



Moving California Forward: Zero and Low-Emission Goods Movement Pathways

**A Report to the
California Cleaner Freight Coalition**

**Prepared by
Gladstein, Neandross and Associates**

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List of Acronyms

AB118	California Assembly Bill 118
AREMA	American Railway Engineering and Maintenance of Way Association
BET	battery-electric truck
BNSF	Burlington Northern-Santa Fe Railroad
CARB	California Air Resources Board
CO	carbon monoxide
CO ₂	carbon dioxide
COFC	container on flat car
EPA	United States Environmental Protection Agency
F	Fahrenheit
FCH	fuel-cell hybrid
g	grams
g/bhp-hr	grams per break horsepower-hour
gal	gallon (U. S.)
hp	horsepower
kg	kilograms
km	kilometer
kW	kilowatt
L	liter
Lbs	pounds
NO _x	nitrogen oxides
Metro	Los Angeles Metropolitan Transit Authority
mi	mile
mpg	miles per gallon
OEM	original equipment manufacturer
PM	particulate matter
POAK	Port of Oakland
POLA	Port of Los Angeles
POLB	Port of Long Beach
PBET	plug-in battery-electric truck
PHET	plug-in hybrid electric truck
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SO _x	sulfur oxides
TOFC	trailer on flatcar
TrOFC	truck on flatcar
UP	Union-Pacific Railroad

Introduction and Summary

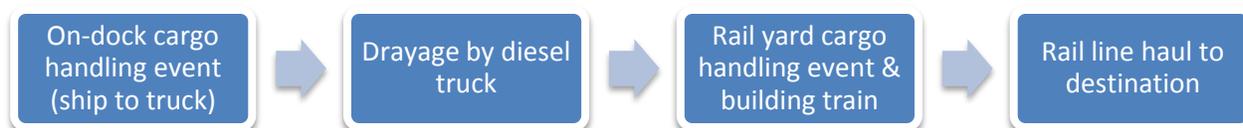
California faces significant challenges in years to come as it grapples with increasing demands to move goods within and through the state, while meeting increasingly stringent air pollution standards, requirements and goals.

This report is designed to help the California Cleaner Freight Coalition (the “Coalition”) evaluate local, regional, and statewide proposals to introduce new zero- and low-emission strategies and technologies that aim to address the state’s growing freight transport demands while concurrently meeting increasingly stringent air pollution and other environmental requirements.

Comparing and contrasting different freight strategies and technologies is a complex and difficult task. It requires the ability to gauge the multiple environmental impacts of different fuels and technologies, different transportation modes, and in different applications. Plus, what works in one location may be wholly unsuited for use in another location. These are always apples-to-oranges comparisons, and as such, exact quantitative comparisons are difficult, and sometimes impossible.

In this report, we have tried to resolve this difficulty by developing the concept of “freight pathways” as a way to compare the emissions of different freight movement strategies on a ton-mile or per container basis. Conceptually, the “freight pathway” is the series of freight movement strategies and technologies that is used to transport goods between two end points. For example, the movement of a shipping container between a port terminal and an inland intermodal facility typically involves a combination of cargo handling events, which could include transport by on-road truck and/or rail. In some locations, short-sea shipping could add a third option. To make matters even more complicated, the truck or locomotive could be powered by diesel, natural gas, or a variety of hybrid and electric technologies.

The specific combination of these events defines the “freight pathway.” By estimating the emissions of nitrogen oxides (NO_x), particulate matter < 2.5 μm (PM), and greenhouse gases (GHG) associated with each step along the pathway, the total emissions associated with the freight pathway may be constructed. Further, new pathways can be constructed by combining alternative steps. For example, a pathway that uses near-dock rail facilities for transport may be compared to a pathway that uses on-dock rail for transport by replacing near-dock truck drayage activities with on-dock rail activities, while leaving the rail line-haul activities unmodified. The figure below illustrates this concept. (We assume that the beginning and end of the pathways are the same to create an apples-to-apples comparison of emissions.)



Freight pathway: Drayage to Near-dock Rail



Freight pathway: On-dock Rail

To produce quantitative results from each freight pathway, the emissions associated with each step in the pathway has been calculated. In this study, GNA has relied on our analyses of the existing research literature, publicly-available emissions inventories, and project and program proposals from a variety of California public agencies to construct our own emissions model. We then used this emissions model to quantify the emission reductions of 32 different freight pathways.

Because of the sensitivity of emissions to the specific equipment used and geographic region of operation, the figures provided in this study should be considered as illustrative only. Moreover, some unavoidable, regional biases exist in the presented data.¹ However, the freight pathway model provides a framework for the Coalition to make judgments about freight proposals that exist or that will be made, and will give the Coalition the tools to conduct further site-specific and project-specific investigations that can be tailored to a particular location, region, and equipment inventory.

Both emissions from the tailpipe and those created upstream are included in the analysis. Upstream emissions are those associated with producing various fuels and transporting them. While this analysis quantifies the amount of both types of emissions, it does not assess the geographical differences in where they occur. For example, upstream emissions associated with power plants often occur far from freight-impacted communities and outside regions that suffer from extreme air pollution, although some power is generated in urbanized and polluted areas as well. When evaluating the health risks and benefits of various strategies, the location of the emissions and the amount of emissions must be considered, as well as the impact of various pollution regulations impacting stationary sources such as power plants or hydrogen production facilities. Upstream emissions associated with electricity and hydrogen production are based on CARB's VISION model

¹For example, emissions inventories for the Port of Los Angeles and Port of Long Beach (POLA/POLB) reflect the operational conditions specific to these ports. The emissions rates estimated from the POLA/POLB inventories (or any other inventory for that matter) are not purely a function of the technology, but how that technology is used in that specific location. To illustrate, POLA/POLB on-dock rail operations are different than those at other California ports in Oakland, San Diego, or elsewhere. In this report, we use the POLA/POLB on-dock rail emissions as a surrogate for all port on-dock rail emissions, but recognize that doing so might not account for some regional differences that exist among California's ports.

for heavy duty trucks. Specifically, this analysis uses the VISION model emissions estimates for 2020. The 2020 California average grid mix is assumed to include 10% coal, 30% natural gas, and the remainder derived from renewables and large hydro (47%) and nuclear power plants (13%). By 2050, the grid mix is assumed to be 20% natural gas with the remainder being renewables and large hydro (72.5%) and nuclear power plants (7.5%). These changes in the grid mix reduce the well-to-tank emissions, as shown in Figure 1, between 2020 and 2050. Hydrogen production estimates assume a combination of steam reforming of natural gas (80%) and renewably produce hydrogen (20%). Other electricity and hydrogen production scenarios were not evaluated.

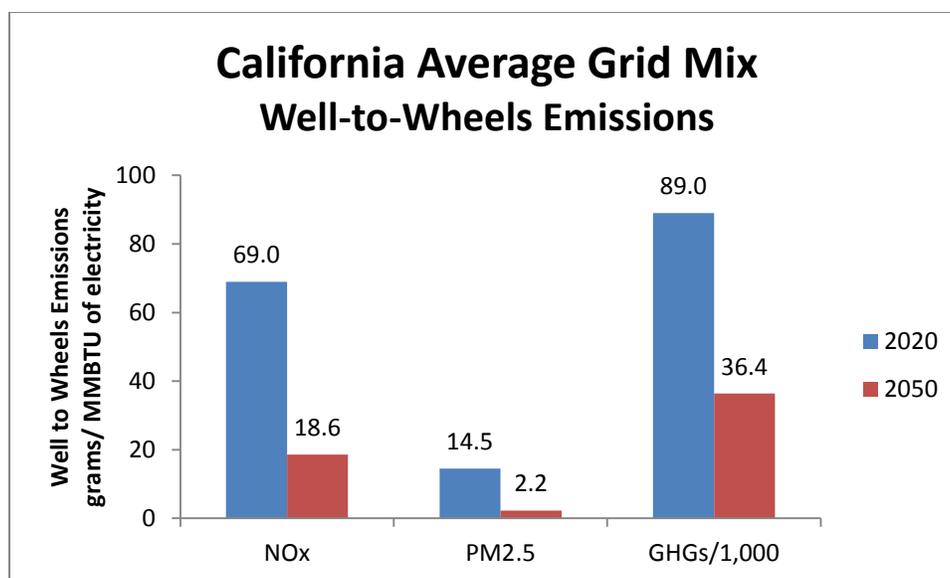


Figure 1. Well-to-Wheels emissions from California average grid mix

The assumptions for the carbon intensity of liquid fuels also reflect the year 2020. In particular, diesel fuel is assumed to meet the requirements of the low carbon fuel standards (LCFS) which calls for a 10 percent reduction in carbon intensity. While the LCFS allows replacement fuels such as electricity and biogas to contribute to LCFS compliance, for this analysis diesel fuel itself is assumed to achieve a 10 percent reduction. No reduction in the carbon intensity of natural gas is assumed. This report does not reflect recent updates to Argonne National Laboratory's GREET model released in October, 2013. The most significant changes to the GREET model that relate to this report include significant reductions in the upstream GHG emissions associated with natural gas. Under the updated GREET model, it is expected that natural gas-fueled trucks would show additional GHG reductions versus diesel trucks.

It is worth noting that, for some of the freight pathways, there are no specific proposals at specific locations in California – or where there are proposals, the public documents do not enable an effective comparison between the proposed project and other strategies that we have studied in this report. Thus, while we have been able to build an emissions model to estimate the comparative emissions of our freight pathways, there is no way to build a cost model to eliminate the inherent apples-to-oranges comparisons that we are faced with. Thus, costs are presented where they exist, but further cost information is not available at this time.

This analysis includes a select set of freight pathways and is not inclusive of all freight pathways or technologies. Further analysis is warranted, especially in the areas of air cargo movement, cross boarder freight movement, cargo handling equipment, marine strategies such as cold ironing, urban delivery trucks, and others.

In each section that follows, we present our material in the following manner:

- The technology in a nutshell: a brief summary of the technology or strategy
- Who is developing the technology and where: a summary of the key government or industry stakeholders involved in the technology or strategy, plus a summary of where the technology or strategy may be in use, under development or proposed in California. In some cases, non-California projects are also discussed.
- Where appropriate, a series of tables and charts that demonstrate the relative emissions performance of each of the technologies or strategies that comprise the freight pathways discussed in the section.
- A summary of the strengths, weaknesses, opportunities and challenges to the further progress of the technology or strategy.

The strategy and technology summaries and emissions modeling presented in this report should provide a valuable tool to the Coalition as it considers the wide range of potential projects that will be proposed for California's Freight transport system in years to come.

Key takeaways from this report include the following points:

- Due to major improvements made in emission controls in on-road heavy duty engines over the past decade, trucks meeting the EPA 2010 emission standard can produce comparable or fewer NO_x and PM emissions than *some* current "baseline" versions of more efficient technologies (on a ton-mile basis), such as marine vessels and locomotives. However, diesel trucks generally produce greater greenhouse gas emissions than other technologies.
- In the 2020 timeframe, many of the baseline offroad equipment groups considered in this report will be replaced by equipment meeting more stringent emissions standards (e.g. Tier 2 engines will be replaced by Tier 4 engines). As existing marine and locomotive engines are replaced with new engines meeting these Tier 4 emissions standards, the marine and rail pathways tend to become significantly cleaner than pathways based on on-road trucks meeting EPA 2010 emissions standards.
- The combination of improved efficiency from electrified drivetrains and the relatively low-emission California grid mix make electrified pathways the cleanest options, where electrification is applicable.

Part One – Local Freight Movements/Near-Dock Drayage

“Local freight movement” describes the hauling of cargo between a port or rail terminal and another location, typically an intermodal facility or warehouse. In the shipping world, this local, short-mileage routing is called “drayage.” Drayage also applies to short-mileage border crossings and air cargo coming from airports.

Drayage trucks in California are predominantly Class 8 semi-tractors, often referred to as “big rigs.” The California Air Resources Board (CARB) estimates that there are approximately 18,400 drayage trucks in the state, travelling a combined total of more than 1 billion miles annually.²

The economics of the drayage market have historically produced a drayage fleet that was significantly older and less well-maintained than other Class 8 truck fleets. In fact, NRDC and other port clean-up advocates often describe the port drayage market as “the place where old trucks go to die.”³

Notwithstanding the foregoing, recent emission reduction programs like the Clean Truck Program at the Port of Los Angeles (POLA) and the Clean Trucks Program at the Port of Long Beach (POLB), as well as fleet emissions rules promulgated by CARB, have created a cleaner drayage fleet in southern California than drayage fleets at other ports.⁴

The Clean Truck Programs at POLA and POLB⁵ have forced turnover of the drayage fleet serving these ports from the older, dirty diesel trucks typically used in port drayage to a new generation of much cleaner trucks that meet relatively modern (2007) EPA and CARB emissions standards. This fleet also includes nearly 1,000 drayage trucks operating on natural gas and represents the single largest concentration of natural gas trucks in the freight transport sector.⁶

The success of the Clean Truck Programs at POLA and POLB, covering 14,000 drayage trucks, or 78% of the entire California drayage fleet, helped lead to a ban on dirty trucks serving the Port of Oakland. Also, a statewide drayage truck clean up measure now requires clean trucks serving all major ports and rail yards, resulting in an unusually clean drayage truck fleet throughout the state.

Near-dock drayage is a subset of drayage activity and generally involves travel between a marine terminal and a nearby rail yard, warehouse, or other marine terminal. Typical travel distances for

² California Air Resources Board, EMFAC 2011 emissions model. Data accessed March, 2013

³ http://switchboard.nrdc.org/blogs/dp Pettit/your_witness_at_last.html

⁴ Note also that the Ports of LA and Long Beach have a Technology Advancement Program that funds the development of cleaner and near-zero emission trucks among other projects. See: San Pedro Bay Ports Clean Air Action Plan Technology Advancement Program, 2012 Annual Report, May 2013.

⁵ Officially, the program at the POLA is called the Clean Truck Program, while the program at the POLB is called the Clean Trucks Program. For ease of use, we will refer to them collectively as the Clean Truck Programs.

⁶ Port of Long Beach, Truck Activity Report, April 2013

near-dock drayage vary by region, but are approximately five to six miles (one-way) at POLA/POLB, and approximately 1.5 miles (one-way) at Port of Oakland.⁷

Frequent callers to the ports may complete between three and six round trips per day. This means that emerging zero- and low-emission drayage trucks⁸ need to have a range of up to 80 miles of range per shift, plus sufficient on-board energy storage to supply cabin heating and cooling loads and other accessories. These accessory loads can be significant in part because drivers often spend a significant portion of their work day waiting in truck queues at terminals and other facilities.

Battery Electric Drayage Trucks

The technology in a nutshell

Battery-electric trucks operate with zero tailpipe emissions, so have been a primary R&D target for the drayage market at POLA since 2007, with some limited participation from the neighboring POLB. Although they operate with zero tailpipe emissions, they have upstream emissions associated with them, due to the electricity generated from power plants that powers these trucks. Communities benefit from clean tailpipes of electric vehicles, but the use of these trucks does not mitigate congestion-related concerns at the community level.

In addition to obvious cost challenges (i.e., the incremental cost of batteries and charging infrastructure, which can be significant), these trucks must overcome the per-shift range requirements of 60+ miles and weight increases that result from the large battery packs (200 kw-hrs or more) that are necessary to meet the per-shift range requirements. One approach to reduce battery size is to install “opportunity charging” infrastructure at one or both ends of the truck route, thereby creating mid-day charging opportunities.

A number of strategies have been proposed to provide opportunity charging infrastructure, including (1) conductive or inductive chargers embedded in truck queue lanes, (2) parking stalls with charging equipment, and (3) battery-swapping stations (e. g. A Better Place).⁹ For the purposes of the freight pathway comparisons, a battery-electric truck is assumed to have a battery pack sufficient to complete an entire shift without opportunity charging.

Who is developing this technology and where?

The primary development partner for the Port of Los Angeles has been Balqon Corporation. Balqon’s current product offering is the Nautilus XE30, which uses lithium iron phosphate battery packs to provide up to 150 miles of range between charges. However, the truck’s performance is

⁷ California Air Resources Board, “Emissions Estimation Methodology for On-Road Diesel-Fueled Heavy-Duty Drayage Trucks at California Ports and Intermodal Rail Yards” Appendix B, 2007

⁸ Near-zero emission trucks can also include natural gas and diesel-fueled trucks with advanced emission controls. For example, South Coast AQMD recently approved a project to develop heavy duty natural gas engines that reduce NOx by 90% compared to the EPA 2010 standard. SCAQMD Governing Board Meeting, October 4, 2013, Agenda Item 9

⁹ En route charging via wayside power has also been proposed, but is discussed under the Catenary Truck section, below. CALSTART, Technologies, Challenges & Opportunities I-710 Zero-Emission Freight Corridor Vehicle Systems. June, 2012

limited to a top speed of 45 mph and 200 horsepower – approximately 1/3 to 2/3 of the typical power of existing diesel and natural gas drayage trucks.

A more recent entrant into the electric drayage truck arena, Transpower, is actively developing its ElecTruck product in partnership with Navistar. Current development efforts are being funded through a number of partnerships including the POLA, POLB, the South Coast AQMD, and the California Energy Commission. The current design of the ElecTruck calls for a 100-mile range between charges and motor power levels equivalent to current diesel drayage trucks (>400 HP).

The Port of Los Angeles and Port of Long Beach have been the primary locations of development and demonstration activities for electric drayage trucks in California. Demonstrations of similar battery-electric cargo handling equipment (e. g., yard tractors) are also happening at POLA and POLB, as well as at ports in other states including Texas, New York, and New Jersey. To date, only a limited number of prototypes have been produced for demonstration projects. Battery-electric drayage trucks are not yet providing commercial drayage service on a daily basis anywhere.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Zero tailpipe emissions of pollutants
- Higher efficiency and reduced climate impact
- Quiet electric motors

Weaknesses:

- Lack of charging infrastructure
- High and uncertain costs for truck and infrastructure
- Range limitations
- Does not address concerns related to congestion

Opportunities:

- Clear interest and active pilot programs at POLA and POLB for zero-emission alternatives
- Potential for public funding to cover incremental costs and infrastructure development

Challenges:

- Weaknesses are not overcome in a timely manner
- Other alternatives could emerge that provide better value for environmental performance
- Time for manufacturing of new electric vehicles to meet demand as the technology goes from pilot to mainstream use.

Fuel Cell Hybrid Drayage Trucks

The technology in a nutshell

Hybrid drayage trucks are very similar in concept to those used in light-duty hybrid vehicles, i.e., an onboard generator provides electricity to power the vehicle. In a fuel cell hybrid (FCH) format, a proton exchange membrane fuel cell, which operates on pure hydrogen, provides the electricity to power the truck.

Fueling infrastructure for hydrogen vehicles is currently very limited, but the presence of a hydrogen pipeline in the POLA/POLB area may provide an impetus to provide large amounts of hydrogen for vehicle fuel in southern California that is not available elsewhere.

Like electric trucks, fuel cell trucks produce zero tailpipe emissions, and have upstream emissions that come from fuel production and distribution. Similarly, incremental costs can be significant and remain uncertain, given the limited use of the technology so far. For the purposes of the freight pathway comparison below, fuel cell trucks are assumed to receive hydrogen reformed from methane at the fuel station (80%) and the remainder from the renewable thermo conversion of water (20%).

Who is developing this technology and where?

From an energy storage perspective, FCH trucks should be viable on the short drayage routes of near-dock drayage trucks. Vision Motors is currently the only vehicle manufacturer developing a Class 8 FCH truck for drayage. Much of this development work is being conducted in partnership with Total Transportation Services Inc (TTSI), a motor carrier with operations at several major ports in the U. S. Vision's truck platform is the Tyrano.

The truck's range is reported to be 200 miles with a standard fuel tank package. The truck's performance specifications indicate that the truck will exceed the typical power of existing diesel and natural gas drayage trucks.

Vision Motors has deployed one Tyrano prototype with TTSI in the POLA/POLB region. TTSI has also announced the intent to purchase 100 Tyrano trucks, although this has yet to occur. Vision and TTSI are also partnering on a 20-truck demonstration in the Port of Houston that will include participation from the Houston Galveston Area Council, Air Products, and the Environmental Defense Fund (EDF).

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Zero tailpipe emissions of pollutants
- Higher efficiency and reduced climate impact
- Quiet electric motors

Weaknesses:

- Lack of refueling infrastructure
- High and uncertain costs for truck and infrastructure

- Does not address concerns related to congestion

Opportunities:

- Clear interest at POLA and POLB for zero-emission alternatives
- Port of Houston demonstration will provide real-world experience and visibility for the technology
Potential for public funding to cover incremental costs and infrastructure development

Challenges:

- Weaknesses may not be overcome in a timely manner
- Other alternatives could emerge that provide better value for environmental performance
- Time for manufacturing of new electric vehicles to meet demand as the technology goes from pilot to mainstream use.

Catenary Hybrid Drayage Trucks

The technology in a nutshell

Catenary systems are a proven technology that uses overhead power lines to provide electrical power from the electricity grid to vehicles that are propelled by onboard electric motors. A device known as a pantograph connects the vehicle to the overhead wires.

Although their use in trucking is new, they have been used in fixed guideway systems like trains and trolley systems for decades. They have also been used in some onroad applications, such as urban transit buses, for example in San Francisco. In those systems, the vehicles are confined to fixed routes with few, if any, entrance and exit points from the catenary system. Recent advances in the pantograph technology are enabling the use of catenary systems to power more traditional on-road applications, including heavy duty trucks that have many points of entrance and exit from the catenary system onto roadways.

When connected to a catenary line, the vehicle operates as an electric vehicle. When braking, regenerative braking systems feed electrical energy back into the overhead lines. This allows the vehicle to recover more energy than is possible on traditional hybrid vehicles where the battery pack is unable to absorb all of the power available during a regenerative braking event.

When it leaves the catenary system, the hybrid vehicle transitions to whatever on-board power sources are present. In other words, a catenary hybrid drayage truck will be powered by diesel, natural gas, batteries, or whatever other power source is installed on the vehicle. In southern California, catenary systems are being envisioned to provide zero-emission operational capability for trucks along commonly-traveled routes and facilities near these routes through the use of limited, on-board, all-electric range.

Who is developing this technology and where?

Advanced pantographs, the key enabling technology for catenary hybrid trucks, are being developed and demonstrated by Siemens. Several agencies have expressed interest in the

technology, including the SCAQMD, POLA, POLB, Los Angeles METRO, Gateway Cities COG, and the Southern California Association of Governments.

Catenary systems seem to be compatible with many different vehicle architectures (including PHETs, BETs and FCTs). This has created interest among several manufacturers of these trucks. Discussions are ongoing with Volvo, Transystems, and Vision Motors to develop catenary-enabled versions of each manufacturer's vehicle platform.

Siemens has successfully demonstrated a pair of catenary-enabled European-style trucks on a closed test track in Germany as a proof of concept. In the U. S., a \$13.5 million one mile demonstration has just begun (contracts executed as of April 5, 2013/ building and testing to come in the next 3 years) along a major drayage truck route in Carson, between the ports and near-dock rail yards in Los Angeles.¹⁰ Another \$3.2 million contract also has gone to TransPower to develop one battery electric truck and one CNG-hybrid truck, each with pantographs to utilize the catenary system. Catenary trucks are also the "placeholder" technology proposed for the I-710 zero emission truck corridor, which would provide dedicated truck lanes for 21 miles along the I-710 and Alameda Corridor.

Note that a similar electric truck technology is being developed by Volvo in Sweden with the power supplied by cables embedded in the roadway.¹¹ Another similar electric truck technology that is under development is called On-Line Electric Vehicles (OLEV).¹² OLEV technology, which is being pilot tested in buses in South Korea, can be wirelessly charged through power cables embedded under the road.¹³ Similar to the catenary and roadway cable technology above, OLEV does not require charging stations or large battery capacity; it also does not require direct contact with electrical cables, as the power is transmitted through magnetic fields.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Zero tailpipe emissions of pollutants along the catenary system
- Flexibility to operate away from catenary system increases its range and applicability
- Higher efficiency and reduced climate impact
- Quiet electric motors

Weaknesses:

- Requires catenary infrastructure, which may create concerns about construction and visibility impacts
- High and uncertain costs for truck and infrastructure
- Does not address concerns related to congestion

¹⁰ South Coast AQMD, April 5, 2013 board meeting Agenda No. 4 information on contracts to develop and demonstrate a Catenary Zero Emissions Goods Movement System.

¹¹ <http://www.environmentalleader.com/2013/05/29/volvo-tests-electric-roads/>

¹² <http://olevtech.com/>

<http://www.ipi-singapore.org/cos/o.x?ptid=1071682&c=/ipi/ipcat&func=preview&rid=794>

¹³ <http://blogs.wsj.com/korearealtime/2013/08/08/korean-electric-buses-go-wireless/>

Opportunities:

- Clear interest at POLA and POLB for zero-emission alternatives
- German demonstration went successfully, giving momentum to proponents of the technology
- Potential for public funding to cover incremental costs and infrastructure development

Challenges:

- Weaknesses may not be overcome in a timely manner
- Other alternatives could emerge that provide better value for environmental performance
- Time for manufacturing of new catenary hybrid trucks and building of infrastructure to meet demand as the technology goes from pilot to mainstream use.

Plug-in Hybrid Drayage Trucks

The technology in a nutshell

Plug-in Hybrid Electric Trucks (PHET) are similar in concept to light-duty plug-in hybrid-electric cars. In both cases, the vehicle is equipped with a moderately-sized battery pack that provides a limited all-electric range. Once the battery pack is depleted, an engine (typically diesel or gasoline-fueled) is used to supply propulsive energy to the vehicle. The battery pack can be recharged from the electric grid and, provided the range travelled by the vehicle between charges does not exceed the all-electric range, the truck can operate solely as a battery electric vehicle. Incremental costs can be significant and remain uncertain, given the limited use of the technology so far.

Opportunity charging infrastructure could potentially be used to extend the all-electric range of these trucks, assuming they commonly travel to a specific location where the infrastructure has been built into queue lanes or parking stalls. Where opportunity charging is not available, the truck could rely on its on-board fuel supply to complete a work shift.

Who is developing this technology and where?

Plug-in hybrid electric diesel drayage trucks have not been deployed in a commercial or demonstrating setting in California.¹⁴ However, both Kenworth and Volvo are currently engaged in an effort with the South Coast AQMD to develop and demonstrate Class 8 plug-in hybrid drayage trucks with an estimated 10-40 miles of all-electric range.¹⁵ Leadership at the Ports and the South Coast AQMD have been a major deciding factor in expanded availability of heavy-duty alternative fuel vehicles in the past; just as the Ports have prioritized the development of FCHs and BETs, we expect them to similarly encourage the development of PHETs.

¹⁴ Note however, that there is an ample supply of heavy-duty diesel-electric hybrid trucks available that do not have plug-in capability. See for example, the hybrid electric trucks eligible for funding through California's HVIP: <http://www.californiahvip.org/>

¹⁵ <http://www.aqmd.gov/news1/2011/bs11411.htm>

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Ability to utilize on-board fuel supply eliminates range anxiety faced by battery-electric trucks (BET)
- Zero tailpipe emissions of pollutants when operating on electric power
- Higher efficiency and reduced climate impact
- Meets range requirements for near-dock drayage

Weaknesses:

- Technology has not reached commercialization stage yet, limited selection of manufacturers and lack of maintenance understanding and knowledge
- High and uncertain costs for charging infrastructure
- Higher emissions profile than BETs or FCHs
- Does not address concerns related to congestion

Opportunities:

- Clear interest at POLA and POLB for zero-emission alternatives
- Potential for public funding to cover incremental costs and infrastructure development
- Potential for using renewable sources of electricity

Challenges:

- Weaknesses may not be overcome in a timely manner
- Other alternatives could emerge that provide better value for environmental performance
- Time for manufacturing of new plug-in hybrid electric vehicles to meet demand as the technology goes from pilot to mainstream use.

Fixed Guideway Systems (Freight Shuttle and Maglev)

The technologies in a nutshell

Freight Shuttle and Maglev systems are two closely-related freight pathways for regional Freight transport. Both use rail-like technology along a dedicated, fixed guideway, but with new, purpose-built equipment and infrastructure. Both systems use a dedicated track to transport containers. Because both systems use electricity from the power grid, they are able to meet CARB's definition of zero-emissions.¹⁶ And, for both systems, cost issues are the primary barrier to commercialization.

In Maglev systems, the container is carried by a special platform that levitates above the track using opposing magnetic forces. The absence of physical contact between the platform and the track eliminates friction and greatly reduces the energy needed to propel the container forward.

¹⁶ Under 13 CCR 1962.1, a zero-emission vehicle must emit zero criteria pollutants under all conceivable operating conditions. CARB does not consider the emissions associated with the production of fuel or electricity when certifying a zero-emission vehicle. Electricity generated to power vehicles based on electric propulsion produces substantially lower NOx emissions, and no diesel particulate matter emissions, than would occur using combustion-based propulsion.

Freight Shuttle systems also use a dedicated track and cars (or “transporters”), but propel the unit forward using a linear-induction motor within the individual transporter.¹⁷ The transporters draw power from a permanent power line built into the dedicated guideway. The transporters glide along a steel surface, reducing friction and energy consumption.¹⁸ In this way, freight shuttle systems are similar to “Monorail” or “people mover” systems found at airports and other locations around the world.

Cost and other infrastructure issues stand in the way of the deployment of these technologies. These systems can deliver significant speed and efficiency enhancements over competing technologies that rely upon existing freight corridors, but they require major investment in new equipment and physical infrastructure. Moreover, developing these systems require significant coordination between public and private partners to secure necessary rights of way, and to mitigate and minimize environmental and community impacts from construction and ongoing maintenance. While constructing along existing highway medians can mitigate some of the right-of-way issues or community concerns that exist when any new fixed rail or guideway system is proposed, this must be balanced against the reduced routing flexibility that comes with using existing rights of way.

Who is developing this technology and where?

Maglev

Maglev systems have been successfully deployed for passenger use in Shanghai (P. R. China), Daejeon (South Korea), and Aichi (Japan). Maglev systems, however, have not reached commercialization stage in the United States. As a result, accurate estimates of capital and operating costs are difficult to estimate. A group of private investors has proposed a passenger train service could be constructed between Anaheim and Las Vegas, at an estimated cost of \$1.5 billion (or \$45 million per mile),¹⁹ but has not been able to secure necessary financing to begin construction.

Researchers have proposed a similar system could be constructed in Southern California between the POLA, POLB, and inland freight depots.²⁰ This system would be built along the I-710 corridor, where 40,000 to 50,000 truck trips are completed each day currently. (A four-lane dedicated roadway for trucks was approved by local communities in 2004. Since that time there has been much discussion about including a zero-emission requirement on the proposed dedicated roadway, which travels through an environmentally and socially disadvantaged area.). A feasibility study commissioned by the Los Angeles County Metropolitan Transit Authority (Metro) estimated capital costs for a maglev system at between \$4.6 billion and \$6.6 billion, with an additional \$172 million

¹⁷ <http://tti.tamu.edu/documents/tti-freight-shuttle.pdf>

¹⁸ <http://www.star-telegram.com/2012/06/06/4013913/freight-shuttle-may-be-the-future.html>

¹⁹ <http://www.canv-maglev.com/pid7financing.html>

²⁰ http://www.thetransitcoalition.us/grid/images/Inland_Ports_METRANS.pdf;

<http://www.metrans.org/nuf/documents/Roop.pdf>; <http://www.metrans.org/nuf/documents/KenJames.pdf>.

to \$241 million in first-year operating costs.²¹ General Atomics has also had a 400' working test track in San Diego, CA that has been functional since 2006²².

Freight Shuttle

A consortium of public universities, local planning commissions, and private contractors has proposed a Freight Shuttle System along the right of way of Interstate 35 in East Texas. The initial 250-mile stretch would connect San Antonio to Waxahachie, but could eventually stretch north to Dallas-Fort Worth and south to El Paso and the U.S./Mexico border.²³ In this proposed project, cargo freight would travel inside driverless electric transporters along an elevated guideway. The guideway would be constructed between highway medians or other rights of way, reducing traffic congestion on public roads while still guaranteeing continuous operation in two directions.²⁴

Costs for this project are very high, and are inhibiting its development and implementation. The project's sponsor, Freight Shuttle International Inc (comprised of members from Texas Transportation Institute and a group of private contractors²⁵), estimates the initial segment could be completed in six years at a total cost of \$2.5 billion. In 2011, the Company reached a three-year, exclusive lease option with the Texas Department of Transportation for rights along Interstate 35, but has struggled to secure funding.²⁶ In consultation with the El Paso Regional Development Corporation, FSI has also proposed a similar 10-15 mile segment be built between El Paso and Ciudad Juarez.²⁷ The proponents hope that this system could simplify cross-border Freight transport traffic, for the more than 700,000 trucks that cross between the United States and Mexico each year.²⁸

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Zero tailpipe emissions of pollutants
- Higher efficiency and reduced climate impact
- Reduces congestion and pressure for roadway expansions

Weaknesses:

- Technology has not reached commercialization stage yet for freight
- High and uncertain costs for infrastructure

Opportunities:

- Clear interest in Southern California and in Texas

²¹ http://www.metro.net/projects_studies/l710/images/710_dr_agmta.pdf

²² Presentation by General Atomics. General Atomics Maglev Technologies: A solution for Port Congestion, July 2007

²³ <http://www.star-telegram.com/2012/06/06/4013913/freight-shuttle-may-be-the-future.html>

²⁴ <http://www.freightshuttle.com/concept/>

²⁵ http://tti.tamu.edu/wp/wp-content/uploads/2012/02/Freight_Shuttle.pdf

²⁶ http://www.mysanantonio.com/business/business_columnists/david_hendricks/article/Freight-shuttle-system-needed-but-moving-slowly-4349244.php

²⁷ http://www.elpasoinc.com/news/local_news/article_c13d7138-9a1a-11e2-a483-0019bb30f31a.html; ²⁷

http://home.elpasotexas.gov/mayor/_documents/2011%2008%2012%20EI%20Paso%20Border%20Mayors.pdf

²⁸ http://transborder.bts.gov/programs/international/transborder/TBDR_BC/TBDR_BC_QuickSearch.html

- Potential for public funding to cover incremental costs and infrastructure development

Challenges:

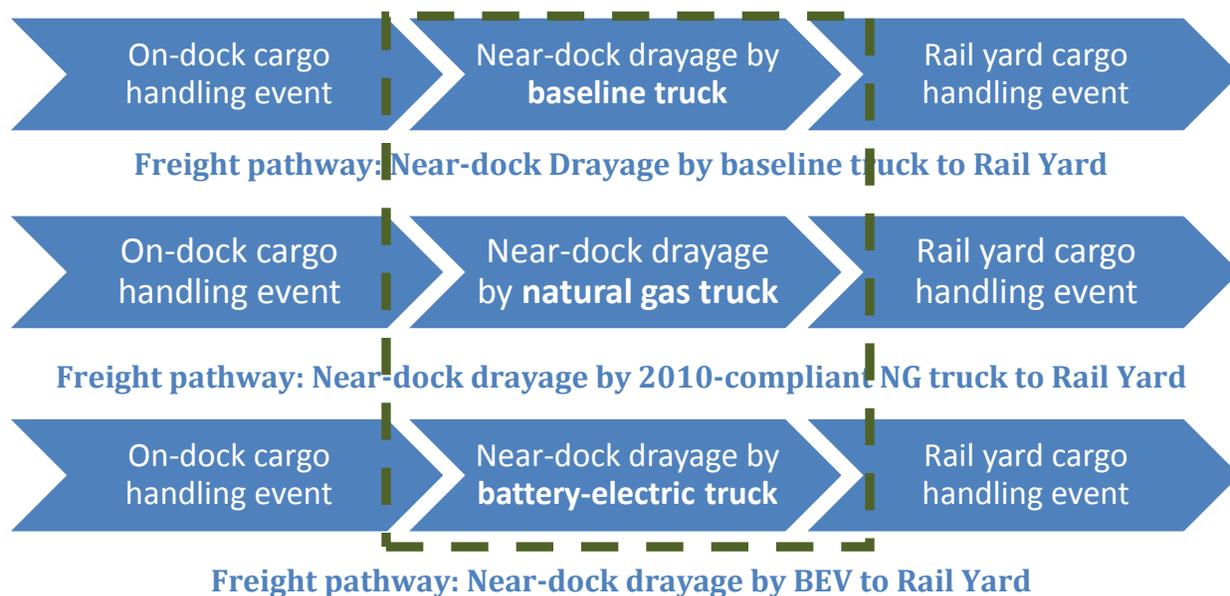
- Weaknesses may not be overcome in a timely manner
- Other alternatives could emerge that provide better value for environmental performance
- System construction time could be lengthy.

Summary of Freight Pathway Comparisons for Local Freight/Near-Dock Drayage

In order to move goods from a port to an inland railyard, all containers must go through three separate events: an on-dock cargo handling event, near-dock drayage to a railyard, and a railyard cargo handling event.

In developing our freight pathway comparisons for local freight/near-dock drayage, we have focused on the middle section, i.e., the near-dock drayage, where a wide range of zero-emission and low-emission alternatives are under consideration as options for transporting containers between marine terminals and near-dock rail yards.

This approach does not include a shift in the number of cargo handling events. Because the cargo handling events are the same, the following emissions comparisons focus only on the emissions associated with the drayage event, as shown in the following figure.



The pathway for freight shuttles is similar to drayage trucks because the shuttle move is similarly preceded by an on-dock cargo handling event and followed by a rail yard cargo handling event. (For the purposes of the current analysis, it is assumed that there are no significant differences in the emissions associated with cargo handling events for drayage trucks and freight shuttles.) Hence, as with drayage trucks, only the emissions associated with transport between the dock and rail yard are estimated and compared.

Pathway	Description
2007-compliant Diesel Short Range Drayage Truck ("currently required")	EPA 2007-compliant diesel-fueled drayage truck
2010 Diesel Short Range Drayage Truck	EPA 2010-compliant diesel-fueled drayage truck
2010 NG Short Range Drayage Truck	EPA 2010-compliant natural gas-fueled drayage truck
BEV Short Range Drayage Truck	Battery-electric drayage truck technologies, including catenary hybrid and plug-in hybrid vehicles operating with their all-electric range. Upstream emissions based on California average grid mix in 2020. ²⁹
Advanced NOx Standard Diesel Short Range Drayage Truck	Diesel-fueled drayage truck with NOx emissions 80% below EPA 2010 standard
FCV Short Range Drayage Truck	Fuel cell drayage truck – hydrogen produced from NG reformation. Upstream emissions assume 80% of the hydrogen is produced from natural gas reformation as the fueling station and 20% is produced from renewable sources via thermochemical conversion of water. ²⁹
Electrified Freight Shuttle	Electrified freight shuttle on dedicated guide way (e. g. maglev, linear synchronous motor, or catenary). Assumes no idle emissions.

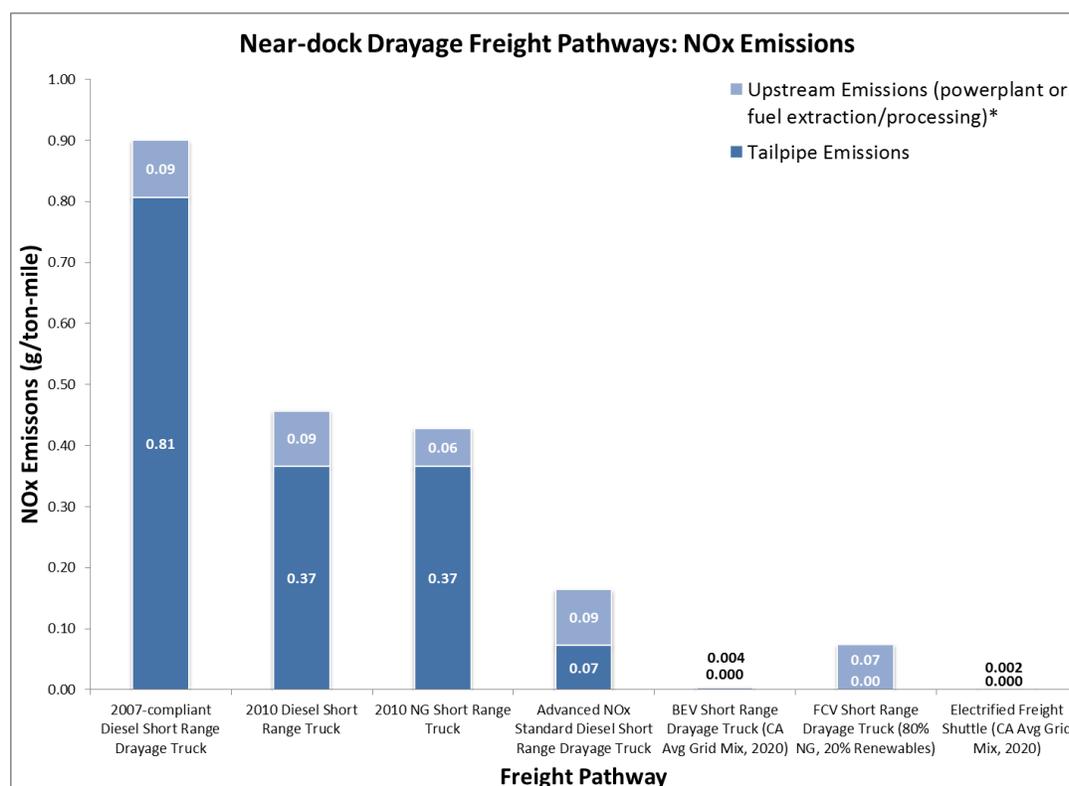


Figure 2. Near-dock Drayage Pathway: NOx Emissions (grams/ton-mile)

²⁹ California Air Resources Board, Vision Heavy Duty Vehicle Model, 2012
<http://www.arb.ca.gov/planning/vision/vision.htm>

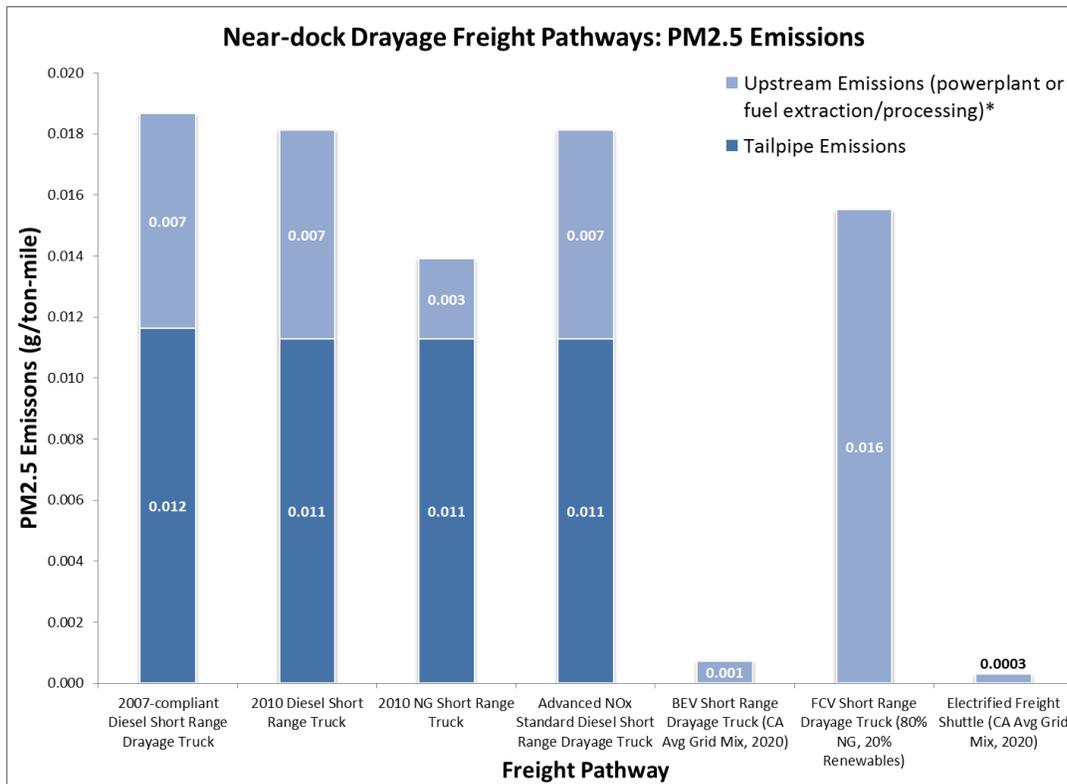


Figure 3. Near-dock Drayage Pathway: PM2.5 Emissions (grams/ton-mile)

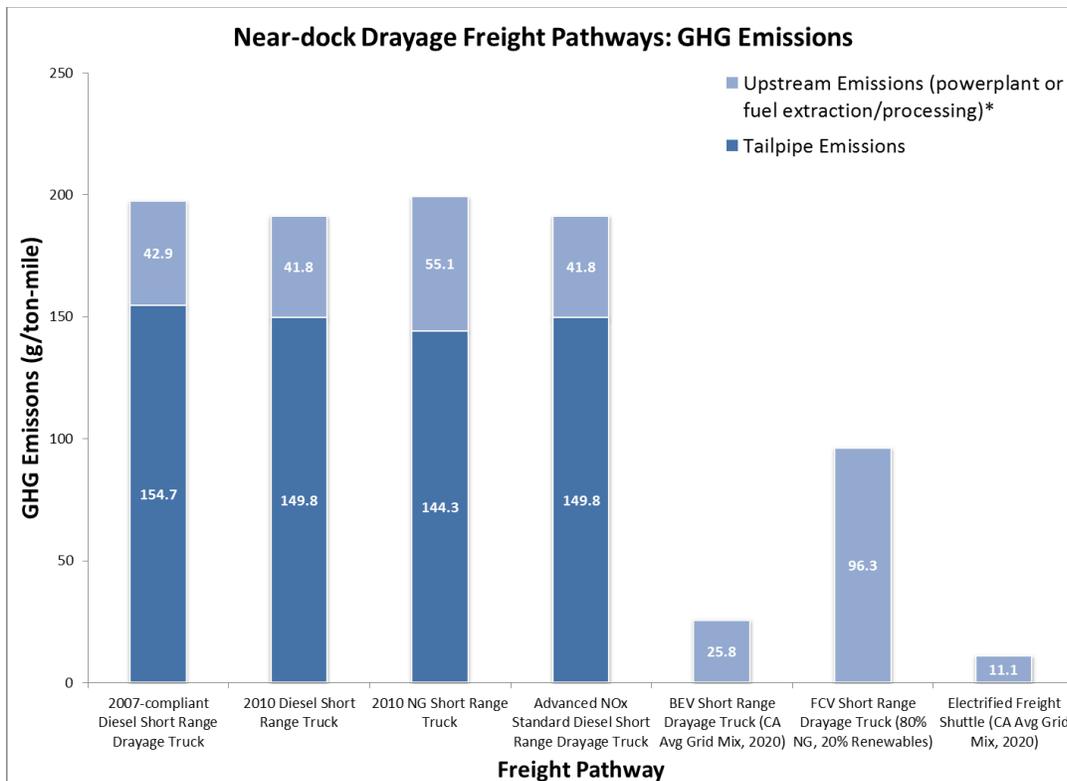


Figure 4. Near-dock Drayage Pathway: CO2e Emissions (grams/ton-mile)

*Upstream emissions are unlikely to occur within the freight-impacted community and therefore, while important to consider, should not be taken as a potential exposure concern within a freight-impacted community.

Figure 2 through Figure 4 summarize the upstream and tailpipe emissions for each of the drayage truck technologies considered. Both NO_x and PM tailpipe emissions from diesel and natural gas drayage trucks follow the associated reductions in the 2007 and 2010 emission standards. CO₂e emissions for 2010-compliant diesel trucks are reduced slightly from 2007-compliant trucks due to fuel economy gains enabled by selective catalytic reduction technologies employed to meet the 2010 standard. It is also assumed that diesel fuel meets the 2020 LCFS target of a 10% reduction in carbon intensity, while natural gas carbon intensity is not assumed to change.

The “zero emission” technologies modeled, including battery-electric, fuel cell, and electrified freight shuttles, produce zero tailpipe emissions. Hence, only upstream emissions associated with fuel production and distribution are shown. Emissions from the electric technologies (BEV, catenary truck, PHEV, and freight shuttle) are exceptionally low, due to a combination of increased efficiency from the electric drivetrain and the assumed California grid mix in 2020. The freight shuttle pathway is particularly low because it combines the efficiencies of electric drive trains with the efficiency of rail freight movement. FCV emissions are markedly higher than other “zero emission” technologies largely due to the emissions associated with the steam methane reformation process assumed to be used to produce 80% of the hydrogen used by the FCV.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Conventional diesel- and natural gas-fueled solutions are proven and cost-effective
- Opportunities for zero-emission solutions exist that would provide higher efficiency and reduced climate impact

Weaknesses:

- Lack of charging infrastructure
- High and uncertain costs for zero-emission truck and infrastructure
- Range limitations for zero-emission solutions
- Does not address concerns related to congestion

Opportunities:

- Clear interest and active pilot programs at POLA and POLB for zero-emission alternatives
- Potential for public funding to cover incremental costs and infrastructure development

Challenges:

- Zero-emission weaknesses are not overcome in a timely manner
- Low-emission alternatives could emerge that provide better value for environmental performance

On-dock and Near-dock Rail

The technologies in a nutshell

Near-dock rail yards are rail facilities that transfer freight between trucks and rail cars, and that are located in close proximity to a port. Trucks typically serve as the transportation link between the rail yard and port terminals or warehouses. Because cargo is transferred between two modes of transport (trucks and rail), the freight pathways involving near-dock rail yards typically include multiple cargo handling events to load and unload cargo. By comparison, single modes of transportation (e.g., truck only, rail only, etc) typically have fewer cargo handling events than near-dock rail pathways.

Distances between these near-dock rail yards and port facilities can vary significantly. For example, the near-dock rail yard at the Port of Oakland is approximately one mile from the marine terminals while the near-dock rail yard for the Port of Los Angeles and Port of Long Beach is approximately five miles from the marine terminals. In contrast, on-dock rail brings a short section of rail line directly to the marine terminal. This allows the transfer of containers and other cargo from the marine terminal to the rail car—without the intervening movement of the container to a near-dock facility by a drayage truck.

Two versions of on-dock rail facilities exist. In the first version, cargo is transferred from the ship to a yard truck and then moved across the terminal to the rail yard where it is loaded onto a rail car. It should be noted that some port terminals that do not have on-dock rail, shuttle containers to neighboring terminals with on-dock rail. This inefficient practice requires multiple cargo handling events that increase pollution. These on-dock rail examples could not be further evaluated in this report because refined emissions data was lacking for on-dock rail activity.³⁰ In the second version, cargo can be loaded directly onto the rail car from the ship-to-shore crane, eliminating any additional cargo handling.³¹

Who's involved and where?

The Port of Los Angeles, the Port of Long Beach, and the Port of Oakland currently provide near-dock rail access to intermodal facilities. Additional on and near-dock rail will require extensive coordination among shipping companies, terminal operators, port authorities and railroads. Complex rights-of-way and use agreements will need to be agreed on and executed by multiple parties, and communities along these routes must be consulted.

³⁰ While the Ports of Los Angeles and Long Beach each have detailed emissions inventories, a technical working group including the major environmental agencies continues to work to refine the locomotive portion of the emissions data. For example, the current method employed to evaluate locomotive emissions dramatically overestimates emissions because it cannot account for on port activities that involve significant delays where trains are stopped for long periods.

³¹ Other strategies have been proposed that represent a more radical change to the way cargo is transferred from ship to rail. For example, GRID Logistics envisions marine terminals dedicated to on-dock ship-to-rail transfers using a unique terminal construct with many cranes operating in parallel.
<http://s474091609.onlinehome.us/gridweb/>

Outside of California, it is worth noting the Port of Savannah’s Garden City terminal that provides direct on-dock, ship-to-rail facilities. Rail cranes lift cargo directly from ships to rail cars in a terminal configuration called “live on-dock rail”. This type of operation minimizes cargo lifts. Further, because ship-to-shore cranes are typically electrically powered via the electrical grid, there are no direct emissions associated with this cargo handling activity.

The Port of Rotterdam is currently developing the APM Terminal’s Maasvlakte II facility that will employ fully electric cargo handling equipment, essentially eliminating direct emissions from on-dock equipment.³² This program is an example of a best practice in operation. Ship-to-shore cranes transfer containers to battery-electric automatically guided vehicles that carry the containers to automated gantry cranes. Containers are stacked and sorted on-terminal and then transferred to on-dock rail cars that are then directed to one of two “Rail Service Centers” (located in Eemhaven and Massvlakte, both in the vicinity of primary container terminals).³³ From there, cargo is shipped to destinations across Europe. A new, 24-hour, 7-days a week dedicated-freight railway further connects the Port directly to Germany and other destinations in Central and Eastern Europe.³⁴

On-dock rail access is also provided at the Port of Tacoma at the Olympic Container Terminal, Husky Terminal, Pierce County Terminal, and the recently-opened Washington United Terminal (WUT)³⁵. Each of these is located within or in close proximity to the respective terminals. All four intermodal facilities are serviced by BNSF and Union Pacific, connecting into the national rail network.³⁶

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- On-dock rail eliminates drayage truck moves and related emissions and other community impacts of drayage truck operations
- Using on-dock rail with Tier 4-compliant locomotives will be much cleaner and efficient than near-dock alternatives
- Compared to on-dock rail, ear-dock rail
 - Maintains drayage truck moves, and related emissions and other community impacts of drayage truck operations
 - Maintains cargo handling events of drayage truck operations
 - May not mitigate truck-related congestion near port, depending on location

Weaknesses:

- On-dock rail with Tier 2 locomotives could emit more PM and NOx than near-dock rail combined with 2010 drayage trucks

³² [http://www.apmterminals.com/uploadedFiles/corporate/Media_Center/Press_Releases/120625%20Future%20Begins%20as%20Maasvlakte%20II%20Progresses\(2\).pdf](http://www.apmterminals.com/uploadedFiles/corporate/Media_Center/Press_Releases/120625%20Future%20Begins%20as%20Maasvlakte%20II%20Progresses(2).pdf)

³⁴ <http://www.portofrotterdam.com/en/Brochures/Railport-Eng.pdf>

³⁴ <http://www.portofrotterdam.com/en/Brochures/Railport-Eng.pdf>

³⁵ <http://www.portoftacoma.com/wut>

³⁶ <http://www.portoftacoma.com/intermodal>

Opportunities:

- Near-dock rail already exists at POLA, POLB, and Port of Oakland
- Port of Rotterdam shows potential for low-emission on-dock operations

Challenges:

- Requires extensive coordination among shipping companies, terminal operators, port authorities and railroads
- Communities along the rail routes need to be consulted

Freight Pathway Emissions

A direct ship to on-dock rail freight pathway was compared to several near-dock freight pathways by estimating the emissions produced by moving a single container from a ship-to-shore crane at a marine terminal to a rail car at a near-dock facility.

The table and figures below summarize the estimated emissions for each freight pathway. The largest reductions in emissions are seen by limiting the number of cargo handling events and employing Tier 4-compliant locomotives – as shown in the On-dock Scenario.

Table 1. On-dock and Near-dock rail pathways

Pathway	Description
“Live” On-dock Rail Scenario	Transfer container directly from ship to on-dock rail car. On-dock rail activity includes movement to near-dock facility and assumes switcher and line haul locomotives meet Tier 4 standards. Scenario is similar to operations at the Port of Savannah’s Garden City terminal.
Near-dock Rail Scenario A (Baseline- 2010 Drayage Truck)	Transfer container to drayage truck. Drayage hauls to near-dock rail terminal using 2010-compliant drayage truck. Load container onto Tier 2 rail car.
Near-dock Rail Scenario B (2010 Drayage Truck + Tier 4 Rail)	Transfer container to drayage truck. Drayage hauls to near-dock rail terminal using 2010-compliant drayage truck. Load container onto rail car. Assumes switcher and line haul locomotives meet Tier 4 standards.

Assumptions

Container weight	10.6 tons
Distance to near-dock facility	5 miles

Emissions from On-dock and Near-dock Freight Pathways

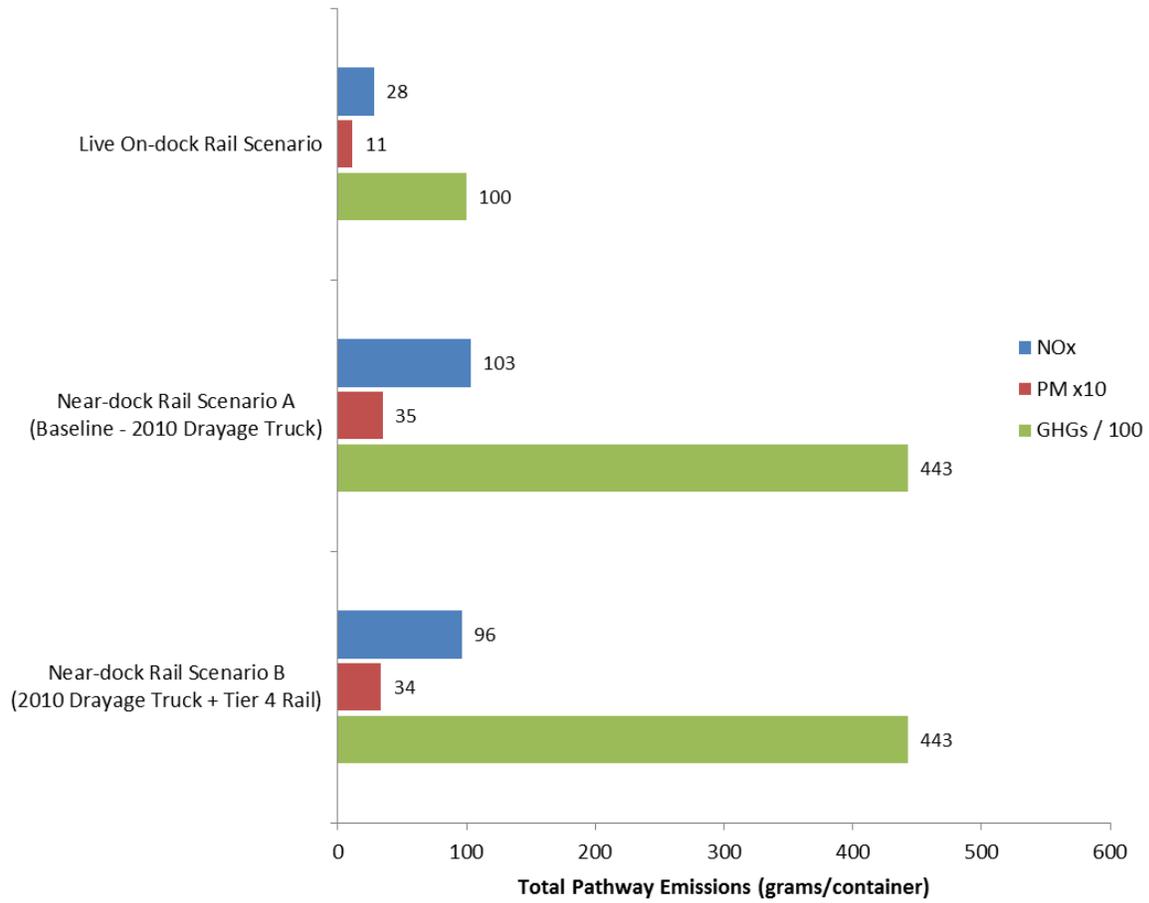


Figure 5. Emissions from On-dock and Near-dock Freight Pathways (grams/container)

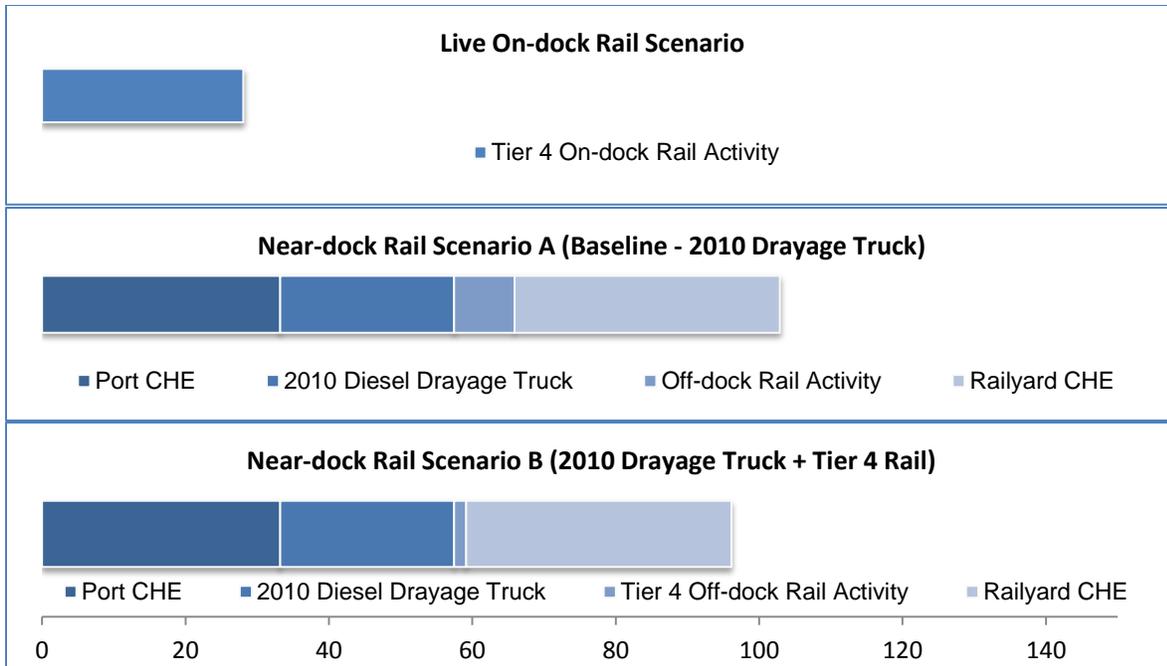


Figure 6. On-dock and Near-dock Rail Pathway: NOx Emissions (grams/container)

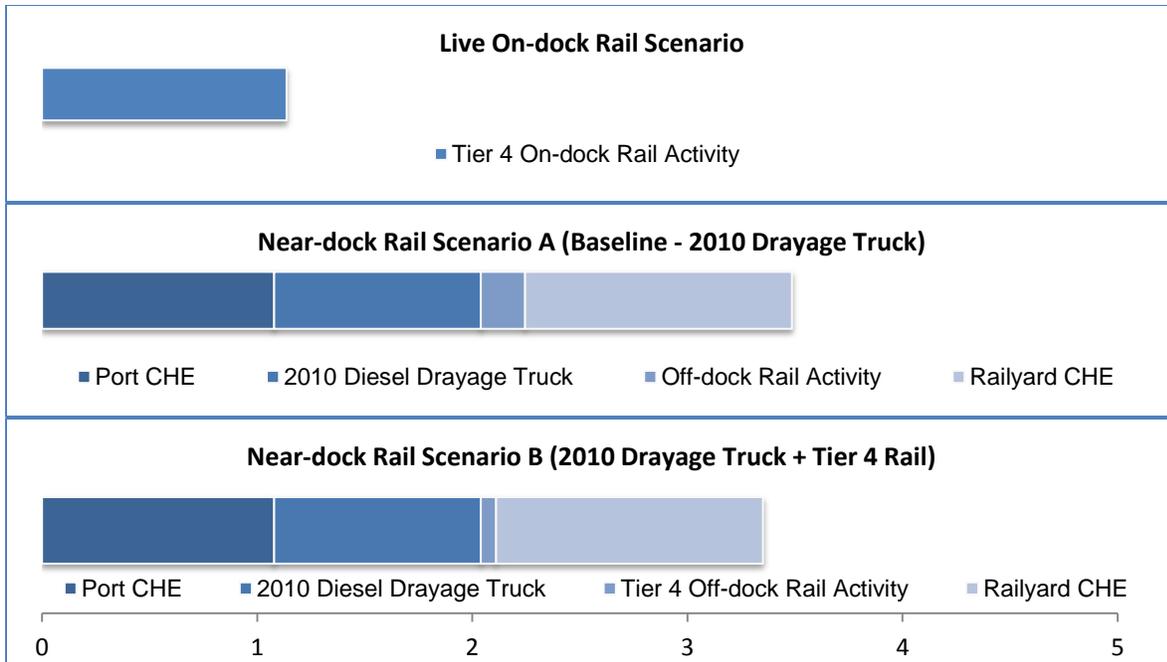


Figure 7. On-dock and Near-dock Rail Pathway: PM Emissions (grams/container)

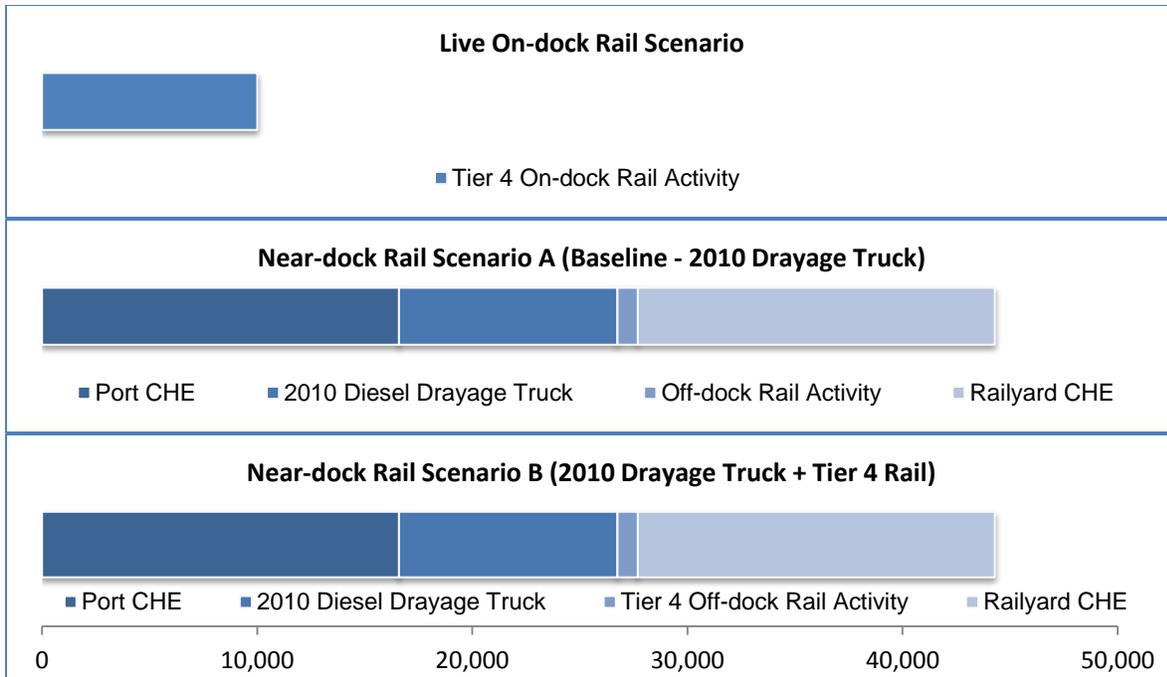


Figure 8. On-dock and Near-dock Rail Pathway: CO2e Emissions (grams/container)

Part Two – Regional Strategies

Electrified Rail

The technology in a nutshell

Electrified Rail is a proven technology that provides reduced (and in some cases, zero) tailpipe emissions during freight or passenger rail operations. Electrified rail systems are common in Europe and Asia, especially France, Germany, Japan, Sweden, and the United Kingdom.³⁷

Electrified rail has not reached the same level of usage in the United States,³⁸ although interest seems to be growing. Proponents of electrified rail point to projections of fuel cost savings and reduced emissions. On the flip side, investing in electrified rail involves very high upfront capital costs, impacts on existing rail operations, the risk of projecting long-term electricity cost and supply, and the upstream environmental impacts of electricity generation.

There are several different types of electrified rail. These vary in the ways that electricity is supplied to the trains. In the near term, straight electric catenary and dual mode locomotives are likely to be the most feasible options.

The most commonly considered technologies for electrified rail are:

1. **Straight-Electric Locomotives—Catenary.** The electric motor is connected to the train via overhead connecting wires that draw electricity from the surrounding grid.
2. **Dual Mode Locomotives—Electrified Catenary.** This strategy uses catenary connectors and power lines where available, but switches to a conventional diesel engine when electric current is not available. (As LNG becomes more prevalent in high horsepower sectors like rail, one should assume that LNG locomotives may be used in these systems where the economics make sense). Dual Mode locomotives can be designed to have a high power mode and a low power mode. Depending upon the specification, either the diesel or electric mode can be made to operate as the low power or high power mode.
3. **Linear Synchronous Motor (LSM) system.** LSM technology is still unproven, and remains at the conceptual stage.³⁹ LSM technology requires electric linear motors to be installed along the entire length of railroad track, which react against magnets that are installed on the underside of the train; meanwhile, a “helper car” passively propels the train in the direction of travel.
4. **Hybrid diesel-electric locomotives.** Hybrid diesel-electric locomotives are being developed that use large, onboard batteries to store energy captured during regenerative braking and then use it during acceleration or other high-power events. This is estimated to reduce fuel consumption by up to 15 percent. Typically, the batteries are placed between

³⁷ See, e.g., http://news.bbc.co.uk/2/hi/uk_news/8164070.stm;

http://www.rff.fr/?page=gtext&id_article=1068&lang=en.

³⁸ <ftp://ftp.elet.polimi.it/users/Marino.Gatto/ASPCourse2009/LecturePonti/Vassallo%20-%20Nature%20or%20nurture%20freight%20rail%20USA%20EU.pdf>

³⁹ <http://freightworks.migcom.com/docManager/1000000129/Draft%20Freight%20Rail%20Electrification.pdf>

the main power source (e.g., the diesel or LNG locomotive) and the traction transmissions system connected to the wheels. Since most diesel locomotives are actually diesel-electric, they already have all of the components of a series hybrid system except the storage battery. Thus, the transition to hybrid-electric locomotives should not be a difficult one, technically speaking.

5. **Battery Electric Tender Car Technology.** This technology uses battery tender cars that carry batteries, which then power diesel-electric locomotives. Although still in the R & D phase of development, proponents think that this technology may eventually become an attractive option for diesel powered locomotives that pass through non-attainment areas or other locations that have emission restrictions.

All of these systems face cost and infrastructure challenges. Most are still in various development phases (catenary systems are the exception). Batteries are expensive, future costs of new technologies like LSM are impossible to estimate presently, and dual mode locomotives come with the costs of two different propulsion systems (e.g., straight electric catenary locomotives are estimated to cost \$5 million per locomotive while dual mode is estimated to cost \$8 million per locomotive).

Electric rail investment is a long-term investment. American Railway Engineering and Maintenance-of-Way Association (AREMA) research showed that after six years of operation of an electric rail system, the costs of operations are equal to a diesel system.⁴⁰

Who is developing this technology in California?

The Southern California Association of Governments (SCAG) has investigated three different implementation options for proposed rail electrification in southern California. For each option, they analyzed straight electric catenary locomotive, dual mode locomotive, and LSM technologies.⁴¹

1. Option I—this option would run 51 track miles from the Long Beach Intermodal Container Transfer Facility (ICTF) near the Ports to the northern terminus of the Alameda corridor. From preliminary engineering to initial locomotive testing, the development is expected to take 5 years and cost \$1.2 billion for straight electric catenary and \$1.8 billion for dual mode locomotives.
2. Option II—this 422-mile option includes Option I, and extends electrification to West Colton and San Bernardino. It would follow Union Pacific's Alhambra Sub and LA Sub rail lines out to the West Colton Yard and the BNSF Transcon line to San Bernardino. These lines are the most heavily traveled freight lines in some of the most densely populated areas in southern California. Electrifying these lines, therefore, should yield a meaningful reduction in diesel exposure for the communities along these corridors. One of the major challenges of this option is that construction would have to happen without interrupting the functionality of the existing rail service along this route. From preliminary engineering to initial testing, the

⁴⁰ Analysis of Freight Rail Electrification in the SCAG Region. August 26, 2011. Southern California Association of Governments.

⁴¹ *Ibid.*

development is expected to take 15 years and cost \$6.1 billion for straight electric catenary and \$8.6 billion for dual mode locomotives.

3. Option III— this 863-mile option spreads the electrified rail pathway from the Ports even further, out to Barstow, Indio, and Chatsworth. It also includes Union Pacific’s Santa Clara and Coast lines. As with Option II, keeping portions of the track open while building electric infrastructure will add complexity, time and costs. From preliminary engineering to initial testing, the development is expected to take 17 years and cost \$15.5 billion for straight electric catenary and \$22.4 billion for dual mode locomotives.

Given the lengthy time of construction, emissions benefits in the South Coast would not be realized until 2023 for Option I—and until at least 2035 for Options II and III. SCAG assumes zero emissions equipment will be in use in the SCAB, even for dual mode locomotives. This would translate into the following estimated emissions reductions:⁴²

1. Option I: 484 tons/year of NO_x, 9 tons/year of PM_{2.5}, and 110,689 tons/year of CO₂
2. Option II: 2,516 tons/year of NO_x per year, 46 tons/year of PM_{2.5} per year, and 574,762 tons/year of CO₂
3. Option III: 3,741 tons/year of NO_x, 68 tons/year of PM_{2.5} per year, and 854,603 tons/year of CO₂

Where is it happening outside of California?

As noted above, there is a great deal of interest in these technologies outside of the US. The following provides a sample of projects around the world:

Straight Electric—Catenary Locomotives:

- LKAB, a Swedish mining company, uses catenary trains for its heavy-haul iron ore freight train in Torneträsk, Sweden. The trains are built in Germany by Adtranz and Bombardier Transportation.
- Queensland Rail operates Siemens 3800 model electric locomotives to transport coal.
- South African Railways (SAR) is using straight-electric locomotives (Mitsui Class 15E locomotive) on the 535-mile long Sishen-Saldanha iron-ore railway. These models are compliant with AAR standards and can easily be incorporated for use in the U. S.
- Indian Railways (IR) utilizes heavy-haul locomotives produced by ABB and Chittranjan Locomotive Works (CLW), which comply with British and US standards.

Dual-Mode Locomotives:

- New Jersey Transit and Montreal’s Agence Métropolitaine de Transport are using the Bombardier ALP-45DP in dual-mode passenger service.
- Transnet Freight Rail operates 50 Siemens Class 38-000 3kV DC dual-mode freight locomotives, in South Africa.
- In Spain, Ferrocarriles Suroccidentales SA (Fesur) has used a Spanish-built dual-mode locomotive since 2009.

⁴² *Ibid.*

- Switzerland's SBB Cargo currently has an order underway for 30 Stadler Eem 923 dual-mode locomotives.

Linear Synchronous Motor (LSM) Locomotives:

- Although General Atomics has been developing the technology in San Diego, this technology is still years from feasibility and certification by the Federal Railroad Administration.

Hybrid diesel-electric locomotives

- Both U.S. locomotive engine manufacturers are developing hybrid diesel-electric locomotive technology. GE's Evolution Series uses the hybrid diesel-electric technology, and EMD F40PHM-2 uses a Diesel-electric transmission.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- All regional rail freight pathways reduce PM, NO_x, and GHG emissions compared to truck pathways
- Implementation of EPA Tier 4 standards and new locomotive technologies should greatly reduce (in some cases, to zero) PM, NO_x, and GHG emissions during rail operations further

Weaknesses:

- High battery and other capital costs; dual-mode locomotives include costs of two different propulsion systems
- Infrastructure challenges remain, including impacts on existing rail operations

Opportunities:

- Both U.S. locomotive manufacturers are actively developing hybrid-electric locomotives in anticipation of upcoming Tier 4 standards)
- New Jersey Transit is using dual-mode locomotives
- SCAG actively considering different rail electrification options

Challenges:

- Emissions profile of dual-mode and hybrid-electric locomotive systems depends on the locomotive engine used
- Some technologies remain at the conceptual stage

Freight Pathway Emissions

Regional rail pathways using various linehaul locomotive and switcher locomotive technologies were compared by estimating the emissions produced by moving a single container from a rail facility to a second rail facility 25 miles away. The 25-mile distance is similar to the length of the Alameda corridor, a route that has been considered for electrification. Figure 6 summarizes the estimated emissions for each freight pathway. Based on these results, the largest contributor to

NO_x and PM emissions is the linehaul event. Compared to the total pathway emissions, emissions from switching are much lower but are concentrated at the rail yards.

Table 2. Rail linehaul pathways

Pathway	Description
Regional Rail Scenario A (Baseline)	Line haul with Tier 2 diesel locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 2 diesel) and emissions.
Regional Rail Scenario B (Tier 4 Diesel)	Line haul with Tier 4 diesel locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 4 diesel) and emissions.
Regional Rail Scenario C (Electrified Rail)	Line haul with electrified locomotive to second rail facility. Unload container from rail train. Includes electrified train switching activity and emissions.
2010 Diesel Drayage Truck	Haul to second rail facility using 2010-compliant diesel drayage truck. Unload container from truck.
2010 NG Drayage Truck	Haul to second rail facility using 2010-compliant natural gas drayage truck. Unload container from truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	25 miles

Emissions from Regional Rail Freight Pathways

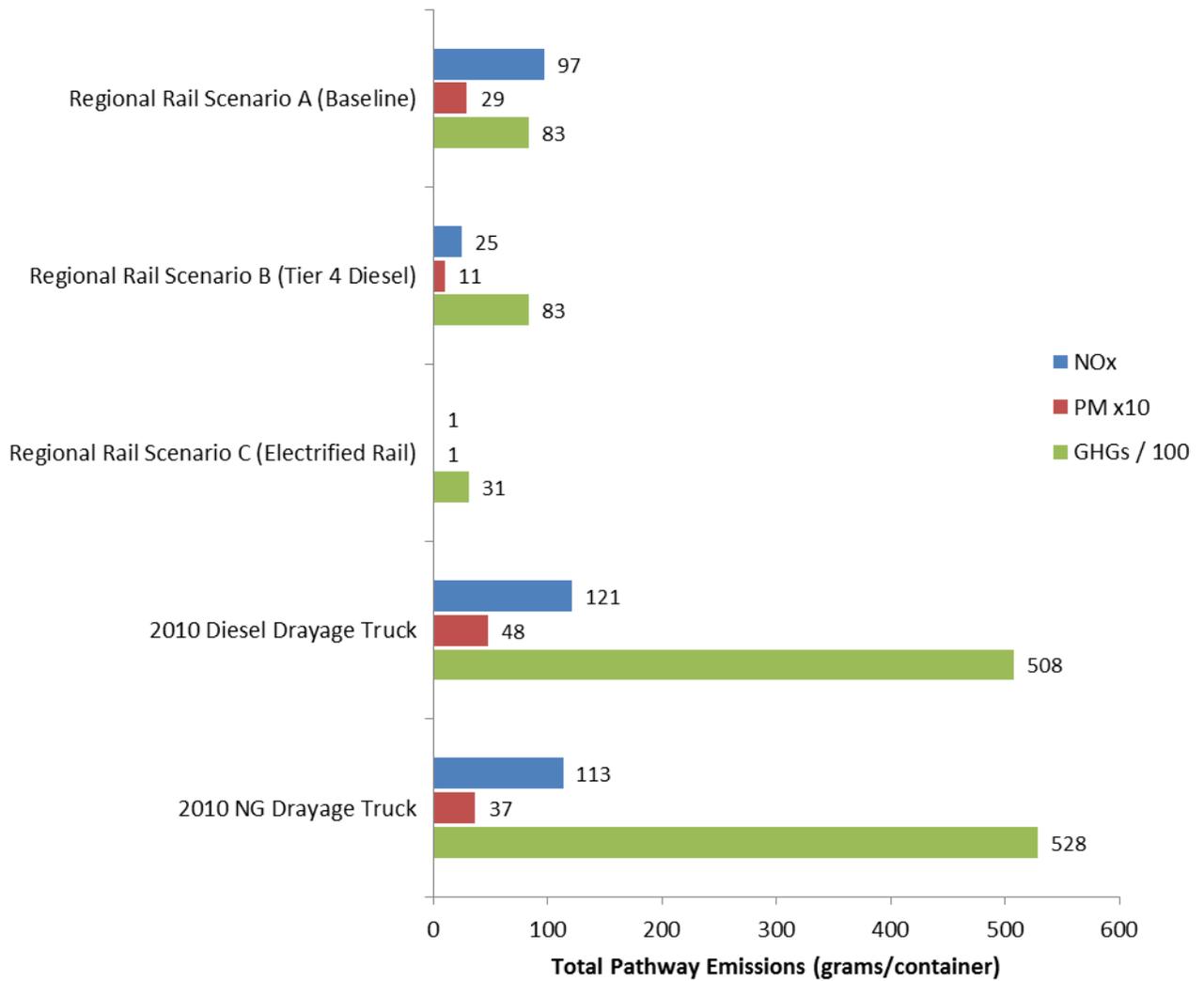


Figure 9. Emissions from Regional Rail Freight Pathways (grams/container)

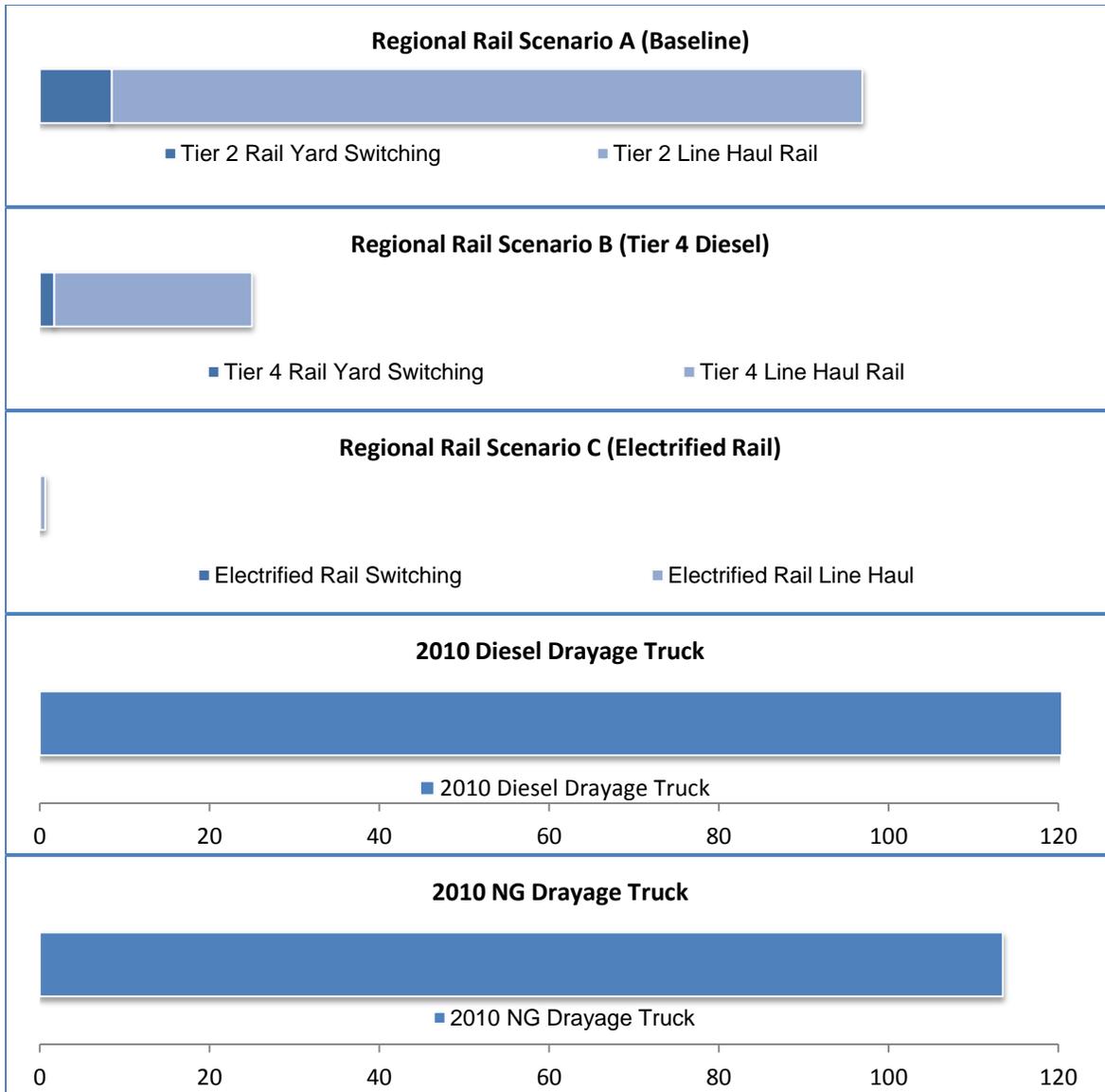


Figure 10. Regional Rail Freight Pathways: NOx emissions (grams/container)

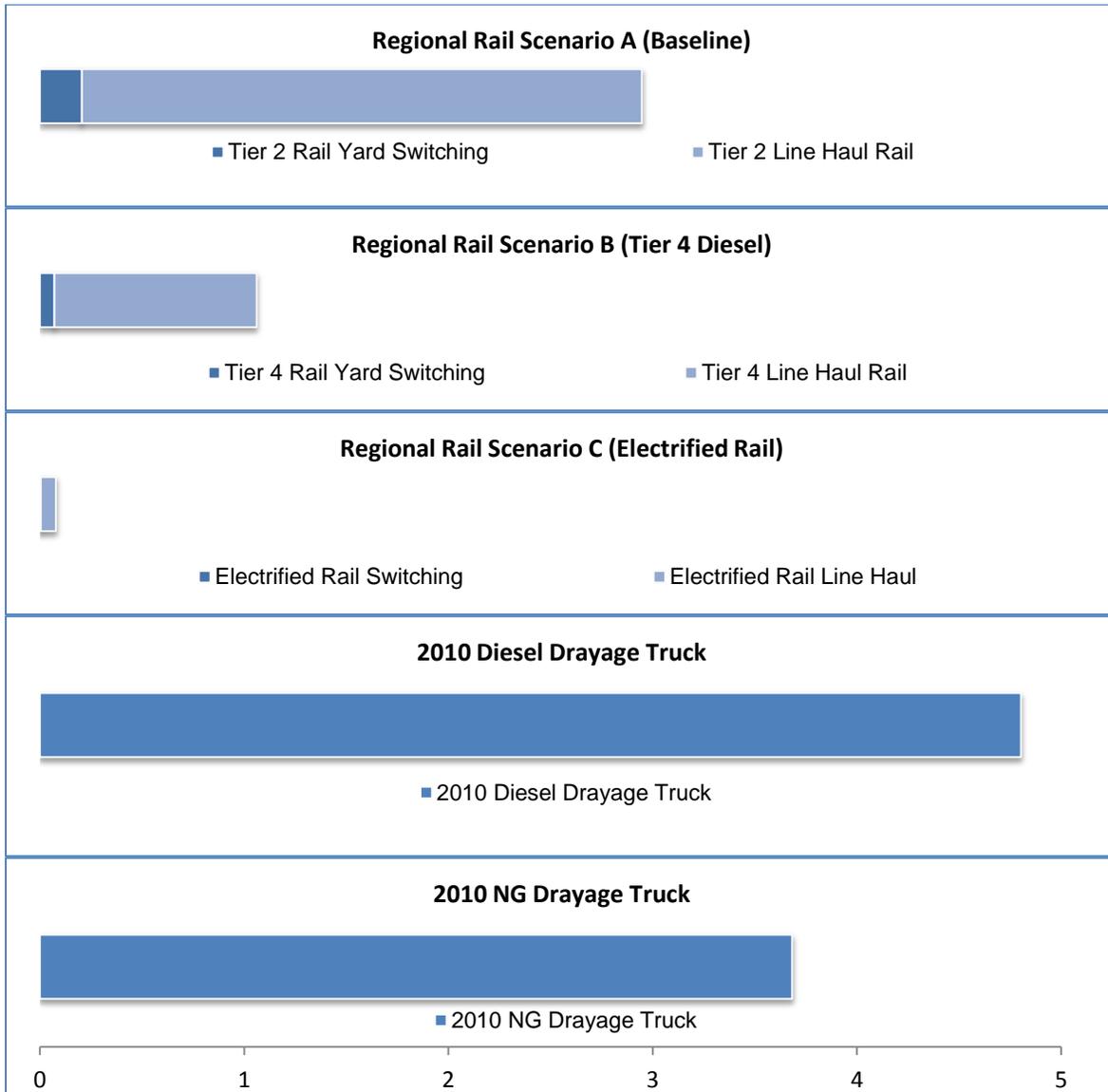


Figure 11. Regional Rail Freight Pathways: PM emissions (grams/container)

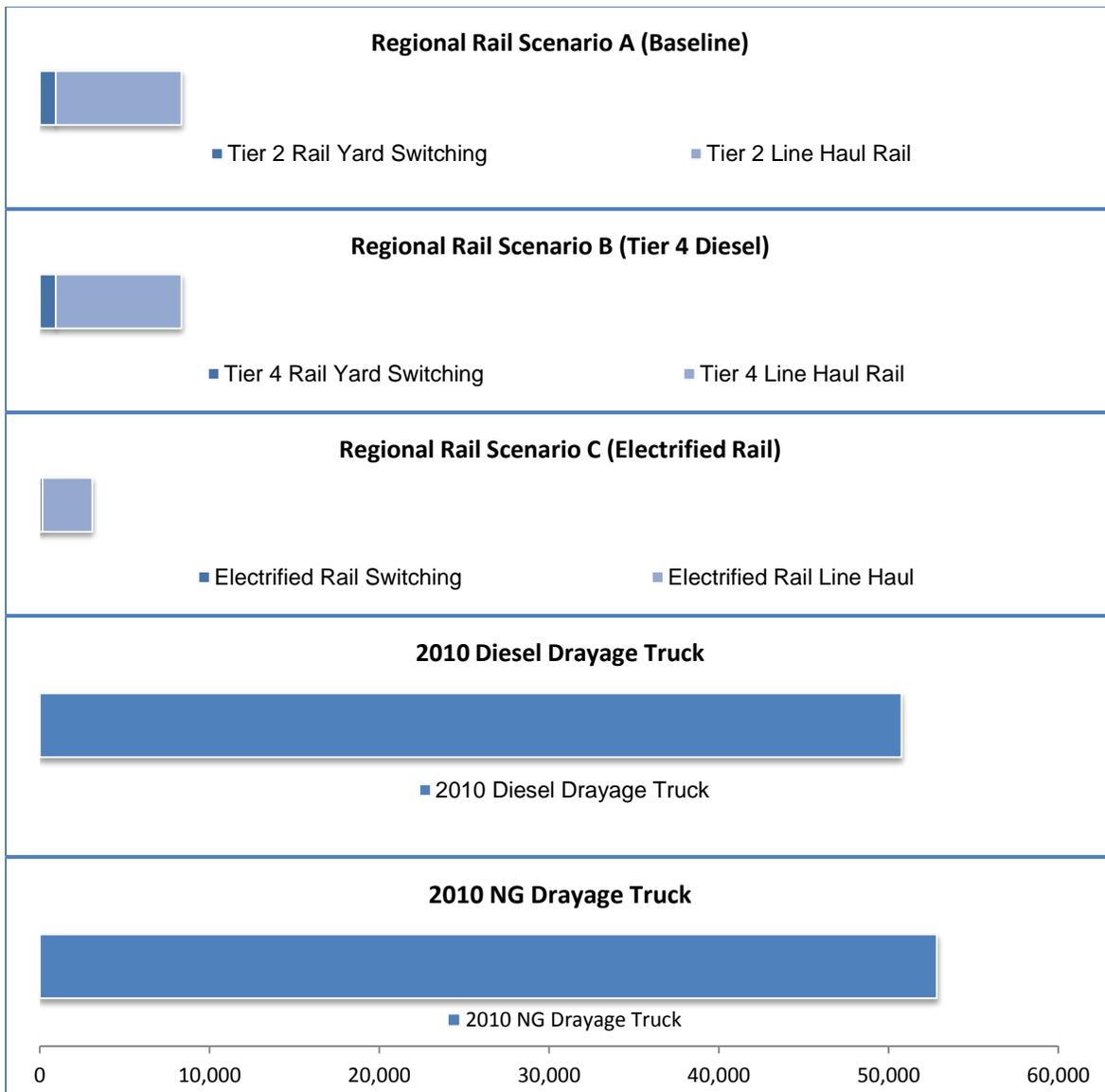


Figure 12. Regional Rail Freight Pathways: CO2e emissions (grams/container)

Short Sea Shipping

The technology in a nutshell

Short-sea shipping (often referred to as a “marine highway”) is the term used to describe the movement of cargo and passengers over water, using sea lanes near the coast or via inland waterways.

Short-sea shipping comprises a wide range of route types, cargo types, and ship sizes. Examples of short-sea shipping routes in the U. S. include routes within the Great Lakes, cargo that moves up and down the Mississippi River system, and coastal routes that can be as long as from New Orleans to Philadelphia. Cargo types include wet and dry bulk cargo,⁴³ containers, and passengers. As for ship sizes, typical ships used in short-sea shipping can range from 1,000 deadweight tonnes (dwt) to 15,000 dwt, with drafts ranging from 3 to 6 meters. Typical barge examples show that a 1,000 dwt vessel is equivalent to between 25-50 trucks.

In regions with heavy road congestion, short-sea shipping is often considered by businesses that hope to reduce shipping time and costs, while increasing their shipping efficiency. A Federal Maritime Administration survey found that tug-and-barge operations could be as much as 3.7 times as efficient in moving goods, on a BTU/ton-mile basis, as trucks.⁴⁴

In theory, the main advantages of short-sea shipping are congestion reduction, decreased air pollution, and overall cost savings to the shipper. These advantages are premised on the knowledge that water-borne freight uses less fuel per ton-mile than truck-borne freight, and that this efficiency should translate into lower emissions, as well as reduced congestion due to the modal shift from truck to ship.

In reality, there are many variables that need to be considered in determining whether short-sea shipping is actually a lower-emissions strategy than using the clean trucks that increasingly operate in California. For example, California’s Commercial Harbor Craft rule requires tug boats, tow boats, and barges (among other types of vessels) to meet Tier 2 or greater emissions standards, and to use the same ultra-low sulfur diesel fuel as on-road trucks when the vessels are within 24 nautical miles of the California coastline (including within any inland marine highway that will be developed between the Port of Oakland, Sacramento, or Stockton). New trucks are equipped with diesel particulate filters that enable them to meet very clean standards of 0.01 g/bhp-hr. In contrast, the tugs and barges that are typically used in marine highway situations are not likely to be equipped with the same particulate filter technology.

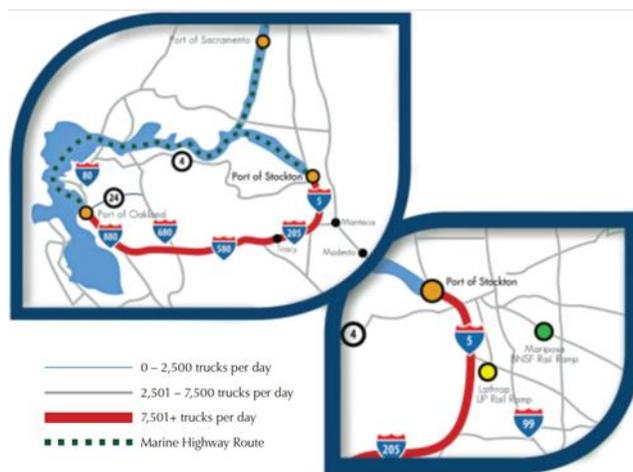
⁴³ Typical dry bulk cargo includes grain, fertilizer, steel, coal, and minerals. Typical wet bulk cargo includes bulk quantities of petroleum products.

⁴⁴ U.S. Department of Transportation, Maritime Administration, “America’s Marine Highway: Report to Congress,” April 2011. DOT reported that it takes an average of 842 BTU per ton-mile to move goods by truck, 316 BTU/ton-mile to move goods by rail, and 227 BTU/ton-mile to move goods with a tug-and-barge operation.

Short-sea shipping is widely used in Europe, and less used in the U. S. In Europe, roughly 40% of all freight is moved via rivers and other inland waterways.⁴⁵ In contrast, short-sea shipping is rarely used in the U. S. outside of the Great Lakes Saint Lawrence Seaway System and regional networks like the Port Inland Distribution Network, which was launched in 2002 to transport containers by barge between marine terminal facilities at the Port of New York and New Jersey and regional terminals in five northeast states.⁴⁶

Who is developing it and where?

MARAD has identified a marine highway corridor (M-580) that would connect the Port of Oakland with eastern terminal points in West Sacramento and Stockton. It is hoped that M-580 would relieve traffic congestion, excessive air emissions, and other environmental concerns along the existing truck route when it is completed. In particular, the project aims to decrease congestion on the I-580, I-80, I-205, and local highways. (See map) When fully developed, the project could eliminate 180,000 truck trips along the existing land corridor each year. This is expected to save up to 7 million gallons of diesel fuel.⁴⁷



The M-580 marine highway project was initiated with a \$30 million grant under the American Recovery and Reinvestment Act of 2009 TIGER program. This program is managed by the Port of Stockton with support from the Ports of Oakland and West Sacramento. \$13 Million of the million TIGER grant went to the Port of Stockton to help purchase two 140-ton mobile harbor cranes. In addition to making necessary retrofits to the Port to accommodate the project, the Port of Stockton purchased two barges for the project, which are being modified to handle containers.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Short-sea shipping reduces truck VMT and related congestion and emissions; using Tier 4 marine engines provides cleanest alternative
- Potential to reduce shipping times and costs, while improving efficiency

⁴⁵ http://ec.europa.eu/transport/modes/maritime/doc/sss_2009_list_of_actions.pdf

⁴⁶ PANYNJ. "Port Authority Launches Unique Cargo Distribution System by Establishing First Regional Port in Upstate New York." December 13, 2002, available at http://www.panynj.gov/press-room/press-item.cfm?headLine_id=251 When launched, roughly 84 percent of the containers that moving through the Port of NY and NJ were carried by truck. When all of the ports are on line by 2020, the percentage of maritime containers moved by truck could be reduced to 57 percent, eliminating more than 1,000 daily truck trips on New York roadways.

⁴⁷ "Marine Highway Corridors." US Department of Transportation. Maritime Administration. 2012. http://www.marad.dot.gov/documents/2012_Marine_Highway_Corridors_-_PRINTER_FRIENDLY_-_V_10.pdf

Weaknesses:

- Many location-specific variables make generalizations about emissions, efficiency, and costs difficult

Opportunities:

- Short-sea shipping is in place in the Great Lakes-St. Lawrence Seaway System and some northeast locations, providing lessons for California
- MARAD M-580 project being developed between Port of Oakland and eastern terminal points in West Sacramento and Stockton

Challenges:

- Ensuring that Tier 4 marine engines are used when they become available
- Ensuring adequate funding for M-580 project

Freight Pathway Emissions

The M-580 marine highway project between the Port of Oakland and Port of Stockton served as the basis for modeling the short sea shipping freight pathway. As cargo destined for the Port of Oakland (and eventual export) enters the Port of Stockton, it is loaded onto a barge via ship-to-shore crane. The barge then travels approximately 80 miles via M-580 to the Port of Oakland. Cargo is unloaded from the barge via crane at a marine terminal. The baseline alternative is movement of cargo via drayage truck along I-580 for approximately 70 miles, arriving at the Port of Oakland where it is unloaded from the truck. Hence, both the baseline scenario and the short sea shipping scenario include similar cargo handling events at the end of the freight pathway but the short sea shipping scenario includes an extra cargo handling event at the beginning of the pathway associated with the mode shift between truck and barge.

By 2020, the California Air Resources Board's Commercial Harbor Craft rule will require that vessels in the size class envisioned for use in this marine highway scenario⁴⁸ meet or exceed Tier 2 emissions standards. Hence, the baseline scenario assumes the use of a barge/tug boat meeting Tier 2 standards. A Clean Barge scenario is also modeled that assumes the use of a marine engine meeting Tier 4 standards.

The figures below summarize the estimated emissions for each freight pathway. Based on these results, NO_x emissions from the short sea shipping baseline scenario are expected to be slightly less than 2010-compliant drayage trucks while PM emissions are expected to be significantly reduced as compared to diesel drayage trucks. The Clean Barge scenario further improves on emissions reductions relative to drayage trucks and is the cleanest of the five scenarios considered. Short-sea shipping in this scenario also emits the fewest GHGs.

⁴⁸ C1 and C2 marine engines with <5L/cylinder displacement

Table 3. Short Sea Shipping pathways

Pathway	Description
Short-Sea Shipping Scenario A (Baseline)	Load container onto barge. Barge meeting Tier 2 standards transits to seaside port facility. Container unloaded from barge.
Short-Sea Shipping Scenario B (Clean Barge)	Load container onto barge. Barge meeting Tier 4 standards transits to seaside port facility. Container unloaded from barge.
Baseline Rail Comparison	Load container onto rail car. Line haul with Tier 2 diesel locomotive to near-dock rail facility.
Tier 4 Rail Comparison	Load container onto rail car. Line haul with Tier 4 diesel locomotive to near-dock rail facility.
2010 Diesel Drayage Truck	Haul to seaside port facility using 2010-compliant diesel drayage truck.
2010 NG Drayage Truck	Haul to seaside port facility using 2010-compliant natural gas drayage truck.

Assumptions

Container weight	10.6 tons
Marine/rail transit distance	80 miles
Drayage truck transit distance	70 miles

Emissions from Short Sea Shipping Freight Pathway

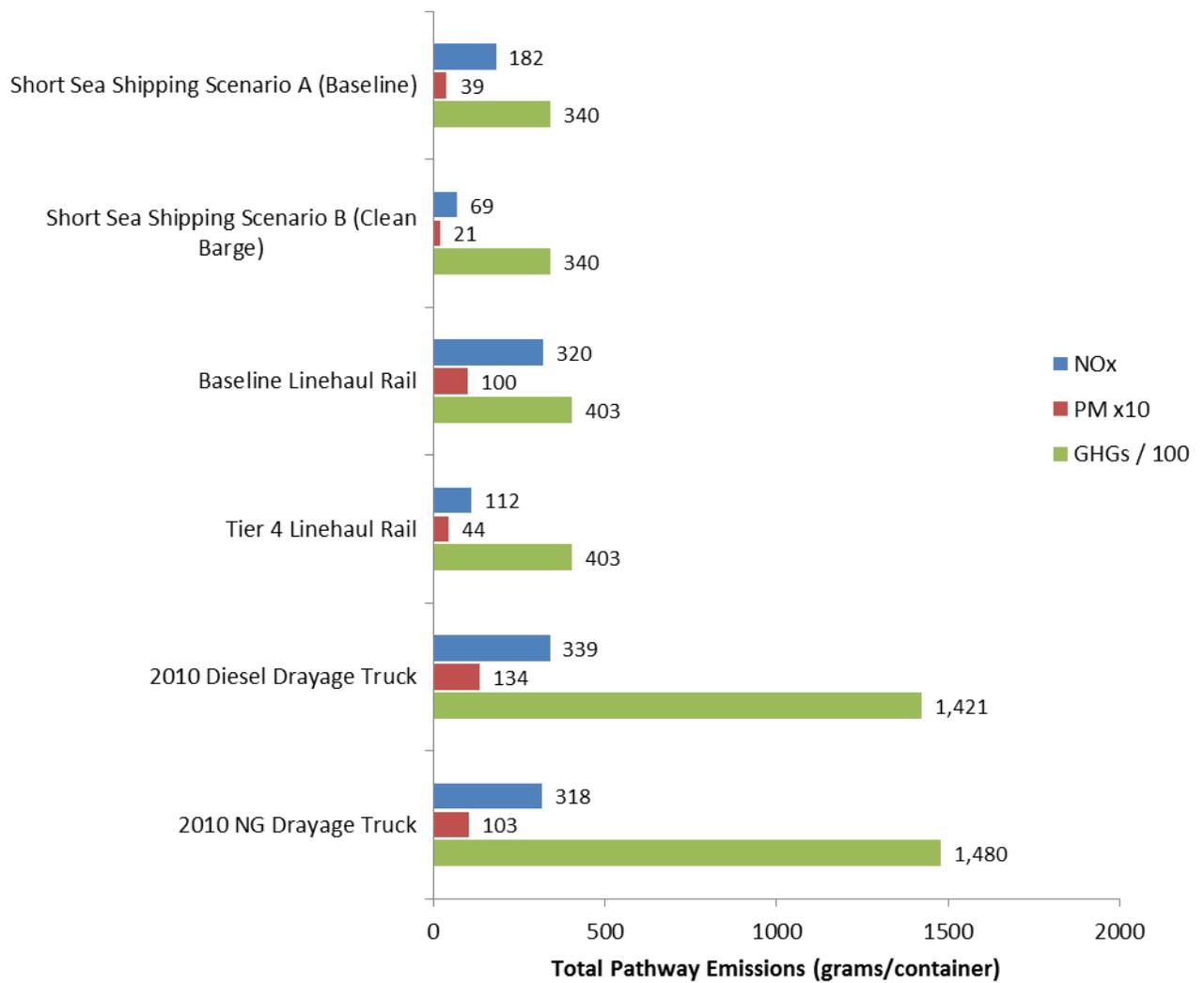


Figure 13. Emissions from Short Sea Shipping Freight Pathways (grams/container)

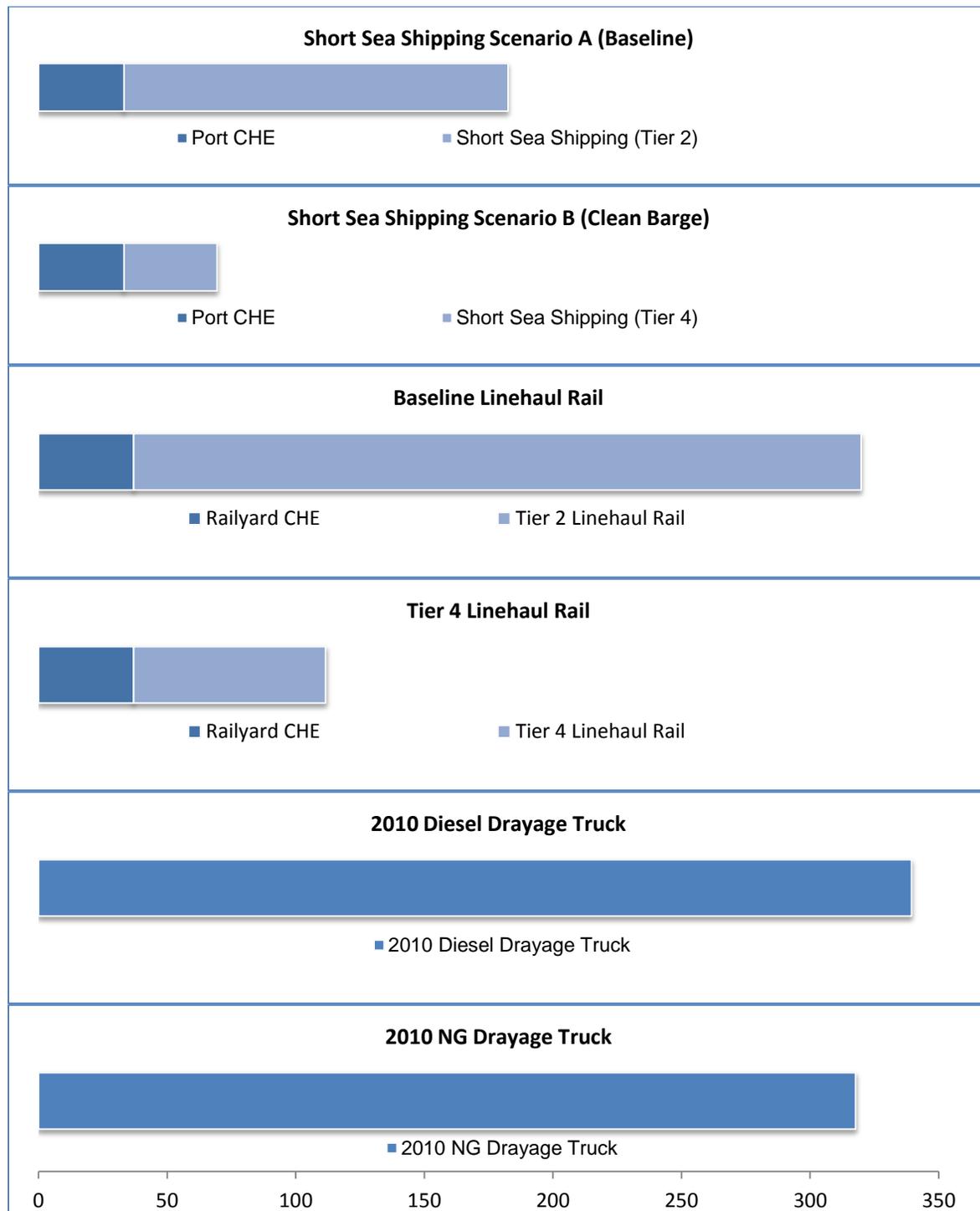


Figure 14. Short Sea Shipping Freight Pathways: NOx emissions (grams/container)

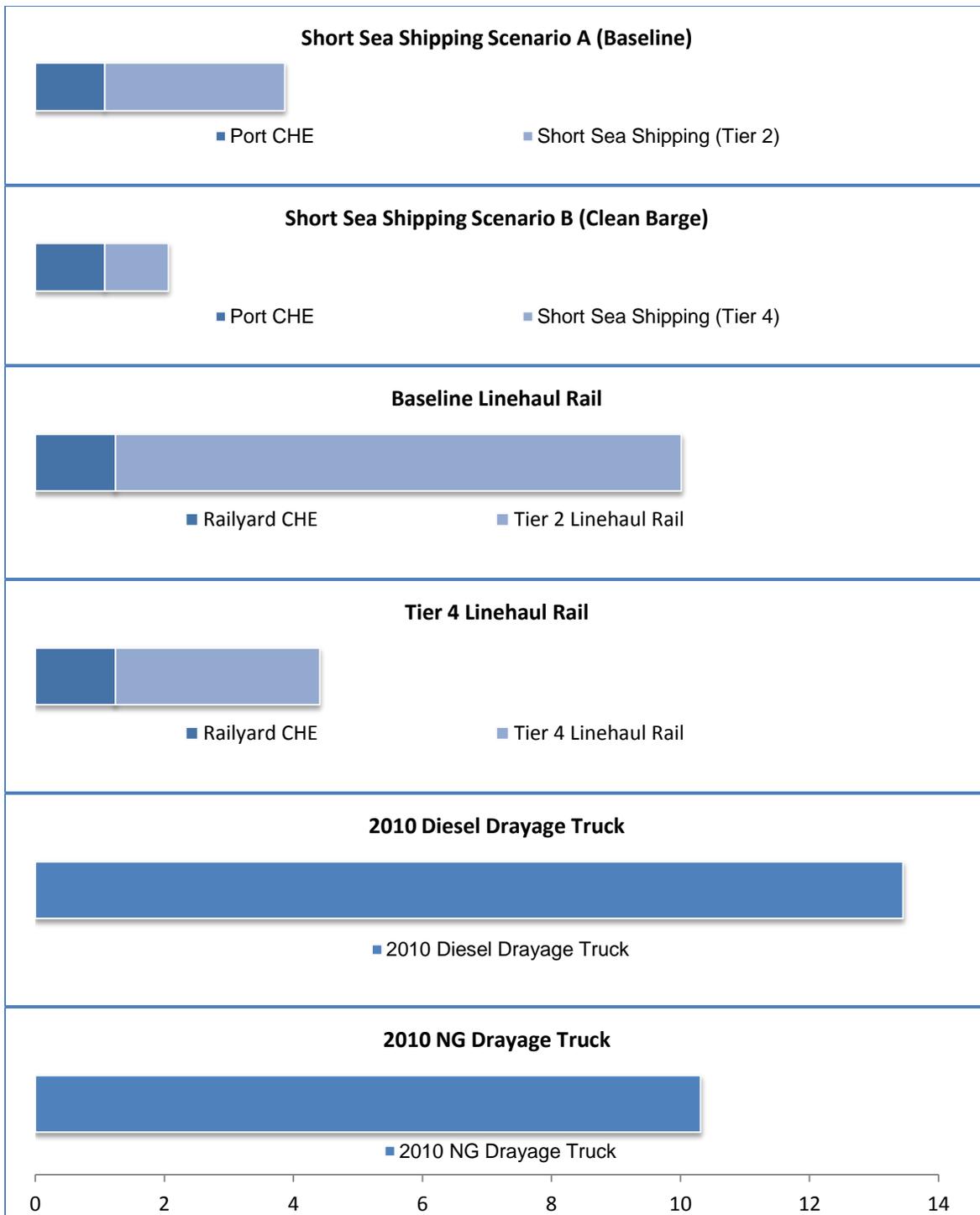


Figure 15. Short Sea Shipping Freight Pathways: PM emissions (grams/container)

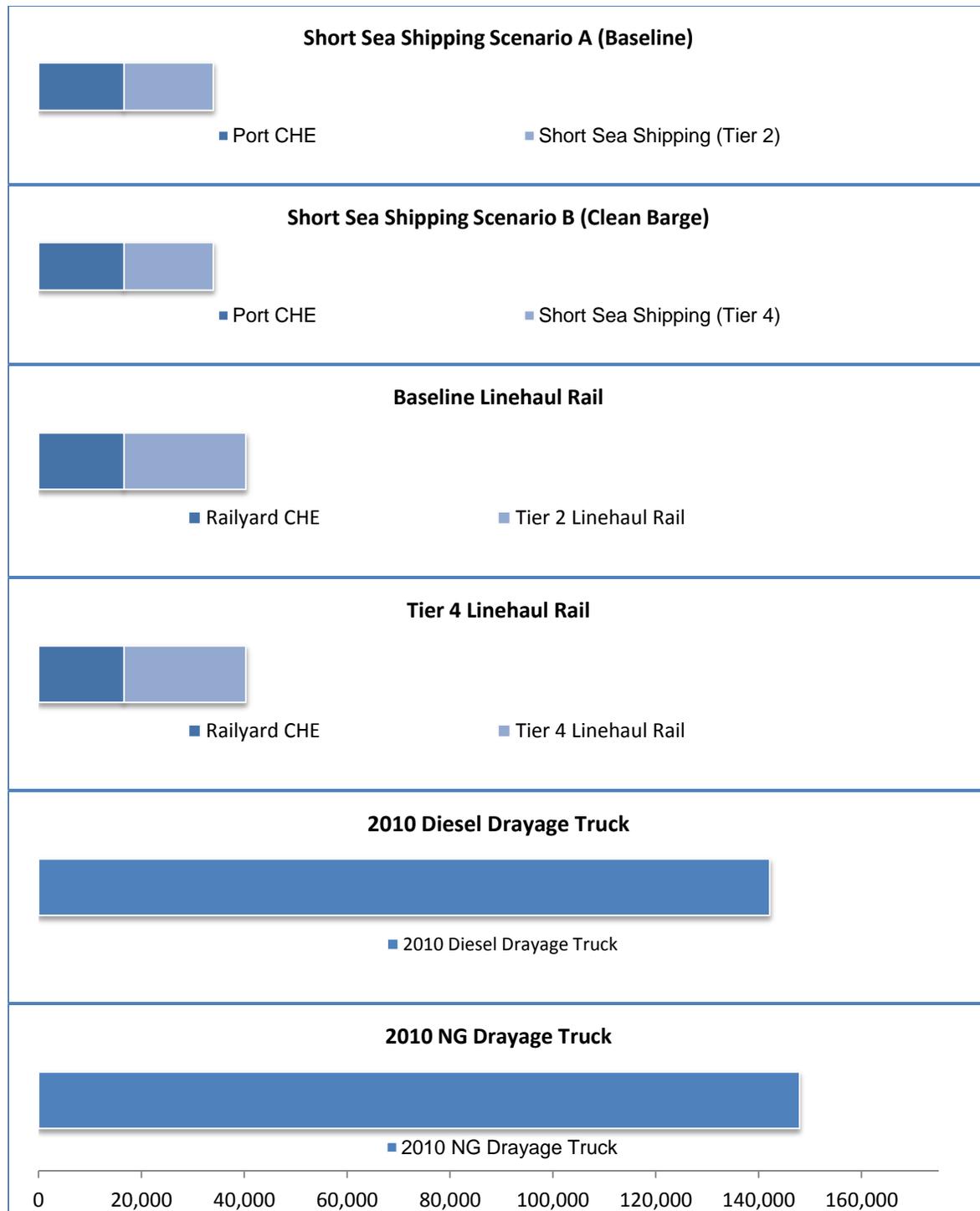


Figure 16. Short Sea Shipping Freight Pathways: CO2e emissions (grams/container)

Trailer/Container on Flat Car and Rolling Highways

The technology in a nutshell

Trailer on flat car (TOFC), container on flat car (COFC) and rolling highways are three methods of transporting intermodal containers and on-road vehicle freight using rail. Today, TOFC and COFC make up a significant volume of California freight rail volume, while rolling highways are an emerging approach which has yet to see significant deployment in North America. Each technology provides certain economic, logistic, and environmental advantages—and can successfully divert trucks from their current routes, an important feature for community groups organizing around trucks operating in their communities.

The first Trailer on Flat Car (TOFC) service was introduced by Southern Pacific Railroad in 1953. The development of TOFR service (also known as “piggybacking”⁴⁹) was a response to declining American industrial capacity and consolidation of the rail industry in the 1950s and 1960s. As the primary origin of freight movement shifted from domestic factories to marine terminals and intermodal facilities, piggybacking allowed rail operators to close lower volume and less profitable lines, replacing them with trucks. Smaller spur lines could be replaced with on-road trucks, which could be loaded onto a rail flatcar at a centralized facility and transported to an intermediate point, then unloaded and driven to their final destination point. Early piggyback units were loaded with the entire truck (including its tractor), but today virtually all TOFC units today are loaded without a tractor. Today, a tractor-trailer is dispensed from the point of origin (typically a factory, distribution facility, or marine terminal) to the rail operator’s facility, where the trailer driven onto a flatcar and disconnected from the tractor. When the train reaches its destination, another tractor pulls the load off the flatcar and drives the unit to the final destination.

The containerization movement encouraged operators to standardize the size and dimensions of marine, rail, and on-road units, and removed the need for attached trailers for many shipments. Units loaded without an attached trailer are known as COFCs, or container on flatcar. In its most simple form, a COFC is an intermodal container that has been removed from its trailer chassis and loaded onto a flatcar. Today, most intermodal containers are removed from the trailer, lifted and double-stacked onto a specially-designed car. Double-stacking reduces strain on rail infrastructure by shortening the overall convey length, and allows for faster, more efficient travel. Double-stacking is particularly common in the western United States, where higher clearances and taller bridge and tunnel infrastructure makes it most practical. Because of their significant cost savings, COFC has come to dominate intermodal freight shipping in North America, particularly since the 1980s.⁵⁰ The primary disadvantage of COFC is that the container must be lifted onto and from the well car, while TOFCs can be removed from the flatcar using a tractor. TOFC is also utilized for dry vans, which do not have a removable chassis.

Rolling highways are distinguished from contemporary TOFC and COFC service in that the tractor is loaded with the trailer as a single unit. Rolling highways are much like early TOFC service in that

⁴⁹ <http://www.uprr.com/customers/intermodal/integlos.shtml>

⁵⁰ http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/NA_intermodal_composition.html

the truck is transported as one unit. Rolling highways, also known as truck on flatbed, are common in Europe, where mountainous terrain makes driving individual trucks challenging and lower bridge and tunnel clearances prevent double-stacking. Despite the increased weight of the tractor, rolling highways are typically able to transport an equivalent load using less energy than trucks driven individually. COFR and TOFR get an additional efficiency boost because the weight of the tractor (and, in the case of COFR, the trailer) is eliminated. Our analysis shows that, while rolling highways, TOFC, and COFC use significantly less fuel to transport an equivalent load compared to on-road trucks, they release more particulate matter and nitrous oxide at current Tier 2 standards.

The additional weight of the tractor adversely affects the overall emissions reduction performance of rolling highways when compared to TOFC or COFC. Rolling highways, however, provide significant flexibility and logistic advantages. Units travelling on rolling highways need only to disconnect from the flatcar and drive down a ramp once they reach their destination, while COFC units must be removed using a crane and TOFC need to meet another tractor at their destination.

Who's involved and where?

Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) both provide COFC and TOFC service along routes traversing the San Joaquin Valley. Union Pacific operates intermodal facilities with COFC and TOFC capabilities in Oakland, Stockton, Los Angeles, and Long Beach.⁵¹ BNSF operates intermodal facilities with COFC and TOFC capabilities in Fresno, Oakland, Stockton, Los Angeles, and San Bernardino.⁵² These facilities are notably collocated with major marine terminals.

Rolling highways are not available in the United States, but have been deployed throughout Europe and in India. In Austria, "Rolling Road" service is offered by Rail Cargo Austria under the Ökombi brand name⁵³. Entire trucks are loaded onto special low-loading cars and then transported by rail. The truck driver accompanies the truck in a special passenger car where food and drink service is provided.⁵⁴ A similar service has been provided since 2003 between Aiton, France and Orbassano, Italy under the Autoroute Ferroviaire Alpine (Alpine Rolling Highway). The 175 km (110 mile) route is jointly maintained by the French and Italian state-owned railways (SNCF and Trenitalia). Konkan Railways began offering "roll-on roll-off" service in 1999; the service stretches almost 500 kilometers (300 miles) along India's western coastline, and loading/unloading activities typically take between 15-20 minutes.⁵⁵

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- By diverting trucks from road to rail, each scenario reduces community impacts from trucking
- Each rail scenario emits significantly lower GHG emissions than drayage truck scenarios
- If Tier 4 locomotive is used, PM and NO_x are much lower than drayage truck scenarios

⁵¹ <http://www.uprr.com/customers/intermodal/intmap/index.shtml>

⁵² <http://www.bnsf.com/customers/support-services/facilities/>

⁵³ <http://www.oekombi.at/download.php?lan=2&f=2354&fd=478>

⁵⁴ <http://www.oekombi.at/index.php?lan=2>

⁵⁵ <http://www.konkanrailway.com/node/298>

Weaknesses:

- If Tier 2 locomotive is used, rail freight scenario can produce higher PM and NOx than 2010 drayage truck scenarios

Opportunities:

- Many COFC and TOFC options exist in California already

Challenges:

- Ensuring that Tier 4 locomotive engines are used when they become available

Freight Pathway Emissions

Freight pathways for truck on flatbed operations were compared against a drayage truck already loaded with a container. This is based on the assumption that the baseline alternative to a TrOFC strategy is a drayage truck that continues along its route rather than stopping at the flatbed car loading facility. As a result, there are no cargo handling events to load containers onto the trucks in the baseline scenario. As with the longer transportation distances modeled in the Statewide Freight Pathways section of this report below, NOx and PM emissions from Tier 2 locomotives over this pathway exceed emissions from 2010-compliant drayage trucks. Tier 4 locomotives provide significant NOx, PM, and GHG reductions relative to drayage trucks.

Table 4. Regional Truck on Flatbed Rail pathways

Pathway	Description
Regional Rail Scenario A (Tier 2 Locomotive; Truck on Flatbed)	Load truck with container onto train. Line haul with Tier 2 diesel locomotive to second rail facility. Unload truck with container from train. Includes train switching activity (Tier 2 diesel) and emissions to represent emissions associated with train idling at loading stations.
Regional Rail Scenario B (Tier 4 Locomotive; Truck on Flatbed)	Load truck with container onto train. Line haul with Tier 4 diesel locomotive to second rail facility. Unload truck with container from train. Includes train switching activity (Tier 4 diesel) and emissions to represent emissions associated with train idling at loading stations.
2010 Diesel Drayage Truck (Baseline)	Container already loaded on drayage truck. Haul to second rail facility using 2010-compliant diesel drayage truck.
2010 NG Drayage Truck	Container already loaded on drayage truck. Haul to second rail facility using 2010-compliant natural gas drayage truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	100 miles

Emissions from Regional Truck on Flatbed Rail Freight Pathways

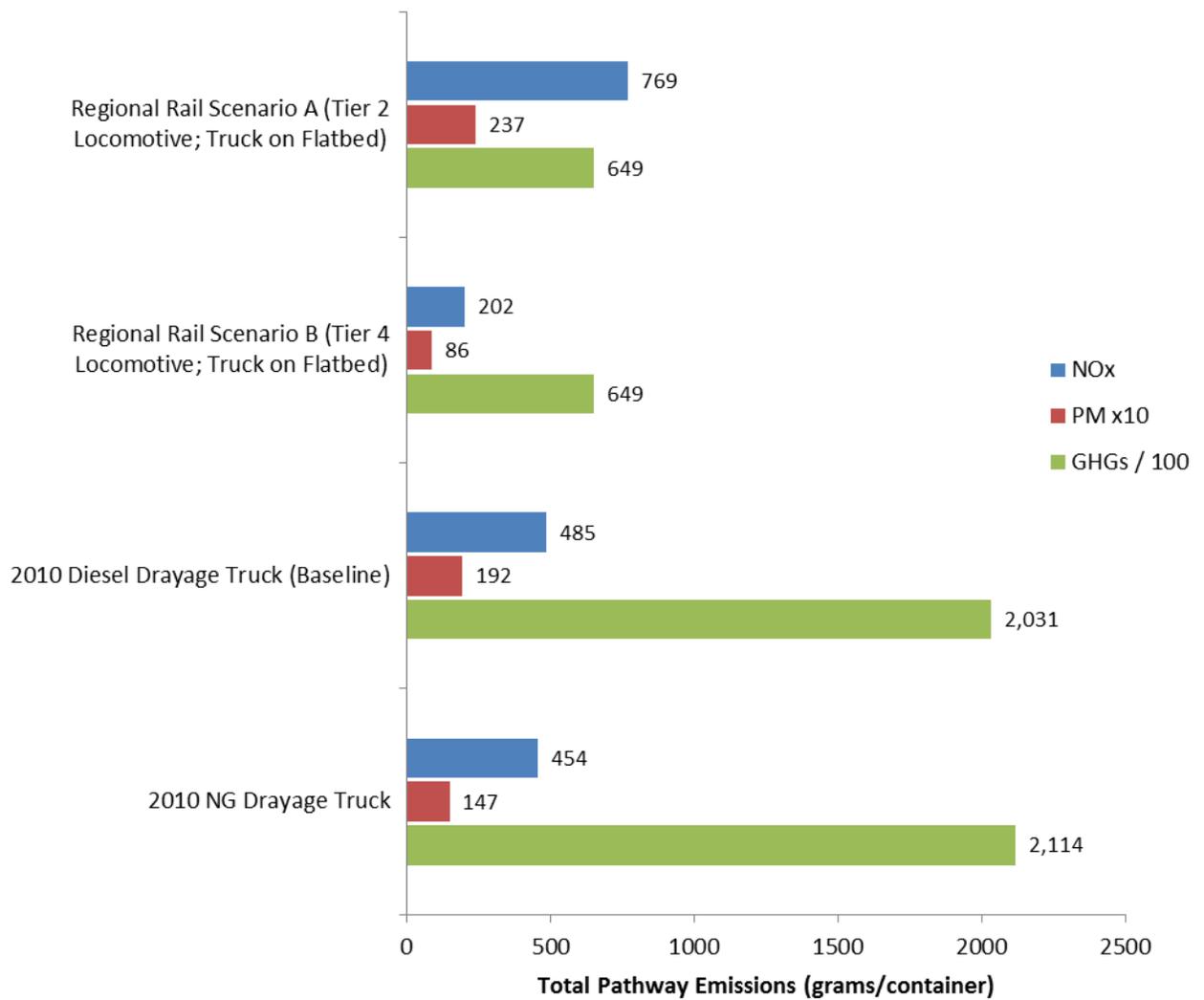


Figure 17. Emissions from Regional Truck on Flatbed Rail Freight Pathways (grams/container)

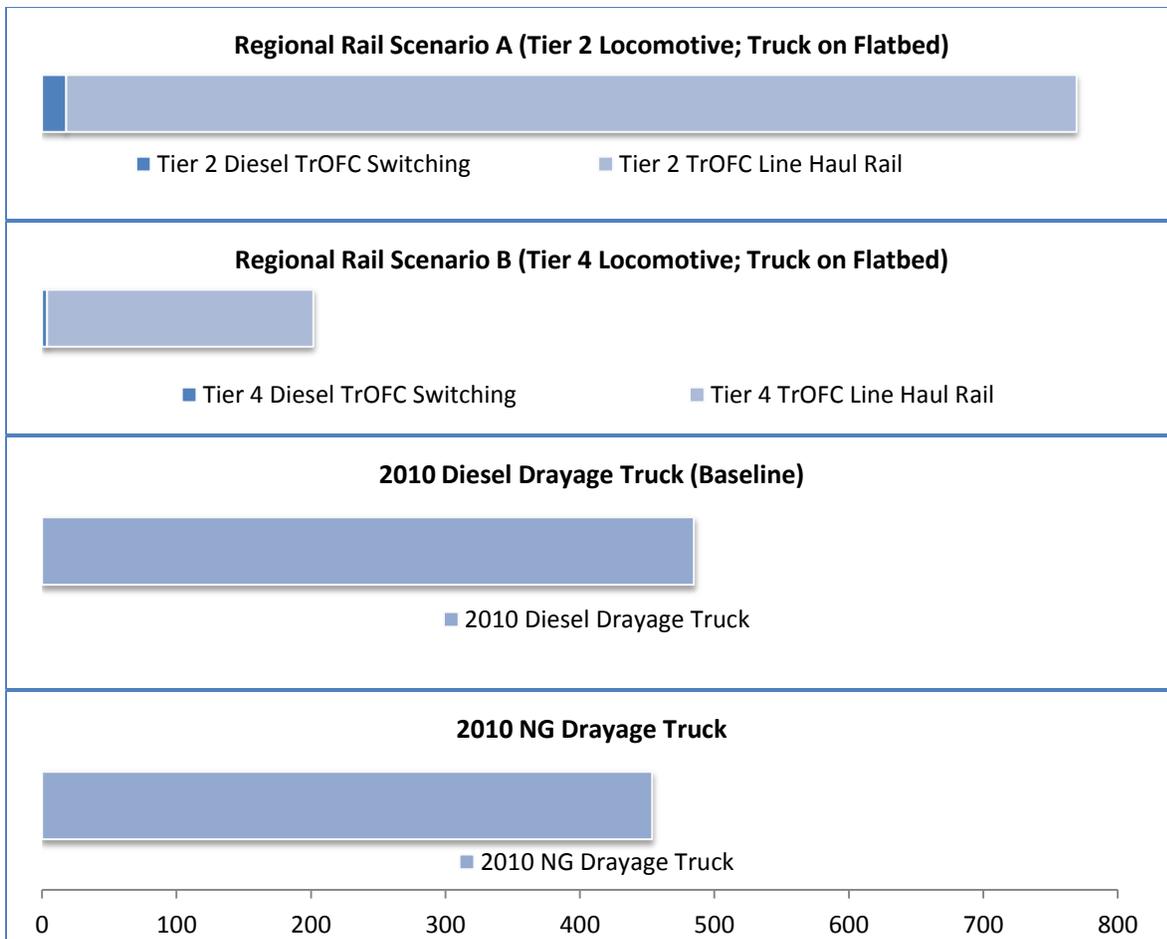


Figure 18. Regional Truck on Flatbed Rail Pathways: NOx emissions (grams/container)

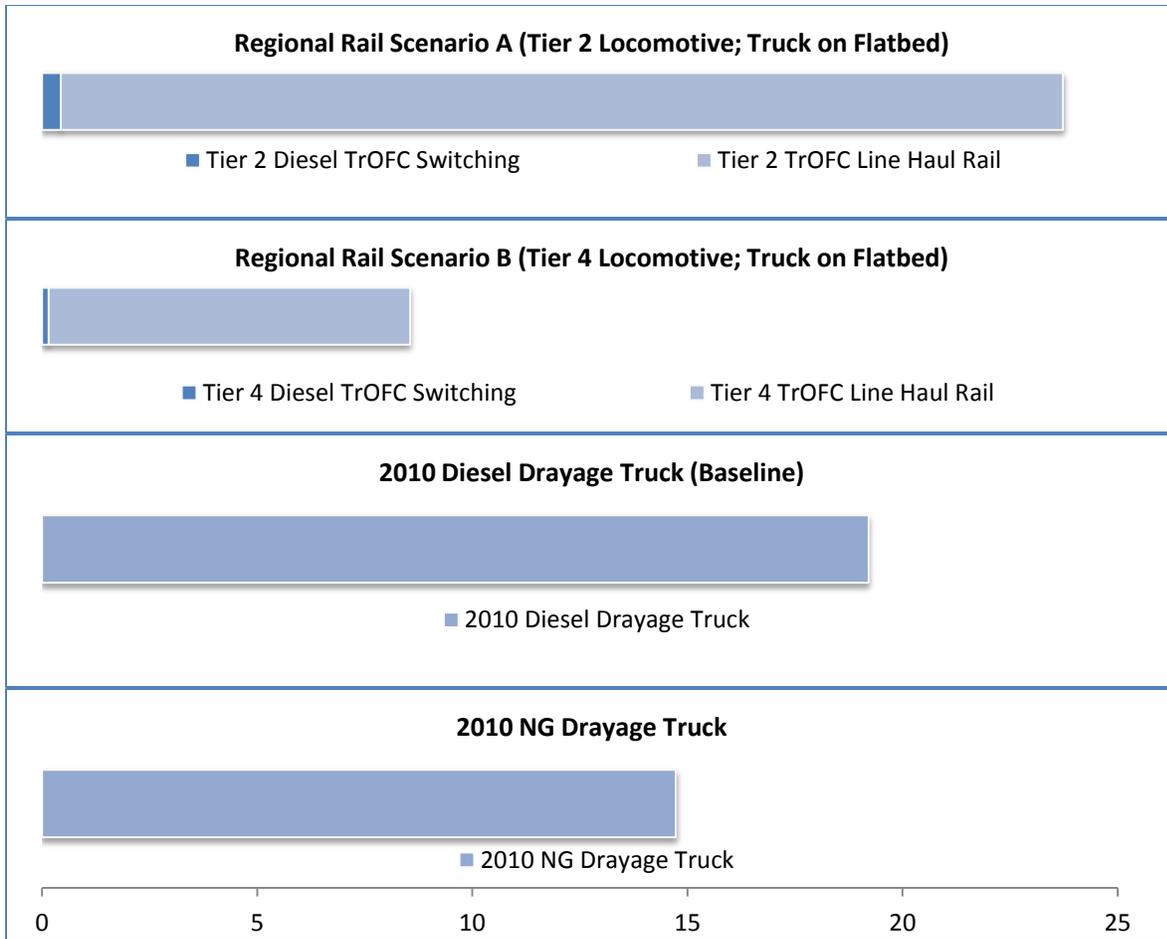


Figure 19. Regional Truck on Flatbed Rail Pathways: PM emissions (grams/container)

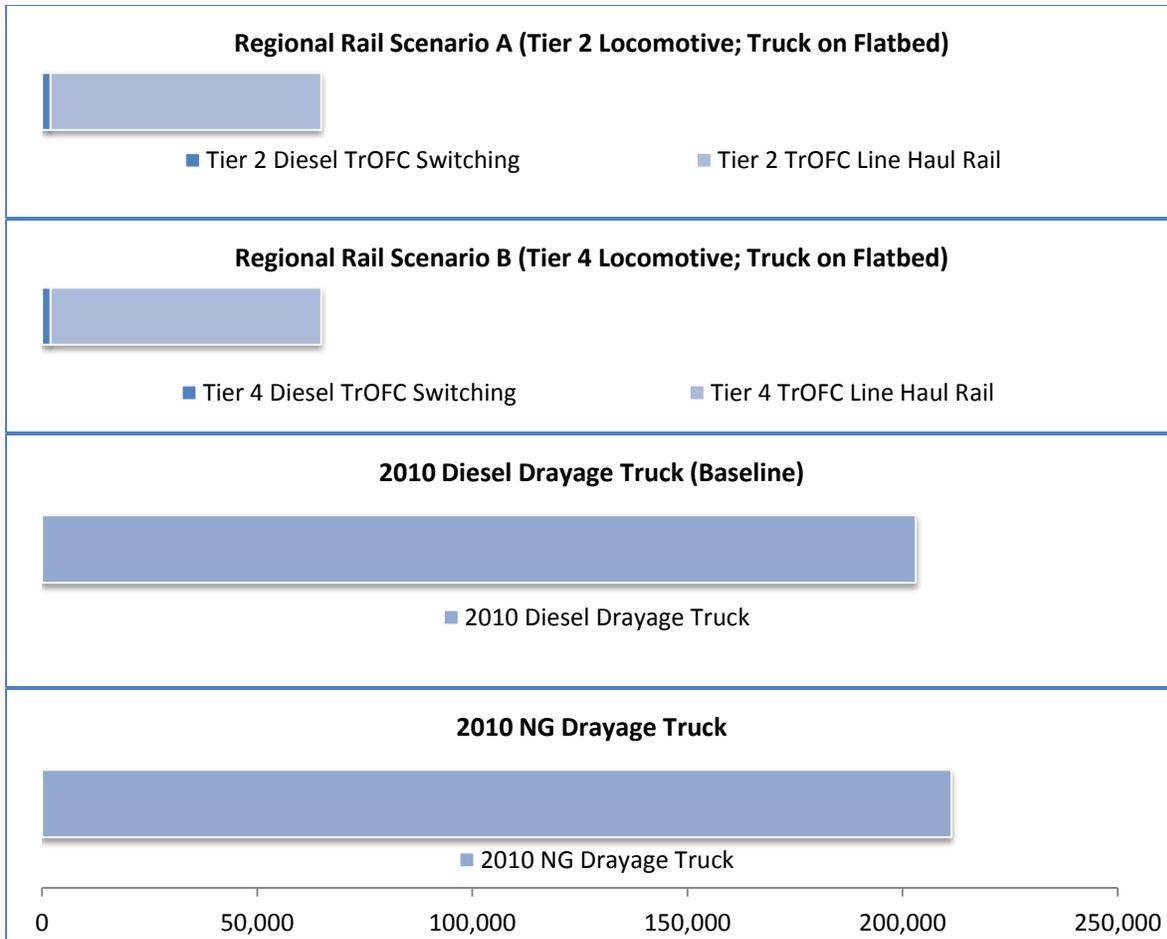


Figure 20. Regional Truck on Flatbed Rail Pathways: CO2e emissions (grams/container)

Part Three – Statewide Strategies

Logistics and Efficiency improvements

The technology in a nutshell

Increased logistics and efficiency improvements can help reduce emissions and other environmental impacts of freight transport in specific applications, but there is little data to quantify the extent of the general benefits. Indeed, there are more anecdotes than publicly-available data when it comes to using logistics and efficiency improvements to reduce emissions on a large scale.

Companies may strive to be as efficient as possible in the logistics of their operations to save money. Trucks travelling empty consume 80% as much fuel and those travelling fully loaded, which translates into significant gains when they increase their load factors. Indeed, their ability to eliminate the transport of empty containers as much as possible is a critical piece of their profitability.

Unfortunately, individual companies that take innovative steps to reduce their fuel consumption and turn times rarely publicize those actions because they don't want their competitors to copy them. Companies like Fed Ex, UPS, BNSF, Maersk and others may be doing a lot to increase their logistical efficiency, but their best practices are closely-held secrets. Plus, what increases efficiency for Fed Ex would not necessarily be useful to BNSF or drayage operators at POLA, or vice versa

Nevertheless, we can make some generalizations about logistics and efficiency improvements. These generalizations fall into two main categories, depending on the basic location of the operation: at a port or railyard, or offsite.

Within a port or railyard, there are many ways that operations can be streamlined and made more efficient, such as implementing appointment schedules for container pick-up and drop-offs, relocating or electrifying gates, extending hours, and installing faster cargo-handling equipment.

Each of these can have a modest impact on emissions, collectively adding up to a potentially significant, yet difficult to quantify amount of reductions.⁵⁶ To the truck company, faster turns and more efficient operations mean that they can move more containers in a day, week, month, and year. But, to a community, those faster turns and more efficient operations could translate directly into more trucks – and more truck pollution, congestion, and noise—on community streets. Outside of the port or railyard gates, techniques like virtual container yards (discussed below) are being used to reduce emissions and congestion at the port or railyard. There is evidence that virtual container yards can reduce the number of empty containers on the roads somewhat, increasing the efficiency of the overall Freight transport system. But again, caution is warranted: companies don't generally want to consolidate their deliveries or their logistics systems with their competitors, and

⁵⁶ When the Port Authority of New York and New Jersey tried to quantify these impacts, they concluded that they were not quantifiable with any degree of certainty.

even when they do,⁵⁷ moving the truck turn to another location simply shifts the congestion, emissions and noise to the neighborhood of the virtual container yard.

It is important to note the example of UPS, which has touted their work to optimize their delivery routes to improve their fuel efficiency.⁵⁸ Apparently, a key strategy was to require their drivers to avoid left turns whenever possible. By avoiding idling at intersections while waiting to make left turns across traffic, they improved their fuel efficiency—but by making a number of right turns to get to the same spot, they increased their overall VMT in the neighborhoods that they were operating in.

In the end, it is extremely difficult to legislate or regulate logistical efficiency. Public agencies usually lack the expertise to design the efficiency improvements that work for both industry and communities, and companies are loathe to share their information and best practices with each other. Port or railyard operators and public agencies can strive to create a turn-time or other efficiency goals, but whether or not those goals are met will be determined by many variables on the ground – the operations of many different port or railyard stakeholders, truck owners and operators, ship schedules, rail capacity, community concerns, and others.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- By implementing appointment schedules, relocating or electrifying gates, and taking other steps to streamline operations and increase efficiency, ports and railyards can improve efficiencies, reduce emissions, and reduce community impacts from drayage operations

Weaknesses:

- Very hard to generalize or quantify benefits due to location-specific and company-specific strategies and reluctance of companies to share their success stories for competitive reasons
- Many strategies have modest impact on emissions (but if aggregated, can be potentially significant)

Opportunities:

- Companies have economic incentive to implement their own company-specific and location-specific strategies that improve efficiency and reduce fuel costs

⁵⁷ The Japanese city of Fukuoka provides an example of successful delivery consolidation at an urban level. Over 30 freight operators formed a co-operative to manage logistics in the high traffic city center. As a result, the number of freight vehicles was reduced by 67% and freight vehicle kilometers travelled was reduced by 87%. However, this required the type of central government control and willingness to cooperate across company lines that is hard to imagine working in California.

<http://www.tc.gc.ca/eng/programs/environment-utsp-casestudyefficiency-2568.htm>

⁵⁸

<http://www.pressroom.ups.com/Fact+Sheets/ci.Saving+Fuel%3A+UPS+Saves+Fuel+and+Reduces+Emission+s+the+%22Right%22+Way+by+Avoiding+Left+Turns.print>

Challenges:

- Improving efficiencies has potential to reduce community impacts from trucking, but also has risk of shifting impacts from one community to another
- Extremely difficult to regulate or legislate logistical efficiency, given the many variables involved

Virtual Container Yards

The technology in a nutshell

Despite increases in logistics and efficiency throughout the Freight transport industry, empty containers remain a major efficiency challenge for statewide Freight transport. Steady increases in international shipping and a growing trade imbalance with East Asia have caused an influx of empty containers at port terminals, container depots, and rail yards across California, as well as on California highways. This phenomenon is causing unnecessary time, expense, and emissions in the state.

It has been estimated that 30 to 40 percent of intermodal trucks are hauling empty containers at any given time.⁵⁹ Empty container traffic occurs in two dimensions—from vehicles returning empty to a terminal from their landside destinations, and from vehicles traveling empty from the port to be loaded up with goods at an exporter’s facility.

The “Virtual Container Yard” (“VCY”) is one approach to solving this problem. While the specifics of each VCY system differ, the basic concept of a VCY is a real-time (typically web-based) platform that allows users to match empty container availability with empty container demand. Using a VCY enables empty trucks to pick up filled containers at a neutral location (i.e., not a container depot or rail yard) before return to a marine terminal. Because the transfer happens in a neutral location, it is known as a “street turn.”

The VCY concept is a relatively simple approach. It is an extension of the existing vehicle and container tracking systems used by transportation carriers to manage operations internally. Unlike most other concepts discussed within this report, virtual container yards have relatively-low initial costs, and do not require significant investments in new infrastructure or any new fuels or vehicle technology. A 2008 study estimated the 25-year operating cost of a VCY system at the Port of Los Angeles-Long Beach at roughly \$4.2 million.⁶⁰

⁵⁹ IAS, a leading developer of Virtual Container Yard (VCY) technology solutions.

http://www.interasset.com/news/pr/2007/2007_03_pressrelease_iaslaunchesinterturntntservice_topowervirtualcontaineryardinitiativestnationwide.pdf

⁶⁰ SCAG, “Analysis of Goods Movement Emissions Reduction Strategies,” available at

http://s3.amazonaws.com/zanran_storage/www.scag.ca.gov/ContentPages/509500638.pdf

The primary barrier to widespread adoption of VCY systems is logistical and behavioral. A successful VCY system requires sharing of information that stakeholders in the freight transport industry might normally consider proprietary or otherwise sensitive. Individual fleets, who may actively seek to reduce unnecessary trips and maximize vehicle capacity within their internal operations, are often unwilling to share such information with companies they view as competitors. Likewise, their customers may feel uncomfortable seeing the volume and character of their import/export operations be shared with competing firms. A neutral third-party is therefore necessary, and is unlikely to evolve independent of a Port-mandated policy or highly coordinated effort within the freight transport industry itself.

There is little verifiable data about the success of these programs. Utilization rates and the number reductions of street turns are not generally available to the public. However, several studies have suggested that only 2 percent of trips use street turns in a VCY system.⁶¹ A 2006 presentation by eModal suggested that each VCY street turn should reduce NO_x levels by 300g, and should reduce VMT by 15 miles.⁶²

While VCYs may increase in use, the logistical and behavioral barriers seem to limit projections of future growth. A Hofstra University study found that the benefits of VCY growth should not be expected to be significant. The authors found that VCYs in Southern California could accommodate up to 10% of turns (rather than today's 2%).⁶³ The Metrans study also concluded that VCYs could grow to accommodate 5-10% of containers by 2020. Because only 2 percent of the trucks are using a VCY system, an increase to 5-10 percent would only reduce overall truck trips by 3-8% overall.

There are community concerns about VCYs that are important considerations. Without adequate oversight, street turns can happen anywhere, including trucking company facilities, import/export company locations, and rail yards—but also in residential neighborhoods, near parks and schools, and other sensitive locations. While overall truck trips, VMT, and emissions in the air basin or state can be somewhat reduced by the effective use of VCYs, there could be increases in congestion and emissions at a local level, at and near the site of the VCYs.

Who's involved and where?

Virtual container yard systems have been deployed at the Port of Los Angeles-Port of Long Beach and the Port of Oakland. Oakland launched California's first VCY system in 2003, using a system designed and maintained by Pleasanton-based SynchroMet. Long Beach and Los Angeles, in consultation with the Alameda Corridor Transportation Authority, initiated a VCY system in 2006, using technology from Oakland-based International Asset Systems (IAS). This initiative was unique in that it was incorporated into the Ports' existing eModal reservation system, which is used by

⁶¹ IAS, Id.; SCAG, Id.; Le Dam Hanh, "The Logistics of Empty Containers in the Southern California Region," 2003, available at http://www.metrans.org/research/final/01-05_Final.htm.

⁶² <http://www.fasterfreightcleanerair.com/pdfs/Presentations/FFCACA2006/John%20Cushing%20-%20Virtual%20Container%20Yards.pdf>.

⁶³ <http://people.hofstra.edu/geotrans/eng/ch5en/appl5en/ch5a3en.html>

virtually all fleets operating within the vicinity of the Ports. Outside California, virtual container yard systems have been deployed at the Port of New York and New Jersey (also using eModal).

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- Reduces number of empty containers, saving emissions and fuel consumption overall
- Reduces congestion at ports and railyards because it shifts container moves elsewhere
- Very low start-up and implementation costs
- Companies willing to work together to improve efficiencies can reduce their emissions, fuel costs, and time hauling empty containers

Weaknesses:

- Only 2% of trips use VCYS where they are available, suggesting companies are not interested in these cooperative arrangements
- Increases congestion and emissions at the site of the VCY, and overall emissions reductions are not significant
- Current growth projections will have modest impacts on congestion, emissions, and fuel savings overall

Opportunities:

- With only 2% of trips using VCYS at present, growth opportunities clearly exist

Challenges:

- Companies are typically unwilling to share logistics, pricing and other operations information with each other
- Community concerns about increased congestion, emissions and noise at the VCY site

Statewide rail capacity increases

The technology in a nutshell

The recently-released draft California State Rail Plan (CSRP) provides a window into future statewide freight rail capacity increases that are being contemplated in California. Prepared by AECOM for the California Department of Transportation's Division of Rail, the CSRP describes the current conditions of rail infrastructure in California and outlines the challenges and opportunities that must be addressed to maintain the network's state of good repair and prepare for future capacity increases. It does not address the environmental impacts or benefits of investing in the rail network, nor does it address community concerns that may arise with increased freight rail capacity and the construction thereof.

California's existing freight rail network is the nation's 8th largest, in terms of rail tons originated.⁶⁴ It is a critically important economic link between containers and trailers to other transportation

⁶⁴ http://californiastaterailplan.com/wp-content/uploads/2013/02/CSRP_Public-Draft_Main_2013-02-09.pdf (page 115)

modes within the supply chain within and beyond the state. Indeed, the success of California's ports is dependent on the quality of the rail network and the intermodal facilities that connect the ships at the ports to the rail lines that take goods beyond the state. Moreover, California's freight rail system plays an important role in many sectors that are not port-specific, such as agriculture, manufacturing, wholesale and retail trade, construction, transportation and warehousing, and mining sectors.⁶⁵

Managing the rail network's growth is critical because Freight transport activity in California is expected to grow through at least 2040. By 2040, roughly 366 million tons are projected to move on the State's rail system. Outbound traffic is anticipated to grow to 197 million tons, an annual growth rate of 3.8 percent. Inbound tonnage is anticipated to grow at a slower rate (1.0 percent), reaching 139.7 million tons by 2040.⁶⁶

The draft CSRP outlined the planned and programmed projects in the freight rail category. Overall, \$8.4 billion is the projected financial cost of maintaining and expanded the freight rail system. Of this, roughly \$3.3 billion will be directed toward mainline capacity improvements, and nearly \$3 billion will fund port-related rail investments.⁶⁷ Some examples of freight railroad improvement projects to improve reliability include rail grade separation, double track construction, and freight facility improvements.

A summary of the largest projects on the Planned and Programmed Trade Corridor Projects list include (including name, projected cost, and project start or end date if provided):⁶⁸

- Many short-term on-dock rail improvements at the POLA, \$2.536 billion, dates not provided
- Double-track improvements on UPRR Alhambra, Los Angeles and Mojave Subdivisions, \$2.087 billion, dates not provided
- Add 3rd and 4th tracks to BNSF Cajon Subdivision, \$762 million, dates not provided
- Intermodal rail improvements in South Coast, \$673 million, dates not provided
- Intermodal Container Transfer Facility modernization, electrify cranes and add 6 new tracks, \$500 million, to be completed by 2016
- SCIG construction of new near-dock facility for BNSF, \$500 million, to be completed by 2016
- Outer Harbor Intermodal Terminals, \$385 million, to begin June 2013
- Add rail service from Air Expressway at Southern California Logistics Airport, \$250 million, dates not provided

⁶⁵ http://californiastaterailplan.com/wp-content/uploads/2013/02/CSRP_Public-Draft_Main_2013-02-09.pdf (page 136)

⁶⁶ http://californiastaterailplan.com/wp-content/uploads/2013/02/CSRP_Public-Draft_Main_2013-02-09.pdf (page 137)

⁶⁷ http://californiastaterailplan.com/wp-content/uploads/2013/02/CSRP_Public-Draft_Main_2013-02-09.pdf (page 280)

⁶⁸ http://californiastaterailplan.com/wp-content/uploads/2013/02/CSRP_Public-Draft_Main_2013-02-09.pdf (page 280 et seq.)

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- CSRP provides window into future statewide freight rail capacity increases

Weaknesses:

- CSRP does not address the environmental impacts or benefits of investing in the rail network
- CSRP does not address community concerns that may arise with increased freight rail capacity

Opportunities:

- California's existing freight rail network is the nation's 8th largest, creating capacity for increased rail freight

Challenges:

- Managing growth of rail freight will be critical to managing growth in both outbound and inbound goods movement in the state
- Ensuring adequate funding for capacity expansion and other capital needs is critical

Rail Linehaul

The technology in a nutshell

Rail linehaul refers to the long distance transport of freight by train, in contrast to the shorter distances traveled by switcher operations and short line operations.⁶⁹ Transport of cargo by rail linehaul is much more fuel efficient than hauling by a diesel truck. The average cargo train moves 460 ton-miles of freight using one gallon of diesel fuel, whereas a diesel truck typically moves approximately 65 ton-miles of freight on one gallon of diesel fuel.⁷⁰

Locomotives do not typically show NO_x and PM emissions reductions commensurate with the high fuel economy of their typical linehaul operations. This is because locomotives have very long useful lives—often 30 to 40 years. As a result, these locomotives typically use engines that are frequently rebuilt to their original emissions standard, rather than replaced with modern engines meeting the more stringent Tier 3 and Tier 4 emissions standards.

Who's involved and where?

Linehaul rail operations are ubiquitous in California and the United States. Two Class 1 railroads operate in California: Union Pacific (UP) and Burlington Northern Santa Fe (BNSF). Both railroads have rail lines running the length of California.

⁶⁹ Switcher operations are a crucial part of all rail facilities and use smaller locomotives to break up and build trains through the positioning of train cars. Short line operations include switching operations but also involve moving trains several miles to larger rail facilities.

⁷⁰ Assumes a standard loaded container weighing 10.6 tons and a diesel drayage truck with an average fuel economy of 6 miles per gallon.

At near-dock rail facilities, Class 3 railroads (short line railroads) may interface with the BNSF and UP facilities. For example, PHL (at the Ports of Los Angeles and Long Beach) and Central California Traction Company (Port of Stockton) are two Class 3 railroads that transfer rail cars between port terminals and rail yards.

The locomotive market is challenging for new technology because there are few incentives to innovate – traditionally, emissions standards have been lax, engines are very expensive, and turnover times are very slow because of the long useful lives of the engines. However, with new Tier 4 emissions regulations coming, plus an ability to adapt promising components and technologies from other diesel sectors, the hybrid locomotive is expected to become more prevalent later this decade. In addition, both GE and EMD are developing LNG versions of their locomotive engines. It is worth noting that both UP and BNSF have announced that they are considering these LNG locomotives.

Genset locomotives will provide tough competition, with the market expanding at a compound annual growth rate (CAGR) of 6.7% between 2010 and 2020. However, hybrid locomotives will grow quickly towards the end of the decade with a CAGR of 19.4% by 2020, under a baseline forecast scenario. Because the LNG market is just developing, we do not have growth rates for LNG locomotive growth.

Summary of strengths, weaknesses, opportunities and challenges:

Strengths:

- All rail linehaul scenarios are lower in PM, NO_x and GHG emissions than 2010 drayage truck scenarios

Weaknesses:

- Because locomotives are usually rebuilt to their original emissions standards rather than replaced, the baseline rail linehaul scenario is only marginally lower in PM and NO_x emissions than the 2010 drayage truck scenarios
- Few incentives to innovate exist

Opportunities:

- Linehaul rail operations are ubiquitous in California
- New Tier 4 emissions standards and the ability to adapt hybrid genset technologies creates new opportunities later this decade

Challenges:

- Ensuring that Tier 4 locomotive engines are used when they become available

Freight Pathway Emissions

Rail linehaul pathways using various linehaul locomotive and switcher locomotive technologies were compared by estimating the emissions produced by moving a single container from a rail facility to a second rail facility 400 miles away. This distance was selected because it is similar to the distance between the southern California ports and the Port of Stockton.

This approach enables us to compare and put into perspective the relative emissions contributions of linehaul, switching, and cargo handling equipment for a container moving by rail between these two locations. Because linehaul operations generally start with the building of a train (i.e., the adding of containers to be shipped) by switcher locomotives, the linehaul freight pathway modeled below includes a switching operation prior to the linehaul move. Short line operations are not included as they are assumed to be related to the movement of the container to the rail facility where the modeled pathway begins.

The table and figures below summarize the estimated emissions for each freight pathway. Based on these results, the largest contributor to NOx and PM emissions is the linehaul event. Emissions from switching are generally insignificant compared to the total pathway emissions. The largest reductions in emissions are seen by employing Tier 4-compliant locomotives – as shown in Linehaul Rail Scenarios B, C, and D. Slight reductions in PM and GHG emissions are seen by using natural gas locomotives. It is also worth noting that 2010-compliant drayage trucks offer NOx and PM emissions comparable to current Tier 2 linehaul locomotives. This is contrary to a popular belief that shifting freight from truck to rail will produce significant emissions benefits due to the efficiency of rail movement – in fact, the emissions reductions are only achieved if the locomotive is a Tier 4 engine. Thus, communities that seek to divert truck traffic to rail should strive to ensure that the locomotives used in the future will be certified to Tier 4 levels, to ensure statewide benefits as well as the benefits of reduced truck traffic in their communities.

Table 5. Rail linehaul pathways

Pathway	Description
Linehaul Rail Scenario A (Baseline)	Load container onto train. Line haul with Tier 2 diesel locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 2 diesel) and emissions.
Linehaul Rail Scenario B (Tier 4 Diesel)	Load container onto train. Line haul with Tier 4 diesel locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 4 diesel) and emissions.
Linehaul Rail Scenario C (Tier 4 LNG)	Load container onto train. Line haul with Tier 4 LNG locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 4 LNG) and emissions.
Linehaul Rail Scenario D (Tier 4 Hybrid Switcher / LNG Linehaul)	Load container onto train. Line haul with Tier 4 LNG locomotive to second rail facility. Unload container from rail train. Includes train switching activity (Tier 4 diesel hybrid) and emissions.
2010 Diesel Drayage Truck	Transfer container to drayage truck. Haul to second rail facility using 2010-compliant diesel drayage truck. Unload container from truck.
2010 NG Drayage Truck	Transfer container to drayage truck. Haul to second rail facility using 2010-compliant natural gas truck. Unload container from truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	400 miles

Emissions from Rail Linehaul Freight Pathways

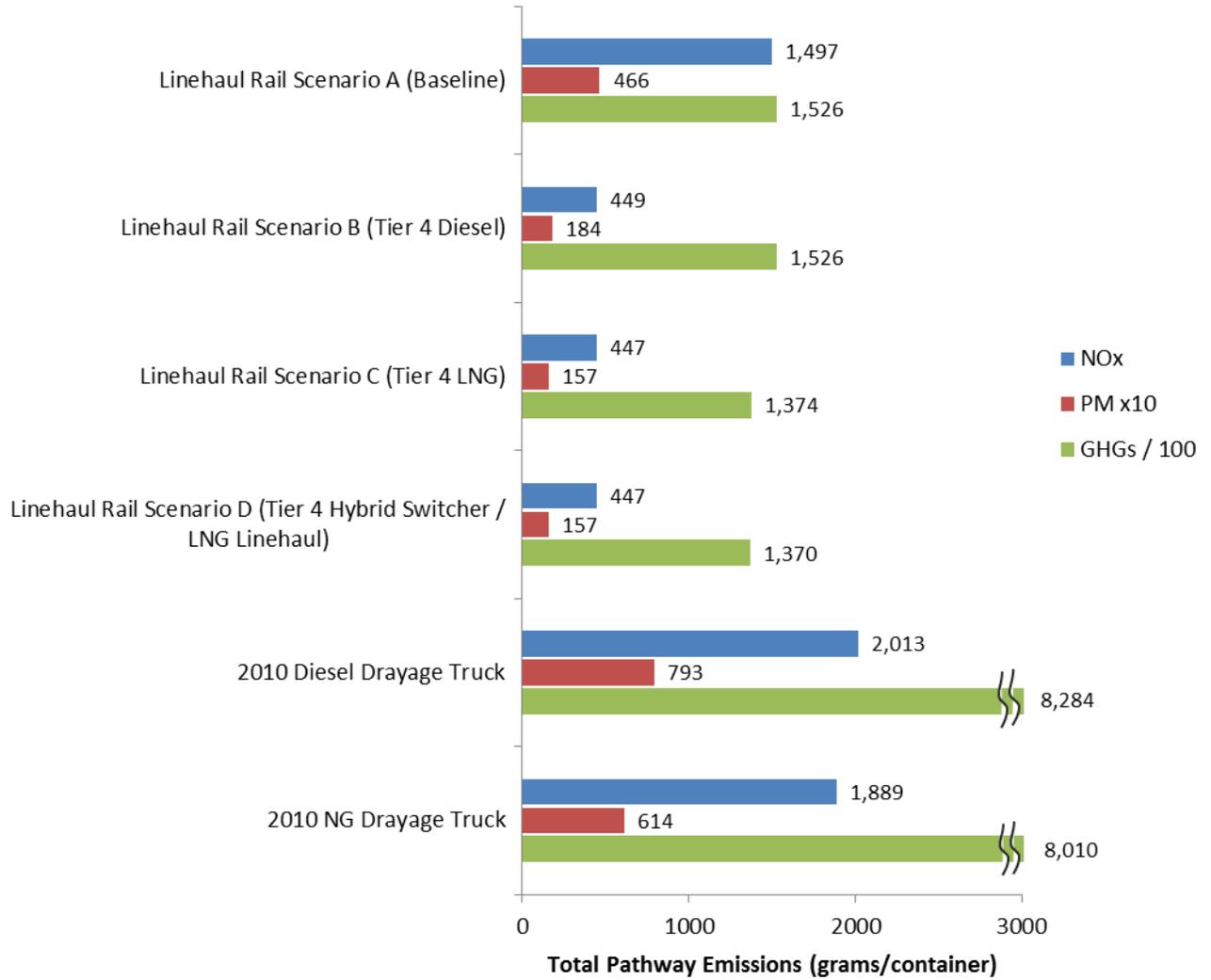


Figure 21. Emissions from Rail Linehaul Freight Pathways (grams container)

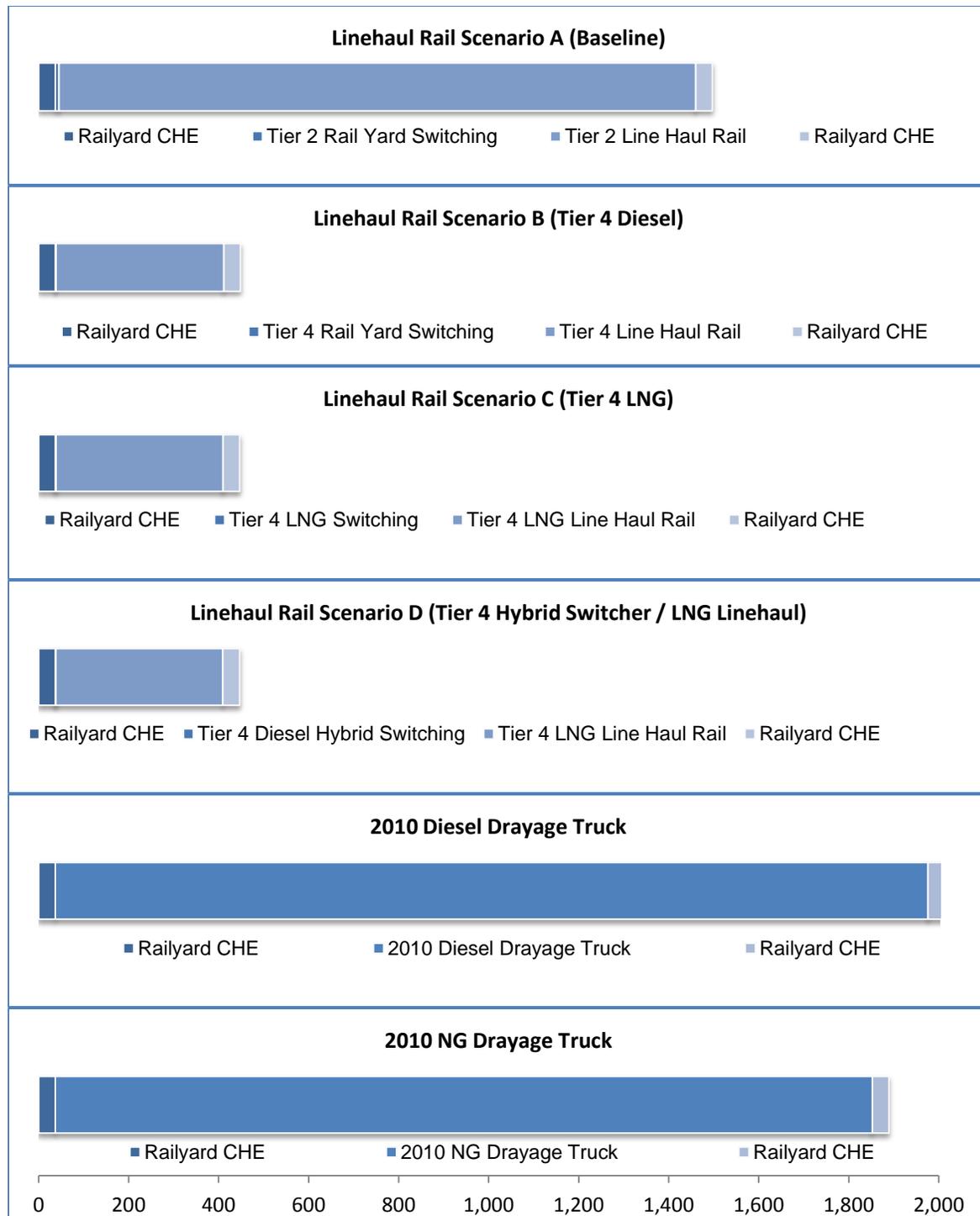


Figure 22. Rail Linehaul Pathways: NOx emissions (grams/container)

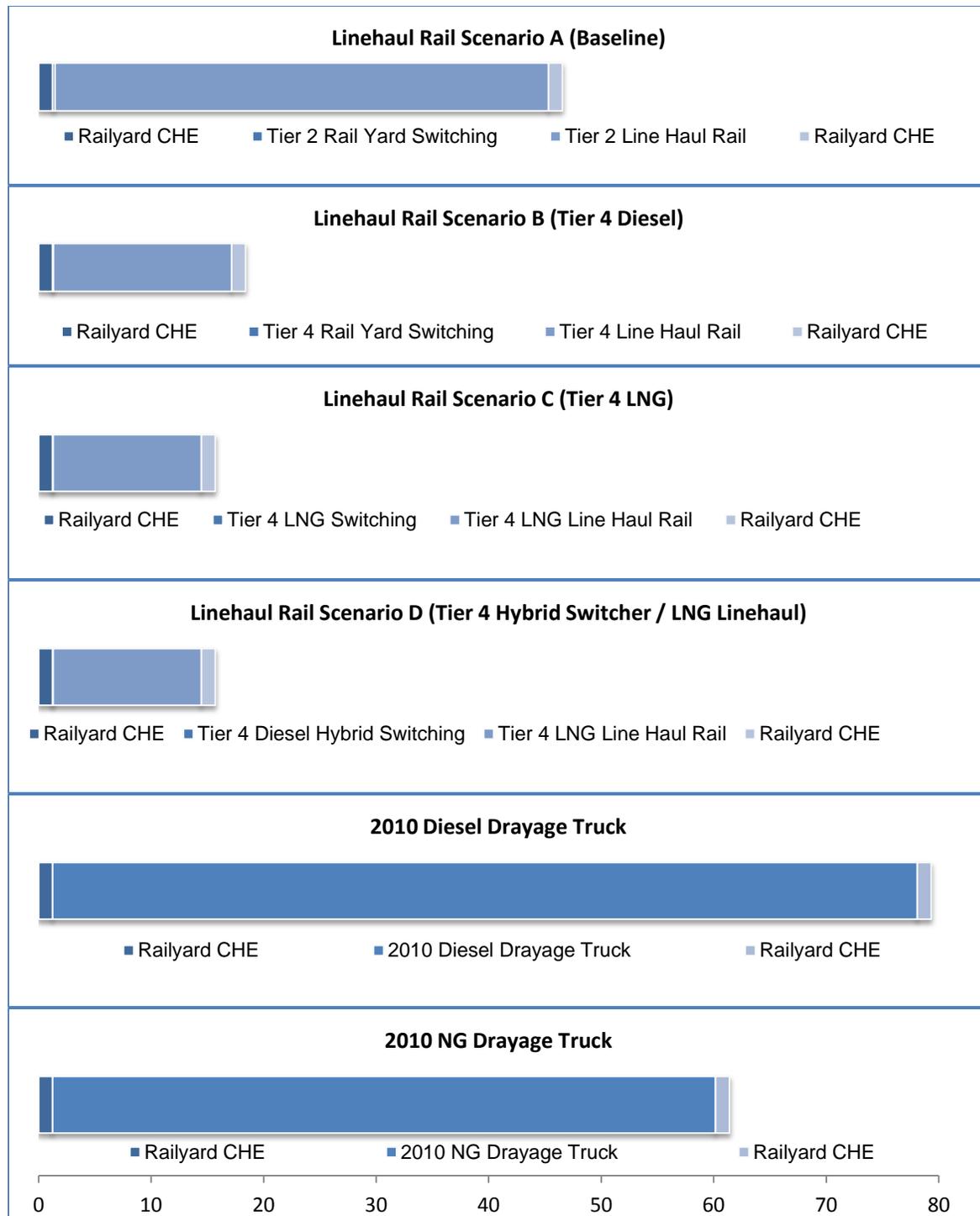


Figure 23. Rail Linehaul Pathways: PM emissions (grams/container)

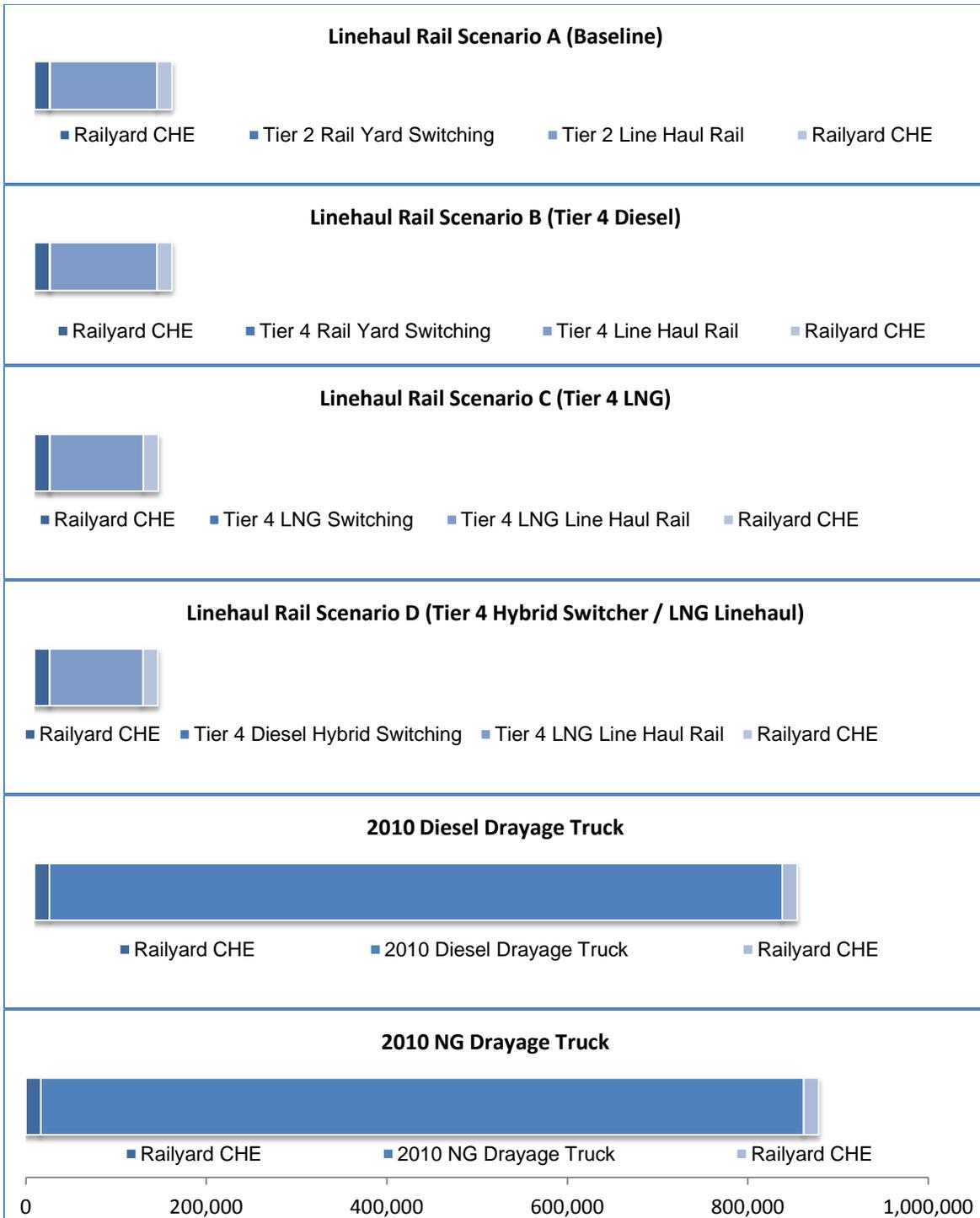


Figure 24. Rail Linehaul Pathways: CO2e emissions (grams/container)

Conclusion and Summary

California faces significant challenges in years to come as it grapples with increasing demands to move goods within and through the state, while meeting increasingly stringent air pollution standards, requirements and goals.

This report is designed to help the California Cleaner Freight Coalition evaluate local, regional, and statewide proposals to introduce new zero- and low-emission strategies and technologies that aim to address the state's growing freight transport demands while concurrently meeting increasingly stringent air pollution and other environmental requirements.

The strategy and technology summaries and emissions modeling presented in this report should provide a valuable tool to the Coalition as it considers the wide range of potential projects that will be proposed for California's Freight transport system in years to come.

Key takeaways from this report include the following points:

- Trucks meeting the EPA 2010 emission standard often produce comparable or fewer NO_x and PM emissions than current "baseline" versions of more efficient technologies (on a ton-mile basis), such as marine vessels and locomotives. This result highlights the major improvements of emission controls in on-road heavy duty engines over the past decade.
- In the 2020 timeframe, many of the baseline offroad equipment groups considered in this report will be replaced by equipment meeting more stringent emissions standards (e.g. Tier 2 engines will be replaced by Tier 4 engines). As existing marine and locomotive engines are replaced with new engines meeting these Tier 4 emissions standards, the marine and rail pathways tend to become significantly cleaner than pathways based on on-road trucks meeting EPA 2010 emissions standards.
- The combination of improved efficiency from electrified drivetrains and the relatively low-emission California grid mix make electrified pathways the cleanest options, where electrification is applicable.
- While improved logistics strategies such as virtual container yards can provide both emissions reductions and financial benefits, quantifying those potential benefits is extremely difficult and dependent on many factors specific to the local market.