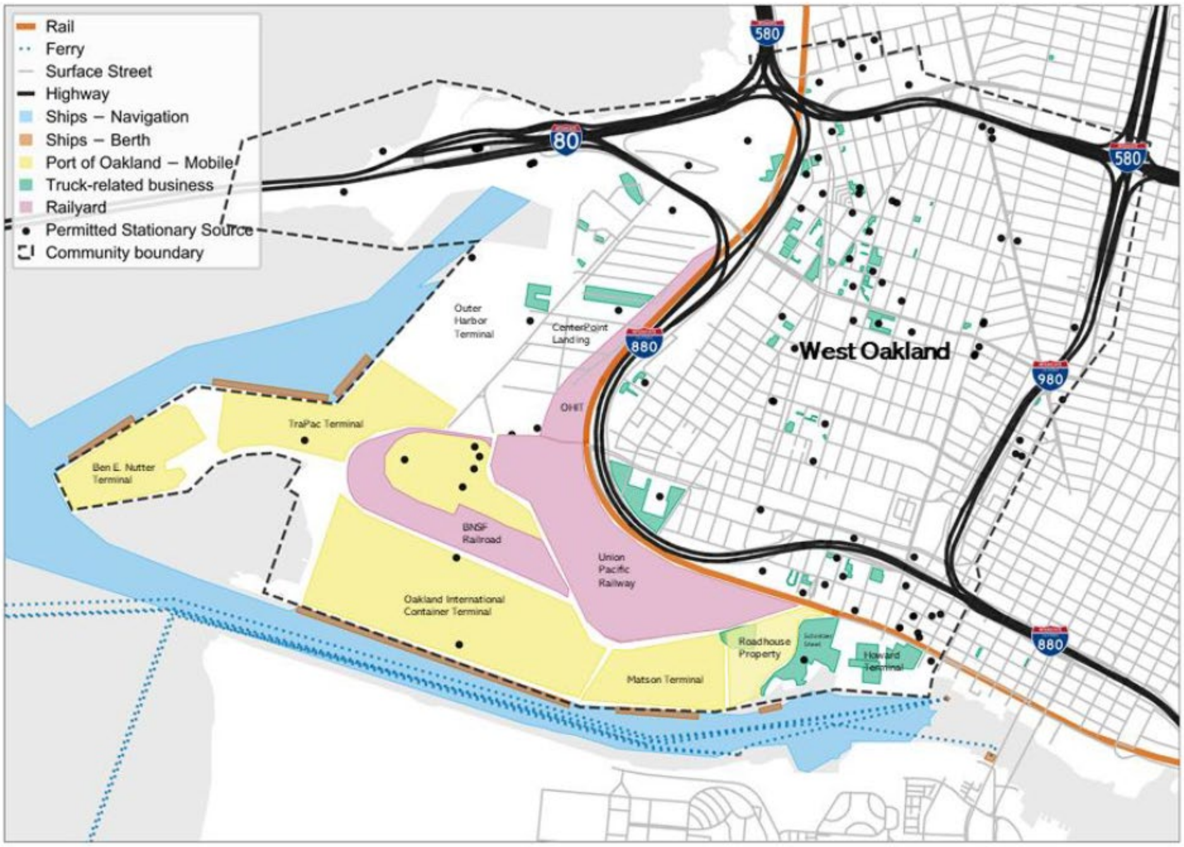

*Figure 2-12. Air Pollution Emission Sources in West Oakland*[21]

## ELECTRIC SWITCH LOCOMOTIVE EMISSIONS

The possibility of electric locomotives is attractive from an emissions standpoint. Currently there are clean diesel and diesel-electric hybrid switcher locomotives available. A fully electric switcher locomotive, however, is not available.

- BAAQMD[10] recently included zero emission switcher locomotives in a list of options for reducing emissions from port related activity. In fact, the option referenced a demonstration project funded jointly by ARB and South Coast Air Quality Management District which has not moved beyond the planning stage.

- A joint BNSF and Wabtec project[11] seeks to develop electric locomotives including a project involving converting a line-haul locomotive to all electric. However, this project intends to use the electric locomotive grouped with a diesel locomotive to

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[10] https://www.baaqmd.gov/~/media/files/board-of-directors/2019/msc_agenda_102419-pdf.pdf?la=en

[11] https://www.railjournal.com/locomotives/bnsf-and-wabtec-to-trial-battery-electric-locomotive-in-2020/

form a hybrid consist. The electric locomotive will supplement the diesel power and recover braking energy rather than operating as a standalone unit.

## TIER 4 SWITCH LOCOMOTIVE EMISSIONS

We estimate here the benefit of replacing older switch locomotives with Tier 4 switchers, which are the cleanest diesel switching engines currently available. Hybridization may further reduce emissions through optimization of the engine operating modes, energy recovery, or other methods to recharge onboard batteries under optimal conditions, but emissions data for specific hybrid switch locomotive models are not currently available. Until such data become available, estimates of additional emissions benefits from hybridization are purely speculative.

EPA provided the switch locomotive emission factors by Tier level as shown in Table 7, which, analogous to the line-haul emission factors described above, account for the different duty cycle of switch and line-haul vocations. Table 7 provides a basis for estimating the reduction in emissions from introducing Tier 4 switchers relative to the 2017 base emissions inventory.

**Table 7. Switch Locomotive Emissions Factors (g/hp-hr)**

| Tier | HC | CO | NOx | PM10 (DPM) |
|---|---|---|---|---|
| Uncontrolled | 1.01 | 1.83 | 17.4 | 0.44 |
| Tier 0 | 1.01 | 1.83 | 12.6 | 0.44 |
| Tier 0 + | 0.57 | 1.83 | 10.6 | 0.23 |
| Tier 1 | 1.01 | 1.83 | 9.9 | 0.43 |
| Tier 1 + | 0.57 | 1.83 | 9.9 | 0.23 |
| Tier 2 | 0.51 | 1.83 | 7.3 | 0.19 |
| Tier 2 + | 0.26 | 1.83 | 7.3 | 0.11 |
| Tier 3 | 0.26 | 1.83 | 4.5 | 0.08 |
| Tier 4 | 0.08 | 1.83 | 1 | 0.015 |

In 2017, all switch locomotives at OIG and OGRE were older uncontrolled engines. The OGRE switch locomotives were captive to the Port area, while BNSF rotated switchers in and out of the yard based on need and maintenance requirements. Due to the nature of their operations, BNSF may not be able to dedicate a switch locomotive exclusively to OIG. Nevertheless, assuming that the switch operations could be dedicated exclusively to a Tier 4 locomotive, the potential emission reductions would be as shown in Table 8.

In 2017, grant funding was awarded by the U.S. EPA[12] to replace one of the existing OGRE switchers with a Tier 4 locomotive. Table 8 shows what emissions would be after completion of the project, assuming the one new locomotive replaced the work that both existing older switchers did. The OGRE Tier 4 locomotive was delivered in 2019, so much of the benefit shown in Table 8 is likely already being realized.

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[12] https://westcoastcollaborative.org/files/grants/2017/2017-dera-baaqmd.pdf

**Table 8. Switch Locomotive Emissions and Tier 4 Benefits (tons)**

| Source | Tier | HC | CO | NOx | PM10 (DPM) |
|---|---|---|---|---|---|
| 2017 OIG Yard | Uncontrolled | 0.50 | 0.70 | 10.88 | 0.175 |
| 2017 OGRE | Uncontrolled | 0.20 | 0.49 | 5.55 | 0.077 |
| | | | | | |
| OIG Yard | Tier 4 | 0.04 | 0.70 | 0.63 | 0.006 |
| OGRE | Tier 4 | 0.02 | 0.49 | 0.32 | 0.003 |
| | | | | | |
| OIG Yard | Tier 4 Benefit (Tier 4 – Uncontrolled) | 0.46 | 0.00 | 10.25 | 0.169 |
| OGRE | | 0.18 | 0.00 | 5.23 | 0.074 |

Data on the cost of a Tier 4 switching locomotive are not widely published. The OGRE Tier 4 project analyzed above had a combined cost (grant plus matching funds) of $2,571,462 for one locomotive. There have been several other Tier 4 projects in California and in other US States. Many of these have been funded with available grants including Carl Moyer, Diesel Emissions Reduction Act (DERA), and other funding mechanisms. Grant money commonly only makes up a portion of the total cost of the program because matching funds are nearly always required. Below is a sample of Tier 4 switch locomotive projects for which some public data are available:

1. *"The Sacramento Metropolitan Air Quality Management District and the Bay Area Air Quality Management District recently awarded approximately $15 million in grants to repower 10 diesel-electric switching locomotives into new Environmental Protection Agency (EPA)-certified Tier 4 single-engine switching locomotives."* (Union Pacific)[13]

2. *"The Waste Management of New York (WMNY) project repowered an old unregulated four-axle 1,200-hp locomotive used in switcher service with a Knoxville Locomotive Works (KLW) Near Zero Emissions Tier 4 Certified 2,300-hp mother-slug locomotive combination… This configuration allows the 2300-hp mother-slug locomotive to move more train cars than just the locomotive alone – achieving more work with the very-low emission engine. EPA provided $1 million in DERA funding and the project partners provided a cost share of $2,897,560."*[14]

3. *"OmniTRAX Inc. and the Stockton Terminal and Eastern Railroad yesterday unveiled a new environmentally friendly locomotive at the railroad's depot in San Joaquin County, California. The KLW SE10B T4L unit built by Knoxville Locomotive Works in Tennessee complies with the Environmental Protection Agency's Tier 4 emission standard."*[15]

4. *"The San Joaquin Valley Air Pollution Control District, San Joaquin Valley Railroad and Knoxville Locomotive Corporation held a ribbon-cutting for four near-zero*

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[13] https://www.up.com/aboutup/community/inside_track/repowered-switchers-11-16-2018.htm

[14] https://www.epa.gov/ports-initiative/new-york-city-locomotive-repowers-collaborative-efforts-improve-air-quality

[15] https://www.progressiverailroading.com/mechanical/news/OmniTRAX-short-line-inaugurates-new-Tier-4-locomotive--57412

> *emission locomotive switchers on Wednesday, Feb. 26, 2020, in Exeter. The locomotives replaced three switchers from the 70s and one from 1964."*[16]

Grant funding for the first project mentioned above (10 Union Pacific switch locomotives) averages $1.5 million per locomotive. Matching funds were not disclosed but could be as much as the grant, which would mean each locomotive cost $3 million. For the Stockton and San Joaquin projects (numbers 3 and 4 above), as well as other projects, the full project costs may be available via follow-up with the funding agency or project proponent. The second project (WMNY) listed above does show the full cost of the project with the grant ($1 million) and matching ($2.9 million) funds reported for a total cost of $3.9 million. This project included both a locomotive and a companion 'slug' to raise the amount of available wheel power and traction. The locomotive has a diesel engine powering an electric motor to drive the wheels, and the slug is a second non-powered locomotive with an electric motor powered by the diesel engine located on the first locomotive. This project was the first of its kind, so some nonrecurring development costs may be reflected in the project cost. In consideration of the above we will assume for purposes of estimating cost efficiency that a Tier 4 switching locomotive would cost somewhere in the range of $2.6 to $3.9 million.

During 2017, BNSF operated one locomotive at any given time at OIG but the locomotive was traded in and out of the yard. OGRE operated two locomotives but for only a limited number of hours suggesting that their operations could be largely performed by the one new locomotive if necessary, as analyzed in Table 8 above. Based on this, the cost of replacing the locomotives at OIG with Tier 4 switch locomotives could be as little as $2.6 million for one locomotive, or more than $6.6 million for two locomotives at an average of more than $3.3 million each.

The annualized cost would depend on the project life, which could be defined as the expected remaining life of the locomotives currently in use. Switchers can last for decades. For example, the SF Bay Railroad just replaced their 1940s vintage locomotive in early 2019[17]. It seems reasonable to expect that the remaining life of the locomotives in use would be at least 10 years. Based on this, and the locomotive costs given above, the annualized cost effectiveness ranges from $2.1 million to $4.1 million per PM ton reduced. Using the Carl Moyer pollutant-weighted method (ROG + NOx + 20x PM), the cost effectiveness ranges from $25,000 to $48,000 per Carl Moyer ton.

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[16] https://www.visaliatimesdelta.com/story/news/2020/02/26/new-sjvr-locomotives-dramatically-cut-emissions-valley/4881854002/

[17] https://sfport.com/sites/default/files/Maritime/Maritime%20Commerce%20Advisory%20Committee/Documents/SFBR%20032119.pdf

RAMBOLL

ENVIRONMENT
& HEALTH

# MEMORANDUM

Date: **May 13, 2020**

To: **Tracy Fidell**

Cc: **Susanne von Rosenberg**

From: **Chris Lindhjem, Till Stoeckenius and Lit Chan**

Subject: **Analysis of Clean Ship Program and Sulfur Content of Fuel**

## INTRODUCTION

This memorandum describes the effect on emissions of increasing the fraction of newer Tier 3 ocean-going vessels (OGVs) arriving and departing the Port of Oakland (Port). This analysis forms a basis to analyze the impact that the West Oakland Community Action Plan (WOCAP)[1] strategy 63 (Screened Action 199) may have:

> *"The Port of Oakland implements a Clean Ship Program to increase the frequency of visits by ships with International Maritime Organization Tier 2 and Tier 3 engines."*

There is no international, federal or state requirement that carriers need to upgrade or turnover their fleets.

Also described in this memo is the impact of fuel sulfur content on OGV diesel particulate matter (DPM) emissions. Lower fuel sulfur content results in lower DPM emissions. While vessels visiting the Port are required to use fuel with a maximum sulfur content of 0.1%, actual fuel sulfur contents are lower, averaging approximately 0.05%. Diesel fuel used for on-road and off-road vehicles and equipment (but not OGVs) is required to have a maximum sulfur content of 0.0015% (15 ppm).

## OGV FLEET CHARACTERIZATION AND EMISSION BENEFITS

The OGV fleet characterization by model year and tier level from the 2017 Port of Oakland Seaport Emission Inventory[2], were used as a base condition for this analysis.

Table 1 shows the 2017 fleet mix and the diesel engine emission factors provided by the California Air Resources Board (ARB)[3] in their 2019 OGV emissions model for those tier levels. According to the ARB model, only NOx emission factors are affected by the tier level of the ship. This is important because it implies that increasing the frequency of Tier 2 and Tier 3 ship visits will not help reduce DPM or greenhouse gas emissions.[4] As a result, this strategy will not further the goals of the WOCAP (which has no NOx reduction goal) or the

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[1] WOCAP 2019. "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October.

[2] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

[3] https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

[4] While new ships with Tier 3 engines may be slightly more energy efficient than the older ships they replace, thus slightly reducing GHG emissions, this is not part of the Tier 3 requirement. Similarly, emission rates for some criteria pollutants could be slightly lower depending on engine and vessel design but this is not always guaranteed to the case.

primary goals of the Port of Oakland Seaport Air Quality 2020 and Beyond Plan, which is focused on DPM and greenhouse gasses.

We assume here for the sake of simplicity that steamships have the Tier 0 emission rates shown in Table 1. Diesel-fueled boilers used to power steamships actually have lower NOx emissions but are less fuel-efficient than diesel engines and produce higher PM and CO emissions. Steamships are aging ships (average build year 1977) and are being used less each year.

**Table 1. 2017 OGV Fleet Characterization and Average NOx Emission Factors**

| Tier | 2017 Fleet | Main Engine NOx (g/kW-hr) | Auxiliary Engine NOx (g/kW-hr) |
|---|---|---|---|
| 0 | 15% [a] | 17 | 13.8 |
| I (1) | 62% | 16 | 12.2 |
| II (2) | 23% | 14.4 | 10.5 |
| III (3) | 0% | 3.4 | 2.6 |
| **Fleet Average** | | **15.8** | **12.1** |

[a] – About 7% of the 2017 fleet (about half of the Tier 0 vessels) consisted of steamships which have lower NOx emission factors than the ARB values for Tier 0 diesel vessels listed here.

The benefit of using more Tier 2 ships would be a modest NOx reduction because NOx emission factors for Tier 2 ships are 10 – 24% lower than for Tier 0/1. Potentially larger benefits could be realized by switching to Tier 3 ships which have NOx emission factors that are 75 – 81% lower than Tier 0/1/2 ships.

Table 2 shows the fleet average emission factors and emission reduction percentage assuming 10% of the fleet visiting Oakland switches to Tier 3 with 1/3 each or about 3% corresponding reductions in percentages of Tier 0, 1, and 2 ship calls (a reasonable assumption since we have no information about which ships visiting Oakland are more likely than others to be replaced by Tier 3 ships). As shown in Table 2, the average fleet NOx emission rates were reduced from 15.8 and 12.1 g/kW-hr to 14.5 and 11.1 g/kW-hr for main and auxiliary engines, respectively, or an 8% fleet average NOx emission reduction.

**Table 2. 2017 Fleet NOx Emissions Factors with 10% Tier 3**

| Tier | Fleet | Main Engine NOx (g/kW-hr) | Auxiliary Engine NOx (g/kW-hr) |
|---|---|---|---|
| 0 | 12% | 17 | 13.8 |
| 1 | 59% | 16 | 12.2 |
| 2 | 19% | 14.4 | 10.5 |
| 3 | 10% | 3.4 | 2.6 |
| **Fleet Average** | | **14.5** | **11.1** |
| **NOx Reduction from 2017 Base** | | **7.9%** | **7.9%** |

In the 2017 Port of Oakland Seaport Emissions Inventory (2017EI) referenced above, the annual NOx emissions for the OGV fleet ranged from 1,981 tons (2017EI Table 2-11) to 2,345 tons (2017EI Table 2-10), depending upon input estimates of vessel speeds and load emission factor adjustments. The NOx reduction from a 10% increase in Tier 3 ship calls would translate to 156 to 185 tons of NOx reduced. The emissions benefits by mode are shown in Table 3. It is important to note that the at-berth emission reductions, and thus the benefit of introducing cleaner ships, will decrease as shore power usage increases.

**Table 3. 2017 Fleet NOx Emissions Benefits with 10% Tier 3 (tons)**

| Mode | POAK EI Table 2-11 | POAK EI Table 2-10 |
|---|---:|---:|
| At Berth | 35 | 35 |
| Maneuvering | 22 | 42 |
| All Modes | 156 | 185 |

The Port of Los Angeles[5] provides an incentive grant of $5,000 per call for Tier 3 vessels. In 2017, there were 1,596 voyages[6] that involved a call at the Port of Oakland. If we assume the same incentive level as the Port of Los Angeles, 10% Tier 3 ship voyages would have resulted in 160 calls by Tier 3 ships, which would cost the Port $800,000. Thus, a $5,000 incentive per call that results in 10% Tier 3 vessel calls would result in a cost-effectiveness range of $4,300 - $5,100 per ton of NOx reduced.

## OGV FLEET FUEL SULFUR CONTENT

In the 2017 Port of Oakland Seaport Emissions Inventory, emissions were estimated using emission factors based on the maximum allowed fuel sulfur content of 0.1%. Subsequent data[7] has shown that actual in-use OGV fuel sulfur is averaging about 0.05%. On-road and off-road diesel in the US is now required to be ultra-low sulfur diesel with a maximum allowed sulfur content of 15 ppm (0.0015%). While current safety and design considerations may preclude the use of on-road and off-road (including commercial marine) ultra-low sulfur diesel in larger marine vessels, it represents a possible avenue towards reducing emissions from OGVs in the future. ARB is using a new OGV emissions model for OGV activity[8] that uses emission factors for two different sulfur levels (0.3% and 0.1%) from which we linearly extrapolated to 0.05%, 0.0015% and 0.0% sulfur. Table 4 shows the results in terms of the emission factors and reduction from 0.1% sulfur.

**Table 4. PM10 (DPM) Emission Factors (g/kW-hr) by Sulfur Level and Engine Type (Percent Reduction from 0.1% Sulfur Fuel)**

| Sulfur Wt. % | Slow Speed Main Engine | Auxiliary |
|:---:|---:|---:|
| 0.3 | 0.247459[a] | 0.250479 |
| 0.1 | 0.189262 | 0.182215 |
| 0.05 Estimated | 0.174713 (-7.7%) | 0.165149 (-9.4%) |
| 0.0015 Estimated | 0.160600 (-15.1%) | 0.148595 (-18.5%) |
| 0.00 Estimated | 0.160163 (-15.4%) | 0.148083 (-18.7%) |

[a] – all decimal places from the ARB model are shown here.

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[5] https://www.portoflosangeles.org/environment/air-quality/environmental-ship-index
[6] Most voyages involved one call to the Port, but a few ships had more than one call per voyage.
[7] ARB Enforcement Data for the OGV fuel sulfur rule for 2019.
[8] https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

Applying the auxiliary engine benefit to the at berth emissions and slow speed engine benefit to all other modes results in the expected benefit of lower sulfur fuel shown in Table 5. Higher levels of shore power usage post-2017 will reduce the berthing emissions, and thus the corresponding benefit of lower sulfur fuel (in terms of tons of emissions), below values shown in Table 5.

**Table 5. 2017 Fleet DPM Emissions Benefits (tons) at 0.05% and 0.00% Sulfur Relative to 0.1% Sulfur**

| **Mode** | **2017EI Table 2-11** | | | **2017EI Table 2-10** | | |
|---|---|---|---|---|---|---|
| | **0.1% S Base** | **0.05% S Benefit** | **0.0% S Benefit**[b] | **0.1% S Base** | **0.05% S Benefit** | **0.0% S Benefit** |
| At Berth[a] | 8.84 | 0.83 | 1.65 | 8.84 | 0.83 | 1.65 |
| Maneuvering | 5.87 | 0.45 | 0.90 | 10.60 | 0.82 | 1.63 |
| All Modes | 37.24 | 3.02 | 6.03 | 42.21 | 3.40 | 6.79 |

[a] – results based on level of shore power usage that occurred in 2017.

[b] – effectively the same as ultra-low sulfur fuel

## COST-EFFECTIVENESS

The cost of using ultra-low (15 ppm) sulfur (S) fuel instead of 0.1% S bunker fuels fluctuates with fuel prices. Fuel prices are difficult to evaluate because the published price may or may not include taxes and delivery cost, or a bulk price may differ from the actual "as delivered" price. No market currently exists for ultra-low sulfur diesel (ULSD) use in OGVs so the potential price differential relative to the current bunker fuel is highly uncertain.

Fuel costs were reasonably stable until near the end of 2019 when the COVID 19 pandemic began to affect China and reduce oil demand. Using prices in the November 2019 time frame provides an estimate of the price difference between the current marine gas oil (MGO, below 0.1% S) and California diesel (15 ppm S) fuel.

During November 2019, MGO could be purchased in California at about $700/tonne (metric tonne or 1,000 kilograms).[9] At around this same time, retail prices of USLD for on-road use in California were about $4 per gallon[10], but over $0.7 of this was fuel taxes[11] resulting an expected cost of approximately $3.30 per gallon for off-road use such as in marine vessels. Diesel fuel used in vessels is not subject to the same taxes levied on retail diesel. Cal Maritime[12] estimated marine ULSD fuel prices at $3 per gallon for harbor craft. Diesel fuel density is about 3.2 kg/gallon, so a range of $3 – $3.30 per gallon is equivalent to $938 – $1,031/tonne compared with MGO at about $700/tonne.

ULSD sold in California must conform to certain fuel specifications in addition to being limited to a maximum of 15 ppm S. US diesel fuel sold outside of California meets a 15 ppm S limit without the fuel property requirements of California diesel. Therefore, ULSD sold for use in OGVs may not cost as much as the $3 – $3.30 per gallon estimated here. As an example of what diesel prices are in and outside of California, Foss[13] reports that the diesel

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[9] https://shipandbunker.com/prices/am/nampac/us-lax-la-long-beach#MGO
[10] https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_SCA_DPG&f=M
[11] https://www.taxpolicycenter.org/taxvox/ups-and-downs-californias-gas-tax
[12] https://ww2.arb.ca.gov/resources/documents/commercial-harbor-craft-tier-4-feasibility-report
[13] https://www.foss.com/fuel-prices/

fuel price in Portland, OR and Seattle was $0.22 to $0.36 per gallon lower than in California and was as low as $2.20 per gallon in January 2020 (during a period of falling oil prices so not comparable to November 2019 bunker fuel prices, but before the pandemic affected the US). So if non-California compliant ULSD could be purchased, the likely comparable November 2019 price could have been as low as $2.64 per gallon or $825/tonne.

PM emission factors (g/kW-hr) shown in Table 4 indicate the emissions reduction benefit of ULSD. ARB estimated an average fuel consumption rate of 185 g/kW-hr for OGV main engines and 217 g/kW-hr for OGV auxiliary engines to estimate fuel costs per kW-hr. Combining these factors with the price difference between MGO and California diesel yields a cost effectiveness of $2,800,000 - $3,900,000 per PM ton reduced (equivalent to $140,000 - $195,000 per Carl Moyer ton). Using the lower non-California compliant diesel price, the cost effectiveness would be as low as $1,500,000 per PM ton ($75,000 per Carl Moyer ton) reduced.

# MEMORANDUM

| | |
|---|---|
| Date: | **May 8, 2020** |
| To: | **Tracy Fidell** |
| Cc: | **Susanne von Rosenberg** |
| From: | **Chris Lindhjem, Till Stoeckenius and Lit Chan** |
| Subject: | **Tug Repower and Retrofit Emissions Reductions** |

## INTRODUCTION

This memorandum describes potential emission reductions from repowering or retrofitting tug engines. This analysis forms a basis to analyze the impact that the West Oakland Community Action Plan (WOCAP)[1] strategy 50 may have:

> *"The Air District plans to offer financial incentives to upgrade tugs and barges operating at the Port of Oakland with cleaner engines every year."*

Also included in this memo is a discussion of the emission reduction benefits and cost of using renewable diesel to power tugs.

## EMISSIONS REGULATIONS

There is a California state requirement[2] that harbor craft owners fully upgrade their fleets to Tier3 or higher engines by 2023, and early indication is that there will be another regulation[3] requiring further fleet upgrades to Tier 4+ diesel particulate filter (DPF) after 2023. Under the current regulation, the last year that 2005 model year (MY) engines can be used is 2020, 2006MY in 2021, and 2007MY in 2022.

Table 1 outlines the EPA new engine emission regulations[4] and California Air Resources Board (ARB) estimated emission factors (EF)[5] for engines of a size typically used in tugs. Most tugs use engines with about 4.3 – 4.8 liters per cylinder and engine power of 2,000 hp (~1,500 kW) to 3,400 hp (~2,500 kW) according to the reported main engine models used and listed on fleet websites.[6]

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[1] WOCAP 2019. "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October.

[2] https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-regulatory-documents

[3] https://ww2.arb.ca.gov/sites/default/files/2020-03/chcwebinar03052020.pdf

[4] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA0B.pdf

[5] https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

[6] https://www.amnav.com/fleet; http://www.harleymarine.com/companies-sms.asp

**Table 1. Marine Compression-Ignition Engine Certification Emission Factors (g/hp-hr)**

| Engine Size | | Tier | Model Year | | ARB New Engine EF | |
|---|---|---|---|---|---|---|
| | | | EPA Start | ARB EFs 1st Year | NOx | PM |
| 2.5 to 5.0l per cylinder | | 1 | 2004[a] | 2000 | 7.31 | 0.361 |
| 2.5 to 5.0l per cylinder | | 2 | 2007 | 2007 | 5.529 | 0.200 |
| 3.5 to 7.0l per cylinder | >600kW | 3 | 2012 | 2013 | 4.37 | 0.100 |
| | >3300 hp | 3 | --- | 2014 | 4.94 | 0.25 |
| 1,400 to <2,000 kW | | 4 | 2016 | 2016 | 1.30 | 0.03 |
| 2,000 to <3,700 kW | | 4 | 2014 | 2016 | 1.30 | 0.03 |

[a] - International standard started 2000

## ASSIST TUG FLEET CHARACTERIZATION

The assist tug fleet characteristics presented in the 2017 Port of Oakland Seaport Emission Inventory[7] were developed based on information from tug company websites and follow-up discussions with tug operators. Every attempt was made to best characterize the fleet as it existed at that time. Because of the interaction of the engine size and model year within the regulations, the Tier level is often uncertain without a thorough inspection of the documentation for each engine.  Fleets have performed upgrades either during the normal course of business, in response to the California regulations, or with the assistance from grant programs such as Carl Moyer.  Table 2 presents our understanding of the status of the fleet in 2017 along with planned rebuilds as of 2020.

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[7] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

**Table 2. Assist Tug Fleet Characterization in 2017 and Planned BAAQMD-Funded Projects**

(Green indicates best estimate; Blue is a different tug from 2017.)
(Two each Main and Auxiliary engines are assumed to be installed)

| Company | Name | Main Engine Model | MY | Tier Estimated | Main Power (hp) | Aux. Power (kW) | After BAAQMD Funding |
|---|---|---|---|---|---|---|---|
| AMNAV | Patricia Ann | Cat 3512B | 2008 | 2 | 5080 | 210 | Tier 3 |
| AMNAV | Revolution | Cat 3512B | 2006 | 1 | 5080 | 210 | Tier 3 |
| AMNAV | Sandra Hugh | Cat 3512B | 2006 | 1 | 5080 | 210 | Tier 3 |
| AMNAV | Liberty | Cat 3512B | 2008 | 2 | 4000 | 210 | |
| AMNAV | Patriot | EMD 12-645-E6[8] | 2006 | 1 | 4800 | 210 | |
| BayDelta | Delta Billie | Cat 3516C | 2009 | 2 | 6712 | 215 | |
| BayDelta | Delta Cathryn | Cat 3516C | 2009 | 2 | 6712 | 215 | |
| BayDelta | Delta Audrey | Cat 3516C | 2014 | 3 | 6712 | 215 | |
| BayDelta | Vigilant | unknown[a] | 2007 | 2 | 6772 | 215 | Tier 4 |
| Crowley | Valor | Cat 3516C | 2007 | 2 | 6772 | 215 | Tier 4 |
| Crowley | Goliah | unknown[a] | 2013 | 3 | 5150 | 215 | |
| Foss | Keegan Foss | unknown[a] | 1998 Original | Tier 2 Upgrade | 3900 | 198 | Tier 4 |
| Foss | Pacific Star | MTU 16v - 4000 | 2008 | 2 | 6610 | 198 | |
| Foss | Caden Foss | unknown[a] | 2017 | 4 | 6772 | 365 | |
| Foss | America | MTU 16v – 4000 (4.3 – 4.8l) | 2008 | 2 | 6610 | 198 | |
| Foss | Lynn Marie | unknown[a] | 2001 | 1 | 6250 | 210 | |
| Foss | Jamie Ann | MTU | 2019 | 4 | 6866 | | |
| Starlight | Ahbra Franco | Cat C-175 (5.3l) | 2013 | 2 | 6850 | 290 | |
| Starlight | Z-3 | Cat 3516B (4.3 – 4.9l) | 1998 Original | Tier 3 Upgrade | 4000 | 204 | Tier 3 |
| Starlight | Z-4 | Cat 3516B | 1998 Original | Tier 3 Upgrade | 4000 | 204 | Tier 3 |
| Starlight | Z-5 | Cat 3516B | 1998 Original | Tier 3 Upgrade | 4000 | 204 | Tier 3 |

[a] – Assumed 4 – 5 liters/cylinder engine group.

For this analysis, potential emissions reductions focus on tugs currently using Tier 1, Tier 2, or Tier 3 engines. In many cases, Tier 1 and 2 engines can be upgraded to Tier 3 without a complete engine replacement as has been done, for example, for the Starlight Z-3, Z-4, and Z-5 tugs. Upgrades to Tier 4 engines involve a complete replacement, and the aftertreatment systems of Tier 4 engines may either require a new vessel to be built or significant reconfiguration of an existing vessel.

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[8] This engine is 10.6 l/cylinder.

## TUG EMISSIONS

Emission factors and emissions adjustment factors for harbor craft engines are provided in the ARB harbor craft emissions model[9] and are used to estimate emissions by mode or annual activity as shown in the following equation.

**Emissions = Emission Factors** x **Fuel Correction** x **(1 + Det. Factor x Age/Life)** x **Engine Rated Power** x **Load Factor** x **Hours of Operation**

Emission factors for main propulsion engines are shown in Table 1, deterioration factors in Table 3, and fuel correction factors in Table 4. In the above equation, Age/Life represents the current age divided by the expected useful life of the engine. ARB estimates the useful life of tugboats at 21 years.

**Table 3. Marine Engine Deterioration Factors (unitless)**

| Power Grouping (hp) | Power Range (hp) | HC | CO | NOx | PM |
|---|---|---|---|---|---|
| 25-50 | 25-50 | 0.51 | 0.41 | 0.06 | 0.31 |
| 51-120 | 51-120 | 0.28 | 0.16 | 0.14 | 0.44 |
| 121-175 | 121-175 | 0.28 | 0.16 | 0.14 | 0.44 |
| 176-250 | 176-250 | 0.28 | 0.16 | 0.14 | 0.44 |
| 251-500 | 251-500 | 0.44 | 0.25 | 0.21 | 0.67 |
| 501-750 | 501-750 | 0.44 | 0.25 | 0.21 | 0.67 |
| 751-1900 | ≥751 | 0.44 | 0.25 | 0.21 | 0.67 |
| 1901-3300 | ≥751 | 0.44 | 0.25 | 0.21 | 0.67 |
| 3301-5000 | ≥751 | 0.44 | 0.25 | 0.21 | 0.67 |

**Table 4. Marine Engine Fuel Correction Factors for California Diesel (unitless)**

| Calendar Year | Power Range (hp) | Model Years | NOx | PM |
|---|---|---|---|---|
| 2007+ | <25 | <1995 | 0.930 | 0.720 |
| 2007+ | 25 to 50 | <1999 | 0.930 | 0.720 |
| 2007+ | 51 to 100 | <1998 | 0.930 | 0.720 |
| 2007+ | 101 to 175 | <1997 | 0.930 | 0.720 |
| 2007+ | 176+ | <1996 | 0.930 | 0.720 |
| 2007+ | <25 | 1995 to 2011+ | 0.948 | 0.800 |
| 2007+ | 25 to 50 | 1999 to 2010 | 0.948 | 0.800 |
| 2007+ | 51 to 100 | 1998 to 2010 | 0.948 | 0.800 |
| 2007+ | 101 to 175 | 1997 to 2010 | 0.948 | 0.800 |
| 2007+ | 176+ | 1996 to 2010 | 0.948 | 0.800 |
| 2007+ | All <25 hp | 2011+ | 0.948 | 0.852 |

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[9] https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

Our emissions estimates relied on the assist tug main engine load factor of 0.31 used in the 2017 and all prior Port of Oakland emission inventories. ARB[10] has indicated that it intends to revise the assumed assist tug main engine load factor to 0.15. Using this revised load factor would result in about a 50% reduction from the emissions shown in this memorandum (meaning this analysis overestimates both emissions and possible emission reductions). ARB has indicated that they also intend to update emission factors, which would further revise emissions up or down.

Based on the 2017 Port of Oakland Seaport Emissions Inventory activity estimates for the AMNAV and Starlight (ST) fleets (the two busiest fleets providing tug assists to vessels visiting the Port), Table 5 shows expected annual emissions once the already scheduled fleet updates have been completed. The activity (hours) estimate is for work assisting only Port of Oakland ships. Because these tugs also work elsewhere around the Bay, emissions shown in Table 5 represent just a portion of the total Bay-wide emissions to which emission reduction benefits from engine upgrades would apply.

**Table 5. Assist Tug Base Case Annual Emissions**

| Fleet | Name | MY | Main HP | Tier | Hours | Emissions (tons/year) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ROG | CO | NOx | PM |
| AMNAV | Patricia Ann | 2013[a] | 5080 | 3 | 1,028 | 1.47 | 7.45 | 8.13 | 0.19 |
| AMNAV | Revolution | 2013[a] | 5080 | 3 | 1,028 | 1.47 | 7.45 | 8.13 | 0.19 |
| AMNAV | Sandra Hugh | 2013[a] | 5080 | 3 | 1,028 | 1.47 | 7.45 | 8.13 | 0.19 |
| AMNAV | Liberty | 2008 | 4000 | 2 | 1,028 | 1.26 | 6.18 | 8.47 | 0.33 |
| AMNAV | Patriot | 2006 | 4800 | 1 | 1,028 | 1.55 | 7.56 | 13.67 | 0.75 |
| ST | Ahbra Franco | 2013 | 6850 | 2[b] | 875 | 1.69 | 8.55 | 11.81 | 0.43 |
| ST | Z-3 | 2013[a] | 4000 | 3 | 875 | 0.98 | 4.99 | 5.45 | 0.13 |
| ST | Z-4 | 2013[a] | 4000 | 3 | 875 | 0.98 | 4.99 | 5.45 | 0.13 |
| ST | Z-5 | 2013[a] | 4000 | 3 | 875 | 0.98 | 4.99 | 5.45 | 0.13 |

[a] – Assumed model year for Tier 3 upgrade
[b] – Ahbra Franco engines are larger with different ARB EFs, and possibly different Tier levels by model year.

We estimated emission reductions from engine upgrades in two ways as shown in top and bottom portions of Table 6. First, we estimated emission reductions from engine upgrades to Tier 3 for the three tugs with lower Tier engines. We then estimated emission reductions which would result from upgrading all tugs to Tier 4. The benefit of upgrading the three tugs not already scheduled for an upgrade to Tier 3 results in a 28% NOx and 44% PM reduction relative to the baseline for just those three vessels. Upgrading all tugs to Tier 4 would result in a 76% NOx and 85% PM reduction relative to the total baseline emissions shown in Table 5.

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[10] CARB Commercial Harbor Craft - Public Webinar, March 5, 2020. https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-meetings-workshops

**Table 6. Assist Tug Annual Emissions Reduction with Repower**

| Fleet | Name | MY | Main HP | New Tier | Hours | Emissions Benefit (tons/year)[c] ROG | CO | NOx | PM |
|---|---|---|---|---|---|---|---|---|---|
| **Upgrade Remaining Tugs to Tier 3** | | | | | | | | | |
| AMNAV | Liberty | 2013[a] | 4000 | 3 | 1,028 | 0.10 | 0.31 | 2.07 | 0.18 |
| AMNAV | Patriot | 2013[a] | 4800 | 3 | 1,028 | 0.17 | -3.04 | 5.99 | 0.57 |
| ST | Ahbra Franco | 2014[a] | 6850 | 3 | 875 | 0.03 | 0.09 | 1.35 | -0.10 |
| | | | | | **Total** | **0.30** | **-2.64** | **9.41** | **0.66** |
| **Upgrade All Tugs to Tier 4** | | | | | | | | | |
| AMNAV | Patricia Ann | 2020[b] | 5080 | 4 | 1,028 | 1.13 | 0.55 | 5.87 | 0.14 |
| AMNAV | Revolution | 2020[b] | 5080 | 4 | 1,028 | 1.13 | 0.55 | 5.87 | 0.14 |
| AMNAV | Sandra Hugh | 2020[b] | 5080 | 4 | 1,028 | 1.13 | 0.55 | 5.87 | 0.14 |
| AMNAV | Liberty | 2020[b] | 4000 | 4 | 1,028 | 0.99 | 0.75 | 6.69 | 0.30 |
| AMNAV | Patriot | 2020[b] | 4800 | 4 | 1,028 | 1.24 | -2.52 | 11.53 | 0.71 |
| ST | Ahbra Franco | 2020[b] | 6850 | 4 | 875 | 1.30 | 0.64 | 9.21 | 0.38 |
| ST | Z-3 | 2020[b] | 4000 | 4 | 875 | 0.76 | 0.37 | 3.93 | 0.09 |
| ST | Z-4 | 2020[b] | 4000 | 4 | 875 | 0.76 | 0.37 | 3.93 | 0.09 |
| ST | Z-5 | 2020[b] | 4000 | 4 | 875 | 0.76 | 0.37 | 3.93 | 0.09 |
| | | | | | **Total** | **9.20** | **1.65** | **56.83** | **2.09** |
| | | | | | **Reduction** | **56%** | **3%** | **76%** | **85%** |

[a] Assumed model year for Tier 3 upgrade; Ahbra Franco engines are larger with different ARB EFs, and possibly different Tier levels by model year.

[b] Assumed model year for Tier 4 repower.

[c] Positive values indicate a reduction in emissions relative to baseline. Negative values indicate an increase in emissions relative to baseline.

## DIESEL PARTICULATE FILTERS (DPF)

One aspect of the ARB Proposed Concepts[11] for Harbor Craft regulations is the requirement for DPFs to be retrofitted to Tier 4 marine engines by a future date. ARB commissioned a study[12] to evaluate the retrofit and use of DPFs on marine vessels based on experience with DPFs on truck and off-road equipment as an analog for the maintenance and operating experience.

ARB[13] provides the retrofit standards in three levels, Level 3 at 85% PM control, Level 2 at 50%, and Level 1 at 25%. As of March 2020, the only verified PM aftertreatment device for marine applications is a Level 2 (50% PM control) device. However, there are several truck and off-road Level 3 DPFs available, and our assumption is that a Level 3 device is intended under the ARB Proposed Concepts for Harbor Craft regulations. Table 7 shows the benefit of

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[11] CARB Commercial Harbor Craft - Public Webinar, March 5, 2020. https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-meetings-workshops

[12] California State University Maritime Academy 2019. "Evaluation of the Feasibility and Costs of Installing Tier 4 Engines and Retrofit Exhaust Aftertreatment on In-Use Commercial Harbor Craft." https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft

[13] ARB Verification Procedure - Currently Verified, https://ww3.arb.ca.gov/diesel/verdev/vt/cvt.htm

a Tier 4 repower with a DPF added assuming 50% HC, 50% CO and 85% PM control on top of the benefit of Tier 4 repower only. Addition of the DPF increases the total Tier 4 PM emissions benefit from 2.09 tons/year to 2.40 tons/year.

**Table 7. Assist Tug Annual Emissions Reduction with DPF added to Tier 4**

| Fleet | Name | MY | Main HP | New Tier | Hours | Emissions Benefit (tons/year) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ROG | CO | NOx | PM |
| AMNAV | Patricia Ann | 2020[b] | 5080 | 4 | 1,028 | 1.30 | 4.00 | 5.87 | 0.18 |
| AMNAV | Revolution | 2020[b] | 5080 | 4 | 1,028 | 1.30 | 4.00 | 5.87 | 0.18 |
| AMNAV | Sandra Hugh | 2020[b] | 5080 | 4 | 1,028 | 1.30 | 4.00 | 5.87 | 0.18 |
| AMNAV | Liberty | 2020[b] | 4000 | 4 | 1,028 | 1.12 | 3.46 | 6.69 | 0.33 |
| AMNAV | Patriot | 2020[b] | 4800 | 4 | 1,028 | 1.40 | 0.74 | 11.53 | 0.74 |
| ST | Ahbra Franco | 2020[b] | 6850 | 4 | 875 | 1.49 | 4.59 | 9.21 | 0.42 |
| ST | Z-3 | 2020[b] | 4000 | 4 | 875 | 0.87 | 2.68 | 3.93 | 0.12 |
| ST | Z-4 | 2020[2] | 4000 | 4 | 875 | 0.87 | 2.68 | 3.93 | 0.12 |
| ST | Z-5 | 2020[2] | 4000 | 4 | 875 | 0.87 | 2.68 | 3.93 | 0.12 |
| **Total** | | | | | | **10.52** | **28.85** | **56.83** | **2.40** |
| **Reduction from Base Case** | | | | | | **64%** | **51%** | **76%** | **98%** |

## TIER 4 REPOWER AND DPF RETROFIT COST EFFECTIVENESS

ARB commissioned a study by California State University Maritime Academy[14] (Cal Maritime) to determine engineering requirements for installing Tier 4 engines and retrofitting harbor craft with DPF. The Cal Maritime cost analysis included the design, engineering, fabrication, and equipment purchase price to reconfigure the vessel and install Tier 4 engines. Cal Maritime also estimated annual operating costs for the Tier 4 engines including fuel consumption, maintenance, and diesel emission fluid (DEF) consumption.

The Cal Maritime costing results for an assist tug repower and retrofit are summarized here (referenced tables can be found in the Cal Maritime report):

1) Main engine configuration: 2x 3425 hp (represents maximum power within the fleet serving the Port)
2) Annual fuel cost: $360,000 at $3/gal
3) Table 56: Annual Operation Costs for Tier 4 - $62,950
    a. Includes 4% fuel reduction or $14,400 benefit
    b. Includes SCR maintenance
    c. Includes cost of DEF consumption
4) Table 57: Capital Costs: $2,812,000 Tier 4 engine purchase and installation
5) Table 58: Annual Operation Cost for DPF - $35,978 (based on fuel penalty for DPF regeneration)

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[14] Moorhead K., Storz Ryan, and Pinisetty Dinesh 2019. "Evaluation of the Feasibility and Costs of Installing Tier 4 Engines and Retrofit Exhaust Aftertreatment on In-Use Commercial Harbor Craft," Prepared for the California Air Resources Board by California State University Maritime Academy.

6) Table 59: Capital Costs: $614,000 DPF retrofit on Tier 4 engines

This study highlights that the increased efficiency of the Tier 4 engines will be outweighed by the added fuel consumption required to regenerate[15] the DPF. The likely resulting net fuel penalty (and therefore greenhouse gas penalty) for DPF regeneration could increase fuel consumption by 6% overall. In addition, the DEF is a urea-water solution, and urea has a carbon footprint[16] of its own. So overall, this measure will have a net negative impact on (increase in) GHG emissions.

Cost effectiveness is defined as the annual cost divided by the annual benefit, or dollars per ton of emissions reduced. Annual cost is the annualized capital cost of the repower and retrofit plus any projected annual operating expenses. The annualized capital cost is the initial capital outlay amortized over the expected project life. With interest rates currently near zero, this is approximately equal to the one-time capital cost divided by the project life.

In March 2020, ARB presented a planned regulation that would require current Tier 3 (model years 2013 – 2015) engines to be updated to a Tier 4 plus DPF equivalent standard by 2026[17]. Assuming the repower and retrofit were completed by the end of 2020, this means that at most five or six years of emission reduction benefits in excess of potential future California regulatory requirements would be realized. This time period defines the expected project life for the cost effectiveness calculation.

PM, ROG and NOx benefits of these projects can also be taken into consideration. Carl Moyer Guidelines[18] use a weighted sum of PM, ROG, and NOx reductions to generate a combined multi-pollutant emission reduction measure:

**Carl Moyer Weighted tons = NOx (tons) + ROG (tons) + (20 * PM (tons))**

Assuming a six-year project life and using the emissions reductions shown in Table 7, the cost effectiveness of the Tier 4 plus DPF repower/retrofit is $2,500,000 per ton of DPM reduced and $52,000 per Carl Moyer Weighted ton. Costs may be somewhat overestimated because tugs have lower power on average than the sample tug Cal Maritime used in its costing.

Annualized cost estimates vary depending on assumptions made about the project life. The annual costs noted earlier based on a six-year project life are underestimated because the project life will be shorter for the three Tier 1 and 2 tugs listed in Table 5 base case as the Tier 1 tug engines need to be replaced by the end of 2021 under the current rule and those Tier 2 engines need to be replaced by the end of 2024 under the Proposed Concepts. On the other hand, annual costs would be lower if the project life were extended beyond six years, for example as a result of a delay in implementation of the planned harbor craft rule revisions. In addition, the emission reduction benefits noted earlier are undercounted

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[15] Most DPF systems regenerate by feeding excess fuel to heat the DPF to a temperature which will oxidize the captured soot.

[16] *"One ton of urea will emit about 0.73 tons of CO2, but its carbon footprint, derived through a full life-cycle analysis, will be closer to 5.15 tons CO2-equivalent (CO2e)."* https://ammoniaindustry.com/urea-production-is-not-carbon-sequestration/

[17] The proposed concepts do not indicate if the compliance date is January 1 or December 31 of the year stated, but the original harbor craft rule was December 31.

[18] https://ww3.arb.ca.gov/msprog/moyer/guidelines/current.htm

because emissions reductions that also accrue on non-Port of Oakland business (including assisting ships to and from Schnitzer) are not included in Table 7, which reflects only emission reductions during Oakland assist tug operations. Assist tugs based in Oakland do not work exclusively with ships coming to Oakland. As a result, the actual cost effectiveness may be substantially improved relative to the values cited above (i.e., lower cost per ton of emissions reduced) when these additional emission reductions are accounted for.

## RENEWABLE DIESEL

Renewable diesel is defined by ARB as a "diesel fuel that is produced from nonpetroleum renewable resources but [unlike biodiesel] is not a mono-alkyl ester".[19] Renewable diesel is typically made by hydrotreating any of a variety of natural oils including animal (tallow and fish oil) and plant based (soybeans) oils. As a drop-in replacement fuel, renewable diesel is a feasible option to reduce emissions with a short transition period and few if any technical issues. We use here emission reduction factors reported by ARB and others to calculate emission reductions for all equipment using neat (100%) renewable diesel fuel (R100) as compared to conventional diesel:

> *"For R100, PM emissions results showed an average decrease of about 30%. NOx emissions results showed a decrease of about a 10%. THC and CO generally decreased by about 5% and 10%, respectively."*[20]

For greenhouse gases, ARB[21] has certified the carbon intensity for several 'current fuel pathways' (essentially brands and types of fuel) for renewable diesel with carbon intensity averaging 32.2 $gCO_2e/MJ$ with a minimum of 16.9 and a maximum of 58.3 compared with the average non-renewable diesel fuel value of 100.45. On average, 100% renewable diesel (R100) should therefore be expected to reduce carbon dioxide emissions by about 68% compared with conventional diesel fuel.

Table 8 shows the emissions benefit that can be realized immediately from the use of renewable diesel from the base case fleet.

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[19] CalEPA 2015. "Multimedia Evaluation of Renewable Diesel," Prepared by the Multimedia Working Group, May 2015. https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf

[20] CalEPA 2015. "Multimedia Evaluation of Renewable Diesel," Prepared by the Multimedia Working Group, May 2015. https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf

[21] https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

**Table 8. Assist Tug Annual Emissions Reductions with Renewable Diesel**

| Fleet | Name | MY | Main HP | Tier | Hours | Emission Reductions (tons/year) | | | | Fuel Consumption (Gallons) (w/o 5% penalty) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ROG | CO | NOx | PM | |
| AMNAV | Patricia Ann | 2013[a] | 5080 | 3 | 1,028 | 0.07 | 0.74 | 0.81 | 0.06 | 93,167 |
| AMNAV | Revolution | 2013[a] | 5080 | 3 | 1,028 | 0.07 | 0.74 | 0.81 | 0.06 | 93,167 |
| AMNAV | Sandra Hugh | 2013[a] | 5080 | 3 | 1,028 | 0.07 | 0.74 | 0.81 | 0.06 | 93,167 |
| AMNAV | Liberty | 2008 | 4000 | 2 | 1,028 | 0.06 | 0.62 | 0.85 | 0.10 | 73,360 |
| AMNAV | Patriot | 2006 | 4800 | 1 | 1,028 | 0.08 | 0.40 | 1.37 | 0.23 | 88,031 |
| ST | Ahbra Franco | 2013 | 6850 | 2[b] | 875 | 0.08 | 0.86 | 1.18 | 0.13 | 106,969 |
| ST | Z-3 | 2013[a] | 4000 | 3 | 875 | 0.05 | 0.50 | 0.55 | 0.04 | 62,464 |
| ST | Z-4 | 2013[a] | 4000 | 3 | 875 | 0.05 | 0.50 | 0.55 | 0.04 | 62,464 |
| ST | Z-5 | 2013[a] | 4000 | 3 | 875 | 0.05 | 0.50 | 0.55 | 0.04 | 62,464 |
| | | | | | **Total** | **0.59** | **5.61** | **7.47** | **0.74** | **735,252** |

[a] Assumed model year for Tier 3 upgrade
[b] Ahbra Franco engines are larger with different ARB EFs, and possibly different Tier levels by model year.

The Port has reported that the contracted price of renewable and California diesel for late 2019 was $3.299 and $3.135 per gallon, respectively. Engines operating on renewable diesel are reported to experience a 5% fuel economy penalty relative to California diesel[22]. The total consumption for the fleets and activity shown in Table 8 is estimated to be 735,252 gallons of California diesel using the same calculation as for emissions with engine load multiplied by hours of operation and the ARB estimated fuel consumption factor (184.16 g/hp-hr) divided by a fuel density of 3200 g/gallon. Combining the emissions reductions shown in Table 8 with these fuel cost and consumption estimates results in a cost effectiveness for renewable fuel of $330,000/PM ton reduced and $11,000 per Carl Moyer ton reduced.

We note that the tug activity estimates used in the above calculations represent only tugs engaged in assisting ships to and from the Port. This does not include all the work that these tugs do throughout the Bay nor does it include ship assists to Schnitzer within the Oakland area. Including this additional tug activity in the cost effectiveness calculations would lower (improve) the cost efficiency estimates.

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[22] CalEPA 2015. "Multimedia Evaluation of Renewable Diesel," Prepared by the Multimedia Working Group, May 2015. https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf

RAMBOLL

ENVIRONMENT
& HEALTH

# MEMORANDUM

Date: **May 8, 2020**

To: **Tracy Fidell**

Cc: **Susanne von Rosenberg**

From: **Chris Lindhjem, Till Stoeckenius, and Lit Chan**

Subject: **Truck Emission Reduction Measures**

## INTRODUCTION

This memorandum quantitatively analyzes measures associated with reducing drayage truck emissions or activity at the Port of Oakland (Port). This analysis forms a basis to analyze the impact of West Oakland Community Action Plan (WOCAP)[1] strategy 43 might have:

> *"The Port of Oakland studies the effects on truck flow and congestion due to increasing visits from larger container ships, the feasibility of an off-terminal container yard that utilizes zero-emission trucks to move containers to and from the marine terminals, and the potential efficiency gains from increasing the number of trucks hauling loaded containers on each leg of a roundtrip to the Port."*

Evaluating the potential emissions impacts of an increase in visits by larger ships or any size ships carrying a larger number of containers to be offloaded at the Port involves a range of logistical issues that make it difficult to quantify. These issues might include fewer OGV calls but by larger vessels with potentially larger engines; the relative impact on berthing time and associated emissions, which depend upon discharge/loading scenarios and shoreside capacity; demand for CHE use within short berthing windows; and the required yard or truck capacity for handling more containers in a shorter time period. Similarly, evaluating the potential efficiency improvements and any potential emission reductions resulting from use of off-terminal container yards would require a full logistical analysis based on a specific, detailed yard layout.

Given the complexities noted earlier, we address in this memorandum only the potential emission reduction benefits of using zero-emissions (ZE) trucks, and of double cycling truck trips when containers are moved on both incoming and outgoing trips.

## TRUCK ACTIVITY

In the 2017 Port of Oakland Seaport Emission Inventory[2], the number of truck moves (in plus out) at the marine terminal gates was 2,081,932 and the number of lifts (counted as movement of a container either from or onto a ship) was 1,361,006. Note that a lift of a twenty-foot container is counted the same as a lift of a forty-foot container. However, a truck can carry two twenty-foot containers but only one forty-foot container per trip. Double cycling of twenty-foot containers could thus theoretically result in four lifts per truck round

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[1] WOCAP 2019. "Owning Our Air, The West Oakland Community Action Plan - Volume 1," Bay Area Air Quality Management District and West Oakland Environmental Indicators Project, October.
[2] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

trip through the terminal gates. However, the number of twenty-foot containers handled at the Port has been decreasing each year. In 2017, the estimated average twenty-foot equivalent (TEU) per lift was 1.8 implying that 20% of lifts were of twenty-foot containers and 80% were of forty-foot containers.

For the 2017 inventory, Ramboll estimated that, of the 2,081,932 truck moves in plus out of the marine terminals, 464,616 moves were to/from the adjacent railyards (the OIG yard operated by BNSF and the non-Port Union Pacific yard) and all of these moves were assumed to be single cycle trips, i.e., carrying a container in and no container out or vice versa.

Because the railyards are close to the terminals (across the street from some terminals as shown in Figure 2-12 from the WOCAP which is reproduced below), the benefit of double cycling truck moves is reduced from what it otherwise might be because each trip is quite short. Railyard activity may be difficult to schedule for double cycling because trains are either unloading or loading but unlikely to be doing both. Trucks engaged in local short trips such as those serving the railyards may, however, have the vocation most suited to zero emissions (battery electric) trucks where recharging facilities could be made readily available and truck range between recharging is less of a constraint.

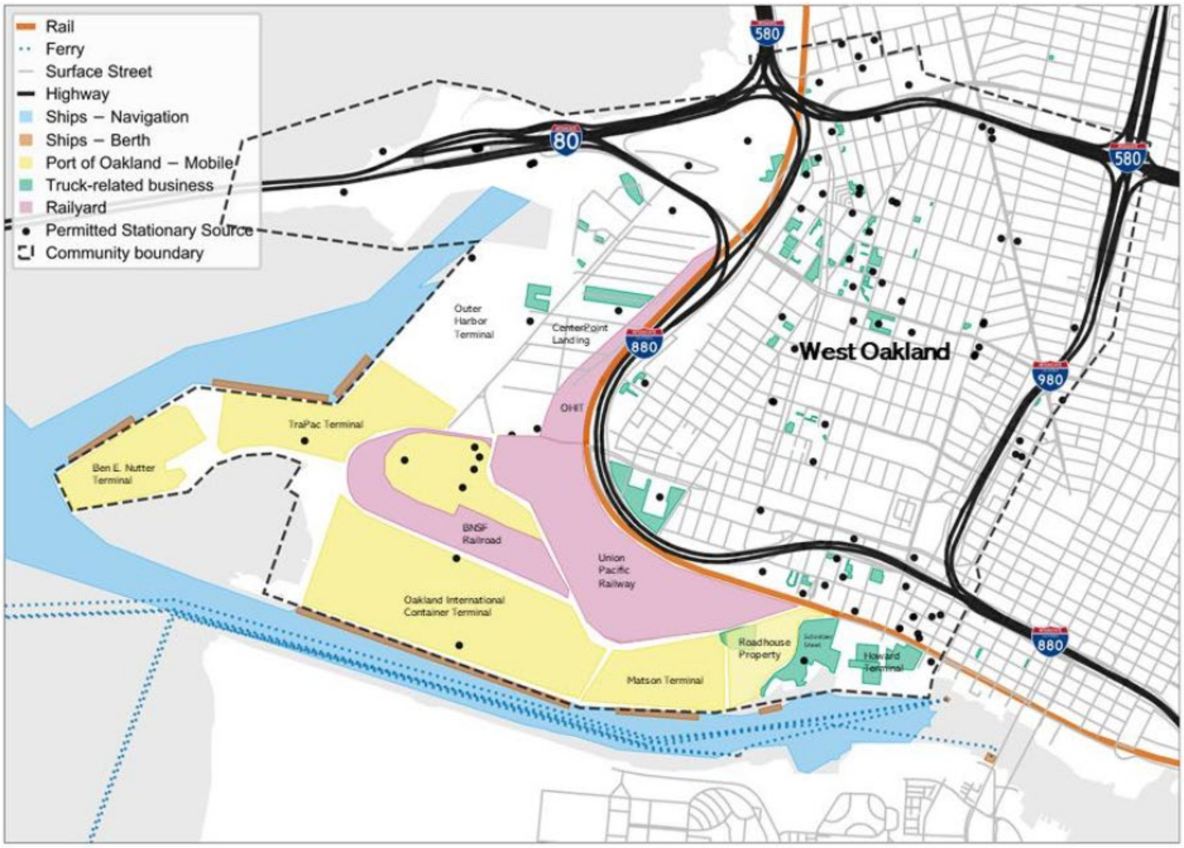

*Figure 2-12. Air Pollution Emission Sources in West Oakland*[21]

## EMISSIONS BENEFITS FROM DOUBLE CYCLING AND ZE TRUCKS

Not counting the railyard truck trips for reasons cited above, the remaining one-way truck trips in 2017 were 1,617,316 (or 808,658 round trips) serving 1,128,698 lifts (of individual containers). This means that 320,040 truck trips would have been double cycling assuming all lifts were of forty-foot containers. In reality, 20% of all lifts were of twenty-foot containers so a good fraction of the "double cycling" activity probably actually consisted of moving two twenty-foot containers in one direction. If all trucks were double cycling, the number of round trips would be 564,349 (number of one-way trips equal to the number of lifts), reducing container truck traffic by 23%. Based on the 2017 truck emission estimates, a 23% reduction in truck trips would result in the emission reductions shown in Table 1. As noted earlier, however, railyard activity is likely more difficult to schedule for double cycling, so the full benefit noted in Table 1 may not be achievable. On the other hand, if at least some of the railyard trips could be performed by ZE trucks, then that portion of truck emissions listed in Table 1 as "Port-Rail Trucking Subset" could be eliminated.

**Table 1. Potential Benefits of Double-Cycling Truck Trips in 2017 Emission Inventory**

| Emissions | Emissions (tons/year) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ROG | CO | $NO_x$ | $PM_{10}$ Total | $PM_{10}$ Exhaust[a] | $PM_{2.5}$ Total | $SO_x$ | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ |
| 2017 Truck Emissions | 4.68 | 24 | 79.91 | 0.901 | 0.261 | 0.482 | 0.18 | 18,992 | 0.22 | 2.71 | 19,805 |
| Port-Rail Trucking Subset | 0.93 | 5 | 14.72 | 0.154 | 0.045 | 0.083 | 0.03 | 3,561 | 0.04 | 0.49 | 3,710 |
| Maximum Additional Double Cycling Benefit (23%) | 1.10 | 5.61 | 18.76 | 0.211 | 0.061 | 0.113 | 0.04 | 4,457 | 0.05 | 0.64 | 4,648 |

[a] Diesel particulate matter

Emission reductions shown on Table 1 are based just on travel within the Port boundaries as defined in the 2017 Emissions Inventory. However, the double-cycling of longer haul (non-railyard) trucks represents additional truck travel beyond the Port boundaries. A reduction in these longer trips would thus result in greater Bay-wide emission reductions than shown in Table 1.