United States
Environmental Protection
Agency

NATIONAL PORT STRATEGY ASSESSMENT: Reducing Air Pollution and Greenhouse Gases at U.S. Ports

Office of Transportation Air Quality
EPA-420-R-16-011
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Note

ICF International provided technical support to the U.S. Environmental Protection Agency in the development of the methodologies, emission inventories, emission reduction strategy analyses, and other tasks related to this assessment.

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1. Executive Summary

1.1. Introduction

Ports are a vital part of the United States economy, with seaports, Great Lakes ports, and inland river ports serving as gateways for moving freight and passengers across the country and around the world. Seaports alone account for more than 23 million jobs and seaport cargo activity accounts for 26% of the United States economy.[1] The U.S. Army Corps of Engineers estimates that bigger Post-Panamax size ships that currently call at U.S. ports will dominate world trade and represent 62% of total container ship capacity by 2030.[2] As our nation adapts to meet these emerging economic and infrastructure demands, it is critical to understand the potential impacts on air pollution, greenhouse gases (GHGs), and the people living, working, and recreating near ports.

The U.S. Environmental Protection Agency (EPA) developed this national scale assessment to examine current and future emissions from a variety of diesel sources operating in port areas, and to explore the potential of a range of available strategies to reduce emissions from port-related trucks, locomotives, cargo handling equipment, harbor craft, and ocean-going vessels.[3] Diesel engines are the modern-day workhorse of the American economy, and although they can be reliable and efficient, older diesel engines can emit significant amounts of air pollution, including fine particulate matter ($PM_{2.5}$), nitrogen oxides (NOx), air toxics, and carbon dioxide (CO_2), which impact human health and the planet.

The entire nation benefits from economic activity from the trade that passes through commercial ports located around the country. And while those emissions can reach significantly inland,[4] it is the people who live, work, and recreate near ports that experience the most direct impacts on their health and welfare. EPA estimates that about 39 million people in the United States currently live in close proximity to ports[5]; these people can be exposed to air pollution from diesel engines at ports and be at risk of developing asthma, heart disease, and other health problems.[6] Port-related diesel-powered vehicles, equipment, and ships also produce significant GHG emissions that contribute to climate change. Even though EPA has adopted stringent emission standards for diesel engines, many ports and related freight

[1] American Association of Port Authorities (AAPA), http://www.aapa-ports.org/advocating/content.aspx?ItemNumber=21150.

[2] U.S. Army Corps of Engineers, *U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels: Report Summary*, June 20, 2012.

[3] This assessment was conducted to evaluate the emission reduction potential of a range of available strategies based upon a national scale approach, rather than the cost and other details necessary to apply strategies in a specific area.

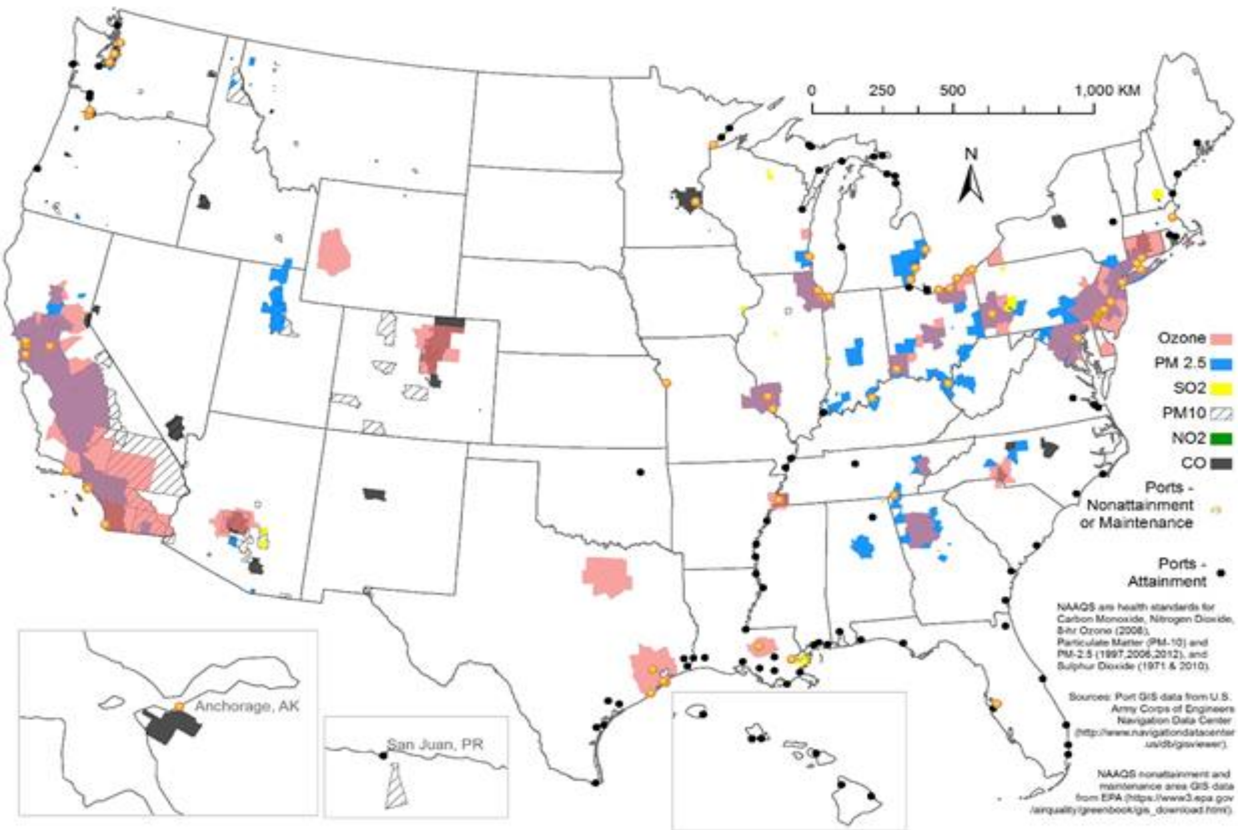
[4] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* 75 FR 24802, April 30, 2010.

[5] EPA's analysis is based on overlaying and merging U.S. Census tract level geospatial data (Census Bureau 2010) with EPA's National Emission Inventory (NEI 2011) ports data indicating that approximately 39 million people lived within 5 kilometers of ports in the United States.

[6] U.S. Environmental Protection Agency, *Near Roadway Air Pollution and Health: Frequently Asked Questions*, EPA-420-F-14-044, 2014, https://www3.epa.gov/otaq/nearroadway.htm.

corridors and facilities are located in nonattainment or maintenance areas for EPA's ozone and $PM_{2.5}$ national ambient air quality standards (NAAQS), per Figure 1-1.[7]

Figure 1-1. Ports in Areas Designated Nonattainment or Maintenance for the Clean Air Act's NAAQS



This assessment supports the vision of EPA's Ports Initiative to reduce air pollution and GHGs through a collaboration of industry, government, and communities.[8] EPA already supports voluntary efforts to reduce diesel emissions through EPA's Clean Diesel Campaign and its SmartWay program. State and local governments, ports and port operators, Tribes, communities, and other stakeholders can use this assessment as a tool to inform their priorities and decisions for port areas and achieve more emission reductions across the United States. Economic growth can go hand-in-hand with continued improvements in the health and welfare of near-port communities and the safeguarding of our planet.

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[7] Based on a review of available data, EPA approximates that 40% of "Principal Ports" are located in or near areas that have violated a NAAQS (nonattainment areas) or have previously violated but are now meeting a NAAQS (maintenance areas).

[8] The goals of EPA's Ports Initiative are to reduce air pollution and GHGs, to achieve environmental sustainability for ports, and improve air quality for near-port communities. For more information, see https://www.epa.gov/ports-initiative.

EPA developed this assessment in consultation with the Mobile Sources Technical Review Subcommittee (MSTRS) of the Clean Air Act Advisory Committee (CAAAC) over a two-year period. In 2014, the MSTRS formed a Ports Workgroup to develop recommendations for developing an EPA-led voluntary ports initiative, and effectively measuring environmental performance at ports. The MSTRS Ports Workgroup included technical and policy experts from a range of stakeholders, including industry, port-related agencies, communities, Tribes, state and local governments, and public interest groups.[9]

[9] For further information on MSTRS Ports Working Group participants, see https://www.epa.gov/sites/production/files/2016-06/documents/portsinitiativewkgrp_2016.pdf.

1.2. Port-related diesel emissions impact public health and the climate.

Emissions from diesel engines, especially $PM_{2.5}$, NOx, and air toxics such as benzene and formaldehyde, can contribute to significant health problems—including premature mortality, increased hospital admissions for heart and lung disease, and increased respiratory symptoms—for children, the elderly, outdoor workers, and other sensitive populations.[10] EPA has determined that diesel engine exhaust emissions are a likely human carcinogen,[11] and the World Health Organization has classified diesel emissions as carcinogenic to humans.[12] Many ports and port-related corridors are also located in areas with a high percentage of low income and minority populations who are often disproportionately impacted by higher levels of diesel emissions.[13]

Port-related diesel emissions, such as CO_2 and black carbon, also contribute to climate change. Research literature increasingly documents the effects that climate change is having and will increasingly have on air and water quality, weather patterns, sea levels, human health, ecosystems, agricultural crop yield, and critical infrastructure.[14] Other health impacts that are projected from climate change include heat stroke and dehydration from more frequent and longer heat waves and illnesses from an increase in water and food-borne pathogens.[15] This assessment provides options to inform voluntary, place-based actions that may be taken by federal, state, and local governments, Tribes, ports, communities, and other stakeholders to reduce these impacts and enhance public health and environmental protection.

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[10] *Third Report to Congress: Highlights from the Diesel Emission Reduction Program*, EPA, EPA-420-R-16-004, February 2016, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OHMK.pdf; and *EPA's Health Assessment Document for Diesel Engine Exhaust*, 2002.

[11] *Health Assessment Document for Diesel Engine Exhaust*, prepared by the National Center for Environmental Assessment for EPA, 2002.

[12] *Diesel Engine Exhaust Carcinogenic*, International Agency for Research on Cancer (IARC), World Health Organization, June 12, 2012, http://monographs.iarc.fr/ENG/Monographs/vol105/.

[13] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* 75 FR 24802 (April 30, 2010).

[14] U.S. Environmental Protection Agency, *Climate Change Indicators in the United States*, 4th edition, 2016, https://www.epa.gov/climate-indicators.

[15] United States Global Change Research Program, *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, April 2016, http://www.globalchange.gov/health-assessment.

1.3. Progress is already happening, but more emission reductions are possible.

EPA's technology standards and fuel sulfur limits are expected to significantly reduce emissions as new diesel trucks, locomotives, cargo handling equipment (CHE), and ships enter the in-use fleet. For example, the North American and U.S. Caribbean Sea Emissions Control Areas require lower sulfur fuel to be used for large ocean-going vessels (OGVs). This has reduced fuel-based PM emissions by about 90%. Some stakeholders have also adopted voluntary strategies like those examined in this assessment. EPA supports these efforts, encourages them to continue in the future, and hopes that this assessment will encourage more areas to adopt and incentivize such voluntary programs.

EPA developed this national scale assessment based on estimated emissions from a representative sample of seaports. EPA estimated Business as Usual (BAU) emissions by projecting future trends under the status quo. As shown in Figure 1-2, total $PM_{2.5}$ emissions are projected to decrease in the future for most mobile source sectors and years. The assessment considered the impact from all mobile source sectors, and the levels of emissions shown in Figure 1-2 are based on the assessment's geographic scope.

Figure 1-2. Total BAU $PM_{2.5}$ Emissions by Mobile Source Sector

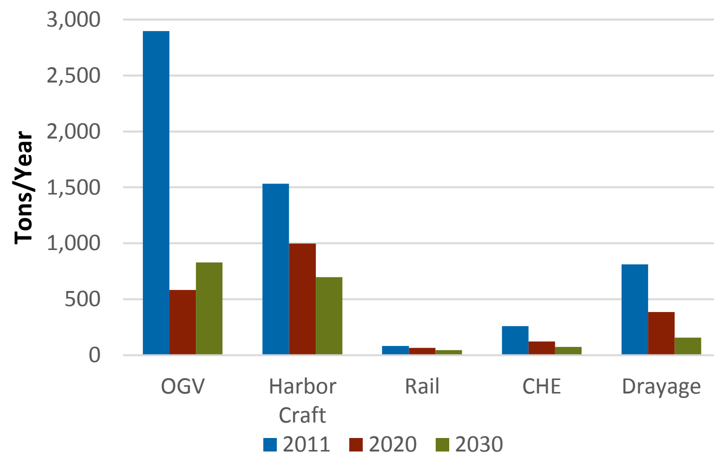
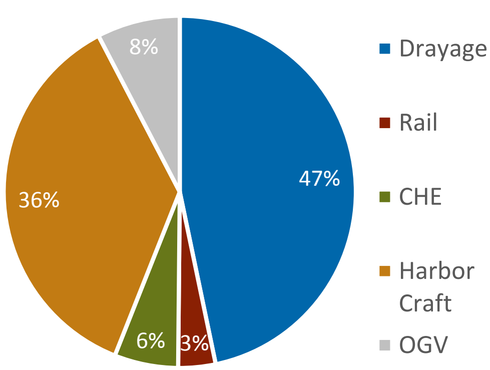


Figure 1-3. Relative Reductions for $PM_{2.5}$ in 2020 (Scenario A)



EPA then estimated the potential reductions from a suite of available strategies for all mobile source sectors for the years 2020, 2030, and 2050. For example, Figure 1-3 shows the break-out of $PM_{2.5}$ reductions for all mobile source sectors for Scenario A in the year 2020, with the highest emission reductions being achieved in the drayage truck sector. In this scenario, total $PM_{2.5}$ emissions are projected to be reduced by 47% in the year 2020 by replacing older trucks with newer, cleaner trucks. This example illustrates that voluntary, place-based actions can reduce emissions from port activity and benefit public health in the communities living near truck corridors.

1.4. We can reduce emissions with effective strategies that are currently available.

This assessment examined a suite of currently available strategies, including zero emissions (e.g., electric) technologies that can be used to develop voluntary programs to achieve additional emission reductions. Some ports are already using the strategies in this assessment, including emerging technologies, and their wider use could achieve even greater public health benefits.

Table 1-1 provides examples of some of the strategies in this assessment. The categories include replacing older diesel fleets; operational improvements to reduce idling; and switching to cleaner fuels. The strategies examined are not exhaustive; there may be other strategies that could also be effective at a given port or for another application. For example, diesel retrofit technology has been a highly effective strategy to reduce diesel emissions from school buses, transit buses, and long-haul trucks. EPA did not include this technology option in its analysis since retrofitting port drayage trucks is less effective than simply replacing them. While this assessment included a few strategies to improve operational efficiency at ports, the focus was primarily on assessing technological strategies. EPA continues to believe that operational strategies (e.g., reducing truck or locomotive idling) can be effective at reducing diesel emissions.

Table 1-1. Examples of Strategy Scenarios Assessed

Sector	Scenario Description
Drayage Trucks	Replace older diesel trucks with trucks that meet cleaner EPA standards and plug-in hybrid electric vehicles.
Rail	Replace older line-haul locomotive engines with cleaner technologies, including electric locomotives.
	Improve fuel economy.
	Replace older switcher locomotive engines with cleaner technologies and Generator Set (GenSet) technology.
Cargo Handling Equipment	Replace older yard truck, crane, and container handling equipment with cleaner technologies, including electric technologies.
Harbor Craft	Replace or repower older tugs and ferries with cleaner technologies, including hybrid electric vessels.
Ocean-going Vessels	Switch to lower sulfur fuel levels that are below EPA's regulatory standards, and liquified natural gas for certain vessel types.
	Utilize shore power to reduce hoteling of container, passenger, and reefer vessels.
	Apply Advanced Marine Emission Control Systems for container and tanker vessels.

1.5. Replace older, dirtier diesel vehicles and equipment first.

As noted earlier, EPA's regulations for new diesel vehicles and equipment are projected to significantly reduce NOx and $PM_{2.5}$ emissions into the future. However,older trucks and equipment are longstanding fixtures of many port operations, and it will take many years before these fleets turn over to newer technology. Accelerating the retirement of older port vehicles and equipment and replacing them with the cleanest technology will reduce emissions and increase public health benefits beyond what would be achieved without further voluntary actions.

Table 1-2 provides examples of the emission reduction potential of port strategies evaluated in this assessment. For example, the potential for replacing older drayage trucks with cleaner diesel trucks is significant, with NOx being reduced in 2020 by 19–48% and $PM_{2.5}$ being reduced by 43–62% as compared to the BAU case. In 2030, adding plug-in hybrid electric vehicle fleets resulted in even more NOx and $PM_{2.5}$ relative reductions. In another example, shore power reductions of NOx and $PM_{2.5}$ were also significant, with higher reductions being expected if shore power was applied to a larger portion of OGVs.

Table 1-2. Examples of Effective Port Strategies to Reduce NOx and $PM_{2.5}$ Emissions

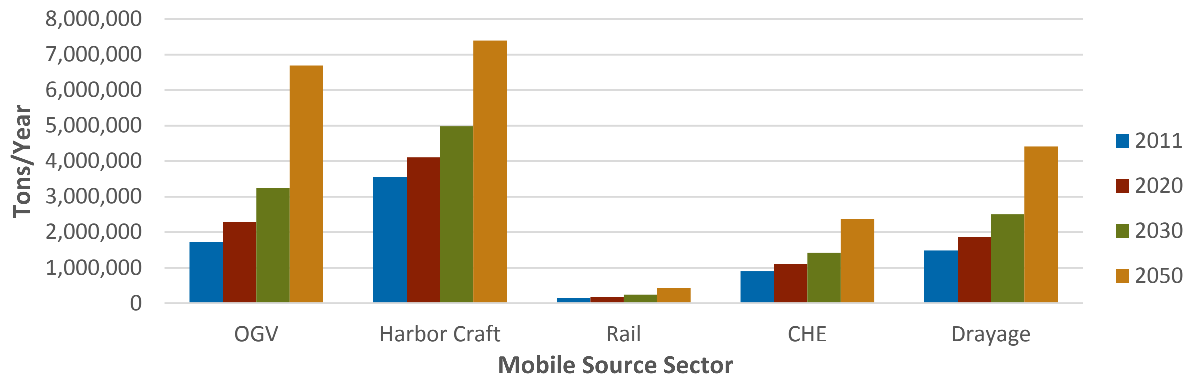
Strategy Scenario	Percent reduction from BAU			
	NOx		$PM_{2.5}$	
	2020	2030	2020	2030
Replace older drayage trucks	19–48%	48–60%	43–62%	34–52%
Replace older switcher locomotives	16–34%	17–43%	22–44%	24–47%
Replace older CHE	17–39%	13–25%	18–37%	12–25%
Replace or repower harbor craft	10–24%	25–38%	13–41%	28–37%
Reduce OGV hoteling emissions with shore power[16]	4–9%	7–16%	3–8%	7–16%

[16] The shore power results also account for the emissions from generating electricity.

1.6. CO_2 continues to increase, but effective strategies are available.

Port-related CO_2 emissions are projected to increase from current levels for all mobile sources in all future years, as shown in Figure 1-4, in large part due to significant increases in economic trade and activity. In addition, most of EPA's existing regulations and standards do not address CO_2 emissions for port mobile source sectors.[17]

Figure 1-4. Total BAU CO_2 Emissions by Mobile Source Sector



This assessment evaluated voluntary replacements of diesel vehicles and equipment with zero emissions and other advanced technologies that are currently in use or in development for most port sectors. Several strategies reduced the magnitude of increasing CO_2 levels. Examples of some of the assessment's strategy scenarios and estimated relative CO_2 reductions are included in Table 1-3.

Table 1-3. Examples of Effective Port Strategies to Reduce CO_2 Emissions

Strategy Scenario	Percent reduction from CO_2 BAU	
	2030	2050
Replace older drayage trucks with plug-in hybrid electric trucks	0–4%	6–12%
Replace older locomotives with electric locomotives, GenSets, and fuel efficiency	3–6%	11–23%
Replace older CHE with electric technologies	7–18%	27–45%
Reduce OGV hoteling emissions with shore power[18]	2–5%	4–10%

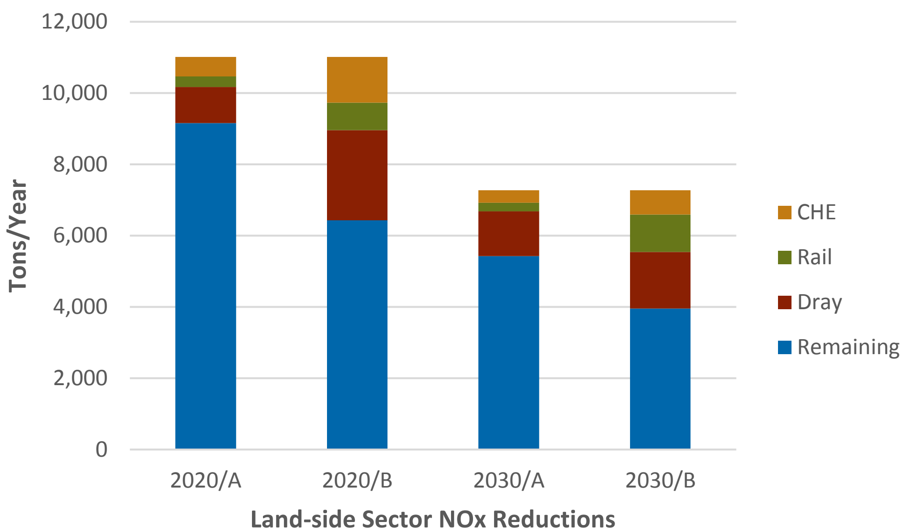
[17] The assessment's estimates for drayage trucks and OGVs do not include the impacts of recent CO_2 reduction programs. Specifically, the CO_2 reductions of EPA's heavy-duty engine and vehicle GHG regulations and the International Maritime Organization's Energy Efficiency Design Index and Ship Energy Efficiency Management Plan were not included due to the timing of the assessment. If such programs were included, EPA would expect smaller CO_2 increases in drayage truck and OGV emissions in 2030 and 2050.

[18] The shore power results also account for the emissions from generating electricity.

1.7. Reduction potential varies across mobile source sectors.

The voluntary strategies examined in this assessment do not achieve the same level of reductions across all mobile source sectors and pollutants. Specifically, strategy scenarios that target land-side operations (i.e., drayage trucks, locomotives, and CHE) are generally expected to result in greater emission reductions than those targeting water-side operations (i.e., harbor craft and OGVs). This is illustrated in Figure 1-5, which shows the total tons of NOx reduced from the 2020 and 2030 BAU cases assumed in this assessment for land-side mobile source sectors.

Figure 1-5. Total NOx Reductions for Land-side Mobile Source Sectors



The 2020 and 2030 BAU emission levels are the total bars for 2020 and 2030, with the amount of NOx emissions reduced from CHE, rail, and drayage truck strategies shown in different colors respectively. For each of these years, there were two strategy scenarios examined (i.e., Scenarios A and B),[19] with Scenario B being a more aggressive suite of strategies than Scenario A. The significant levels of reductions shown above are especially important for the drayage truck and rail sectors since these are the sectors that are typically closer to neighborhoods, schools, and other parts of communities located in close proximity to ports.

In contrast, the scenarios for harbor craft and OGV sectors produced lower, but still significant, reductions from these respective 2020 and 2030 BAU emission levels. In practice, the most effective emission reduction strategies for any mobile source sector would be those that are tailored to the specific circumstances of a given port area.

[19] For example, "2020/A" shows the emissions reduced from Scenario A in 2020.

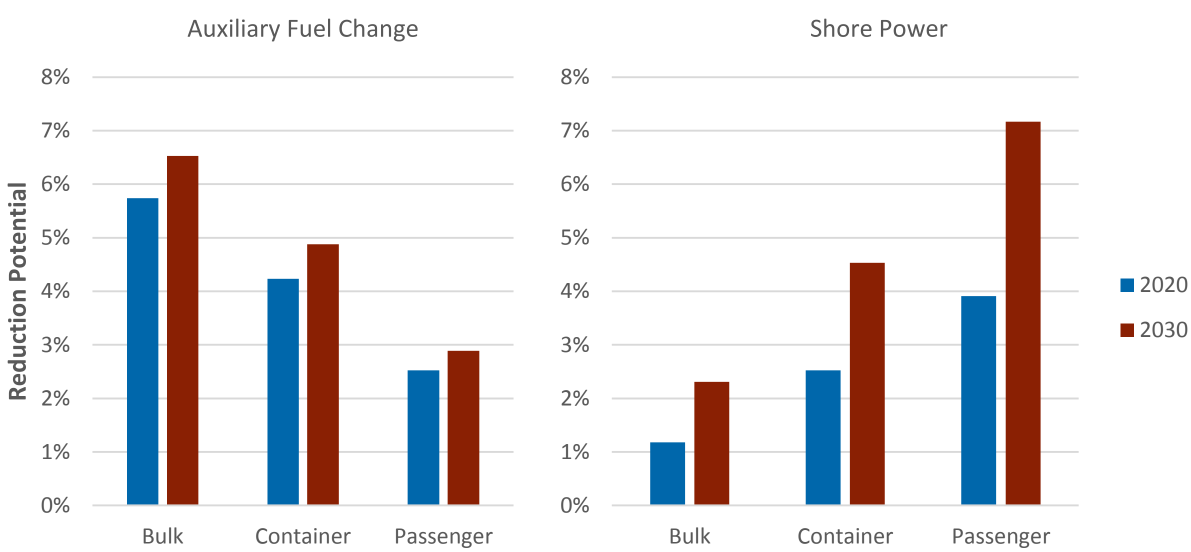
1.8. Effective strategies are available for every type and size of port.

EPA recognizes that many strategies reduce diesel emissions across different port emission profiles, as illustrated by the effective strategies examined at the assessment's representative sample of U.S. seaports. But the assessment could also be informative for voluntary decisions at other seaports, Great Lakes and inland river ports, or other freight and passenger facilities with similar mobile source profiles. EPA conducted a stratification analysis to further understand the assessment results, since U.S. ports vary in size, purpose, mix of vessels, and ground transportation. This analysis assessed the effectiveness of strategies for ports of different types: container, bulk, and passenger; and sizes: large and small.[20]

The stratification analysis shows that not all strategies can be expected to have the same results at all ports. For example, Figure 1-6 illustrates the effectiveness of reducing emissions while OGVs are operating their auxiliary engines. For the year 2020, switching to a cleaner fuel was projected to be more effective for reducing emissions from ships carrying bulk cargo while shore power technology was more effective at reducing NOx emissions for passenger ships. Shore power is expected to be more effective at reducing NOx emissions for a passenger port because passenger ships tend to call the same ports frequently, making it more feasible to adapt these vessels to use shore power.[21] In contrast, ships carrying bulk cargo typically do not call on the same port as often in a given year.

Stakeholders should consider what combination of strategies should be used to reduce emissions for a particular port area, depending upon the type of activity at a port.

Figure 1-6. NOx Reduction Effectiveness of Different Strategies at Different Kinds of Ports (Scenario B)



[20] These terms are not official classifications, but were defined and used in this analysis to differentiate among port sources considered in this assessment.

[21] The shore power results also account for the emissions from generating electricity.

1.9. More focus is needed to reduce port-related emissions.

State and local governments, ports and port operators, Tribes, communities, and other stakeholders can use this assessment as a tool to inform priorities and decisions about their port area. EPA's assessment illustrates how more investment in reducing port-related emissions through voluntary place-based programs can make a difference. This is important to consider in future planning, with U.S. port and private sector partners projected to spend $154.8 billion on port-related infrastructure, with an additional $24.8 billion of investment by the federal government in U.S. ports through 2020.[22]

Many of the strategies in this assessment are also eligible for existing federal funding sources, such as EPA's Diesel Emissions Reduction Act (DERA) grant program, which has been instrumental in furthering emission reductions through clean diesel projects located at ports and goods movement hubs. Since the first appropriation of the DERA program in Fiscal Year 2008, $148 million has gone toward 129 grants to fund projects at or near ports, with $80 million of this amount going to projects specifically at port facilities, including CHE upgrades, drayage truck replacements, locomotive engine repowers, and more. Other sources of federal funding that have been used for port-related emission reduction projects include the Department of Transportation's Transportation Investment Generating Economic Recovery (TIGER) and Congestion Mitigation and Air Quality Improvement (CMAQ) programs, and the Department of Energy's Clean Cities program.

When assessing strategies for a specific port area, here are some questions to consider:

- ✓ Is there a port-specific emission inventory or clean air plan available to inform decisions?
- ✓ What is the type and size of the port?
- ✓ What source sectors are the most significant diesel emitters at the port?
- ✓ How old are the diesel fleets of each port sector?
- ✓ Is there an existing forum for stakeholder participation?

[22] Results of AAPA's Port Planned Infrastructure Investment Survey: Infrastructure investment plans for U.S. ports and their private sector partners, 2016 through 2020, AAPA, April 6, 2016, http://aapa.files.cms-plus.com/SeminarPresentations/2016Seminars/2016PRCommitteeMarchMeeting/2016-2020%20Port%20Planned%20Infrastructure%20Investment%20Survey%203-3-2016.pdf.

2. Introduction

2.1. Purpose of Assessment

EPA developed this assessment to:

- Examine current and future emissions from a variety of diesel sources operating at ports;
- Explore the potential effectiveness of a range of emission reduction strategies; and
- Inform EPA's Ports Initiative and voluntary port-related efforts across the country.

Ports are a vital part of the U.S. economy, with seaports, Great Lakes ports, and inland river ports serving as gateways for moving freight and passengers across the country and around the world. Seaports alone account for more than 23 million jobs and seaport cargo activity accounts for 26% of the U.S. economy.[23] The expansion of the Panama Canal was completed in June 2016, doubling its capacity.[24] The U.S. Army Corps of Engineers estimates that Post-Panamax ships are expected to dominate world trade and represent 62% of total container ship capacity by 2030.[25] In addition, EPA estimates that about 39 million people in the United States currently live in close proximity to ports.[26] These people can be exposed to air pollution from diesel engines at ports and be at risk of developing asthma, heart disease, and other health problems.[27] This assessment is intended to update our understanding of current and future trends in air pollution and climate emissions as well as the potential impacts on the people living, working, and recreating near ports.

This assessment also explored the potential of a range of available strategies to reduce diesel emissions from port-related activity. EPA recognizes that to reduce diesel emissions at the national level, it is important to identify strategies that are effective for ports with different emission profiles. Ports serve a variety of purposes as freight and passenger hubs on the seacoasts, freshwater lakes, and rivers across the United States. Therefore, EPA assessed the effectiveness of a range of available emission reduction strategies under different scenarios, such as replacing older diesel fleets with newer technologies,

[23] American Association of Port Authorities. For further information, see http://www.aapa-ports.org/advocating/content.aspx?ItemNumber=21150.

[24] The expansion is anticipated to increase the number of ships passing through the canal as well as introduce a new larger size of ships (i.e., post-Panamax), which are approximately one and a half times the size of and can carry over twice as much cargo as ships that currently call at U.S. ports.

[25] U.S. Army Corps of Engineers, *U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels: Report Summary*, June 20, 2012.

[26] EPA's analysis is based on overlaying and merging U.S. Census tract level geospatial data (Census Bureau 2010) with EPA's National Emission Inventory (NEI 2011) ports data indicating that approximately 39 million people lived within 5 kilometers of ports in the United States.

[27] U.S. Environmental Protection Agency, *Near Roadway Air Pollution and Health: Frequently Asked Questions*, EPA-420-F-14-044, 2014, https://www3.epa.gov/otaq/nearroadway.htm.

improving operational efficiency to reduce idling, and switching to cleaner fuels. EPA also examined the potential of zero emissions (e.g., electric) vehicles and equipment and other emerging technologies.

Finally, this assessment can support EPA's Ports Initiative[28] and voluntary port-related efforts across the country. While EPA's regulations have substantially reduced emissions and continue to improve air quality as new vehicles, engines, and equipment enter the in-use fleet, the large number and high activity levels of older fleets at port facilities warrant further action. It is critical to focus future efforts on improving the lives and health of communities impacted by ports and providing place-based options that improve environmental performance in port areas.

EPA developed this assessment in consultation with the Mobile Sources Technical Review Subcommittee (MSTRS) of the Clean Air Act Advisory Committee (CAAAC)[29] over a two-year period. In 2014, the MSTRS formed a Ports Workgroup to develop recommendations for developing an EPA-led voluntary ports initiative, and effectively measuring environmental performance at ports. The MSTRS Ports Workgroup included technical and policy experts from a range of stakeholders, including industry, port-related agencies, communities, Tribes, state and local governments, and public interest groups.[30]

2.2. Public Health and Climate Impacts

Emissions from diesel engines, especially particulate matter (PM), nitrogen oxides (NOx), and air toxics such as benzene and formaldehyde, can contribute to significant health problems – including premature mortality, increased hospital admissions for heart and lung disease, and increased respiratory symptoms. EPA has determined that diesel engine exhaust emissions are a likely human carcinogen,[31] and the World Health Organization has classified diesel emissions as carcinogenic to humans.[32] Moreover, many ports and port-related corridors are located in areas with a high percentage of low income and minority populations who are often disproportionately impacted by higher levels of diesel emissions.[33] NOx also contributes to the formation of ozone and PM through chemical reactions, and many ports and related freight corridors and facilities are located in nonattainment or maintenance

[28] For more information, see https://www.epa.gov/ports-initiative.

[29] Chartered under the Federal Advisory Committee Act (FACA), CAAAC was established to advise EPA on issues related to implementing the Clean Air Act, as amended in 1990. Learn more at: https://www.epa.gov/caaac.

[30] For further information on MSTRS Ports Working Group participants, see https://www.epa.gov/sites/production/files/2016-06/documents/portsinitiativewkgrp_2016.pdf.

[31] *Health Assessment Document for Diesel Engine Exhaust*, prepared by the National Center for Environmental Assessment for EPA, 2002.

[32] *Diesel Engine Exhaust Carcinogenic*, International Agency for Research on Cancer (IARC), World Health Organization, June 12, 2012, http://monographs.iarc.fr/ENG/Monographs/vol105/.

[33] For example, EPA conducted a screening-level modeling analysis in 2008 of 45 nationally representative marine harbor areas (including port authority and private port operations) in support of EPA's 2010 emission standards for new marine compression-ignition engines at or above 30 liters per cylinder. The modeling analysis estimated that at least 18 million people, including a disproportionate number of low-income households, African-Americans, and Hispanics, living in the vicinity of these 45 ports were exposed to ambient diesel PM levels that were at least 0.2 $\mu g/m^3$ above levels in areas farther from these facilities. See 75 FR 22896 (April 30, 2010).

areas for EPA's ozone and fine particulate matter ($PM_{2.5}$) national ambient air quality standards (NAAQS). Exposure to ozone can aggravate asthma and other respiratory conditions, with children, the elderly, outdoor workers, and people with heart and lung conditions being most at risk.[34]

Port-related diesel emissions—such as carbon dioxide (CO_2) and black carbon—also contribute to climate change. Research literature increasingly documents the effects that climate change is having and will increasingly have on air and water quality, weather patterns, sea levels, human health, ecosystems, agricultural crop yield, and critical infrastructure.[35] Black carbon is a component of PM and is linked to a range of adverse climate impacts, including increased temperatures and accelerated snowmelt.[36] Other health impacts that are projected from climate change include heat stroke and dehydration from more frequent and longer heat waves, asthma attacks, illnesses from an increase in water and food-borne pathogens, and exacerbation of other respiratory and cardiovascular health effects.[37]

These are significant impacts that further highlight the importance of understanding current and future port-related diesel emissions and identifying opportunities to reduce these emissions.

2.3. Mobile Source Sectors Analyzed

This assessment focused on the potential of strategies to reduce emissions from diesel-powered vehicles and equipment.[38] More details are included below on the five mobile source sectors that were analyzed.

2.3.1. Drayage Trucks

Drayage trucks are combination short-haul trucks that move cargo into and out of ports. Drayage trucks typically travel short distances to and from the port to a nearby rail yard or distribution center. This truck activity typically involves significant idle or creep time to enter and exit a port as well as load or unload containers or other cargo.[39] Drayage trucks are generally older than the average truck fleet, since they are usually sold by long-haul trucking firms that tend to have newer fleets and a much faster turnover rate.

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[34] *Third Report to Congress: Highlights from the Diesel Emission Reduction Program*, EPA-420-R-16-004, February 2016; and *EPA's Health Assessment Document for Diesel Engine Exhaust*, 2002.

[35] U.S. Environmental Protection Agency, *Climate Change Indicators in the United States*, 4th edition, 2016, https://www.epa.gov/climate-indicators.

[36] For further information on black carbon, see EPA's website at: https://www3.epa.gov/blackcarbon/.

[37] United States Global Change Research Program, *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, April 2016, http://www.globalchange.gov/health-assessment.

[38] While other emission sources exist at or near ports (such as electricity generators, boilers, and refineries), these were not considered in this mobile source assessment.

[39] This type of drayage activity includes taking significant time to move short distances, with multiple starts and stops.

2.3.2. Rail

The rail emission sources in this assessment include switcher and line-haul locomotives. Switchers move rail cars short distances within a rail yard,[40] and line-haul locomotives travel out of the port to distant locations. Switchers connect individual rail cars to form the trains that line-haul locomotives move out of the port.

2.3.3. Cargo Handling Equipment

Cargo handling equipment (CHE) are located on a port and move cargo on and off ocean-going vessels (OGVs) and harbor craft. CHE move cargo around the port so that it can be loaded onto trucks and rail cars. There are many different kinds of CHE, including forklifts, cranes, and bulk handling equipment (e.g., tractors, loaders, etc.). This assessment focused on a subset of diesel-powered CHE, specifically yard tractors, rubber tire gantry (RTG) cranes, and container handlers (top picks and side picks).

2.3.4. Harbor Craft

Harbor craft assist in moving OGVs around the harbor, move cargo and people into and out of the port harbor area, and provide fuel to OGVs; they also transport crew and supplies to offshore facilities. Harbor craft are vessels with engines less than 30 liters per cylinder and are classified as Category 1 and 2 vessels. There are many different kinds of diesel-powered harbor craft, including commercial fishing boats, government vessels, and dredges. This assessment focused on tugs and ferries.

2.3.5. Ocean Going Vessels

OGVs move cargo and people into and out of a port and typically travel long distances to or from foreign ports or may travel to or from other domestic ports. OGVs are vessels with engines of 30 liters per cylinder or more (i.e., Category 3 vessels); many of the ship types considered in this assessment are described in Table 2-1.

Table 2-1. Ocean-Going Vessel Ship Types

Ship Type	Description
Auto Carrier	Self-propelled dry-cargo vessel that carries containerized automobiles
Bulk Carrier	Self-propelled dry-cargo ship that carries loose cargo
Container Ship	Self-propelled dry-cargo vessel that carries containerized cargo
General Cargo	Self-propelled cargo vessel that carries a variety of dry cargo
Passenger	Self-propelled cruise ships
Reefer	Self-propelled dry-cargo vessel that often carries perishable items
Roll-on/Roll-off	Self-propelled vessel that handles cargo that is rolled on and off the ship
Tanker	Self-propelled liquid-cargo vessels including chemical tankers, petroleum product tankers, liquid food product tankers, etc.

[40] Please note that in this assessment, on-dock rail is generally characterized as a rail yard in a port.

This assessment considered OGV diesel emissions for both propulsion and auxiliary engine activity. The main propulsion engines on most large ships can stand over three stories tall and run the length of two school buses. Auxiliary engines on large ships typically range in size from small portable generators to locomotive size engines.[41]

2.4. Pollutants Characterized in This Work

Port-related emissions and reductions were estimated for several different criteria pollutants and precursors, climate change pollutants, and air toxics. Criteria pollutants include common air pollutants that are identified by the Clean Air Act, such as $PM_{2.5}$[42] and ground-level ozone; precursors are air pollutants that form criteria pollutants, such as NOx and volatile organic compounds (VOCs) which are emissions that combine to form ground-level ozone. Climate change pollutants include GHGs that contribute to global warming, while air toxics are hazardous air pollutants that are known or suspected to cause serious health effects.

The following list includes the specific pollutants characterized in this assessment:

- Criteria pollutants and precursors
  - NOx
  - $PM_{2.5}$
  - sulfur dioxide (SO_2)
  - VOCs[43]

- Climate change pollutants
  - carbon dioxide (CO_2)
  - black carbon (BC)

- Air toxics
  - benzene
  - acetaldehyde
  - formaldehyde

SO_2 was not analyzed for the non-OGV mobile source sectors since these sectors in the United States currently use ultra-low sulfur diesel (ULSD), which is a cleaner-burning diesel fuel that has significantly reduced the SO_2 emitted by these sources. SO_2 emissions from OGVs were estimated because although these vessels use low sulfur distillate fuels at ports (up to 1000 ppm sulfur), further reductions may be gained from use of even lower sulfur fuels. In addition, EPA determined that it is premature to evaluate air toxics that are emitted by OGVs due to data limitations identified with projecting emissions for these

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[41] Auxiliary boilers were not included in this assessment as they were considered to be a much smaller source of emissions. The energy consumption of auxiliary boilers is not considered significant, and these engines are not prevalent on every ship.

[42] $PM_{2.5}$ are particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers.

[43] NOx and VOCs are precursors of ozone and $PM_{2.5}$ criteria pollutants. SO_2 is a precursor for $PM_{2.5}$, as well as a criteria pollutant.

sources, particularly for the future years of interest in this assessment. Air toxic emissions from OGVs are an area that warrants further research and analysis.

2.5. Overview of Assessment Approach

This assessment was designed to provide a national picture of port-related emission trends and the potential for emission reduction strategies based on estimated emissions from a representative sample of 19 seaports. The ports selected featured a range of diverse characteristics, such as different sizes, types of activity, and geographic location. Baseline and Business as Usual (BAU) national scale inventories were developed from aggregating inventories from the port areas, followed by the analysis of various strategies to reduce port-related mobile source emissions.

Separate emission inventories were developed for the drayage truck, rail, CHE, harbor craft, and OGV sectors. Baseline inventories were developed for the year 2011, while BAU inventories were developed for all pollutants for 2020 and 2030, and the 2050 BAU inventory was developed for CO_2 only. Table 2-2 summarizes the mobile source emission sectors included in this assessment, as well as the pollutants and geographic area covered by each sector.

Table 2-2. Summary of Sources, Pollutants, and Geographic Area Covered by Assessment

Mobile Source Sector	Type of Emission Source	Pollutants Analyzed	Geographic Area Covered
Drayage Trucks	On-road Class 8 diesel trucks	NOx, $PM_{2.5}$, VOCs, CO_2, BC, and select air toxics	All drayage activity within 0.5 km (0.3 mi) from port boundary.
Rail	Line-haul and switcher diesel locomotives	NOx, $PM_{2.5}$, VOCs, CO_2, BC, and select air toxics	All rail activity within 0.5 km from port boundary.
CHE	Diesel-powered CHE	NOx, $PM_{2.5}$, VOCs, CO_2, BC, and select air toxics	All CHE activity assumed to occur on-port.
Harbor Craft	Diesel-powered tugs and ferries	NOx, $PM_{2.5}$, VOCs, CO_2, BC, and select air toxics	All harbor craft activity within 5 km (3 mi) from port boundary.
OGV	Diesel propulsion and auxiliary engines	NOx, $PM_{2.5}$, VOCs, SO_2, CO_2, and BC	All OGV activity within 5 km from port boundary.

The geographic boundaries of each sector used in this assessment contributed to the relative differences between the amounts of emissions between sectors. Mobile source impacts along port-related transportation corridors (e.g., highways and rail lines) are an important environmental challenge, but this assessment did not focus on corridor impacts.

The data sources and methodology for developing these inventories varied by sector, as summarized in Table 2-3 below. The assessment relied primarily on existing EPA data and models or other publically available data.

Table 2-3. Summary of Data and Methodology Sources for Baseline and BAU Emission Inventories

Sector	Primary Sources for Baseline (2011)	Primary Sources for BAU Projections (2020, 2030, 2050)
Drayage Trucks	DrayFLEET USACE Waterborne Commerce Statistics FHWA Freight Analysis Framework	2008 Research Triangle Institute (RTI) regional growth rates EPA MOVES2010b model
Rail	EPA National Emissions Inventory Published rail emission inventories	2008 RTI regional growth rates EPA Locomotive and Marine Emission Standards Rulemaking
CHE	Published CHE emission inventories USACE Waterborne Commerce Statistics	2008 RTI regional growth rates EPA NONROAD2008a model
Harbor Craft	EPA National Emissions Inventory	2008 RTI regional growth rates EPA Locomotive and Marine Emission Standards Rulemaking
OGV	EPA C3 Regulatory Impact Analysis USACE Entrances and Clearances Lloyd's Register of Ships Published OGV emission inventories	2008 RTI bunker fuel growth rates EPA C3 Regulatory Impact Analysis EPA North America Emission Control Area Standards

Further details on these sources are included in Sections 3 and 4 of the report. It should be noted that this assessment was not intended to provide specific data for local decision-making at individual ports or specific neighborhoods; the assessment does not report inventory impacts for a particular port.

2.6. Port-related Strategies Analyzed

As described in Sections 5 and 6, based on a literature review and consultations with industry and other experts, EPA developed a matrix of port-related emission reduction strategies for more detailed analysis. Two emission reduction scenarios were developed for each mobile source sector and are described as follows:

- **Scenario A** reflected an increase in the introduction of newer technologies in port vehicles and equipment beyond what would occur through normal fleet turnover. Operational strategies in Scenario A reflected a reasonable increase in expected efficiency improvements.
- **Scenario B** reflected a more aggressive suite of strategies as compared to Scenario A. Scenario B was intended to further accelerate the introduction of clean diesel and zero emissions vehicles and equipment, in addition to other fuels and technologies. Operational strategies in Scenario B assume further operational efficiency improvements beyond Scenario A.

Both scenarios would necessitate a major investment in new technologies, with Scenario B requiring a larger investment than Scenario A. In selecting strategies, EPA qualitatively considered several factors, such as capital costs, market barriers, and potential for market penetration by analysis year. However, an in-depth cost-benefit analysis was not conducted.

Table 2-4 provides an overview of the strategy scenarios that were analyzed in this assessment.

Table 2-4. Overview of Strategy Scenarios

Sector	Strategy	Scenario Summary Description
Drayage Trucks	Technological	Truck replacement strategies to accelerate turnover to cleaner EPA standards and plug-in hybrid electric vehicles (PHEVs).
	Operational	Reduced gate queues.
Rail	Line-haul Technology	Locomotive engine replacement strategies, including electric locomotives.
	Line-haul Operational	Fuel economy improvements.
	Switcher Technology	Switcher locomotive engine replacement strategies, including use of GenSets.
CHE	Yard Truck	Yard truck replacement strategies, including battery electric vehicles.
	Rubber Tire Gantry Crane	Crane replacement strategies, including electric cranes.
	Container Handler	Container handling equipment replacements, including electric equipment.
Harbor Craft	Tug	Tug repower and replacement strategies, including hybrid electric vessels.
	Ferry	Ferry repower and replacement strategies, including hybrid electric vessels.
OGV	Fuel Change in Propulsion Engines	Fuel use switch strategies to 500 ppm sulfur fuels, 200 ppm sulfur fuels, and liquefied natural gas (LNG) for bulk, container, passenger, and tanker vessels.
	Fuel Change in Auxiliary Engines	Fuel use switch strategies to ultra-low sulfur diesel (ULSD) fuel and LNG for bulk, container, passenger, and tanker vessels.
	Shore Power	Shore power for container, passenger, and reefer vessels.
	AMECS	Advanced Marine Emission Control Systems (AMECS) for container and tanker vessels.
	Reduced Hoteling	Hoteling time reduction for container vessels.

2.7. Organization of Assessment Report

This report is organized as follows:

- **Section 3** describes how the 2011 baseline emission inventory for this assessment was developed, and additional supporting documentation is included in Appendix A.
- **Section 4** describes how the BAU inventories for 2020, 2030, and 2050 were developed, and Appendix B contains further details on the BAU methodology.
- **Section 5** includes an assessment of the range of available port-related emission reduction strategies, and identifies the most effective strategies for the years 2020 and 2030 for NOx, $PM_{2.5}$, and CO_2 reductions. In addition, this section includes a generic analysis of the potential of emission reductions for all mobile source sectors at a hypothetical port.
- **Section 6** contains the sector-by-sector analysis of different strategies under Scenarios A and B. See Appendix C for further information on the development of the strategy analysis methodology.
- **Section 7** includes an analysis that stratifies the emission reduction results from the assessment by port type and size, with additional details in Appendix D.

3. Baseline Emission Inventory Development

3.1. Overview

Baseline emission inventories for 2011 were developed for the five mobile source emissions sectors. Each sector inventory was developed separately using the best available data and methodologies for this national scale assessment. An overview of the data, methodologies, and results for each of the five sectors is detailed below. As noted in Section 2, the totals presented in each of the results sections are the aggregated baseline emissions of all port areas included in this assessment. Additional details for the baseline emission inventories are included in Appendix A.

3.2. Drayage Trucks

The 2011 baseline inventory for the drayage truck sector was developed using the EPA DrayFLEET Model.[44] Port-specific truck activity was estimated from total freight activity at each port, as reported in the U.S. Army Corps of Engineers' (USACE) Waterborne Commerce Statistics, and allocated to the share of freight moved by truck using the Federal Highway Administration's (FHWA's) Freight Analysis Framework (FAF).

3.2.1. Methodology and Available Data

The baseline emission inventories were calculated using DrayFLEET, a model designed to estimate the impact of management practices, terminal operations, and cargo volume on drayage truck emissions and activity. Some of the primary inputs to the model include an estimate of annual containerized freight throughput in twenty-foot equivalent units (TEUs) and the distance traveled to common off-port destinations. A secondary input is tons of truck freight throughput, which captures bulk, liquid, and other kinds of drayage truck traffic.

Annual port-specific freight activity data came from Waterborne Commerce Statistics on TEUs[45] and tonnage[46] by port for the 2011 base year. Since this source only includes data on domestic empty containers and not foreign empty containers, data on foreign empty containers were collected separately from ports or other sources.[47]

The percentage of containers and non-containerized freight moved by drayage at each port was estimated using the 2012 FAF[48] and applied to the 2011 base year data. FAF identifies the port of export, the domestic mode of transportation, and the foreign mode. For freight moving via water in the foreign

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[44] U.S. Environmental Protection Agency, *SmartWay DrayFLEET, Truck Drayage Environment and Energy Model: Version 2.0 User's Guide*, EPA Report EPA-420-B-12-065, June 2012.

[45] Available at: http://www.navigationdatacenter.us/wcsc/by_portnames11.html.

[46] Available at: http://www.navigationdatacenter.us/db/wcsc/archive/xls/man11/.

[47] Available at: http://aapa.files.cms-plus.com/Statistics/NORTH%20AMERICAN%20PORT%20CONTAINER%20TRAFFIC%202011.pdf.

[48] Available at: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/.

mode of transportation, exports and imports were combined and the percentage moving by truck for the domestic mode was estimated. TEUs moved by drayage were converted to number of truckloads by estimating the average TEUs per container, which was 1.75 for most ports. The number of non-containerized truckloads was determined based on the cargo densities and payload estimates by commodity.

Using the activity estimates described above, DrayFLEET was used to estimate port-specific drayage emission inventories. Where the information was available, port-specific gate queues and average marine terminal transaction times were also used; the default values were otherwise retained. The age distribution of drayage trucks come from EPA's MOVES2010b national default age distribution for combination short-haul trucks.

In addition to the on-port emissions, this assessment included a 0.5 km (0.3 mi) port boundary extension, modeled separately. This was accomplished by estimating the distance drayage vehicles travel inside the port and the distance they travel outside the port within a 0.5 km of the port boundary. A visual inspection of port maps was made to estimate these distances. For more details on the 2011 baseline analysis for drayage trucks, including pollutants not estimated in DrayFLEET, please see Appendix A.

3.2.2. Results

The total 2011 baseline emissions for the drayage truck sector for this assessment are given in Table 3-1.

Table 3-1. Baseline 2011 Emissions for Drayage Trucks, Tons per Year

NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
9,819	811	785	625	1,486,914	32	7	77

3.3. Rail

The 2011 baseline inventory for the rail sector was derived from published port emission inventories where available and from EPA's 2011 National Emissions Inventory (NEI) for all other ports. This sector was divided into two categories: rail line and rail yard. Rail line corresponds to emissions from line-haul locomotives and rail yard corresponds to switcher locomotive emissions. The emission inventories include both emissions that occur within port boundaries and emissions that occur within a 0.5 km extension of rail lines leading to and from the port.

3.3.1. Methodology and Available Data

There were four ports with published rail inventories that were included in this assessment. However, in some cases, these published inventories did not include all the pollutants covered for this assessment (i.e. VOC, CO_2, black carbon (BC), acetaldehyde, benzene, and formaldehyde). Inventories for these pollutants were calculated from speciation factors, using methodologies discussed in Appendix A.

Version 1 of EPA's 2011 NEI was used to develop the baseline rail emissions estimates for the other ports.[49] In the NEI, emissions are reported by source classification codes (SCCs). Table 3-2 shows the rail sector SCCs and their categories (point and nonpoint). Rail yards are categorized in the NEI as point sources.[50] It should be noted that the SCCs do not distinguish between the types of rail activities; therefore, there is no way to explicitly differentiate the port-related locomotive emissions from other rail emissions in the NEI.

Table 3-2. Relevant SCCs for Rail Inventory Analysis

SCC	NEI Data Category	Description
2285002006	Nonpoint	Line-haul Locomotives: Class I Operations
2285002007	Nonpoint	Line-haul Locomotives: Class II / III Operations
28500201	Point	Yard Locomotives

Using NEI port and rail shapefiles,[51] the rail lines were mapped in a geographic information system (GIS) program. These shapefiles were updated for some ports where better data were available. Rail yards were also mapped using latitude and longitude data associated with each rail yard in the NEI point source database. The rail lanes used in this assessment extend 0.5 km from the port boundaries to include line-haul emissions. The ratio of the area of the 0.5 km rail line compared to the whole rail line length in the NEI was used to adjust the emissions proportionally. For example, if 10% of a rail line length lies within the 0.5 km buffer, 10% of the total line haul emissions assigned to that shape were allocated to the port.

The 2011 NEI database and shapefiles identify counties with Federal Information Processing Standard (FIPS) codes. For the rail line inventory, total county locomotive emissions were allocated to each rail segment according to the length of the line within the assessment area. The rail yard inventory was then calculated by summing all rail emissions that occurred within the assessment area.

Using these steps, the emissions for the rail lines and rail yards in this area were estimated. However, these emissions were limited to those pollutants quantified in the first version of the 2011 NEI, including NOx, VOCs, $PM_{2.5}$, benzene, acetaldehyde, and formaldehyde. The other pollutants assessed in this assessment (i.e., BC and CO_2) were estimated as described in Appendix A.

3.3.2. Results

The total 2011 baseline emissions for the rail sector are given in Table 3-3.

[49] Version 1 was the latest version available at the time of this analysis. The 2011 NEI is available at: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data.

[50] There is an additional SCC in the NEI for nonpoint yard locomotives (2285002010). However, all EPA estimates in the NEI for yard locomotive emissions are recorded as point sources, so the additional SCC was not included in this assessment.

[51] Available at: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-documentation.

Table 3-3. 2011 Baseline Emissions for Rail, Tons per Year

Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
Rail Yard	1,248	35	86	27	60,455	1	0	2
Rail Line	1,491	46	81	36	83,806	1	0	3
Total	**2,739**	**81**	**167**	**63**	**144,261**	**2**	**0**	**5**

3.4. Cargo Handling Equipment

The 2011 baseline inventory for the cargo handling equipment (CHE) sector was based on published CHE emission inventories. A regression model was developed to establish the relationship between cargo throughput and CHE emissions using the published inventories. This was then applied at all ports without a published inventory.

3.4.1. Methodology and Available Data

A regression model was used to estimate CHE emissions based on the observed relationship between port cargo throughput and CHE emissions. This involved:

- Collecting recent CHE emission inventories
- Filling any gaps to determine total annual CHE emissions for all pollutants considered
- Collecting cargo throughput in both tonnage[52] and TEUs[53] from USACE
- Processing USACE data to represent throughput by various conveyance methods at ports
- Building statistical regression relationships of emissions against throughput for known ports
- Using these relationships to estimate CHE emissions at the remaining ports

Four published inventories formed the basis of this regression analysis. Since there are many different kinds of CHE and each published inventory included different kinds of CHE, the analysis was performed using total CHE emissions instead of using emissions from individual equipment types.

Regression was performed to determine trends of NOx, VOC, $PM_{2.5}$, and CO_2 emissions in tons per year against cargo throughput. Three different methods were explored, each regressing total CHE emissions for each pollutant against the following cargo throughput quantifications:

- Method 1: cargo throughput categorized as bulk, container, liquid, or other
- Method 2: cargo throughput in total non-container tonnage and number of TEUs
- Method 3: total tonnage of cargo throughput, excluding conveyance type

When compared back to the published inventories, the success of each method varied by pollutant. Lacking a clear distinction in the prediction capabilities between the three methods, an unweighted average of the predictions from the above three methods was employed to calculate the inventories at

[52] Available at: http://www.navigationdatacenter.us/db/wcsc/archive/xls/man11/.
[53] Available at: http://www.navigationdatacenter.us/wcsc/by_portnames11.html.

all of the modeled ports. The results presented in the next section include values from the four published inventories combined with the modeled results for the other ports.

This regression model has a similar level of detail as the rail and harbor craft analysis, which relied on NEI values. As with those sectors, it does not allow characterization of emissions by equipment age, fuel type, terminal type, existing use of control technology, or other discriminators. For more details on the CHE baseline inventory and why the NEI was not used for this sector, see Appendix A.

3.4.2. Results

The total 2011 baseline emissions for the CHE sector are given in Table 3-4.

Table 3-4. 2011 Baseline Emissions for CHE, Tons per Year

NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
6,701	258	361	199	893,188	18	7	40

3.5. Harbor Craft

The 2011 baseline inventory for the harbor craft sector was derived from the 2011 NEI for all ports. This sector includes emissions from harbor craft that occur both within the port boundaries in addition to a 5 km buffer zone surrounding each port. The results are reported by two activity modes: maneuvering and cruise.

3.5.1. Methodology and Available Data

The term “harbor craft” is used synonymously for all vessels with Category 1 and Category 2 (C1/C2) engines, including tugs, ferries, commercial fishing boats, government vessels, work boats, and dredges. Version 2 of EPA’s 2011 NEI was used to develop the baseline harbor craft emissions estimates for all ports.[54] Existing port inventories were not used to assess harbor craft emissions because most port inventories only included harbor craft emissions related to their own port operations, and did not include other harbor craft activity, such as activity occurring at private terminals. The NEI includes such activity and was used to develop the baseline harbor craft inventory for this assessment.

In the NEI, emissions are reported by source classification codes (SCCs). Table 3-5 shows the harbor craft sector SCCs and their emission type codes (maneuvering or cruise). Maneuvering emissions occur within a port’s boundaries and cruise emissions occur at sea. The NEI does not estimate at-berth emissions for C1/C2 as it assumes that neither propulsion nor auxiliary engines would be operating at dockside.

[54] Available at: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data.

Table 3-5. Relevant SCCs for Port Inventory Analysis

SCC	Emission Type Code*	Description
2280002100	M	Harbor Craft at Port
2280002200	C	Harbor Craft underway

* Emission type codes for C1/C2 vessels are defined as M=maneuvering (in port) and C=cruise (out of port).

Using NEI port and rail shapefiles,[55] near-port shipping lanes were mapped in a GIS program. These shapefiles were updated for some ports where better data were available. The off-port corridors used in this assessment extend 5 km from the port boundaries in order to include harbor craft cruising emissions. Since all ports have differently shaped and sized marine corridors leading to them, having a uniform 5 km buffer zone allowed future reduction strategies to be modeled on the same basis at each port. However, since the NEI's defined shipping lanes extended beyond 5 km for most ports, the emissions assigned by the NEI to each shipping lane were scaled proportionally. For example, if 10% of a shipping lane shape lies within the 5 km buffer, 10% of the total cruising emissions assigned to that shape were allocated to the port.

The emission inventories for this sector were determined by summing the maneuvering emissions at each port combined with the proportion of cruise emissions allocated to each port. However, these emissions were limited to NOx, VOCs, and $PM_{2.5}$. The other pollutants in this assessment (i.e. BC, CO_2, benzene, acetaldehyde, and formaldehyde) were estimated as described in Appendix A.

3.5.2. Results

The total 2011 baseline emissions for the harbor craft sector are given in Table 3-6.

Table 3-6. 2011 Baseline Emissions for Harbor Craft, Tons per Year

Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
Cruise	24,239	777	555	598	1,800,965	26	7	52
Maneuver	23,541	755	539	581	1,749,103	30	8	60
Total	**47,780**	**1,532**	**1,093**	**1,179**	**3,550,068**	**56**	**15**	**112**

3.6. Ocean Going Vessels

The 2011 baseline inventory for the ocean going vessel (OGV) sector was calculated using EPA's Category 3 Marine Engine Rulemaking (C3 RIA)[56] methodology, which used energy-based emission factors together with activity profiles for each vessel. The shipping activity came from USACE's Entrances and Clearances data, and four activity modes were included: reduced speed zone (RSZ), maneuvering, hoteling, and at anchor.

[55] Available at: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-documentation.

[56] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines*, EPA Report EPA-420-R-09-019, December 2009. Available at: http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf.

3.6.1. Methodology and Available Data

The OGV sector includes emissions from Category 3 (C3) commercial marine vessels' main propulsion engines and auxiliary engines. C3 vessels are propelled by engines with 30 liters per cylinder displacement or more. Emissions for each ship and for each mode were estimated for both main propulsion and auxiliary engines using the following equation:

$$E = P \times LF \times A \times EF \qquad \textbf{Eq. 3-1}$$

Where

E = Emissions (grams [g]),

P = Maximum Continuous Rating Power (kilowatts [kW]),

LF = Load Factor (percent of vessel's total power),

A = Activity (hours [h]) (hours/call * # of calls), and

EF = Emission Factor (grams per kilowatt-hour [g/kWh]).

The other components of the above equation are dependent on individual ship characteristics, such as ship type, size, power, and cruise speed. The ship calls from the 2011 USACE Entrances and Clearances data were matched to Lloyd's data[57] to determine the maximum continuous power rating, load factor, and emission factor that should be applied to each activity record.

The emission factors were based on the C3 RIA and vary by engine type (propulsion or auxiliary), tier, fuel type, fuel sulfur level, ship type, and load factor. In addition to the other criteria pollutants and precursors, SO_2 is analyzed for OGVs. This is because the fuel that OGVs use has a much higher sulfur content than the other sectors. While the introduction of the North American Emission Control Area (ECA) fuel sulfur limit (1000 ppm sulfur) will reduce SO_2 in projected years, additional reductions may be gained from the use of even lower sulfur fuels. It was assumed that all ships' propulsion engines and most ships' auxiliary engines operated on heavy fuel oil (HFO) with a sulfur level of 2.7% in the 2011 baseline year.[58]

Cruise emissions were not included since ships were expected to be operating at speeds less than cruise speed within the areas of interest for this assessment (which focused on in-port activity and as ships approach or leave the port entrance) for safety and/or environmental reasons. However, activity in reduced speed zones (RSZs), maneuvering, hoteling, and at anchorage was included. Most hoteling and maneuvering times come from Marine Exchange/Port Authorities data as detailed in a 1999 report[59] that described how to calculate marine vessel activity at deep seaports and contained detailed port activities of eight deep seaports. More recently published emission inventories that contain data on hoteling and

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[57] Produced by IHS Global Limited and available at: http://www.sea-web.com.

[58] It was assumed that ships that did not use HFO in their auxiliary engines used distillate instead. For more details, see Appendix A.

[59] ARCADIS Geraghty & Miller, *Commercial Marine Activity for Deep Sea Ports in the United States*, EPA Report EPA420-R-99-020, September 1999. Available at http://www.epa.gov/otaq/models/nonrdmdl/c-marine/r99020.pdf.

maneuvering times were used where appropriate. See Table 3-7 for a description of the various activity modes and their associated analysis. Further details on the activity data sources, emission boundaries, derivation of emission factors, the definition of RSZ boundaries, and the calculation of RSZ, maneuvering, hoteling, and anchorage activity may be found in Appendix A.

Table 3-7. Vessel Movements and Time-In-Mode Descriptions

Summary Table Field	Description
Call	A call is one entrance and one clearance. Since the USACE Entrances and Clearances data do not provide a record for an entrance where no foreign cargo discharged or a record of a clearance where no foreign cargo is loaded at a port, the number of entrances and clearances may not be the same. Therefore, the number of calls were taken as the maximum of the entrances or clearances at a port as grouped by ship type, engine type, and deadweight tonnage bin.
Reduced Speed Zone (RSZ) (hr/call)	Time when a ship reduces speed before entering a port. This can be a long distance down a river or channel and generally ends at the port entrance.
Maneuver (hr/call)	Time when a ship is being berthed or de-berthed, traveling to an anchorage or moving between berths. Maneuvering is assumed to occur within the port area, generally beginning and ending at the entrance of the port. This will include shifts within a port area moving from one berth to another. For purposes of calculating load factors, maneuvering was assumed to occur at an average speed of 5.8 knots. Maneuvering times were taken from the typical port data or calculated from published inventories.
Hoteling (hr/call)	Hoteling is the time at berth when the vessel is operating auxiliary engines only. Auxiliary engines are operating at some load conditions the entire time the vessel is manned, but peak loads will occur after the propulsion engines are shut down. The auxiliary engines are then responsible for all onboard power or are used to power off-loading equipment, or both.
Anchorage (hr/call)	If the port data included anchorage, it is broken out separately for this analysis. Some emission reduction techniques cannot be applied while at anchorage. This mode was ignored if not specifically identified.

Emission inventories for air toxics were not developed for OGVs due to data limitations. Air toxic emissions from OGVs is an area that warrants further research and analysis.

3.6.2. Results

The total 2011 baseline emissions for the OGV sector are given in Table 3-8.

Table 3-8. 2011 Baseline Emissions for OGVs, Tons per Year

Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	SO_2
RSZ	3,838	324	169	10	160,787	2,582
Maneuver	3,661	361	296	11	157,023	2,375
Hotel	26,016	2,209	836	66	1,408,951	20,115
Anchor	44	4	1	0	2,345	32
Total	**33,560**	**2,897**	**1,302**	**87**	**1,729,106**	**25,104**

3.7. Summary of Baseline Inventory Results

The above sections listed the baseline emission inventory results for this assessment by sector and by operating mode or subsector within each, where included in the analysis. Table 3-9 summarizes the resulting total inventory for all ports included in this assessment and for all pollutants. Note that since SO_2 is not estimated for non-OGV sectors and air toxics are not estimated for OGVs, totals are not presented for these pollutants.

Table 3-9. 2011 Baseline Emissions for All Sectors and Pollutants, Tons per Year

Pollutant	Drayage	Rail	CHE	Harbor Craft	OGV	Total
$PM_{2.5}$	811	81	258	1,532	2,897	**5,580**
NOx	9,819	2,739	6,701	47,780	33,560	**100,599**
CO_2	1,486,914	144,261	899,701	3,550,068	1,729,106	**7,810,049**
VOC	785	167	361	1,093	1,302	**3,708**
BC	625	63	199	1,179	87	**2,153**
SO_2	-	-	-	-	25,104	**N/A**
Formaldehyde	77	5	40	112	-	**N/A**
Acetaldehyde	32	2	18	56	-	**N/A**
Benzene	7	0.3	7	15	-	**N/A**

See Section 4.9 of this report for comparisons between the 2011 baseline and 2020, 2030, and 2050 business as usual inventories for relevant pollutants and precursors.

4. Business as Usual Emission Inventory Development

4.1. Overview

Projected Business as Usual (BAU) port emission inventories for years 2020 and 2030 were developed for the five mobile source sectors: drayage trucks, rail, CHE, harbor craft, and OGVs. The inventories include NOx, $PM_{2.5}$, VOC, BC, and CO_2. In addition, the non-OGV inventories include select air toxics (acetaldehyde, benzene, and formaldehyde), and the OGV inventory includes SO_2. Projected inventories of CO_2 emissions in 2050 were also developed for all sectors.

The methodology for projecting the baseline 2011 emissions inventories to future years varied by sector. In addition to baseline growth, the BAU inventory analysis also considered recent or planned changes in port operations that were anticipated to impact future emission inventories. An overview of the methodology and results is presented for each of the five mobile source sectors below. Additional details for the BAU emission inventories are included in Appendix B.

4.2. Summary of Growth Rates

Non-OGV growth rates for projecting the baseline inventories to 2020 and 2030 were derived from commodity movements (both imports and exports) in a 2008 study by Research Triangle Institute (RTI).[60] Compound annual growth rates relative to the 2011 baseline year were calculated for each commodity and region and are shown in Table 4-1.

Table 4-1. Compound Annual Growth Rates for 2020 and 2030 by Region and Commodity

Conveyance Category	U.S. ATLANTIC – Imports + Exports		U.S. PACIFIC NORTH – Imports + Exports		U.S. PACIFIC SOUTH – Imports + Exports		U.S. GULF COAST – Imports + Exports	
	2020	2030	2020	2030	2020	2030	2020	2030
Bulk	3.2%	2.7%	4.0%	4.0%	3.9%	3.8%	3.3%	3.2%
Container	4.0%	4.4%	4.0%	4.5%	4.3%	4.9%	3.8%	4.1%
Liquid	0.5%	1.1%	1.5%	1.6%	1.1%	1.1%	1.4%	1.6%
Other	5.0%	4.9%	5.0%	4.8%	7.4%	7.2%	3.9%	4.2%
Total	2.7%	2.9%	3.8%	4.0%	3.5%	4.0%	2.2%	2.3%

The OGV growth rates for projecting the baseline inventories to 2020 and 2030 were derived from regional annual growth rates in bunker fuel used by the international cargo fleet (including both imports and exports) in the 2008 RTI study. The average annual growth factors by region that were used in EPA's C3 RIA and this assessment are presented in Table 4-2.

[60] Research Triangle Institute, *Global Trade and Fuel Assessment – Future Trends and Effects of Requiring Cleaner Fuels in the Marine Sector*, EPA Report EPA420-R-08-021, November 2008.

Table 4-2. Annual Average Growth Rates by Region Based upon Bunker Fuel Use

Region	Average Annual Growth Rate
East Coast	4.5%
Gulf Coast	2.9%
South Pacific	5.0%
North Pacific	3.3%

4.3. Infrastructure Changes That Modify BAU Growth Values

In addition to baseline growth, the projected BAU inventory analysis also considered recent or planned changes in port operations that could substantially change operational efficiency, and thus emissions, in future years. For example, plans for construction of on-dock rail would change the mode split and shift cargo from truck to rail, and would need to be included in this analysis. Only minor adjustments were made due to such considerations; more information may be found in Appendix B.

4.4. Drayage Trucks

The baseline 2011 drayage truck activity was grown using the commodity growth rates. This projected activity was then used with the EPA DrayFLEET Model[61] to develop the projected BAU inventory.

4.4.1. Methodology

The cargo tonnage moved by drayage trucks at each port in 2011 was grown to 2020 and 2030 using the region-specific total compound annual growth rates listed in Table 4-1. The percentage of total cargo throughput at ports moved by drayage was assumed to stay constant at the base year level. However, changes in truck age distributions were incorporated based on national default age distributions in MOVES2010b.

DrayFLEET was run as described in Section 3.2.1 with the baseline 2011 cargo volumes and the 2020 age distribution. These intermediate emission inventories were then scaled by the ratio of projected truck tonnage in 2020 to the baseline 2011 truck tonnage to calculate the 2020 drayage BAU inventory. This was then repeated with the 2030 age distribution and projected 2030 tonnage. Finally, the 2030 inventories were scaled to 2050 using projected tonnage for CO_2 only. As such, EPA's heavy-duty greenhouse gas (GHG) regulations are not reflected in this analysis.[62]

For pollutants not included in DrayFLEET and more details on the drayage truck BAU methodology, please see Appendix B.

[61] U.S. Environmental Protection Agency, *SmartWay DrayFLEET, Truck Drayage Environment and Energy Model: Version 2.0 User's Guide*, EPA Report EPA-420-B-12-065, June 2012.

[62] Specifically, the CO_2 reductions of EPA's heavy-duty engine and vehicle GHG regulations were not included in the drayage inventory, due to the timing of the assessment. If such programs were included, EPA would expect smaller CO_2 increases in drayage truck emissions in 2030 and 2050.

4.4.2. Results

Total projected BAU emissions for drayage trucks for 2020, 2030, and 2050 are given in Table 4-3.

Table 4-3. Total BAU Emissions for Drayage Trucks, Tons per Year

Year	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020	5,241	386	433	297	1,866,145	23	4	64
2030	2,630	155	205	120	2,509,173	13	3	41
2050	--	--	--	--	4,417,155	--	--	--

4.5. Rail

The baseline 2011 rail sector activity was grown using the commodity growth rates shown in Table 4-1. Emission factors were then calculated from the baseline inventories and adjusted for EPA's future emission standards. The emission factors were then applied to the projected activity to determine the BAU inventories.

4.5.1. Methodology

The projected 2020 and 2030 BAU emission inventories for rail were developed as the product of emission factors and activity data. Gross emission factors were calculated from the baseline rail inventory using the following equation:

$$EF = E / (C \times S) \qquad \textbf{Eq. 4-1}$$

Where

EF = Emission factor for a specific pollutant, port, and locomotive type (grams per ton [g/ton]),

E = Total annual emissions for a specific pollutant, port, and locomotive type (grams),

C = Total cargo throughput for a specific port (tons), and

S = Share of cargo throughput moved by rail for a specific port (percent of total cargo tonnage).

To calculate the gross emission factors, the total annual emissions came from the baseline rail inventories (see Section 3.3), which were distinguished by locomotive type (line-haul or switcher locomotives). The total cargo throughput came from USACE's Waterborne Commerce Statistics,[63] as used in the drayage and CHE baseline inventories (see Sections 3.2.1 and 3.4.1, respectively). The share of cargo throughput moved by rail came from the Freight Analysis Framework,[64] which was assumed to remain constant in the projected years for consistency with other sectors. Combining all of these yields gross emission factors that are valid for the 2011 locomotive fleet at each port. However, since fleets turn over to newer models in future years that meet stricter emission

[63] Available at: http://www.navigationdatacenter.us/db/wcsc/archive/xls/man11/.
[64] Available at: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/.

standards, these emission factors needed to be adjusted. Therefore, the gross emission factors were scaled for use in 2020 and 2030 based on projected fleet emission factors listed in EPA's 2008 Locomotive and Marine Emission Standards Rulemaking.[65] The emission factors given in the rulemaking were not used directly because they are in terms of grams per gallon, and the units required here were grams per ton of cargo moved.

For the projected BAU inventories for this assessment, the cargo tonnage moved by rail at each port in 2011 was grown to 2020 and 2030 using the region-specific total compound annual growth rates listed in Table 4-1. Projected BAU inventories were calculated by multiplying the grown activities by the corresponding gross emission factors. For more detail on this methodology, please see Appendix B.

4.5.2. Results

Total projected BAU emissions for rail for 2020, 2030, and 2050 are given in Table 4-4.

Table 4-4. Total BAU Emissions for Rail, Tons per Year

Year	Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020	Rail Yard	1,282	35	83	27	78,198	3	1	7
	Rail Line	1,233	30	47	23	104,327	2	0	4
	Total	**2,515**	**65**	**130**	**50**	**182,525**	**5**	**1**	**11**
2030	Rail Yard	1,091	29	66	22	104,899	3	1	7
	Rail Line	863	17	32	13	136,692	1	0	4
	Total	**1,954**	**46**	**98**	**35**	**241,591**	**4**	**1**	**11**
2050	Rail Yard	--	--	--	--	189,988	--	--	--
	Rail Line	--	--	--	--	232,236	--	--	--
	Total	**--**	**--**	**--**	**--**	**422,224**	**--**	**--**	**--**

4.6. Cargo Handling Equipment

The baseline 2011 cargo handling equipment (CHE) sector activity was grown using the commodity growth rates shown in Table 4-1. Emission factors were calculated from the baseline inventories and adjusted for future emission standards. The emission factors were then applied to the projected activity to determine the BAU inventories.

4.6.1. Methodology

The projected 2020 and 2030 BAU emission inventories for CHE were developed as the product of emission factors and activity data. Gross emission factors were calculated from the baseline CHE inventory using the following equation:

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[65] *Emission Factors for Locomotives*, EPA-420-F-09-025, April 2009, Tables 5-7.

$$EF = E / C \qquad \text{Eq. 4-2}$$

Where

EF = Emission factor for a specific pollutant and port (grams per ton [g/ton]),

E = Total annual emissions for a specific pollutant and port (grams), and

C = Total cargo throughput for a specific port (tons).

To calculate the gross emission factors, the total annual emissions came from the baseline CHE inventories (see Section 3.4), which were not distinguished by equipment type. The total cargo throughput came from USACE's Waterborne Commerce Statistics,[66] which was also used in the drayage and CHE baseline inventories (see Sections 3.2.1 and 3.4.1, respectively). Combining these yields gross emission factors that are valid for the 2011 CHE fleet at each port. However, since fleets turn over to newer models in future years that meet stricter emission standards, these emission factors needed to be adjusted. Therefore, the gross emission factors were scaled for use in 2020 and 2030 based on changes in average emission factors per unit of CHE derived from running EPA's NONROAD model.[67] The emission factors calculated from NONROAD were not used directly because they are in terms of grams per unit of CHE, and the units required here were grams per ton of cargo moved.

For the projected BAU inventories, the total cargo tonnage throughput at each port in 2011 was grown to 2020 and 2030 using the region-specific total compound annual growth rates listed in Table 4-1. Projected BAU inventories were calculated by multiplying the grown activities by the corresponding gross emission factors. For more detail on this methodology, please see Appendix B.

4.6.2. Results

The total projected BAU emissions for CHE for 2020, 2030, and 2050 are given in Table 4-5.

Table 4-5. Total BAU Emissions for CHE, Tons per Year

Year	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020	3,251	121	361	93	1,106,410	3	6	7
2030	2,686	73	213	56	1,422,146	3	7	6
2050	--	--	--	--	2,376,567	--	--	--

4.7. Harbor Craft

The baseline 2011 harbor craft sector activity related to goods movement was grown using the commodity growth rates shown in Table 4-1. Emission factors were calculated from the baseline inventories and adjusted for future emission standards. The emission factors were then applied to the projected activity to determine the BAU inventories.

[66] Available at: http://www.navigationdatacenter.us/db/wcsc/archive/xls/man11/.

[67] Available at: https://www.epa.gov/otaq/nonrdmdl.htm.

4.7.1. Methodology

The projected 2020 and 2030 BAU emission inventories were developed as the product of emission factors and activity data. To facilitate this, the sector was split into two categories: goods-moving and non-goods moving. For the goods-moving harbor craft, gross emission factors were calculated from the baseline inventory using the following equation:

$$\mathbf{EF = E / C} \qquad \textbf{Eq. 4-3}$$

Where

EF = Emission factor for a specific pollutant and port (grams per ton [g/ton]),

E = Goods-moving annual emissions for a specific pollutant and port (grams), and

C = Total cargo throughput for a specific port (tons).

To calculate the gross emission factors for goods-moving harbor craft, the total annual emissions came from the baseline inventory (see Section 3.5), which were further allocated by vessel type. Only vessels directly tied to goods movement (e.g., tug, tow, and push) were included in these calculations. The total cargo throughput came from USACE's Waterborne Commerce Statistics,[68] which was also used in the drayage and CHE baseline inventories (see Sections 3.2.1 and 3.4.1, respectively). Combining these yields gross emission factors that are valid for the 2011 goods-moving harbor craft fleet at each port.

For non-goods moving harbor craft, gross fuel-based emission factors were calculated from the baseline inventory using the following equation:

$$\mathbf{EF = E / FC} \qquad \textbf{Eq. 4-4}$$

Where

EF = Emission factor for a specific pollutant and port (grams per gallon [g/gal]),

E = Non-goods moving annual emissions for a specific pollutant and port (grams), and

FC = Non-goods moving annual fuel consumption (gallons).

The non-goods moving portion of the total annual emissions came from the baseline inventory, including vessel types such as ferries, support, fishing, and government. The fuel consumption was estimated from the non-goods moving baseline CO_2 inventories: E_{CO2} [g] / (26.34% [fuel carbon content] * 3207 [g/gal] * 3.664 [CO_2 to C ratio]). Combining these yields gross emission factors that are valid for the 2011 non-goods moving harbor craft fleet at each port.

However, since fleets turn over to newer models in future years that meet stricter emission standards, both sets of emission factors needed to be adjusted. Therefore, the gross emission factors were scaled for use in 2020 and 2030 based on projected emissions per vessel as calculated from EPA's 2008

[68] Available at: http://www.navigationdatacenter.us/db/wcsc/archive/xls/man11/.

Locomotive and Marine Emission Standards Rulemaking.[69] The emission factors calculated from the rulemaking were not used directly because they are in terms of grams per vessel, and the units required here were grams per ton of cargo moved and in grams per gallon of fuel consumed.

For the goods-moving projected BAU inventories, the cargo tonnage moved at each port in 2011 was grown to 2020 and 2030 using the region-specific total compound annual growth rates listed in Table 4-1. For the non-goods moving BAU inventories, the activity was assumed to be inelastic to changes in cargo movement and therefore assumed to have no growth.

The total harbor craft projected BAU inventories were calculated by multiplying the activities by the corresponding emission factors, and summed together. For more detail on this methodology, please see Appendix B.

4.7.2. Results

The total projected BAU emissions for harbor craft for 2020, 2030, and 2050 are given in Table 4-6.

Table 4-6. Total BAU Emissions for Harbor Craft, Tons per Year

Year	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020	35,079	997	814	768	4,106,875	30	7	66
2030	23,937	699	535	538	4,977,640	20	4	46
2050	--	--	--	--	7,398,445	--	--	--

4.8. Ocean Going Vessels

The baseline 2011 OGV sector activity was grown using the bunker fuel growth rates presented in Table 4-2. The emission factors used for the baseline inventory development were adjusted for future emission standards and fuel changes. The emission factors were then applied to the projected activity to determine the BAU inventories.

4.8.1. Methodology

The projected 2020 and 2030 BAU emission inventories were developed by adjusting the 2011 baseline inventories to account for growth in activity and reductions in emission factors due to fleet turnover and fuel changes as described in the following equation:

$$\mathbf{E_{fy} = E_{2011} \times EAF_{fy} \times A_{fy} / A_{2011}} \qquad \textbf{Eq. 4-5}$$

Where

E_{fy} = Emissions of a pollutant at a specific port in a future year (tons),

[69] U.S. Environmental Protection Agency, *Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters per Cylinder*, EPA420-R-08-001, March 2008.

E_{2011}= Emissions of a pollutant at a specific port in 2011 (tons),

EAF_{fy} = Emission adjustment factor for a future year,

A_{fy} = Total activity at a specific port in a future year (kWh), and

A_{2011} = Total activity at a specific port in 2011 (kWh).

The 2011 emissions came directly from the baseline calculations (see Section 3.6). The ratio of increased activity came from applying the region-specific bunker fuel growth rates listed in Table 4-2 to the base year activity. The emission adjustment factor for NOx was dependent on changes in age distributions, whereas the adjustment factors for the other pollutants depended on the changes in fuel sulfur content. Average NOx emission factors for 2020 and 2030 were calculated by applying the future expected age distributions to NOx emission rates (which vary by engine type and regulatory tier), based on the C3 RIA.[70] The NOx EAF_{fy} was calculated by taking the ratio of the future year emission factor to the base year factor. Average PM, BC, SO_2, and CO_2 emission adjustment factors were calculated by taking the ratio of the 0.1% sulfur fuel emission rates to the 2.7% sulfur fuel emission rates. It is assumed that all propulsion and auxiliary engines will use 0.1% sulfur fuel in 2020 and 2030 as required by EPA's North America Emission Control Area (ECA) Regulations.[71] Additional information on this methodology may be found in Appendix B.

4.8.2. Results

Total projected BAU emission inventories for OGVs for 2020, 2030, and 2050 are given in Table 4-7. Note that, due to data limitations, this does not include reductions for air toxics emitted from OGVs. Air toxic emissions from OGVs is an area that warrants further research and analysis.

Table 4-7. BAU Emissions for OGVs, Tons per Year

Year	Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	SO_2
2020	RSZ	3,432	60	232	4	211,091	131
	Maneuver	3,410	71	418	4	213,414	132
	Hotel	24,047	450	1,131	28	1,863,177	1,139
	Anchorage	43	1	2	0	3,405	2
	Total	**30,932**	**582**	**1,783**	36	2,291,088	1,404
2030	RSZ	2,230	85	332	5	300,887	187
	Maneuver	2,271	105	617	6	313,268	194
	Hotel	15,063	637	1,600	40	2,636,134	1,612
	Anchorage	31	1	3	0	5,288	3
	Total	**19,595**	**828**	**2,552**	**52**	**3,255,577**	**1,995**

[70] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines*, Report EPA-420-R-09-019, December 2009.

[71] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* Federal Register, Vol 75, No 83, April 30, 2010.

Year	Mode	NOx	$PM_{2.5}$	VOC	BC	CO_2	SO_2
2050	RSZ	--	--	--	--	622,272	--
	Maneuver	--	--	--	--	685,835	--
	Hotel	--	--	--	--	5,372,510	--
	Anchorage	--	--	--	--	12,753	--
	Total	**--**	**--**	**--**	**--**	**6,693,370**	**--**

4.9. Summary of Business as Usual Inventory Results

The bar charts shown below, which combine the 2011 baseline inventories with the future year BAU emission projections, illustrate the anticipated trends across the analysis period. For all pollutants, this includes 2011, 2020, and 2030; 2050 is also included for CO_2 only. In each case, emissions in each sector are aggregated across all ports considered in this assessment. Figure 4-1 presents total NOx emissions from OGV, harbor craft, CHE, rail, and drayage trucks. Figures 4-2 and 4-3 present emission inventories for $PM_{2.5}$ and CO_2, respectively. Similar charts for SO_2, BC, VOC, acetaldehyde, benzene, and formaldehyde are presented in Appendix B.

In general, the trends seen in these emissions are as expected. For most sectors and pollutants, emissions decrease over time due to the effect of EPA's emission regulations. For example, $PM_{2.5}$ trends show an initial reduction due to EPA's ECA fuel sulfur regulations, which reduce fuel sulfur from 2.7% to 0.1%. However, $PM_{2.5}$ then increases in 2030 due to growth in the OGV sector. This is in contrast to NOx, where the effects of the phase-in of more stringent standards[72] overcome the anticipated growth in this sector for the 2020 and 2030 inventories. For VOCs from the OGV sector and for CO_2 in all sectors, there are no controls in the BAU case to reduce these emissions, so they increase over time with sector growth. Note that, for CO_2, the growth rates used for emissions from OGVs do not take into consideration of CO_2 improvements resulting from the Energy Efficient Design Index[73] (EEDI), any shift in cargo movements from expansion of the Panama Canal, or any potential impacts from slow steaming. In addition, the CO_2 reductions of EPA's heavy-duty engine and vehicle GHG regulations were not included in the drayage inventory, due to the timing of the assessment. If such programs were included, EPA would expect smaller CO_2 increases in drayage truck and OGV emissions in 2030 and 2050.

[72] For example, Tier III NOx regulations, which represent an 80% reduction from Tier I, become effective for engines above 130 kW installed on ships built in 2016 and later.

[73] See: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx.

Figure 4-1. Total NOx Emissions Aggregated by Sector, Tons/Year

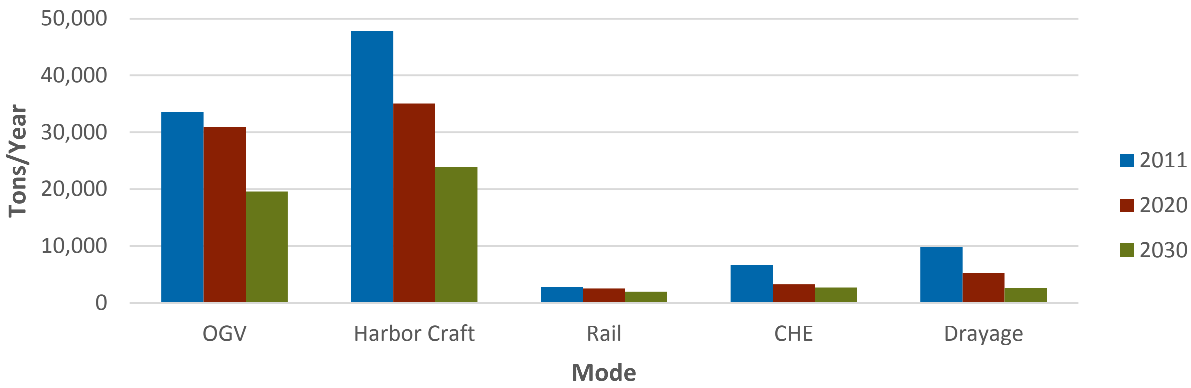


Figure 4-2. Total $PM_{2.5}$ Emissions Aggregated by Sector, Tons/Year

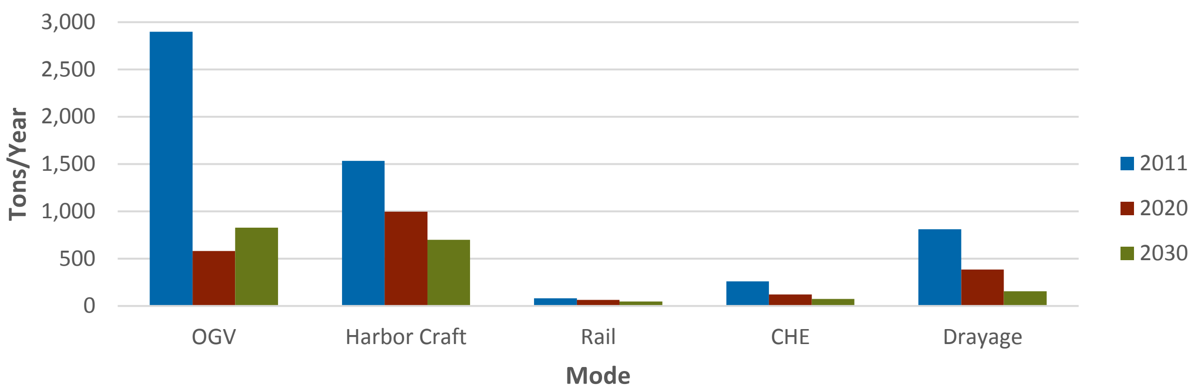
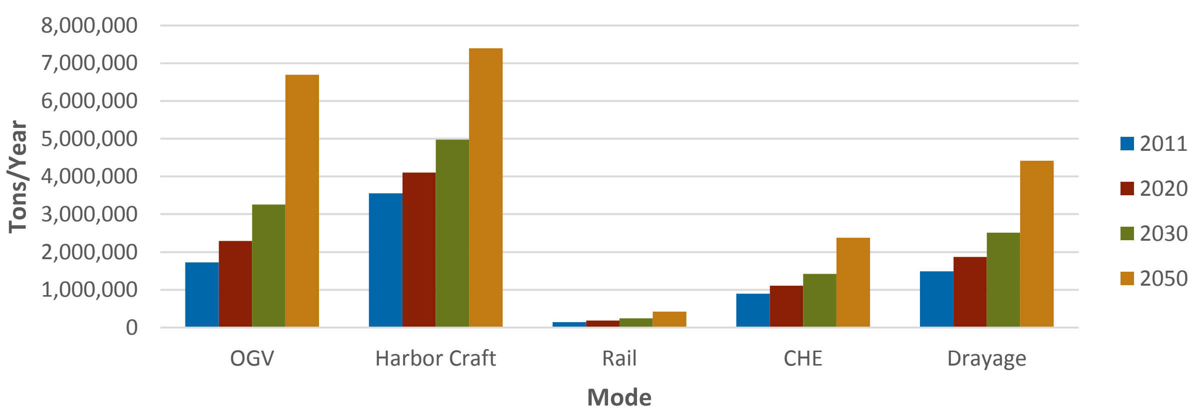


Figure 4-3. Total CO_2 Emissions Aggregated by Sector, Tons/Year



5. Assessment of Emission Reduction Strategies

5.1. Introduction

One of the purposes of this assessment is to assess the effectiveness of port-related emission reduction strategies. This section describes the "screening" assessment that was conducted to determine which strategies would be most effective in reducing port-related NOx, $PM_{2.5}$, and CO_2 emissions in future years. This section is organized to assess the effectiveness of strategies for the five mobile source sectors: drayage trucks, rail, cargo handling equipment (CHE), harbor craft, and ocean going vessels (OGVs). The final part of this section summarizes all of the most promising strategies and potential reductions for a "typical port".[74] The results of this screening assessment were then used to develop the more detailed strategy scenarios described in Section 6 and Appendix C of this report.

The most promising strategies are assessed for their potential impact in 2020 and 2030, since these are the future analysis years of interest for all pollutants. In addition, this section documents the considerations that EPA used to determine potential strategies to be modeled for CO_2 reductions in 2050. The screening assessment involved identifying potential strategies for each sector, estimating a "baseline" emissions level, and calculating the effectiveness of each strategy based on additional reductions beyond this baseline.[75] In most cases, this was estimated for the strategy as applied to a single vehicle, piece of equipment, or vessel. The results of this screening are presented as percent reductions in NOx, $PM_{2.5}$, and CO_2 emissions as well as annual tons reduced.

As described further below, other criteria were used to categorize and assess the available strategies to reduce emissions at U.S. ports:

- **Capital Cost**: Cost for most technological strategies, such as replacements or repowers, to be applied to a single vehicle, piece of equipment, or vessel. Cost for infrastructure and operational strategies to be implemented as an entire program or installation.
- **Market Penetration**: Current market penetration and maximum potential market penetration at U.S. ports in future years.
- **Market Barriers**: Market barriers, including technological and logistical barriers, preventing adoption by U.S. marine and inland ports.
- **Funding**: Availability of funding sources and other incentives to encourage adoption.

[74] A "typical port" in this assessment is intended to establish a hypothetical port that allows EPA to illustrate the relative impacts of a particular strategy and/or scenario.

[75] Please note that the "baseline emissions level" in this screening assessment is different from the 2011 baseline inventory described in Section 3 of this report.

Table 5-1 includes examples of some of the strategies that were assessed in this section.

Table 5-1. Example Emission Reduction Strategies for Assessment

Target Sector/Mode	Strategy
Drayage Truck	Replace with model year (MY) 2007+ or MY2010+ truck
	Replace with plug-in hybrid electric vehicles (PHEVs)
	Replace with battery electric vehicles (BEVs)
	Reduce truck queue idling
Rail – Line-haul	Replace with Tier 4 locomotive
	Rebuild Tier 0/pre-Tier 0 engines to meet Tier 0+ standard
	Automatic shut-down devices
Rail – Switcher	Replace with Tier 4 locomotive
	Repower Tier 3 GenSet switcher with Tier 4 nonroad engine
	Rebuild to meet Tier 1+ standard
Cargo Handling Equipment	Replace with Tier 3 or 4 equipment
	Repower with Tier 3 or 4 engine
	Replace with compressed natural gas (CNG)/liquified natural gas (LNG) equipment
	Replace diesel RTG crane with electric RTG
Harbor Craft	Diesel particulate filter (DPF)
	Repower with Tier 2 or 3
	Replace with diesel hybrid-electric tug
	Use ultra-low sulfur diesel (ULSD) fuel (15 ppm sulfur)
Ocean Going Vessels	Use ULSD fuel in auxiliary engines
	Use 500 ppm sulfur diesel fuel
	Shore power
	Advanced marine emission control system
	Improve land-side operational efficiency

Additional documentation on the screening assessment is provided below, including assumptions and data sources, capital costs, and feasibility. Where capital cost is a major factor in the adoption of specific strategies, it is expected that a combination of public and private funds would be necessary for implementation purposes. Finally, while many strategies were initially assessed for this section of the report, not all of the strategies were included in the final strategy scenarios in Section 6.

5.2. Drayage Trucks

Drayage trucks are used to move cargo to and from a port. Nearly all existing drayage trucks are Class 8b tractor-trailer vehicles, and most drayage trucks in the U.S. are diesel-fueled.[76] Drayage truck activity and emissions tend to be much higher at container terminals than bulk terminals. In this screening assessment, EPA considered both technological and operational strategies for reducing drayage truck emissions.

5.2.1. Technological Strategies

5.2.1.1. Baseline Emissions

To evaluate emission reduction strategies, emissions were estimated from typical drayage trucks that are using current (baseline) technologies (i.e., no application of emission reduction strategies was assumed). Baseline emission factors were assumed to be equal to the EPA emission standard in effect for the original truck year of manufacture, as shown in Table 5-2.[77]

Table 5-2. EPA Emission Standards for Heavy Duty Vehicles (g/bhp-hr)

Beginning Model Year	NOx	PM
1988	10.7	0.6
1990	6	0.6
1991	5	0.25
1994	5	0.1
1998	4	0.1
2004	2	0.1
2007	1.2	0.01
2010	0.2	0.01

The following activity assumptions for a typical drayage truck were applied to the baseline emission factors (i.e., activity multiplied by the emission factors) to calculate the baseline emissions:[78]

- 1.5 shifts per day, 8-hour shifts (or 12 hours per day)
- 199.4 kWh/shift
- 250 days operation per year

[76] Exceptions include the Port of Los Angeles and the Port of Long Beach, where there are significant numbers of natural gas drayage trucks.

[77] U.S. Environmental Protection Agency, *Emission Standards Reference Guide*. Available at: http://www.epa.gov/otaq/standards/heavy-duty/hdci-exhaust.htm.

[78] TIAX, *Roadmap to Electrify Goods Movement*, Phase 1, Vol 1, Prepared for Edison International, 2012.

5.2.1.2. Strategy Effectiveness

Next, the per truck percent reduction was estimated for the application of each of the following strategies:

- For **truck replacements and repowers** using conventional technology, the emission reduction was based on the EPA standards shown in Table 5-2.
- For diesel oxidation catalysts (**DOCs) and DPFs**, a 25% and 85% reduction in $PM_{2.5}$, respectively was assumed, consistent with typical EPA and California Air Resources Board (CARB) verified diesel emission control values. There are no NOx or CO_2 reduction benefits for these technologies.
- For **CNG/LNG**, a 35% reduction in NOx and 20% reduction in $PM_{2.5}$ was assumed, as compared to a MY2010 diesel truck, based on CARB engine certification values.[79] A 16% reduction in CO_2 emissions was assumed, based on parameters in Argonne National Laboratory's 2013 GREET model.[80] Note, the magnitude of these benefits are uncertain. Natural gas engines can likely achieve larger reductions but have not been required to demonstrate emission levels below current standards. There are also concerns regarding high levels of ammonia emissions from some natural gas trucks; ammonia can produce secondary particulates that could offset the $PM_{2.5}$ benefits of natural gas.
- For **biodiesel** (B20), NOx and $PM_{2.5}$, impacts were based on MOVES2010b simulations—a 0.4% increase in NOx and a 3.2% reduction in $PM_{2.5}$. CO_2 impacts were based on the 2013 GREET model[81] and assumed a 14% reduction in CO_2 on a well-to-wheels[82] basis.
- For hybrid electric vehicles (**HEVs), PHEVs, and BEVs**, emission reductions were based on an analysis for the Southern California Regional Goods Movement Plan[83] and a review of recent literature, including a 2010 National Academy of Sciences report.[84] Emission reductions were based on limited testing of HEVs and assumptions about the portion of vehicle operation in electric mode for HEVs and PHEVs. For BEVs, zero tailpipe emissions were assumed; BEVs were assumed to generate a small amount of $PM_{2.5}$ due to tire and brake wear. For CO_2 emissions, a 20% reduction for HEVs, a 25% reduction for PHEVs, and a 55% reduction for BEVs was assumed (all on a well-to-wheels basis).

For this assessment, the percentage reductions for each strategy was applied to the baseline annual per truck emissions. Tables 5-3 and 5-4 show the results of the analysis with typical annual NOx and $PM_{2.5}$

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[79] ICF International, *Comprehensive Regional Goods Movement Plan and Implementation Strategy: Task 10.2 Evaluation of Environmental Mitigation Strategies*, prepared for the Southern California Association of Governments, April 2012. Available at: www.freightworks.org/DocumentLibrary/Task%2010%202%20report%20April%202012%20final%20no%20watermark.pdf.

[80] Argonne National Laboratory's 2013 GREET model released October 2013. Available at: https://greet.es.anl.gov/greet/index.htm.

[81] *Ibid*.

[82] "Well-to-wheels" refers to all CO_2 emissions that are generated in the extraction, processing, shipment and final combustion of the fuel. This is in contrast to "tail-pipe" emissions that are typically just the emissions from final combustion.

[83] ICF International, *Comprehensive Regional Goods Movement Plan and Implementation Strategy: Task 10.2 Evaluation of Environmental Mitigation Strategies*, prepared for the Southern California Association of Governments, April 2012. Available at: www.freightworks.org/DocumentLibrary/Task%2010%202%20report%20April%202012%20final%20no%20watermark.pdf.

[84] *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, National Academy of Sciences, 2010.

emission impacts for each strategy combination, for a typical drayage truck. Negative values denote emission reductions.

Table 5-3. Typical Emission Impact per Truck per Year – NOx (lbs)

	Model Year	New/Improved Equipment								
		2007-09	2010+	DOC	DPF	CNG/LNG	B20	HEV	PHEV	BEV
Old Equipment	pre-1991	-1,061	-1,282	0	0	-1,298	5	-1,298	-1,301	-1,326
	1991-93	-840	-1,061	0	0	-1,077	4	-1,077	-1,080	-1,105
	1994-97	-840	-1,061	0	0	-1,077	4	-1,077	-1,080	-1,105
	1998-2003	-619	-840	0	0	-856	4	-856	-859	-884
	2004-06	-177	-398	0	0	-413	2	-414	-417	-442
	2007-09		-221	0	0	-237	1	-237	-240	-265
	2010+			0	0	-15	0	-16	-19	-44

Table 5-4. Typical Emission Impact per Truck per Year – $PM_{2.5}$ (lbs)

	Model Year	New/Improved Equipment								
		2007	2010+	DOC	DPF	CNG/LNG	B20	HEV	PHEV	BEV
Old Equipment	pre-1991	-130.4	-130.4	-33.2	-112.7	-130.9	-4.2	-130.7	-131.2	-132.2
	1991-93	-53.1	-53.1	-13.8	-47.0	-53.5	-1.8	-53.4	-53.9	-54.8
	1994-97	-19.9	-19.9	-5.5	-18.8	-20.3	-0.7	-20.2	-20.7	-21.7
	1998-2003	-19.9	-19.9	-5.5	-18.8	-20.3	-0.7	-20.2	-20.7	-21.7
	2004-06	-19.9	-19.9	-5.5	-18.8	-20.3	-0.7	-20.2	-20.7	-21.7
	2007-09		0.0	0.0	0.0	-0.4	-0.1	-0.3	-0.5	-1.8
	2010+			0.0	0.0	-0.4	-0.1	-0.3	-0.5	-1.8

Table 5-5 shows CO_2 emission impacts for each strategy combination, for a typical drayage truck. These values reflect well-to-wheel emissions.

Table 5-5. Typical Emission Impact per Truck per Year – CO_2 (tons)

	Model Year	New/Improved Equipment								
		2007	2010+	DOC	DPF	CNG/LNG	B20	HEV	PHEV	BEV
Old Equipment	pre-1991	0.0	0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	1991-93	0.0	0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	1994-97	0.0	0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	1998-2003	0.0	0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	2004-06	0.0	0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	2007-09		0.0	0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1
	2010+			0.0	0.0	-3.5	-3.1	-4.4	-5.5	-12.1

Next, the future year distribution of port drayage trucks was estimated by model year bins corresponding to the EPA heavy-duty vehicle emission standards.[85] This distribution, shown in Table 5-6, was based on a MOVES2010b analysis for all the counties with port activity considered in this assessment. Note that in some cases, this may underestimate the number of older drayage trucks remaining in operation, because the drayage truck fleet may be older than the total countywide truck fleet.

Table 5-6. Distribution of Trucks by Model Year

Model Year	2011	2020	2030	2050
pre-1991	20%	5%	0%	0%
1991-93	9%	6%	0%	0%
1994-97	21%	13%	0%	0%
1998-2003	24%	16%	7%	0%
2004-06	12%	9%	5%	0%
2007-09	10%	8%	5%	0%
2010+	4%	44%	84%	100%
Total	100%	100%	100%	100%

By understanding how fleet turnover is expected to occur without additional action, the screening assessment could identify which strategies would be most effective in accelerating fleet turnover to cleaner future fleets. However, the truck distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover for a specific port or area.

5.2.1.3. Most Effective Drayage Truck Technological Strategies in 2020

In 2020, more than half of drayage trucks in operation would pre-date EPA's MY2010 emission standards, and 48 percent would pre-date the MY2007 standards. By 2020, pre-2007 trucks would be at least 14 years old and not likely be good candidates for DPFs. The older age of these trucks, combined with their low average speed, which can increase the maintenance requirements for the DPFs, makes scrappage and replacement with post-MY2007 or 2010 trucks a more cost-effective alternative.

Repowering older trucks with MY2007-compliant or MY2010-compliant engines is generally not feasible, because the new engine and aftertreatment devices do not fit on older chassis. Thus, to achieve both NOx and $PM_{2.5}$ reductions, an effective strategy in 2020 would be to replace and scrap pre-2007 trucks. MY2010+ diesel trucks provide significant emissions benefits over pre-2007 trucks; for example, a MY2010 truck has 90% lower NOx and $PM_{2.5}$ emissions than a MY2006 truck.[86] The cost of a new Class 8

[85] The assessment's estimates for drayage trucks do not include the impacts of EPA's heavy-duty engine and vehicle GHG regulations, due to the timing of the assessment.

[86] Based on the percent difference between the MY2007 and MY2010 emission standards for trucks. U.S. EPA's Office of Transportation and Air Quality, *Emission Standards Reference Guide*. Available at: http://www.epa.gov/otaq/standards/heavy-duty/hdci-exhaust.htm.

tractor is approximately \$110,000.[87] A used truck is considerably less expensive and can still provide nearly equivalent emissions benefits. Based on CARB's estimates for the California "Truck and Bus Regulation" and the "Drayage Truck Regulation," a cost of a four-year-old Class 8 tractor is about 50 percent that of a new tractor (\$55,000).[88]

When focused on replacing pre-MY2007 trucks, the alternative fuel and advanced technology trucks provide only small additional criteria pollutant emissions benefits as compared to a MY2010+ truck. For example, replacing a pre-2007 truck with a natural gas, HEV, or PHEV would reduce NOx and $PM_{2.5}$ emissions by 92–95%, as compared to a 90% reduction with a newer conventional diesel truck. These advanced technology trucks carry a price premium of \$40,000 to \$80,000 compared to conventional diesel, and therefore are less cost effective as replacements for pre-2007 trucks. However, these same technologies, while higher in cost, can also be effective in helping to reduce CO_2 emissions.

5.2.1.4. Most Effective Drayage Truck Technological Strategies in 2030

As shown in Table 5-6, 84% of the drayage fleet are assumed to meet the MY2010 emission standards in 2030, and those that do not are likely to have a short remaining useful life. Due to the significant fleet turnover of older fleets assumed in this assessment to occur by 2030, the most effective strategies involve replacing conventional diesel trucks with advanced technology and alternative fuel trucks. To date, there has been limited commercial release of Class 8 HEV trucks, and Class 8 PHEV and BEV trucks are still in demonstration and research and development phases. EPA acknowledges that there may be limitations for applying these technologies for port drayage operations. However, advances in battery technology could enable all-electric port drayage trucks by 2030.

The cost of HEV, PHEV, and BEV trucks in 2030 is uncertain but likely to be 1.5 to 2 times the cost of a conventional diesel truck. Because a dray fleet operator would be purchasing a new diesel truck anyway under a replacement strategy, the cost incurred by a port or other public agency would likely be the incremental cost difference between a conventional diesel truck and an advanced technology truck. Given the expected emission benefits of BEVs over PHEVs and HEVs, and the likelihood that an all-electric option would be viable for drayage truck applications by 2030, the replacement with BEV may be the most cost-effective drayage truck strategy for 2030.

[87] California Air Resources Board, *Truck and Bus 2010 Rulemaking Initial Statement of Reasons, Appendix I: Costs and Cost Methodology*, p. I-5, 2010. Available at: http://www.arb.ca.gov/regact/2010/truckbus10/truckbusappi.pdf.
[88] *Ibid*.

5.2.1.5. Summary of Most Promising Drayage Truck Technological Strategies

Table 5-7 summarizes the most promising technological strategies for drayage trucks in 2020 and 2030 in this screening assessment.

Table 5-7. Most Promising Drayage Truck Technological Strategies

Strategy	Per Truck Reduction			Cost Per Truck	Years Effective
	NOx (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)		
Replace MY1998-2003 with MY2010+	840	19.9	0.0	$110,000 (new); $55,000 (4 yrs used)	2020
Replace MY2004-2006 with MY2010+	398	19.9	0.0	$110,000 (new); $55,000 (4 yrs used)	2020
Replace MY 2010+ Diesel with Battery Electric	44	1.8	12.1	$220,000 (new, est.)	2030

5.2.2. Operational Strategies

Operational strategies for drayage trucks focus on efficiency improvements that reduce truck delay and/or reduce truck travel at and around ports. DrayFLEET[89] was used to conduct a screening assessment of operational strategies that reduce truck idling:[90]

- **Reduced Inbound Gate Queues**: Reducing the time drayage drivers spend waiting in queues outside terminal gates.
- **Automated Gates**: Handling containers at automated terminal gates (e.g., via optical character recognition (OCR), swipe card, radio frequency identification (RFID), or other technology) typically reduces time at the gates.
- **Container Information Systems**: Developing container status and appointment systems to reduce terminal congestion and waiting time. This may also reduce non-productive trips when containers are not ready to move.
- **Extended Gate Hours**: Changing the hours of operation at a port. Marine terminal hours can start at 7–8 am and end at 4–5 pm, depending on local practice. Access outside those times requires “extended” gate hours. Extended gate hours tend to reduce peak period congestion and idling/queuing time. Extended gate hours may also reduce the need for drayage firms to park and store containers overnight.
- **Minutes per Transaction**: Improving on-terminal drayage operations can reduce the transaction time spent by drayage trucks, which reduces idle time. This factor reflects the minutes required inside the marine terminal container yard to complete a single transaction. Such transactions

[89] U.S. Environmental Protection Agency, *SmartWay DrayFLEET, Truck Drayage Environment and Energy Model: Version 2.0 User's Guide*, EPA Report EPA-420-B-12-065, June 2012.

[90] Strategy descriptions are taken from *DrayFLEET: EPA SmartWay Drayage Activity and Emissions Model and Case Studies*, Prepared for U.S. EPA and U.S. Federal Highway Administration, Prepared by The Tiaoga Group, Inc., 2008.

include picking up or draying a loaded or empty container or chassis, locating or draying a bare chassis, switching containers between chassis (a “chassis flip”), or live lifts of containers on or off a chassis.

To evaluate these strategies, the DrayFLEET model was applied to a typical port, based on the average annual twenty-foot equivalent units (TEUs) and tonnage for the port profiles considered in this assessment (i.e., 1.7 million TEUs, 7.5 million export tons, and 8.7 million import tons). Default values in the DrayFLEET model were otherwise used. Variations in the five operational strategies were explored by changing assumptions for the level of penetration or participation in the model. For example, DrayFLEET was used to analyze the impact of reducing average inbound gate queues from 20 to 10 minutes. Using the port’s drayage fleet size, age distribution, and annual number of trips, DrayFLEET, in this example, can calculate the reduction in creep idle emissions that would occur from reducing gate queues.

Table 5-8 shows the approximate annual emission reductions for each strategy, for a typical container port in 2020. These reductions are compared against baseline annual drayage truck emissions of 1,105 tons of NOx, 77.0 tons of $PM_{2.5}$, and 339,084 tons of CO_2 (well-to-wheels).

Table 5-8. Approximate Annual Typical Port Emission Impacts for Truck Operational Strategies, 2020

Strategy	NOx		$PM_{2.5}$		CO_2	
	Tons	Percent	Tons	Percent	Tons	Percent
Reduce Inbound Gate Queues						
50% Reduction (from 20 to 10 min)	-5.3	-0.5%	-1.54	-2.0%	-6,933	-2.0%
25% Reduction (from 20 to 15 min)	-2.6	-0.2%	-0.77	-1.0%	-3,466	-1.0%
Automated Gates						
100% of Gate Transactions	-10.8	-1.0%	-3.10	-4.0%	-13,918	-4.1%
50% of Gate Transactions	-5.4	-0.5%	-1.55	-2.0%	-6,959	-2.1%
25% of Gate Transactions	-2.7	-0.2%	-0.78	-1.0%	-3,479	-1.0%
Container Information System						
75% of TEUs Covered	-3.1	-0.3%	-0.21	-0.3%	-708	-0.2%
50% of TEUs Covered	-2.1	-0.2%	-0.14	-0.2%	-472	-0.1%
Extended Gate Hours						
50% of traffic off-peak	-7.7	-0.7%	-1.71	-2.2%	-7,480	-2.2%
30% of traffic off-peak	-4.6	-0.4%	-1.02	-1.3%	-4,488	-1.3%
10% of traffic off-peak	-1.5	-0.1%	-0.34	-0.4%	-1,496	-0.4%
Minutes per Transaction						
20% reduction (from 30 min to 24)	-17.0	-1.5%	-1.00	-1.3%	-3,831	-1.1%

By varying input parameters in DrayFLEET, a generalized drayage truck operational strategy was developed to demonstrate how much emissions were reduced for every 10% reduction in the amount of time dray trucks spend in idle and creep mode. This outcome could be achieved in a variety of ways. One way, for example, would be to reduce drayage truck transaction time from 30 minutes to 24 minutes and also deploy extended gate hours for 30% to achieve drayage truck visits during off-peak hours. Table 5-9 shows the average “typical” emission reductions resulting from this generalized strategy. If drayage idle and creep were reduced by 20%, it would double these benefits. For terminals that substantially reduce major congestion or delay problems, the benefits could be double or triple the amounts presented.

Table 5-9. Typical Port Emission Impacts for Each 10 Percent Reduction in Idle/Creep Time, 2020 and 2030

Strategy	NOx		$PM_{2.5}$		CO_2	
	Tons	Percent	Tons	Percent	Tons	Percent
10% reduction in Idle and Creep time	-22	-2.0%	-2	-2.6%	-8,940	-2.6%

5.3. Rail

As noted earlier, port-related rail can include both line-haul and switcher locomotives. The baseline emissions and reduction options differ for these two categories, so they are discussed separately below.

5.3.1. Line-haul Locomotives

5.3.1.1. Baseline Emissions

To conduct a screening-level assessment of emission reduction strategies, emissions from a typical line-haul locomotive were calculated using current (baseline) technologies (i.e., no application of emission reduction strategies). Line-haul locomotives typically travel long distances across multiple states, and an individual locomotive spends only a small fraction of its operating time at a port. However, it is useful to analyze emission reduction strategies on a per-locomotive basis, to be consistent with the approach used for most other port strategies in this section.

To develop a representative estimate of line-haul locomotive activity at a typical port, an approach was used that was similar to the Port of Los Angeles 2012 emission inventory.[91] This report estimated that line-haul locomotives operate for 35,292 hours by year "on-port." The vast majority of these locomotives were used to move container trains. The 2012 container throughput at the Port of Los Angeles was 8,077,714 TEUs. For this screening assessment, an annual container throughput of 3 million TEUs was assumed, which is similar to the median container throughput at the ports examined in this assessment. This corresponds to 13,107 line-haul locomotive operating hours at a typical port.

The Port of Los Angeles inventory report also assumed line-haul locomotives had a load factor of 0.28 and an average horsepower of 4,000. Thus, the annual aggregate line-haul locomotive horsepower hours at a typical port for the purposes of this screening assessment was estimated to be 14,680,000 (i.e., 13,107 * 0.28 * 4,000).

[91] Port of Los Angeles, *Inventory of Air Emissions for Calendar Year 2012*, prepared by Starcrest Consulting Group, July 2013. Available at: https://www.portoflosangeles.org/pdf/2012_Air_Emissions_Inventory.pdf.

An individual line-haul locomotive typically consumes 250,000 to 500,000 gallons of fuel per year.[92] Using the mid-point of this range, and assuming brake-specific fuel consumption (BSFC) of 20.8 hp-hr per gallon, an individual line-haul locomotive was estimated to have 7,800,000 annual horsepower hours, or roughly one-half of the total line-haul locomotive horsepower hours at a typical port. Therefore, for the purposes of this screening assessment, one can assume that the equivalent of two line-haul locomotives are operating full-time at a typical port, recognizing that in reality there are many locomotives each spending a fraction of their time at the port.

To estimate baseline emissions for this section, emission factors based on EPA's regulations were applied; EPA's in-use emission factors are shown in Table 5-10.[93]

Table 5-10. EPA Emission Factors for Line-Haul Locomotives

Tier	Year of Manufacture	In-Use Emission Factors (g/hp-hr)	
		NOx	PM_{10}
Pre-Tier 0	Pre-1973	13	0.32
Tier 0	1973 – 2001	8.6	0.32
Tier 0+	2008 / 2010	7.2	0.2
Tier 1	2002 – 2004	6.7	0.32
Tier 1+	2008 / 2010	6.7	0.2
Tier 2	2005	4.95	0.18
Tier 2+	2008 / 2013	4.95	0.08
Tier 3	2012 – 2014	4.95	0.08
Tier 4	2015 / 2017	1	0.015

5.3.1.2. Strategy Effectiveness

EPA evaluated the effectiveness of a range of line-haul locomotive strategies that included:

- **Replacements or rebuilds of older locomotives**: Due to the extended lifetime and turnover, there is great potential to reduce emissions from replacing or rebuilding older line-haul locomotives.
- **Idle reduction**: There are several technologies currently available to reduce unnecessary locomotive idling, including use of an auxiliary power unit (or APU) or automatic engine stop/start system.

The primary emission reduction strategies for line-haul locomotives involve replacing or rebuilding of older line-haul locomotives. Tier 0, Tier 1, and Tier 2 locomotives are required to meet a more stringent emission standard upon rebuild. For line-haul locomotives, the Tier 2 rebuild (Tier 2+) emission rates are equivalent to Tier 3. Tier 4 standards were required for new locomotives beginning in 2015.

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[92] California Air Resources Board, *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*, August 2009. Available at: https://www.arb.ca.gov/railyard/ted/083109tedr.pdf.

[93] U.S. Environmental Protection Agency, *Technical Highlights: Emission Factors for Locomotives*. EPA-420-F-09-025. April 2009.

EPA estimates that a line-haul locomotive idles for 38 percent of its operating time, or about 1,650 hours per year.[94] There are several technologies currently available to reduce unnecessary locomotive idling. An auxiliary power unit (APU) employs a small diesel engine to run cab accessories, heat and circulate water and oil, and charge the locomotive batteries, rather than operating the much larger locomotive engine. An APU costs $25,000 to $32,000, according to EPA.[95] Another option is the automatic engine stop/start system (AESS), which is an electronic control system that shuts down a locomotive engine when it is idling unnecessarily. The AESS alone may not significantly reduce idling in cold weather, because of the need to idle the locomotive to prevent freezing of engine coolant (i.e., water). However, an AESS can be combined with an APU to provide substantial idle reduction in all weather. EPA estimates the cost of an AESS system to be $10,000.[96]

Because of their effectiveness and relatively low cost, EPA now requires an AESS on all newly-built Tier 3 and Tier 4 locomotives, and on all existing locomotives when they are first remanufactured. According to EPA's projections for the Regulatory Impact Analysis for the 2008 standards (presented below), it was expected that nearly all line-haul locomotives will be Tier 3, Tier 4, or remanufactured units by 2020. Thus, additional benefits from AESS would only accrue where the port was working with locomotive operators to insure that the AESS system was being implemented beyond the minimum requirements.

Tables 5-11 and 5-12 show annual NOx and $PM_{2.5}$ emission reductions expected for each replacement strategy, assuming a typical line-haul locomotive as outlined above.

Table 5-11. Typical Emission Impact per Line-Haul Locomotive per Year – NOx (lbs)

		Tier 0+	Tier 1+	Tier 2+	Tier 3	Tier 4
Old Equipment	Pre-Tier 0	-99,736	-108,334	-138,427	-138,427	-206,351
	Tier 0	-24,074	-32,672	-62,765	-62,765	-130,689
	Tier 0+		-8,598	-38,691	-38,691	-106,614
	Tier 1		0	-30,093	-30,093	-98,017
	Tier 1+			-30,093	-30,093	-98,017
	Tier 2			0	0	-67,924
	Tier 2+				0	-67,924
	Tier 3					-67,924
	Tier 4					

[94] U.S. Environmental Protection Agency, 2008. *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder*. EPA-420-R-08-001, February 2008.
[95] *Ibid*.
[96] *Ibid*.

Table 5-12. Typical Emission Impact per Line-Haul Locomotive per Year – $PM_{2.5}$ (lbs)

		Tier 0+	Tier 1+	Tier 2+	Tier 3	Tier 4
Old Equipment	Pre-Tier 0	-2,064	-2,064	-4,127	-4,127	-5,245
	Tier 0	-2,064	-2,064	-4,127	-4,127	-5,245
	Tier 0+		0	-2,064	-2,064	-3,181
	Tier 1		-2,064	-4,127	-4,127	-5,245
	Tier 1+			-2,064	-2,064	-3,181
	Tier 2			-1,720	-1,720	-2,837
	Tier 2+				0	-1,118
	Tier 3					-1,118
	Tier 4					

EPA's emission standards for line-haul locomotives are not designed to address CO_2 emissions. Although newer locomotive tend to be more fuel efficient, it is difficult to determine the fuel or CO_2 reduction that would be associated with replacement of an older locomotive with a newer one. The aggregate fuel efficiency of U.S. freight railroads improved about 31% between 1990 and 2010, or 1.4% annually, in terms of gallons per revenue ton-mile. However, those improvements are the net outcome of multiple changes in railroad traffic mix, technological improvements, and operating practices. For the purposes of this screening analysis, no change in CO_2 emissions was assumed when moving from one tier to another for line-haul locomotives. In this assessment, any further reductions in CO_2 emission rates from technological changes was assumed to come from the implementation of zero emissions technologies.

Table 5-13 shows the expected distribution of line-haul locomotives by tier in 2011, 2020, 2030, and 2050, using assumptions from EPA's Regulatory Impact Analysis for the 2008 locomotive emission regulation.[97] Compared to trucks, the locomotive fleet has a slower assumed fleet turnover resulting in a significant fraction of older (pre-Tier 4) engines remaining in the fleet even in 2030.

Table 5-13. Distribution of Line-Haul Locomotives by Tier

Tier	2011	2020	2030	2050
Pre-Tier 0	10%	0%	0%	0%
Tier 0	37%	3%	0%	0%
Tier 0+	19%	33%	10%	0%
Tier 1	4%	0%	0%	0%
Tier 1+	6%	9%	5%	0%
Tier 2	24%	0%	0%	0%
Tier 2+	0%	22%	17%	0%
Tier 3	0%	10%	9%	0%
Tier 4	0%	23%	59%	100%
Total	100%	100%	100%	100%

[97] U.S. Environmental Protection Agency, 2008. *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder*. EPA-420-R-08-001, February 2008.

It is important to understand when baseline fleet turnover is expected to occur, to accurately assess the potential of reducing line-haul locomotive emissions through replacement and rebuild strategies. However, the line-haul locomotive distributions shown in Table 5-13 are national default assumptions and are not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.3.1.3. Most Effective Line-haul Strategies in 2020

In the year 2020 for this analysis, strategies should focus on replacing Tier 0+ line-haul locomotives with newer equipment. A new Tier 4 locomotive costs approximately $3 million and would provide the largest emission reduction benefit. However, significant benefits could also be obtained from replacing Tier 0+ with a (used) Tier 2+ or Tier 3 locomotive. If the railroad serving the port is a short line and therefore operates a small fleet over a limited area, it could be cost effective to use a combination of private and government funds to scrap the Tier 0+ locomotives and replace them with Tier 2+/3 locomotives obtained from another railroad. The cost effectiveness of this strategy would depend on the locomotive purchase price.

5.3.1.4. Most Effective Line-haul Strategies in 2030

In 2030, the remaining Tier 0+ locomotives will have little useful service life and will probably be used sparingly. Therefore, for this assessment, the emission reduction strategies should focus on replacing the Tier 2+ and Tier 3 locomotives with Tier 4 locomotives. The cost effectiveness of this strategy would depend on whether the replacement engines are purchased new or used, and whether the old equipment is re-deployed or scrapped.[98]

5.3.2. Switcher Locomotives

5.3.2.1. Baseline Emissions

For switcher locomotives (unlike line-haul), it was assumed for the purposes of this screening assessment that a small fleet of switchers would be dedicated to port service and operated entirely in and around a port. To estimate baseline emissions (i.e., without emission reduction strategies), a typical switcher locomotive was assumed to have the following parameters:[99]

- Annual fuel consumption of 50,000 gallons
- Brake-specific fuel consumption (BSFC) of 20.8 hp-hours per gallon

To estimate baseline emissions, EPA's in-use emission factors as shown in Table 5-14 were applied.[100]

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[98] Detailed information on trends in locomotive fuel efficiency and strategies are discussed in *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*, Final Report for the Federal Railroad Administration, March 31, 2009. Available at: https://www.fra.dot.gov/eLib/details/L04317.

[99] California Air Resources Board, *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*, August 2009.

[100] U.S. Environmental Protection Agency, *Technical Highlights: Emission Factors for Locomotives*. EPA-420-F-09-025. April 2009.

Table 5-14. EPA Emission Factors for Switcher Locomotives

Tier	Year of Manufacture	In-Use Emission Factors (g/hp-hr)	
		NOx	PM_{10}
Pre-Tier 0	Pre-1973	17.4	0.44
Tier 0	1973 – 2001	12.6	0.44
Tier 0+	2008 / 2010	10.6	0.23
Tier 1	2002 – 2004	9.9	0.43
Tier 1+	2008 / 2010	9.9	0.23
Tier 2	2005	7.3	0.19
Tier 2+	2008 / 2013	7.3	0.11
Tier 3	2012 – 2014	4.5	0.08
Tier 4	2015 / 2017	1	0.015
Tier 3 GenSet	2006	3	0.15
Tier 4 GenSet	2011-2014	0.3	0.01

5.3.2.2. Strategy Effectiveness

EPA evaluated the effectiveness of a range of switcher locomotive strategies:

- **Replacements, rebuilds, and Generator Sets (GenSets)**: Accelerating fleet turnover to newer EPA standards and/or the use of GenSets could reduce significant levels of emissions attributed to older switcher locomotives.
- **Idle reduction**: EPA also considered the potential impact of reducing switcher locomotive emissions through the use of automatic engine stop/start systems (AESS).

Switcher locomotive emission reduction strategies are similar to line-haul strategies, but also include GenSet technology. GenSets are typically powered by a bank of three nonroad engines, one or two of which can be shut down during periods of lower demand. By 2015, new-model GenSets will by fully compliant with EPA's Tier 4 nonroad engine standards, so they can significantly reduce emissions and fuel use.

Idle reduction could also be an effective strategy for switcher locomotives in 2020. As discussed above, the addition of idle reduction technology is not expected to provide additional benefits for line-haul locomotives in 2020 and later because nearly all line-haul locomotives will have an AESS installed upon rebuild. However, switchers are not rebuilt as frequently, and EPA projected that approximately 46% of the switcher fleet will already be pre-Tier 0, Tier 0, or Tier 2 in 2020 (see below). EPA estimated that use of an AESS could reduce Tier 2 switcher emissions by 880 lbs of NOx and 14 lbs of $PM_{2.5}$ annually.[101] Installation on pre-Tier 0 and Tier 0 switchers would provide larger reductions, but these retrofits may

[101] U.S. Environmental Protection Agency, 2008. *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder*. EPA-420-R-08-001, February 2008.

be impractical for very old locomotives facing retirement. The cost of a basic AESS is approximately \$10,000. EPA notes that the system was assumed to would reduce operating cost by saving 2,000 gallons of fuel per year; this equates to about 22 tons of CO_2 emissions reduced per year.[102]

Tables 5-15 and 5-16 show the results of the screening assessment with annual NOx and $PM_{2.5}$ emission reductions expected for each replacement strategy, assuming a typical switcher locomotive that consumes 50,000 gallons of fuel per year.

Table 5-15. Typical Emission Impact per Switcher Locomotive per Year – NOx (lbs)

		New/Improved Equipment						
	Tier	**Tier 0+**	**Tier 1+**	**Tier 2+**	**Tier 3**	**Tier 4**	**T3 GenSet**	**T4 GenSet**
Old Equipment	Pre-Tier 0	-15,591	-17,196	-23,157	-29,577	-37,602	-33,016	-39,207
	Tier 0	-4,586	-6,191	-12,152	-18,572	-26,596	-22,011	-28,201
	Tier 0+		-1,605	-7,566	-13,986	-22,011	-17,425	-23,616
	Tier 1		0	-5,961	-12,381	-20,406	-15,820	-22,011
	Tier 1+			-5,961	-12,381	-20,406	-15,820	-22,011
	Tier 2			0	-6,420	-14,445	-9,859	-16,049
	Tier 2+				-6,420	-14,445	-9,859	-16,049
	Tier 3					-8,025	-3,439	-9,630
	Tier 4							-1,605
	Tier 3 GenSet							-6,191
	Tier 4 GenSet							

Table 5-16. Typical Emission Impact per Switcher Locomotive per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment						
	Tier	**Tier 0+**	**Tier 1+**	**Tier 2+**	**Tier 3**	**Tier 4**	**T3 GenSet**	**T4 GenSet**
Old Equipment	Pre-Tier 0	-481	-481	-757	-825	-974	-665	-986
	Tier 0	-481	-481	-757	-825	-974	-665	-986
	Tier 0+		0	-275	-344	-493	-183	-504
	Tier 1		-459	-734	-802	-952	-642	-963
	Tier 1+			-275	-344	-493	-183	-504
	Tier 2			-183	-252	-401	-92	-413
	Tier 2+				-69	-218	92	-229
	Tier 3					-149	160	-160
	Tier 4							-11
	Tier 3 GenSet							-321
	Tier 4 GenSet							

CO_2 emission reductions will result from replacement with GenSet locomotives, or an equivalent strategy. The fuel savings from GenSet switchers can vary depending on duty cycle—values of 20% to

[102] *Ibid*.

50% are reported,[103] and 25% fuel savings was assumed for the purpose of this screening assessment. It was assumed that replacements of any non-GenSet switcher with a GenSet switcher would reduce CO_2 emissions by 177 tons per year, assuming typical operation. As discussed above for line-haul locomotives, no CO_2 reductions resulted from replacements with newer conventional locomotives.

Table 5-17 shows the expected distribution of switcher locomotives by Tier in 2011, 2020, 2030, and 2050, using assumptions from EPA's Regulatory Impact Analysis for the 2008 locomotive emission regulations. Unlike line-haul locomotives, EPA projected the switcher fleet would contain a significant portion (38%) of Pre-Tier 0 (uncontrolled) locomotives in 2020, in addition to 46% Tier 0/0+. Even in 2030, EPA projected that 60% of the switcher fleet will be Pre-Tier 0 or Tier 0+. Pre-Tier 0 are exempt from EPA's rebuild requirements.

Table 5-17. Distribution of Switcher Locomotives by Tier

	2011	2020	2030	2050
Pre-Tier 0	74%	38%	8%	0%
Tier 0	7%	1%	0%	0%
Tier 0+	10%	45%	52%	0%
Tier 1	1%	0%	0%	0%
Tier 1+	0%	1%	1%	0%
Tier 2	7%	7%	0%	0%
Tier 2+	0%	0%	6%	0%
Tier 3	1%	3%	3%	0%
Tier 4	0%	5%	29%	100%
Total	100%	100%	100%	100%

As stated elsewhere, the switcher locomotive distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.3.2.3. Most Effective Switcher Strategies in 2020

Based on this assessment's assumptions, switcher strategies in 2020 should focus on the Pre-Tier 0 and Tier 0+ locomotives, which will dominate the fleet Pre-Tier 0 engines could potentially be re-built to meet Tier 0+ standards at relatively low cost, even though Pre-Tier 0 locomotives are exempt from the re-build requirement.[104] However, there may be little economic incentive for railroads to remanufacture these older pre-Tier 0 switch locomotives to reduce emissions because they have little residual value. Thus, this screening assessment supports the use of 2020 strategies that focus on scrapping and replacing the Pre-Tier 0 and Tier 0+ locomotives with newer equipment.

[103] California Air Resources Board, *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*, August 2009. Available at: https://www.arb.ca.gov/railyard/ted/083109tedr.pdf.
[104] California Air Resources Board, *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*, August 2009.

The greatest emission reduction benefits are assumed to come from deployment of Tier 4 GenSet switchers. Large emission reductions in 2020 can also be obtained through deployment of Tier 2+, Tier 3, Tier 3 GenSet, and Tier 4 switchers. The cost of a new GenSet locomotive is approximately $1.5 million. The cost of a Tier 2+ or Tier 3 locomotive will depend on its age; it has been common for railroads to redeploy older line-haul locomotives to switcher service. The cost effectiveness of each of these strategy options will depend on the purchase price of the new or used equipment and the remaining service life of the old locomotive to be replaced. In addition, GenSets have lower power than conventional switchers and may not be suitable for some switching applications with high power demands. As a result, some of the switcher replacements may involve conventional Tier 4 units rather than GenSets. A combination of private and public funds may be the most effective option for encouraging early adoption of these cleaner technologies.

Installation of AESS to reduce idling has relatively small emission reduction benefits but is very cost effective. The fuel savings from this strategy ensures a payback period of less than three years. AESS installation should focus on Tier 2 locomotives that have not been rebuilt, as well as any pre-Tier 0 switchers that have expected remaining service life.

5.3.2.4. Most Effective Switcher Strategies in 2030

In 2030, switcher strategies should focus on replacement of the remaining Tier 0+ locomotives and the Tier 2+/Tier 3 locomotives. The new replacement locomotives should be Tier 4 or Tier 4 GenSets. The Tier 4 GenSets have the lowest emissions. However, as noted for 2020, GenSets can have lower power than conventional switchers, so some of the switcher replacements may also involve conventional Tier 4 units.

5.3.3. Summary of Most Promising Locomotive Strategies

Table 5-18 summarizes the most promising locomotive strategies for this assessment. The costs are approximate values for the full purchase price of new equipment, with the assumption that used equipment could be purchased at a lower cost.

Table 5-18. Most Promising Locomotive Emission Reduction Strategies

Type	Strategy	Per Locomotive Reduction			Cost	Years Effective
		NOx (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)		
Line-Haul	Replace Tier 0+ with Tier 2+/3	38,691	2,064	0	$3,000,000	2020
	Replace Tier 2+/3 with Tier 4	67,924	1,118	0	$3,000,000	2030
Switcher	Replace Pre-T0 and T0+ with Tier 2+/3	7,566	275	0	$1,500,000	2020
	Replace Pre-T0, T0+ with Tier 4 GenSet	23,616	504	177	$1,500,000	2020, 2030
	Install AESS on Tier 2	880	14	28	$10,000	2020
	Replace Tier 2+/3 with T4 or T4 GenSet	9,630	160	177	$1,500,000	2030

5.4. Cargo Handling Equipment

The cargo handling equipment (CHE) emission source category encompasses a wide variety of equipment types, and the mix of CHE at a given port can vary widely depending on the types of cargo.

At a typical port with significant container operations, the bulk of CHE emissions are associated with yard trucks, cranes, and container handlers (side picks and top handlers).[105] Thus, this assessment focused on potential CHE emission reduction strategies for yard trucks, cranes, and container handlers.

5.4.1. Yard Trucks

Yard trucks are assumed to make up the bulk of CHE emissions at container terminals, and are referred to as terminal tractors or yard hostlers. A yard truck is typically a low power semi-tractor with a single-person cab and a very short wheelbase.

5.4.1.1. Baseline Emissions

First, for this screening assessment, baseline emissions were estimated for typical yard trucks that are using current (baseline) technologies (i.e., no application of emission reduction strategies). To do this, the following assumptions were made for a typical yard truck:[106]

- Average engine size of 206 hp
- Load factor of 0.65
- 1,861 hours of operation per year

Baseline emission factors were assumed to be equal to the federal Nonroad Compression-Ignition Engine Exhaust Emission Standard in effect for the average rated power (i.e., 206 hp) and model year of the engine, as shown in Table 5-19. CO_2 emission factors for all tiers were assumed to be 396 g CO_2 / kW-hr.[107]

Table 5-19. EPA Emission Standards Applicable to Typical Yard Trucks

Tier	Model Year (beginning)	NMHC	NMHC + NOx	NOx	PM
1	1996	1.3	-	9.2	0.54
2	2003	-	6.6	-	0.2
3	2006	-	4	-	0.2
4	2011	-	4	-	0.02
4	2014	0.19	-	0.4	0.02

5.4.1.2. Strategy Effectiveness

Next, the per yard truck percent reduction in emissions was estimated for the application of each of the following strategies:

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[105] This assumption is based on a review of the emission inventories for the Ports of Charleston, Oakland, Long Beach, Los Angeles, and Virginia that found these three CHE types collectively account for more than 80% of CHE emissions.

[106] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, April 2009.

[107] *Ibid*.

- **Vehicle replacement and repower**. Using conventional equipment, the emission reduction is based on the EPA Nonroad Emission Standards shown in Table 5-19.
- **Diesel particulate filters (DPFs).** An 85% reduction in $PM_{2.5}$ was assumed, consistent with typical EPA-verified diesel emission control strategy values.[108] Please note that DPFs have no impact on NOx and CO_2 emissions.
- **Compressed natural gas (CNG) and liquified natural gas (LNG).** The screening assessment assumed a 20% reduction in NOx and $PM_{2.5}$ compared to a Tier 4 diesel yard truck, based on the California Air Resources Board's certification tests of natural gas versus diesel engines.[109] Note that the magnitude of these benefits are uncertain. Natural gas engines can likely achieve larger reductions, but have not been required to demonstrate emission levels below current standards. There have also been concerns regarding high levels of ammonia emissions from some natural gas trucks; ammonia can produce secondary particulates that could offset the $PM_{2.5}$ benefits of natural gas. This assessment assumed a 16% reduction in CO_2 emissions, based on Argonne National Laboratory's GREET model.[110]
- **Plug-in hybrid electric vehicle (PHEV), hydraulic hybrid, and all-electric yard trucks**. Emission reductions were based on emission rate estimates from a 2009 report at the Port of Long Beach.[111] Emission reductions were calculated based on comparing the study's emission rates for pluggable hybrid electric terminal tractors (PHETTs) and Tier 3 yard trucks. Because in-use emissions data were not available for hydraulic hybrids, it was assumed that they experience the same reductions as plug-in hybrids. Zero tailpipe emissions were assumed for all-electric tractors. CO_2 emissions for plug-in hybrids were based on the average fuel rates measured in the PHETT study; CO_2 emissions for hydraulic hybrids were based on EPA estimates of 50–60% fuel efficiency increases.[112]

Further details on these strategies are offered below. In this screening assessment, the percentage reductions for each strategy were applied to the baseline annual per yard truck emissions.

Tables 5-20 and 5-21 show estimated annual NOx and $PM_{2.5}$ emission reductions per yard truck for each strategy combination for this screening assessment.

[108] U.S. Environmental Protection Agency, *Technologies Diesel Retrofit Devices*. Available at: http://www.epa.gov/cleandiesel/technologies/retrofits.htm.

[109] California Air Resources Board, On-Road New Vehicle & Engine Certification Program. Available at: http://www.arb.ca.gov/msprog/onroad/cert/cert.php.

[110] Argonne National Laboratory's 2013 GREET model released October 2013. Available at: https://greet.es.anl.gov/greet/index.htm.

[111] TIAX, *Pluggable Hybrid Electric Terminal Tractor (PHETT) Demonstration at the Port of Long Beach*, prepared for the Port of Long Beach, September 2009. Available at: http://www.cleanairactionplan.org/documents/capacity-plug-in-hybrid-terminal-tractor-phett-demonstration-polb-final-report.pdf.

[112] U.S. Environmental Protection Agency. *Hydraulic Hybrid Yard Hostlers*. Faster Freight – Cleaner Air Conference. July 9, 2008. Presentation. Available at: http://www.fasterfreightcleanerair.com/pdfs/Presentations/FFCAEC2008/John%20Kargul.pdf.

Table 5-20. Typical Emission Impact per Yard Truck per Year – NOx (lbs)

		New/Improved Equipment							
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	CNG/LNG	PHEV	Hydraulic Hybrid	Electric
	Tier 1	-1,065	-2,130	-3,605	0	-3,638	-3,669	-3,669	-3,769
	Tier 2		-1,065	-2,540	0	-2,573	-2,604	-2,604	-2,704
	Tier 3			-1,475	0	-1,508	-1,539	-1,539	-1,639
	Tier 4				0	-33	-64	-64	-164

Table 5-21. Typical Emission Impact per Yard Truck per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment							
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	CNG/LNG	PHEV	Hydraulic Hybrid	Electric
	Tier 1	-139	-139	-213	-188	-215	-217	-217	-221
	Tier 2		0	-74	-70	-75	-78	-78	-82
	Tier 3			-74	-70	-75	-78	-78	-82
	Tier 4				0	-2	-4	-4	-8

Table 5-22 shows estimated annual CO_2 emission reductions per yard truck for each strategy combination, calculated on a well-to-wheels basis.

Table 5-22. Typical Emission Impact per Yard Truck per Year – CO_2 (tons)

		New/Improved Equipment							
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	CNG/LNG	PHEV	Hydraulic Hybrid	Electric
	Tier 1	0	0	0	0	-17	-19	-52	-34
	Tier 2		0	0	0	-17	-19	-52	-34
	Tier 3			0	0	-17	-19	-52	-34
	Tier 4				0	-17	-19	-52	-34

To identify strategies that would be applicable and the most effective in future years, the future year distribution of yard trucks was estimated with using EPA's NONROAD2008 model.[113] Table 5-23 shows the assumed distribution of yard trucks by tier in 2011, 2020, 2030, and 2050.

[113] Yard trucks are identified in NONROAD as Terminal Tractors (SCC: 2270003070).

Table 5-23. Distribution of Yard Trucks by Tier

	2011	2020	2030	2050
Tier 1	9%	0%	0%	0%
Tier 2	17%	0%	0%	0%
Tier 3	64%	3%	0%	0%
Tier 4	10%	97%	100%	100%
Total	100%	100%	100%	100%

EPA notes that the yard truck distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.4.1.3. Most Effective Yard Truck Strategies in 2020

In 2020, based on the NONROAD national default age distribution, nearly all yard tractors are expected to meet EPA's highest emission standards (i.e., Tier 4). Therefore, strategies to further reduce emissions is limited in this screening assessment to replacing conventional diesel yard trucks with advanced technology or alternative fuel equipment. Hybrid yard trucks are in the early stages of commercialization. In 2009, Capacity released its PHETT, and in 2010, Kalmar/Cargotec produced a hydraulic hybrid terminal tractor. Demonstration hybrid yard truck projects at the Port of Los Angeles and Port of Long Beach found significant emission reduction benefits compared to a Tier 3 baseline vehicle.[114]

EPA has supported development of a hydraulic hybrid yard truck, which increases system efficiency by capturing energy from braking as pressurized hydraulic fluid. This vehicle was tested at the Port of Long Beach and Port of New York/New Jersey.[115] Because a typical yard truck duty cycle is characterized by frequent starting and stopping, low travel speeds, and significant idling, hybrid technologies can potentially realize significant emission benefits. However, the magnitude of emission reduction benefits and the incremental costs of these technologies compared to conventional Tier 4 diesel yard trucks are uncertain. It was assumed that a PHEV and hydraulic hybrid truck would both yield 39% NOx and 53% $PM_{2.5}$ reductions, based on demonstrations at the Port of Long Beach. To estimate CO_2 impacts, for this screening assessment, a PHEV is assumed to reduce fuel use by 34% (based on the Long Beach demonstration) and a hydraulic hybrid would reduce fuel use by 50% (based on EPA's demonstration).

[114] TIAX LLC, *Pluggable Hybrid Electric Terminal Truck (PHETT™) Demonstration at the Port of Los Angeles*, prepared for the Port of Los Angeles. May 2010. Available at: http://www.cleanairactionplan.org/documents/capacity-plug-in-hybrid-terminal-tractor-phett-demonstration-polb-final-report.pdf.

[115] Calstart, *Hybrid Yard Hostler Demonstration and Commercialization Project*, prepared for Ports of Los Angeles and Long Beach. March 2011. Available at: http://www.cleanairactionplan.org/documents/hybrid-yard-hostler-demonstration-and-commercialization-project-final-report.pdf.

In terms of costs, a pilot project study found that the costs for hybrid-electric yard trucks were currently 60% higher than a conventional diesel truck, with the project prototypes costing $134,000.[116] In the future, this cost increment may decline, but hybrid-electric vehicles are still expected to carry a significantly higher purchase price than conventional diesel trucks. Like other advanced technologies, adoption of these strategies would require a combination of public and private funds.

An all-electric yard truck would offer emission reductions beyond Tier 4 standards and hybrid technologies, with zero tailpipe emissions. Like hybrids, battery electric yard trucks are in the development and demonstration phase. Tenants at the Port of Los Angeles have been testing plug-in battery electric yard trucks made by Balqon Corporation—the Nautilus XE20 and XR E20 models.[117] The vehicles operate on lithium-ion batteries. The vehicle and charging equipment for a Port of Los Angeles demonstration project cost approximately $210,000; future costs for all-electric vehicles are uncertain but would be substantially higher than a diesel yard truck.[118]

Some CNG and LNG yard trucks are available from heavy-duty truck manufacturers (e.g., Capacity, Cargotec/Kalmar). Because they are also relatively early in their development and use, emission reductions are not well documented, particularly as compared to Tier 4 diesel yard trucks. In the future, advanced natural gas engines may offer NOx and $PM_{2.5}$ benefits beyond Tier 4 levels. This screening assessment assumed a 20% NOx and $PM_{2.5}$ benefit, based on CARB certification tests of natural gas versus diesel engines,[119] as well as a 16% CO_2 benefit.

Natural gas vehicles are expected to carry a higher purchase price than diesel for the foreseeable future. Natural gas vehicles are estimated to cost approximately $30,000 more than comparable diesel vehicles in future years.

5.4.1.4. Most Effective Yard Truck Strategies in 2030

By 2030, as described above, this assessment assumes that all yard truck are expected to meet the Tier 4 emission standards. Thus, to achieve emission reductions beyond baseline emissions, vehicle technologies with lower tailpipe emissions than Tier 4 systems (e.g., electric trucks) would need to be employed. Therefore, the same strategies presented above for 2020 would also be effective strategies to reduce emissions in 2030.

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116 *Ibid*.

117 The Port of Los Angeles, *Electric Truck Demonstration Project Fact Sheet*, prepared for The Port of Los Angeles. Available at: http://www.portoflosangeles.org/DOC/Electric_Truck_Fact_Sheet.pdf.

118 *Ibid*.

119 California Air Resources Board, On-Road New Vehicle & Engine Certification Program. Available at: http://www.arb.ca.gov/msprog/onroad/cert/cert.php.

5.4.2. Cranes

Cranes include rubber tire gantry (RTG) cranes, rail-mounted gantry (RMG) cranes, wharf (ship-to-shore) cranes, aerial lifts, and cable cranes. RTG cranes are typically powered by diesel engines and account for the bulk of crane emissions at most container terminals. In contrast, RMG cranes and wharf cranes are often electrically powered. As a result, this screening assessment focused on strategies that reduce diesel emissions from RTG cranes.

5.4.2.1. Baseline Emissions

The following assumptions for a typical RTG crane were used to estimate baseline emissions:[120]

- Average engine size of 453 hp
- Load factor of 0.43
- 2,641 hours of operation per year

Baseline emission factors were assumed to be equal to EPA's Nonroad Compression-Ignition Engine Exhaust Emission Standard in effect for the average rated power (i.e., 453 hp) and model year of the engine, as shown in Table 5-24.[121]

Table 5-24. EPA Emission Standards Applicable to RTG Cranes (g/kWh)

Tier	Model Year (beginning)	NMHC[122]	NMHC + NOx	NOx	$PM_{2.5}$
1	1996	1.3	-	9.2	0.54
2	2001	-	6.4	-	0.2
3	2006	-	4	-	0.2
4	2011	-	4	-	0.02
4	2014	0.19	-	0.4	0.02

5.4.2.2. Strategy Effectiveness

Next, the per crane percent reduction in emissions was estimated for the application of each of the following strategies:

- **Replacements or repowers**. For the vehicle replacement and repower strategies using a lower emission diesel engine, the emission reductions were based on the EPA's Nonroad Emission Standards shown in Table 5-24 above.
- **Diesel particulate filters (DPFs)**. Consistent with typical EPA-verified diesel emission control strategy values, an 85% reduction in $PM_{2.5}$ was assumed. The California Air Resources Board (CARB)

[120] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, April 2009.

[121] U.S. Environmental Protection Agency, *Emission Standards Reference Guide for Nonroad Compression-Ignition Engines*. Available at: http://www.epa.gov/otaq/standards/nonroad/nonroadci.htm.

[122] NMHC stands for Nonmethane hydrocarbons.

has approved a DPF specifically for use on RTG cranes for reducing $PM_{2.5}$; DPFs do not affect NOx or CO_2 emissions.

- **Installation of a hybrid energy storage system**. Cranes with energy storage systems (ESS) can reduce, but not eliminate, diesel engine emissions by using stored energy to supplement diesel power. Reductions in NOx and $PM_{2.5}$ emissions are estimated to be up to 25%, based on a CARB staff assessment.[123] CO_2 emission reductions were estimated based on fuel saving measurements from a 2008 study of recapturing energy in cranes through flywheels.[124]
- **Conversion to all-electric cranes**. For all-electric cranes (e-RTG), zero NOx and $PM_{2.5}$ emissions were assumed. Well-to-wheel CO_2 emissions are assumed to be 58 percent of a diesel RTG crane's CO_2 emissions, based on the GREET model.[125]

The percentage reductions for each strategy were applied to the baseline annual per crane emissions in this screening assessment. Tables 5-25 and 5-26 show the annual emission reduction for each strategy alternative for a typical RTG crane.

Table 5-25. Typical Emission Impact per RTG Crane per Year – NOx (lbs)

		New/Improved Equipment					
		Tier 2	Tier 3	Tier 4	DPF	RTG ESS	Electric
Old Equipment	Tier 1	-2,368	-4,398	-7,442	0	-1,945	-7,781
	Tier 2		-2,030	-5,074	0	-1,353	-5,413
	Tier 3			-3,045	0	-846	-3,383
	Tier 4				0	-85	-338

Table 5-26. Typical Emission Impact per RTG Crane per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment					
		Tier 2	Tier 3	Tier 4	DPF	RTG ESS	Electric
Old Equipment	Tier 1	-288	-288	-440	-388	-114	-457
	Tier 2		0	-152	-144	-42	-169
	Tier 3			-152	-144	-42	-169
	Tier 4				0	-4	-17

Table 5-27 shows estimated annual CO_2 emission reductions per RTG crane for each strategy combination, calculated on a well-to-wheels basis.

[123] California Air Resources Board. *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*. August 2009.

[124] Mark M. Flynn, Patrick McMullen, & Octavio Solis. *Saving Energy Using Flywheels: Energy recovery and emission cutting in a mobile gantry crane*. IEEE Industry Applications Magazine. 2008.

[125] Argonne National Laboratory's 2013 GREET model released October 2013. Available at: https://greet.es.anl.gov/greet/index.htm.

Table 5-27. Typical Emission Impact per Yard Truck per Year – CO_2 (tons)

		New/Improved Equipment					
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	RTG ESS	Electric
	Tier 1	0	0	0	0	-45	-70
	Tier 2		0	0	0	-45	-70
	Tier 3			0	0	-45	-70
	Tier 4				0	-45	-70

To identify strategies that would be applicable and the most effective in future years, the future year distribution of RTG cranes was estimated using EPA's NONROAD2008 model.[126] Table 5-28 shows the expected distribution of RTG cranes by Tier in 2011, 2020, 2030, and 2050. This assessment's assumption for a crane's long lifespan results in a slower turnover of equipment compared to other CHE and greater potential reductions.

Table 5-28. Distribution of RTG Cranes by Tier

Tier	2011	2020	2030	2050
Uncontrolled	6%	1%	0%	0%
Tier 1	27%	3%	0%	0%
Tier 2	20%	5%	1%	0%
Tier 3	38%	17%	2%	0%
Tier 4	9%	74%	98%	100%
Total	100%	100%	100%	100%

EPA notes that the crane distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.4.2.3. Most Effective Crane Strategies in 2020

In 2020, for this screening assessment, approximately a quarter of the RTG crane fleet was estimated to be below the Tier 4 nonroad engine standards, making engine repowering and replacement reasonable strategies to consider for this screening assessment. The cost to repower a RTG crane is estimated to be \$200,000. However, since RTG cranes have high horsepower engines (typically 500hp to 800hp), high activity rates, and long service lives, strategies to replace or repower older cranes can provide significant benefits per piece of equipment.

In addition to engine replacements, adding DPFs can provide $PM_{2.5}$ reductions at a lower cost. DPF installation costs were assumed to be equivalent to the DPF installation costs for drayage trucks (\$10,000).[127] However, DPF retrofits as a stand-alone strategy are most likely only applicable in the short term because exhaust aftertreatment devices are expected to become integrated into Tier 4 rebuilds or replacements; thus, DPFs were not considered a relevant strategy for the 2020 analysis year for this assessment.

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[126] RTG cranes are identified in NONROAD as Cranes (SCC: 2270002045).

[127] U.S. Environmental Protection Agency, *Technical Bulletin: Diesel Particulate Filter General Information*, prepared by EPA's Clean Diesel Program.

5.4.2.4. Most Effective Crane Strategies in 2030

By 2030, Tier 4 RTG cranes are projected in this assessment to dominate the fleet and advanced technology hybrid and electric systems would be needed to achieve additional emission reductions. A hybrid ESS could be added to a crane to recapture energy in its lift mechanisms; regenerative brakes could be applied as a crane lowers materials, reducing energy demands from the engine. The flywheel system made by VYCON Energy is one example of this technology. CARB has estimated the cost of these systems as $160,000 – $320,000.[128] However, as long as this system is applied in tandem with a diesel engine, there would still be some level of diesel emissions.

To fully eliminate emissions, some ports have deployed electric RTG cranes. An electric RTG (e-RTG) crane removes the diesel generator and powers the motors directly from an external electricity supply. In some cases, diesel RTG cranes have been converted to fully electric RTG cranes; in many cases, e-RTG cranes are selected when new cranes are installed. E-RTG cranes are a relatively new technology, with most appearing in the last 6 years. China appears to be adopting this technology; much of the testing for e-RTGs was found in this study to be completed at Chinese ports. Other countries with marine terminals using e-RTGs include Japan, South Korea, Vietnam, Brazil, and the United Kingdom. In 2012, the Port of Savannah became the first North American port to permanently install an e-RTG crane.[129] Retrofitting a crane for full electrification may range from $200,000 to $300,000, and a demonstration project at the Port of Los Angeles totaled $1.2 million for two electric RTG cranes.[130] Costs and cost-effectiveness would vary widely depending on the remaining life of a crane, the drivetrain of a crane,[131] and the electrical infrastructure needs at a terminal.

5.4.3. Container Handlers

Container handlers are pieces of mobile equipment that lift, move, and stack containers in a port terminal; they include side picks and top picks (also called top handlers).

5.4.3.1. Baseline Emissions

The following assumptions were made to estimate baseline emissions for a typical top handler:[132]

- Average engine size of 282 hp
- Load factor of 0.59
- 1,955 hours of operation per year

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[128] California Air Resources Board. *Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Railyards*. August 2009.

[129] Port Technology, *GPA Introduces North America's First ERTG*, December 17, 2012. Available at: http://www.porttechnology.org/news/gpa_introduces_north_americas_first_ertg.

[130] Port of Los Angeles, Environmental Management Division, *Electric Rubber-Tire Gantry Crane Demonstration Project With West Basin Container Terminal At Berths 97-109, China Shipping Container Lines*, March 25, 2009.

[131] Some cranes already have electric drivetrains powered by diesel generators, making it possible to retrofit the equipment.

[132] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, April 2009.

Baseline emission factors were assumed to be equal to the EPA Nonroad Compression-Ignition Engine Exhaust Emission Standards in effect for the average rated power (i.e., 282 hp) and model year of the engine, as shown in Table 5-29.[133]

Table 5-29. EPA Emission Standards Applicable to Typical Container Handlers (g/kWh)

Tier	Model Year (beginning)	NMHC	NMHC + NOx	NOx	$PM_{2.5}$
1	1996	1.3	-	9.2	0.54
2	2003	-	6.6	-	6.6
3	2006	-	4	-	4
4	2011	-	4	-	4
4	2014	0.19	-	0.4	0.02

5.4.3.2. Strategy Effectiveness

Next, the per vehicle percent reduction in emissions was estimated for the application of the following strategies:

- **Replacements or repowers.** For vehicle replacement and repower using a lower emission diesel engine, the emission reductions were based on the EPA Nonroad Emission Standards shown in Table 5-29 above.
- **DPF retrofits.** Aftertreatment of diesel exhaust was assumed an 85% reduction in $PM_{2.5}$ consistent with typical EPA-verified diesel emission control strategy values.[134] DPFs do not result in NOx or CO_2 reductions.
- **Electric container handlers.** This assessment assumed zero emissions from employing electric container handler technology. EPA notes that such an option was modeled in this screening assessment, even though electric hybrid or full electric options for container handlers are not currently available. It is possible that such options may become available in the future.

The percentage reductions for each strategy were applied to the baseline annual per vehicle emissions for this screening assessment.

Tables 5-30 and 5-31 show the results of the screening assessment of the expected annual emission reduction per container handler for each strategy option.

Table 5-30. Typical Emission Impact per Container Handler per Year – NOx (lbs)

		New/Improved Equipment				
		Tier 2	Tier 3	Tier 4	DPF	Electric
Old Equipment	Tier 1	-1,390	-2,781	-4,706	0	-4,920
	Tier 2		-1,390	-3,315	0	-3,529
	Tier 3			-1,925	0	-2,139
	Tier 4				0	-214

[133] U.S. Environmental Protection Agency, *Emission Standards Reference Guide for Nonroad Compression-Ignition Engines*. Available at: http://www.epa.gov/otaq/standards/nonroad/nonroadci.htm.

[134] U.S. Environmental Protection Agency, *Technologies Diesel Retrofit Devices*. Available at: http://www.epa.gov/cleandiesel/technologies/retrofits.htm.

Table 5-31. Typical Emission Impact per Container Handler per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment				
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	Electric
	Tier 1	-182	-182	-278	-245	-289
	Tier 2		0	-96	-91	-107
	Tier 3			-96	-91	-107
	Tier 4				0	-11

Table 5-32 shows estimated annual CO_2 emission reductions per container handler for each strategy combination, calculated on a well-to-wheels basis.

Table 5-32. Typical Emission Impact per Container Handler per Year – CO_2 (tons)

		New/Improved Equipment				
Old Equipment		Tier 2	Tier 3	Tier 4	DPF	Electric
	Tier 1	0	0	0	0	-44
	Tier 2		0	0	0	-44
	Tier 3			0	0	-44
	Tier 4				0	-44

To identify strategies that would be applicable and the most effective in future years, the future year distribution of container handlers was estimated using EPA's NONROAD2008 model.[135] Table 5-33 shows the expected distribution of container handlers by Tier in 2011, 2020, 2030, and 2050.

Table 5-33. Distribution of Container Handlers by Tier

Tier	2011	2020	2030	2050
Uncontrolled	2%	0%	0%	0%
Tier 1	26%	1%	0%	0%
Tier 2	23%	2%	0%	0%
Tier 3	44%	15%	0%	0%
Tier 4	5%	81%	100%	100%
Total	100%	100%	100%	100%

EPA notes that the container handler distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.4.3.3. Most Effective Container Handler Strategies in 2020

In 2020, in this screening assessment, approximately 18% of all container handlers are still expected to have engines at Tier 3 standards or below. Retrofitting equipment with at least seven years of remaining useful life with DPFs would be a cost-effective strategy for reducing $PM_{2.5}$ emissions, although DPFs do not affect NOx or CO_2. DPF installation costs were assumed to be equivalent to the costs for installing DPFs for drayage trucks ($19,000).

[135] Container handlers are identified in NONROAD as Rubber Tire Loader (SCC: 2270002060).

Repowering or replacing/scrapping older equipment to meet Tier 4 standards would be an effective strategy to reduce both NOx and $PM_{2.5}$ emissions. As with yard trucks, it is unclear at this time if repowering with Tier 4 engines would be feasible for all container handlers, since Tier 4 compliance would likely involve use of selective catalytic reduction (SCR) systems. A number of container handlers were repowered in Diesel Emission Reduction Act (DERA) funded projects for an average full unit cost (equipment and installation) of $53,484 and top handlers for $63,641. When repowering with Tier 4 is feasible, it would be the most cost effective option; otherwise, replacement with Tier 4 handlers would be preferable.

5.4.3.4. Most Effective Container Handler Strategies in 2030

By 2030, all container handlers were expected to be at the highest emission standards based on the national fleet turnover assumed. To reduce emissions beyond the Tier 4 standards, container handlers would have to shift towards advanced technology options, possibly including hybrids, alternative fuels, and electric technologies. Given the increasing availability of hybrid options in other types of port vehicles and equipment, such as drayage trucks and yard trucks, it may be possible that manufacturers would offer hybrid handlers in the future. However, given that top and side picks use a considerable portion of energy to lift containers, hybrid drivetrains may not provide significant reductions at this time. Similarly, battery-electric systems may not be available at this time to meet the energy-intensive lifting demands.[136] Top picks must be able to repeatedly lift up to 75,000 lbs by 10 to 40 feet.[137]

Equipment manufacturers may also develop natural gas options for container handlers. CNG or LNG engines could potentially reduce emission levels beyond level of Tier 4 standards; however, these options have not been tested for this type of equipment and little information was found on their emission reduction potential. The relatively low production volumes of side picks and top picks might also affect manufacturers from pursuing advanced technology options.

5.4.4. Summary of Most Promising CHE Strategies

Table 5-34 summarizes the most promising emission reduction strategies for CHE in 2020 and 2030.

Table 5-34. Most Promising CHE Emission Reduction Strategies

CHE Type	Strategy	Per Vehicle Reduction			Cost	Years Effective
		NOx (lbs)	PM2.5 (lbs)	CO_2 (tons)		
Yard Truck	Replace Tier 4 with CNG/LNG	33	2	17	$30,000	2020, 2030
	Replace Tier 4 with PHEV	64	4	19	$150,000	2020, 2030
	Replace Tier 4 with Battery Electric	164	8	34	$210,000	2020, 2030
RTG Crane	Retrofit Tier 3 with DPF	0	144	0	$19,000	2020
	Repower Tier 3 with Tier 4	3,045	152	0	$200,000	2020
	Install Tier 4 with ESS	85	4	45	$240,000	2020, 2030
	Convert Tier 4 to Electric	338	17	70	$500,000	2020, 2030
Container Handler	Retrofit Tier 3 with DPF	0	91	0	$19,000	2020
	Repower Tier 3 with Tier 4	1,925	96	0	$64,000	2020

[136] TIAX, *Roadmap to Electrify Goods Movement Subsystems for the Ports of Los Angeles and Long Beach, Phase 1: Near-Dock Container Movements*, January 2012.
[137] TIAX, *Assessment of Zero-Emissions Cargo Handling Equipment at the San Pedro Bay Ports*, Presented at the AQMD Clean Fuels Program Advisory Group Meeting, August 29, 2012.

5.5. Harbor Craft

Harbor craft includes a wide array of vessel types that largely stay within or near a harbor or port area. Harbor craft includes tugs, ferries, commercial fishing boats, government vessels, work boats, and dredges, and they have Category 1 or 2 engines. After ocean going vessels, harbor craft are generally the next largest contributors of emissions at ports.[138]

To evaluate emission reduction strategies for harbor craft, this screening assessment considered the two types of harbor vessels that are the largest contributors to port emissions: tugs and ferries. EPA based this assumption on existing port emission inventories that identified tugs and ferries as the largest sources of harbor craft emissions.[139, 140]

5.5.1. Tugs

5.5.1.1. Baseline Emissions

First, emissions were estimated from typical assist tugs that were assumed to be using current (baseline) technologies (i.e., no application of emission reduction strategies). To do this, the following assumptions were made for an average assist tug:[141]

- Two Category 1 propulsion engines per tug
- Average engine power of 1,540 kW
- 1,861 annual operating hours
- Load factor of 0.79, based on average tug engine displacement category and power[142]

Baseline emission factors were obtained from the EPA Regulatory Impact Analysis for the 2008 Locomotive and Marine Compression Ignition Engine rulemaking.

Table 5-35 summarizes the emission factors from EPA's 2008 rulemaking that apply to the engine displacement and power category for tugs.

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[138] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, April 2009.

[139] Starcrest Consulting Group, LLC, *Puget Sound Maritime Air Emissions Inventory*, prepared for Puget Sound Maritime Air Forum, pg. 156, 2011. Available at: http://www.pugetsoundmaritimeairforum.org/uploads/PV_FINAL_POT_2011_PSEI_Report_Update__23_May_13__scg.pdf.

[140] Port of Long Beach, *Air Emissions Inventory*, pg. 46, 2013. Available at: http://www.polb.com/civica/filebank/blobdload.asp?BlobID=12238.

[141] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, 2009. Document references Puget Sound emissions inventory, which indicates 90% of all tug engines are Category 1.

[142] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder*, 2008.

Table 5-35. EPA Emission Factors Applicable to Assist Tugs (g/kW-hr)

Tier	Beginning Standards Year	NOx	PM_{10}
Pre-Control		11	0.3
Tier 1	2000	9.2	0.3
Tier 2	2004-2007	6	0.13
Tier 3	2012	4.81	0.07
Tier 4	2016	1.3	0.03

5.5.1.2. Strategy Effectiveness

Next, the percent reduction in emissions was estimated, per tug, for each strategy. More details on the strategies and relevant assumptions are listed as follows:

- **Replacements and repowers**. For vessel engine replacement and repower using conventional equipment, the emission reduction for the screening assessment was based on the emission factors shown in Table 5-35.
- **Diesel oxidation catalysts (DOCs) and DPFs.** For these technologies, a 25% and 85% reduction in $PM_{2.5}$ was assumed, respectively, consistent with typical EPA-verified diesel emission control strategy values. These strategies do not impact NOx and CO_2 emissions.
- **Biodiesel (B20).** For this fuel, NOx and $PM_{2.5}$impacts were based on comparisons with diesel using MOVES2010b simulations for heavy-duty vehicles—a 0.4% increase in NOx and a 3.2% reduction in $PM_{2.5}$.[143] CO_2 impacts were based on the GREET model and assumed a 14% reduction compared to diesel on a well-to-wheels basis.
- **Hybrid-electric tugs**. The assessment assumed for this alternate technology, a 30%, 25%, and 30% reduction in NOx, $PM_{2.5}$, and CO_2 respectively, consistent with EPA-verified retrofit technology.[144]
- **LNG**. The emissions benefits of LNG tugs as compared to Tier 4 are uncertain at this time, as this is an emerging technology and has not been subject to extensive testing.[145] This screening assessment assumed LNG provided a 25% NOx reduction, a 20% $PM_{2.5}$ reduction, and CO_2 reductions similar to a Tier 4 diesel engine, based on evidence from other diesel sectors.[146]

The percentage reductions for each strategy were applied to the baseline annual per tug emissions.

Tables 5-36, 5-37, and 5-38 show estimated annual emission reductions for a typical tug for each potential strategy. CO_2 emission reductions are calculated on a well-to-wheels basis.

[143] For purposes of this screening assessment, results were taken from a prior analysis done with MOVES2010b. This is not expected to differ significantly from MOVES2014 or MOVES2014a, and is the best available model for estimating these effects since the current NONROAD model does not predict emissions for the commercial marine sector.

[144] Based on EPA-verified Foss Maritime/AKA XeroPoint Hybrid Tugboat Retrofit System. Available at: https://www.epa.gov/verified-diesel-tech/verified-technologies-list-clean-diesel.

[145] The world's first LNG tug was announced in early 2012. See: http://articles.maritimepropulsion.com/article/Worlde28099s-First-LNG-Fuelled-Tug65983.aspx.

[146] ICF International, *Comprehensive Regional Goods Movement Plan and Implementation Strategy: Task 10.2 Evaluation of Environmental Mitigation Strategies*, prepared for the Southern California Association of Governments, April 2012. Available at: www.freightworks.org/DocumentLibrary/Task%2010%202%20report%20April%202012%20final%20no%20watermark.pdf.

Table 5-36. Typical Emission Impact per Tug per Year – NOx (lbs)

		New/Improved Equipment								
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid	LNG
Old Equipment	Pre-Control	-17,970	-49,917	-61,798	-96,840	0	0	439	-100,733	-100,084
	Tier 1		-31,947	-43,828	-78,870	0	0	367	-82,763	-82,114
	Tier 2			-11,880	-46,922	0	0	240	-50,816	-50,167
	Tier 3				-35,042	0	0	192	-38,936	-38,287
	Tier 4					0	0	52	-3,894	-3,245

Table 5-37. Typical Emission Impact per Tug per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment								
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid	LNG
Old Equipment	Pre-Control	0	-1,697	-2,296	-2,696	-749	-2,546	-96	-2,770	-2,755
	Tier 1		-1,697	-2,296	-2,696	-749	-2,546	-96	-2,770	-2,755
	Tier 2			-599	-998	-324	-1,103	-42	-1,073	-1,058
	Tier 3				-399	-175	-594	-22	-474	-459
	Tier 4					0	0	-10	-75	-60

Table 5-38. Typical Emission Impact per Tug per Year – CO_2 (tons)

		New/Improved Equipment								
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid	LNG
Old Equipment	Pre-Control	0	0	0	0	0	0	-627	-1,320	-903
	Tier 1		0	0	0	0	0	-627	-1,320	-903
	Tier 2			0	0	0	0	-627	-1,320	-903
	Tier 3				0	0	0	-627	-1,320	-903
	Tier 4					0	0	-627	-1,320	-903

To identify which strategies would be most effective in future years, the future year distributions of tugs were modeled using a methodology based on the growth and scrappage assumptions in EPA's NONROAD2008 model. Table 5-39 shows expected distribution of tugs by tier in the future analysis years.

Table 5-39. Distribution of Tugs by Tier

Tier	2011	2020	2030	2050
Tier 0	61%	10%	0%	0%
Tier 1	35%	24%	3%	0%
Tier 2	4%	33%	7%	0%
Tier 3	0%	30%	80%	61%
Tier 4	0%	3%	10%	39%
Total	**100%**	**100%**	**100%**	**100%**

EPA notes that the tug national distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.5.1.3. Most Effective Tug Strategies in 2020

In this screening assessment, by 2020, only a small fraction of tugs are projected to be Tier 0, and these vessels may have limited remaining useful service life, so they were not considered for the strategy scenarios in this assessment. Tier 1 vessels accounted for nearly a quarter of all tugs in 2020; provided these tugs have some remaining service life, the most cost-effective strategies would target these vessels. Repowering of tug propulsion engines costs approximately $500,000 (installation plus purchase cost) per vessel, based on past DERA grants. Repowering with a Tier 4 engine requires additional space in the engine room and would not be possible in all tugs. Given the long useful life of these engines, combining public and private funds may help pay the costs of repowering a tug and result in cost-effective emission reductions; such an approach would be less expensive than buying a new vessel.

Retrofitting with DPFs would also be an effective $PM_{2.5}$ reduction strategy for tug engines with significant remaining service life. In this assessment, a large fraction (33%) of the 2020 tug fleet would be Tier 2, with engines 13–16 years old, and 24% would be Tier 1, with engines 16–20 years old. $PM_{2.5}$ reductions of approximately 85% can be achieved using DPF retrofits. The cost of a DPF retrofit for a tug is approximately $60,000.[147] As noted above, this strategy does not affect NOx or CO_2 emissions.

Another potential strategy would be replacement of a Tier 2 tug with a new Tier 4 tug. This strategy achieved large NOx and $PM_{2.5}$ reductions. However, the full cost of a new assist tug would be high, often more than $10 million. Advanced technology LNG and hybrid tugs are estimated to add an additional 20 to 40% above cost of new conventional diesel boats. If a port is replacing a Tier 2 vessel with Tier 4, the additional cost of an LNG or hybrid technology may not be warranted, given the small additional emission reduction benefit.

5.5.1.4. Most Effective Tug Strategies in 2030

In 2030, an estimated 90% of tugs would still be pre-Tier 4 tugs, based on the assumptions in this assessment. Thus, retirement and replacement with Tier 4 vessels could yield significant NOx and $PM_{2.5}$ benefits. The cost-effectiveness of this strategy depends on the remaining useful service life of the older tugs. For tugs with the space configuration to accommodate Tier 4 technologies, repowering would be an option and significantly more cost-effective than a full tug replacement.

Advanced technologies or alternative fuels would be necessary to achieve emission reductions beyond Tier 4 levels for tugs. These vessels are just starting to become commercially available, so the emission reduction benefits and costs of these options are uncertain. The world's first LNG tug was placed in commercial service in Norway in 2014.[148] Foss Maritime has operated two diesel-hybrid tugs

[147] ICF International, *Tug/Towboat Emission Reduction Feasibility Study*, Prepared for U.S. EPA, 2009.

[148] Maritime Journal, *Sanmar completes the world's first LNG tug*, Nov 12, 2013. Available at: http://www.maritimejournal.com/news101/tugs,-towing-and-salvage/sanmar-completes-the-worlds-first-lng-tug.

at the Ports of Los Angeles and Long Beach.[149] Both of these options have the potential to produce lower emissions than a conventional diesel Tier 4 tug, but the magnitude of emission reduction benefits is uncertain at this time. These advanced technology tugs would also carry a higher cost than diesel, with the incremental costs likely to decline if production volumes grow in the future.

Shore power (or cold ironing) is another potential strategy that was considered for tugs, but this technology may not be as feasible for tugs because of their typical operating cycles.[150] However, shore power is being used to various degrees in select locations. For example, Constellation Maritime keeps all their tugs on shore power whenever they are at the dock at the Port of Boston.[151] Tugboat cold ironing has also been done at the Port of Philadelphia.[152] This strategy was not included in the screening assessment, as this assessment did not include idling emissions from tugs at dock. However, that assumption may not apply to every port in practice, and ports with significant tug idling can consider shore power as a potential strategy.

5.5.2. Ferries

Ferries can be a major source of emissions at some ports. For example, in the 2011 Puget Sound emission inventory, ferries were responsible for about half of harbor craft emissions and 10 to 15% of total NOx and PM emissions included in the inventory.[153] At other ports, ferries may be a much smaller contributor.

5.5.2.1. Baseline Emissions

The emissions from "typical" ferries in this screening assessment were estimated using current (baseline) technologies (i.e., no application of emission reduction strategies). The following assumptions were made for an average ferry:[154]

- Average of 1.9 Category 2 propulsion engines per vessel
- Average engine power of 857.5 kW
- 1,693 annual operating hours
- Load factor of 0.85, based on average tug engine displacement category and power[155]

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[149] Foss Maritime Company, *World's First True Hybrid to be Built by Foss Maritime*, March 2, 2007. Available at: http://www.foss.com/press-releases/worlds-first-true-hybrid-tug-to-be-built-by-foss-maritime/.

[150] ICF International, *Tug/Towboat Emission Reduction Feasibility Study*, Prepared for U.S. EPA, 2009.

[151] *Ibid*.

[152] *Ibid*.

[153] Port of Seattle, *Puget Sound Maritime Air Emissions Inventory*, 2011. Available at: https://www.portseattle.org/Environmental/Air/Seaport-Air-Quality/Pages/Puget-Sound-Maritime-Air-Emissions-Inventory.aspx.

[154] U.S. Environmental Protection Agency, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, 2009.

[155] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder*, 2008.

Baseline emission factors were obtained from the EPA Regulatory Impact Analysis for the 2008 Locomotive and Marine Compression Ignition Engine rulemaking, and Table 5-40 summarizes the emission factors that apply to the engine displacement and power category for ferries.

Table 5-40. Emission Factors Applicable to Ferries (g/kW-hr)

Tier	Beginning Standards Year	NOx	PM_{10}
Tier 0	-	13.36	0.32
Tier 1	2004	10.55	0.32
Tier 2	2007	8.33	0.32
Tier 3	2013	5.97	0.11
Tier 4	2018	1.3	0.03

5.5.2.2. Strategy Effectiveness

The per-ferry percent reduction in emissions was estimated for the application of each of the following strategies:

- **Replacements and repowers**. For vessel engine replacement and repower using conventional equipment, the emission reduction was based on the emission factors shown in Table 5-40.
- **DOCs and DPFs**. For these technologies, a 25% and 85% reduction in $PM_{2.5}$ was assumed, respectively, consistent with typical EPA-verified diesel emission control strategy values.[156] These strategies do not reduce NOx and CO_2 emissions.
- **Biodiesel (B20)**. NOx and $PM_{2.5}$ impacts from B20 fuel were based on comparisons with diesel using MOVES2010b simulations for heavy-duty vehicles—a 0.4% increase in NOx and a 3.2% reduction in PM_{143}. CO_2 impacts are based on the GREET model and assumed a 14% reduction compared to diesel on a well-to-wheels basis.
- **Hybrid-electric ferries.** There is little emissions data available in the literature for hybrid-electric technology for ferries, so the same emission reductions were assumed as for hybrid tugs: a 30%, 25%, and 30% reduction in NOx, $PM_{2.5}$, and CO_2 respectively.

The percentage reductions for each strategy were applied to the baseline annual per ferry emissions.

Tables 5-41, 5-42, and 5-43 show typical annual emission reductions for each ferry strategy considered in this screening assessment. CO_2 emission reductions are calculated on a well-to-wheels basis.

[156] U.S. EPA, *Technologies Diesel Retrofit Devices*. Available at: https://www.epa.gov/verified-diesel-tech/verified-technologies-list-clean-diesel.

Table 5-41. Typical Emission Impact per Ferry per Year – NOx (lbs)

		New/Improved Equipment							
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid
Old Equipment	Pre-Control	-14,524	-25,999	-38,198	-62,336	0	0	276	-64,352
	Tier 1		-11,475	-23,673	-47,812	0	0	218	-49,828
	Tier 2			-12,198	-36,337	0	0	172	-38,353
	Tier 3				-24,139	0	0	123	-26,154
	Tier 4					0	0	27	-2,016

Table 5-42. Typical Emission Impact per Ferry per Year – $PM_{2.5}$ (lbs)

		New/Improved Equipment							
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid
Old Equipment	Pre-Control	0	0	-1,085	-1,499	-414	-1,406	-53	-1,538
	Tier 1		0	-1,085	-1,499	-414	-1,406	-53	-1,538
	Tier 2			-1,085	-1,499	-414	-1,406	-53	-1,538
	Tier 3				-414	-142	-483	-18	-452
	Tier 4					0	0	-5	-39

Table 5-43. Typical Emission Impact per Ferry per Year – CO_2 (tons)

		New/Improved Equipment							
		Tier 1	Tier 2	Tier 3	Tier 4	DOC	DPF	B20	Hybrid
Old Equipment	Pre-Control	0	0	0	0	0	0	-325	-683
	Tier 1		0	0	0	0	0	-325	-683
	Tier 2			0	0	0	0	-325	-683
	Tier 3				0	0	0	-325	-683
	Tier 4					0	0	-325	-683

To identify which strategies would be most effective in future years, the future year distributions of ferries was modeled using a methodology based on the growth and scrappage assumptions in EPA's NONROAD2008 model. Table 5-44 shows the estimated distribution of ferries by tier by analysis year for this assessment. Ferries have longer service life and consequently slower fleet turnover than tugs, and therefore, relatively few ferries are projected to meet Tier 4 standards in 2020 and 2030.

Table 5-44. Distribution of Ferries by Tier

Tier	2011	2020	2030	2050
Tier 0	75%	39%	10%	0%
Tier 1	21%	18%	12%	0%
Tier 2	4%	10%	8%	1%
Tier 3	0%	28%	59%	60%
Tier 4	0%	5%	11%	39%
Total	100%	100%	100%	100%

EPA notes that the national ferry distribution used in this screening assessment is not intended to be reflective of the rate of fleet turnover in practice for a specific port or area.

5.5.2.3. Most Effective Ferry Strategies in 2020

Strategies to reduce ferry emissions in 2020 focused on the vessels with pre-control (Tier 0) and Tier 1 engines, since they account for a large fraction of the ferry fleet in this screening assessment and have the highest emission rates. Repowering ferries with Tier 3 engines has been a successful use of DERA funds, and the cost is approximately $200,000—far less expensive than full vessel replacement. It is unclear if repowering with Tier 4 engines would be feasible for ferries, given the additional space requirements for Tier 4 emission controls. Given the long useful life of these engines, repowering a ferry can result in cost-effective emission reductions, especially if combining public and private funds to pay for such an investment.

Another cost-effective option for $PM_{2.5}$ reductions is a retrofit with a DPF, provided the engine has substantial remaining service life. DPFs eliminate approximately 85% of PM emissions, but this strategy does not affect NOx or CO_2 emissions. The cost of a DPF retrofit for a ferry is approximately $60,000.[157]

Large NOx and PM emission reductions in 2020 could be achieved in this assessment by replacing older ferries with new Tier 4 ferries, or possibly with used Tier 3 ferries. The full cost of a large new ferry can be extremely high. For example, Washington State Ferries is adding two new 144-car, 1,500 passenger ferries for service in Puget Sound; each will cost about $130 million.[158]

5.5.2.4. Most Effective Ferry Strategies in 2030

By 2030, 89% of the ferry fleet would still be below Tier 4 standards in this assessment, and strategies could focus on replacing or repowering these ferries. For ferries that have the spatial configuration to accommodate the emission control technologies, the most cost-effective approach would be to repower these vessels with Tier 4 engines. Additionally, repowering would be more cost-effective for newer vessels with longer remaining service lives. The cost of repowering with Tier 4 is unknown, but may likely be higher than costs to date for Tier 2 or 3 repowers. This assessment assumed $300,000 for the purposes of this screening assessment.

[157] ICF International, *Tug/Towboat Emission Reduction Feasibility Study*, Prepared for U.S. EPA, 2009.

[158] Washington State Department of Transportation, *Ferries – Olympic Class (144-Car) Ferries*, 2015. Available at: http://www.wsdot.wa.gov/projects/ferries/144carferries/.

For Tier 2 ferries, retrofits with DPFs are an effective strategy to reduce $PM_{2.5}$ emissions. However, because the Tier 2 ferries would be approximately 20 years old in 2030 in this assessment, retrofits will only make sense for ferries and engines with significant remaining service life. In most cases, retirement of old Tier 2 ferries is more likely to be in the best interest of the operator.

Because the bulk of the ferry fleet is projected in this assessment to be Tier 3 or lower in 2030, there may be little incentive to pursue the use of advanced technologies that can potentially achieve emission rates lower than Tier 4 standards. However, when new ferries are purchased, advanced technologies like diesel hybrids would likely be viable and potentially cost-effective by 2030, since they reduce operating costs. Hybrid ferries are an emerging technology—with several in service or on order in the United States and Europe. The magnitude of emission reduction benefits and incremental costs associated with hybrid ferries is difficult to predict in future years. This screening assessment assumed 30% NOx, 25% $PM_{2.5}$, and 30% CO_2 emission reductions over new Tier 4 diesel ferries.

Shore power may be another potential strategy to reduce ferry emissions; but since ferry idling at dock was not included in this assessment, it was not considered in this screening assessment. The cost effectiveness of this approach is uncertain because infrastructure costs range widely depending on a number of terminal-specific factors. However, as shore power projects are implemented around the world, more data on the benefits and costs of this strategy may be available in the future.

5.5.3. Summary of Most Promising Harbor Craft Strategies

Table 5-45 summarizes the most promising emission reduction strategies for harbor craft in 2020 and 2030.

Table 5-45. Most Promising Harbor Craft Emission Reduction Strategies

Vessel Type	Strategy	Per Vessel Reduction			Cost	Years Effective
		NOx (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)		
Tugs	Retrofit Tier 1 with DPF	0	2,546	0	$60,000	2020
	Retrofit Tier 2 with DPF	0	1,103	0	$60,000	2020
	Repower Tier 1 with Tier 3	43,828	2,296	0	$500,000	2020
	Replace Tier 3 with Tier 4	35,042	399	0	$10 million	2030
Ferries	Retrofit Tier 1/2 with DPF	0	1,406	0	$60,000	2020
	Repower Tier 0 with Tier 3	38,198	1,085	0	$200,000	2020
	Repower Tier 1 with Tier 3	23,673	1,085	0	$200,000	2020
	Repower Tier 1/2 with Tier 4	36,337	1,499	0	$300,000	2030
	Repower Tier 3 with Tier 4	24,139	414	0	$300,000	2030

5.6. Ocean Going Vessels

5.6.1. Introduction

Ocean Going Vessels (OGVs) have historically been the largest contributor to port emissions. Examples of OGVs include containerships, tankers, bulk carriers, auto carriers, refrigerated vessels (reefers), roll-on/roll-off (RORO), and passenger cruise ships. OGV emissions are produced by main (propulsion) engines and by auxiliary engines. OGV activity modes include reduced speed zone (RSZ), maneuvering, and hoteling. During hoteling, the propulsion engine is turned off and only the auxiliary engine operates unless the vessel is relying on shore power (i.e., plugging the OGV into the shore-side electricity grid). The majority of the emissions from OGVs within the boundaries of this assessment are from hoteling.

5.6.2. Baseline Emissions

The baseline emissions for the screening assessment include the impacts of EPA's OGV engine and fuel standards for appropriate years. The methodology is generally consistent with the methodology used in EPA's Category 3 Marine Engine Rulemaking,[159] unless otherwise noted. The following paragraphs describe the background and factors considered when quantifying baseline emissions.

The International Maritime Organization (IMO) adopted mandatory NOx emission limits in Annex VI to the International Convention for Prevention of Pollution from Ships in 1997. These NOx limits apply for all marine engines over 130 kilowatts (kW) for engines built on or after January 1, 2000, including those engines that underwent a major rebuild after January 1, 2000. For the Category 3 Marine Engine Rulemaking Regulatory Impact Analysis (C3 RIA)[160], EPA determined the effect of the IMO standard to be a reduction in the NOx emission rate of 11% below that for engines built before 2000. For engines built between 2000 and 2010 (Tier I), a NOx factor of 0.89 should be applied to the calculation of NOx emissions for both propulsion and auxiliary engines. IMO Tier II NOx emission standards start in 2011 and EPA determined the effect of Tier II to be a NOx reduction of 2.5 g/kWh reduction over Tier I engines. In addition, starting August 2012, any ships traveling within 200 nautical miles of the U.S. coastline must adhere to regulations set for the North American Emission Control Area (ECA)[161]. These include fuel sulfur levels at 1% starting August 2012 and 0.1% starting 2015. Furthermore any engine above 130 kW installed on a ship constructed beginning in 2016 must meet Tier III NOx levels which EPA determined were an 80% reduction from Tier I. Thus Tier III emission factors are 20% of Tier I emission factors. NOx emission factors by Tier and engine type are shown in Table 5-46. Engine types include

[159] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* Federal Register, Vol 75, No 83, April 30, 2010.

[160] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines*, EPA Report EPA-420-R-09-019, December 2009. Available at: http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf.

[161] U.S. Environmental Protection Agency, *Designation of North American Emission Control Area to Reduce Emissions from Ships*, Fact Sheet EPA-420-F-10-015, March 2010.

medium speed diesel (MSD) propulsion engines, slow speed diesel (SSD) propulsion engines and auxiliary engines.

Table 5-46. NOx Emission Factors by Engine Type and Tier (g/kWh)

Emission Tier	MSD	SSD	Auxiliary
0	13.2	17	13.9
I	11.7	15.1	12.4
II	9.4	12.1	9.9
III	2.3	3.0	2.5

In addition to the MARPOL Annex VI emission limits that apply to all ships engaged in international transportation, U.S. vessels must also comply with EPA's Clean Air Act requirements for engines and fuels. The NOx emission limits for Category 3 (C3) engines are equivalent to the MARPOL Annex VI NOx limits. EPA's sulfur limit for distillate locomotive or marine (LM) diesel fuel sold in the United States is more stringent than the ECA fuel sulfur limit; the sulfur limit for ECA fuel for use on C3 marine vessels is equivalent to the MARPOL Annex VI SOx limits. EPA also has standards for C3 engines[162] which are generally the same or more stringent. However, almost all C3 engines used in international shipping fall under IMO regulations.

In addition, as part of the new IMO standards, marine diesel engines built between 1990 and 1999 that are 90 liters per cylinder or more need to be retrofitted to meet Tier I emission standards upon engine rebuild if a retrofit kit is available to the ships. Also consistent with the C3 RIA, this assessment assumed that 80% of all ships > 90L / cylinder will have retrofit kits available. In the C3 RIA, it was assumed that this phase in will happen over 5 years, 20% of eligible ships each year, starting in 2011. Since the 2011 phase in represents less than 0.4% of NOx emissions by ships at the 19 ports, no engines were assumed to be rebuilt in this assessment's baseline estimated. However for 2015 and later, 80% of 1990 through 1999 engines greater than 90 liters per cylinder were assumed rebuilt to Tier I standards.

In order to calculate NOx reductions due to fleet turnover, NOx adjustment factors were calculated for 2020 and 2030.[163] To accomplish this, installed power age profiles by engine type for propulsion engines and by vessel type for auxiliary engines were developed using 2011 Entrances and Clearances data[164] and Lloyd's vessel characterization data.[165] It was important to calculate separate baseline emissions for both propulsion and auxiliary engines, to reflect the different types of operation modes that occur as well as to target specific emission reduction strategies.

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[162] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* 75 FR 83, April 30, 2010.

[163] The same NOx emission factors were applied across the entire OGV inventory in this analysis.

[164] U.S. Army Corps of Engineers, *Vessel Entrances and Clearances*. Available at: http://www.navigationdatacenter.us/data/dataclen.htm.

[165]Available at: http://www.sea-web.com.

For OGV propulsion engines that operate when the vessel is maneuvering, installed power by engine type was calculated for each model year based upon the sum of the total propulsion power over the Entrances and Clearances data. In addition, to calculate the effect of retrofitting Tier 0 engines of more than 90 liters per cylinder, installed power was also calculated for MSD and SSD engines that were over 90 liters per cylinder. Ages were determined by subtracting the build year from 2011. This 2011 age profile was then used in both 2020 and 2030, adjusting model years to fit the age profile.[166] This same methodology was used in the EPA's C3 RIA.

Auxiliary engines typically operate when a vessel is hoteling. In this assessment, auxiliary power was calculated from the propulsion power using the auxiliary power to propulsion power ratios by ship type. This is a slight variation from the C3 RIA, which used the propulsion installed power to calculate auxiliary engine NOx factors. Auxiliary engines were only segregated into passenger ships and other because in 2011 different residual oil (RO) to marine gas oil (MGO) ratios were used.

Average NOx emission factors by year and engine type, calculated as described above, are listed below in Table 5-47. Auxiliary engines are broken into those in passenger ships and those in other vessels because passenger ships were assumed to use different RO/distillate fuel ratios in 2011 than other ships, as described in Appendix B.

Table 5-47. Average NOx Emission Factor (g/kWh) by Engine Type and Year

	Propulsion Engines		Auxiliary Engines	
Year	**MSD**	**SSD**	**Passenger**	**Other**
2020	9.4	10.6	10.3	8.6
2030	3.7	5.0	3.7	4.1

$PM_{2.5}$ emissions factors for various fuel sulfur levels are shown in Table 5-48. These were calculated by using the equations listed below which were determined by EPA in its C3 rulemaking and applying the 0.92 conversion factor for $PM_{2.5}$ to PM_{10} emissions.

$$\mathbf{PM_{10}\ EF = 0.23 + BSFC \times 7 \times 0.02247 \times (Fuel\ Sulfur\ Fraction - 0.0024)} \qquad \textbf{Eq. 5-1}$$

Table 5-48. $PM_{2.5}$ Emission Factors by Engine Type and Fuel Type (g/kWh)

Fuel	Sulfur (ppm)	MSD	SSD	Auxiliary
MDO/MGO	1,000	0.17	0.17	0.17
	500	0.16	0.16	N/A
	200	0.15	0.15	N/A
ULSD	15	N/A	N/A	0.14

[166] For example, a 5-year old engine in 2011 is a 2006 model year, but in 2020, such an engine is a 2015 model year (and in 2030 a 2025 model year).

Exhaust CO_2 emission factors are assumed to only vary by engine type and are shown in Table 5-49.

Table 5-49. CO_2 Emission Factors by Engine Type (g/kWh)

MSD	SSD	Auxiliary
646	589	691

For the purpose of this assessment, LNG emission factors are determined from the IMO GHG study[167] and are shown in Table 5-50. They are applied for both propulsion and auxiliary engines.

Table 5-50. LNG Emission Factors (g/kWh)

NOx	$PM_{2.5}$	CO_2
1.3	0.03	457

Finally well-to-pump/plug emission factors are shown in Table 5-51 and were determined using GREET2014.[168]

Table 5-51. Well-to-Pump/Plug CO_2 Emission Factors (g/kWh)

Fuel	SSD		MSD		Auxiliary		Otto	
	2020	2030	2020	2030	2020	2030	2020	2030
MGO/MDO	99	105	108	115	116	123	N/A	N/A
ULSD	N/A	N/A	N/A	N/A	115	123	N/A	N/A
LNG	N/A	N/A	N/A	N/A	N/A	N/A	98	94
Electricity	N/A	N/A	N/A	N/A	517	477	N/A	N/A

5.6.3. Strategy Effectiveness

The primary opportunities to reduce OGV emissions analyzed for this report are listed below with additional details.

- **Diesel fuel with 500 ppm sulfur in propulsion engines for bulk carriers, container ships, passenger ships and tankers**. Conventional OGV propulsion engine fuel has been residual fuel oil, which can have sulfur content of 2 to 3%. Since 2015, all vessels entering the ECA are required to use 0.1% sulfur (1,000 ppm) distillate (MDO/MGO). Using 500 ppm sulfur diesel fuel instead of MDO/MGO in propulsion engines would reduce $PM_{2.5}$ emissions per call by 0.5 to 1.4%, depending on ship type. This strategy does not affect NOx and CO_2 emissions.

[167] International Maritime Organization, *Third IMO GHG Study*, June 2014. Available at http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Relevant-links-to-Third-IMO-GHG-Study-2014.aspx.

[168] Argonne National Laboratories, *GREET Model 2014*. Available at: https://greet.es.anl.gov/.

- **Diesel fuel with 200 ppm sulfur in propulsion engines for bulk carriers, container ships, passenger ships and tankers**. Using 200 ppm diesel fuel instead of MDO/MGO in propulsion engines would reduce $PM_{2.5}$ emissions per call by 0.7 to 2.2%, depending on ship type. However, this strategy does not affect NOx and CO_2 emissions.
- **Ultra-low sulfur diesel (ULSD) fuel in auxiliary engines for bulk carriers, container ships, passenger ships and tankers.** ULSD has sulfur content of 15 ppm. Compared to the 1,000 ppm MDO/MGO required for all vessels entering the ECA as of 2015, use of ULSD would further reduce $PM_{2.5}$ emissions by 15.1 to 17.4%, depending on ship type. This strategy does not affect NOx or exhaust CO_2 emissions but reduces well-to-generator CO_2 emissions by 0.1%.
- **LNG in propulsion engines for bulk carriers, container ships and tankers**. LNG has negligible sulfur content and reduces NOx, $PM_{2.5}$ and CO_2 emissions. Use of LNG to replace 1,000 ppm sulfur MDO/MGO in propulsion engines reduces per call NOx emissions by 4.8 to 14.0% depending on ship type, $PM_{2.5}$ emissions by 5.6 to 14.9%, exhaust CO_2 emissions by 1.0 to 2.2% and well-to-propeller CO_2 emissions by 0.9 to 2.0%.
- **Use of LNG in auxiliary engines for bulk carriers, container ships and tankers.** Use of LNG to replace 1,000 ppm sulfur MDO/MGO in auxiliary engines reduces per call NOx emissions by 57.5 to 79.3% depending on ship type, $PM_{2.5}$ emissions by 67.3 to 76.6%, exhaust CO_2 emissions by 30.6 to 32.3% and well-to-propeller CO_2 emissions by 28.2 to 30.3%.
- **Shore power for container ships, passenger ships and reefers**. In this strategy, the ship is connected to the electrical grid while at berth. This strategy would be limited to frequent callers because of the retrofit cost per vessel to accept shore power. A frequent caller is a vessel that goes to the same port multiple times during the same year. This assessment assumed that approximately 2 hours per call would be used to connect and disconnect the cables to the ship. During the time the cables are connected, auxiliary engines are shut off, greatly reducing ship emissions. There are some CO_2 emissions generated from the power plant supplying electricity to the ship, but these are generally less than those generated by the auxiliary engines. Exhaust emissions during hoteling are reduced 80 to 97% depending upon ship type. This reduces per call NOx emissions by 62.1 to 89.9% depending on ship type, $PM_{2.5}$ emissions by 62.0 to 89.4%, exhaust CO_2 emissions by 62.3 to 90.9% and well-to-propeller CO_2 emissions by 22.4 to 37.6%.
- **Advanced Marine Emission Control System (AMECS) for container ships and tankers.** In this strategy, the ship's exhaust is captured and processed, and the AMECS is barge mounted and uses the barge auxiliary engine to power the system. The AMECS draws 165 kW to operate the emission reduction equipment. The bonnet captures 90% of the exhaust and reduces captured NOx emissions by 90% and $PM_{2.5}$ emissions by 95%.[169] However, AMECS strategies do not reduce CO_2 emissions. Like shore power, it is assumed that roughly 2 hours is necessary to install and remove the AMECS from a given vessel, during which time both the barge and ship auxiliary engines are operating and

[169] California Air Resources Board, *Executive Order AB-15-01 – Clean Air Engineering-Maritime, Inc.*, June 2015. Available at http://www.arb.ca.gov/ports/shorepower/eo/ab-15-01.pdf.

producing emissions. This strategy would be most applicable for use on non-frequent caller vessels. This reduces per call NOx emissions by 67.0 to 80.0% depending on ship type, $PM_{2.5}$ emissions by 65.7 to 80.3%, and increases exhaust CO_2 emissions by 7.4 to 9.5% as well as well-to-propeller CO_2 emissions by the same amount.

- **Reduced hoteling time for container ships**. By improving cargo handling equipment operation, unloading and loading times for a container ship can be improved. For this strategy, hoteling time is estimated to be reduced by 10%, which directly reduces hoteling emissions by 10%. This reduces per call NOx emissions by 7.3%, $PM_{2.5}$ emissions by 7.1%, CO_2 emissions (both exhaust and well-to-propeller) by 7.8%.

As part of this analysis, a screening assessment was conducted for OGV strategies in 2020 for three typical ship types: an average container ship, an average passenger (cruise) ship, and an average tanker ship. In practice, these three vessel types can account for the vast majority of OGV emissions at most ports. The screening assessment relied on assumptions for typical vessel size and operating characteristics for these vessels. These are shown in Table 5-52.

Table 5-52. Ship Characteristics for Screening Analysis

	Propulsion							Auxiliary						
	Engine		Service Speed	RSZ		Maneuver		Engine	RSZ		Maneuver		Hotel	
Ship Type	kW	Type	(knots)	LF	Hrs	LF	Time	kW	LF	Hrs	LF	Hrs	LF	Hrs
Container	47,172	SSD	23.8	0.18	0.40	0.02	1.4	10,325	0.25	0.40	0.50	1.4	0.17	30.8
Passenger	49,970	MSD-ED	22.6	0.24	0.40	0.02	1.4	13,892	0.80	0.40	0.80	1.4	0.64	10.1
Tanker	10,842	SSD	14.9	0.34	0.50	0.05	3.1	2,288	0.27	0.50	0.45	3.1	0.67	37.9

A frequent caller was defined in this screening assessment as a ship making 6 calls per year at a given port during a year for all vessel types other than passenger ships. Frequent calling passenger ships were defined as those making five calls per year at each port. Percent of installed power relating to frequent callers for each ship type was calculated at each port from 2011 Entrances and Clearances data. Frequent caller percentages for the three ship types are shown in Table 5-53.

Table 5-53. Percent Frequent Callers by Ship Type

Ship Type	Frequent Caller Percentage
Container Ship	65%
Passenger Ship	97%
Tanker	13%

5.6.4. Most Effective Strategies – Container Ships

This screening assessment relied upon the following assumptions for a “typical” container port:

- 718 total container ship calls in a given year
- 65% of calls by frequent callers and 35% by infrequent callers

Container ship strategies were reflected as follows:

- Fuel strategies were applied to 25% of the ships calling at the port.
- Shore power was applied to 80% of the frequent caller calls.
- AMECS were applied to 20% of the non-frequent callers.
- Reduced hoteling time was applied to 100% of calls.

Table 5-54 shows the impacts of strategies on a typical container ship and port for this screening assessment.

Table 5-54. Typical Emission Impact per Year for Container Ships

Strategy	Reduction Per Call (lbs)				Reduction Per Port (tons)			
	NOx	$PM_{2.5}$	CO_2	CO_2 WTW	NOx	$PM_{2.5}$	CO_2	CO_2 WTW
500 ppm in Propulsion Engines	-	0.39	-	-	-	0.03	-	-
200 ppm in Propulsion Engines	-	0.62	-	-	-	0.06	-	-
ULSD in Auxiliary Engines	-	4.25	-	64	-	0.38	-	6
LNG in Propulsion Engines	196.41	4.18	2,279	2,295	17.63	0.38	205	206
LNG in Auxiliary Engines	1,002.97	18.91	32,150	34,624	90.02	1.70	2,885	3,108
Shore Power	958.42	18.68	77,008	32,294	178.92	3.49	14,376	6,029
AMECS	941.68	18.46	(7,742)	(9,039)	23.66	0.46	(195)	(227)
Reduced Hoteling	102.50	2.00	8,236	9,616	36.80	0.72	2,957	3,452

5.6.5. Most Effective Strategies – Passenger Ships

To estimate the reduction for a “typical” passenger port, the following assumptions were used:

- 194 total passenger ship calls in a given year
- 97% of calls by frequent callers and 3% by infrequent callers

Passenger ship strategies were reflected as follows:

- Fuel strategies were applied to 25% of the ships calling at the port.
- Shore power was applied to 80% of the frequent caller calls.

Table 5-55 shows the impacts of strategies on a typical passenger ship and port for this screening assessment.

Table 5-55. Typical Emission Impact per Year for Passenger Ships

Strategy	Reduction Per Call (lbs)				Reduction Per Port (tons)			
	NOx	$PM_{2.5}$	CO_2	CO_2 WTW	NOx	$PM_{2.5}$	CO_2	CO_2 WTW
500 ppm in Propulsion Engines	-	0.20	-	-	-	0.00	-	-
200 ppm in Propulsion Engines	-	0.32	-	-	-	0.01	-	-
ULSD in Auxiliary Engines	-	7.49	-	113	-	0.18	-	3
Shore Power	1,635.29	26.62	109,707	46,007	123.09	2.00	8,258	3,463

5.6.6. Most Effective Strategies – Tanker Ships

To estimate the reduction for a "typical" tanker port, the following assumptions were used:

- 913 total tanker calls in a given year
- 13% of calls by frequent callers and 87% by infrequent callers

Tanker ship strategies were reflected as follows:

- Fuel strategies were applied to 25% of the ships calling at the port.
- AMECS was applied to 20% of the non-frequent caller calls.

Table 5-56 shows the impacts of strategies on a typical tanker ship and port for this screening assessment.

Table 5-56. Typical Emission Impact per Year for Tankers

Strategy	Reduction Per Call (lbs.)				Reduction Per Port (tons)			
	NOx	$PM_{2.5}$	CO_2	CO_2 WTW	NOx	$PM_{2.5}$	CO_2	CO_2 WTW
500 ppm in Propulsion Engines	-	0.18	-	-	-	0.02	-	-
200 ppm in Propulsion Engines	-	0.28	-	-	-	0.03	-	-
ULSD in Auxiliary Engines	-	4.20	-	63	-	0.48	-	7
LNG in Propulsion Engines	100.84	1.89	1,397	1,407	11.51	0.22	159	161
LNG in Auxiliary Engines	991.36	18.69	31,778	34,223	113.14	2.13	3,627	3,906
AMECS	1,025.59	20.10	(9,526)	(11,123)	81.46	1.60	(757)	(883)

5.6.7. Most Effective OGV Strategies

From the analysis presented above, some conclusions can be made about the most effective OGV emission reduction strategies, and the circumstances under which a given strategy would be most effective. It is more difficult to assess the costs of the OGV strategies than with the other source categories, because the costs of shore-side improvements can vary widely and the costs of ship improvements will be largely borne by the ocean carriers.

Switching to lower sulfur fuels beyond EPA's existing requirements can be an effective strategy to further reduce $PM_{2.5}$. ULSD was one of the most effective of these strategies where using ULSD in auxiliary engines would achieve roughly 30 to 40 times the $PM_{2.5}$ reduction per vessel call as compared to switching to 200 or 500 ppm sulfur diesel fuel in propulsion engines. While passenger ships showed the biggest reduction, other considerations may limit the practical application of ULSD in passenger ships.[170] Applying ULSD for container and tanker ships would be feasible, and based on the screening assessment, show significant reductions of auxiliary engine emissions.

[170] For example, many passenger ships use Category 3 engines in a diesel-electric configuration. While those engines are MSD and more likely to handle ULSD than SSD engines, there may be some compatibility issues in using ULSD in those engines.

Using LNG in propulsion and auxiliary engines produced a large reduction in NOx, $PM_{2.5}$ and CO_2 emissions. This strategy produced roughly nine times the benefit of using it in the propulsion engines in this screening assessment; this result also reflects the larger amount of hoteling emissions (from auxiliary engines) that are included in the baseline for this assessment. NOx reductions in 2020 are much larger than in 2030 due to the expected penetration of Tier III engines by 2030.

Shore power was highly effective at reducing NOx, $PM_{2.5}$ and CO_2 emissions. Because it requires upgrades to ships, however, shore power would be most feasible for frequent calling ships, and may be cost-prohibitive for infrequent callers. Thus, the largest benefits from shore power would be expected to occur at terminals and ports with a high fraction of frequent callers (i.e., usually cruise ship terminals and container terminals). Tankers and other bulk ships are less likely to be frequent callers. Shore power requires extensive work by a port to install the shore-side infrastructure, including trenching and installation of cables, switchgear, and transformers. The costs to install shore power infrastructure can vary widely. For example, the Port of Long Beach has invested approximately $200 million in shore power infrastructure, while the Port of Los Angeles has invested approximately $70 million. Long Beach has faced higher costs because of the need to bring new electrical service lines from Interstate 405 into the Harbor District in order to supply the appropriate power. In contrast, the Port of Los Angeles already had the main electrical trunk lines in place from which to “step-down” and condition power for use by ships.[171]

Per call, the effectiveness of the AMECS at reducing emissions is comparable to shore power for both NOx and $PM_{2.5}$. However, the CO_2 emissions increase due to the barge auxiliary engines operating to support the emission reduction equipment. This approach could be considered at ports and terminals with large numbers of infrequent callers, since the AMECS can be applied without special equipment or fuel storage capacity on a given vessel. This is considered an emerging technology, and its cost and feasibility may change in the future.

Finally, reduced hoteling time for container ships produced larger reductions than using lower sulfur distillate in propulsion engines. Such strategies would also be expected to increase productivity by moving ships in and out of a port more efficiently.

5.7. Example Application of Port Strategies in Screening Assessment

The final step in the screening assessment was to estimate the impacts of the strategies for a “typical” port, which allows comparison across sectors and comparison of technology-based strategies with operational or port-wide strategies. To do this, the hypothetical port was assumed to handle 2 million TEUs per year. Based on a review of existing port emission inventories, representative populations for each equipment type were selected, as shown in Table 5-57. Please note that OGV strategies were

[171] Port of Los Angeles and Port of Long Beach, *San Pedro Bay Ports Clean Air Action Plan 2010 Update*, October 2010.

applied only to container and tanker vessels in this example, and not passenger cruise vessels. See Section 5.6 above for further information on effective strategies for that vessel type.

Table 5-57. Equipment Count Assumptions for a Typical Port in Screening Assessment

Equipment Type	Count
Drayage Trucks	1,000
Line-Haul Locomotives	2
Switch Locomotives	3
Yard Tractors	200
RTG Cranes	25
Container Handlers	50
Tugs	20
Ferries	5
Containership Total Calls	718
Tanker Ship Total Calls	913

Note that some strategies in these tables are aggregations of individual retrofit, replacement, and/or repower combinations. For example, “Retrofit Tier 1/2 Tug with DPF” includes retrofitting Tier 1 and Tier 2 tugs, each of which can have different emission reduction benefits. For the sake of simplicity, in these cases, emission reductions are presented for the strategy permutation that affects the newest equipment (i.e., Tier 2 in this example), which is conservative in that the emission reduction benefits will be lower than if applied to the older equipment.

Table 5-58 and Table 5-59 present a summary of the most effective strategies from this example to help illustrate the relative impacts these different strategies can have on reducing emissions at a “typical” port. For drayage trucks, rail, CHE, and harbor craft, the tables show annual emission reductions per vehicle or per equipment piece—consistent with the estimates presented earlier in this section. OGV emission reductions are shown on a per vessel call basis, consistent with Section 5.6. The tables also show the estimated cost per vehicle or per equipment piece.

The middle set of columns show the number of vehicle/equipment pieces (or OGV calls) that would be affected by a given strategy, and the affected vehicle/equipment as a percent of total vehicle/equipment. For example, of the 50 container handlers at the typical port, 15% will be Tier 3 in 2020, so the strategy was applied to eight container handlers in that year. Note that line-haul locomotives usually travel long distances, and therefore, the equivalent annual operation of two locomotives was assumed here although the actual number affected in practice would be larger. Note also that, for this screening assessment, OGV per-call results are the same as are the grid-based CO_2 emission factors, but per-port results differ due to an increased penetration assumed in future years.

The final set of columns show the emission reduction assuming the strategy is applied to all affected vehicle/equipment pieces or OGV calls at the typical port.

Table 5-58. Example Application of Potential Strategies for 2020

Sector	Strategy	Per Vehicle/Equipment or Per OGV Call Reduction				Affected Vehicle/Equipment or OGV Calls per Port		Per Port Reduction		
		NOx (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)	Cost	Count	% of Total	NOx (tons)	$PM_{2.5}$	CO_2 (tons)
Drayage Trucks	Replace pre-2007 with MY 2010+	398	20	0	$110,000	320	32%	63.7	3.2	0
	Operational Efficiency (Reduce Idle and Creep 10%)	N/A	N/A	N/A	N/A	N/A	N/A	22.0	2.0	8,940
Rail	Replace Tier 0+ Line-haul with Tier 2+/3	38,691	2,064	0	$3,000,000	1	33%	19.3	1.0	0
	Install AESS on Tier 2 Switcher	880	14	28	$10,000	1	7%	0.4	0.0	28
	Replace Pre-Tier 0/Tier 0+ Switcher with Tier 2+/3	7,566	275	0	$1,500,000	2	61%	7.6	0.3	0
	Replace Pre-Tier 0/Tier 0+ Switcher with T4 GenSet	23,616	504	177	$1,500,000	2	61%	23.6	0.5	354
CHE	Replace Tier 4 Yard Truck with CNG/LNG	33	2	17	$30,000	195	97%	3.2	0.2	3,313
	Replace Tier 4 Yard Truck with PHEV	64	4	19	$150,000	195	97%	6.2	0.4	3,667
	Retrofit Tier 3 RTG Crane with DPF	0	144	0	$19,000	4	17%	0.0	0.3	0
	Repower Tier 3 RTG Crane with Tier 4	3,045	152	0	$200,000	4	17%	6.1	0.3	0
	Retrofit Tier 3 Container Handler with DPF	0	91	0	$19,000	8	15%	0.0	0.4	0
	Repower Tier 3 Container Handler with Tier 4	1,925	96	0	$64,000	8	15%	7.7	0.4	0
Harbor Craft	Retrofit Tier 1/2 Tug with DPF	0	1,103	0	$60,000	11	56%	0.0	6.1	0
	Repower Tier 1 Tug with Tier 3	43,828	2,296	0	$500,000	5	24%	109.6	5.7	0
	Retrofit Tier 1/2 Ferry with DPF	0	1,406	0	$60,000	1	28%	0.0	0.7	0
	Repower Tier 0/1 Ferry with Tier 3	23,673	1,085	0	$200,000	3	57%	35.5	1.6	0
OGVs (Container)	500 ppm in Propulsion Engines	0	0	0	N/A	108	15%	0.0	0.0	0
	200 ppm in Propulsion Engines	0	1	0	N/A	108	15%	0.0	0.0	0
	ULSD in Auxiliary Engines	0	4	0	N/A	108	15%	0.0	0.2	3
	LNG in Propulsion Engines	196	4	1	N/A	108	15%	10.6	0.2	124
	LNG in Auxiliary Engines	1,003	19	17	N/A	108	15%	54.0	1.0	1,865
	Shore Power	958	19	16	varies	287	40%	137.6	2.7	4,637
	AMECS	942	18	-5	N/A	72	10%	33.8	0.7	-324
	Reduced Hoteling	102	2	5	N/A	359	50%	18.4	0.4	1,726
OGVs (Tanker)	500 ppm in Propulsion Engines	0	0	0	N/A	137	15%	0.0	0.0	0
	200 ppm in Propulsion Engines	0	0	0	N/A	137	15%	0.0	0.0	0
	ULSD in Auxiliary Engines	0	4	0	N/A	137	15%	0.0	0.3	4
	LNG in Propulsion Engines	101	2	1	N/A	137	15%	6.9	0.1	96
	LNG in Auxiliary Engines	991	19	17	N/A	137	15%	67.9	1.3	2,343
	AMECS	1,026	20	-6	varies	91	10%	46.8	0.9	-508

Table 5-59. Example Application of Potential Strategies for 2030

Sector	Strategy	Per Vehicle/Equipment or Per OGV Call Reduction				Affected Vehicle/Equipment or OGV Calls per Port		Per Port Reduction		
		NOx (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)	Cost	Count	% of Total	NOx (tons)	$PM_{2.5}$ (tons)	CO_2 (tons)
Drayage Trucks	Replace MY 2010+ Diesel with BEV	44	2	12	$220,000	840	84%	18.6	0.7	10,145
	Operational Efficiency (Reduce Idle and Creep 10%)	N/A	N/A	N/A	N/A	N/A	N/A	15.4	1.4	8,940
Rail	Replace Tier 2+/3 Line-haul with Tier 4	67,924	1,118	0	$3,000,000	1	25%	34.0	0.6	0
	Replace Tier 0+ Switcher with Tier 4 GenSet	23,616	504	177	$1,500,000	2	52%	23.6	0.5	354
	Replace Tier 2+/3 Switcher w/ T4 or T4 GenSet (avg)	9,630	160	177	$1,500,000	1	9%	4.8	0.1	177
CHE	Replace Tier 4 Yard Truck with CNG/LNG	33	2	17	$30,000	200	100%	3.3	0.2	3,398
	Replace Tier 4 Yard Truck with Battery Electric	164	8	34	$210,000	200	100%	16.4	0.8	6,773
	Install Tier 4 RTG Crane with ESS	85	4	45	$240,000	24	98%	1.0	0.1	1,072
	Convert Tier 4 RTG Crane to Electric	338	17	70	$500,000	24	98%	4.1	0.2	1,679
Harbor Craft	Replace Tier 3 Tug with Tier 4	35,042	399	0	$10 million	3	14%	52.6	0.6	0
	Repower Tier 1/2 Ferry with Tier 4	36,337	1,499	0	$300,000	2	35%	36.3	1.5	0
	Repower Tier 3 Ferry with Tier 4	24,139	414	0	$300,000	2	35%	24.1	0.4	0
OGVs (Container)	500 ppm in Propulsion Engines	0	0	0	N/A	180	25%	0.0	0.0	0
	200 ppm in Propulsion Engines	0	1	0	N/A	180	25%	0.0	0.1	0
	ULSD in Auxiliary Engines	0	4	0	N/A	180	25%	0.0	0.4	6
	LNG in Propulsion Engines	196	4	1	N/A	180	25%	17.6	0.4	206
	LNG in Auxiliary Engines	1,003	19	17	N/A	180	25%	90.0	1.7	3,108
	Shore Power	958	19	16	varies	574	80%	275.3	5.4	9,275
	AMECS	942	18	-5	N/A	144	20%	67.6	1.3	-649
	Reduced Hoteling	102	2	5	N/A	718	100%	36.8	0.7	3,452
OGVs (Tanker)	500 ppm in Propulsion Engines	0	0	0	N/A	228	25%	0.0	0.0	0
	200 ppm in Propulsion Engines	0	0	0	N/A	228	25%	0.0	0.0	0
	ULSD in Auxiliary Engines	0	4	0	N/A	228	25%	0.0	0.5	7
	LNG in Propulsion Engines	101	2	1	N/A	228	25%	11.5	0.2	161
	LNG in Auxiliary Engines	991	19	17	N/A	228	25%	113.1	2.1	3,906
	AMECS	1,026	20	-6	varies	183	20%	93.6	1.8	-1,015

6. Analysis of Emission Reduction Scenarios

This section describes the scenario analyses that were conducted for various combinations of emission reduction strategies (i.e., "strategy scenarios"). This section provides an overview of EPA's intent in developing the scenarios as well as the specific strategies and analysis results for each mobile source sector. Further details on the methodology and assumptions for this section are included in Appendix C.

6.1. Overview

The strategy scenarios were composed of various technological and operational strategies that could be applied to the Business as Usual (BAU) inventories for the five mobile source sectors. As described in Section 5, EPA conducted a screening-level assessment of the range of potential technological and operational strategies to reduce port-related emissions, and considered the potential to accelerate the introduction of newer technologies that reflect EPA's most recent emission standards. EPA also developed the strategy scenarios in consultation with the Mobile Sources Technical Review Subcommittee (MSTRS) of the Clean Air Act Advisory Committee (CAAAC). In 2014, the MSTRS formed a Ports Workgroup to develop recommendations for an EPA-led voluntary ports initiative, and effectively measuring environmental performance at ports. The MSTRS Ports Workgroup included technical and policy experts from a range of stakeholders, including industry, port-related agencies, communities, Tribes, state and local governments, and public interest groups.[172] After extensive discussions and other research, a final list of strategy scenarios was determined for more detailed analysis.

Strategy scenarios were developed for each mobile source sector for the years 2020 and 2030 for all pollutants[173] and for only CO_2 in 2050. Although the specific strategies differ between sectors, the scenarios were intended to address the following:

- **Scenario A** reflected an increase in the introduction of newer technologies in port vehicles and equipment beyond what would occur through normal fleet turnover. Operational strategies in Scenario A reflected a reasonable increase in expected efficiency improvements for drayage truck, rail, and OGV sectors. For the OGV sector, moderate levels of fuel switching and other emission control strategies were also analyzed.
- **Scenario B** reflected a more aggressive suite of strategies as compared to Scenario A. Scenario B was intended to further accelerate the introduction of clean diesel and zero emissions vehicles and equipment, in addition to other fuels and technologies. Operational strategies in Scenario B assume further operational efficiency improvements beyond Scenario A.

[172] For further information on MSTRS Ports Working Group participants, see https://www.epa.gov/sites/production/files/2016-06/documents/portsinitiativewkgrp_2016.pdf.

[173] See Section 2 for more background on the pollutants that were analyzed for the different mobile source sectors.

Both scenarios would necessitate a major investment in new technologies, with Scenario B requiring a larger investment than Scenario A. In selecting strategies, EPA qualitatively considered several factors, such as capital costs, market barriers, and potential for market penetration by analysis year. However, an in-depth cost-benefit analysis was not conducted.

In many cases, a sector was broken down into groups of scenarios applied to a specific subtype or operational mode of the sector. In these cases, the impact of selected strategies was applied to the applicable portion of the BAU inventory. For example, there are rail sector scenarios for line-haul technologies, line-haul operational scenarios, and switcher technologies, with the applicable strategies being applied to the relevant portion of the BAU inventory (e.g., switcher strategies were applied to the switcher emissions in the BAU inventory for each analysis year). Emission reductions for all pollutants in the BAU emission inventory were considered here. However, analysis results are provided for NOx, $PM_{2.5}$, and CO_2 reductions in this section, with the remaining pollutant results included in Appendix C.

Finally, strategy scenarios were estimated by developing typical or average emission relative reduction factors (RRFs) for each sector/mode under each scenario. In general, once an RRF was determined, it was applied uniformly to the applicable BAU emission inventory at each port in this national scale analysis, except for cases where a sector was not in service at a port or where an existing local program produced the same or better results than the proposed scenario.

Assessment results are reported for each scenario as both percent and total reductions from the relevant BAU inventory for a given sector. Unless otherwise noted, all scenario reductions were determined relative to the same BAU emission inventories that are described in Section 4 of this report, independently, in order to allow comparison across scenarios in a consistent manner. Accordingly, the reductions presented here would be reasonable for each individual strategy, but in some cases, may overestimate the cumulative impact if multiple strategies were applied simultaneously (without accounting for overlap between scenarios).[174]

[174] For example, the reduction from applying both fuel switching and shore power for OGV hoteling emissions should be less than the sum of the OGV strategies. If in practice, fuel switching was applied first, there would be less available emissions to which shore power could be applied.

6.2. Drayage Trucks

Strategy scenarios for drayage trucks fall into two categories: Technological and Operational. Table 6-1 shows the strategy scenarios analyzed for Scenarios A and B for the different analysis years. For example, column "2020/A" for the Technological category includes the drayage truck technological strategies assumed for Scenario A in the 2020 analysis year.

Table 6-1. Drayage Truck Strategy Scenarios

Strategy	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Technological	Replace all pre-1994 trucks with 50% post-1998, 30% 2007, 20% 2010 or newer trucks	Replace all pre-1998 trucks with 50% 2007, 40% 2010, and 10% PHEV	Replace 100% of pre-2004 trucks with 2010 trucks. Replace 20% of 2004-09 trucks with PHEV	Replace 100% of pre-2007 trucks with 50% 2010 and 50% PHEV. Replace 10% of post-2010 with PHEV	Replace 25% of post-2010 trucks with PHEV	Replace 50% of post-2010 trucks with PHEV
Operational	Reduce gate queues by 25%	Reduce gate queues by 50%	Reduce gate queues by 25%	Reduce gate queues by 50%	Reduce gate queues by 25%	Reduce gate queues by 50%

The Technological category includes truck replacement strategies from accelerating turnover to cleaner diesel trucks that meet EPA's more recent emission standards. Plug-in hybrid electric vehicles (PHEV) were also assumed in this category for most scenarios, and PHEVs were assumed to also be a surrogate for the potential reductions from other types of electric trucks (such as hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs).[175] Reduced gate queues were assumed to occur at different levels in the Operational category.

For the drayage truck sector, technological and operational strategies were applied separately, but to the same BAU inventory, which caused some overlap between the two sets of scenarios for all pollutants.[176] See Section 5 and Appendix C for further background on drayage truck strategies and the methodology used in the scenario analyses.

6.2.1. Technological Strategies

The Technological strategy scenarios for drayage trucks are found in the first row of Table 6-1.

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[175] PHEVs were determined to be the most likely technology for commercial availability, based on the screening assessment in Section 5.

[176] As described in Section 4, the BAU emission inventories for drayage trucks were based on projected port cargo tonnage multiplied by composite drayage truck fleet emission factors (in terms of emissions per ton) that were developed using EPA's DrayFLEET model. The BAU inventory also included adjustments for select ports where existing local programs had modified the age distribution of drayage trucks.

6.2.1.1. Relative Reduction Factors

A relative reduction factor (RRF) was calculated for each scenario strategy, and then applied to the relevant BAU inventory for each analysis year. For each strategy scenario, a fleet-average RRF was calculated as follows:

$$\mathbf{RRF = 1 - Scenario\ EF/BAU\ EF} \qquad \textbf{Eq. 6-1}$$

Where

Scenario EF = the emission factor for a given scenario, and

BAU EF = the emission factor for the given Business as Usual inventory.

Equation 6-1 shows how a fleet-average RRF was calculated as the scenario emissions divided by the BAU emissions. To simplify calculations, the DrayFLEET model was used to develop a generic, average fleet RRF to represent an average port (or "typical port"), rather than generating a separate model for each port that is part of this national scale assessment. This is different from how the BAU inventories for drayage trucks were developed, where a default truck fleet age distribution from MOVES2010b was used in the DrayFLEET model. For each strategy scenario analysis, the BAU age distribution was replaced with alternative distributions for respective replacements in each scenario.

Criteria pollutant emission factors for conventional diesel drayage trucks were drawn from EPA emission standards, and emission factors for air toxics were derived from existing EPA methods and models. CO_2 emission factors came from GREET 2015,[177] and for these calculations, no change in fuel economy or CO_2 emission rates were assumed between model year standards.[178]

Because the DrayFLEET model cannot readily model each of the scenarios, the fleet-average emission factors were weighted by truck population distributions specific to each scenario. To develop the truck population distributions for each scenario, the default truck fleet age distribution from the BAU methodology was used, which was drawn from MOVES2010b. No PHEV trucks were assumed in the BAU fleet mixes.

Table 6-2 shows the resulting Technological strategy scenario RRFs for the drayage truck sector, applicable to a typical port.[179]

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[177] GREET2015 was released Oct 2, 2015. All calculations in this draft have been updated to GREET2015 results. For information on the model, see https://greet.es.anl.gov/.

[178] Note that BAU inventories are based on the DrayFLEET model, which was based on MOVES2010b. As a result and as noted in Section 4, the drayage results in this assessment do not include EPA's heavy-duty engine and vehicle GHG regulations.

[179] A "typical port" in this assessment is intended to establish a hypothetical port that that allows EPA to illustrate the relative impacts of a particular strategy and/or scenario.

Table 6-2. Relative Reduction Factors for Drayage Truck Technological Strategy Scenarios

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	19%	43%	14%	43%	0%	10%	11%	7%
2020/B	48%	62%	35%	62%	1%	21%	26%	12%
2030/A	48%	34%	33%	34%	0%	20%	24%	14%
2030/B	60%	52%	39%	52%	4%	22%	27%	15%
2050/A	-	-	-	-	6%	-	-	-
2050/B	-	-	-	-	12%	-	-	-

Note that use of emission factors to determine RRFs in this manner implies that other technological and operational parameters, such as engine load and power, were unchanged between a BAU inventory and scenario analysis.

6.2.1.2. Application of Relative Reduction Factors

As described above, the RRFs found in Table 6-2 were based on drayage truck fleet averages at a typical port. Next, the RRFs that were estimated for each scenario and pollutant were then applied to each port's BAU drayage truck emission inventory for each analysis year. Adjustments were made in 2020 to the BAU drayage age distribution at a limited number of ports to account for local programs in effect that would out-pace the scenarios considered in this assessment. For those cases, no additional emission reductions were applied. No similar changes were made in 2030 and 2050 at any ports, so the full RRF was applied for all scenarios in those analysis years.

6.2.1.3. Result Summary

Table 6-3 shows the total tons reduced from the BAU inventory for the Technological strategy scenarios for the drayage sector.

Table 6-3. Total Drayage Truck Emission Reductions for Technological Strategy Scenarios

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	997.7	166.6	59.6	128.3	-	2.3	0.5	4.6
2020/B	2,503.4	240.7	151.9	185.3	10,827	5.0	1.2	7.8
2030/A	1,250.7	52.1	68.1	40.2	11,987	2.7	0.6	6.0
2030/B	1,573.1	81.0	79.7	62.4	88,511	3.0	0.7	6.4
2050/A	-	-	-	-	276,072	-	-	-
2050/B	-	-	-	-	552,144	-	-	-

6.2.2. Operational Strategies

Next, the Operational strategy scenarios in the second row of Table 6-1 were analyzed.

6.2.2.1. Development and Application of Relative Reduction Factors

The DrayFLEET model was used to estimate the emission impacts of generalized drayage truck efficiency improvements. These improvements would reduce the time drayage trucks spend in idle and creep mode by 25% and 50%, respectively, for Scenarios A and B. These outcomes could be achieved by ports in a variety of ways, as discussed in Section 5 of this report.

Gate queue reduction factors were determined with the DrayFLEET model, and similar to the Technological scenarios, a different RRF was developed for each scenario and pollutant based on activity at a "typical port." Table 6-4 shows the resulting operational strategy RRFs.

Table 6-4. Relative Reduction Factors for Drayage Fleet Operational Strategy Scenarios

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	0%	1%	0%	1%	1%	0%	0%	0%
2020/B	1%	2%	1%	2%	2%	1%	0%	1%
2030/A	0%	1%	0%	1%	1%	1%	0%	0%
2030/B	1%	2%	1%	2%	2%	1%	0%	1%
2050/A	-	-	-	-	1%	-	-	-
2050/B	-	-	-	-	2%	-	-	-

Note that in developing the BAU inventories, the number of drayage trucks increased with each future year to accommodate growth in port throughput. However, in the modeled scenarios the percent of truck operating time spent in gate queues did not vary by calendar year.

The RRFs for each drayage Operational strategy scenario were applied to each port's BAU emissions, similar to how RRFs were applied for the Technological strategy scenarios.

6.2.2.2. Result Summary

Table 6-5 shows the total emission reductions for the drayage Operational strategy scenarios.

Table 6-5. Total Drayage Truck Operational Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	10.5	3.9	1.7	3.0	18,662	0.1	0.0	0.3
2020/B	26.2	7.7	3.0	5.9	37,323	0.2	0.0	0.5
2030/A	5.3	1.6	0.8	1.2	25,092	0.1	0.0	0.2
2030/B	13.1	3.1	1.4	2.4	50,184	0.1	0.0	0.3
2050/A	-	-	-	-	44,172	-	-	-
2050/B	-	-	-	-	88,343	-	-	-

6.2.3. Summary of Drayage Truck Scenarios

Tables 6-6 and 6-7 illustrate the reductions from the Technological and Operational strategy scenarios. In Table 6-6, the relative emission reduction from the drayage BAU inventories are shown as percent reductions for all pollutants. Figure 6-1 graphs the percentage reductions for NOx, $PM_{2.5}$, and CO_2. Table 6-7 shows absolute emission reductions from the BAU inventories by scenario and strategy in tons reduced per analysis year, and Figure 6-2 graphs the tons/year reductions for NOx, $PM_{2.5}$, and CO_2. Similar charts for other pollutants can be found in Appendix C.

Scenarios that supported accelerated fleet turnover had a significant effect on reducing drayage truck emissions for most pollutants and years, and the introduction of electric technologies further decreased CO_2 emissions in the longer term. Technological drayage scenarios produced significant NOx and $PM_{2.5}$ reductions. For example, total relative NOx reductions from drayage technological strategies produced significant reductions between Scenarios A and B; in 2020, reductions ranged from 19-48% and from 48-60% in 2030 from the total drayage BAU inventories for those years. Similar reductions were observed for $PM_{2.5}$, where 2020 $PM_{2.5}$ reductions were estimated between 43-62% and 2030 reductions were 34-52% for the drayage Technological scenarios from the total BAU case. In addition, an estimated 6-12% CO_2 reductions were observed in 2050 for the Technological scenarios for that year.[180]

Not surprisingly, Scenario B consistently showed greater reductions than Scenario A for all Technological scenarios. The Operational scenarios, on the other hand, provided much smaller reductions of criteria pollutant and air toxic emissions as compared to the Technological scenarios. However, EPA believes this is most likely due to how the Operational scenarios were designed in this assessment; operational strategies that significantly reduce truck idling continue to be important options to consider for reducing drayage emissions. In contrast, Operational scenarios were more effective in reducing CO_2 emissions in the 2020/A, 2020/B, and 2030/A scenarios as compared to truck replacement strategies; with the major shift to PHEVs in the 2030/B scenario producing greater results than reduced gate queues.

Please note that drayage reductions for all strategy scenarios were limited to the assessment's modeled domain of 0.5 km from the port boundary, as described in Section 3. In practice, additional emissions and potential reductions would occur beyond the immediate port area, since drayage trucks typically travel through off-port corridors to freight distribution centers or commercial businesses in the larger region. The tables and figures also do not show total emission reductions for the drayage sector. For the drayage sector, all reductions were calculated relative to the total BAU inventory. That is, operational and technological strategies were both computed separately, both relative to the same BAU inventory and could apply to the same vehicles. Thus, there may be significant overlap between the two sets of scenarios for all pollutants.

[180] Please note that EPA's heavy-duty engine and vehicle GHG regulations were not reflected due to the timeframe of the assessment and its reliance on a now older version of the MOVES model.

Table 6-6. Drayage Truck Relative Emission Reduction Summary by Scenario and Strategy, Percent

Scenario	Strategy Type	% reduction from BAU								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Scenario
2020/A	Technological	19%	43%	14%	43%	0%	10%	11%	7%	Replace all pre-1994 trucks with 50% 2004, 30% 2007, 20% 2010 or newer trucks
	Operational	0%	1%	0%	1%	1%	0%	0%	0%	Reduce Gate Queues by 25%
2020/B	Technological	48%	62%	35%	62%	1%	21%	26%	12%	Replace all pre-1998 trucks with 50% 2007, 40% 2010, and 10% PHEV
	Operational	1%	2%	1%	2%	2%	1%	0%	1%	Reduce Gate Queues by 50%
2030/A	Technological	48%	34%	33%	34%	0%	20%	24%	14%	Replace 100% of pre-2004 trucks with 2010 trucks. Replace 20% of 2004-09 trucks with PHEV
	Operational	0%	1%	0%	1%	1%	1%	0%	0%	Reduce Gate Queues by 25%
2030/B	Technological	60%	52%	39%	52%	4%	22%	27%	15%	Replace 100% of pre-2007 trucks with 50% 2010 and 50% PHEV. Replace 10% of post-2010 with PHEV
	Operational	1%	2%	1%	2%	2%	1%	0%	1%	Reduce Gate Queues by 50%
2050/A	Technological	-	-	-	-	6%	-	-	-	Replace 25% of post 2010 trucks with PHEV
	Operational	-	-	-	-	1%	-	-	-	Reduce Gate Queues by 25%
2050/B	Technological	-	-	-	-	12%	-	-	-	Replace 50% of post 2010 trucks with PHEV
	Operational	-	-	-	-	2%	-	-	-	Reduce Gate Queues by 50%

Figure 6-1. Drayage Truck Percent Emission Reductions by Scenario and Strategy for Selected Pollutants

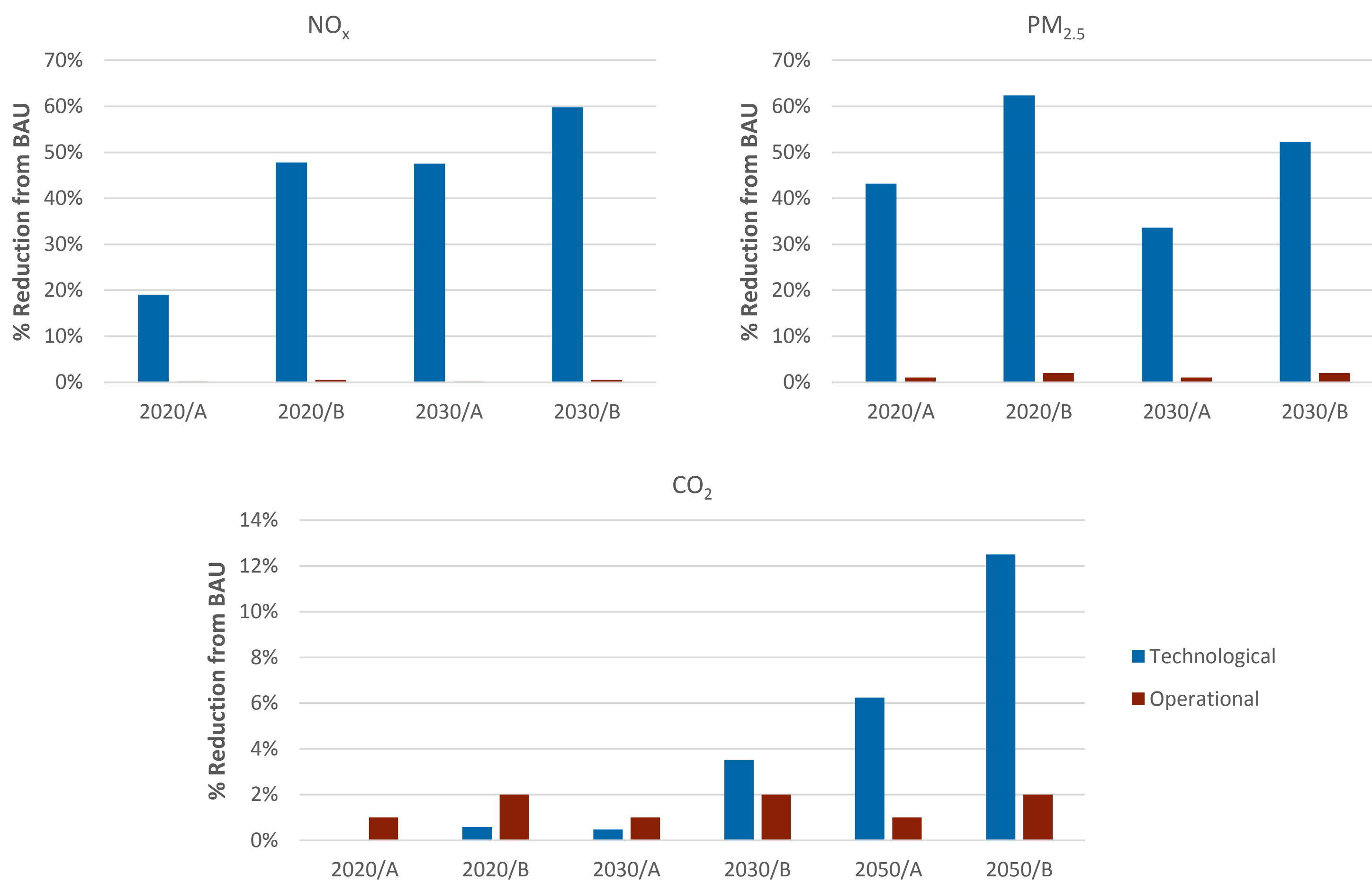
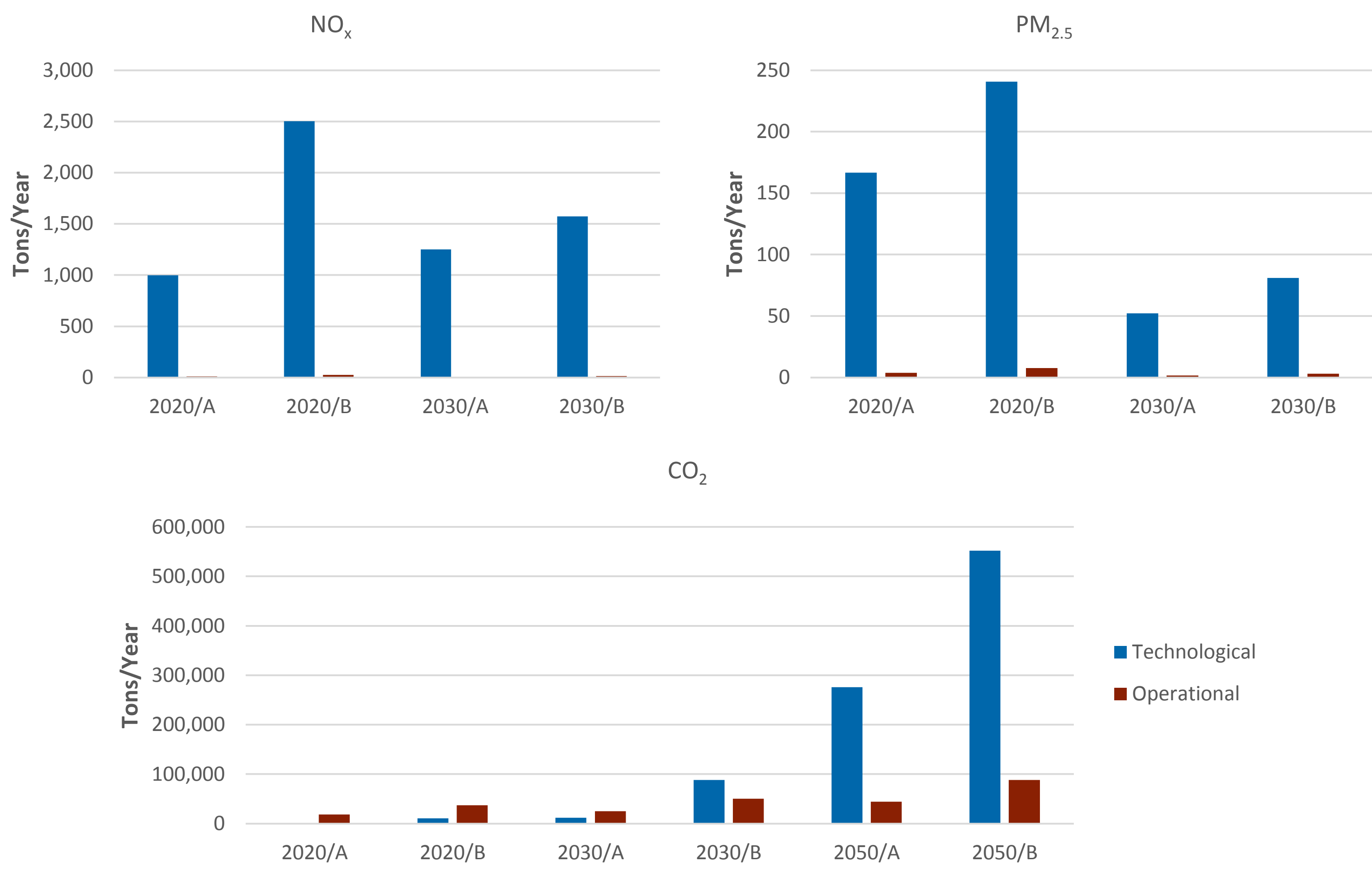


Table 6-7. Drayage Truck Emission Reduction Summary by Scenario and Strategy, Tons per Year

Scenario	Strategy Type	Tons Reduced per Year								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Scenario
2020/A	Technological	997.7	166.6	59.6	128.3	0	2.2	0.5	4.4	Replace all pre-1994 trucks with 50% 2004, 30% 2007, 20% 2010 or newer trucks
	Operational	10.5	3.9	1.7	3.0	18,661	0.1	0.02	0.3	Reduce Gate Queues by 25%
2020/B	Technological	2,503.4	240.7	151.9	185.3	10,827	4.8	1.1	7.5	Replace all pre-1998 trucks with 50% 2007, 40% 2010, and 10% PHEV
	Operational	26.2	7.7	3.0	5.9	37,323	0.2	0.03	0.4	Reduce Gate Queues by 50%
2030/A	Technological	1,250.7	52.1	68.1	40.3	11,987	2.7	0.6	5.9	Replace 100% of pre-2004 trucks with 2010 trucks. Replace 20% of 2004-09 trucks with PHEV
	Operational	5.3	1.6	0.8	1.2	25,092	0.1	0.01	0.2	Reduce Gate Queues by 25%
2030/B	Technological	1,573.1	81.0	79.7	62.6	88,511	3.0	0.7	6.3	Replace 100% of pre-2007 trucks with 50% 2010 and 50% PHEV. Replace 10% of post-2010 with PHEV
	Operational	13.1	3.1	1.4	2.4	50,183	0.1	0.02	0.3	Reduce Gate Queues by 50%
2050/A	Technological	-	-	-	-	276,072	-	-	-	Replace 25% of post 2010 trucks with PHEV
	Operational	-	-	-	-	44,172	-	-	-	Reduce Gate Queues by 25%
2050/B	Technological	-	-	-	-	552,144	-	-	-	Replace 50% of post 2010 trucks with PHEV
	Operational	-	-	-	-	88,343	-	-	-	Reduce Gate Queues by 50%

Figure 6-2. Drayage Truck Absolute Emission Reductions by Scenario and Strategy for Selected Pollutants



6.3. Rail

Rail strategy scenarios fall into three categories: Line-haul Technology, Line-haul Operational, and Switcher Technology. Table 6-8 shows the strategy scenarios analyzed for Scenarios A and B for the different analysis years.

Table 6-8. Rail Strategy Scenarios

Strategy	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Line-haul—Technology	Replace 50% of Tier 0+ engines with Tier 2+ engines	Replace 100% of Tier 0+ engines with 50% 2+ engines and 50% Tier 4 engines	Replace 100% of Tier 1+ and earlier engines with 50% 2+ engines and 50% Tier 4 engines	Replace all pre-Tier 4 engines with Tier 4 engines.	Replace 10% of Tier 4 with zero emissions locomotive	Replace 25% of Tier 4 with zero emissions locomotive
Line-haul—Operational	1% improvement in fuel efficiency	5% improvement in fuel efficiency	5% improvement in fuel efficiency	10% improvement in fuel efficiency	10% improvement in fuel efficiency	20% improvement in fuel efficiency
Switcher Technology	Replace 50% of Pre-Tier 0 engines with 95% Tier 2+ engines and 5% Tier 4 Genset	Replace all Pre-Tier 0 engines with 90% Tier 2+ and 10% Tier 4 Genset	Replace all Pre-Tier 0 engines and 20% of Tier 0+ with 90% Tier 2+ engines and 10% Tier 4 Genset	Replace all Pre-Tier 0 engines and 40% of Tier 0+ with 70% Tier 4 engines and 30% Tier 4 Genset	Assume 30% Tier 4 Genset	Assume 50% Tier 4 Genset

The Line-haul Technology category includes locomotive replacement strategies to accelerate fleet turnover to newer diesel engines that meet cleaner diesel engine standards, with electric technology being included in the 2050 analysis year. Increasing levels of improved fuel efficiency was analyzed for the Line-haul Operational category. Finally, accelerating turnover to cleaner switcher standards, as well as increased use of Genset technologies are considered in the Switcher Technology scenarios.

For the rail sector, emission reductions were applied to the individual parts of the BAU inventory for the individual strategies and to the sector total for the cumulative results. That is, for both the Line-haul Technology and Line-haul Operational categories, relative reductions were applied to the rail line component of the BAU inventory and the rail switcher emission reductions were applied to the rail yard component of the BAU inventory. The total rail reductions are estimated as the sum of Line-haul Technology, Line-haul Operational, and Switcher Technology strategy emission reductions relative to the total rail BAU inventory. See Section 5 and Appendix C for further background on rail strategies and the methodology used in the scenario analysis.

6.3.1. Line-haul Technology Strategies

Line-haul technology strategies are shown in the first row of Table 6-8 above. For each strategy scenario and pollutant, a relative reduction factor (RRF) was calculated using an average emission factor (EF) for both the scenario and the BAU emission inventory. Each emission factor was determined as the emission rate for each tier weighted by the locomotive engine population distribution in that tier. This approach was applied to both the rail line portion of the BAU emissions inventory and the relevant strategy scenario. The RRF was calculated from these as:

RRF = 1 – Scenario EF/BAU EF **Eq. 6-2**

RRFs for the Line-haul Technology strategy scenarios are shown in Table 6-9. Note that it is assumed that the new engines described in Table 6-8 will have similar duty cycles, rated power, and annual usage as the engines they replace, such that emission changes are due solely to changes in the engine emission rates (e.g., in g/kWh).

Table 6-9. Relative Reduction Factors for Line-haul Technology Strategies

Scenario	Overall Emission Reduction Factors (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	7%	16%	15%	16%	0%	17%	26%	15%
2020/B	28%	41%	37%	41%	0%	34%	26%	38%
2030/A	6%	13%	10%	13%	0%	7%	0%	11%
2030/B	66%	76%	62%	76%	0%	65%	69%	62%
2050/A	-	-	-	-	5%	-	-	-
2050/B	-	-	-	-	13%	-	-	-

Note that accelerating fleet turnover for line-haul locomotives to more stringent EPA standards provides $PM_{2.5}$ and NOx reductions. However, as described in Section 5, no CO_2 reductions would be expected from moving to newer line-haul technologies for the years 2020 and 2030. Also, note that Scenario 2030/A has lower RRFs than Scenario 2020/A for all pollutants (other than CO_2 which remains 0 percent). This is due to the significantly reduced BAU emission factors in 2030, due primarily to significant reduction in the Tier 0 and Tier "0+" engines and the increased share of Tier 4 engines between 2020 and 2030. As a result, the scenarios significantly lower the BAU baseline from which scenario reductions are taken. See Appendix C for more information on the methodology and assumptions for calculating RRFs for the Line-haul Technology category.

6.3.1.1. Result Summary

Table 6-10 presents the total emission reductions of the Line-haul Technology strategy scenarios.

Table 6-10. Total Line-haul Technology Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	90.4	4.8	6.9	3.7	0	0.3	0.1	0.6
2020/B	339.6	12.3	17.4	9.5	0	0.6	0.1	1.5
2030/A	56.1	2.2	3.3	1.7	0	0.1	0.0	0.4
2030/B	573.8	13.0	20.0	10.0	0	0.9	0.2	2.2
2050/A	-	-	-	-	10,218	-	-	-
2050/B	-	-	-	-	25,546	-	-	-

6.3.2. Line-haul Operational Strategies

The Line-haul Operational strategy scenarios are shown in the second row of Table 6-8, and these scenarios involve only fuel efficiency improvements. Therefore, it was assumed that these scenarios affect only CO_2 emissions and no other pollutants. Accordingly, the RRFs are based on the increase in fuel efficiency and were applied to the line-haul portion of the CO_2 BAU inventory for each analysis year.

6.3.2.1. Result Summary

Table 6-11 shows the total emission reductions of the Line-haul Operational strategy scenarios.

Table 6-11. Total Line-haul Operational Emission Reductions

CO_2 Tons per Year					
2020/A	**2020/B**	**2030/A**	**2030/B**	**2050/A**	**2050/B**
1,043	5,216	6,835	13,669	23,224	46,447

6.3.3. Switcher Technology Strategies

Switcher Technology strategy scenarios are shown in the last row of Table 6-8. While GenSet locomotives can be built to Tier 3 or Tier 4 standards, it was assumed that the Tier 4 standards are more appropriate for all GenSet locomotives in these scenarios. The RRFs were calculated as described by Equation 6-2 above, and the underlying methodology and assumptions were similar to the Line-haul Technology scenarios. See Appendix C for further details. Table 6-12 shows the resulting RRFs for the Switcher strategy scenarios.

Table 6-12. Relative Reduction Factors for Switcher Technology Strategies

Scenario	Overall Emission Reduction Factors (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	16%	22%	21%	22%	0%	19%	15%	20%
2020/B	34%	44%	41%	44%	1%	39%	10%	40%
2030/A	17%	24%	22%	25%	0%	21%	4%	19%
2030/B	43%	47%	40%	47%	2%	32%	7%	26%
2050/A	-	-	-	-	6%	-	-	-
2050/B	-	-	-	-	10%	-	-	-

6.3.3.1. Result Summary

Table 6-13 presents the total emission reductions of the Switcher Technology strategy scenarios.

Table 6-13. Total Switcher Technology Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	208.6	7.6	17.1	5.9	150	0.6	0.1	1.4
2020/B	431.2	15.4	34.4	11.9	600	1.2	0.3	2.8
2030/A	181.9	7.0	14.8	5.4	396	0.6	0.1	1.4
2030/B	471.7	13.4	26.5	10.3	1,843	0.9	0.2	1.9
2050/A	-	-	-	-	11,399	-	-	-
2050/B	-	-	-	-	18,999	-	-	-

6.3.4. Summary of Rail Scenarios

Table 6-14 summarizes the relative emission reduction results for all pollutants by scenario and strategy for the rail sector. Figure 6-3 shows the relative reductions for NOx, $PM_{2.5}$, and CO_2. Note that line-haul and switcher reductions were calculated separately relative to the respective rail line and rail yard BAU inventories. Table 6-15 lists total emission reductions for the rail sector for each pollutant, and Figure 6-4 graphs the reductions for NOx, $PM_{2.5}$, and CO_2. Similar charts for other pollutants can be found in Appendix C. Summing the reductions in this manner is appropriate for the criteria and air toxics pollutants, since there is no overlap between Line-haul Technology, Line-haul Operational, and Switcher Technology strategy scenarios (as the operational strategies only reduce CO_2). Similarly, there is no overlap between line-haul and switcher strategies for any pollutant because the reductions are determined from separate portions of the BAU inventories. Total CO_2 emission reductions are also shown for the combined impacts of all strategy scenarios, but this overlap only occurs in 2050 scenarios with minimal impact.

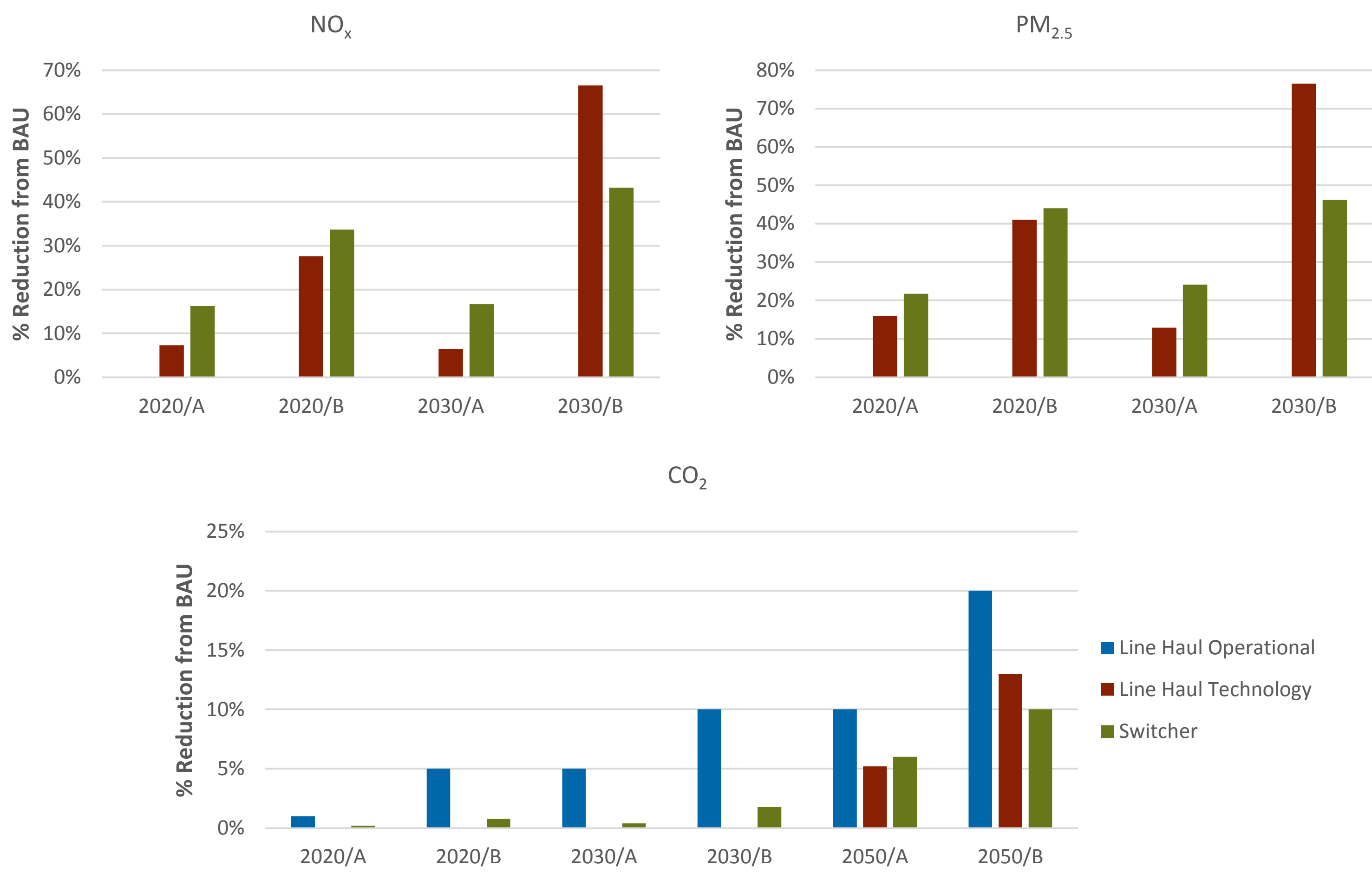
As expected, Scenario B consistently showed greater reductions than Scenario A for all pollutants and years. Rail strategy scenarios that included replacing older locomotive engines showed significant reductions for criteria and air toxics emissions in 2020 and 2030. Total relative NOx reductions from Line-haul and Switcher Technology scenarios reduced 2020 BAU emissions from 12-31% and 2030 BAU emissions from 12-54%. Similar reductions were observed for $PM_{2.5}$, where 2020 $PM_{2.5}$ reductions were estimated between 19-43% and 2030 reductions were 20-58% from the BAU inventories. Line-haul Operational scenarios showed the greatest potential for CO_2 reductions for all years, especially in 2030 and 2050. The potential for further line-haul locomotive reductions for this assessment was not fully realized due to the limited geographic scope of the rail analysis, where the modeled domain was 0.5 km from the facility edge for the baseline and BAU inventories. Additional line-haul reductions could be gained outside a port area for line-haul strategies beyond that quantified here.

Table 6-14. Rail Emission Relative Reduction Summary by Scenario and Strategy, Percent

Scenario	Rail Type	Percent Reduction from BAU								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy Summary
2020/A	Line-haul Technology	7%	16%	15%	16%	0%	17%	26%	15%	Replace 50% of Tier 0+ engines with Tier 2+ engines
	Switcher	16%	22%	21%	22%	0%	19%	15%	20%	Replace 50% of Pre-Tier 0 engines with 95% Tier 2+ engines and 5% Tier 4 GenSet
	Line-haul Operational	-	-	-	-	1%	-	-	-	1% improvement in fuel efficiency
	Total	**12%**	**19%**	**18%**	**19%**	**1%**	**19%**	**19%**	**18%**	
2020/B	Line-haul Technology	28%	41%	37%	41%	0%	34%	26%	38%	Replace 100% of Tier 0+ engines with 50% 2+ engines and 50% Tier 4 engines
	Switcher	34%	44%	41%	44%	1%	39%	10%	40%	Replace all Pre-Tier 0 engines with 90% Tier 2+ and 10% Tier 4 Genset
	Line-haul Operational	-	-	-	-	5%	-	-	-	5% improvement in fuel efficiency
	Total	**31%**	**43%**	**40%**	**43%**	**3%**	**37%**	**12%**	**39%**	
2030/A	Line-haul Technology	6%	13%	10%	13%	0%	7%	0%	11%	Replace 100% of Tier 1+ and earlier engines with 50% 2+ engines and 50% Tier 4 engines
	Switcher	17%	24%	22%	25%	0%	21%	4%	19%	Replace all Pre-Tier 0 engines and 20% of Tier 0+ with 90% Tier 2+ engines and 10% Tier 4 Genset
	Line-haul Operational	-	-	-	-	5%	-	-	-	5% improvement in fuel efficiency
	Total	**12%**	**20%**	**18%**	**20%**	**3%**	**17%**	**3%**	**17%**	
2030/B	Line-haul Technology	66%	76%	62%	76%	0%	65%	69%	62%	Replace all pre-Tier 4 engines with Tier 4 engines.
	Switcher	43%	47%	40%	47%	2%	32%	7%	26%	Replace all Pre-Tier 0 engines and 40% of Tier 0+ with 70% Tier 4 engines and 30% Tier 4 Genset
	Line-haul Operational	-	-	-	-	10%	-	-	-	10% improvement in fuel efficiency
	Total	**54%**	**58%**	**47%**	**58%**	**6%**	**43%**	**13%**	**38%**	

Scenario	Rail Type	Percent Reduction from BAU								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy Summary
2050/A	Line-haul Technology	-	-	-	-	5%	-	-	-	Replace 10% of Tier 4 with zero emissions locomotive
	Switcher	-	-	-	-	6%	-	-	-	Assume 30% Tier 4 Genset
	Line-haul Operational	-	-	-	-	10%	-	-	-	10% improvement in fuel efficiency
	Total	**-**	**-**	**-**	**-**	**11%**	**-**	**-**	**-**	
2050/B	Line-haul Technology	-	-	-	-	13%	-	-	-	Replace 25% of Tier 4 with zero emissions locomotive
	Switcher	-	-	-	-	10%	-	-	-	Assume 50% Tier 4 Genset
	Line-haul Operational	-	-	-	-	20%	-	-	-	20% improvement in fuel efficiency
	Total	**-**	**-**	**-**	**-**	**23%**	**-**	**-**	**-**	

Figure 6-3. Rail Emission Percent Reductions by Scenario and Strategy for Selected Pollutants[181]



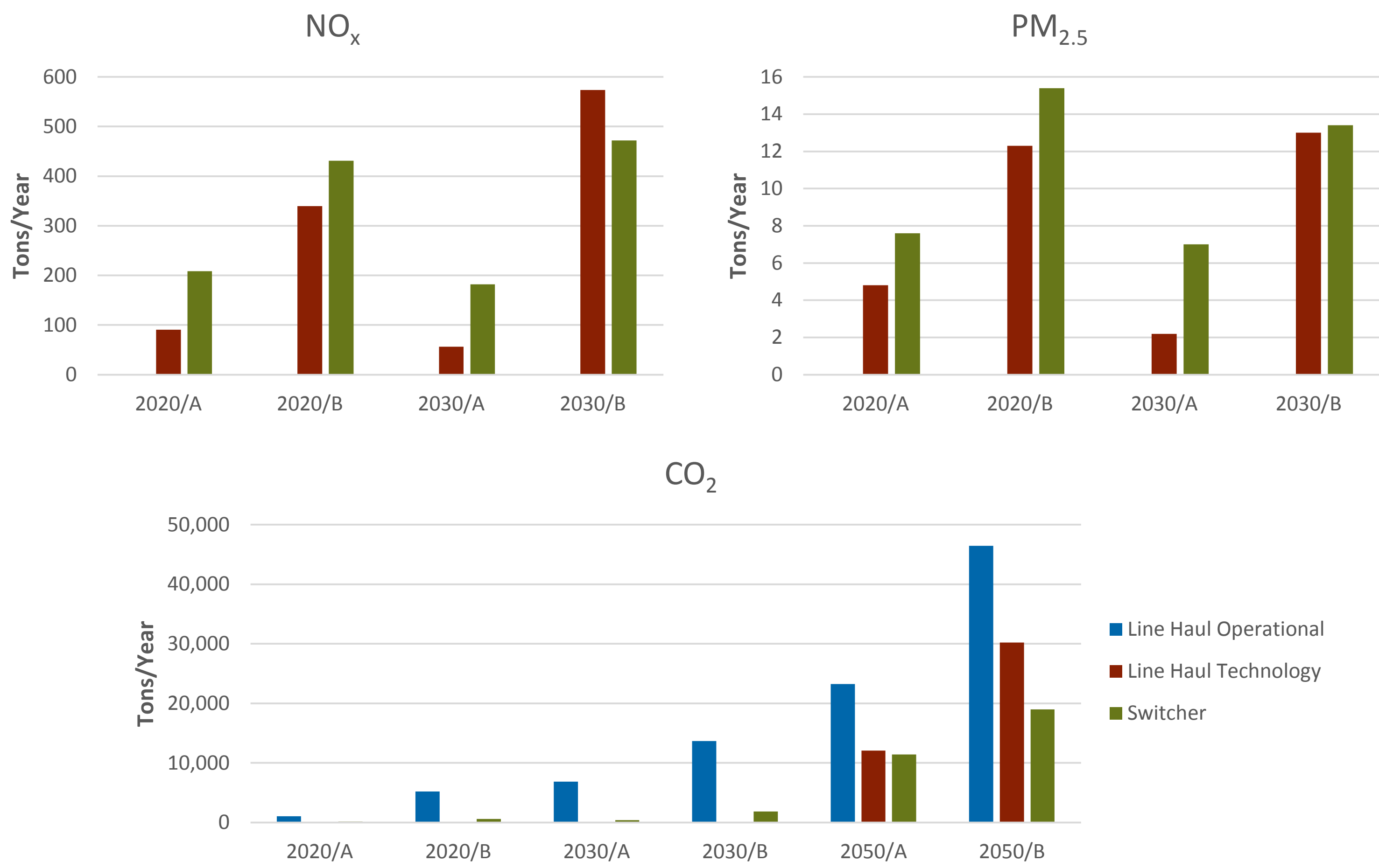
[181] Bars are omitted where no emission reductions were estimated, due to a strategy not being applicable for a specific pollutant. (e.g. Line Haul Operational for NO_x and $PM_{2.5}$)

Table 6-15. Rail Emission Reduction Summary by Scenario and Strategy, Tons per Year

Scenario	Rail Type	Tons Reduced per Year								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy Summary
2020/A	Line-haul Technology	90.4	4.8	6.9	3.7	0	0.3	0.1	0.6	Replace 50% of Tier 0+ engines with Tier 2+ engines
	Switcher	208.6	7.6	17.1	5.9	150	0.6	0.1	1.4	Replace 50% of Pre-Tier 0 engines with 95% Tier 2+ engines and 5% Tier 4 GenSet
	Line-haul Operational	-	-	-	-	1,043	-	-	-	1% improvement in fuel efficiency
	Total	**299.0**	**12.5**	**24.0**	**9.6**	**1,193**	**0.9**	**0.2**	**2.0**	
2020/B	Line-haul	339.6	12.3	17.4	9.5	0	0.6	0.1	1.5	Replace 100% of Tier 0+ engines with 50% 2+ engines and 50% Tier 4 engines
	Switcher	431.2	15.4	34.4	11.9	600	1.2	0.3	2.8	Replace all Pre-Tier 0 engines with 90% Tier 2+ and 10% Tier 4 Genset
	Line-haul Operational	-	-	-	-	5,216	-	-	-	5% improvement in fuel efficiency
	Total	**770.7**	**27.8**	**51.8**	**21.4**	**5,817**	**1.9**	**0.4**	**4.3**	
2030/A	Line-haul	56.1	2.2	3.3	1.7	0	0.1	0.0	0.4	Replace 100% of Tier 1+ and earlier engines with 50% 2+ engines and 50% Tier 4 engines
	Switcher	181.9	7.0	14.8	5.4	396	0.6	0.1	1.4	Replace all Pre-Tier 0 engines and 20% of Tier 0+ with 90% Tier 2+ engines and 10% Tier 4 Genset
	Line-haul Operational	-	-	-	-	6,835	-	-	-	5% improvement in fuel efficiency
	Total	**238.0**	**9.2**	**18.1**	**7.1**	**7,231**	**0.7**	**0.2**	**1.8**	
2030/B	Line-haul	573.8	13.0	20.0	10.0	0	0.9	0.2	2.2	Replace all pre-Tier 4 engines with Tier 4 engines.
	Switcher	471.7	13.4	26.5	10.3	1,844	0.9	0.2	1.9	Replace all Pre-Tier 0 engines and 40% of Tier 0+ with 70% Tier 4 engines and 30% Tier 4 Genset
	Line-haul Operational	-	-	-	-	13,669	-	-	-	10% improvement in fuel efficiency
	Total	**1,045.5**	**26.4**	**46.5**	**20.3**	**15,513**	**1.8**	**0.4**	**4.1**	
2050/A	Line-haul	-	-	-	-	12,076	-	-	-	Replace 10% of Tier 4 with zero emissions locomotive
	Switcher	-	-	-	-	11,399	-	-	-	Assume 30% Tier 4 Genset
	Line-haul Operational	-	-	-	-	23,224	-	-	-	10% improvement in fuel efficiency
	Total	**-**	**-**	**-**	**-**	**46,699**	**-**	**-**	**-**	

Scenario	Rail Type	Tons Reduced per Year								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy Summary
2050/B	Line-haul	-	-	-	-	30,191	-	-	-	Replace 25% of Tier 4 with zero emissions locomotive
	Switcher	-	-	-	-	18,999	-	-	-	Assume 50% Tier 4 Genset
	Line-haul Operational	-	-	-	-	46,447	-	-	-	20% improvement in fuel efficiency
	Total	**-**	**-**	**-**	**-**	**95,637**	**-**	**-**	**-**	

Figure 6-4. Rail Absolute Emission Reductions by Scenario and Strategy for Selected Pollutants[182]



[182] Bars are omitted where no emission reductions were estimated, due to a strategy not being applicable for a specific pollutant (e.g. Line Haul Operational for NO_x and $PM_{2.5}$).

6.4. Cargo Handling Equipment

As described in Section 4, this assessment focused on CHE strategies for those equipment types that contribute the bulk of CHE emissions at most ports: yard trucks, RTG cranes, and container handlers. See Section 5 for further background on CHE strategies,[183] and see Appendix C for more information on the methodology and assumptions used for the CHE scenario analyses.

6.4.1. Yard Truck Strategies

Table 6-16 shows the yard truck strategy scenarios analyzed for Scenarios A and B for the three analysis years. These strategy scenarios focused on replacement, especially for battery electric yard trucks due to the underlying assumptions for fleet turnover in the BAU inventory.[184]

Table 6-16. Yard Truck Strategy Scenarios

2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Replace all Tier 3 with Tier 4	Replace all Tier 3 with Tier 4, and replace 5% of Tier 4 with battery electric	Replace 10% Tier 4 diesel with battery electric	Replace 25% Tier 4 diesel with battery electric	Replace 25% of Tier 4 diesel engines with battery electric	Replace 50% of Tier 4 diesel engines with battery electric

6.4.1.1. Relative Reduction Factors

For each scenario, a relative reduction factor was calculated using the emission rate for each tier weighted by the population distribution in that tier. EPA's nonroad standards[185] were used as criteria pollutant emission factors for conventional diesel yard trucks. CO_2 emission factors were calculated using GREET 2015 and several other assumptions to characterize the diesel and battery technologies in the scenario strategies. RRFs were applied uniformly across the BAU inventory. See Appendix C for further details on the methodology and assumptions used.

RRFs for yard truck strategy scenarios are shown in Table 6-17.

[183] Note that all strategies are presented in terms of diesel equipment. Accordingly, all analyses were based on emission and speciation factors for diesel-fueled CHE.

[184] As described in Section 5 and Appendix C, the yard truck population distribution from the NONROAD model resulted in no Tier 1 and Tier 2 yard trucks in operation in 2020 (and only 3% of the population is Tier 3). By 2030, no Tier 3 yard trucks were assumed to be in operation.

[185] EPA NONROAD Compressed Ignition Emission Standards. Available at http://www.epa.gov/otaq/standards/nonroad/nonroadci.htm.

Table 6-17. Relative Reduction Factors for Yard Truck Strategies[186]

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	20%	21%	1%	21%	-0%	-1%	-0%	-1%
2020/B	24%	25%	6%	25%	4%	4%	5%	4%
2030/A	10%	10%	10%	10%	8%	10%	10%	10%
2030/B	25%	25%	25%	25%	19%	25%	25%	25%
2050/A	-	-	-	-	19%	-	-	-
2050/B	-	-	-	-	39%	-	-	-

6.4.1.2. Result Summary

Table 6-18 presents the total yard truck emission reductions by strategy scenario.

Table 6-18. Total Yard Truck Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	205.9	9.7	0.8	7.4	-3	-0.0	-0.0	-0.0
2020/B	247.1	11.5	4.0	8.8	19,824	0.0	0.1	0.1
2030/A	85.1	2.7	7.1	2.1	52,106	0.1	0.2	0.2
2030/B	212.8	6.9	17.7	5.3	130,266	0.2	0.5	0.5
2050/A	-	-	-	-	218,151	-	-	-
2050/B	-	-	-	-	436,303	-	-	-

6.4.2. RTG Crane Strategies

Table 6-19 shows the RTG crane strategy scenarios analyzed for Scenarios A and B for the three analysis years. These strategy scenarios focused on replacement, especially for battery electric cranes due to the underlying assumptions for fleet turnover in the BAU inventory.[187]

Table 6-19. RTG Crane Strategy Scenarios

2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Replace all Uncontrolled and 50% of Tier 1 and 2 with 50% Tier 3 and 50% Tier 4	Replace all Uncontrolled, Tier 1 and 2 with 75% Tier 4 and 25% electric	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric. Replace 10% Tier 4 with electric	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric. Replace 25% Tier 4 with electric	Replace 50% Tier 4 with electric	Replace 75% Tier 4 with electric

[186] Here and in other tables, very small negative reduction values are shown as "-0%" and "-0.0" Note that the air toxic reductions for Scenario 2020/A were small and negative while the VOC reductions were small and positive. This is due to Tier 4 aftertreatment, which changes the toxic speciation profiles.

[187] As described in Section 5 and Appendix C, the RTG crane population distribution from the NONROAD model resulted in no uncontrolled or Tier 1 cranes in operation in 2030 (and only 3% of the population is Tier 2 or Tier 3, with the rest being Tier 4).

6.4.2.1. Relative Reduction Factors

Relative reduction factors were determined using a similar methodology and assumptions as for yard trucks described above; see Appendix C for further information. RRFs for RTG crane strategy scenarios are shown in Table 6-20.

Table 6-20. Relative Reduction Factors for RTG Crane Strategies

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	19%	24%	9%	24%	-0%	5%	6%	3%
2020/B	42%	44%	21%	44%	2%	11%	13%	6%
2030/A	25%	24%	12%	24%	8%	10%	11%	10%
2030/B	37%	36%	26%	36%	20%	25%	25%	25%
2050/A	-	-	-	-	39%	-	-	-
2050/B	-	-	-	-	58%	-	-	-

6.4.2.2. Result Summary

Table 6-21 presents the total RTG crane emission reductions for the strategy scenarios.

Table 6-21. Total RTG Crane Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	174.4	7.6	5.6	5.9	-16	0.0	0.1	0.1
2020/B	377.6	13.8	13.3	10.6	4,676	0.1	0.2	0.1
2030/A	185.7	4.5	8.2	3.5	29,472	0.1	0.2	0.2
2030/B	272.7	6.8	18.0	5.2	69,368	0.2	0.5	0.5
2050/A	-	-	-	-	227,962	-	-	-
2050/B	-	-	-	-	341,943	-	-	-

6.4.3. Container Handler Strategies

Table 6-22 shows the container handler strategy scenarios analyzed for Scenarios A and B for the three analysis years. These strategy scenarios focused on replacement, especially for battery electric equipment due to the underlying assumptions for fleet turnover in the BAU inventory.[188]

Table 6-22. Container Handler Strategy Scenarios

2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Replace all Tier 1 and 2 engines with 50% Tier 3 and 50% Tier 4.	Replace Tier 1 and 2 engines with Tier 4 engines. Replace Tier 3 with 50% Tier 4 and 50% elec. engines	Replace 10% of Tier 4 diesel engines with electric engines	Replace 25% of Tier 4 diesel engines with electric	Replace 50% of Tier 4 diesel engines with electric	Replace 75% of Tier 4 diesel engines with electric

6.4.3.1. Relative Reduction Factors

Relative reduction factors were determined using a similar methodology and assumptions as for yard trucks described above; see Appendix C for further information. Table 6-23 shows resulting RRFs for container handler scenarios.

Table 6-23. Relative Reduction Factors for Container Handler Strategies

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	17%	14%	10%	14%	-0%	5%	6%	3%
2020/B	68%	69%	23%	69%	6%	8%	11%	3%
2030/A	10%	10%	10%	10%	8%	10%	10%	10%
2030/B	25%	25%	25%	25%	19%	25%	25%	25%
2050/A	-	-	-	-	39%	-	-	-
2050/B	-	-	-	-	58%	-	-	-

6.4.3.2. Result Summary

Table 6-24 presents the total container handler emission reductions by strategy scenario.

Table 6-24. Total Container Handler Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	163.7	4.2	5.6	3.2	-7	0.0	0.1	0.1
2020/B	650.7	19.8	12.3	15.3	13,071	0.1	0.2	0.0
2030/A	78.8	1.7	6.0	1.3	22,873	0.1	0.2	0.2
2030/B	197.0	4.4	15.1	3.4	57,181	0.2	0.4	0.4
2050/A	-	-	-	-	191,518	-	-	-
2050/B	-	-	-	-	287,277	-	-	-

[188] As described in Section 5 and Appendix C, the container handler population distribution from the NONROAD model resulted in only Tier 4 equipment in operation in 2030 and 2050.

6.4.4. Summary of CHE Scenario Impacts

Table 6-25 shows the emission reductions relative to the BAU inventory. The percentages for each CHE type are relative to the individual BAU inventory for that CHE type, whereas the total reductions from all three CHE types considered are shown relative to the total CHE BAU inventory to illustrate the relative magnitude of the reductions.[189] Figure 6-5 shows the percentage reductions for NOx, $PM_{2.5}$, and CO_2 relative to the individual BAU for each CHE type.

Absolute emission reduction results by scenario and strategy are shown in Table 6-26 for all pollutants for the three specific types of CHE considered here. This table includes total emission reductions as the sum over these three types of equipment strategies analyzed. This is appropriate in this situation because there is no overlap for criteria, air toxic, or climate change pollutants between any of the three equipment types since each set of reductions is derived from its own BAU inventory. Figure 6-6 shows the tons/year reductions for NOx, $PM_{2.5}$, and CO_2. Similar charts (as Figures 6-5 and 6-6) for other pollutants can be found in Appendix C.

CHE strategy scenarios resulted in significant emission reductions for criteria, air toxic, and climate change pollutants, and Scenario B consistently showed greater reductions than Scenario A. For example, total relative NOx reductions from technology scenarios for all CHE types reduced 2020 BAU NOx emissions by 17-39% and 2030 BAU emissions from 13-25%. Similar reductions were estimated for $PM_{2.5}$, where 2020 $PM_{2.5}$ reductions were estimated between 18-37% and 2030 reductions were 12-25% from the BAU case. As shown in Figure 6-6, the absolute NOx and $PM_{2.5}$ emission reductions were observed in 2020 and generally larger than or roughly equal to those for 2030, which may reflect the significant rate of fleet turnover between 2020 and 2030. Finally, CO_2 reductions estimated in this analysis were substantial, especially in 2030 and 2050 where reductions were estimated as 7-18% and 27-45% respectively. These significant CO_2 reductions demonstrate the potential of the electric technologies that were modeled in later years.

It is important to caveat the CHE results in accordance with how this assessment was completed. All CHE were considered to operate on-port, and thus all reductions reported here are limited to a modeled port facility. Although the three types of CHE analyzed here were selected due to their dominance in CHE inventories, additional benefits could be gained by applying these, or similar strategies, to other CHE types.

[189] Specifically, the total CHE BAU inventory is the sum of all CHE types, both the three types considered here and other equipment (e.g., forklifts) not targeted for reductions in this analysis. For this reason, the percent reductions calculated from the sum of all three types of CHE is smaller than the sum of the percent reductions of the three CHE types. This would not be the case if the denominator in the percent reductions were limited to the total BAU emissions of only the three types of equipment that these strategies were applied to.

Table 6-25. CHE Emission Relative Reductions by Scenario and Strategy, Percent[190, 191]

Scenario	Equipment Type	Percent Reduction from BAU								
		NOx	PM	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy
2020/A	Yard Tractor	20%	21%	1%	21%	-0%	-1%	-0%	-1%	Replace all Tier 3 with Tier 4
	Container Handler	17%	14%	10%	14%	-0%	5%	6%	3%	Replace all Tier 1 and 2 engines with 50% Tier 3 and 50% Tier 4
	RTG Crane	19%	24%	9%	24%	-0%	5%	6%	3%	Replace all Uncontrolled and 50% of Tier 1 and 2 with 50% Tier 3 and 50% Tier 4
	Total	**17%**	**18%**	**6%**	**18%**	**-0%**	**2%**	**3%**	**1%**	
2020/B	Yard Tractor	24%	25%	6%	25%	4%	4%	5%	4%	Replace all Tier 3 with Tier 4, and replace 5% of Tier 4 with battery electric
	Container Handler	68%	69%	23%	69%	6%	8%	11%	3%	Replace Tier 1 and 2 engines with Tier 4 engines. Replace Tier 3 with 50% Tier 4 and 50% electric engines
	RTG Crane	42%	44%	21%	44%	2%	11%	13%	6%	Replace all Uncontrolled, Tier 1 and 2 with 75% Tier 4 and 25% electric
	Total	**39%**	**37%**	**14%**	**37%**	**3%**	**7%**	**8%**	**4%**	
2030/A	Yard Tractor	10%	10%	10%	10%	8%	10%	10%	10%	Replace 10% Tier 4 diesel with battery electric
	Container Handler	10%	10%	10%	10%	8%	10%	10%	10%	Replace 10% of Tier 4 diesel engines with electric engines
	RTG Crane	25%	24%	12%	24%	8%	10%	11%	10%	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric Replace 10% Tier 4 with electric
	Total	**13%**	**12%**	**9%**	**12%**	**7%**	**9%**	**9%**	**9%**	
2030/B	Yard Tractor	25%	25%	25%	25%	19%	25%	25%	25%	Replace 25% Tier 4 diesel with battery electric

[190] As noted in the text, total percent reductions are determined relative to a total BAU CHE inventory that includes more than the three types of CHE analyzed here. Thus, the total percent reduction values are less than the sum of the percent reductions from each of the three CHE types shown in the table.

[191] Strategies 2020/A Yard Tractor for Benzene emissions and 2020/A CO_2 emissions for all three CHE types produce very small negative percent reductions. These are shown here as -0%, consistent with the resolution of other values.

Scenario	Equipment Type	Percent Reduction from BAU								
		NOx	PM	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy
	Container Handler	25%	25%	25%	25%	19%	25%	25%	25%	Replace 25% of Tier 4 diesel engines with electric
	RTG Crane	37%	36%	26%	36%	20%	25%	25%	25%	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric Replace 25% Tier 4 with electric
	Total	**25%**	**25%**	**22%**	**25%**	**18%**	**21%**	**21%**	**21%**	
2050/A	Yard Tractor	-	-	-	-	19%	-	-	-	Replace 25% of Tier 4 diesel engines with battery electric
	Container Handler	-	-	-	-	39%	-	-	-	Replace 50% of Tier 4 diesel engines with electric
	RTG Crane	-	-	-	-	39%	-	-	-	Replace 50% Tier 4 with electric
	Total	**-**	**-**	**-**	**-**	**27%**	**-**	**-**	**-**	
2050/B	Yard Tractor	-	-	-	-	39%	-	-	-	Replace 50% of Tier 4 diesel engines with battery electric
	Container Handler	-	-	-	-	58%	-	-	-	Replace 75% of Tier 4 diesel engines with electric
	RTG Crane	-	-	-	-	58%	-	-	-	Replace 75% Tier 4 with electric
	Total	**-**	**-**	**-**	**-**	**45%**	**-**	**-**	**-**	

Figure 6-5. CHE Percent Emission Reductions by Scenario and Strategy for Selected Pollutants

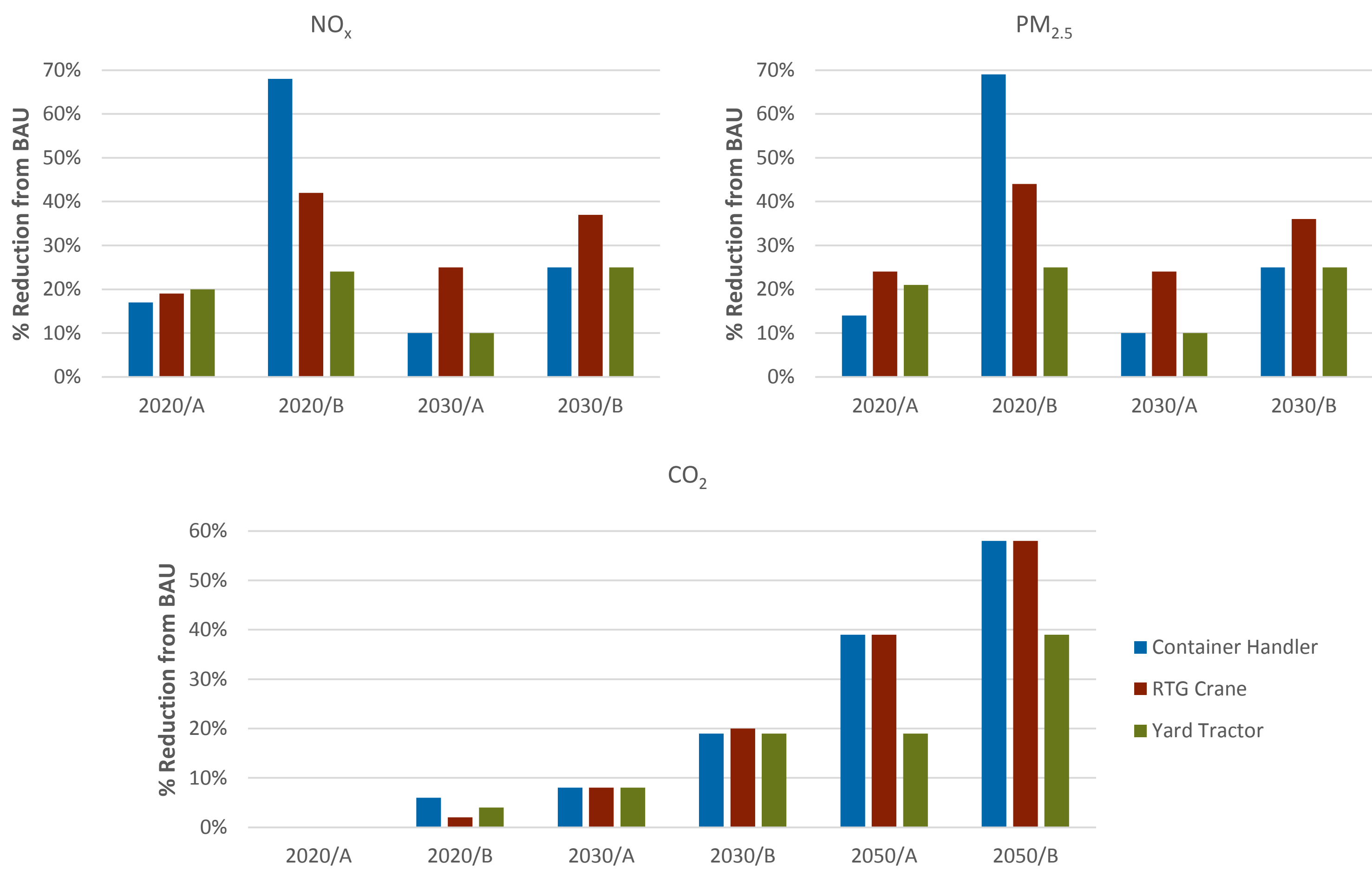


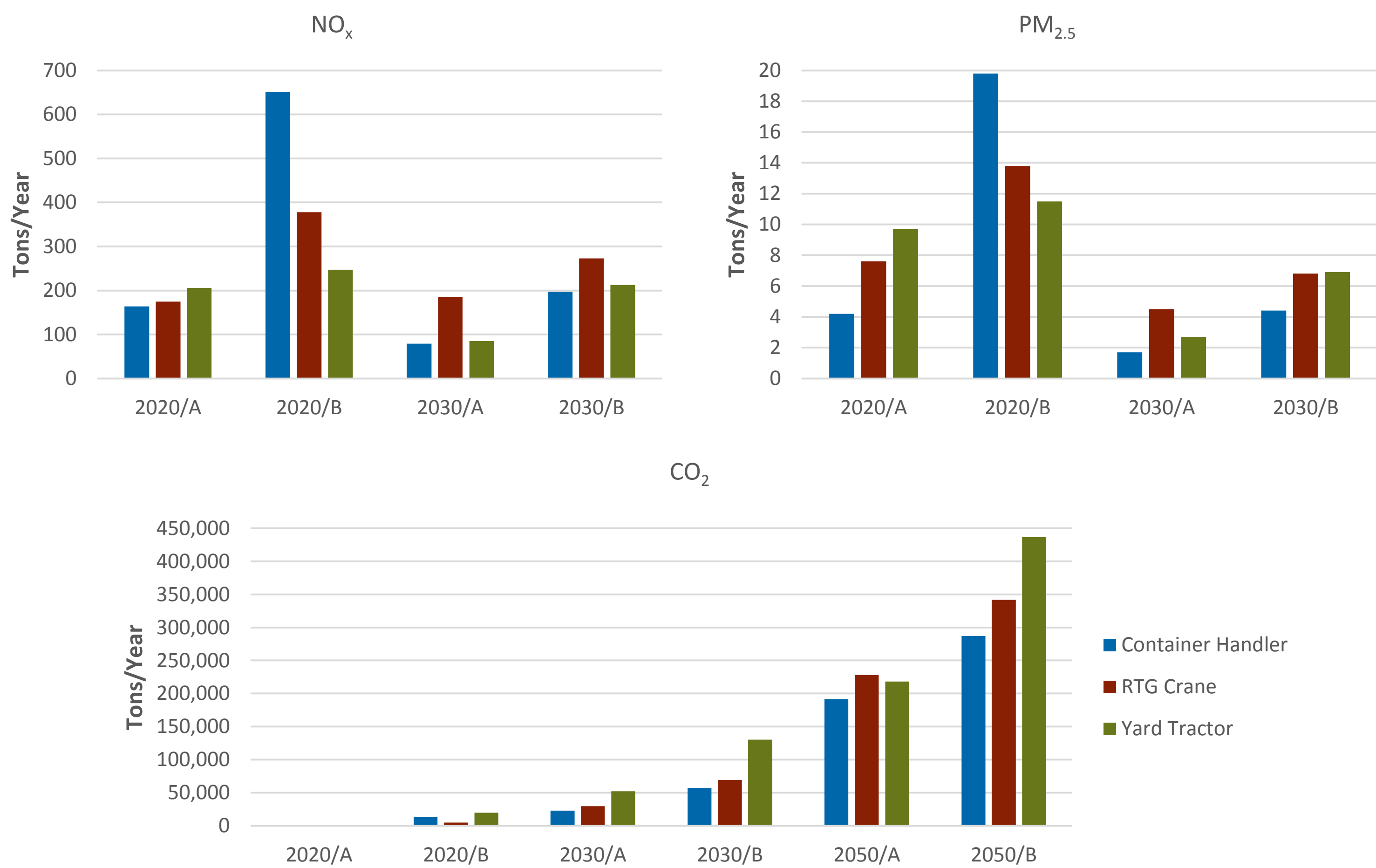
Table 6-26. CHE Emission Reduction Summary by Scenario and Strategy, Tons per Year[192]

Scenario	Equipment Type	Tons Reduced per Year								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy
2020/A	Yard Tractor	205.9	9.7	0.8	7.4	-3	-0.0	-0.0	-0.0	Replace all Tier 3 with Tier 4
	Container Handler	163.7	4.2	5.6	3.2	-7	0.0	0.1	0.1	Replace all Tier 1 and 2 engines with 50% Tier 3 and 50% Tier 4
	RTG Crane	174.4	7.6	5.6	5.9	-16	0.0	0.1	0.1	Replace all Uncontrolled and 50% of Tier 1 and 2 with 50% Tier 3 and 50% Tier 4
	Total	**544.0**	**21.4**	**12.0**	**16.5**	**-26**	**0.1**	**0.2**	**0.1**	
2020/B	Yard Tractor	247.1	11.5	4.0	8.8	19,824	0.0	0.1	0.1	Replace all Tier 3 with Tier 4, and replace 5% of Tier 4 with battery electric
	Container Handler	650.7	19.8	12.3	15.3	13,071	0.1	0.2	0.0	Replace Tier 1 and 2 engines with Tier 4 engines. Replace Tier 3 with 50% Tier 4 and 50% electric engines
	RTG Crane	377.6	13.8	13.3	10.6	4,676	0.1	0.2	0.1	Replace all Uncontrolled, Tier 1 and 2 with 75% Tier 4 and 25% electric
	Total	**1,275.4**	**45.1**	**29.6**	**34.7**	**37,572**	**0.2**	**0.5**	**0.3**	
2030/A	Yard Tractor	85.1	2.7	7.1	2.1	52,106	0.1	0.2	0.2	Replace 10% Tier 4 diesel with battery electric
	Container Handler	78.8	1.7	6.0	1.3	22,873	0.1	0.2	0.2	Replace 10% of Tier 4 diesel engines with electric engines
	RTG Crane	185.7	4.5	8.2	3.5	29,472	0.1	0.2	0.2	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric Replace 10% Tier 4 with electric
	Total	**349.6**	**9.0**	**21.3**	**7.0**	**104,451**	**0.3**	**0.6**	**0.5**	
2030/B	Yard Tractor	212.8	6.9	17.7	5.3	130,266	0.2	0.5	0.5	Replace 25% Tier 4 diesel with battery electric
	Container Handler	197.0	4.4	15.1	3.4	57,181	0.2	0.4	0.4	Replace 25% of Tier 4 diesel engines with electric

[192] Some strategies, particularly 2020/A Yard Tractor TAC emissions, produce very small negative numbers. These are shown here as -0.0, consistent with the resolution of other values.

Scenario	Equipment Type	Tons Reduced per Year								
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	Strategy
	RTG Crane	272.7	6.8	18.0	5.2	69,368	0.2	0.5	0.5	Replace all Tier 2 and 3 with 50% Tier 4 and 50% electric Replace 25% Tier 4 with electric
	Total	**682.5**	**18.0**	**50.8**	**13.9**	**256,815**	**0.6**	**1.4**	**1.3**	
2050/A	Yard Tractor	-	-	-	-	218,151	-	-	-	Replace 25% of Tier 4 diesel engines with battery electric
	Container Handler	-	-	-	-	191,518	-	-	-	Replace 50% of Tier 4 diesel engines with electric
	RTG Crane	-	-	-	-	227,962	-	-	-	Replace 50% Tier 4 with electric
	Total	**-**	**-**	**-**	**-**	**637,631**	**-**	**-**	**-**	
2050/B	Yard Tractor	-	-	-	-	436,303	-	-	-	Replace 50% of Tier 4 diesel engines with battery electric
	Container Handler	-	-	-	-	287,277	-	-	-	Replace 75% of Tier 4 diesel engines with electric
	RTG Crane	-	-	-	-	341,943	-	-	-	Replace 75% Tier 4 with electric
	Total	**-**	**-**	**-**	**-**	**1,065,523**	**-**	**-**	**-**	

Figure 6-6. CHE Absolute Emission Reductions by Scenario and Strategy for Selected Pollutants



6.5. Harbor Craft

The analysis of emission reduction strategies for harbor craft focused on the two types of vessels that contribute the bulk of harbor craft emissions at most ports: tugs and ferries. See Section 5 for further background on harbor craft strategies, as well as Section 4 and Appendix C for more information on the development of the harbor craft BAU inventories and scenario analysis.

6.5.1. Tug Strategies

Table 6-27 shows the tug strategy scenarios analyzed for Scenarios A and B for the different analysis years. Due to the slower fleet turnover assumed, tug strategies analyzed included more repowers and replacements of cleaner diesel engines for all years, with an introduction of hybrid electric technology in 2030 and 2050.

Table 6-27. Tug Strategy Scenarios

2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Repower/ Replace all Pre-Control engines with Tier 3 engines	Repower/ Replace all Pre-Control and Tier 1 with Tier 3 Repower 10% of Tier 2 with Tier 3 hybrid electric	Repower/ Replace all Tier 1 and 2 with Tier 4 Repower/ Replace 25% of Tier 3 engines with Tier 4 engines	Repower/ Replace all Tier 1 and 2 with Tier 4 Repower/ Replace 50% of Tier 3 engines with Tier 4 engines Repower/ Replace 25% of Tier 4 with hybrid electric	Repower/ Replace 50% of Tier 3 engines with Tier 4 engines Repower/ Replace 10% of Tier 4 with hybrid electric	Repower/ Replace all Tier 3 engines with Tier 4 engines Repower/ Replace 25% of Tier 4 with hybrid electric

6.5.1.1. Relative Reduction Factors

A relative reduction factor (RRF) was calculated for each scenario using the emission rate for each tier weighted by the population distribution in that tier. This method was applied consistently for all strategies outlined in Table 6-27 and applied uniformly across the tug portion of the BAU inventory. The resulting RRFs for tug strategy scenarios are shown in Table 6-28.

Table 6-28. Relative Reduction Factors for Tug Strategies

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	9%	14%	9%	14%	0%	9%	9%	9%
2020/B	27%	49%	34%	49%	1%	33%	33%	32%
2030/A	27%	30%	28%	30%	0%	17%	20%	7%
2030/B	42%	41%	39%	41%	1%	21%	27%	6%
2050/A	-	-	-	-	1%	-	-	-
2050/B	-	-	-	-	3%	-	-	-

6.5.1.2. Result Summary

Table 6-29 presents the total emission reductions of tug strategy scenarios.

Table 6-29. Total Tug Emission Reductions

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	2,390.5	102.5	55.5	78.9	0	2.0	0.4	4.4
2020/B	7,108.1	364.2	205.7	280.4	30,300	7.3	1.6	15.9
2030/A	5,099.2	164.4	117.1	126.6	0	2.6	0.7	2.6
2030/B	7,961.4	222.6	165.5	171.4	29,312	3.3	0.9	2.0
2050/A	-	-	-	-	73,301	-	-	-
2050/B	-		-	-	183,253	-	-	-

6.5.2. Ferry Strategies

Table 6-30 shows the ferry strategy scenarios analyzed for the relevant analysis years in this assessment. As with tugs, scenarios included more repower and replacement strategies for cleaner diesel engines, with some opportunity for hybrid electric technology in all analysis years.

Table 6-30. Ferry Strategy Scenarios

2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Repower/ Replace all Pre-Control engines with Tier 3 engines	Repower/ Replace all Pre-Control and Tier 1 with Tier 3 Repower 10% of Tier 2 with Tier 3 hybrid electric	Repower/ Replace all Tier 0, 1 and 2 with Tier 4 Repower/ Replace 25% of Tier 3 engines with Tier 4 engines	Repower/ Replace all Tier 0, 1 and 2 with Tier 4 Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric	Repower/ Replace all Tier 2 and 50% of Tier 3 engines with Tier 4 engines Repower/ Replace 10% of Tier 4 with hybrid electric	Repower/ Replace all Tier 2 and 3 engines with Tier 4 engines Repower/ Replace 25% of Tier 4 with hybrid electric

6.5.2.1. Relative Reduction Factors

A relative reduction factor (RRF) was calculated using the emission rate for each tier weighted by the population distribution in that tier. This method was applied consistently for all strategies outlined in Table 6-30 and applied uniformly to all ports within this national scale analysis.

The RRFs for ferry strategy scenarios are shown in Table 6-31.

Table 6-31. Relative Reduction Factors for Ferry Strategies

Scenario	Overall Emission Reductions (%)							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	30%	33%	23%	33%	0%	22%	23%	22%
2020/B	39%	50%	34%	50%	0%	34%	34%	33%
2030/A	51%	60%	50%	60%	0%	39%	42%	29%
2030/B	62%	68%	59%	68%	1%	44%	49%	32%
2050/A	-	-	-	-	1%	-	-	-
2050/B	-	-	-	-	3%	-	-	-

6.5.2.2. Result Summary

Table 6-32 presents the total ferry emission reductions by strategy scenario.

Table 6-32. Total Ferry Emission Reductions, Tons per Year

Scenario	Tons per Year							
	NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	952.2	30.2	16.8	23.2	0	0.6	0.1	1.3
2020/B	1,249.1	45.2	25.3	34.8	1,124	0.9	0.2	2.0
2030/A	926.4	31.6	20.0	24.3	0	0.6	0.1	1.0
2030/B	1,108.0	35.5	23.6	27.3	3,090	0.6	0.2	1.1
2050/A	-	-	-	-	4,383	-	-	-
2050/B	-	-	-	-	10,957	-	-	-

6.5.3. Summary of Harbor Craft Scenario Impacts

Table 6-33 shows the emission reductions relative to the BAU inventory, and Figure 6-7 shows the percentage reductions for NOx, $PM_{2.5}$, and CO_2. Similar charts for other pollutants can be found in Appendix C. To better illustrate the relative magnitude of the reductions, the values are presented for both the total BAU emissions for the sector (including other types of Category 1 and 2 vessels not characterized here) as well as for specific vessel types. In Table 6-33, the percentages for each vessel type are calculated against the individual BAU inventory for that vessel type, and the total reductions from both vessel types considered are shown relative to the total harbor craft BAU inventory.[193]

Table 6-34 summarizes absolute emission reduction results for all pollutants by scenario and strategy for the two specific types of harbor craft considered here. This table includes total emission reductions as the sum over these two vessel types. This is appropriate in this situation because there is no overlap for criteria, toxic, or CO_2 pollutants between these two vessel types since each set of reductions is derived

[193] Specifically, the total harbor craft BAU inventory is the sum of all harbor craft types, both the two types considered here and other kinds (e.g., research vessels) not targeted for reductions in this analysis. For this reason, the percent reductions calculated from the sum of both kinds of harbor craft is smaller than the sum of the percent reductions of tugs and ferries.

from its own BAU inventory. Figure 6-8 shows the tons/year reductions for NOx, $PM_{2.5}$, and CO_2, and similar charts for other pollutants can be found in Appendix C.

By accelerating fleet turnover through the introduction of cleaner technologies, the harbor craft strategy scenarios produced significant NOx and $PM_{2.5}$ reductions. For example, total relative NOx reductions from all harbor craft strategies produced significant reductions between Scenarios A and B; in 2020, reductions ranged from 10-24% and from 25-38% in 2030 from the total harbor craft BAU inventories for those years. Similar reductions were observed for $PM_{2.5}$, where total 2020 $PM_{2.5}$ reductions were estimated between 13-41% and total 2030 reductions were from 28-37% from the BAU case. In contrast, minimal CO_2 reductions were observed for all scenarios, with a 1-3% CO_2 reduction estimated in 2050; no significant CO_2 reductions were estimated in 2020 or 2030 since no or limited hybrid electric replacements occurred in those analysis years. These particular results should not be viewed as reflecting the full potential of hybrid electric technologies; instead the low performance of these strategies in this assessment is due to the slower rate of turnover assumed for this sector in the analysis (and thus, the reduced opportunity for applying such technologies).

There are also noteworthy differences between comparing relative and absolute reductions for this sector. Figure 6-7 illustrates the importance of assessing the potential of emission reductions for a given scenario, where ferry strategy scenarios show a higher relative reductions in criteria polllutants as compared to tug scenarios for all modeled scenarios. This is most likely due to the higher relative reduction factors for ferry scenarios that reflect more replacement of lower tier diesel engines. In contrast, the opposite is true for total emission reductions in Figure 6-8, where tug strategy scenarios produce a significantly larger absolute emission reduction than ferry scenarios for criteria pollutants, due to the large number of tugs assumed relative to ferries in the harbor craft BAU inventories.

Table 6-33. Harbor Craft Emission Relative Reduction Summary by Scenario and Strategy, Percent[194]

Scenario	Vessel Type	Percent Reduction from BAU								Strategy
		NOX	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	
2020/A	Tug	9%	14%	9%	14%	0%	9%	9%	9%	Repower/ Replace all Pre-Control engines with Tier 3 engines
	Ferry	30%	33%	23%	33%	0%	22%	22%	22%	Repower/ Replace all Pre-Control engines with Tier 3 engines
	Total	**10%**	**13%**	**9%**	**13%**	**0%**	**9%**	**9%**	**9%**	
2020/B	Tug	27%	49%	34%	49%	1%	33%	33%	32%	Repower/ Replace all Pre-Control and Tier 1 with Tier 3. Repower 10% of Tier 2 with Tier 3 hybrid electric.
	Ferry	39%	50%	34%	50%	0%	34%	34%	33%	Repower/ Replace all Pre-Control and Tier 1 with Tier 3. Repower 10% of Tier 2 with Tier 3 hybrid electric.
	Total	**24%**	**41%**	**28%**	**41%**	**1%**	**28%**	**28%**	**27%**	
2030/A	Tug	27%	30%	28%	30%	0%	16%	20%	7%	Repower/ Replace all Tier 1 and 2 with Tier 4. Repower/ Replace 25% of Tier 3 engines with Tier 4 engines.
	Ferry	51%	60%	50%	60%	0%	39%	42%	29%	Repower/ Replace all Tier 0, 1 and 2 with Tier 4. Repower/ Replace 25% of Tier 3 engines with Tier 4 engines.
	Total	**25%**	**28%**	**26%**	**28%**	**0%**	**16%**	**19%**	**8%**	
2030/B	Tug	42%	41%	39%	41%	1%	21%	27%	6%	Repower/ Replace all Tier 1 and 2 with Tier 4. Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Ferry	62%	67%	59%	67%	1%	44%	49%	32%	Repower/ Replace all Tier 0, 1 and 2 with Tier 4. Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Total	**38%**	**37%**	**35%**	**37%**	**1%**	**20%**	**24%**	**7%**	

[194] As noted in the text, total percent reductions are determined relative to a total BAU harbor craft inventory that includes more than the two types of harbor craft analyzed here. (It also includes fishing vessels, government vessels, support vessels, etc.) Thus, the total percent reduction values are less than the sum of the percent reductions from each of the two harbor craft types shown in the table.

Scenario	Vessel Type	Percent Reduction from BAU								Strategy
		NOX	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	
2050/A	Tug	-	-	-	-	1%	-	-	-	Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 10% of Tier 4 with hybrid electric.
	Ferry	-	-	-	-	1%	-	-	-	Repower/ Replace all Tier 2 and 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 10% of Tier 4 with hybrid electric.
	Total	**-**	**-**	**-**	**-**	**1%**	**-**	**-**	**-**	
2050/B	Tug	-	-	-	-	3%	-	-	-	Repower/ Replace all Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Ferry	-	-	-	-	3%	-	-	-	Repower/ Replace all Tier 2 and 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Total	**-**	**-**	**-**	**-**	**3%**	**-**	**-**	**-**	

Figure 6-7. Harbor Craft Percent Emission Reductions by Scenario and Strategy for Selected Pollutants

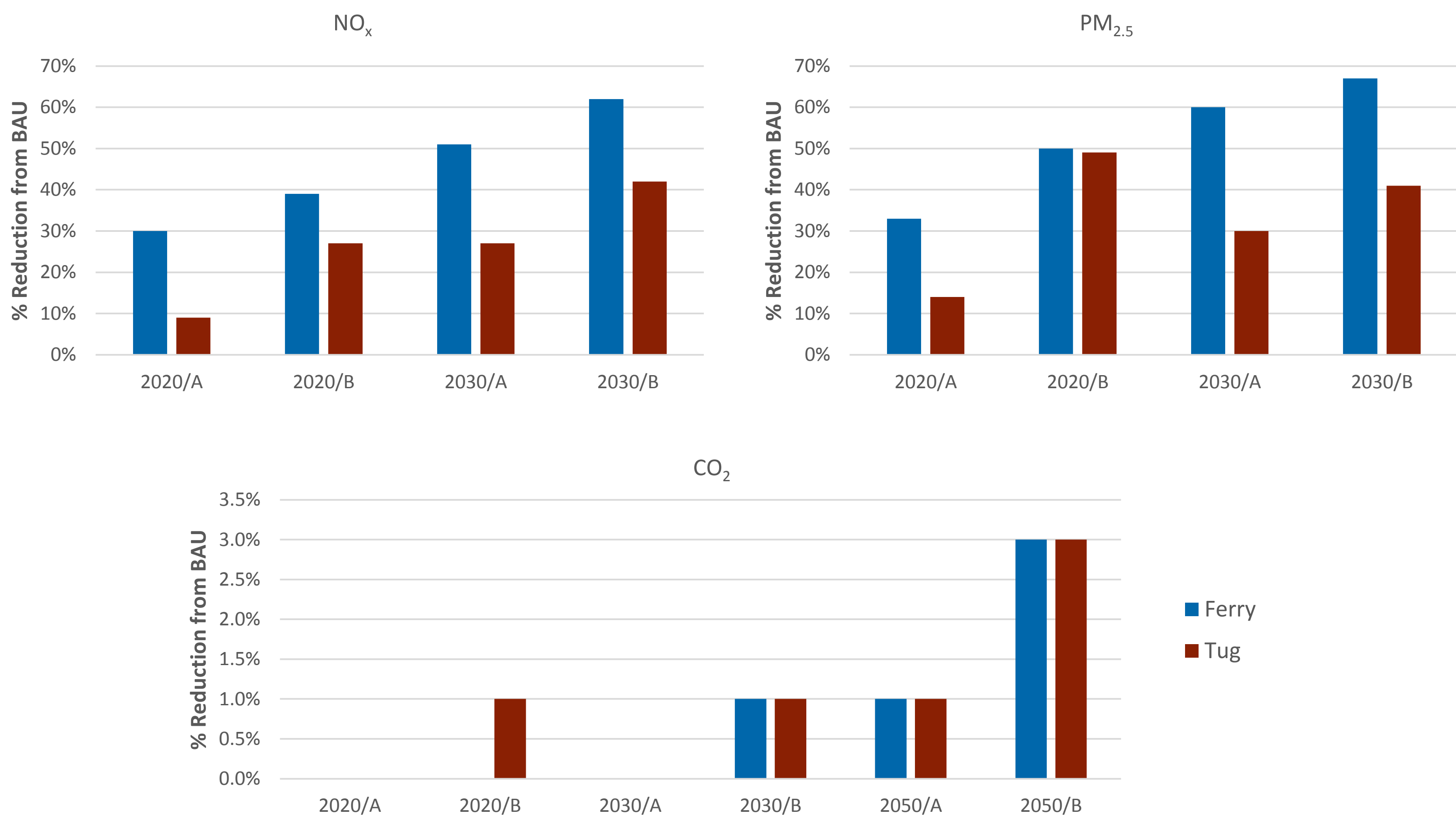
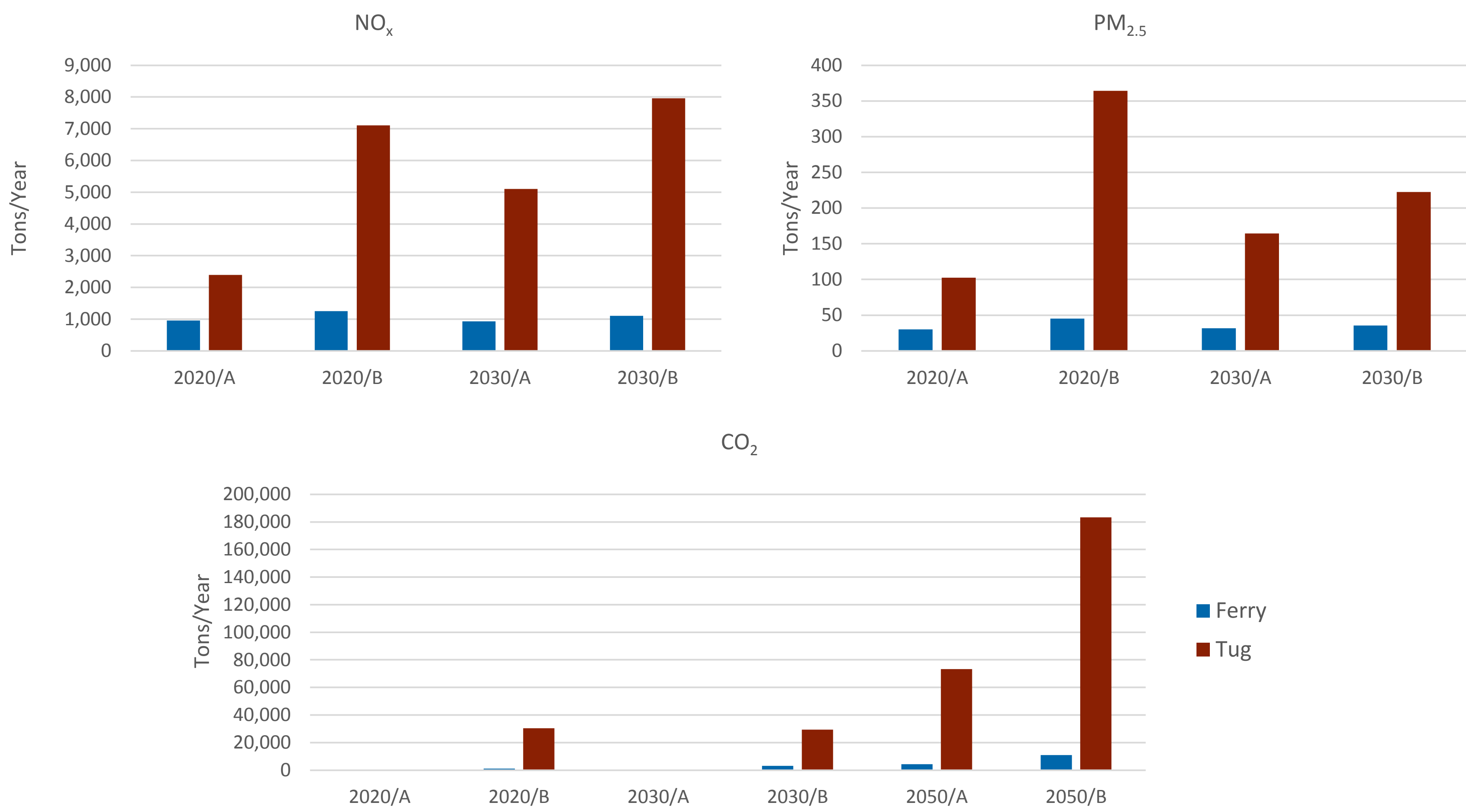


Table 6-34. Harbor Craft Emission Reduction Summary by Scenario and Strategy, Tons per Year

Scenario	Vessel Type	Tons Reduced per Year								Strategy
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	
2020/A	Tug	2,390.5	102.5	55.5	78.9	0	2.0	0.4	4.4	Repower/ Replace all Pre-Control engines with Tier 3 engines
	Ferry	952.2	30.2	16.8	23.2	0	0.6	0.1	1.3	Repower/ Replace all Pre-Control engines with Tier 3 engines
	Total	**3,342.7**	**132.6**	**72.3**	**102.1**	**0**	**2.6**	**0.6**	**5.8**	
2020/B	Tug	7,108.1	364.2	205.7	280.4	30,300	7.3	1.6	15.9	Repower/ Replace all Pre-Control and Tier 1 with Tier 3. Repower 10% of Tier 2 with Tier 3 hybrid electric.
	Ferry	1,249.1	45.2	25.3	34.8	1,124	0.9	0.2	2.0	Repower/ Replace all Pre-Control and Tier 1 with Tier 3. Repower 10% of Tier 2 with Tier 3 hybrid electric.
	Total	**8,357.2**	**409.4**	**231.0**	**315.2**	**31,424**	**8.2**	**1.8**	**17.9**	
2030/A	Tug	5,099.2	164.4	117.1	126.6	0	2.6	0.7	2.6	Repower/ Replace all Tier 1 and 2 with Tier 4. Repower/ Replace 25% of Tier 3 engines with Tier 4 engines.
	Ferry	926.4	31.6	20.0	24.3	0	0.6	0.1	1.0	Repower/ Replace all Tier 0, 1 and 2 with Tier 4. Repower/ Replace 25% of Tier 3 engines with Tier 4 engines.
	Total	**6,025.5**	**196.0**	**137.1**	**150.9**	**0**	**3.2**	**0.8**	**3.6**	
2030/B	Tug	7,961.4	222.6	165.5	171.4	29,312	3.3	0.9	2.0	Repower/ Replace all Tier 1 and 2 with Tier 4. Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Ferry	1,108.0	35.5	23.6	27.3	3,090	0.6	0.2	1.1	Repower/ Replace all Tier 0, 1 and 2 with Tier 4. Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Total	**9,069.5**	**258.1**	**189.1**	**198.7**	**32,402**	**3.9**	**1.1**	**3.1**	
2050/A	Tug	-	-	-	-	73,301	-	-	-	Repower/ Replace 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 10% of Tier 4 with hybrid electric.
	Ferry	-	-	-	-	4,383	-	-	-	Repower/ Replace all Tier 2 and 50% of Tier 3 engines with Tier 4 engines. Repower/ Replace 10% of Tier 4 with hybrid electric.

Scenario	Vessel Type	Tons Reduced per Year								Strategy
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde	
	Total	**-**	**-**	**-**	**-**	**77,684**	**-**	**-**	**-**	
2050/B	Tug	-	-	-	-	183,253	-	-	-	Repower/ Replace all Tier 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Ferry	-	-	-	-	10,957	-	-	-	Repower/ Replace all Tier 2 and 3 engines with Tier 4 engines. Repower/ Replace 25% of Tier 4 with hybrid electric.
	Total	**-**	**-**	**-**	**-**	**194,210**	**-**	**-**	**-**	

Figure 6-8. Harbor Craft Absolute Emission Reductions by Scenario and Strategy for Selected Pollutants



6.6. Ocean Going Vessels

OGV scenarios covered several different types of strategies, and these were grouped under the following categories:

- Fuel Change
- Shore Power
- Advanced Marine Emission Control System (AMECS)[195]
- Reduced Hoteling Time

Several factors were considered here, similar to the considerations that port stakeholders would need to understand when deciding among several strategies. EPA considered the specific vessel types that would best be targeted for a given strategy as well as the feasibility of implementing fuel and technology strategies. Some strategies, such as shore power, were applied only to OGVs that were assumed to visit the same port multiple times a year (i.e., "frequent callers"), while other strategies could be implemented for frequent and non-frequent callers of an appropriate vessel type. In addition, some strategies were applied to either propulsion or auxiliary OGV engines and the respective types of emissions involved (e.g., targeting auxiliary engines would reduce OGV hoteling emissions).

The following sections summarize the methodology and results for each of these four categories of strategy scenarios. Reductions were calculated for all scenarios relative to the applicable portion of the BAU inventories, independently. For example, strategies that address auxiliary engines were compared to the portion of auxiliary emissions in the BAU inventories. Further background on OGV strategies can be found in Section 5 of this report, and see Appendix C for details on the methodology and assumptions for OGV strategy scenarios.

6.6.1. Fuel Change Strategies

The Fuel Change strategy scenarios included several fuel types that substituted for the fuel required in the North American Emission Control Area (ECA) (i.e., 1,000 ppm sulfur distillate fuel).[196]

- Use 500 ppm sulfur diesel fuel in propulsion engines for bulk carriers, container ships, passenger ships and tankers.
- Use 200 ppm sulfur diesel fuel in propulsion engines for bulk carriers, container ships, passenger ships and tankers.
- Use ultra-low sulfur diesel (ULSD) in auxiliary engines for bulk carriers, container ships, passenger ships and tankers.
- Use liquefied natural gas (LNG) in propulsion engines for bulk carriers, container ships and tankers.
- Use LNG in auxiliary engines for bulk carriers, container ships and tankers.

Fuel Change scenarios are presented separately for propulsion and auxiliary engines, and as discussed earlier, these engines are involved in different types of OGV activity that may be important to consider

[195] AMECS is the term used by the California Air Resources Board (CARB) for this technology, sometimes also referred to as "stack bonnets."

[196] U.S. Environmental Protection Agency, *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder,* 75 FR 24802 (April 30, 2010).

when deciding the priority of individual strategies (e.g., propulsion and auxiliary engines are used for OGV maneuvering activity within a harbor while only auxiliary engines are used for hoteling at land-side). Table 6-35 shows the Fuel Change scenarios considered for propulsion engines. Each of these scenarios reflects the penetration rates of new fuel with the remaining fuel assumed to be 1,000 ppm S Marine Diesel Oil (MDO)/Marine Gas Oil (MGO), as required by the ECA. For example, in Scenario A in 2020 ("2020/A"), the total fuel for propulsion engine activity was assumed to be 10% 500 ppm S, 2% LNG, and 88% 1,000 ppm S.

Table 6-35. Fuel Change Strategy Scenarios for OGV Propulsion Engines

Ship Type	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Bulk	10% use 500 ppm sulfur fuel; 2% use LNG	25% use 500 ppm sulfur fuel; 10% use LNG	25% use 200 ppm sulfur fuel; 4% use LNG	50% use 200 ppm sulfur fuel; 15% use LNG	8% use LNG	25% use LNG
Container	10% use 500 ppm sulfur fuel; 1% use LNG	25% use 500 ppm sulfur fuel; 5% use LNG	25% use 200 ppm sulfur fuel; 2% use LNG	50% use 200 ppm sulfur fuel; 5% use LNG	5% use LNG	5% use LNG
Passenger	10% use 500 ppm sulfur fuel	25% use 500 ppm sulfur fuel	25% use 200 ppm sulfur fuel	50% use 200 ppm sulfur fuel	-	-
Tanker	10% use 500 ppm sulfur fuel; 2% use LNG	25% use 500 ppm sulfur fuel; 10% use LNG	25% use 200 ppm sulfur fuel; 4% use LNG	50% use 200 ppm sulfur fuel; 15% use LNG	8% use LNG	25% use LNG

The percentages were applied to that portion of the installed auxiliary power (i.e., calls times total auxiliary power) and the remaining percentage in each scenario was assumed to be 1,000 ppm sulfur fuel. LNG was limited to 5% in container ships, and LNG was not applied to passenger ships due to passenger safety issues.[197] Note also that the 2050 reductions were calculated only for CO_2 emissions, so only strategies that affect CO_2 emission were included for scenarios in that year. Table 6-36 shows the Fuel Change strategy scenarios for auxiliary engines.

[197] Lloyd's Register Marine, *Global Marine Fuel Trends 2030,* 2014. Available at http://www.lr.org/en/_images/213-34172_Global_Marine_Fuel_Trends_2030.pdf.

Table 6-36. Fuel Change Strategy Scenarios for OGV Auxiliary Engines

Ship Type	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Bulk	10% use ULSD; 2% use LNG	20% use ULSD; 10% use LNG	30% use ULSD; 4% use LNG	40% use ULSD; 15% use LNG	8% use LNG	25% use LNG
Container	10% use ULSD; 1% use LNG	20% use ULSD; 5% use LNG	30% use ULSD; 2% use LNG	40% use ULSD; 5% use LNG	5% use LNG	5% use LNG
Passenger	10% use ULSD	20% use ULSD	30% use ULSD	40% use ULSD	-	-
Tanker	10% use ULSD; 2% use LNG	20% use ULSD; 10% use LNG	30% use ULSD; 4% use LNG	40% use ULSD; 15% use LNG	8% use LNG	25% use LNG

As described above, all percentages were applied according to that portion of the installed auxiliary power (i.e., calls times total auxiliary power) and the remaining percentage in each scenario was assumed to be 1,000 ppm sulfur fuel. The LNG assumptions for propulsion engines also were applied to auxiliary engines and the 2050 scenarios.

6.6.1.1. Relative Reduction Factors

To calculate emission reductions for the scenarios listed in Table 6-35 and Table 6-36, BAU emission inventories were separated into propulsion and auxiliary engine emissions for four ship types: bulk carrier, container, passenger, and tanker vessels. Emissions related to propulsion engines during reduced speed zone (RSZ) and maneuvering modes were combined into the propulsion engine emissions. Emissions related to auxiliary engines during RSZ, maneuvering, and hoteling modes were combined into the auxiliary engine emissions. In addition, hoteling-only emissions were also calculated by ship type to use for strategies that affect only hoteling emissions, and were included in the auxiliary engine emissions of the BAU inventories. BAU emissions assumed the use of 1,000 ppm S fuel in propulsion and auxiliary engines.

Relative reduction factors (RRFs) were calculated for each scenario by developing emission factors by engine type and fuel type for each ship type. The RRFs for OGV Fuel Change scenarios are shown in Table 6-37 through Table 6-41.[198]

[198] Please note that use of emissions factors to determine RRF implies that other technical and operational parameters, such as engine load, are unchanged between the BAU and analysis scenario. Negative RRFs imply an increase in emissions from the scenario.

Table 6-37. Relative Reduction Factors for Fuel Scenario 2020/A[199]

Engine	Vessel	Overall Emission Reductions (%)					
		NOx	$PM_{2.5}$	HC[200]	BC	CO_2	SO_2
Propulsion	Bulk	2%	3%	0%	1%	0%	7%
	Container	1%	2%	0%	1%	0%	6%
	Passenger	0%	1%	0%	1%	0%	5%
	Tanker	2%	3%	0%	1%	1%	7%
Auxiliary	Bulk	2%	4%	-1%	2%	1%	12%
	Container	1%	3%	-0%	2%	0%	11%
	Passenger	0%	2%	0%	2%	0%	10%
	Tanker	2%	4%	-1%	2%	1%	12%

Table 6-38. Relative Reduction Factors for Fuel Scenario 2020/B

Engine	Vessel	Overall Emission Reductions (%)					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
Propulsion	Bulk	9%	10%	2%	2%	2%	22%
	Container	4%	6%	1%	2%	1%	18%
	Passenger	0%	2%	0%	2%	0%	13%
	Tanker	9%	10%	2%	2%	2%	22%
Auxiliary	Bulk	9%	12%	-3%	3%	3%	30%
	Container	4%	8%	-1%	4%	2%	25%
	Passenger	0%	5%	0%	5%	0%	25%
	Tanker	9%	12%	-3%	3%	3%	30%

Table 6-39. Relative Reduction Factors for Fuel Scenario 2030/A

Engine	Vessel	Overall Emission Reductions (%)					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
Propulsion	Bulk	3%	6%	1%	3%	1%	24%
	Container	2%	5%	0%	3%	1%	22%
	Passenger	0%	3%	0%	3%	0%	20%
	Tanker	3%	7%	1%	3%	1%	24%
Auxiliary	Bulk	3%	9%	-1%	5%	1%	34%
	Container	1%	7%	-1%	5%	1%	32%
	Passenger	0%	6%	0%	6%	0%	30%
	Tanker	3%	9%	-1%	5%	1%	34%

[199] As done previously, the very small negative percent reductions for HC for Container Ship Auxiliary Engines are shown as -0%.

[200] Note that, consistent with the baseline and BAU emission inventory development, OGV results are reported in hydrocarbons (HC) while all other sectors report volatile organic compounds (VOC).

Table 6-40. Relative Reduction Factors for Fuel Scenario 2030/B

Engine	Vessel	Overall Emission Reductions (%)					
		NO_x	$PM_{2.5}$	HC	BC	CO_2	SO_2
Propulsion	Bulk	11%	19%	3%	6%	3%	55%
	Container	4%	10%	1%	6%	1%	45%
	Passenger	0%	7%	0%	7%	0%	40%
	Tanker	11%	19%	2%	6%	3%	55%
Auxiliary	Bulk	10%	20%	-4%	7%	5%	54%
	Container	3%	12%	-1%	7%	2%	44%
	Passenger	0%	7%	0%	7%	0%	39%
	Tanker	10%	20%	-4%	7%	5%	54%

Table 6-41. Relative Reduction Factors for Scenarios 2050/A and 2050/B

Engine	Vessel	Scenario Reductions (%)	
		2050/A	2050/B
Propulsion	Bulk	1.8%	5.6%
	Container	1.1%	1.1%
	Passenger	0.0%	0.0%
	Tanker	1.8%	5.7%
Auxiliary	Bulk	2.7%	8.5%
	Container	1.7%	1.7%
	Passenger	0.0%	0.0%
	Tanker	2.7%	8.5%

See Appendix C for further details on the methodology and assumptions used to develop RRFs for these scenarios.

6.6.1.2. Result Summary

Table 6-42 shows the total emission reductions of the 2020 and 2030 Fuel Change scenarios for propulsion engines.

Table 6-42. Total Fuel Change Emission Reductions from Propulsion Engines

Scenario	Ship Type	Combined Emission Reductions (Tons per Year)					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Bulk	12.5	0.3	0.2	0.0	177	1.7
	Container	15.4	0.6	0.5	0.0	187	3.1
	Passenger	-	0.0	-	0.0	-	0.4
	Tanker	18.1	0.5	0.3	0.0	264	2.5
	Totals	46.0	1.4	1.0	0.0	628	7.7
2020/B	Bulk	62.5	1.3	1.0	0.0	885	5.5
	Container	77.1	2.3	2.3	0.1	935	9.2
	Passenger	-	0.1	-	0.0	-	0.9
	Tanker	90.2	1.9	1.6	0.0	1,318	8.0
	Totals	229.8	5.6	4.9	0.1	3,139	23.6
2030/A	Bulk	13.5	1.1	0.5	0.0	486	8.0
	Container	18.2	2.7	1.4	0.1	566	17.4
	Passenger	-	0.2	-	0.0	-	2.1
	Tanker	19.2	1.6	0.9	0.1	716.3	11.7
	Totals	50.9	5.6	2.8	0.2	1,769	39.2
2030/B	Bulk	50.5	3.2	2.0	0.1	1,823	18.3
	Container	45.6	5.9	3.4	0.2	1,416	35.6
	Passenger	-	0.3	-	0.0	-	4.3
	Tanker	71.9	4.8	3.3	0.1	2,686	26.7
	Totals	168.0	14.2	8.7	0.4	5,925	85.0

Table 6-43 shows the total emission reductions of the 2020 and 2030 Fuel Change scenarios for auxiliary engines.

Table 6-43. Total Fuel Change Emission Reductions from Auxiliary Engines

Scenario	Ship Type	Combined Emission Reductions (Tons per Year)					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Bulk	63.5	2.6	-0.9	0.1	2,026	21.7
	Container	52.9	3.2	-0.7	0.1	1,677	32.9
	Passenger	-	2.2	-	0.1	-	29.4
	Tanker	124.4	5.1	-1.7	0.2	4,012	43
	Totals	240.9	13.0	-3.3	0.5	7,714	127.1
2020/B	Bulk	317.7	8.7	-4.3	0.1	10,130	54.4
	Container	264.7	9.4	-3.6	0.3	8,383	74.9
	Passenger	-	5.5	-	0.3	-	73.6
	Tanker	622.0	17.3	-8.6	0.3	20,059	107.7
	Totals	1,204.3	40.9	-16.5	1.0	38,572	310.5
2030/A	Bulk	65.9	8.9	-2.4	0.3	5,573	84.6
	Container	59.7	12.9	-2.1	0.6	5,012	143.2
	Passenger	-	9.3	-	0.6	-	127.7
	Tanker	128.7	17.5	-4.7	0.6	10,999	167
	Totals	254.3	48.5	-9.2	2.1	21,584	522.4
2030/B	Bulk	247.2	19.9	-8.9	0.4	20,897	137
	Container	149.3	20.7	-5.4	0.8	12,530	201.4
	Passenger	-	12.4	-	0.7	-	170.3
	Tanker	482.6	39.2	-17.6	0.8	41,247	270.4
	Totals	879.1	92.1	-31.9	2.7	74,675	779.1

Table 6-44 shows total emission reductions for 2050 Fuel Change scenarios for propulsion and auxiliary engines.

Table 6-44. 2050 Total Fuel Change Emission Reductions

Ship Type	CO_2 Tons per Year			
	2050/A		2050/B	
	Propulsion	Auxiliary	Propulsion	Auxiliary
Bulk	1,860	21,370	5,811	66,782
Container	3,273	28,325	3,273	28,325
Passenger	-	-	-	-
Tanker	2,667	41,839	8,335	130,746
Totals	7,799	91,534	17,419	225,853

Table 6-45 shows percent reductions for each Fuel Change scenario when compared with the BAU levels for propulsion and auxiliary engines, respectively.

Table 6-45. Percent Reductions for Fuel Change Scenarios[201]

Scenario	Engine	Emission Reductions Relative to Propulsion/Auxiliary BAU Emissions					
		NO_x	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Propulsion	1%	2%	0%	1%	0%	6%
	Auxiliary	1%	3%	-0%	2%	0%	10%
2020/B	Propulsion	6%	7%	1%	2%	2%	18%
	Auxiliary	5%	8%	-1%	3%	2%	24%
2030/A	Propulsion	2%	5%	0%	3%	1%	21%
	Auxiliary	2%	7%	-1%	5%	1%	29%
2030/B	Propulsion	6%	12%	1%	6%	2%	44%
	Auxiliary	5%	13%	-2%	6%	3%	43%
2050/A	Propulsion	-	-	-	-	1%	-
	Auxiliary	-	-	-	-	2%	-
2050/B	Propulsion	-	-	-	-	3%	-
	Auxiliary	-	-	-	-	3%	-

6.6.2. Shore Power Strategies

As described in Section 5, shore power technology involves connecting a vessel to the electrical grid while at berth. By using land-side power in this manner, an OGV's auxiliary engines can be turned off during the time the shore power cables are connected, with the result being significantly reduced hoteling emissions while at port. The Shore Power strategy scenarios are found below in Table 6-46, with the technology penetration rates are shown for the three ship types for each scenario: container, passenger, and reefer ships.

Table 6-46. Shore Power Strategy Scenarios

Ship Type	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Container	1%	10%	5%	20%	15%	35%
Passenger	10%	20%	20%	40%	30%	60%
Reefer	1%	5%	5%	10%	10%	20%

The technology penetration values in Table 6-46 represent the percentage of installed auxiliary power that shore power is applied to for frequent callers per ship type. Installed power was calculated for frequent callers by ship type at each port in this national scale analysis. Installed power directly relates to emissions for a given ship type, so by specifying the percent of installed power related to frequent callers, the amount of eligible frequent caller emissions can be estimated. The methodology and assumptions for calculating emission reductions for these scenarios is included below and in Appendix C.

[201] As before, the very small negative percent reductions for HC Auxiliary Engines in scenario 2020/A are shown as -0%.

6.6.2.1. Determining Frequent Callers and Relative Reduction Factors

Shore Power strategy scenarios were applied only to frequent callers, due to the significant investment that would be necessary to retrofit a vessel to accept shore power. Frequent callers were defined here as individual vessels calling at a port a minimum number of times per year. For passenger (cruise ship) vessels, frequent callers were defined as 5 calls or more per year, while frequent callers for container and reefer vessel were assumed to call 6 times or more times per year. Table 6-47 shows the resulting average percentages of frequent callers by ship type; overall, the average percentage of frequent callers for these three ship types was 53% for this assessment. See Appendix C for a more detailed explanation of how these percentages were determined.

Table 6-47. Average Percent of Frequent Callers, by Ship Type

Ship Type	% Frequent Caller
Container	56%
Passenger	96%
Reefer	72%

Although there are CO_2 emissions generated from the power plant supplying electricity to the ship, these are generally less than those generated by the auxiliary engines. Similarly, conventional power plants emit criteria air pollutants, thus shore power would be responsible for additional emissions at the location of the power plant. Consistent with ARB's shore power regulation,[202] shore power was applied to container, passenger, and reefer ships that stop at the ports in this assessment.

EPA assumed approximately 2 hours to connect and disconnect cables during a call. Thus, the strategy's effectiveness is based upon the number of hours connected versus the total hoteling time. Average hoteling times by vessel type were used to calculate effectiveness by ship type, and then those values were applied to all ports. The same share of installed power by ship type by port was also applied for all future years. Shore power effectiveness is the number of hours connected divided by total average hoteling time. The number of hours connected is calculated as the total average hoteling time minus 2 hours. Table 6-48 shows per call effectiveness for shore power by ship type, considering only emissions from the vessels themselves.

Table 6-48. Shore Power Effectiveness for Vessel Emissions Only, per call

Ship Type	Average Hoteling Time (hrs)	Shore Power Reduction (%)
Container	30.7	93%
Passenger	10.1	80%
Reefer	64.3	97%

[202] CARB, *Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At- Berth in a California Port,* Final Regulation Order, 2010. Available at: http://www.arb.ca.gov/ports/shorepower/finalregulation.pdf.

Emission reductions for each ship type at the port are calculated as the BAU emissions times the RRF where RRF is defined as:

$$\mathbf{RRF = FC \times PR \times Eff} \qquad \textbf{Eq. 6-3}$$

Where

RRF = is the relative reduction factor,

FC = is the percent of installed power for frequent callers,

PR = is the technology penetration levels (Table 6-46), and

Eff = is the emission reduction effectiveness (Table 6-48).

Since the proportion of frequent callers by ship type vary by port, relative reduction factors are not presented here. See Appendix C for more details.

In addition to vessel emissions, CO_2 and criteria air pollutant emissions were assumed to be generated by the power plants providing the shore power. While these plants would typically be outside a port's footprint, their emissions were considered here because the emissions result from producing electricity used as shore power by the ships. Emission factors for electricity generation are shown in Table 6-49.

Table 6-49. Power Plant Emission Factors at plug (g/kWh)

Year	NOx	PM_{10}	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020	0.119	0.037	0.015	0.004	0.001	489	0.67
2030	0.124	0.040	0.016	0.005	0.001	478	0.633
2050	-	-	-	-	-	460	-

Please note that the Shore Power scenario analysis accounted in the BAU inventory for two ports where shore power is currently being implemented or is sufficiently planned to occur in the future. In those cases, the BAU emissions inventories were revised to account for this technology and any associated impacts; no double counting of strategies occurred for applicable years.

6.6.2.2. Result Summary

The results from the Shore Power strategy scenarios are presented below in Tables 6-50 and 6-51. Table 6-50 presents the total emissions reductions of the Shore Power strategy scenarios for 2020 and 2030.

Table 6-50. Total Shore Power Emission Reductions for 2020 and 2030 Scenarios

Scenario	Ship Type	Auxiliary Engine Emission Reductions (Tons per Year)						Power Plant Emissions from Shore Power (Tons per Year)					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2	NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Container	27.2	0.5	1.3	0.0	2,161	1.3	-0.4	0.0	0.0	0.0	-1,531	-2.1
	Passenger	430.1	7.3	17.4	0.4	29,978	18.4	-5.0	-0.5	-0.2	0.0	-21,230	-29.1
	Reefer	3.0	0.1	0.1	0.0	220	0.1	0.0	0.0	0.0	0.0	-156	-0.2
	Totals	460.3	7.9	18.7	0.5	32,359	19.9	-5.4	-0.6	-0.2	-0.1	-22,916	-31.4
2020/B	Container	272.3	5.3	12.5	0.3	21,612	13.3	-3.8	-0.4	-0.1	0.0	-15,305	-21.0
	Passenger	866.8	14.7	35.0	0.9	60,404	37.1	-10.1	-1.0	-0.4	-0.1	-42,777	-58.6
	Reefer	15.0	0.3	0.6	0.0	1,102	0.7	-0.2	0.0	0.0	0.0	-781	-1.1
	Totals	1,154.1	20.2	48.1	1.2	83,118	51.1	-14.0	-1.4	-0.5	-0.1	-58,863	-80.7
2030/A	Container	95.4	3.9	9.3	0.2	16,076	9.9	-2.9	-0.3	-0.1	0.0	-11,133	-14.7
	Passenger	440.1	20.6	49.1	1.2	84,695	52.0	-14.7	-1.5	-0.6	-0.2	-58,652	-77.6
	Reefer	10.1	0.4	0.9	0.0	1,581	1.0	-0.3	0.0	0.0	0.0	-1,095	-1.5
	Totals	545.6	24.8	59.3	1.5	102,351	62.9	-17.9	-1.9	-0.7	-0.2	-70,879	-93.8
2030/B	Container	381.5	15.6	37.2	0.9	64,303	39.5	-11.6	-1.2	-0.5	-0.1	-44,530	-58.9
	Passenger	919.4	42.9	102.4	2.6	176,789	108.6	-30.6	-3.2	-1.3	-0.3	-122,428	-162.0
	Reefer	20.2	0.8	1.8	0.0	3,162	1.9	-0.6	-0.1	0.0	0.0	-2,189	-2.9
	Totals	1,321.1	59.3	141.5	3.6	244,253	150.0	-42.8	-4.4	-1.8	-0.5	-169,148	-223.8

Table 6-51 presents the resulting emission reductions for 2050 Shore Power scenarios.

Table 6-51. Total Shore Power CO_2 Emission Reductions for 2050 Scenarios (Tons per Year)

Ship Type	2050A		2050/B	
	Auxiliary	Power Plant	Auxiliary	Power Plant
Container	108,073	-71,915	252,170	-167,803
Passenger	262,863	-174,918	545,468	-362,973
Reefer	6,621	-4,406	13,242	-8,811
Totals	377,557	-251,239	810,880	-539,588

Table 6-52 shows the percent reductions for Shore Power scenarios relative to the BAU emission inventories for frequent caller hoteling emissions.

Table 6-52. Percent Reductions for Shore Power Scenarios

Scenario	Engine	Percent Reductions Relative to BAU Frequent Caller Hoteling Emissions					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Auxiliary	4%	3%	3%	3%	3%	3%
	Power Plant	0%	0%	0%	0%	-2%	-5%
	Net	4%	3%	3%	3%	1%	-2%
2020/B	Auxiliary	9%	8%	8%	8%	8%	8%
	Power Plant	0%	-1%	0%	-1%	-6%	-13%
	Net	9%	8%	8%	8%	0%	-5%
2030/A	Auxiliary	7%	7%	7%	7%	7%	7%
	Power Plant	0%	-1%	0%	-1%	-5%	-11%
	Net	7%	7%	7%	6%	2%	-4%
2030/B	Auxiliary	16%	17%	17%	17%	17%	17%
	Power Plant	-1%	-1%	0%	-2%	-12%	-26%
	Net	16%	16%	17%	15%	5%	-9%
2050/A	Auxiliary	-	-	-	-	13%	-
	Power Plant	-	-	-	-	-9%	-
	Net	-	-	-	-	4%	-
2050/B	Auxiliary	-	-	-	-	28%	-
	Power Plant	-	-	-	-	-19%	-
	Net	-	-	-	-	10%	-

Note that in both Tables 6-51 and 6-52, power plant emissions supporting shore power are broken out and reported separately. The net emissions impact (i.e., “Net” in the above tables) reflects the sum of auxiliary engine reductions and power plant emissions increases. In practice, power plants that would supply the electricity for shore power would not be expected to be located near a port or possibly even within an applicable nonattainment or maintenance area.

6.6.3. Advanced Marine Emission Control System Strategies

Advance Marine Emission Control Systems (AMECS) also provide emission reductions while a ship is at berth. This is accomplished by attaching a funnel over the exhaust stack of the ship and then vacuuming ship-generated emissions through a duct to a barge mounted Emission Treatment System (ETS) where 95-99 percent of pollutants are removed. The AMECS that was assumed for this analysis was verified by ARB in 2015.[203]

Table 6-53 shows the technology penetration values of the AMECS strategy scenarios as the percentage of installed auxiliary power by ship type. The AMECS strategy scenarios were applied to non-frequent callers only for container and tanker ships types. In addition, smaller tankers (chemical and product ships) tend may be good candidates for AMECS since these vessels use diesel driven cargo pumps (i.e., the main source of tanker emissions at berth); larger tankers tend to use boilers to power steam driven cargo pumps.

Table 6-53. AMECS Strategy Scenarios

Ship Type	2020/A	2020/B	2030/A	2030/B
Container	1%	5%	5%	10%
Tanker	1%	5%	5%	10%

6.6.3.1. Determining Non-frequent Callers and Relative Reduction Factors

The percent of installed power for non-frequent callers (less than 6 calls at a given port within a year for container ships and tankers) by ship type at each port from 2011 Entrances and Clearances data[204]. Installed power directly relates to emissions for a given ship type, so by specifying the percent of installed power related to non-frequent callers, the amount of eligible non-frequent caller emissions can be estimated.

Table 6-54 shows the resulting average percentages of non-frequent callers by ship type. Overall, non-frequent callers for these ship types were 47%. See Appendix C for a more detailed explanation of how these percentages were determined.

Table 6-54. Average Percent of Non-frequent Callers, by Ship Type

Ship Type	% Non-frequent Caller
Container	44%
Tanker	81%

[203] California Air Resources Board, *Executive Order AB-15-01 – Clean Air Engineering-Maritime, Inc.*, June 2015. Available at: http://www.arb.ca.gov/ports/shorepower/eo/ab-15-01.pdf. The system limits auxiliary power while hoteling to a maximum of 2,500 kW. This excludes its use on passenger ships which generate roughly 9,000 kW while hoteling. Current AMECS use barge auxiliary engines to power the emission reduction system. Based upon the Executive Order, the needed generator load is 166 kW.

[204] U.S. Army Corps of Engineers, *Vessel Entrances and Clearances*. Available at: http://www.navigationdatacenter.us/data/dataclen.htm.

Emissions from the ship auxiliaries and from the AMECS barge auxiliary generator produce emissions during the estimated 2 hours while they are being started and shut down as well as when the system is in place. Consistent with the ARB Executive Order, a 90 and 95% AMECS effectiveness was assumed for NOx and $PM_{2.5}$ emissions, respectively, when the system would be installed; a 95% effectiveness was assumed to also pertain to the other pollutants modeled for OGVs. Table 6-55 shows reduction effectiveness for the two ship types considered.

Table 6-55. AMECS Effectiveness

Ship Type	Reductions		CO_2 Increase
	NOx	Others[a]	
Container	73%	78%	9%
Tanker	75%	80%	7%

[a] Other emissions include PM_{10}, $PM_{2.5}$, HC, SO_2, and TACs.

Emission reductions by ship type by port were calculated as the BAU emissions times the RRF:

$$\mathbf{RRF = NFC \times PR \times Eff} \qquad \textbf{Eq. 6-4}$$

Where

RRF = the relative reduction factor,

NFC = the percent of installed power for non-frequent callers,

PR = the penetration levels given, and

Eff = the emission reduction effectiveness.

Since the proportion of non-frequent callers by ship type vary by port, relative reduction factors are not presented here. See Appendix C for more details.

6.6.3.2. Result Summary

Table 6-56 shows the total emission reductions of the AMECS strategy scenarios; Table 6-57 shows the percent reductions relative to non-frequent caller BAU hoteling emissions.

Table 6-56. Total AMECS Emission Reductions for 2020 and 2030 Scenarios

Scenario	Ship Type	Tons per Year					
		NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	Container	15.9	0.3	0.8	0.0	-163	0.8
	Tanker	43.3	0.9	2.2	0.1	-349	2.3
	Totals	59.2	1.2	2.9	0.1	-512	3.1
2020/B	Container	79.6	1.6	3.9	0.1	-816	4.1
	Tanker	213.3	4.4	10.6	0.3	-1,717	11.2
	Totals	292.8	6.1	14.5	0.4	-2,533	15.4
2030/A	Container	56.0	2.4	5.8	0.2	-1,220	6.2
	Tanker	140.2	6.2	14.8	0.4	-2,396	15.7
	Totals	196.2	8.6	20.6	0.5	-3,616	21.8
2030/B	Container	112.0	4.9	11.6	0.3	-2,440	12.3
	Tanker	280.3	12.4	29.6	0.7	-4,792	31.4
	Totals	392.3	17.3	41.2	1.0	-7,232	43.7

Table 6-57. Percent Reductions for AMECS Scenarios

Scenario	Percent Reductions Relative to BAU Non-frequent Caller Hoteling Emissions					
	NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	1%	1%	1%	1%	-0%	1%
2020/B	3%	3%	3%	3%	-0%	3%
2030/A	3%	3%	3%	3%	-0%	3%
2030/B	6%	6%	6%	6%	-1%	6%

Note that AMECS were not modeled in 2050 since there is no CO_2 benefit. In addition, since the original analysis was done, another AMECS has been verified by ARB that shows reduced emissions due to the use of Tier 4 auxiliary engines on the barge which the AMECS is mounted, in addition to lower energy demand, thus reducing the CO_2 emissions.[205]

6.6.4. Reduced Hoteling Strategies

Improved cargo handling equipment and other efficiency measures can improve unloading and loading times for container ships.[206] Table 6-58 shows the hoteling time reductions by the scenarios analyzed.

Table 6-58. Reduced Hoteling Strategy Scenarios

Ship Type	2020/A	2020/B	2030/A	2030/B	2050/A	2050/B
Container	5%	10%	5%	10%	5%	10%

[205] More information can be found at: http://www.arb.ca.gov/ports/shorepower/shorepower.htm.

[206] Additional study would be necessary to determine if reduced hoteling time is a viable strategy for tanker or bulk vessels, and therefore, other vessel types were not considered for this assessment. For example, tanker hoteling is a function of how fast these vessels can load or unload cargo, which can be limited by several factors, including pipeline sizes.

RRFs and hoteling emissions are equal to the reduction in hoteling time. These reductions were applied to BAU hoteling emissions for container ships at applicable ports in this national scale analysis.

6.6.4.1. Result Summary

Table 6-59 presents the total emission reductions for the Reduced Hoteling strategy scenarios.

Table 6-59. Total Reduced Hoteling Time Emission Reductions for 2020, 2030, and 2050 Scenarios

Scenario	Tons per Year					
	NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	254.0	4.9	11.7	0.3	20,161	12.4
2020/B	508.0	9.8	23.4	0.6	40,321	24.8
2030/A	178.3	7.3	17.4	0.4	18.5	30,055
2030/B	356.6	14.6	34.8	0.9	36.9	60,109
2050/A	-	-	-	-	-	67,607
2050/B	-	-	-	-	-	135,214

Table 6-60 shows the percent emission reductions for the Reduced Hoteling scenarios relative to total hoteling time.

Table 6-60. Percent Reductions for Reduced Hoteling Scenarios

Scenario	Tons per Year					
	NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2
2020/A	1%	1%	1%	1%	1%	1%
2020/B	2%	2%	2%	2%	2%	2%
2030/A	1%	1%	1%	1%	1%	1%
2030/B	2%	2%	2%	2%	2%	2%
2050/A	-	-	-	-	1%	-
2050/B	-	-	-	-	3%	-

6.6.5. Summary of OGV Scenario Impacts

The complexity of the OGV strategy scenarios warrant a more detailed examination of results so that we can understand the potential of applying modeled strategies under appropriate circumstances in practice. Table 6-61 illustrates the potential of OGV strategies to reduce specific types of emissions under relevant situations. This table shows the percent emission reductions relative to the following:

- Fuel Change Propulsion relative to total propulsion engine emissions
- Fuel Change Auxiliary relative to total auxiliary engine emissions
- Shore Power relative to frequent caller hoteling emissions
- Stack Bonnet relative to non-frequent caller hoteling emissions
- Reduced Hoteling Time relative to total hoteling emissions

Understanding the general applicability of these strategies to reducing all or a portion of OGV emissions is critical to making decisions for state and local priorities. For example, Fuel Change scenarios were generally applied to all propulsion or auxiliary emissions, respectively, whereas Shore Power, AMECS and Reduced Hoteling Time scenarios were applied to only a portion of the total OGV BAU emissions for certain vessel types and/or caller frequency.

In contrast, Table 6-62 shows a similar set of values as Table 6-61, but percent reductions are taken relative to the entire OGV BAU inventory (i.e., including the portions of the inventory that are not addressed by a given strategy scenario). Figure 6-9 shows the percentage reductions for NOx, $PM_{2.5}$, and CO_2 relative to the total OGV BAU inventory. Similar charts for other pollutants can be found in Appendix C.

Table 6-63 shows total absolute emission reductions from the BAU case summed by scenario strategy, and Figure 6-10 shows the tons/year reductions for NOx, $PM_{2.5}$, and CO_2. Similar charts for other pollutants can be found in Appendix C; no total values are shown in these charts to avoid potentially overestimating the impact due to interaction between OGV scenarios. For all strategies, it is important to note that the scope of this assessment focused on activity within and near the port and within the harbor; as a result, hoteling emissions from auxiliary engines were the majority of OGV BAU emissions with some propulsion engine emissions occurring as OGVs enter and exit the port and maneuver within the port.

Fuel Change scenarios provide significant emission reductions of $PM_{2.5}$, BC, and SO_2 that are beyond the already significant reductions of EPA's ECA regulations. Significant reductions were observed in the 2020 and 2030 BAU emission inventories due to the low sulfur fuel required and penetration of cleaner engines by 2030. The additional low sulfur fuels modeled in the Fuel Change scenarios only reduced $PM_{2.5}$, BC, and SO_2 emissions, while the reductions for NOx and CO_2 were from the LNG fuel strategy modeled.[207] For example, total relative NOx reductions from using LNG in auxiliary engines (and when compared to the total OGV BAU inventories) produced reductions in 2020 from 1-4% and from 1-5% in 2030. For $PM_{2.5}$, the most significant fuel change was for using ULSD in auxiliary engines, where total 2020 $PM_{2.5}$ reductions were estimated between 2-7% and total 2030 reductions were from 6-11% from the total OGV BAU case. Fuel changes in auxiliary engines shown here provide a much bigger effect than for propulsion engines, since hoteling emissions are the largest portion of the OGV BAU inventories in this assessment. Also, note that the geographic area that assumed was limited to port areas and did not include open ocean cruise activity. If the cruise mode were included, propulsion engines would likely provide a bigger reduction opportunity.

Shore power provides significant per vessel emission reductions for NOx, $PM_{2.5}$ and CO_2, particularly for passenger ships which have high auxiliary engine loads and emissions while hoteling and a high frequent caller percentage. Because it requires upgrades to ships and shore-side port infrastructure, shore power is most feasible for frequent calling ships, and may be cost-prohibitive for infrequent callers. Thus, the

[207] While exhaust CO_2 is lower from LNG use, the potential for increased methane emissions (not quantified here) may offset some of the total GHG emission reductions implied from the estimated LNG CO_2 reduction.

largest benefits from shore power occur at terminals and ports with a high fraction of frequent callers, usually cruise ship terminals and container terminals. However, passenger ships have the highest auxiliary load while hoteling; the container ships have an auxiliary load that is only 15% of that for passenger ships and reefers have an auxiliary load that is 22% of passenger ships while hoteling.

Per call, the effectiveness of AMECS at reducing emissions is comparable to shore power for both NOx and $PM_{2.5}$. However, the CO_2 emissions increase due to the barge auxiliary engines running for the emission reduction equipment are significant; future technology development (including electrification) could improve the efficiency of the technology to mitigate CO_2 emission increases. AMECS strategies may be most feasible at ports and terminals with large numbers of infrequent callers where reductions in NOx and $PM_{2.5}$ are the highest priority.

Finally, the emissions benefits of reduced hoteling time were in the 1-2% range for all pollutants in most years, which is not as significant an impact as other strategies. These results are most likely affected by the lower level of detail used in the assessment's methodology, and therefore, further analysis would be necessary to fully understand the true potential of increasing operational efficiency for reducing the time that container ships spend at the dock while they are loaded or unloaded. Any strategies that reduce hoteling time (and auxiliary engine emissions at berth) are critical to consider for improving air quality and climate change objectives in port areas.

Table 6-61. OGV Emission Reduction Percentages by Scenario and Strategy, Relative to Select Portions of the OGV BAU Inventory[208]

Scenario	Strategy		Percent Reduction from Portion of BAU						Relative to		Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2			
2020/A	Fuel Change	Propulsion	1%	2%	0%	1%	0%	6%	Propulsion BAU	All Ships	Bulk: 10% use 500 ppm sulfur fuel; 2% use LNG. Container: 10% use 500 ppm sulfur fuel; 1% use LNG. Passenger: 10% use 500 ppm sulfur fuel. Tanker: 10% use 500 ppm sulfur fuel; 2% use LNG
2020/A	Fuel Change	Auxiliary	1%	3%	-0%	2%	0%	10%	Auxiliary BAU	All Ships	Bulk: 10% use ULSD; 2% use LNG. Container: 10% use ULSD; 1% use LNG. Passenger: 10% use ULSD. Tanker: 10% use ULSD; 2% use LNG
2020/A	Shore Power	Auxiliary	4%	3%	3%	3%	1%	-2%	Hoteling BAU	Frequent Callers (FCs)	Shore power penetration of: Container: 1%. Passenger: 10%. Reefer: 1%
2020/A	AMECS	Auxiliary	1%	1%	1%	1%	-0%	1%	Hoteling BAU	Non-FCs	AMECS penetration of: Container: 1%. Tanker: 1%
2020/A	Reduced Hoteling Time	Auxiliary	1%	1%	1%	1%	1%	1%	Hoteling BAU	All Ships	Container: 5% hoteling time reduction
2020/B	Fuel Change	Propulsion	6%	7%	1%	2%	2%	18%	Propulsion BAU	All Ships	Bulk: 25% use 500 ppm sulfur fuel; 10% use LNG. Container: 25% use 500 ppm sulfur fuel; 5% use LNG. Passenger: 25% use 500 ppm sulfur fuel. Tanker: 25% use 500 ppm sulfur fuel; 10% use LNG
2020/B	Fuel Change	Auxiliary	5%	8%	-1%	3%	2%	24%	Auxiliary BAU	All Ships	Bulk: 20% use ULSD; 10% use LNG. Container: 20% use ULSD; 5% use LNG. Passenger: 20% use ULSD. Tanker: 20% use ULSD; 10% use LNG
2020/B	Shore Power	Auxiliary	9%	8%	8%	8%	2%	-5%	Hoteling BAU	Frequent Callers	Shore power penetration of: Container: 10%. Passenger: 20%. Reefer: 5%
2020/B	AMECS	Auxiliary	3%	3%	3%	3%	-0%	3%	Hoteling BAU	Non-FCs	AMECS penetration of: Container: 5%. Tanker: 5%
2020/B	Reduced Hoteling Time	Auxiliary	2%	2%	2%	2%	2%	2%	Hoteling BAU	All Ships	Container: 10% hoteling time reduction

[208] Very small negative percent reductions are shown as -0%.

Scenario	Strategy		Percent Reduction from Portion of BAU						Relative to		Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2			
2030/A	Fuel Change	Propulsion	2%	5%	0%	3%	1%	21%	Propulsion BAU	All Ships	Bulk: 25% use 200 ppm sulfur fuel; 4% use LNG. Container: 25% use 200 ppm sulfur fuel; 2% use LNG. Passenger: 25% use 200 ppm sulfur fuel. Tanker: 25% use 200 ppm sulfur fuel; 4% use LNG
	Fuel Change	Auxiliary	2%	7%	-1%	5%	1%	29%	Auxiliary BAU	All Ships	Bulk: 30% use ULSD; 4% use LNG. Container: 30% use ULSD; 2% use LNG. Passenger: 30% use ULSD. Tanker: 30% use ULSD; 4% use LNG
	Shore Power	Auxiliary	7%	7%	7%	6%	2%	-4%	Hoteling BAU	Frequent Callers	Shore power penetration of: Container: 5%. Passenger: 20%. Reefer: 5%
	AMECS	Auxiliary	3%	3%	3%	3%	-0%	3%	Hoteling BAU	Non-FCs	AMECS penetration of: Container: 5%. Tanker: 5%
	Reduced Hoteling Time	Auxiliary	1%	1%	1%	1%	1%	1%	Hoteling BAU	All Ships	Container: 5% hoteling time reduction
2030/B	Fuel Change	Propulsion	6%	12%	1%	6%	2%	44%	Propulsion BAU	All Ships	Bulk: 50% use 200 ppm sulfur fuel; 15% use LNG. Container: 50% use 200 ppm sulfur fuel; 5% use LNG. Passenger: 50% use 200 ppm sulfur fuel. Tanker: 50% use 200 ppm sulfur fuel; 15% use LNG
	Fuel Change	Auxiliary	5%	13%	-2%	6%	3%	43%	Auxiliary BAU	All Ships	Bulk: 40% use ULSD; 15% use LNG. Container: 40% use ULSD; 5% use LNG. Passenger: 40% use ULSD. Tanker: 40% use ULSD; 15% use LNG
	Shore Power	Auxiliary	16%	16%	17%	15%	5%	-9%	Hoteling BAU	Frequent Callers	Shore power penetration of: Container: 20%. Passenger: 40%. Reefer: 10%
	AMECS	Auxiliary	6%	6%	6%	6%	-1%	6%	Hoteling BAU	Non-FCs	AMECS penetration of: Container: 10%. Tanker: 10%
	Reduced Hoteling Time	Auxiliary	2%	2%	2%	2%	2%	2%	Hoteling BAU	All Ships	Container: 10% hoteling time reduction
2050/A	Fuel Change	Propulsion	-	-	-	-	1%	-	Propulsion BAU	All Ships	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Fuel Change	Auxiliary	-	-	-	-	2%	-	Auxiliary BAU	All Ships	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Shore Power	Auxiliary	-	-	-	-	4%	-	Hoteling BAU	Frequent Callers	Shore power penetration of: Container: 15%. Passenger: 30%. Reefer: 10%
	AMECS	Auxiliary	-	-	-	-	N/A	-			N/A

Scenario	Strategy		Percent Reduction from Portion of BAU						Relative to		Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2			
	Reduced Hoteling Time	Auxiliary	-	-	-	-	1%	-	Hoteling BAU	All Ships	Container: 5% hoteling time reduction
2050/B	Fuel Change	Propulsion	-	-	-	-	3%	-	Propulsion BAU	All Ships	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Fuel Change	Auxiliary	-	-	-	-	4%	-	Auxiliary BAU	All Ships	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Shore Power	Auxiliary	-	-	-	-	10%	-	Hoteling BAU	Frequent Callers	Shore power penetration of: Container: 35%. Passenger: 60%. Reefer: 20%
	AMECS	Auxiliary	-	-	-	-	N/A	-			N/A
	Reduced Hoteling Time	Auxiliary	-	-	-	-	3%	-	Hoteling BAU	All Ships	Container: 10% hoteling time reduction

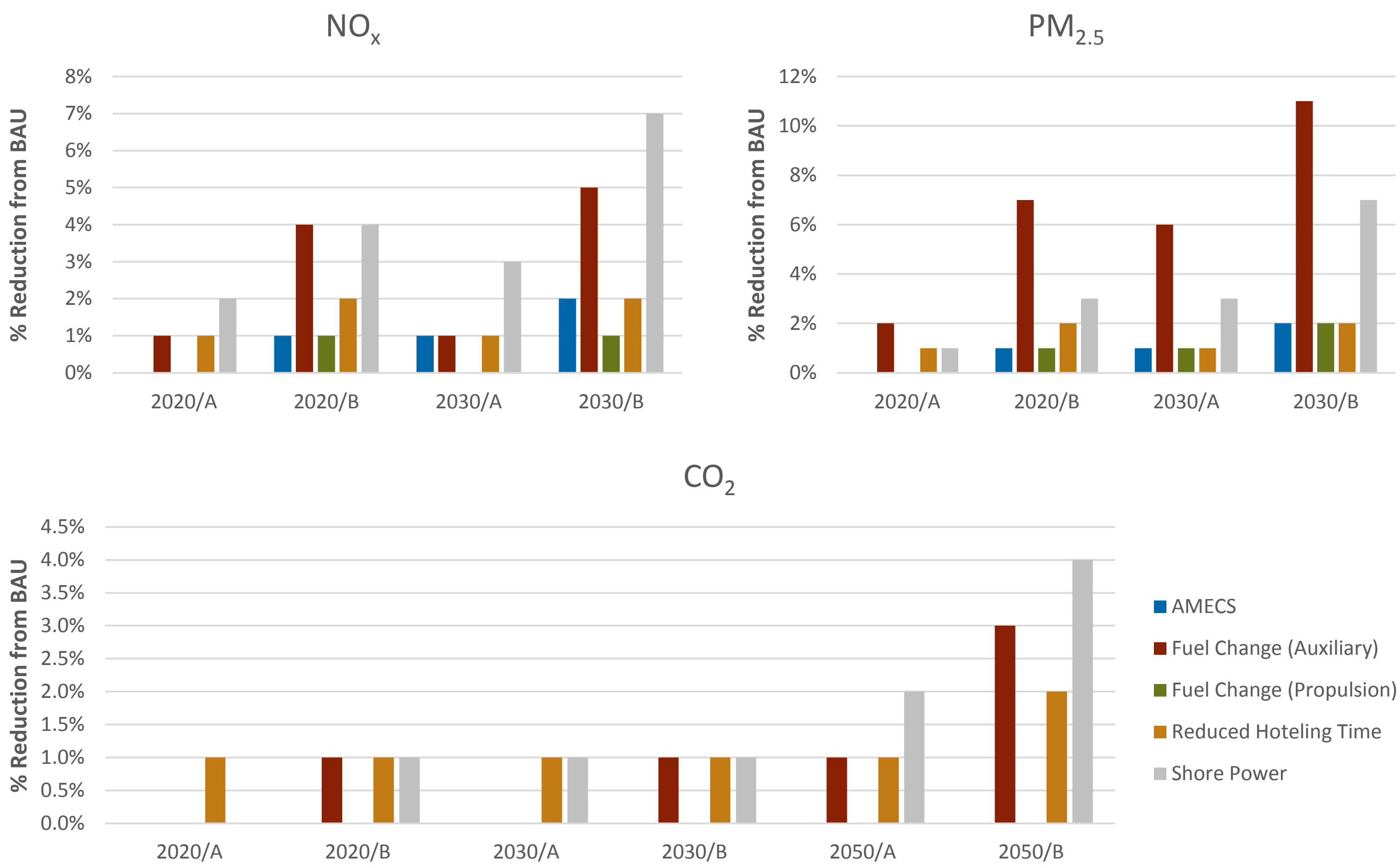
Table 6-62. OGV Emission Reduction Percentages by Scenario and Strategy, Relative to the Total OGV BAU Inventory[209]

Scenario	Strategy		Percent Reduction from Total BAU						Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2	
2020/A	Fuel Change	Propulsion	0%	0%	0%	0%	0%	1%	Bulk: 10% use 500 ppm sulfur fuel; 2% use LNG. Container: 10% use 500 ppm sulfur fuel; 1% use LNG. Passenger: 10% use 500 ppm sulfur fuel. Tanker: 10% use 500 ppm sulfur fuel; 2% use LNG
	Fuel Change	Auxiliary	1%	2%	-0%	1%	0%	9%	Bulk: 10% use ULSD; 2% use LNG. Container: 10% use ULSD; 1% use LNG. Passenger: 10% use ULSD. Tanker: 10% use ULSD; 2% use LNG
	Shore Power	Auxiliary	2%	1%	1%	1%	0%	-1%	Shore power penetration of: Container: 1%. Passenger: 10%. Reefer: 1%
	AMECS	Auxiliary	0%	0%	0%	0%	0%	0%	AMECS penetration of: Container: 1%. Tanker: 1%
	Reduced Hoteling Time	Auxiliary	1%	1%	1%	1%	1%	1%	Container: 5% hoteling time reduction
2020/B	Fuel Change	Propulsion	1%	1%	0%	0%	0%	2%	Bulk: 25% use 500 ppm sulfur fuel; 10% use LNG. Container: 25% use 500 ppm sulfur fuel; 5% use LNG. Passenger: 25% use 500 ppm sulfur fuel. Tanker: 25% use 500 ppm sulfur fuel; 10% use LNG
	Fuel Change	Auxiliary	4%	7%	-1%	3%	1%	22%	Bulk: 20% use ULSD; 10% use LNG. Container: 20% use ULSD; 5% use LNG. Passenger: 20% use ULSD. Tanker: 20% use ULSD; 10% use LNG
	Shore Power	Auxiliary	4%	3%	3%	3%	1%	-2%	Shore power penetration of: Container: 10%. Passenger: 20%. Reefer: 5%
	AMECS	Auxiliary	1%	1%	1%	1%	-0%	1%	AMECS penetration of: Container: 5%. Tanker: 5%
	Reduced Hoteling Time	Auxiliary	2%	2%	1%	2%	1%	2%	Container: 10% hoteling time reduction
2030/A	Fuel Change	Propulsion	0%	1%	0%	0%	0%	2%	Bulk: 25% use 200 ppm sulfur fuel; 4% use LNG. Container: 25% use 200 ppm sulfur fuel; 2% use LNG. Passenger: 25% use 200 ppm sulfur fuel. Tanker: 25% use 200 ppm sulfur fuel; 4% use LNG
	Fuel Change	Auxiliary	1%	6%	-0%	4%	0%	26%	Bulk: 30% use ULSD; 4% use LNG. Container: 30% use ULSD; 2% use LNG. Passenger: 30% use ULSD. Tanker: 30% use ULSD; 4% use LNG
	Shore Power	Auxiliary	3%	3%	2%	3%	1%	-2%	Shore power penetration of: Container: 5%. Passenger: 20%. Reefer: 5%
	AMECS	Auxiliary	1%	1%	1%	1%	-0%	1%	AMECS penetration of: Container: 5%. Tanker: 5%
	Reduced Hoteling Time	Auxiliary	1%	1%	1%	1%	1%	1%	Container: 5% hoteling time reduction

[209] Very small negative percent reductions are shown as -0%.

Scenario	Strategy		Percent Reduction from Total BAU						Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2	
2030/B	Fuel Change	Propulsion	1%	2%	0%	1%	0%	4%	Bulk: 50% use 200 ppm sulfur fuel; 15% use LNG. Container: 50% use 200 ppm sulfur fuel; 5% use LNG. Passenger: 50% use 200 ppm sulfur fuel. Tanker: 50% use 200 ppm sulfur fuel; 15% use LNG
	Fuel Change	Auxiliary	5%	11%	-1%	5%	1%	39%	Bulk: 40% use ULSD; 15% use LNG. Container: 40% use ULSD; 5% use LNG. Passenger: 40% use ULSD. Tanker: 40% use ULSD; 15% use LNG
	Shore Power	Auxiliary	7%	7%	6%	6%	1%	-4%	Shore power penetration of: Container: 20%. Passenger: 40%. Reefer: 10%
	AMECS	Auxiliary	2%	2%	2%	2%	-0%	2%	AMECS penetration of: Container: 10%. Tanker: 10%
	Reduced Hoteling Time	Auxiliary	2%	2%	1%	2%	1%	2%	Container: 10% hoteling time reduction
2050/A	Fuel Change	Propulsion	-	-	-	-	0%	-	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Fuel Change	Auxiliary	-	-	-	-	1%	-	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Shore Power	Auxiliary	-	-	-	-	2%	-	Shore power penetration of: Container: 15%. Passenger: 30%. Reefer: 10%
	AMECS	Auxiliary	-	-	-	-	N/A	-	N/A
	Reduced Hoteling Time	Auxiliary	-	-	-	-	1%	-	Container: 5% hoteling time reduction
2050/B	Fuel Change	Propulsion	-	-	-	-	0%	-	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Fuel Change	Auxiliary	-	-	-	-	3%	-	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Shore Power	Auxiliary	-	-	-	-	4%	-	Shore power penetration of: Container: 35%. Passenger: 60%. Reefer: 20%
	AMECS	Auxiliary	-	-	-	-	N/A	-	N/A
	Reduced Hoteling Time	Auxiliary	-	-	-	-	2%	-	Container: 10% hoteling time reduction

Figure 6-9. OGV Emission Percent Reductions by Scenario and Strategy for Selected Pollutants, Relative to the Total OGV BAU Inventory[210]



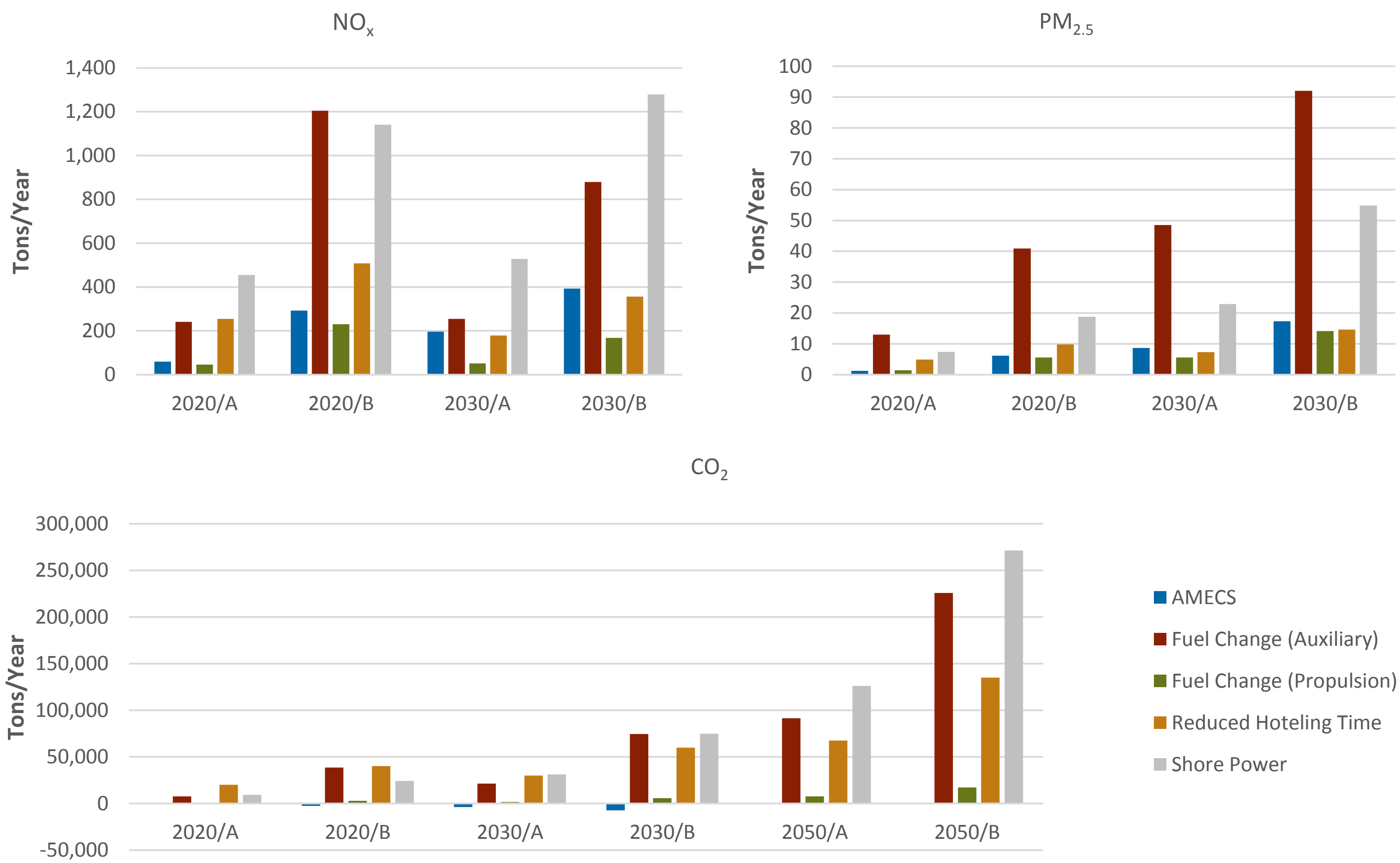
210 Bars are omitted where no emission reductions were estimated, due to a strategy not being applicable for a specific pollutant or due to a strategy increasing emissions.

Table 6-63. OGV Emission Reduction Summary by Scenario and Strategy, Tons per Year

Scenario	Strategy		Tons per Year						Strategy Description
			NO_x	$PM_{2.5}$	HC	BC	CO_2	SO_2	
2020/A	Fuel Change	Propulsion	46.0	1.4	1.0	0.0	628	7.7	Bulk: 10% use 500 ppm sulfur fuel; 2% use LNG. Container: 10% use 500 ppm sulfur fuel; 1% use LNG. Passenger: 10% use 500 ppm sulfur fuel. Tanker: 10% use 500 ppm sulfur fuel; 2% use LNG
	Fuel Change	Auxiliary	240.9	13.0	-3.3	0.5	7,714	127.1	Bulk: 10% use ULSD; 2% use LNG. Container: 10% use ULSD; 1% use LNG. Passenger: 10% use ULSD. Tanker: 10% use ULSD; 2% use LNG
	Shore Power	Auxiliary	454.9	7.4	18.5	0.4	9,443	-11.5	Shore power penetration of: Container: 1%. Passenger: 10%. Reefer: 1%
	AMECS	Auxiliary	59.2	1.2	2.9	0.1	-512	3.1	AMECS penetration of: Container: 1%. Tanker: 1%
	Reduced Hoteling Time	Auxiliary	254.0	4.9	11.7	0.3	20,160	12.4	Container: 5% hoteling time reduction
2020/B	Fuel Change	Propulsion	229.8	5.6	4.8	0.1	3,139	23.6	Bulk: 25% use 500 ppm sulfur fuel; 10% use LNG. Container: 25% use 500 ppm sulfur fuel; 5% use LNG. Passenger: 25% use 500 ppm sulfur fuel. Tanker: 25% use 500 ppm sulfur fuel; 10% use LNG
	Fuel Change	Auxiliary	1,204.3	40.9	-16.5	1.0	38,572	310.5	Bulk: 20% use ULSD; 10% use LNG. Container: 20% use ULSD; 5% use LNG. Passenger: 20% use ULSD. Tanker: 20% use ULSD; 10% use LNG
	Shore Power	Auxiliary	1,140.1	18.8	47.6	1.1	24,256	-29.6	Shore power penetration of: Container: 10%. Passenger: 20%. Reefer: 5%
	AMECS	Auxiliary	292.8	6.1	14.5	0.4	-2,533	15.4	AMECS penetration of: Container: 5%. Tanker: 5%
	Reduced Hoteling Time	Auxiliary	508.0	9.8	23.4	0.6	40,321	24.8	Container: 10% hoteling time reduction
2030/A	Fuel Change	Propulsion	50.9	5.6	2.8	0.2	1,769	39.2	Bulk: 25% use 200 ppm sulfur fuel; 4% use LNG. Container: 25% use 200 ppm sulfur fuel; 2% use LNG. Passenger: 25% use 200 ppm sulfur fuel. Tanker: 25% use 200 ppm sulfur fuel; 4% use LNG
	Fuel Change	Auxiliary	254.3	48.5	-9.2	2.1	21,584	522.4	Bulk: 30% use ULSD; 4% use LNG. Container: 30% use ULSD; 2% use LNG. Passenger: 30% use ULSD. Tanker: 30% use ULSD; 4% use LNG
	Shore Power	Auxiliary	527.7	22.9	58.6	1.3	31,472	-30.9	Shore power penetration of: Container: 5%. Passenger: 20%. Reefer: 5%
	AMECS	Auxiliary	196.2	8.6	20.6	0.5	-3,616	21.8	AMECS penetration of: Container: 5%. Tanker: 5%
	Reduced Hoteling Time	Auxiliary	178.3	7.3	17.4	0.4	30,054	18.5	Container: 5% hoteling time reduction
2030/B	Fuel Change	Propulsion	168.0	14.1	8.7	0.4	5,925	84.9	Bulk: 50% use 200 ppm sulfur fuel; 15% use LNG. Container: 50% use 200 ppm sulfur fuel; 5% use LNG. Passenger: 50% use 200 ppm sulfur fuel. Tanker: 50% use 200 ppm sulfur fuel; 15% use LNG
	Fuel Change	Auxiliary	879.1	92.1	-31.9	2.7	74,675	779.1	Bulk: 40% use ULSD; 15% use LNG. Container: 40% use ULSD; 5% use LNG. Passenger: 40% use ULSD. Tanker: 40% use ULSD; 15% use LNG

Scenario	Strategy		Tons per Year						Strategy Description
			NOx	$PM_{2.5}$	HC	BC	CO_2	SO_2	
	Shore Power	Auxiliary	1,278.3	54.9	139.7	3.1	75,105	-73.8	Shore power penetration of: Container: 20%. Passenger: 40%. Reefer: 10%
	AMECS	Auxiliary	392.3	17.3	41.2	1.0	-7,232	43.7	AMECS penetration of: Container: 10%. Tanker: 10%
	Reduced Hoteling Time	Auxiliary	356.6	14.6	34.8	0.9	60,109	36.9	Container: 10% hoteling time reduction
2050/A	Fuel Change	Propulsion	-	-	-	-	7,799	-	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Fuel Change	Auxiliary	-	-	-	-	91,534	-	Bulk: 8% use LNG. Container: 5% use LNG. Tanker: 8% use LNG
	Shore Power	Auxiliary	-	-	-	-	126,318	-	Shore power penetration of: Container: 15%. Passenger: 30%. Reefer: 10%
	AMECS	Auxiliary	-	-	-	-	N/A	-	N/A
	Reduced Hoteling Time	Auxiliary	-	-	-	-	67,607	-	Container: 5% hoteling time reduction
2050/B	Fuel Change	Propulsion	-	-	-	-	17,419	-	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Fuel Change	Auxiliary	-	-	-	-	225,853	-	Bulk: 25% use LNG. Container: 5% use LNG. Tanker: 25% use LNG
	Shore Power	Auxiliary	-	-	-	-	271,293	-	Shore power penetration of: Container: 35%. Passenger: 60%. Reefer: 20%
	AMECS	Auxiliary	-	-	-	-	N/A	-	N/A
	Reduced Hoteling Time	Auxiliary	-	-	-	-	135,214	-	Container: 10% hoteling time reduction

Figure 6-10. OGV Absolute Emission Reductions by Scenario and Strategy for Selected Pollutants



6.7. Summary of Emission Reduction Scenario Analysis

Table 6-64 shows the potential emission reductions achievable by scenario for each sector and in total. These values were determined from the total absolute emission reductions from each sector individually.

Table 6-64. Total Emission Reductions by Scenario and Sector[211]

Scenario	Sector	Tons Reduced per Year							
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
2020/A	Drayage*	1,008.2	170.5	61.3	131.3	18,661	2.30	0.50	4.60
	Rail	299.0	12.5	24.0	9.6	1,193	0.90	0.20	2.00
	CHE	544.0	21.4	12.0	16.5	-26	0.10	0.20	0.10
	Harbor Craft	3,342.7	132.6	72.3	102.1	0	2.60	0.60	5.80
	OGV*	1,055.0	27.9	32.4	1.4	37,433	-	-	-
	Total	6,248.9	364.9	202.0	260.9	57,261	-	-	-
2020/B	Drayage*	2,529.6	248.4	154.9	191.3	48,150	5.00	1.20	7.90
	Rail	770.7	27.8	51.8	21.4	5,817	1.90	0.40	4.30
	CHE	1,275.4	45.1	29.6	34.7	37,572	0.20	0.50	0.30
	Harbor Craft	8,357.2	409.4	231.0	315.2	31,424	8.20	1.80	17.90
	OGV*	3,375.0	81.2	77.7	3.2	103,755	-	-	-
	Total	16,307.9	811.9	545.0	565.8	226,718	-	-	-
2030/A	Drayage*	1,256.0	53.7	68.9	41.5	37,079	2.70	0.60	6.10
	Rail	238.0	9.2	18.1	7.1	7,231	0.70	0.20	1.80
	CHE	349.6	9.0	21.3	7.0	104,451	0.30	0.60	0.50
	Harbor Craft	6,025.5	196.0	137.1	150.9	0	3.20	0.80	3.60
	OGV*	1,207.4	92.9	95.0	4.5	81,263	-	-	-
	Total	9,076.5	360.8	340.4	211.0	230,024	-	-	-
2030/B	Drayage*	1,586.2	84.1	81.1	65.0	138,694	3.10	0.70	6.50
	Rail	1,045.5	26.4	46.5	20.3	15,513	1.80	0.40	4.10
	CHE	682.5	18.0	50.8	13.9	256,815	0.60	1.40	1.30
	Harbor Craft	9,069.5	258.1	189.1	198.7	32,402	3.90	1.10	3.10
	OGV*	3,074.3	193.0	202.7	8.1	208,582	-	-	-
	Total	15,458.0	579.6	570.2	306.0	652,006	-	-	-
2050/A	Drayage*	-	-	-	-	320,244	-	-	-
	Rail	-	-	-	-	46,699	-	-	-
	CHE	-	-	-	-	637,631	-	-	-
	Harbor Craft	-	-	-	-	77,684	-	-	-

[211] No air toxic pollutant reductions were calculated for the OGV sector as discuss elsewhere in this report, so no totals are shown for those species.

Scenario	Sector	Tons Reduced per Year							
		NOx	$PM_{2.5}$	VOC	BC	CO_2	Acetaldehyde	Benzene	Formaldehyde
	OGV*	-	-	-	-	293,258	-	-	-
	Total	-	-	-	-	1,375,516	-	-	-
2050/B	Drayage*	-	-	-	-	640,487	-	-	-
	Rail	-	-	-	-	95,637	-	-	-
	CHE	-	-	-	-	1,065,523	-	-	-
	Harbor Craft	-	-	-	-	194,210	-	-	-
	OGV*	-	-	-	-	649,779	-	-	-
	Total	-	-	-	-	2,645,636	-	-	-

In cases where the preceding sections showed a total reduction (CHE, harbor craft, and rail), the listed totals accurately reflect the available potential reduction. For the other sectors (drayage and OGV[212]), totals presented would generally overestimate the available reduction because they do not completely account for interaction between the various components of a scenario. These are represented with an asterisk in Table 6-56. The totals shown for OGVs also reflect power plant emissions related to shore power for all pollutants.

[212] Note that HC emissions from OGV are converted to VOC here for comparison to other sectors.

7. Stratified Summary of Results

The results of this assessment were stratified in a number of ways to examine which types of strategies may have more potential to reduce emissions at different kinds of ports. This analysis was performed separately for the OGV and non-OGV sectors due to the nature of the various strategies applied in each sector. This section discusses how the ports were grouped, presents charts showing the stratified emissions reductions, and discusses observations concerning strategies that may be most effective at reducing emissions at different kinds of ports.

7.1. Background on Development of Strategy Scenarios

As described in Section 6, strategy scenarios were developed for each mobile source sector for the years 2020 and 2030 for all pollutants[213] and for only CO_2 in 2050. Although the specific strategies differ between sectors, the purpose of all scenarios are as follows:

- **Scenario A** was intended to reflect an increase in the introduction of newer technologies in port vehicles and equipment beyond what would occur through normal fleet turnover. Operational strategies in Scenario A reflect a reasonable increase in expected efficiency improvements for drayage truck, rail, and OGV sectors. For the OGV sector, moderate levels of fuel switching and other emission reduction strategies are also analyzed. All of the strategies included in Scenario A may be supported by a moderate increase in public and private funding.
- **Scenario B** reflected a more aggressive suite of strategies as compared to Scenario A. Scenario B would necessitate a major public and private investment to accelerate introduction of low emission vehicles, equipment, and vessels, in addition to different fuels and other technologies. Operational strategies in Scenario B assume further operational efficiency improvements beyond Scenario A.

The stratification analysis is based on the emission reduction results that are covered in further detail in Section 6.

7.2. OGV Stratification

To examine the potential impact of the various OGV strategies at different kinds of ports, the ports were grouped by type and size. The ports were broken into three types: container, bulk, and passenger; they were also classified in two sizes: large and small. The ports were classified as “container” if their cargo throughput was greater than 100,000 twenty-foot equivalent units (TEUs). Container ports were further classified as “small” if their cargo throughput was less than 1 million TEUs and “large” if it was more. Additionally, ports were considered “bulk” if their non-container throughput was greater than 20,000 tons per year (tpy); the cutoff between large and small bulk ports was 50,000 tpy. Finally, ports were classified as “passenger” based on a cursory review of available data. Large passenger ports were ports with more than 750,000 annual passengers.

[213] See Section 2 for more information on the pollutants that were analyzed for the different mobile source sectors.

Each classification was made independently of the others, so that each port might fall into any number of categories and may have different size distinctions. For example, a port could be labeled as both a small passenger port and a large container port. However, it is important to note that these classifications and distinctions are not official determinations, but are simply used in this analysis to differentiate generally between the different kinds of ports included in this assessment. The distinctions "large" and "small" only serve to compare between ports in this assessment and do not facilitate other comparisons. The cutoff points between the two distinctions were chosen such that the large and small ports within a classification contained a roughly equal number of ports. The grouping procedure resulted in 14 container ports (7 large and 7 small), 14 bulk ports (7 large and 7 small), and 7 passenger ports (4 large and 3 small). Additional information on how ports were stratified and other details for this analysis may be found in Appendix D.

As discussed in Section 6.6, OGV scenarios covered several different types of strategies, and these were grouped under the following categories:

- Fuel Change
- Shore Power
- Advanced Marine Emission Control System (AMECS)[214]
- Reduced Hoteling Time

The details of these sources and the application of these strategies are discussed in detail in Sections 5 and 6. To analyze the effectiveness of different reduction strategies at different types and sizes of ports, the emissions reductions relevant for each strategy, scenario, year, and pollutant were summed for the ports that fell into the relevant group. For example, the potential $PM_{2.5}$ reduction from the shore power strategy at container ports was determined by summing together all $PM_{2.5}$ emission reductions from shore power at the 14 container ports. This was done for each pollutant and scenario in both 2020 and 2030, as well as in 2050 for CO_2 where applicable, and for all OGV strategies included in this assessment.

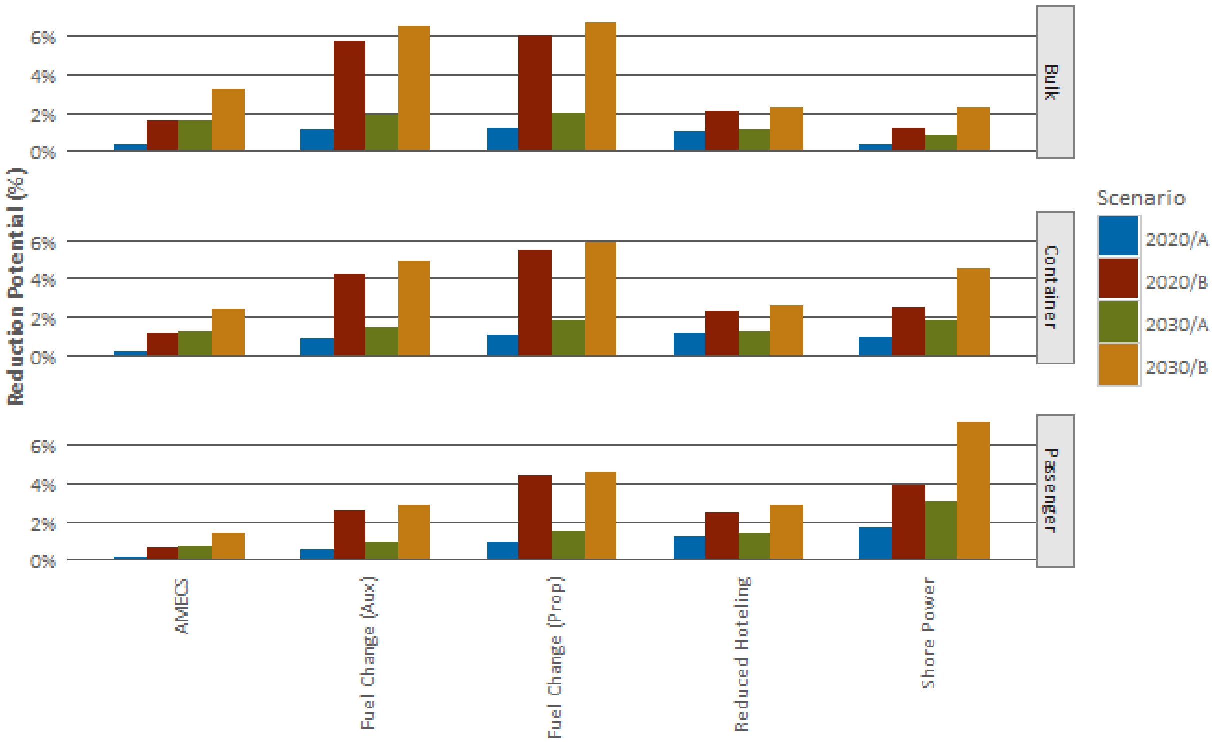
Charts for NOx and $PM_{2.5}$ and a discussion of observations on the types of strategies that might be more effective at the various types and sizes of ports are included below. It is important to note that these stratification results cannot be directly applied to an individual port. The charts and observations are based on the aggregate emissions reductions at all of the ports in a given grouping of ports. The discussion in this section is meant to help guide stakeholders for different kinds of ports as they consider emissions reduction strategies; however, any strategies they select should be based on factors relevant to a given port. For example, the number and type of OGVs and the number that make frequent calls at a specific port must be considered as these factors would influence decisions about the use of shore power and AMECS. Charts for the remaining pollutants are presented in Appendix D.

[214] Advanced Marine Emission Control System (AMECS) is the term used by the California Air Resources Board (CARB) for this technology, sometimes also referred to as "stack bonnets."

7.2.1. Summary by Port Type

Figures 7-1, 7-2, and 7-3 present the relative emission reductions of NOx, $PM_{2.5}$, and CO_2 respectively, resulting from the strategies applied to the OGV source categories stratified by the three types of ports.

Figure 7-1. Comparing NOx Relative Reduction Potential of the OGV Sector



These charts show that switching the fuels that are burned in the propulsion and/or auxiliary engines can be effective in reducing NOx and $PM_{2.5}$ emissions at all types of ports. In this assessment, it was assumed that some ships would use either a lower sulfur fuel or liquified natural gas (LNG) in their propulsion and/or auxiliary engines. It is noteworthy that the more aggressive fuel change strategies applied under Scenario B in both 2020 and 2030 provide about three times the emissions reductions than Scenario A in those years. The primary differences between these scenarios are twofold: Scenario B assumes that more ships switch to LNG as the fuel for either their propulsion or auxiliary engines and more used ULSD (used in auxiliary engines) and lower sulfur fuels (used in propulsion engines). In sum, the results indicate that significant NOx and $PM_{2.5}$ emissions reductions can be achieved from the use of these cleaner fuels, particularly LNG.

Figure 7-2. Comparing $PM_{2.5}$ Relative Reduction Potential of the OGV Sector

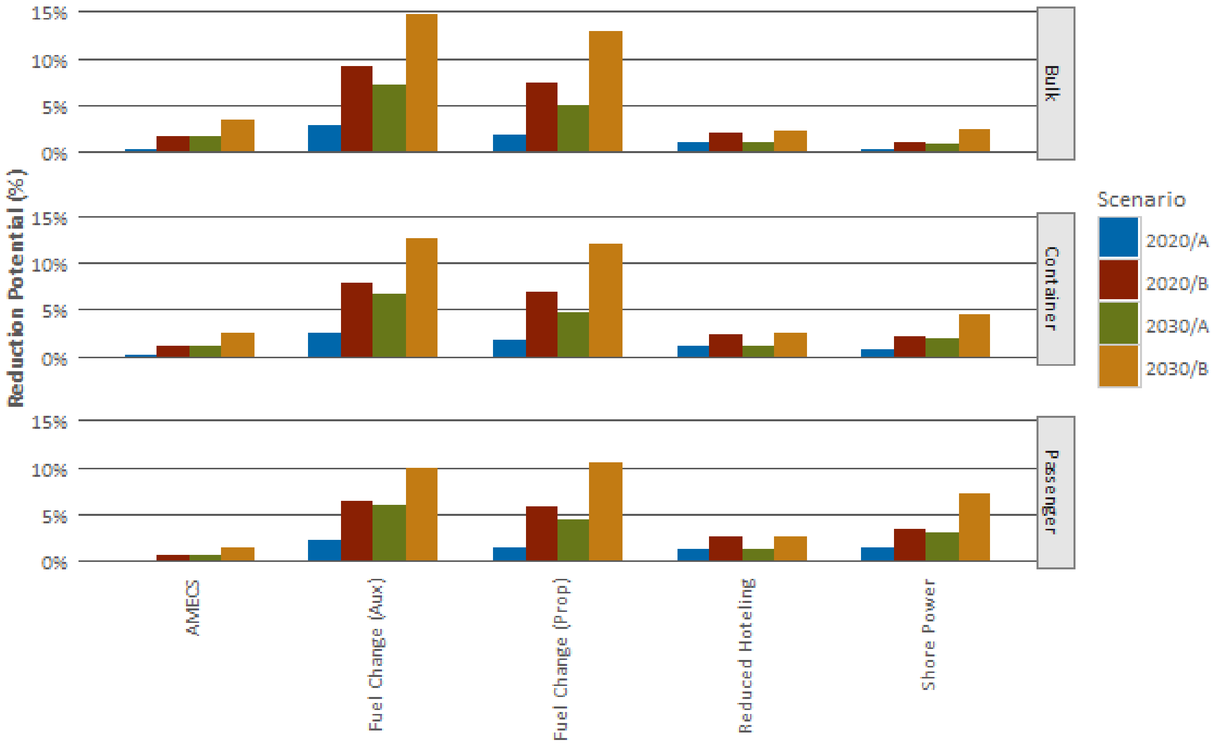
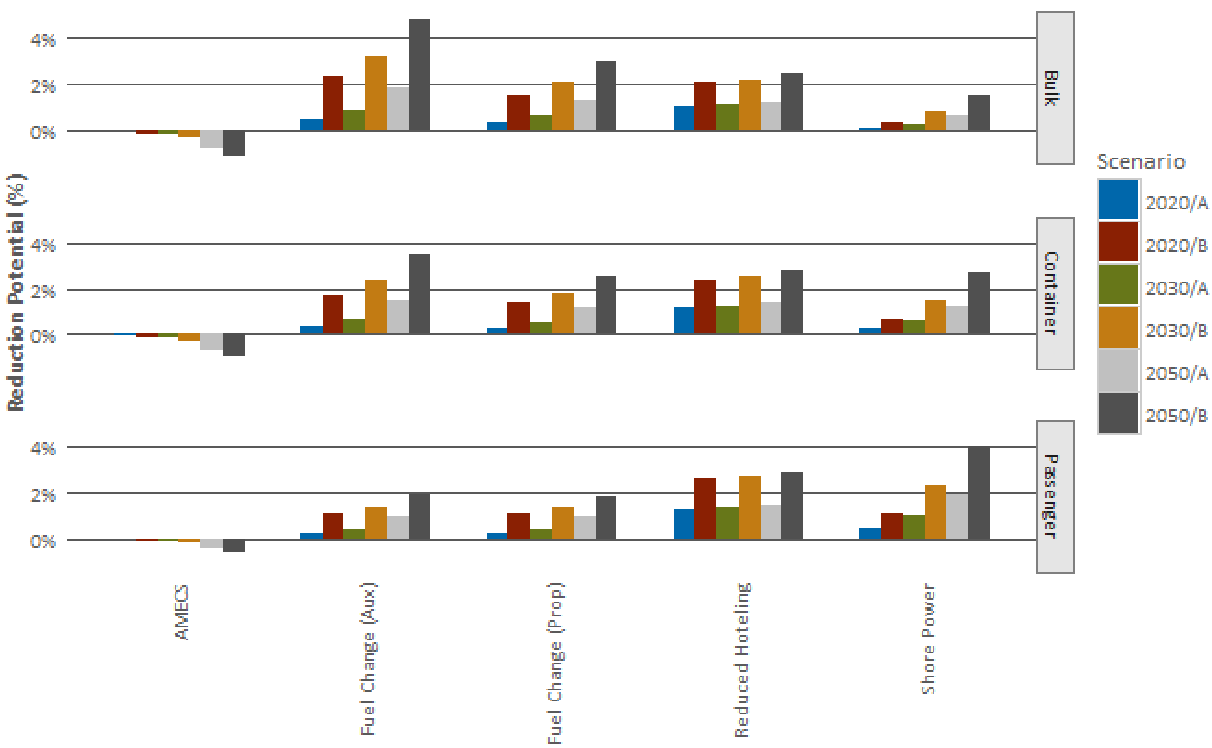


Figure 7-3. Comparing CO_2 Relative Reduction Potential of OGV Sector



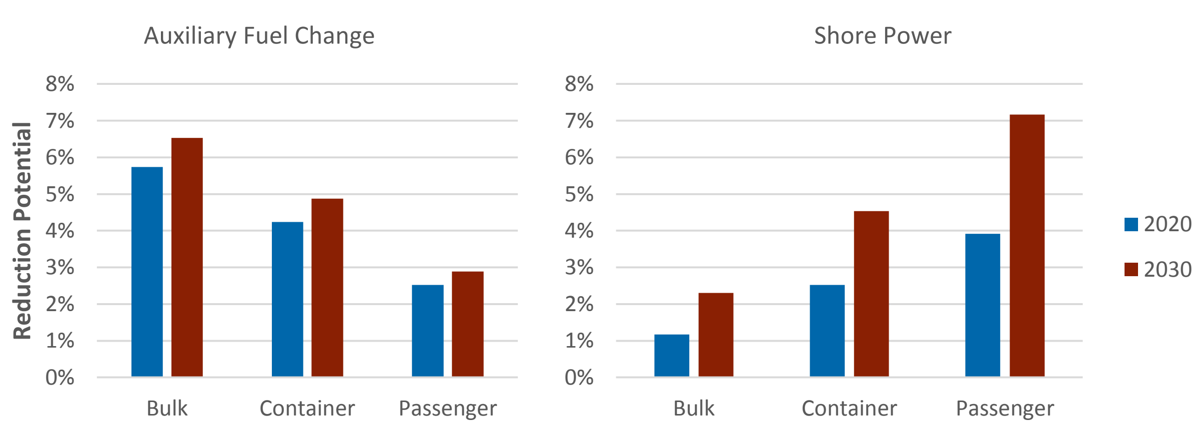
The charts also show that the use of shore power can result in significant emission reductions of NOx and $PM_{2.5}$. However, as discussed in Section 6, the potential emissions reductions largely depend on the number of frequent callers at a port. Available data show that passenger and container ports have significantly more frequent callers than bulk ports. The charts show that on a percent reduction basis passenger and container ports would get two to three times the reductions that are projected at bulk ports. Conversely, bulk ports, which typically have fewer frequent callers than container and passenger ports, are expected to benefit more from the use of AMECS technology. AMECS can be applied to ships that are not frequent callers at a port because these systems do not require modifications to the ships. AMECS is an emerging technology and currently in limited use. It is possible that over the next several years, its use and availability could expand at a greater rate than assumed in this assessment and even greater emissions reductions could be achieved.

It should be noted that use of shore power also results in some reductions in CO_2 because the ship's engines are not being used for power while in port and power plant CO_2 emissions resulting from generating the needed electricity to power the ship are less than the CO_2 that the ship's engines would have produced. However, the use of AMECS results in some CO_2 emission increases because not only are the ship's engines running but also because the AMECS unit is mounted on a barge and the barge engines are used to power the AMECS.

The NOx and $PM_{2.5}$ emissions reductions attributed to reduced hoteling are the result of improving the efficiency of cargo handling operations associated with containers. Therefore, the results are only applicable to container operations and are directly related to the efficiency gains that can be made at a given port.

Figure 7-4 illustrates the effectiveness of reducing emissions while OGVs are operating their auxiliary engines. In the year 2020, switching to a cleaner fuel is expected to be effective for reducing emissions from ships carrying bulk cargo while shore power technology was more effective at reducing NOx emissions for passenger ships. Shore power is expected to be more effective at reducing NOx emissions for a passenger port because passenger ships tend to call the same ports frequently, making it feasible to adapt these vessels to use shore power. In contrast, ships carrying bulk cargo typically do not call on the same port as often in a given year. This shows that stakeholders should consider what combination of strategies should be used to reduce emissions for a particular port area, depending upon the type of activity at a port.

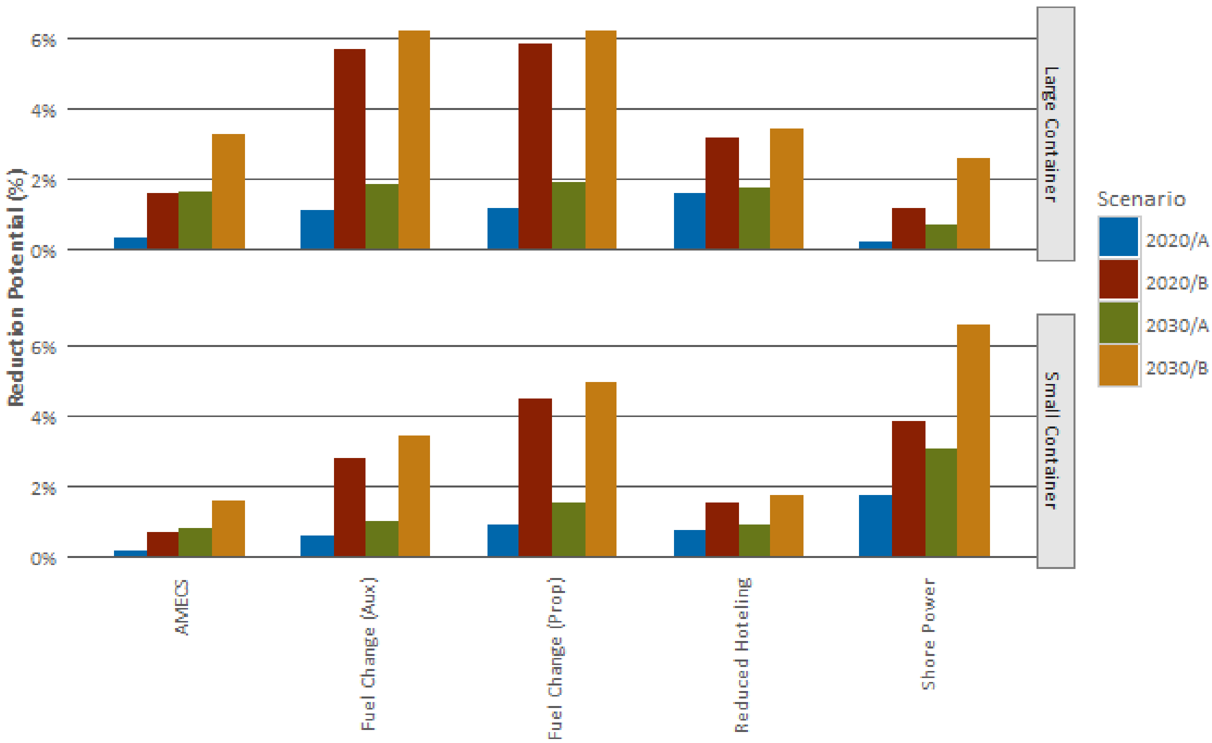
Figure 7-4. NOx Reduction Effectiveness of Different Strategies at Different Kinds of Ports (Scenario B)



7.2.2. Summary by Port Size

The results for container ports are used as an example because the results for this type of port are similar to the results for bulk and passenger ports. As a reminder, the stratification analysis identified 7 large and 7 small container ports. Figures 7-5, 7-6, and 7-7 present the relative reductions for NOx, $PM_{2.5}$, and CO_2 resulting from the strategies applied to OGVs at container ports.

Figure 7-5. NOx Relative Reduction Potential of the OGV Sector for Container Ports



The results presented in these figures are consistent with results presented in Figures 7-1, 7-2, and 7-3. In addition to reinforcing those results, Figures 7-5, 7-6 and 7-7 indicate that reductions from OGVs are possible at both large and small container ports as defined in this assessment. Therefore, the types of strategies applied to OGVs in this assessment are candidates that should be considered at both large and small ports, while taking into account the type of port (container, bulk, and/or passenger).

Figure 7-6. $PM_{2.5}$ Relative Reduction Potential of the OGV Sector for Container Ports

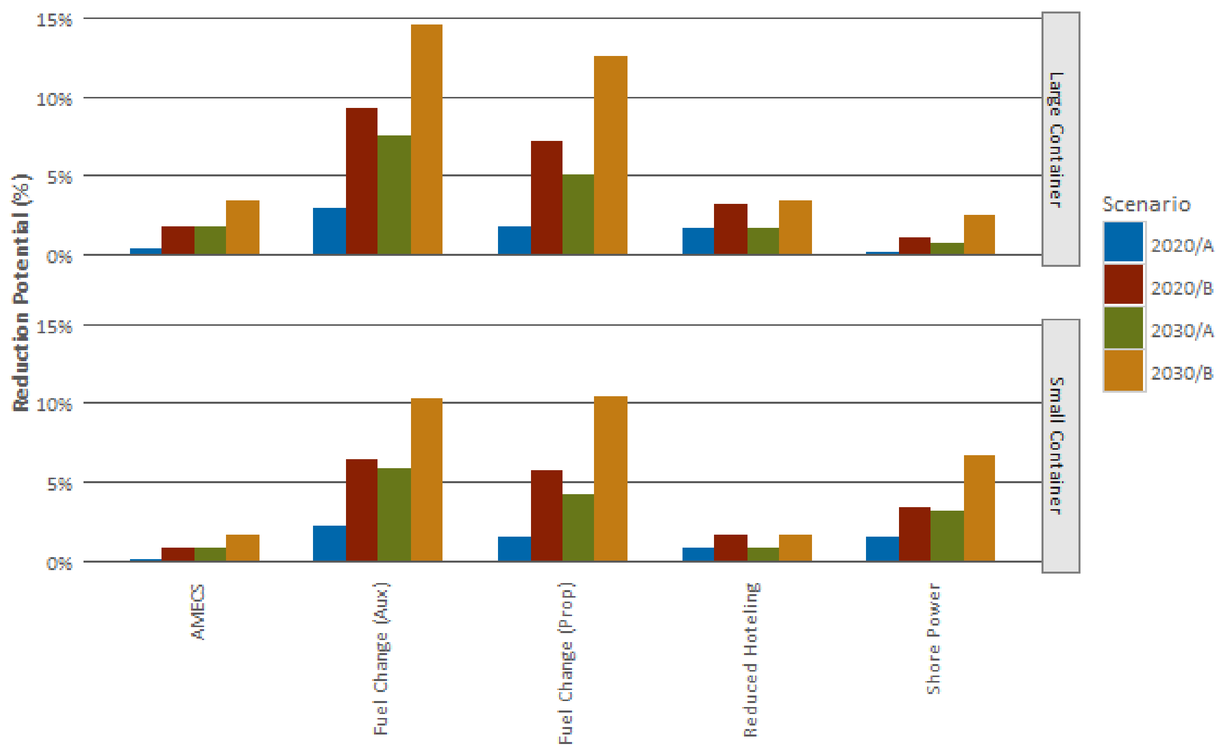
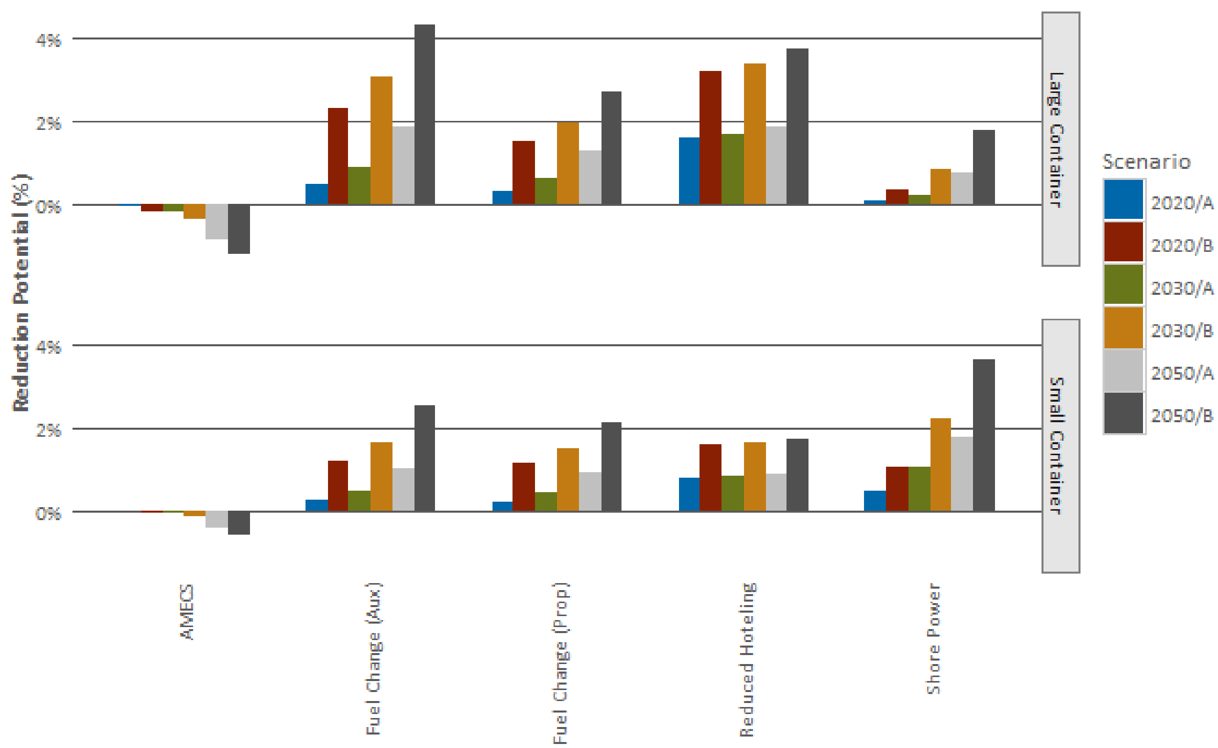


Figure 7-7. CO_2 Relative Reduction Potential of OGV Sector for Container Ports



Charts presenting the results for bulk and passenger port types and the other pollutants examined in this assessment are presented in Appendix D.

7.3. Non-OGV Stratification

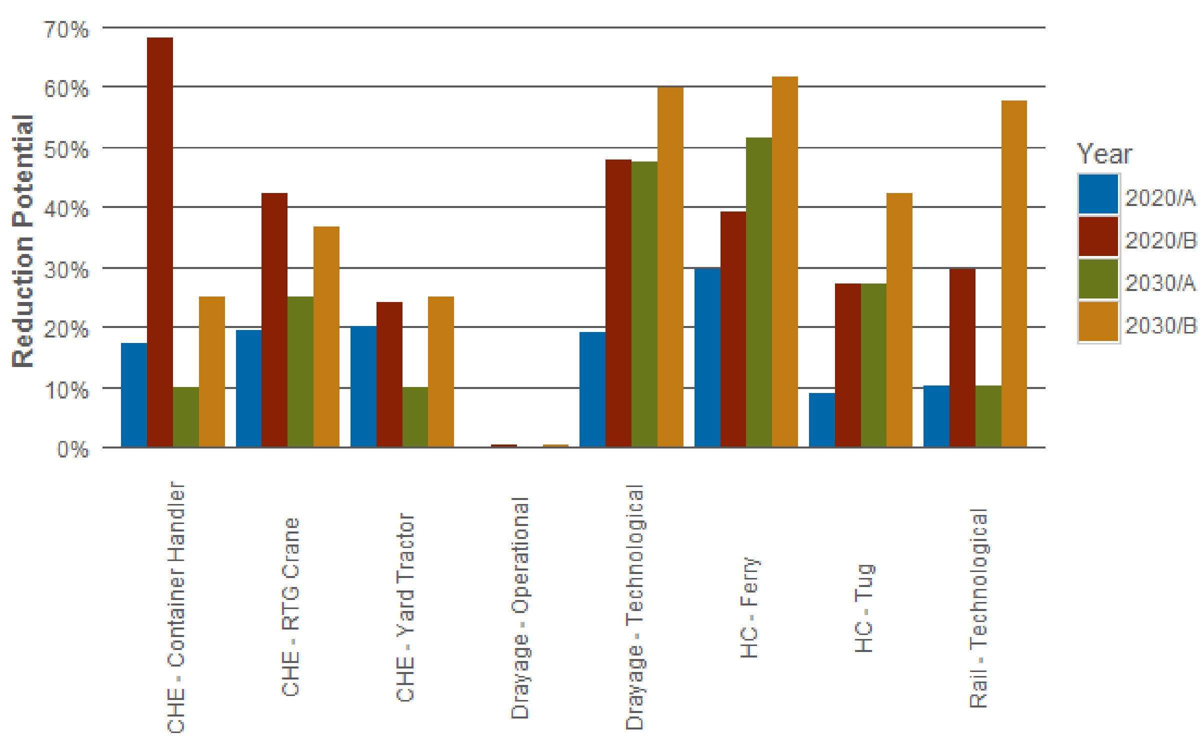
In this assessment, as described in Section 6, the following strategy scenarios were applied to non-OGV sources:

- **Technological** strategy scenarios involved accelerating fleet turnover for cargo handling equipment (CHE) (container handlers, rubber tire gantry (RTG) cranes, and yard tractors), drayage trucks, and harbor craft (tugs and ferries); and
- **Operational** improvement scenarios in drayage and rail.

The OGV sector strategy scenarios were highly dependent on the number and type of vessels that called on the port, but there is no corresponding level of detail in the non-OGV sectors. The relative emission reductions do not depend on the type or size of a port. For example, the drayage strategy scenarios did not examine different kinds of drayage trucks that would operate at a bulk port versus a container port. The result is that any port that has drayage truck activity similar to what was modeled in this assessment would see the same relative reductions in emissions.

Figures 7-8, 7-9, and 7-10 present the relative emission reductions for NOx, $PM_{2.5}$, and CO_2 from the non-OGV source categories.

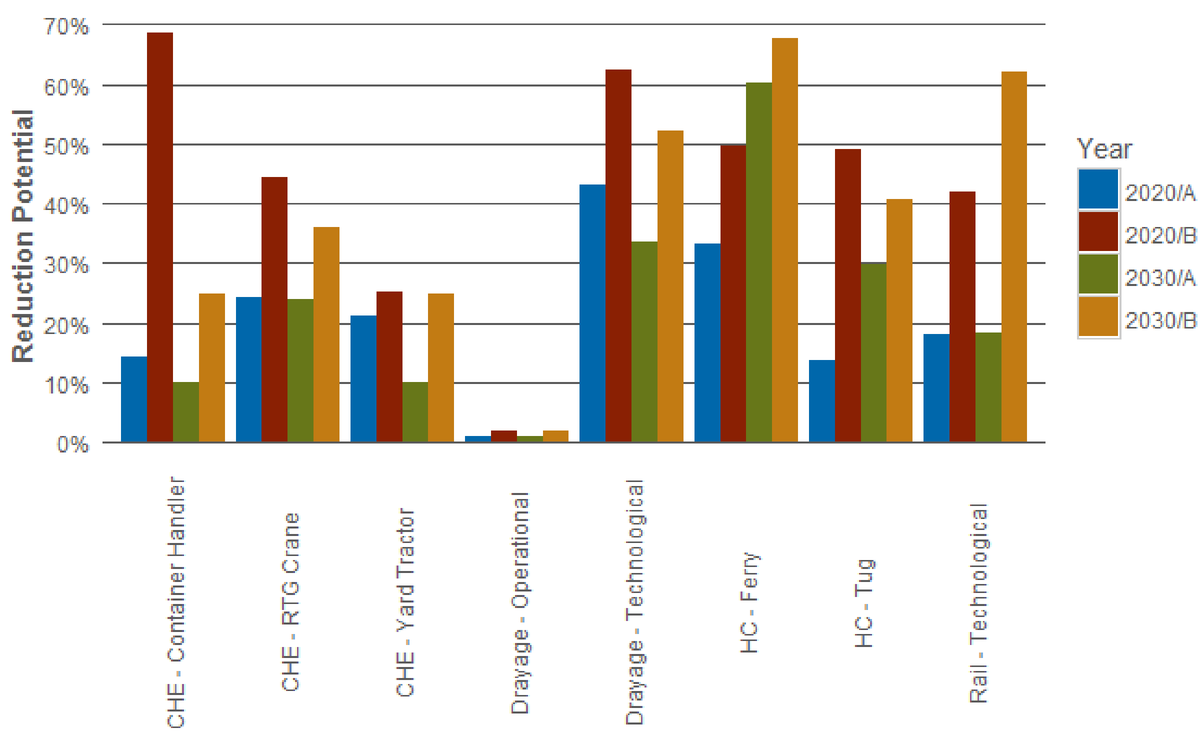
Figure 7-8. NOx Relative Reduction Potential of Non-OGV Sector



Technology strategies applied to CHE could provide NOx, $PM_{2.5}$, and CO_2 emission reductions at some ports, but the magnitude depends on the age and number of pieces of equipment to be repowered or replaced. It would also depend on the types of equipment that operate at the port. In this assessment, several types of equipment (cargo handlers, RTG cranes and yard tractors) that are common at container ports were evaluated. Other types of ports may have other types of equipment that could be repowered or replaced resulting in NOx, $PM_{2.5}$, and/or CO_2 reductions.

The charts also show that accelerating the turnover of older drayage trucks to newer trucks that meet more stringent EPA standards or that employ newer technology engines (e.g., such as plug-in hybrid electric vehicles) can provide significant reductions of NOx and particularly of $PM_{2.5}$ at ports with significant drayage fleets. The potential for the greatest reductions is in the 2020 timeframe, as the assessment's assumptions resulted in the removal of the very oldest trucks from the fleet in that year. In practice, the age distribution of a given port's drayage fleet is expected to vary from the assumptions in this assessment, with the possibility that many older drayage trucks will continue to operate at ports well beyond the year 2020. The amount of emissions from drayage trucks that could be reduced is highly dependent on the number and age of the drayage trucks that operate at a port. It should also be remembered that the drayage truck emissions reductions are based on the trucks operating within 0.5 km of the port. Total emissions reductions would be greater if the total miles traveled by the drayage trucks was considered.

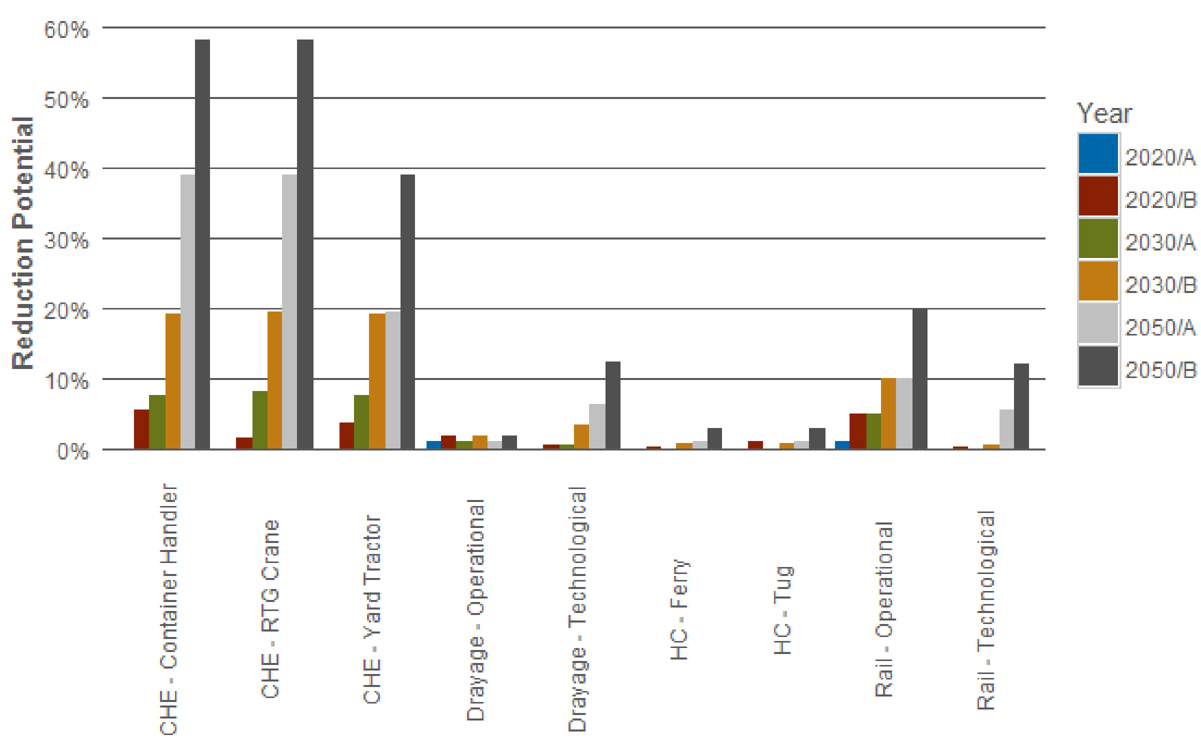
Figure 7-9. $PM_{2.5}$ Relative Reduction Potential of Non-OGV Sector



Technology strategies for ferries and rail can be effective at reducing NOx and $PM_{2.5}$ emissions at some ports, but the amount of emissions that can be reduced will likely vary from port to port and depend on a number of factors such as: the number of ferries that operate at the port, the number of switcher locomotives involved and their hours of operation during a year, the magnitude of the use of line-haul rail to move freight from the port, and the length of the corridor used when calculating the emission reductions from line-haul locomotives. This assessment assumed a line-haul corridor scope of within 0.5 km of the port.

These charts show that accelerating the replacement or repowering of older tugs with newer tugs or engines that meet more stringent emissions standards results in significant emission reductions of both NOx and $PM_{2.5}$. It is likely that there is potential for significant emission reductions at most ports since tugs are typically present at most ports for a number of purposes and tugs generally have a long useful life that may result in older diesel fleets.

Figure 7-10. Comparing CO_2 Relative Reduction Potential of Non-OGV Sectors



Charts presenting the results for other pollutants are presented in Appendix D.