GLADSTEIN, NEANDROSS & ASSOCIATES
Building an Environmentally & Socially Responsible Future

2525 Ocean Park Boulevard, Suite 200
Santa Monica, CA 90405
310.314.1934
1270 Broadway, Suite 1009
New York, NY 10001
646.571.0210
www.gladstein.org

MEMORANDUM
January 5, 2015

To: Diane Bailey
FROM: Rich Kassel and Patrick Couch
SUBJECT: National Freight Pathways Modeling Approach and Results

Introduction

In 2013, GNA prepared a report for NRDC and its partners in the California Clean Freight Coalition (CCFC), entitled "Moving California Forward: Zero and Low-Emission Goods Movement Pathways," which estimated emissions from a series of truck, rail and marine freight pathways in California. After the CCFC report was finalized, NRDC asked GNA to produce an updated version of the report that estimated the emissions from a similar set of truck, rail and marine freight pathway, but on a national level. Although the original intention of this new work was to provide an updated report that would be similar in format to the CCFC report, the deliverable has since been revised to consist of a memorandum summarizing the national level modeling results and an accompanying spreadsheet that documents the emissions analysis.

This memorandum summarizes our modeling of emissions from National Freight Pathways. The majority of this memorandum focuses on describing the key assumptions, methodologies, and results of the modeling. The descriptions, strengths, and challenges of each technology, as provided in the CCFC report, remain applicable to the National Freight Pathways modeling and are not reproduced in this memo.

Differences between the National Freight Pathways and CCFC modeling efforts

The National Freight Pathways (NFP) work follows the same emissions modeling structure defined in the CCFC report, including the use of the same freight pathway definitions.[1] The primary difference between the two works is the use of national-level emissions data for the NFP models, rather than the California-centric emissions data used in the CCFC report.

California arguably has the most complete and sophisticated emissions inventories for onroad and offroad vehicles in the country. Largely due to California's ongoing air quality challenges, these emissions inventories have been critical to the identification of highly polluting emissions sources and the development of air quality regulations. Facing similar air quality challenges, other regions in the US have developed similarly detailed emissions inventories. However, the availability of emissions data is not consistent across the country, and is often not provided for the same emissions sources or pursuant to the same methodologies.

As a result of this inconsistent emissions data, much of the emissions data used in the NFP modeling are taken from EPA models, using default values to represent the "average" emissions rates of mobile sources. For example, EPA's Motor Vehicle Emissions Simulator (MOVES) model provides national average emissions for onroad equipment, based on estimated average vehicle activity and emissions rates. This approach cannot capture the state-to-state variations

[1] Abbreviations not defined herein have the definition used in the CCFC report.

in vehicle operations, but instead provides a high level average set of emissions information that is useful when considering the "typical" emissions from a particular portion of a freight pathway.

Where national level models were not available, GNA compiled emissions data from several non-California based sources. For example, port emissions inventories generally provide the best source of cargo and emissions data for port-related equipment, including cargo handling equipment and on-dock rail. While port emissions inventories have been a good source of information, there is no national database of port emissions inventories. In lieu of such a database, GNA analyzed the emissions inventory documents from four large, non-California ports and developed average emissions rates that are used as surrogates for national averages. The methodologies used for each emissions source are described briefly in this memorandum, and are documented further in the included spreadsheet.

Under the CCFC effort, the California-specific GREET fuel cycle model was used to estimate upstream emissions and fuel carbon intensities. The current NFP work uses the latest GREET model (GREET 1 2013) and reflects national average values for electrical power, diesel fuel, natural gas, and hydrogen. The national electrical grid mix includes significantly more power produced from coal than the California mix, resulting in higher upstream emissions for all fuel types, especially so for electrically-powered vehicles. The current GREET model also includes updated estimates of fugitive methane emissions, affecting natural gas vehicle upstream emissions calculations. Finally, under the California GREET model, diesel fuel is assumed to comply with the Low Carbon Fuel Standard, requiring a ten percent reduction in carbon intensity by 2020. The national level GREET model does not incorporate this assumption. As a result the GHG emissions associated with diesel-fueled vehicles has increased significantly with respect to other fuels, particularly natural gas.

It is worth noting that qualitative differences between California-specific and national emissions may be of interest to NRDC. In this case, a detailed look at the differences in the assumptions used for key emissions inventories or models would be warranted. For example, MOVES makes significantly different assumptions than EMFAC in regard to vehicle activity and fuel use. These differences have significant impacts on the estimated emissions. Indeed, we note that these differences may potentially outstrip the impacts of emissions standards in some cases.

The current NFP analysis does not attempt to align the many different models used in the CCFC and NFP work to provide an apples-to-apples comparison between the two reports. Due to the many differences in the models and methodologies used in the NFP and CCFC work, we caution against making direct comparisons between the two reports. Instead, ***the NFP results presented in this memorandum should only be used to compare the relative emissions of the pathways calculated under the NFP model.***

Drayage and Regional Trucks

Throughout the analysis, various freight pathways are compared to the emissions from diesel and natural gas-fueled trucks. Most freight pathways are compared to emissions from short-range drayage trucks since these pathways originate or end at intermodal terminals and are 100 miles or less in length; within the range of a truck that returns to the same location at the end of each shift. By contrast, the Statewide Rail Pathways involve cargo moves of 400 miles in length and are compared against "regional" diesel and natural gas trucks using EPA's emissions data for long-haul trucks. This approach is in contrast to the CCFC report, where all pathways were compared to emissions from short-range drayage trucks. Figure 1 compares the emissions between short range drayage and regional trucks. Regional truck emissions are based on EPA's MOVES emissions data for long-haul trucks. Short range drayage truck emissions are based on EPA's SmartWay DrayFleet tool. This tool incorporates both EPA MOVES data and additional emissions from queuing and idling activities at port terminals that represent a larger portion of a short range drayage truck's overall activity than of a regional truck's activity.

The key takeaway from this comparison is that regional trucks have lower PM and GHG emissions than drayage trucks, while drayage trucks have lower NOx emissions. The tradeoff between higher NOx emissions and lower emissions of PM and GHGs seem reasonable given that regional trucks are expected to spend a larger fraction of their time operating at higher road speeds. This type of continuous high speed operation lends itself to improved fuel efficiency (lower GHG emissions) and fewer transient loads (lower PM emissions). However, it also typically results in higher engine combustion temperatures, producing more NOx emissions and further reducing PM emissions.

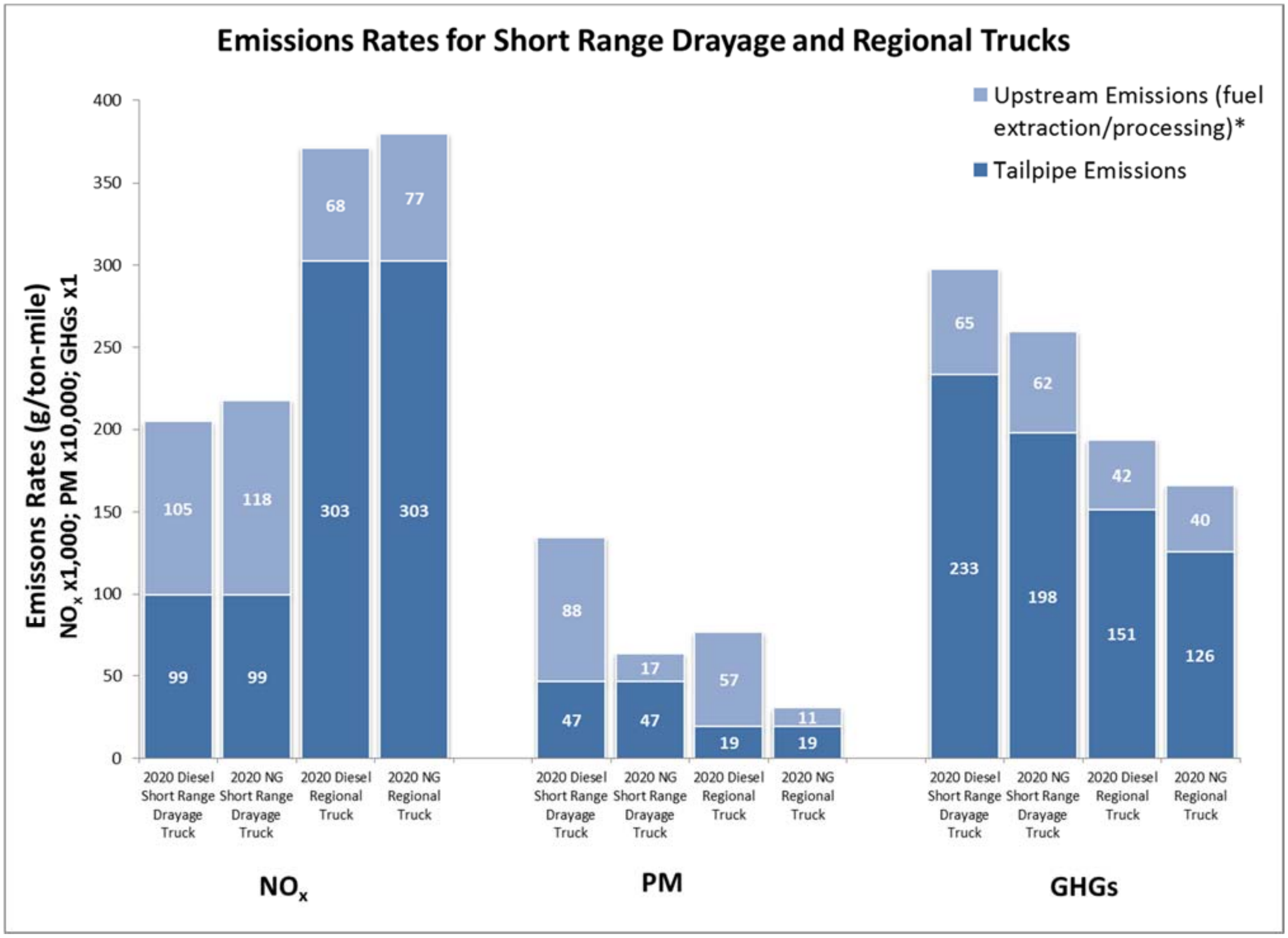

Figure 1. Comparison of emissions rates for short-range and regional trucks

Near-Dock Freight Pathways

GNA previously provided a summary of emissions from near-dock drayage freight pathways that included a comparison of several low or zero emission drayage truck technologies. This summary was based on Argonne National Laboratories (ANL) GREET 1 2012 fuel cycle emissions model. ANL subsequently released an updated version of GREET (GREET 1 2013). GNA has updated the freight pathway models to use the current version of GREET, resulting in significant changes to the near-dock drayage pathways. An updated set of emissions results are provided in Figure 2 through Figure 4, while Table 1 provides a brief description of each truck technology. **Please note that the current analysis assumes that there is no difference in NOx or PM emissions between diesel and natural gas trucks. This assumption is based on a lack of data comparing the in-use emissions between the two fuels. As in-use data emerges, it would be worth reviewing this assumption.**

Previous versions of tools from the US EPA SmartWay program have assumed that natural gas trucks provide PM and NOx reductions relative to diesel trucks. However, those emissions reduction estimates are based on emissions tests conducted during natural gas truck demonstrations dating back to the late 1990's and do not include trucks that meet US EPA 2010 emissions standards. GNA does not consider these emissions reductions estimates to be representative of the expected differences in emissions for new natural gas and diesel trucks in 2020. Therefore, we have not applied these emissions reductions factors to the current analysis. Note that the South Coast Air Quality Management District (SCAQMD) is preparing to release a report that will include in-use emissions for 2010-compliant diesel and natural gas trucks that will help shed light on the relative differences in emissions for these two fuel types.

Table 1. Near-dock Drayage Freight Pathways

Pathway	Description
2020 Diesel Short Range Drayage Truck	New MY2020, EPA 2010-compliant diesel-fueled drayage truck
2020 NG Short Range Drayage Truck	New MY2020 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 US average grid mix in 2020.[2]
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 100% of the hydrogen is produced from natural gas reformation at the fueling station and 20% is produced from electrolysis using electricity from large hydro plants.
Electrified Freight Shuttle	Electrified freight shuttle on dedicated guide way (e. g. maglev, linear synchronous motor, or catenary). Assumes no idle emissions.

[2] Average grid mix given in Argonne National Laboratories, GREET 1 2013

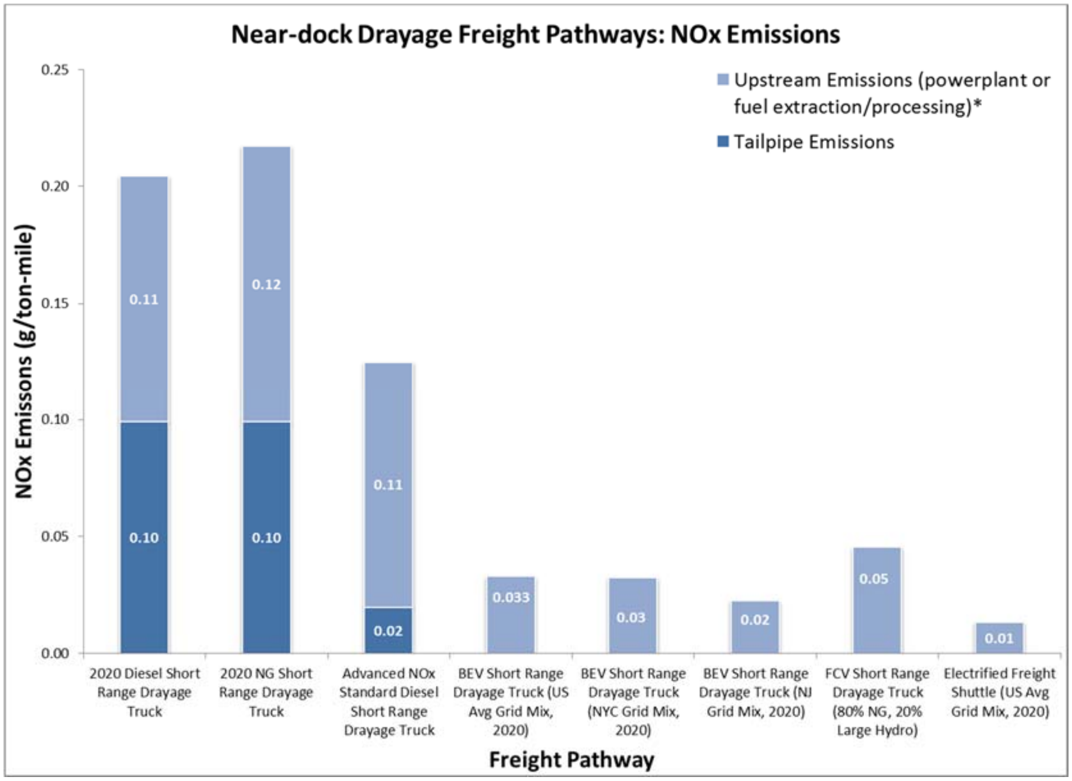

Figure 2. Near-dock Drayage Pathway: NOx Emissions (grams/ton-mile)

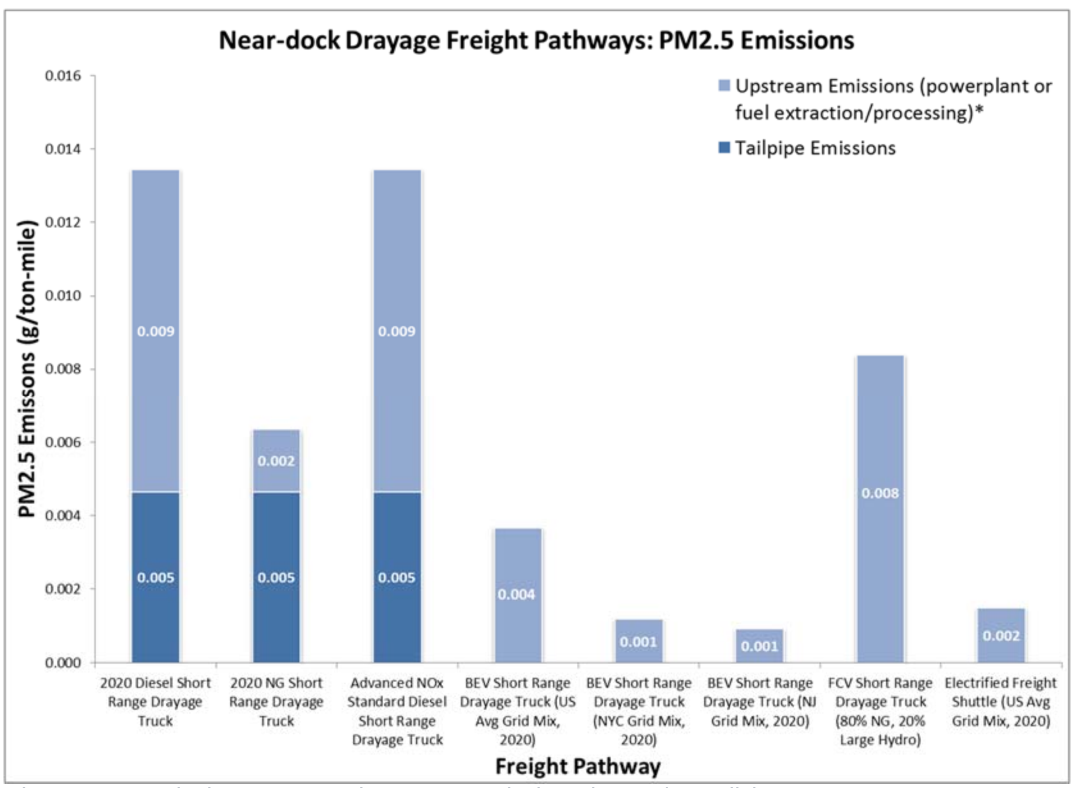

Figure 3. Near-dock Drayage Pathway: PM Emissions (grams/ton-mile)

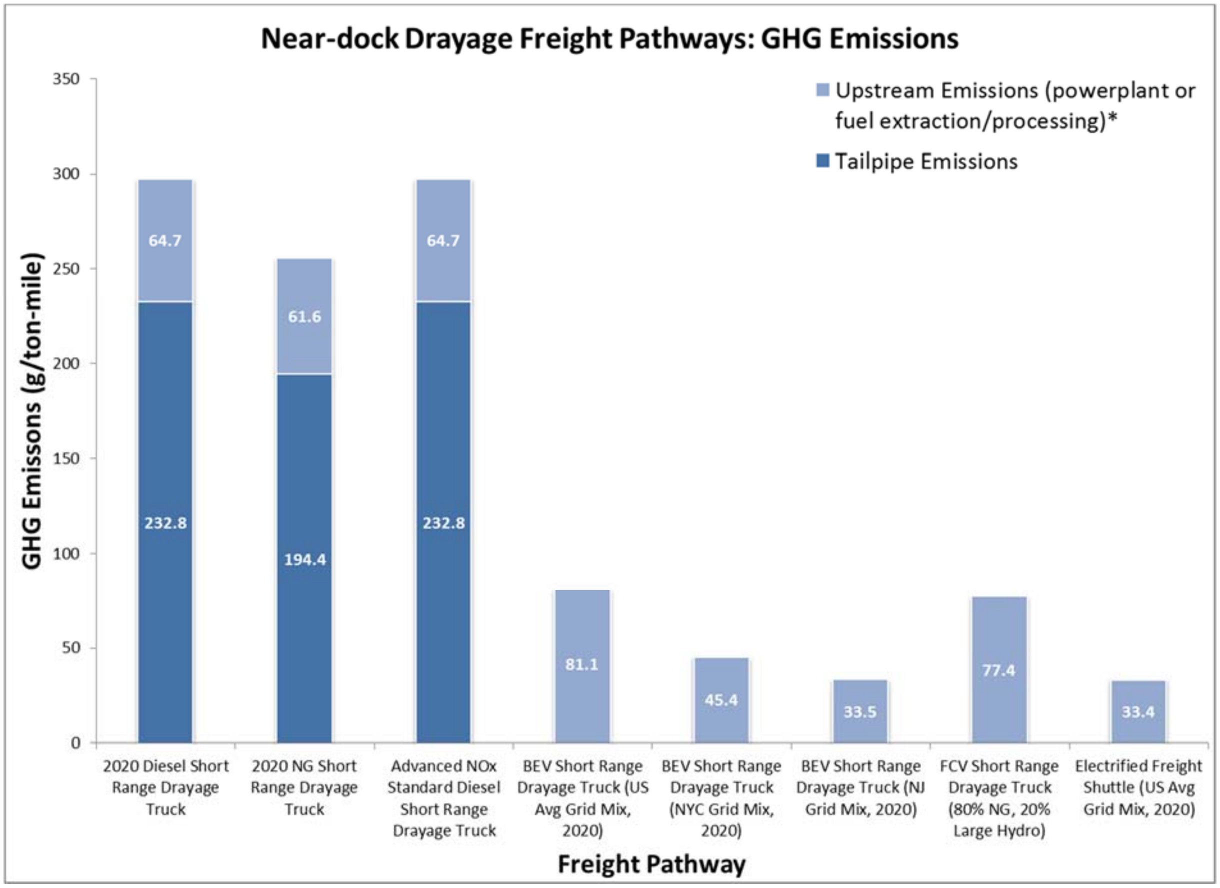

Figure 4. Near-dock Drayage Pathway: GHG Emissions (grams CO_2e/ton-mile)

*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.

On-dock and Near-dock Rail Freight Pathways

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. 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.

As shown in Table 2, 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.

Table 2. 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- 2020 Drayage Truck)	Transfer container to MY2020 drayage truck. Drayage truck hauls to near-dock rail terminal. Load container onto rail car using Tier 3-compliant cargo handling equipment. Assumes switcher and line haul locomotives meet Tier 2 standards.
Near-dock Rail Scenario B (2020 Drayage Truck + Tier 4 Rail)	Transfer container to MY2020 drayage truck. Drayage truck hauls to near-dock rail terminal. Load container onto rail car using Tier 4-compliant cargo handling equipment. 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 the near-dock pathways are primarily attributed to cargo handling equipment at the port and rail yard, as well as off-dock rail activity (train building/switching activity). Port CHE and off-dock activity were estimated from an analysis of port air emissions inventories from four ports; New York/New Jersey, Virginia, Charleston, and Houston. The Port of Houston inventory was ultimately excluded from the emissions estimates as it was several years older than the other three inventories. CHE emissions from the remaining inventories largely reflected Tier 2-compliant equipment. However, EPA anticipates that the majority of non-road diesel engines found in CHE will be Tier 3-compliant by 2020. CHE emissions rates, therefore, assume that Tier 3 engines are the standard by 2020.

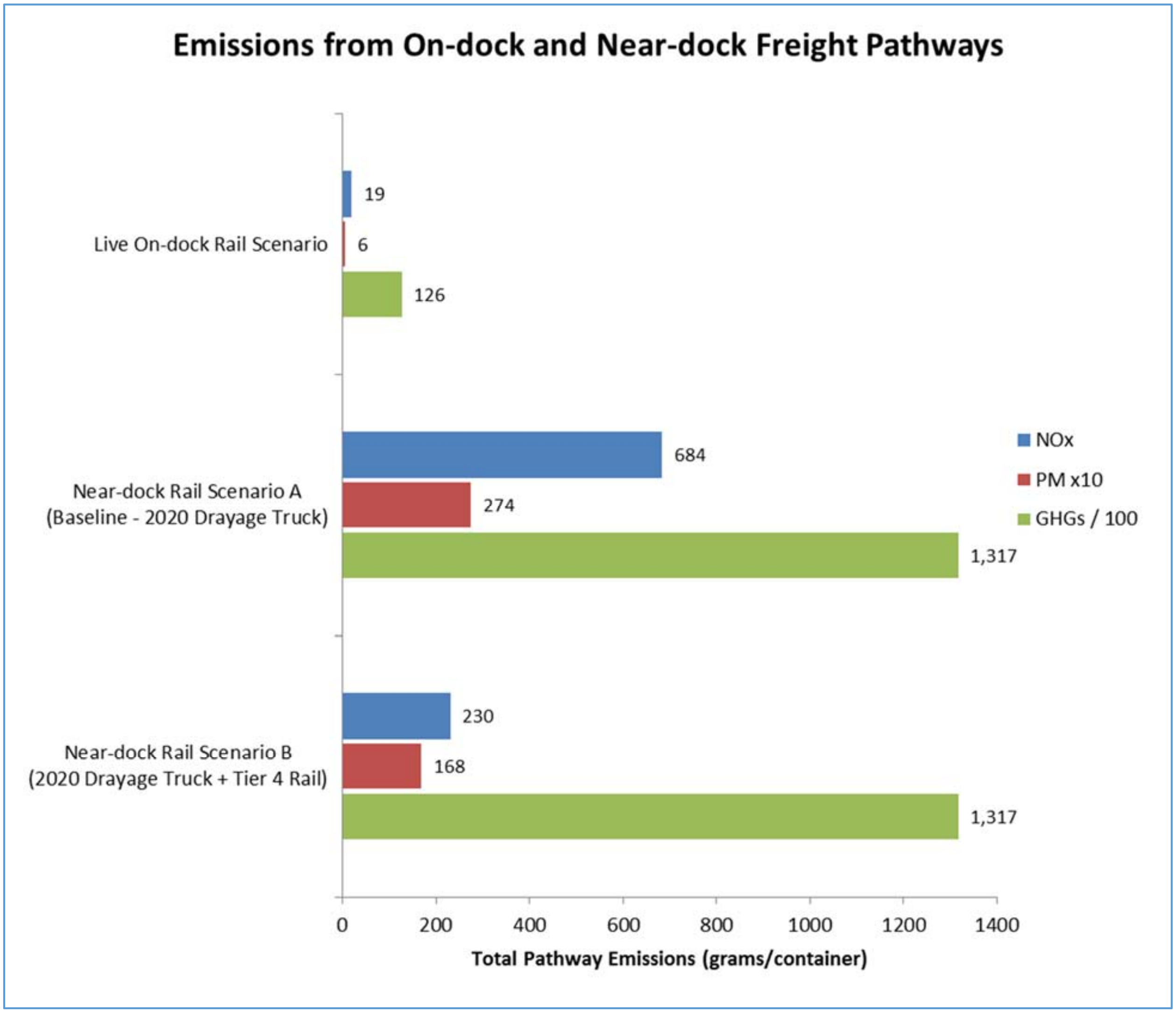

Figure 5. Emissions from On-dock and Near-dock Freight Pathways (grams/container)

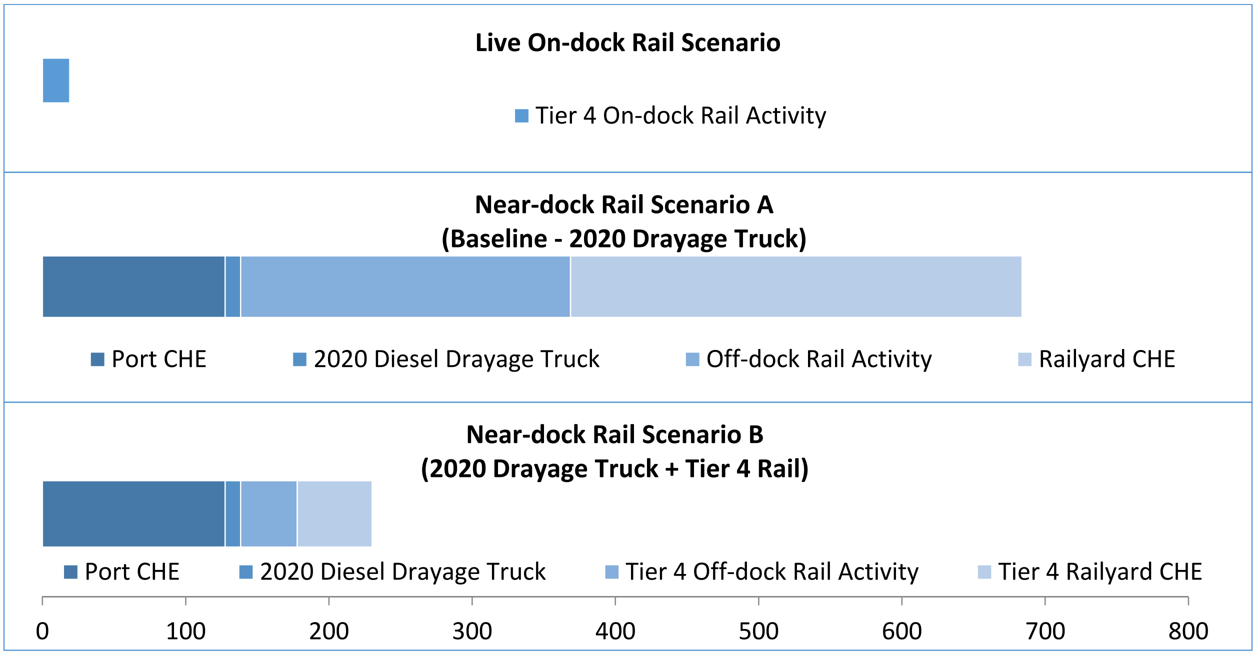

Figure 6. On-dock and Near-dock Rail Pathway: NOx Emissions (grams/container)

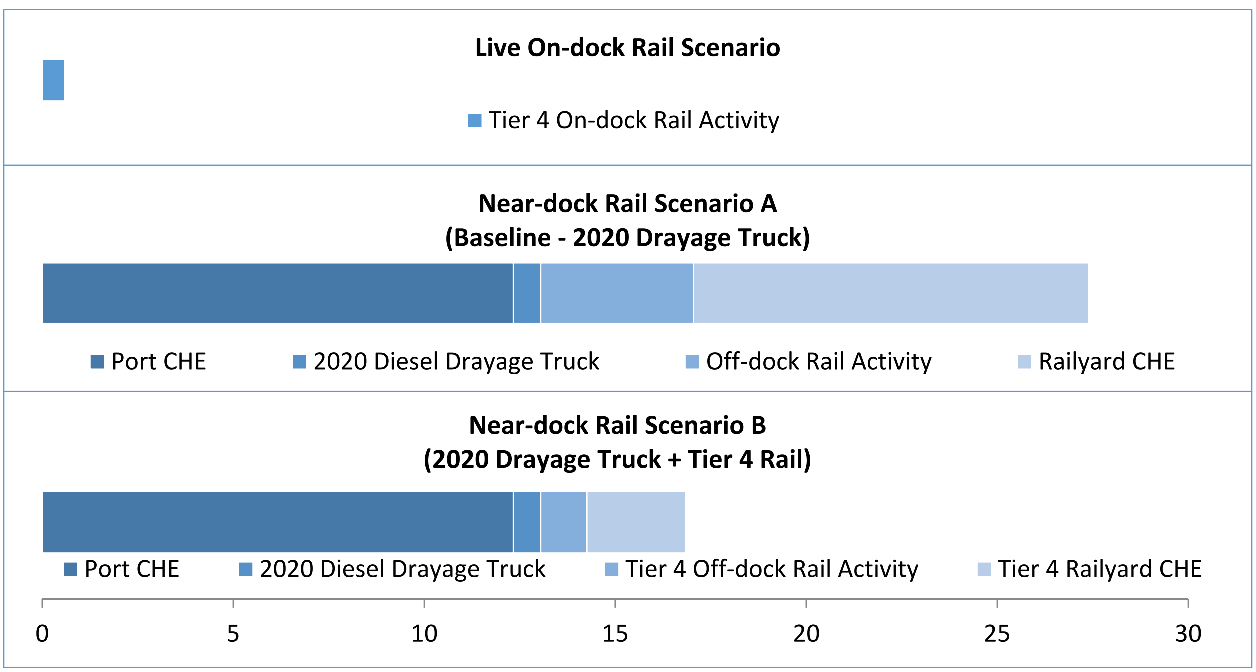

Figure 7. On-dock and Near-dock Rail Pathway: PM Emissions (grams/container)

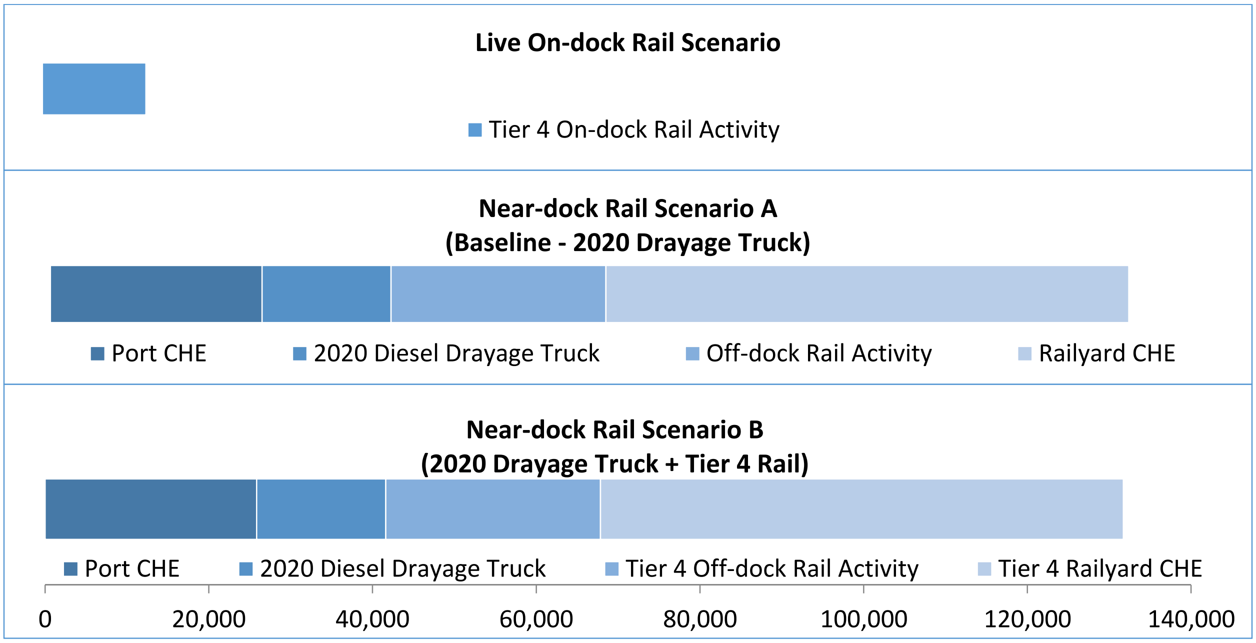

Figure 8. On-dock and Near-dock Rail Pathway: CO_2e Emissions (grams/container)

Regional Rail Freight Pathways

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.

Emissions inventories associated with rail yard switching are not readily, or are not typically provided on a grams/cargo-ton basis. To develop emissions estimates for rail yard switching activity, GNA extracted facility-level intermodal rail yard emissions inventory data from the Eastern Regional Technical Advisory Committee (ERTAC) study[3]. This inventory provides total facility emissions, but does not provide information on the amount of cargo handled by each facility. To estimate emissions on a grams/cargo-ton basis, GNA used intermodal rail yard cargo volumes published in Union Pacific's 2008 Fact Book for seven rail yards around the country. Combining the two inventories allowed for an estimation of fuel required to move one ton of cargo through the rail yard. EPA fuel emissions factors for locomotives were then used to estimate NOx and PM emissions rates.

Figure 9 summarizes the estimated emissions for each freight pathway. Based on these results, the largest contributor to NOx and PM emissions in the Regional Rail Freight Pathway is the railyard switching event.

Table 3. Regional Rail Pathways

Pathway	Description
Regional Rail Scenario A (Baseline)	Linehaul 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)	Linehaul 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)	Linehaul with electrified locomotive to second rail facility. Unload container from rail train. Includes electrified train switching activity and emissions.
2020 Diesel Drayage Truck	Haul to second rail facility using MY2020 diesel drayage truck. Unload container from truck.
2020 NG Drayage Truck	Haul to second rail facility using MY2020 natural gas drayage truck. Unload container from truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	25 miles

[3]http://www.georgiaair.org/airpermit/html/planningsupport/regdev/locomotives/inventories2012.htm

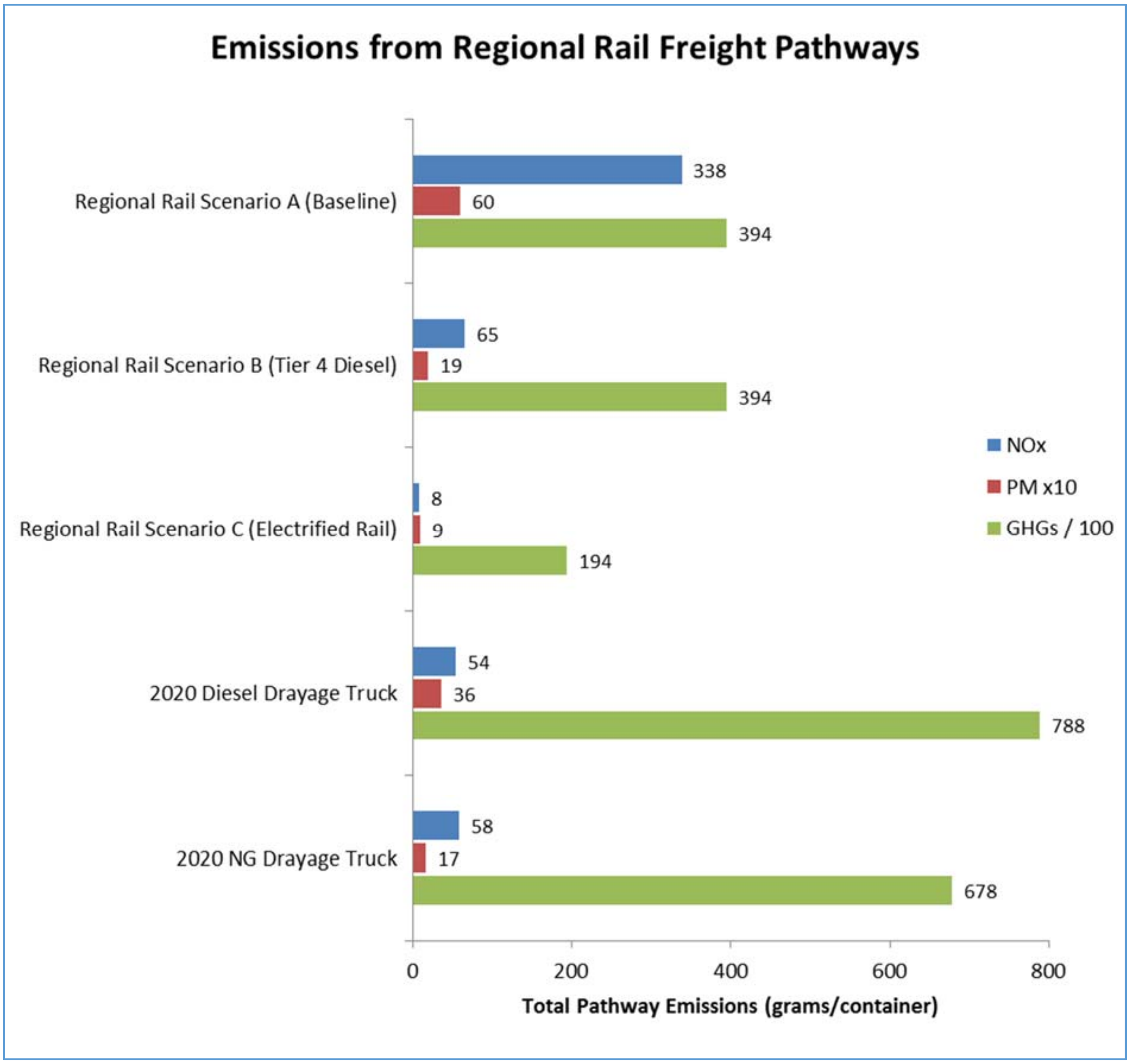

Figure 9. Emissions from Regional Rail Freight Pathways (grams/container)

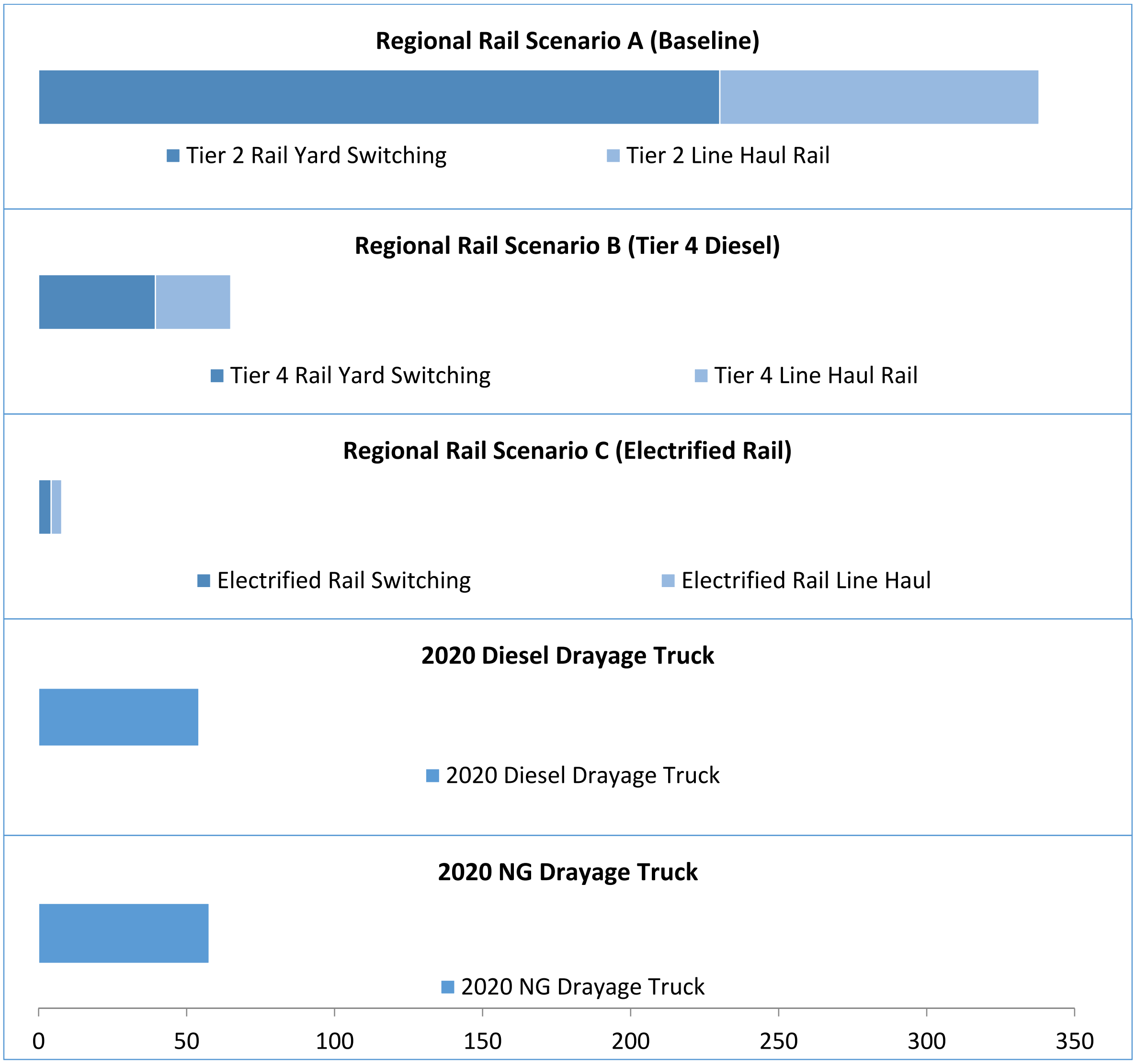

Figure 10. Regional Rail Freight Pathways: NOx emissions (grams/container)

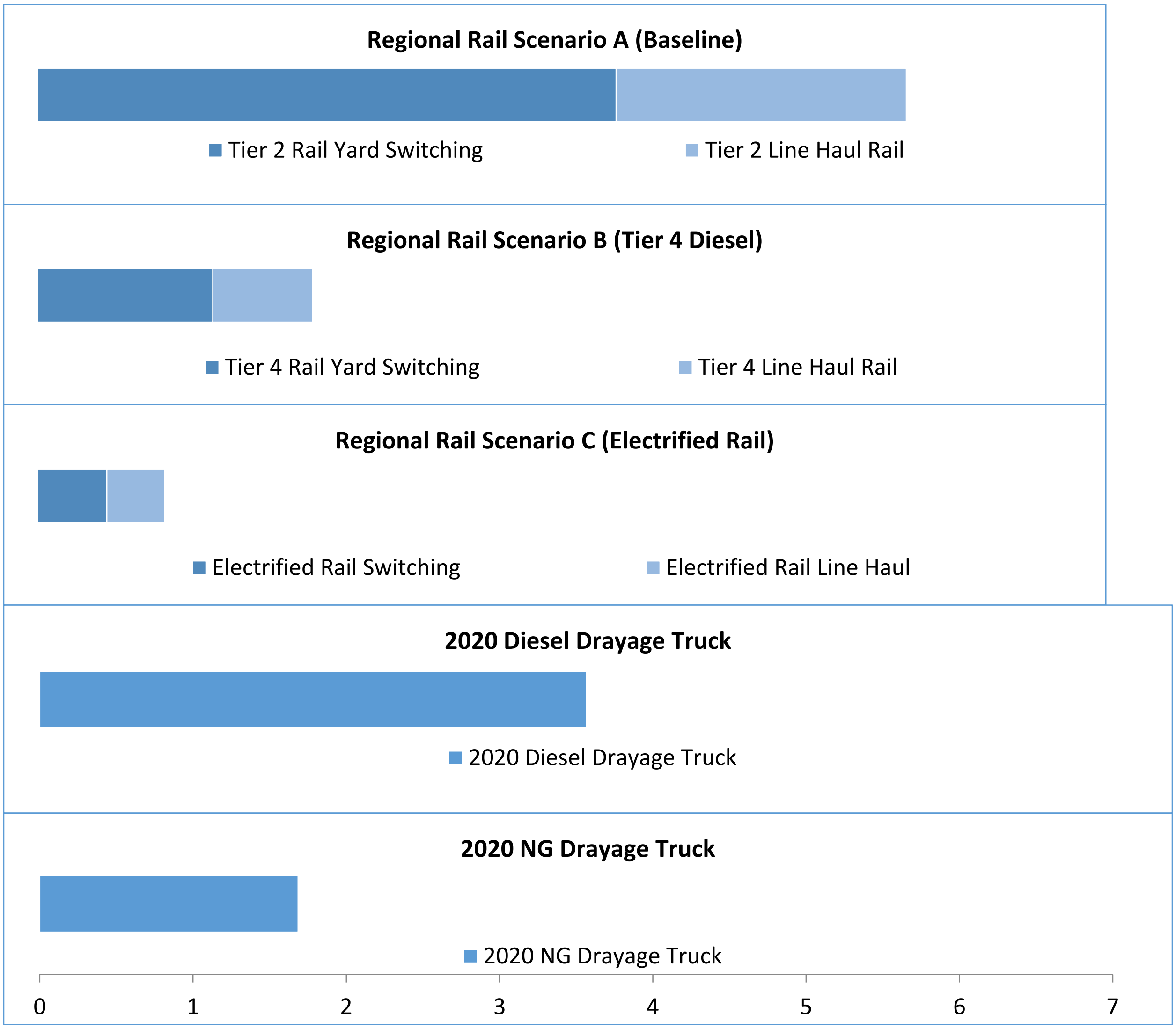

Figure 11. Regional Rail Freight Pathways: PM emissions (grams/container)

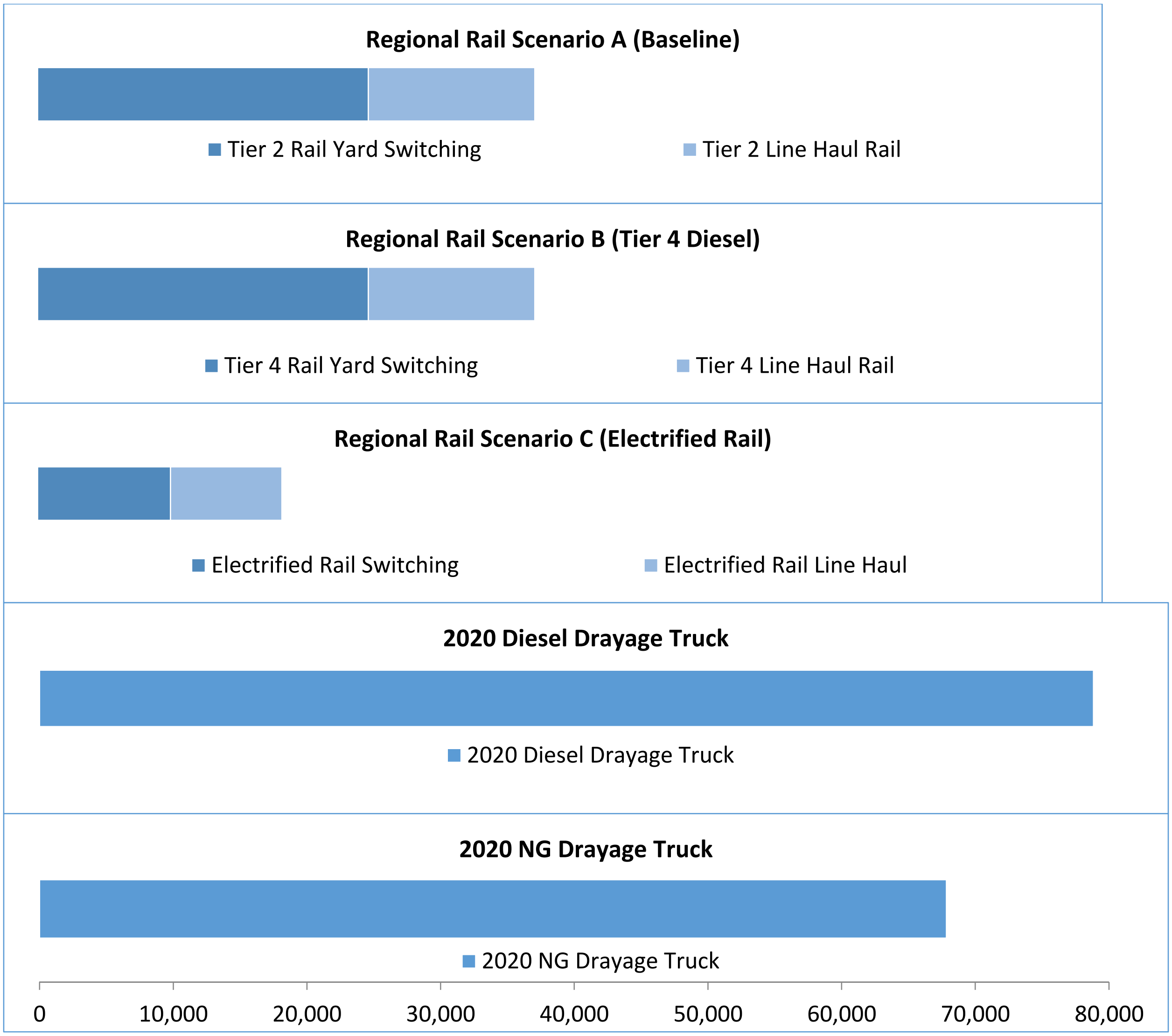

Figure 12. Regional Rail Freight Pathways: CO_2e emissions (grams/container)

Short Sea Shipping Pathways

Short-sea shipping (also 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.

Table 4. 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 with Tier 3 cargo handling equipment. Line haul with Tier 2 diesel locomotive to near-dock rail facility.
Tier 4 Rail Comparison	Load container onto rail car with Tier 4 cargo handling equipment. Line haul with Tier 4 diesel locomotive to near-dock rail facility.
2010 Diesel Drayage Truck	Haul to seaside port facility using MY2020 diesel drayage truck.
2010 NG Drayage Truck	Haul to seaside port facility using MY2020 natural gas drayage truck.

Assumptions

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

The baseline alternative to barging of cargo in this analysis is movement of cargo via drayage truck for approximately 70 miles, arriving at the port where it is unloaded from the truck. As a result, both the baseline scenario and the short sea shipping scenario include similar cargo handling events at the end of the freight pathway. However, 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.

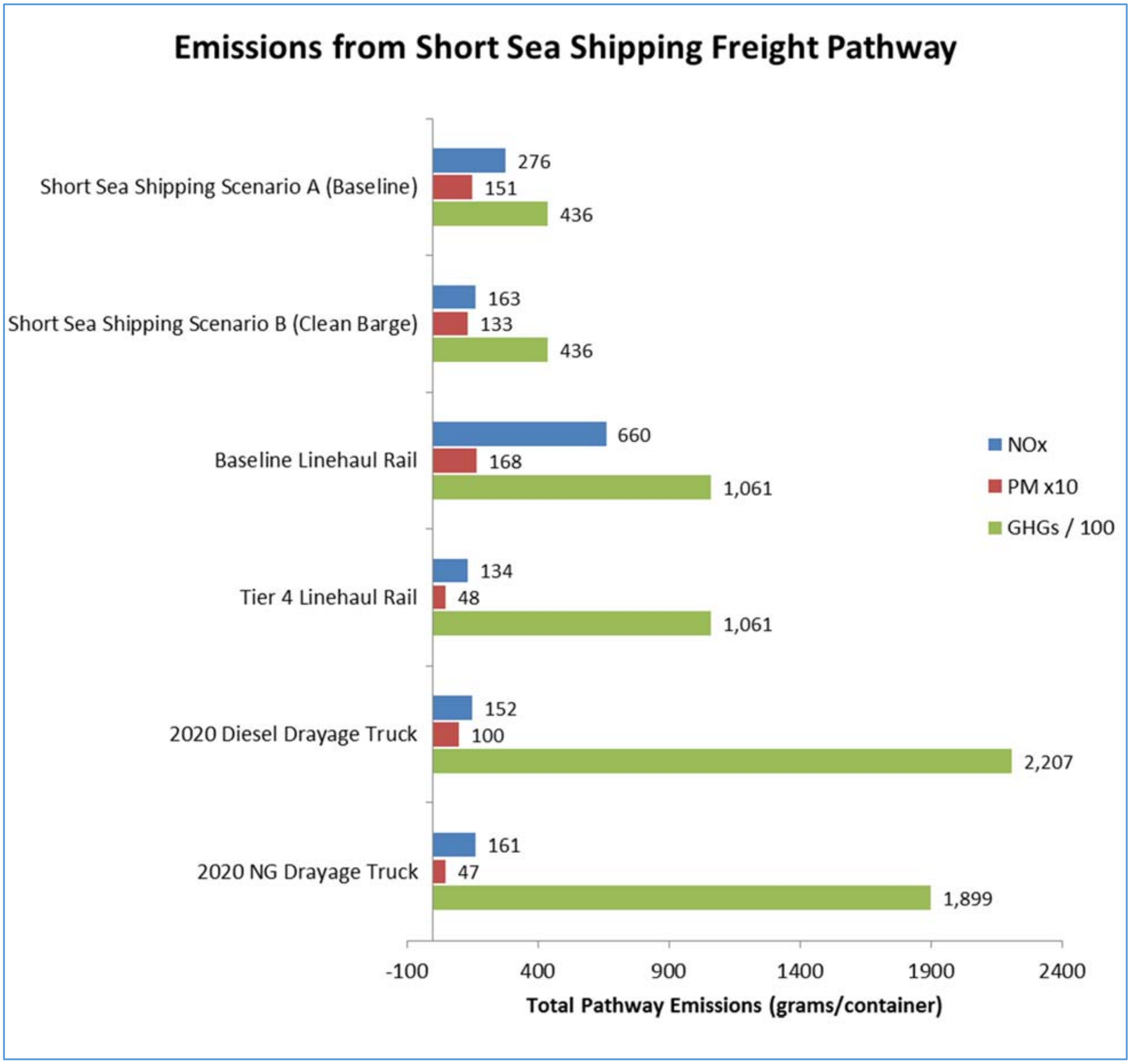

Figure 13. Emissions from Short Sea Shipping Freight Pathways (grams/container)

The current analysis relies on the same assumptions and vessel emissions data used in the CCFC report. Hence, any differences between the two reports in the resulting pathway emissions are based on different fuel cycle emissions (GREET 2013 vs CA-GREET) and on other pathway components (trucks, rail, and CHE). **Based on the results shown in Figure 13, short sea shipping has the lowest GHG emissions and represents the most energy efficient pathway of those shown. However, rail and drayage truck pathways provide similar or lower NOx and PM emissions due to the emissions associated with the additional port cargo handling event.**

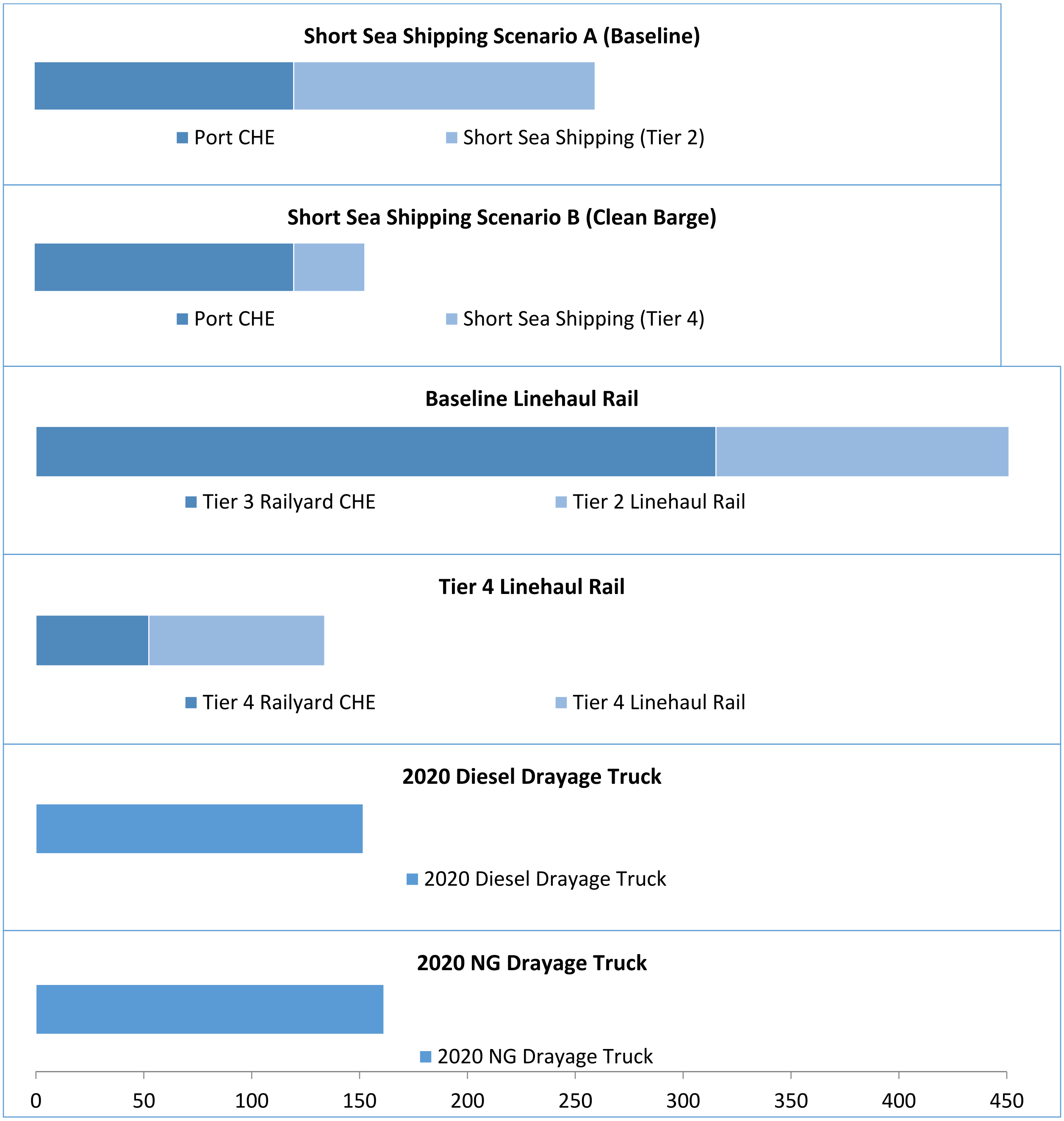

Figure 14. Short Sea Shipping Freight Pathways: NOx emissions (grams/container)

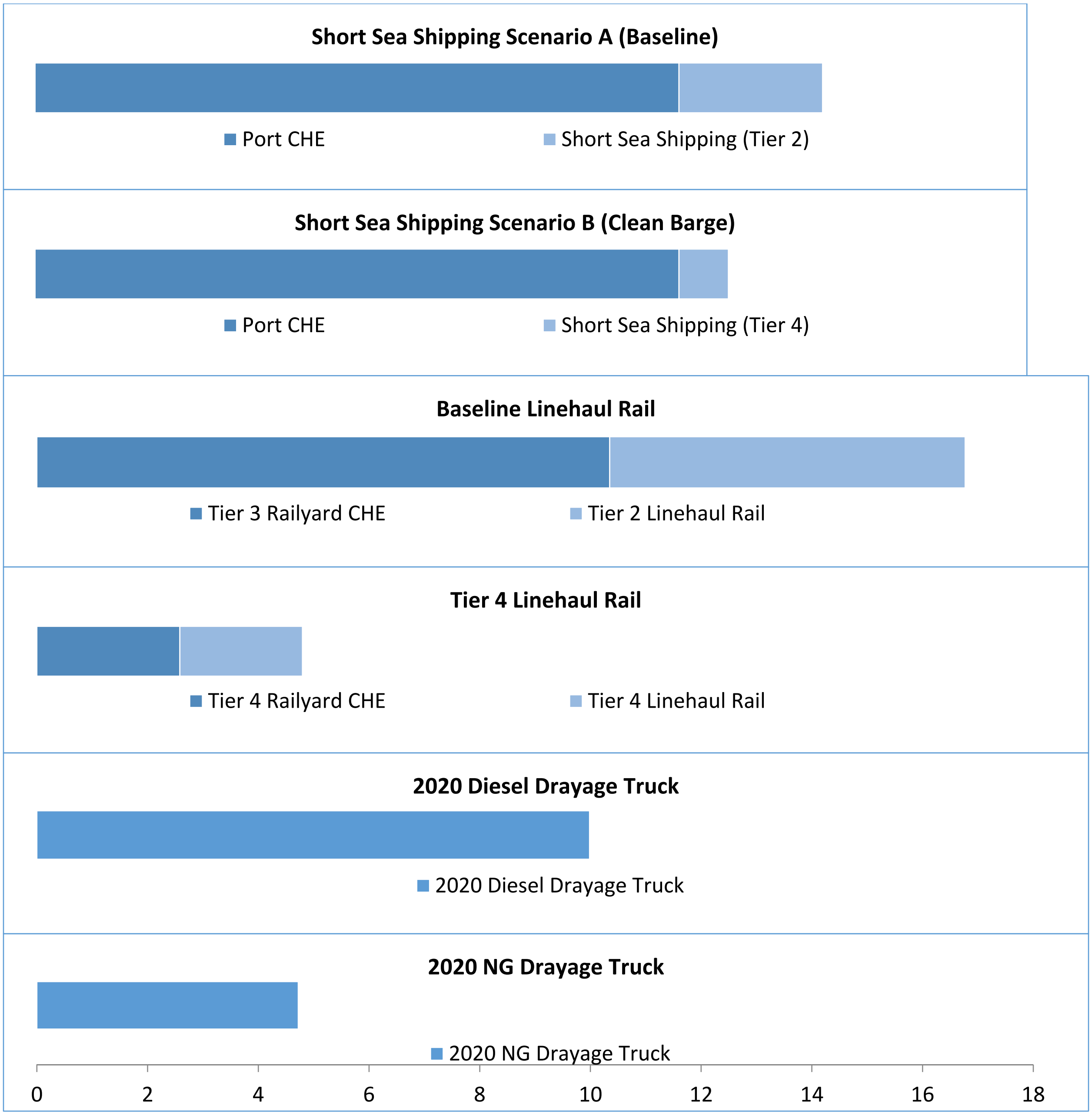

Figure 15. Short Sea Shipping Freight Pathways: PM emissions (grams/container)

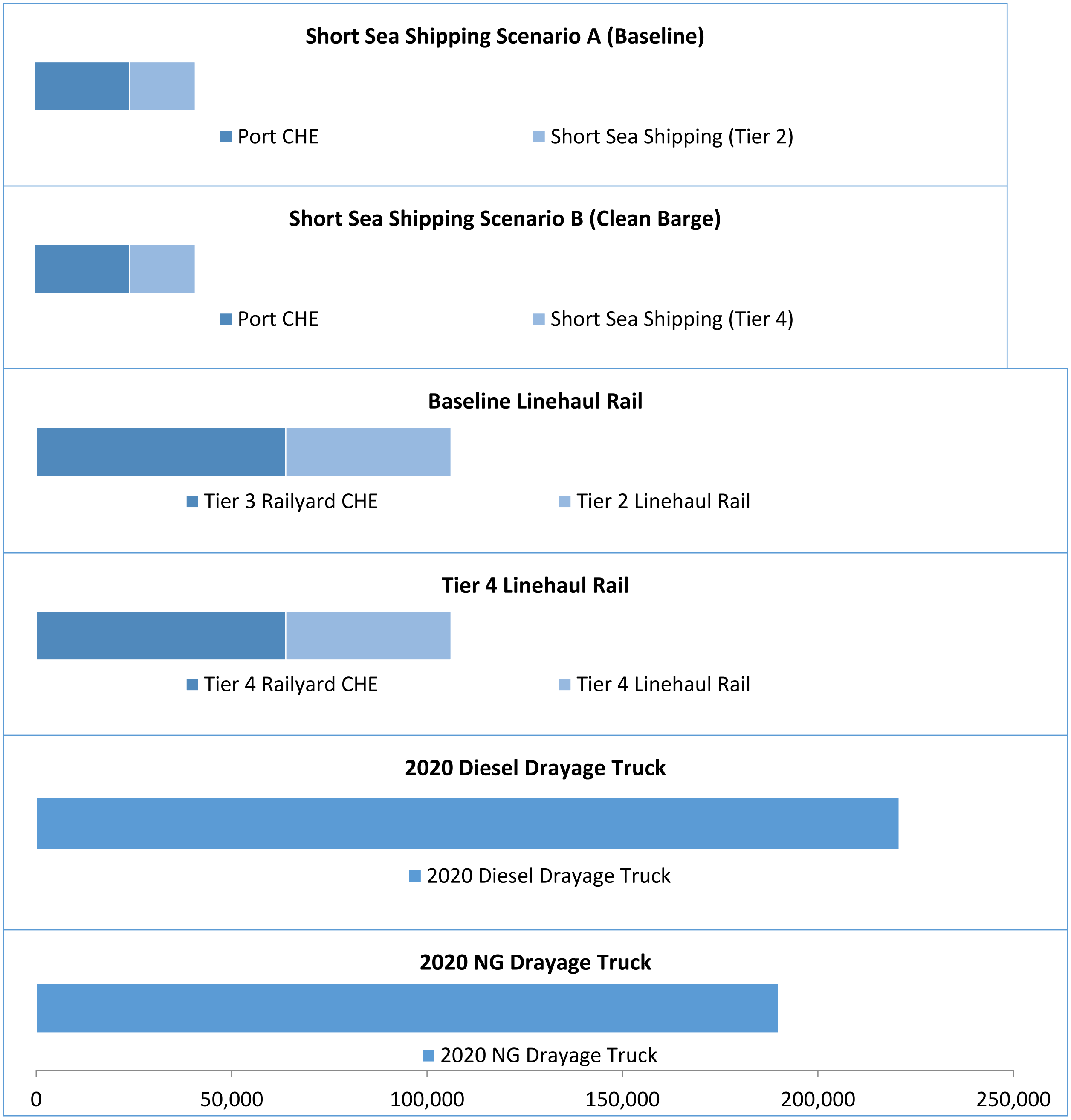

Figure 16. Short Sea Shipping Freight Pathways: CO_2e emissions (grams/container)

Trailer/Container on Flat Car and Rolling Highways

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. 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. To retain consistency with the CCFC report, the same TOFC pathways were modeled and compared to diesel and natural gas drayage truck alternatives, as shown in Table 5.

TOFC pathways offer lower GHG emissions due to the fuel efficiency of rail transport relative to trucking. Despite these efficiency improvements, the natural gas truck pathway produces similar or lower NOx and PM emissions, even when compared to Tier 4 rail technologies. This is partly due to the additional rail switching activity associated with loading the trucks onto the flat cars, and partly due to the weight penalties associated with transporting the truck and trailer.

Table 5. 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.
2020 Diesel Drayage Truck (Baseline)	Container already loaded on drayage truck. Haul to second rail facility using MY2020 diesel drayage truck.
2020 NG Drayage Truck	Container already loaded on drayage truck. Haul to second rail facility using MY2020 natural gas drayage truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	100 miles

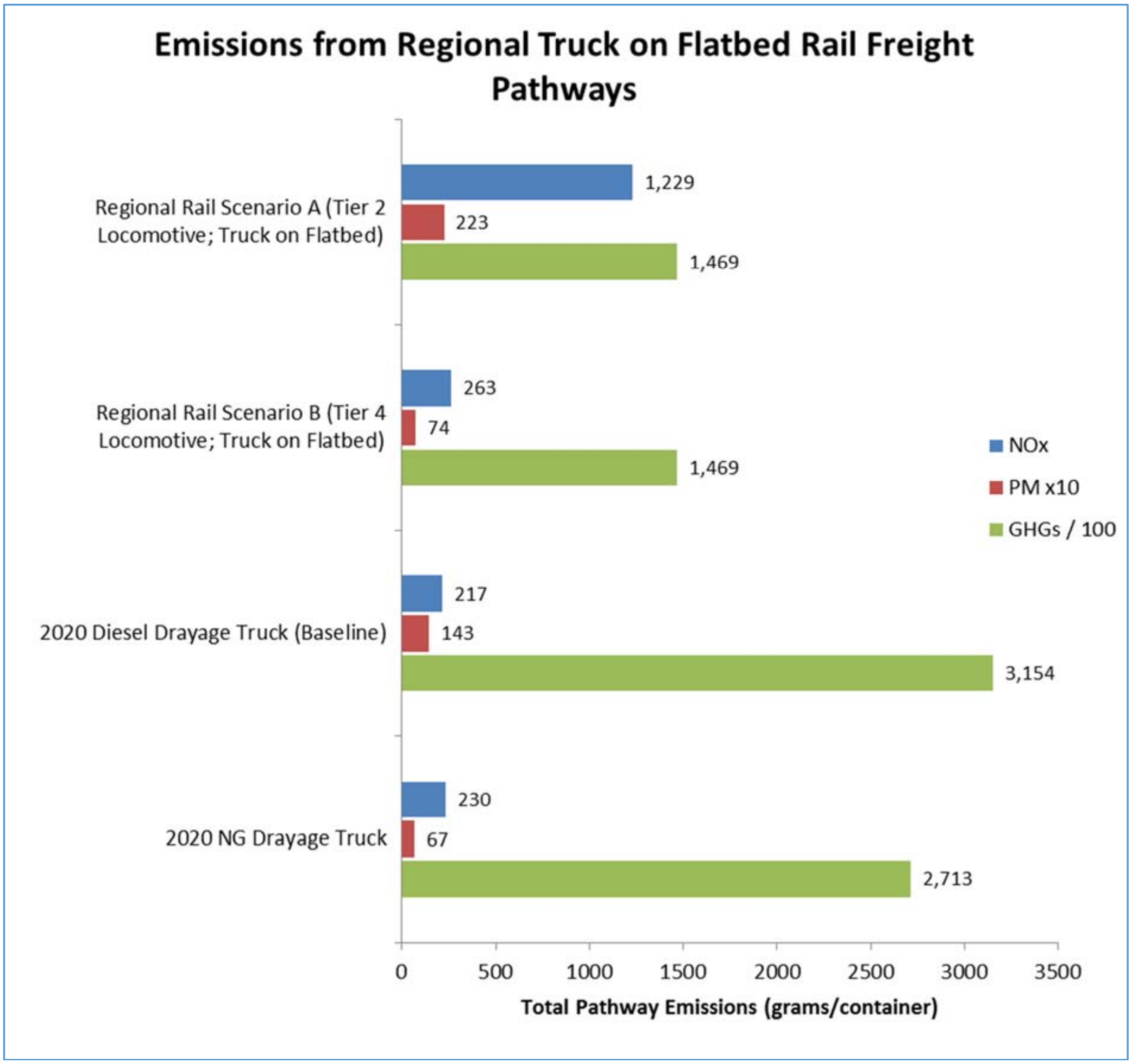

Figure 17. Emissions from Regional Truck on Flatbed Rail Freight Pathways (grams/container)

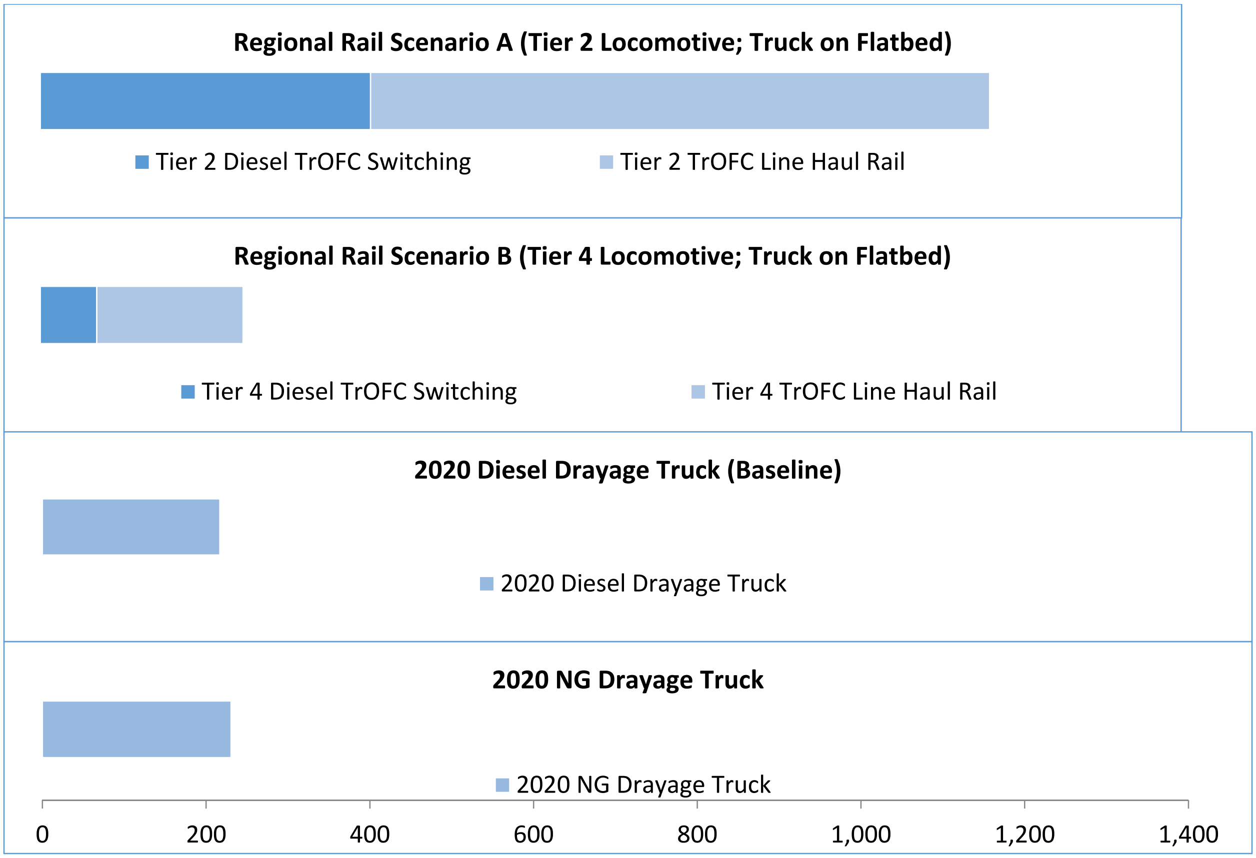

Figure 18. Regional Truck on Flatbed Rail Pathways: NOx emissions (grams/container)

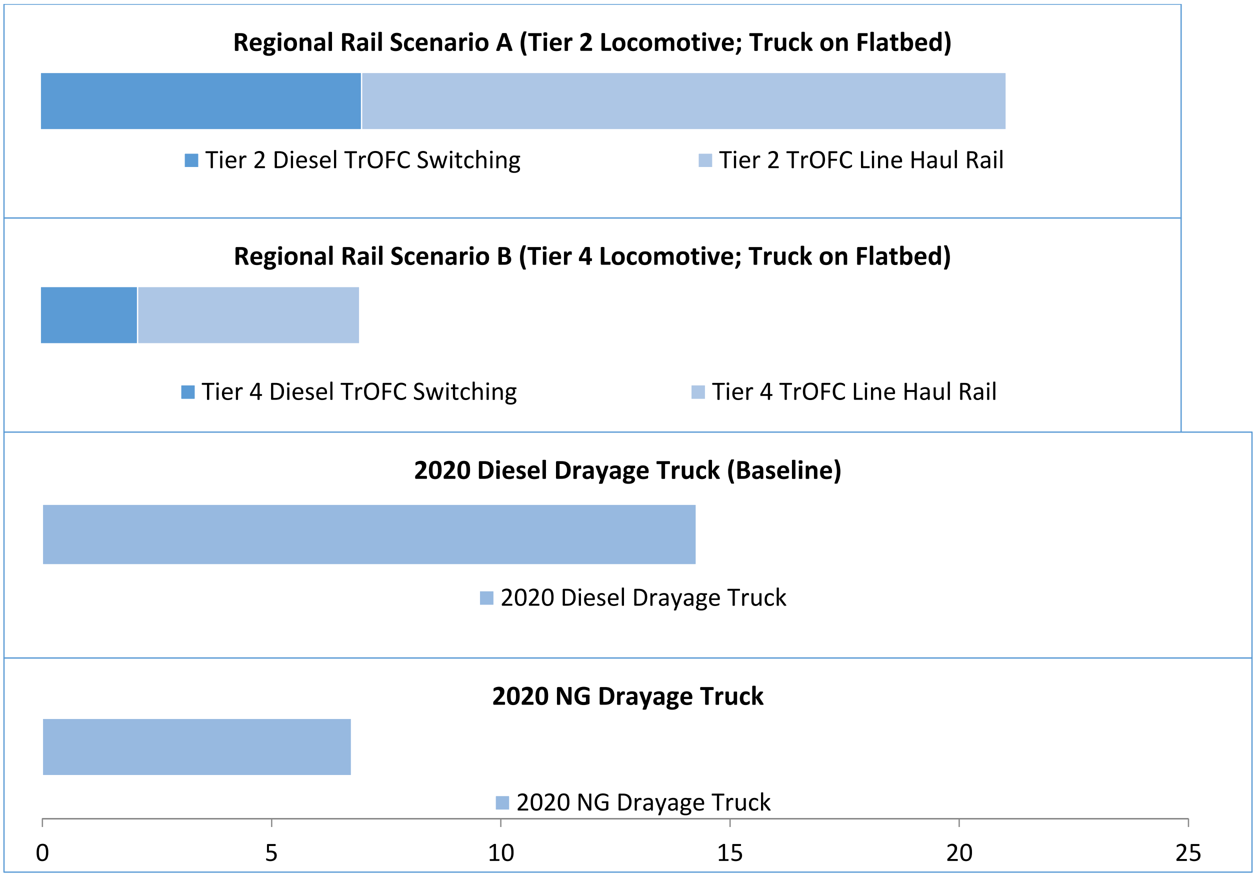

Figure 19. Regional Truck on Flatbed Rail Pathways: PM emissions (grams/container)

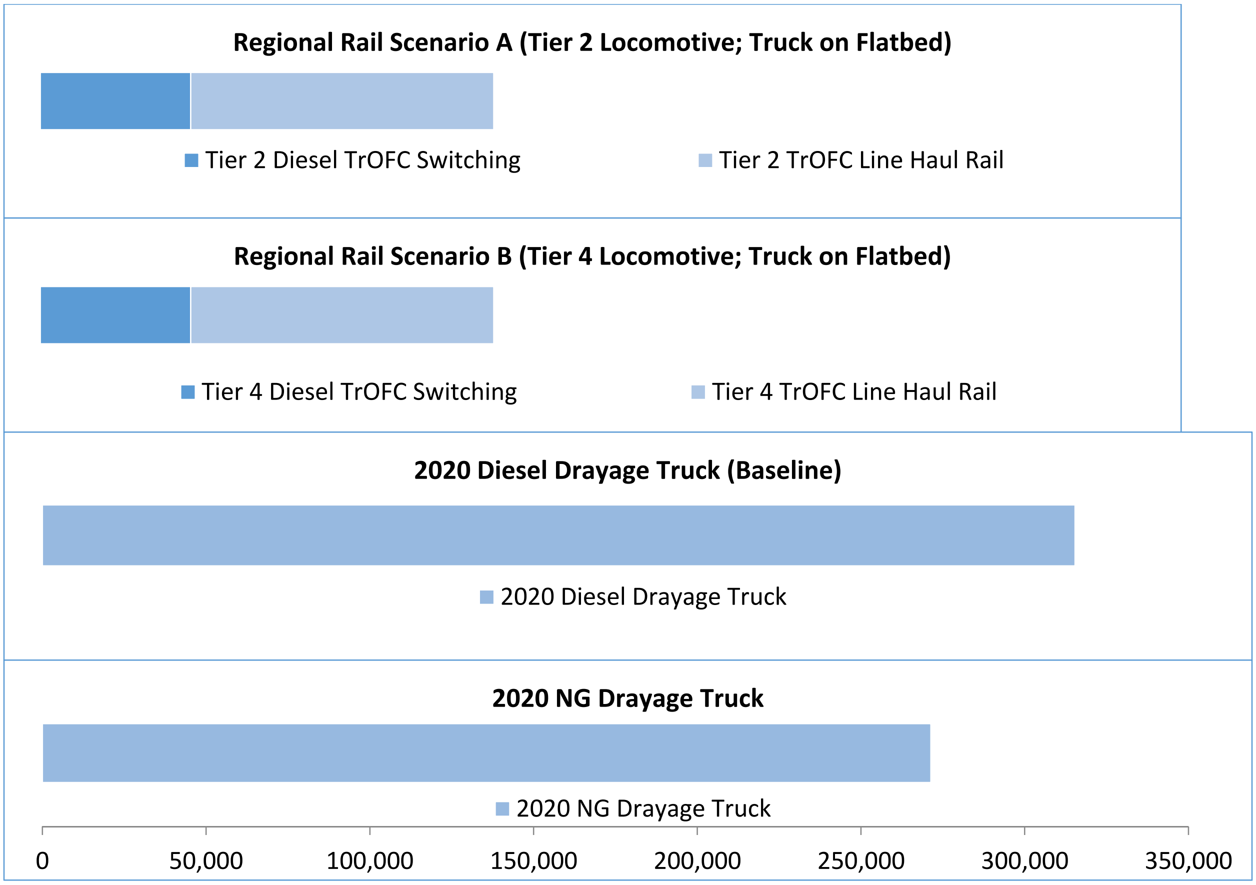

Figure 20. Regional Truck on Flatbed Rail Pathways: CO_2e emissions (grams/container)

Rail Linehaul Freight Pathways

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.[4] 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.[5]

The rail linehaul pathways shown in Table 6 were compared by estimating the emissions produced by moving a single container from a rail facility to a second rail facility 400 miles away. The 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.

Table 6. 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 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 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.
2020 Diesel Drayage Truck	Transfer container to MY2020 diesel drayage truck. Haul to second rail facility. Unload container from truck.
2020 NG Drayage Truck	Transfer container to MY2020 natural gas drayage truck. Haul to second rail facility. Unload container from truck.

Assumptions

Container weight	10.6 tons
Distance between rail facilities	400 miles

[4] 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.

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

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. These results are generally consistent with the findings of the CCFC work.

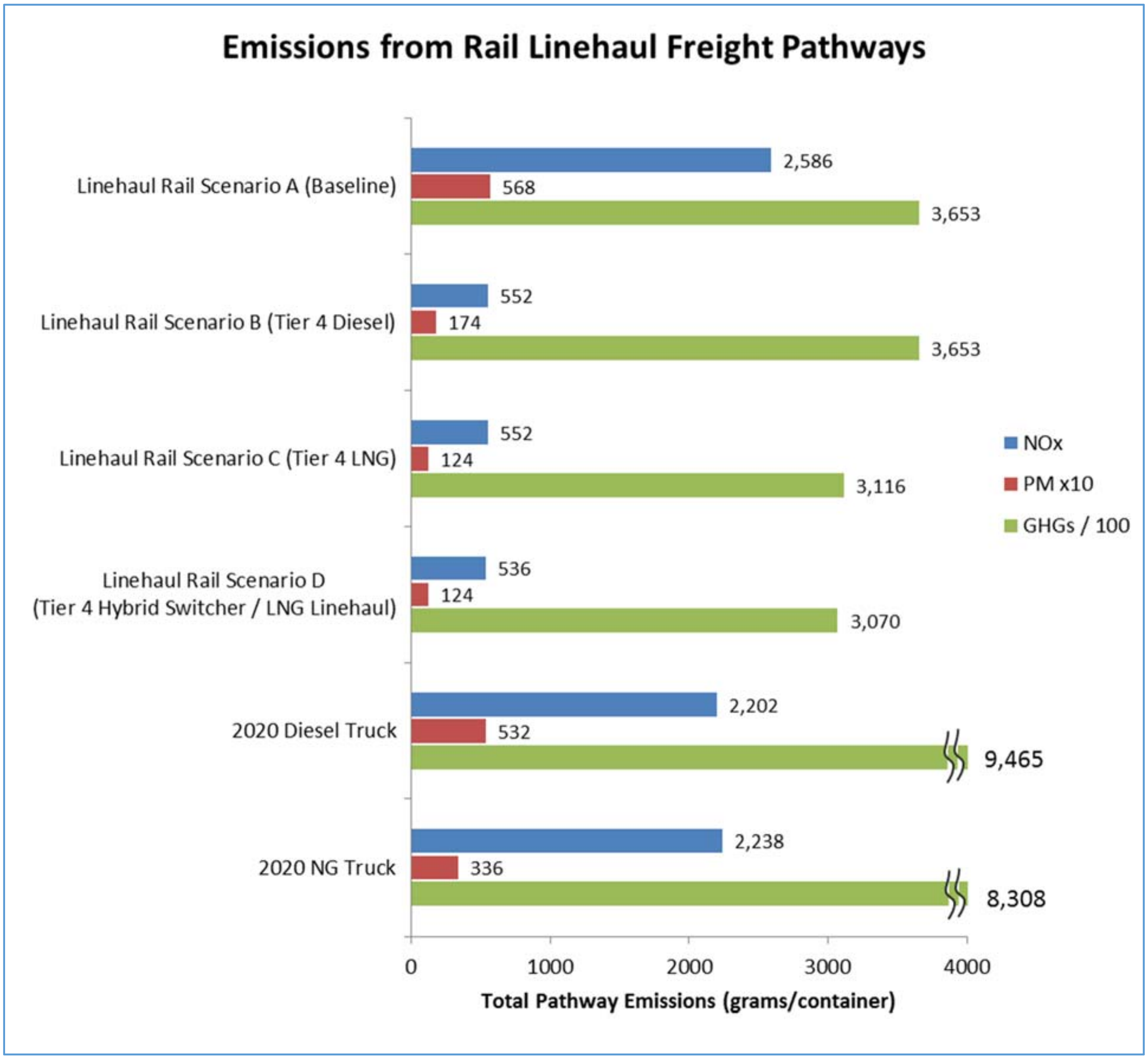

Figure 21. Emissions from Rail Linehaul Freight Pathways (grams container)

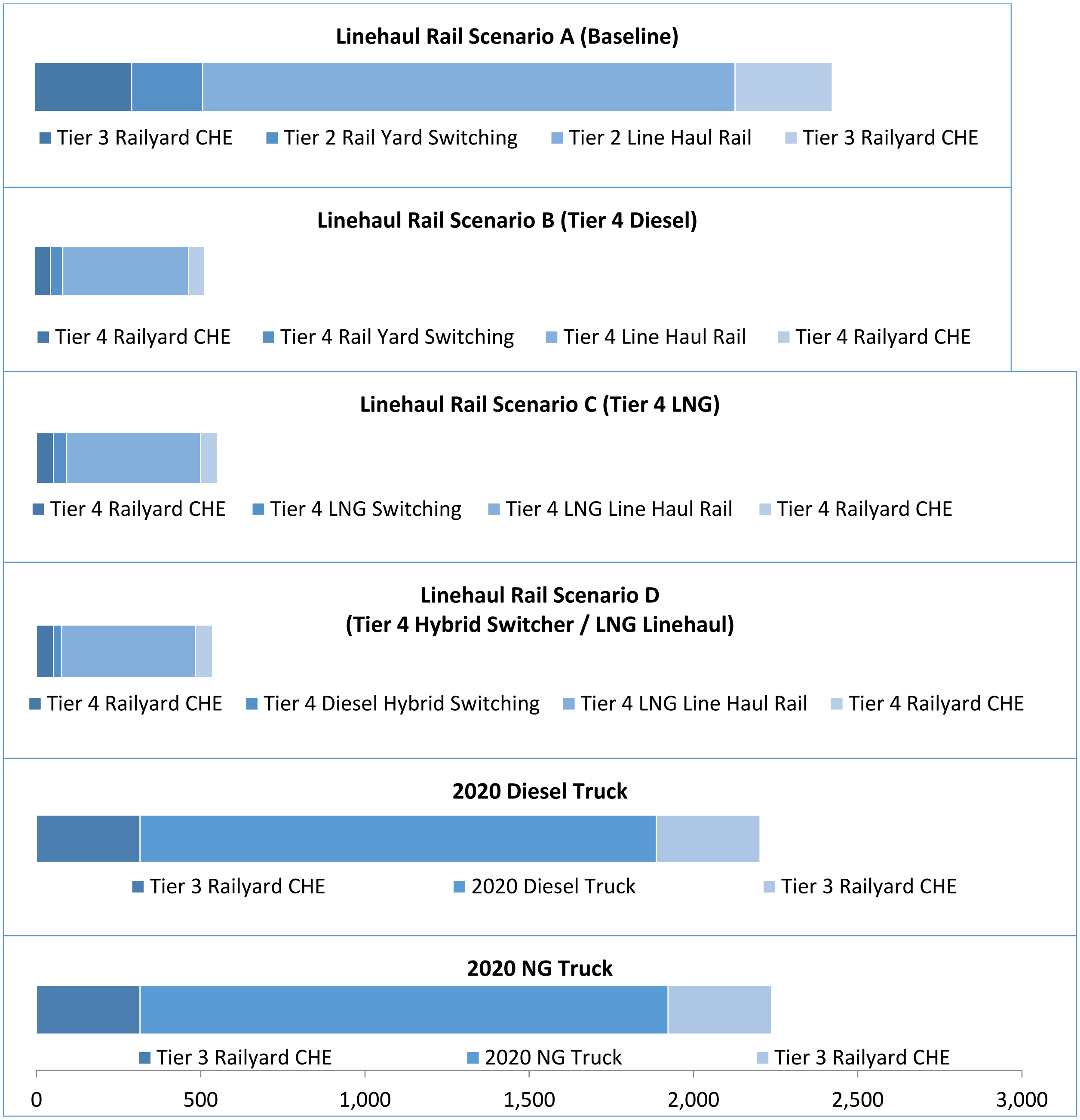

Figure 22. Rail Linehaul Pathways: NOx emissions (grams/container)

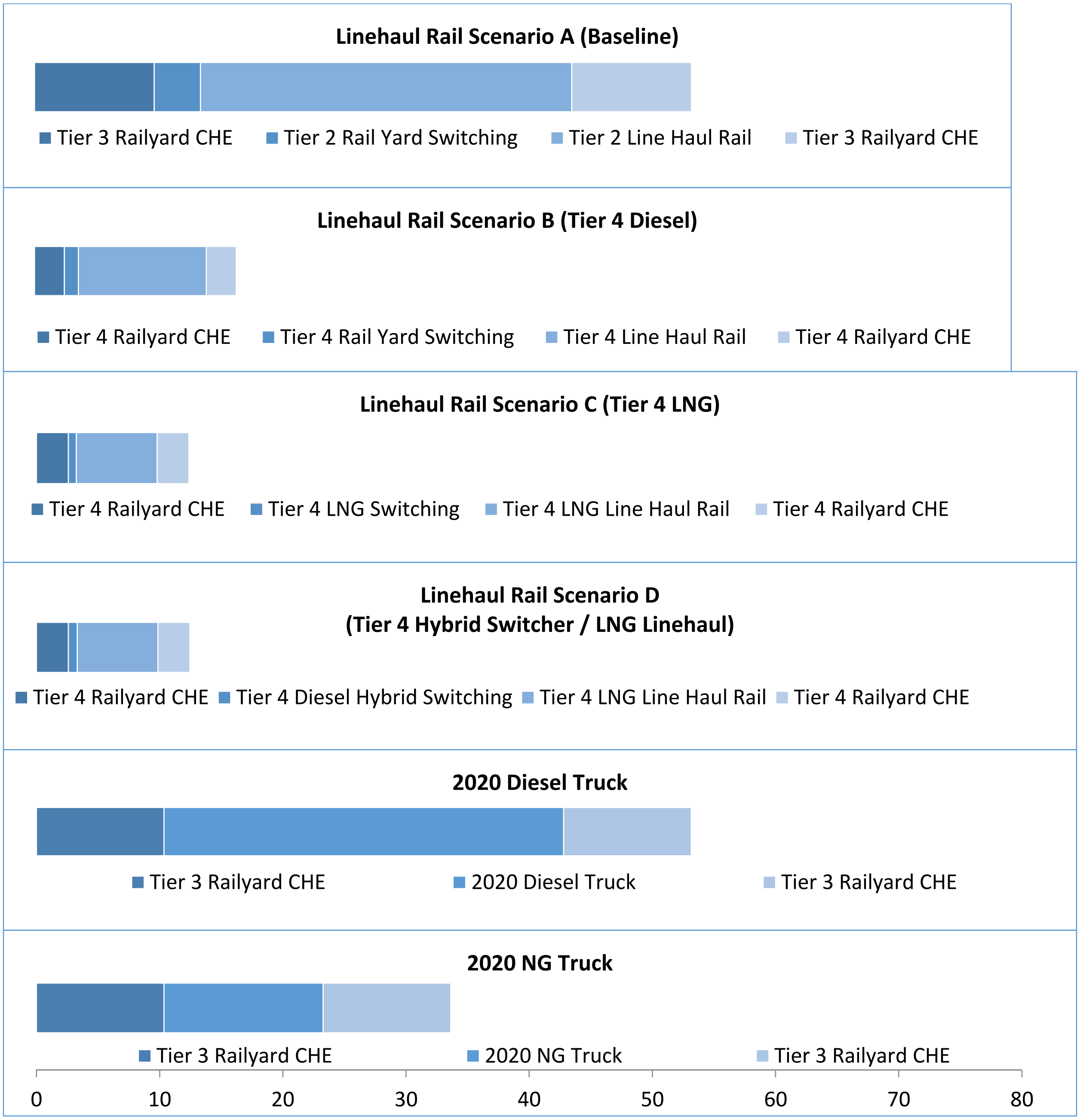

Figure 23. Rail Linehaul Pathways: PM emissions (grams/container)

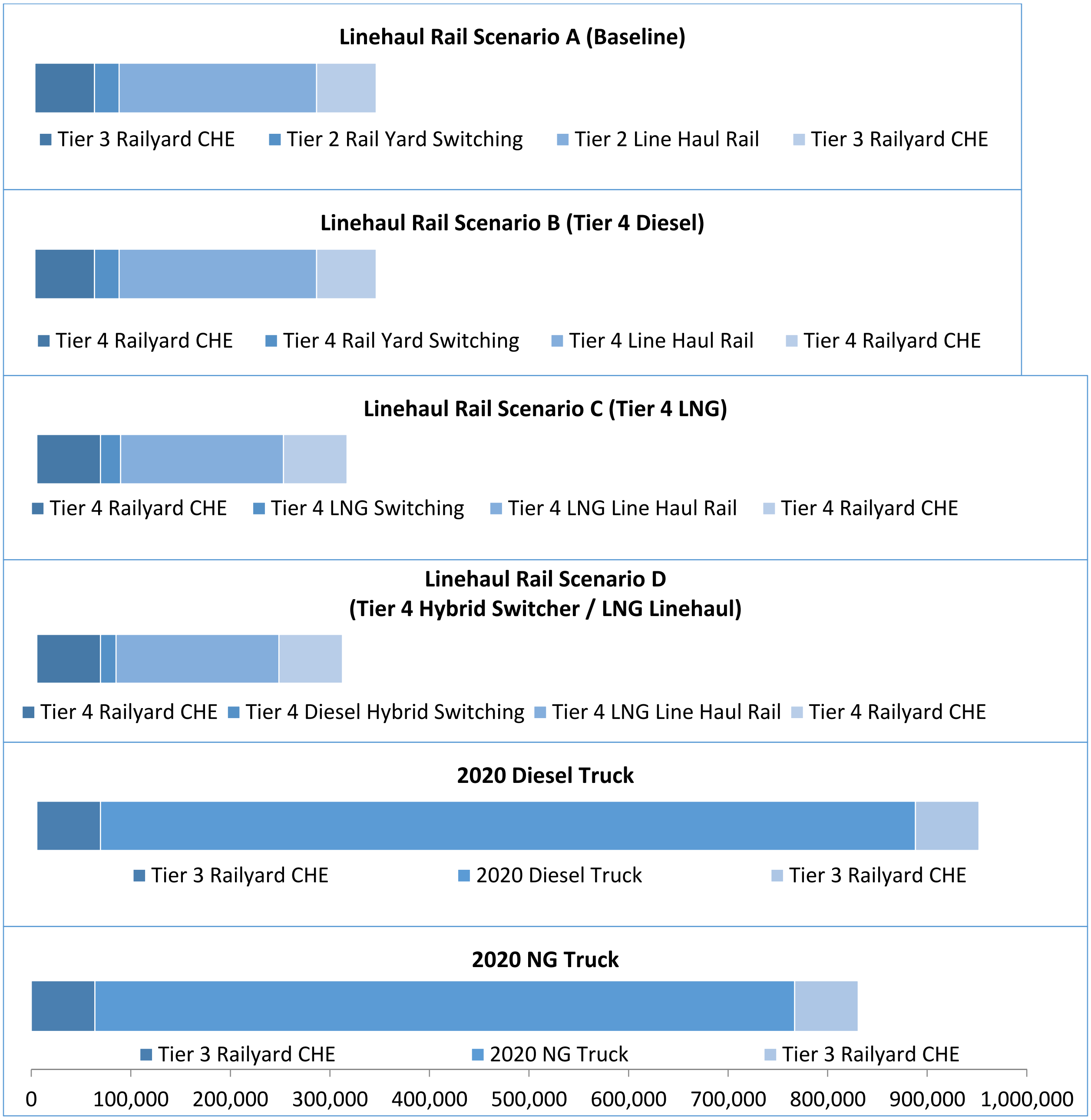

Figure 24. Rail Linehaul Pathways: CO_2e emissions (grams/container)