Air Quality and Climate Implications of Moving Goods and People by Rail

HEI's 2024 Annual Conference

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U.S. DOT Volpe Center

April 30, 2024

Outline

A (Very) Brief Overview of the Rail Industry

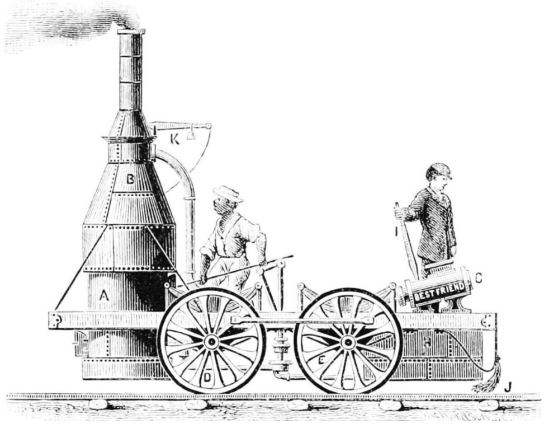
Locomotive Emissions & Impacts

Looking Ahead

A (Very) Brief Overview of the Rail Industry

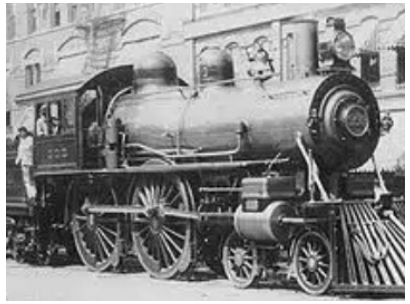
Early Rail

1797: high-pressure steam engine invented



1827: 1st railroad in N.A.

1830: 1st U.S. passenger service



1869: Transcontinental railroad

1893: Train goes >100 mph

1936: Intermodal is born

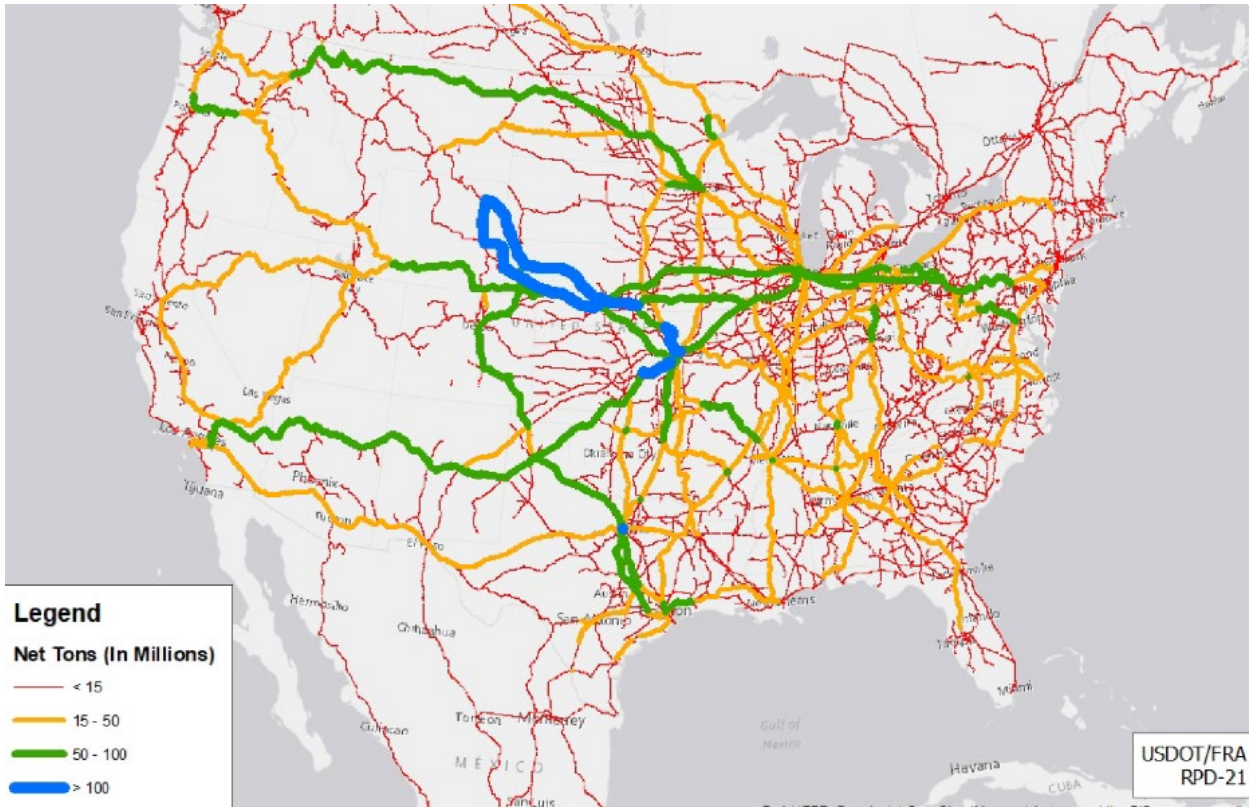
1970: Amtrak

1980: Staggers Rail Act

AAR-Chronology-Americas-Freight-Railroads-Fact-Sheet.pdf

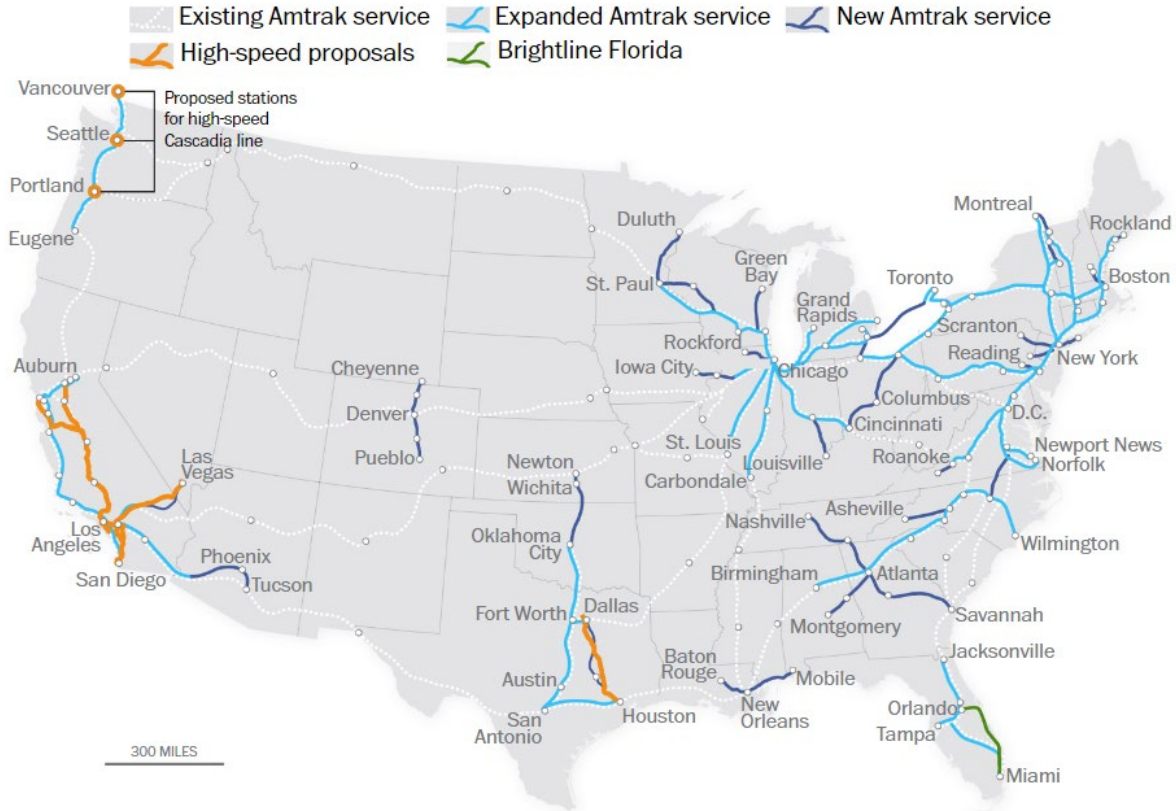
Rail Infrastructure

Freight Network with Commodity Weighting



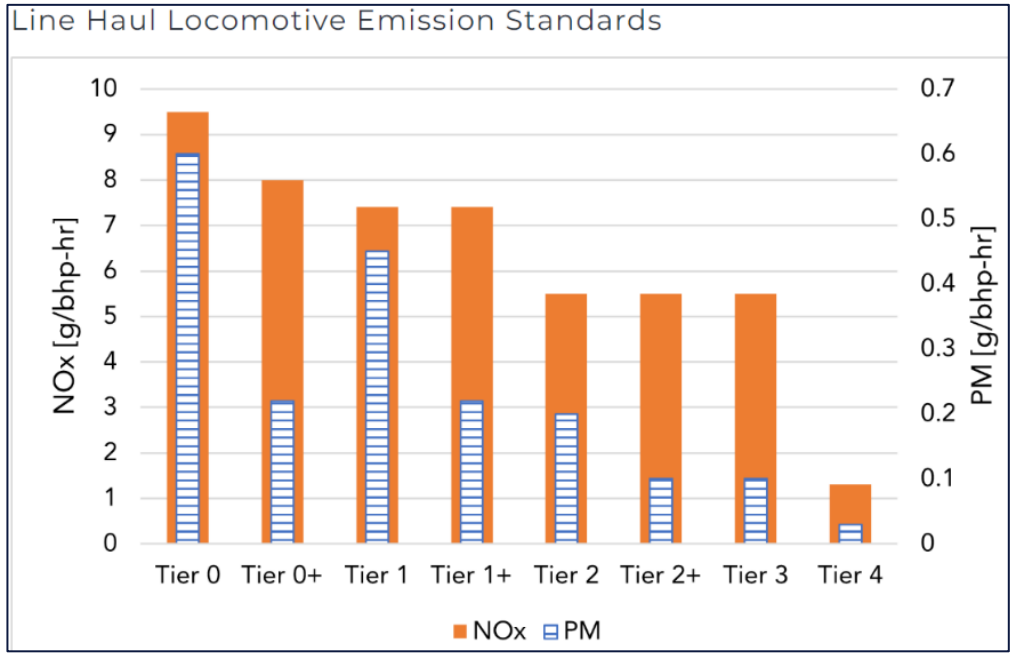
Freight Rail Overview | FRA (dot.gov). Image created by FRA, Office of Railroad Policy and Development, based on Surface Transportation Board's 2018 Carload Waybill Sample.

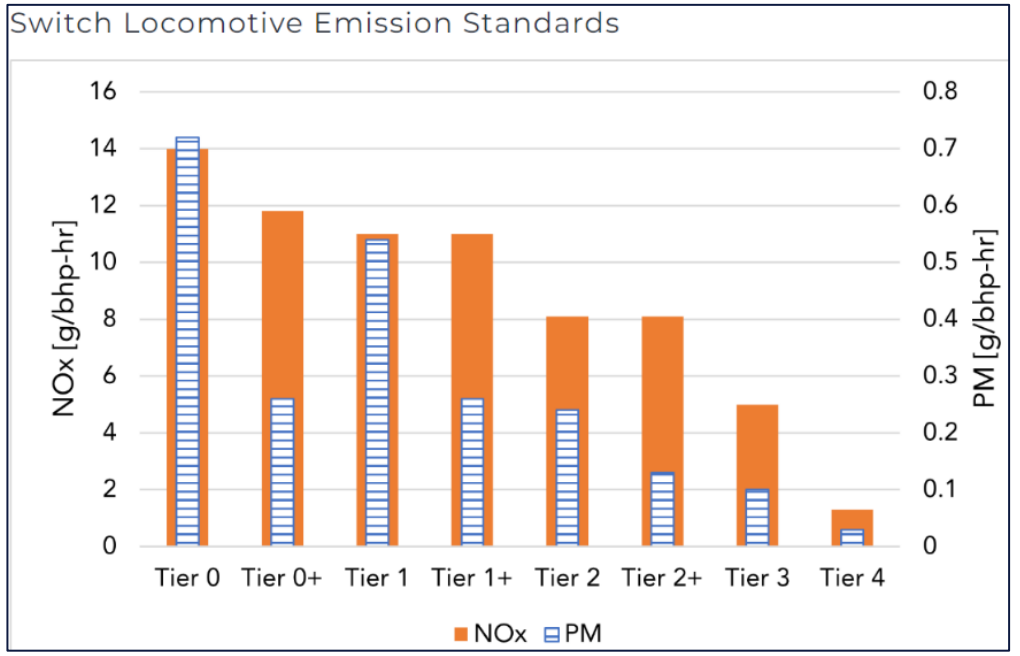
Amtrak Service and High-Speed Rail Proposals



American high-speed rail: The 5 projects taking shape in the U.S. - The Washington Post

Locomotive Emissions Standards





X ultrafine particle (<100 nm diameter) standards

X GHG emissions standards

- Last updated in 2008
- In 2023 EPA allows states to set and enforce stricter standards for non-new locomotives

Locomotive Emissions & Impacts

Big Picture Benefits of Rail – Passengers

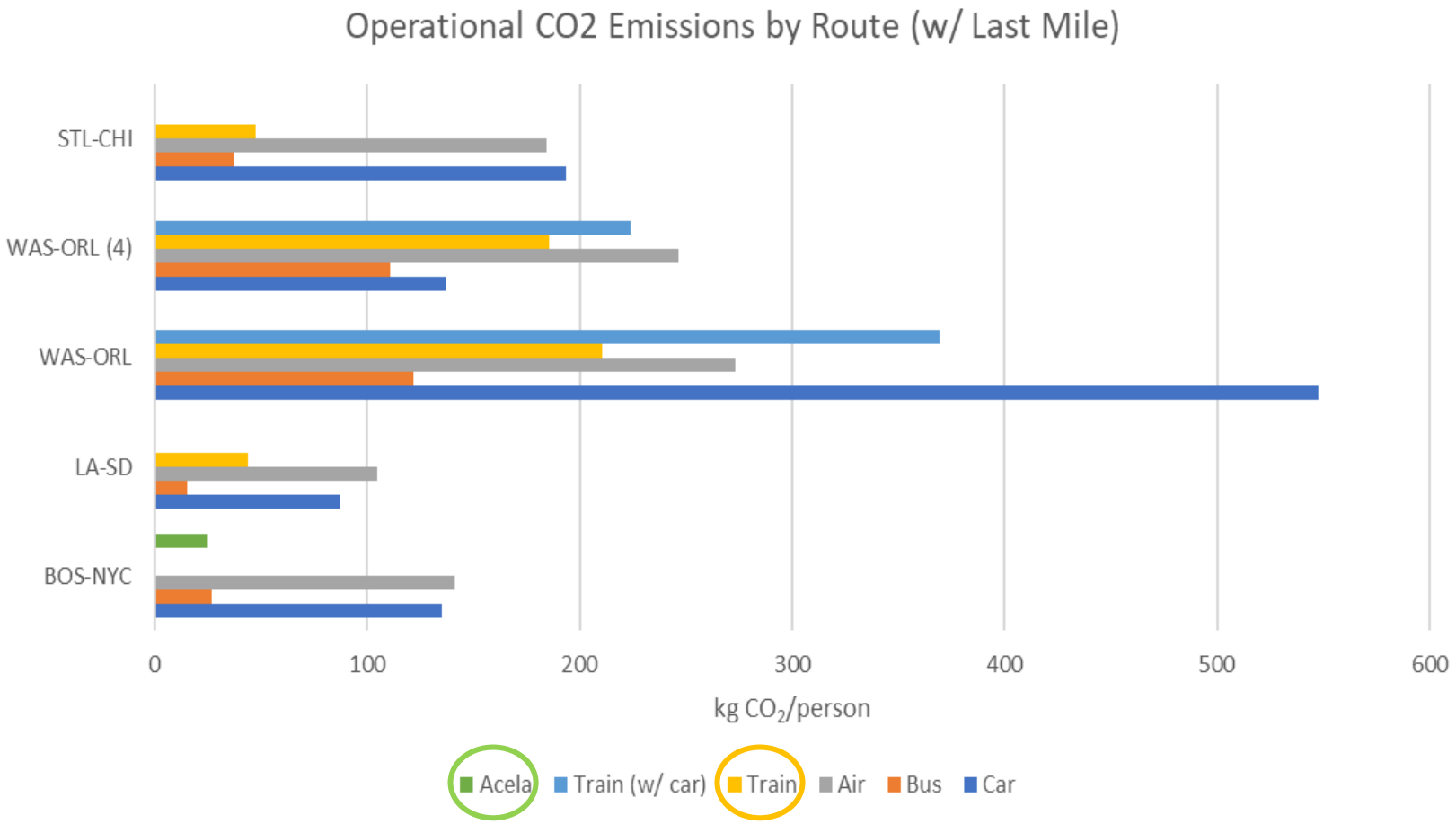


Figure from: Carbon Dioxide Emissions from Four Real World Inter-City Passenger Trips: A Comparison of Rail, Air, and Road Travel Modes by City Pair | FRA (2022)

In brief*:

- **69% reduction in CO_2** operational emissions when going from single-occupancy vehicle to diesel passenger rail
- **85% reduction in CO_2** operational emissions (from electric grid) when going from SOV to electric passenger rail (i.e., NEC)

*Comparison between MOVES4 calculations and reported rail emissions in Miller (2021) J&AWMA, 71(12), 1458–147.

Big Picture Benefits of Rail – Freight

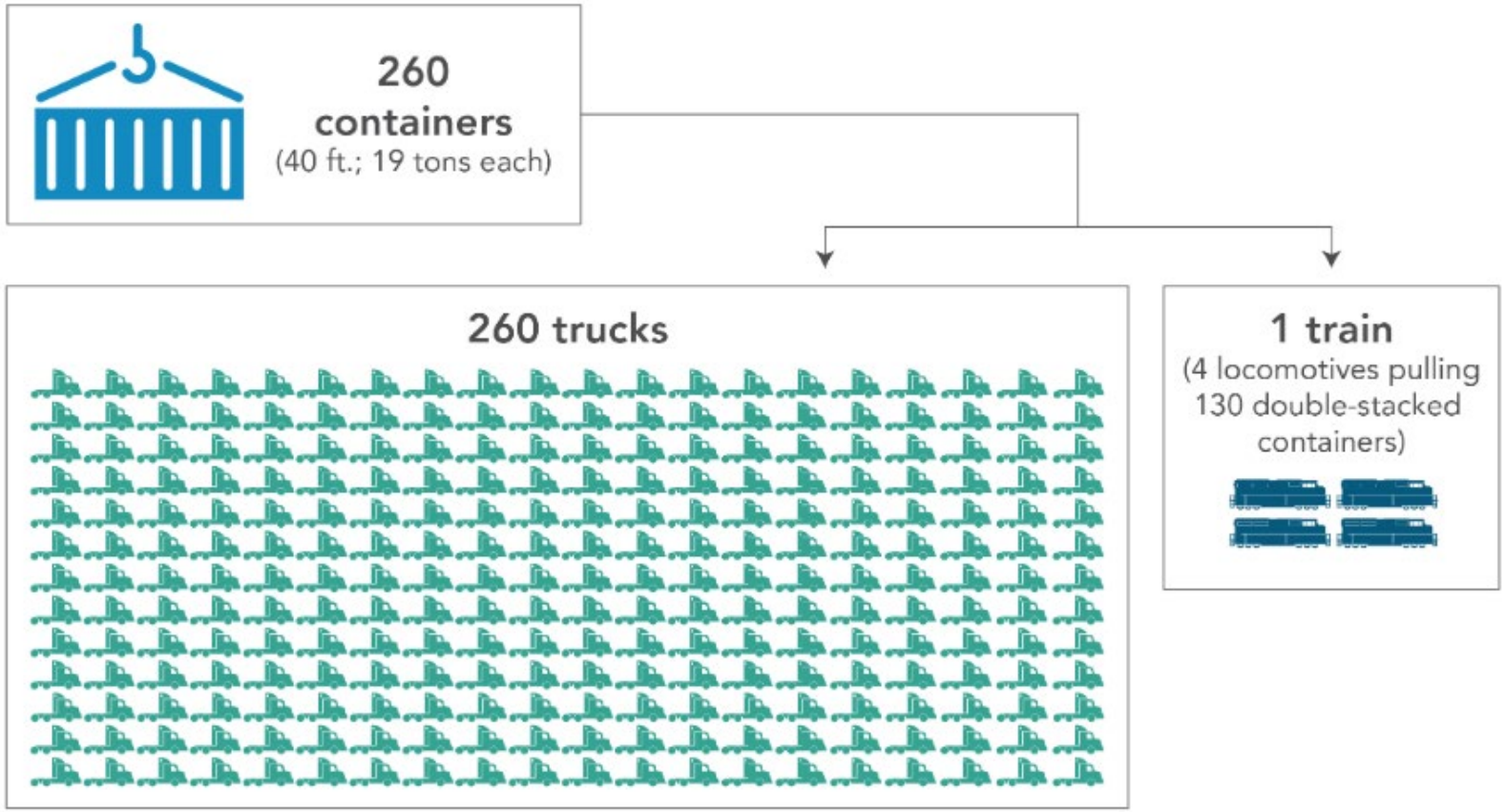
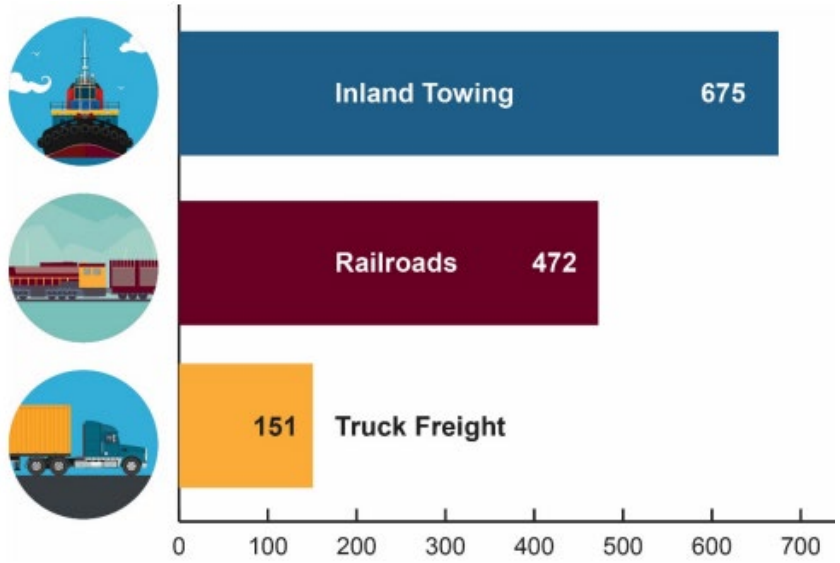


Diagram from: Truck vs. Train Emissions Analysis | California Air Resources Board.

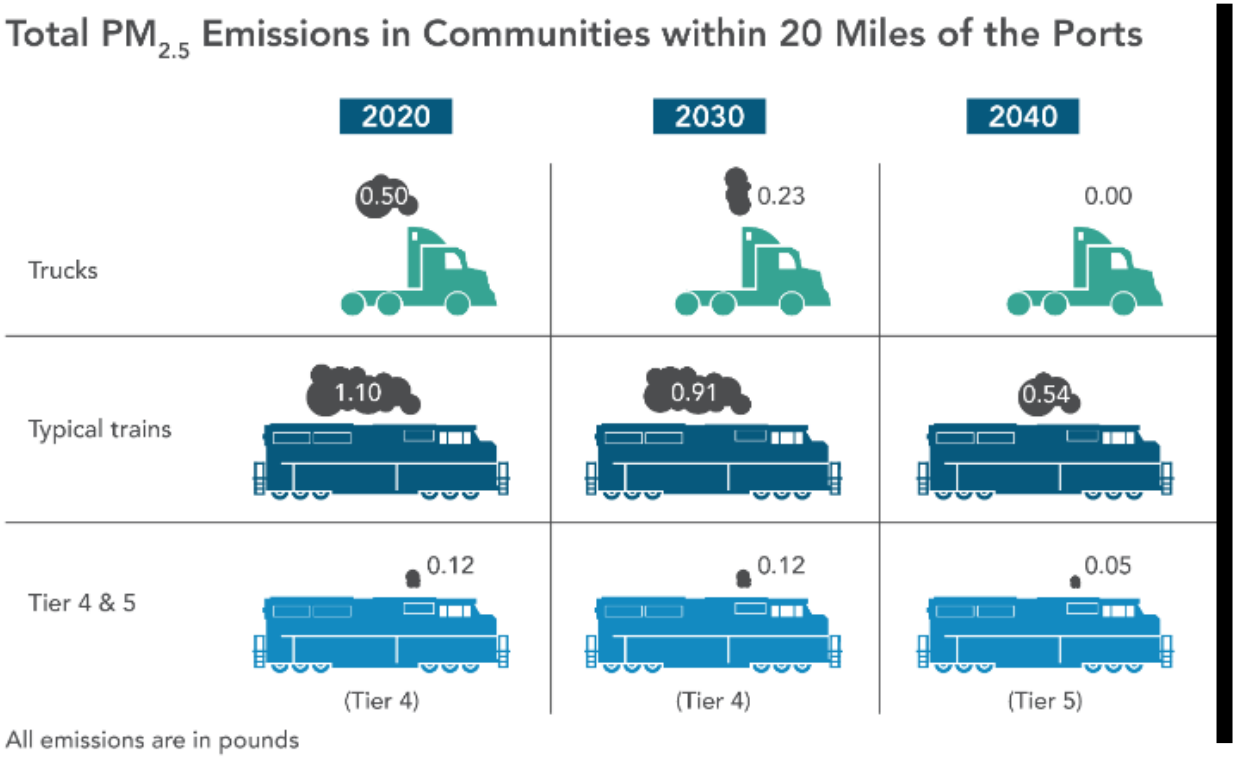
Fuel Efficiency by Mode

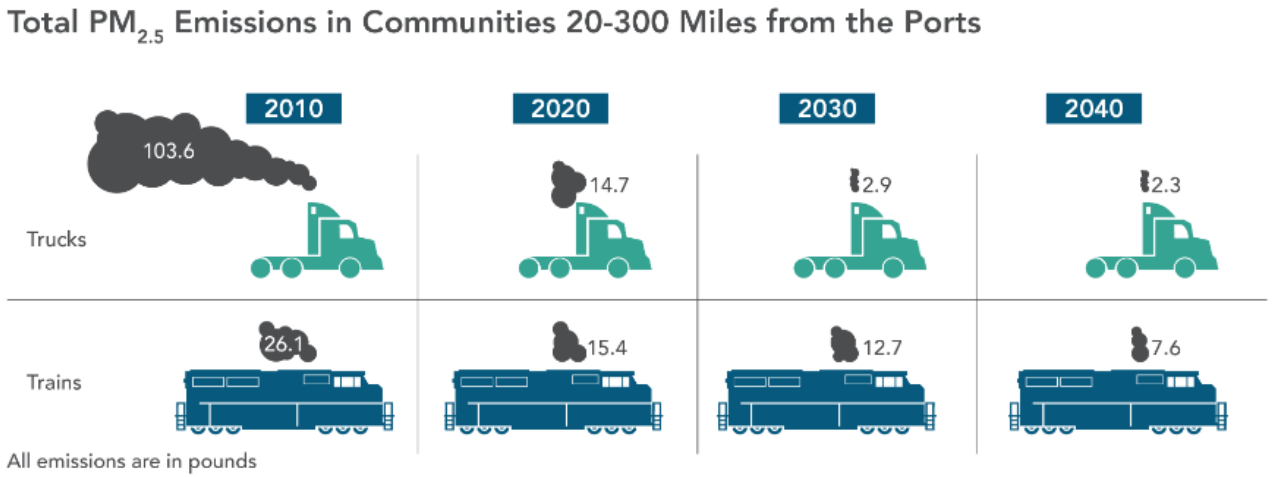


Ton-miles per gallon fuel

Plot from: TTI (2022). A Modal Comparison of Domestic Freight Transportation Effects on the General Public: 2001-2019.

CARB Analysis – Truck vs. Train Emissions



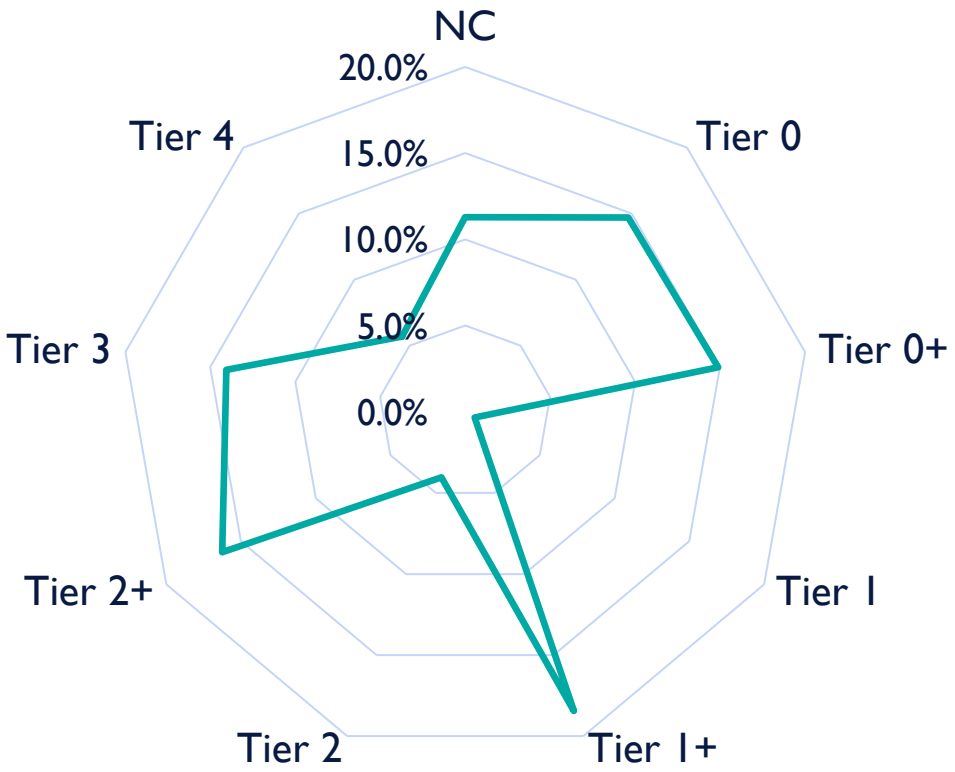


From: Truck vs. Train Emissions Analysis | California Air Resources Board

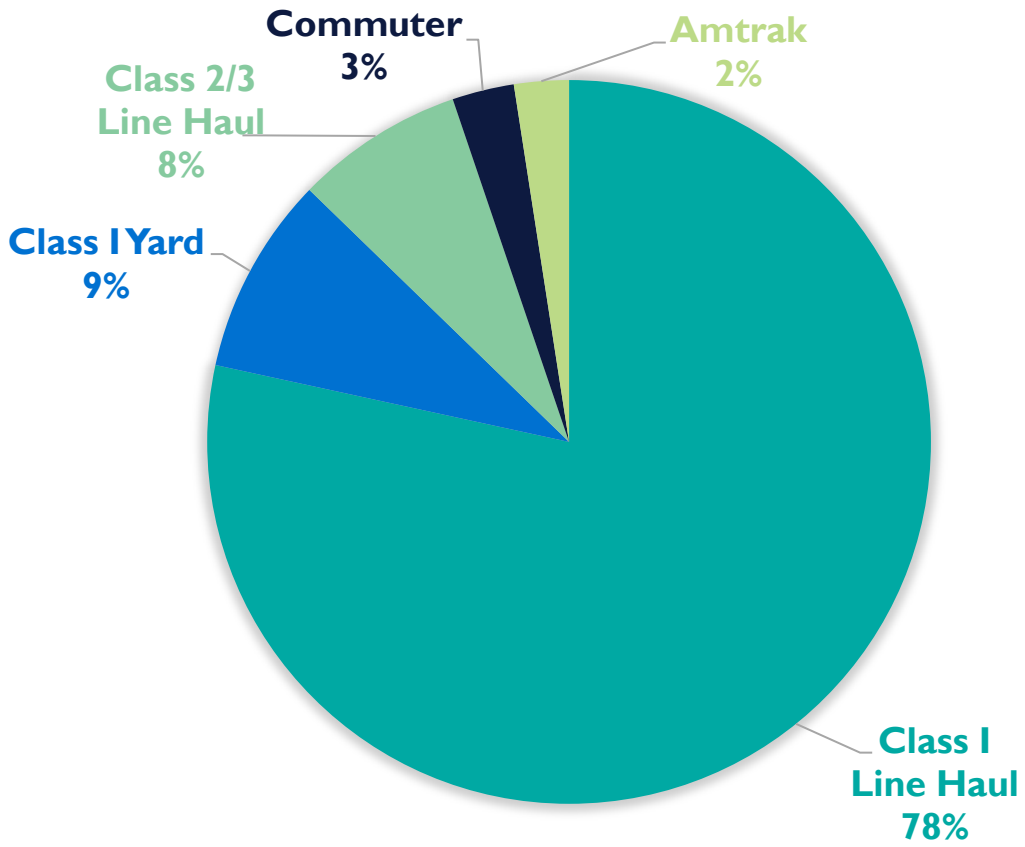
CARB = California Air Resources Board

U.S. 2020 Locomotive Fleet

Fleet Mix by EPA Emissions Tier



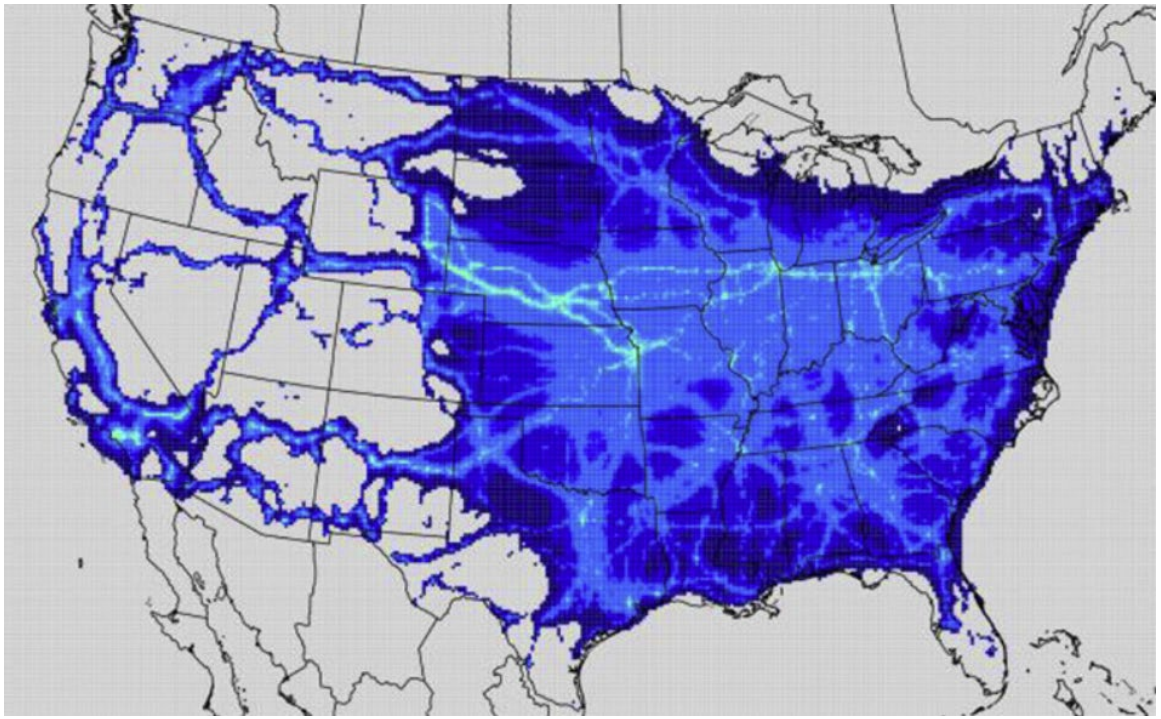
$PM_{2.5}$ Direct Emissions



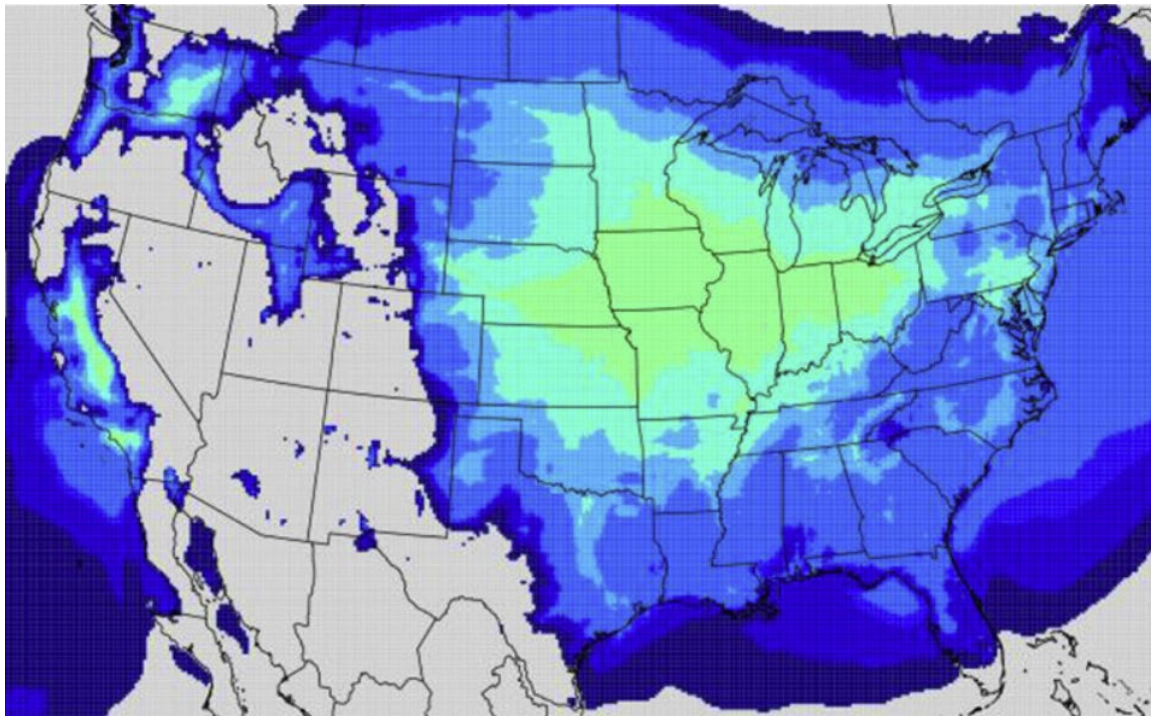
Plots created with data from 2020 National Emissions Inventory: Locomotive Component (epa.gov)

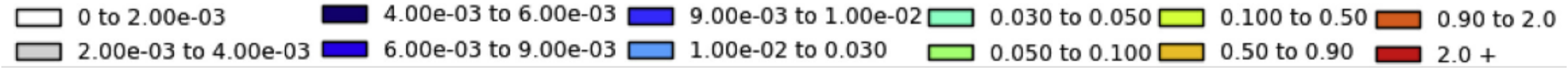
$PM_{2.5}$ Impacts of Rail

Projected primary $PM_{2.5}$ from rail in 2025 ($\mu g/m^3$)



Projected secondary $PM_{2.5}$ from rail in 2025 ($\mu g/m^3$)

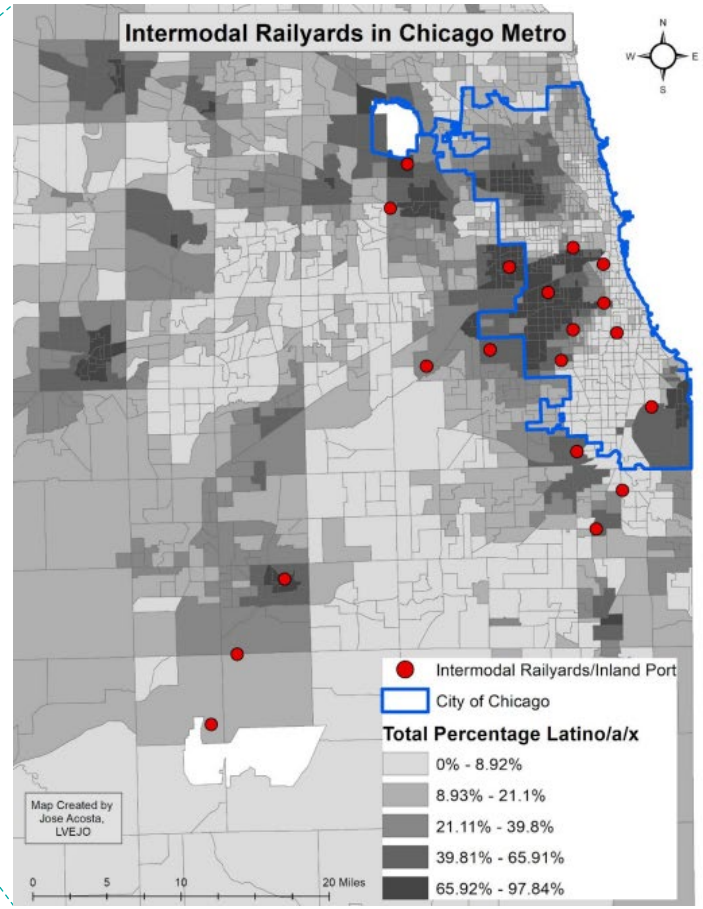


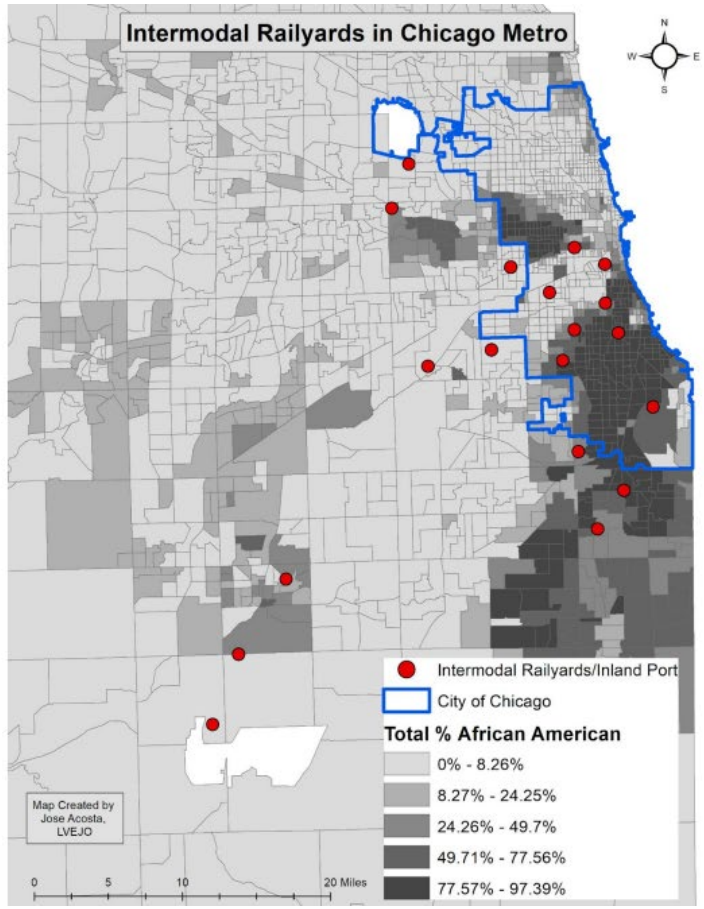


Zawacki et al. (2018) *Atmos. Environ.* https://doi.org/10.1016/j.atmosenv.2018.04.057

Justice40 Rail Explorer – Railyard Emissions

Image created by U.S. DOE National Renewable Energy Laboratory (NREL).





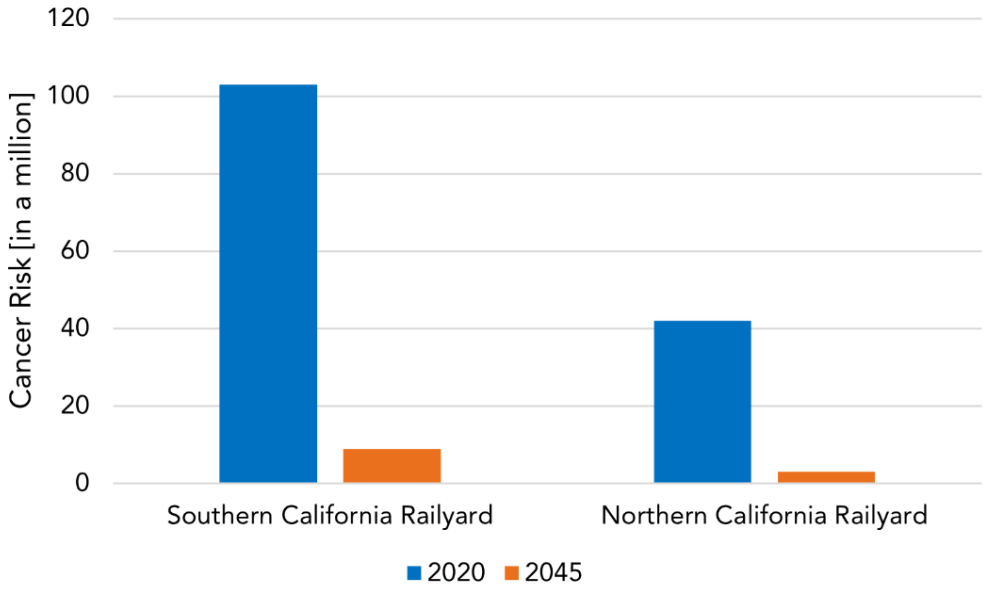
From Presentation by the Moving Forward Network for the Spring 2023 MSTRS Meeting (epa.gov). Maps created by Jose Acosta, Little Village Environmental Justice Organization.

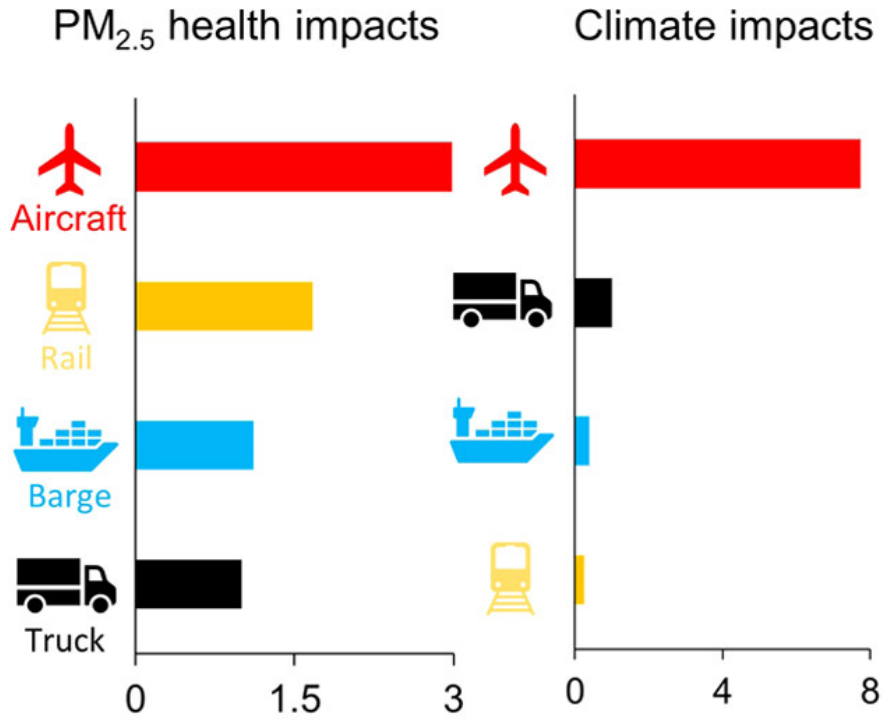
Justice40 Rail Explorer

https://www.transportation.gov/grants/dot-navigator/justice40-rail-explorer

(Select) Health Impacts of Rail

Decrease in Cancer Risk from Transition to Tier 4 Locomotives





Value per megatonne, relative to truck (i.e., truck = 1). Based on Thind et al. (2023). *Environ. Sci. Technol.*, 57, 2, 884–895, https://doi.org/10.1021/acs.est.2c03646.

>1,000 deaths attributed to rail-related AQ in 2011 – more than double the number of fatalities from at-grade rail crossings.
Davidson et al. (2020). *Environ. Res. Lett.* 15 075009, DOI: 10.1088/1748-9326/ab83a8.

Locomotive Technologies

- Battery-electric
- Hydrogen
  - Combustion (transition strategy)
  - Fuel cell
- Sustainable “Diesel”
  - Biofuels
  - Electrofuels (e-fuel)
- Hybrid-electric
  - w/ biofuels or some other SRF
  - Island catenary

BNSF to pilot 4 battery electric locomotives (BELs) in SoCal – largest BELs in North America

CPKC showcases (Apr 2024) their 3rd generation hydrogen fuel cell line-haul locomotive in Calgary, AL (Canada)

Electrified (double-stacked) freight rail in India – could be applied to the U.S. either as end-to-end electrification or island catenary

Locomotive Emissions Comparison Tool (LECT)

Locomotive Replacement

This tool will estimate the reduction in emissions resulting from repower/replacement of a diesel locomotive engine. Emissions benefits may stem from use of newer engines with emissions controls, use of cleaner fuels, and electrification.

INPUT

User Guide

Clear Inputs

Note: Inputs for this tool should be specific to the equipment to be repowered/replaced.

(1) Select the project year and enter the project title.	2023	Year2023
(2) What is the baseline equipment?	Switch Locomotive	*Baseline equipment is assumed to operate on diesel fuel.*
(3) What emission standards tier is the baseline equipment currently held to?	Tier 0	*Refer to the User Guide for help determining the appropriate tier.*
(4) What is the replacement engine type? For Diesel-Hybrid engines and Other Technologies that exceed Tier 4 standards, please input manufacturer-supplied emissions data in	Diesel-Battery Hybrid	For all-electric or equivalent engines, what region is the project located in? *Refer to the Upstream tab for region details. Note that upstream emissions from plug-in hybrids are not currently modelled in the tool.*
(5) How many locomotives will be replaced?	5	*For diesel-hybrid engines and other technologies that exceed Tier 4 standards, please input manufacturer-supplied certification data. Emission factors should be in units of g/bhp-hr.*
(6) What emissions tier will the replacement equipment be held to?	Exceeds Tier 4 *Refer to the User Guide for help with determining the appropriate Tier.*	
(7) Input the annual fuel use for one locomotive being replaced. Use the fleet average if the project involves more than one locomotive. *Reflect any fuel effiency gains for replacement equipment. Refer to the User Guide for detail.*	Before: 33,333 gal/yr After: 25,000 gal/yr	*Fuel use for all-electric locomotives is assumed to be 0.*

Pollutant	Emission Factor (g/bhp-hr)
NOx	0.75
PM_{10}	0.01
$PM_{2.5}$	0.01
HC	0.04
CO	1

(8) OPTIONAL: Do you want to compare this scenario to another scenario? (Results will be calculated first.)

Yes, Save Scenario | Compare Scenarios

OUTPUT

Calculate or Update Results

REDUCTIONS (LOCOMOTIVE OPERATION) Tool version: 12/2023

Reductions in Air Pollutants (short tons/year)	
Carbon Monoxide (CO)	3.016
Nitrogen Oxides (NO_x)	33.615
Particulate Matter ≤2.5 µm ($PM_{2.5}$)	1.172
Particulate Matter ≤10 µm (PM_{10})	1.208
Volatile Organic Compounds (VOC)	2.882
Reductions in Greenhouse Gases (metric tons/year)	
Carbon Dioxide (CO_2)	133.328
Carbon Dioxide Equivalents (CO_2e)	137.390
Methane (CH_4)	0.033
Nitrous Oxide (N_2O)	0.011

Export results to PDF

View Upstream Emission Factors

Upstream Emissions (metric tons/year)

	Baseline	Replacement
	277.014	207.763
	349.447	262.088
	2.343	1.757
	0.005	0.004

**Note: emissions, not emissions reductions*

Energy Consumption (kWh)

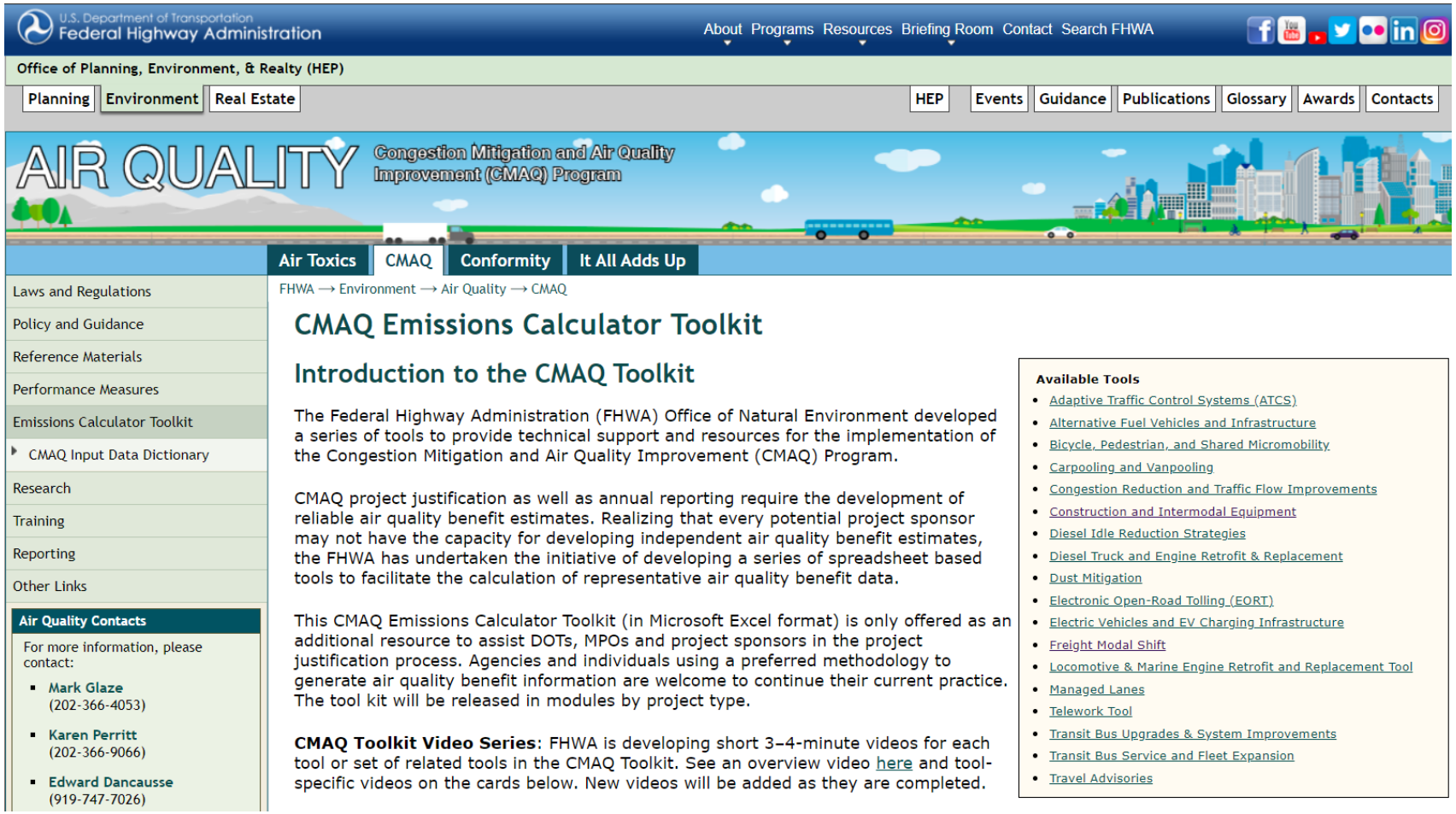
	Baseline	Replacement
Upstream	7,451,592.150	5,588,750.000
Operational	2,261,397.558	1,696,065.129

**Note: energy consumption, not energy reductions*

- Developed for FRA's Consolidated Rail Infrastructure and Safety Improvements (CRISI) Program
- LECT and supporting documentation publicly available on FRA website: https://railroads.dot.gov/elibrary/fra-locomotive-emissions-comparison-tool

Other Relevant Emissions Calculator Tools

Toolkit - CMAQ - Air Quality - Environment - FHWA (dot.gov)



Select Tools:

- Alternative Fuel Vehicles and Infrastructure
- Construction and Intermodal Equipment
- Diesel Idle Reduction Strategies
- Diesel Truck and Engine Retrofit & Replacement
- Freight Mode Shift
- Locomotive & Marine Engine Retrofit and Replacement
- Transit Bus Upgrades & System Improvements
- Transit Bus Service and Fleet Expansion

Looking Ahead

FRA Climate & Sustainability Program

Locomotive Replacement Initiative

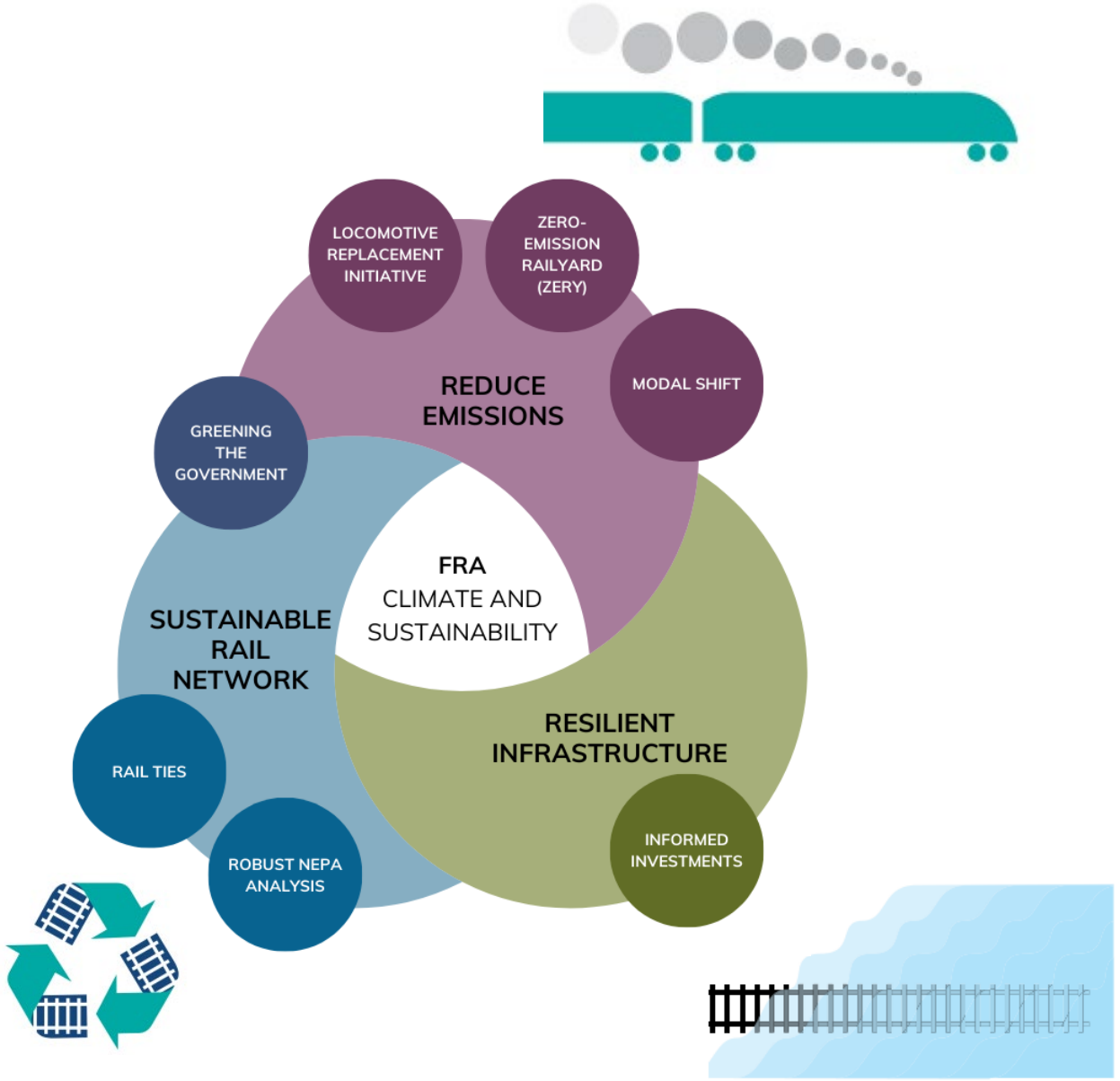
- >40 locomotives upgraded to Tier 2 and better
- 15 battery-powered switchers

Modal shift literature review

Life cycle analysis of rail ties

Zero emissions railyard pilot assessment

- Developing criteria framework
- Seeking Railroad partner & funding mechanisms



(Select) Research Needs & Directions

- Non-diesel locomotive technologies / strategies, and working through:
  - Safety concerns
  - Public perception
  - Green premium
  - Accessibility
  - Infrastructure requirements
- Mode shift:
  - How much additional capacity could be added to the network?
  - What % of trucks could be shifted to rail and what is the impact to surrounding communities? (e.g., AQ, blocked passages)
  - What corridors to target for intercity passenger rail expansion?

Questions?

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www.volpe.dot.gov