

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

HEI's 2024 Annual Conference

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# 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

1830: 1st U.S. passenger service



1827: 1st railroad in N.A.

1869: Transcontinental railroad

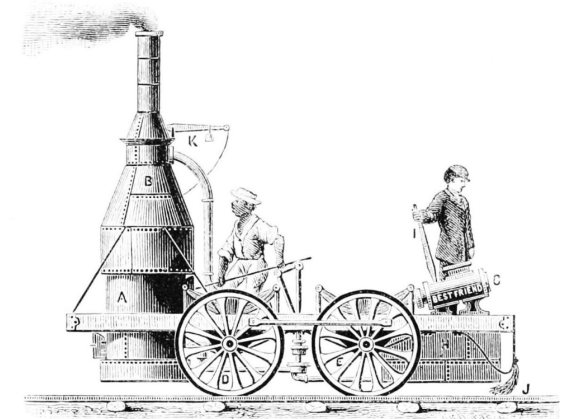
1893: Train goes >100 mph

1936: Intermodal is born

1970: Amtrak

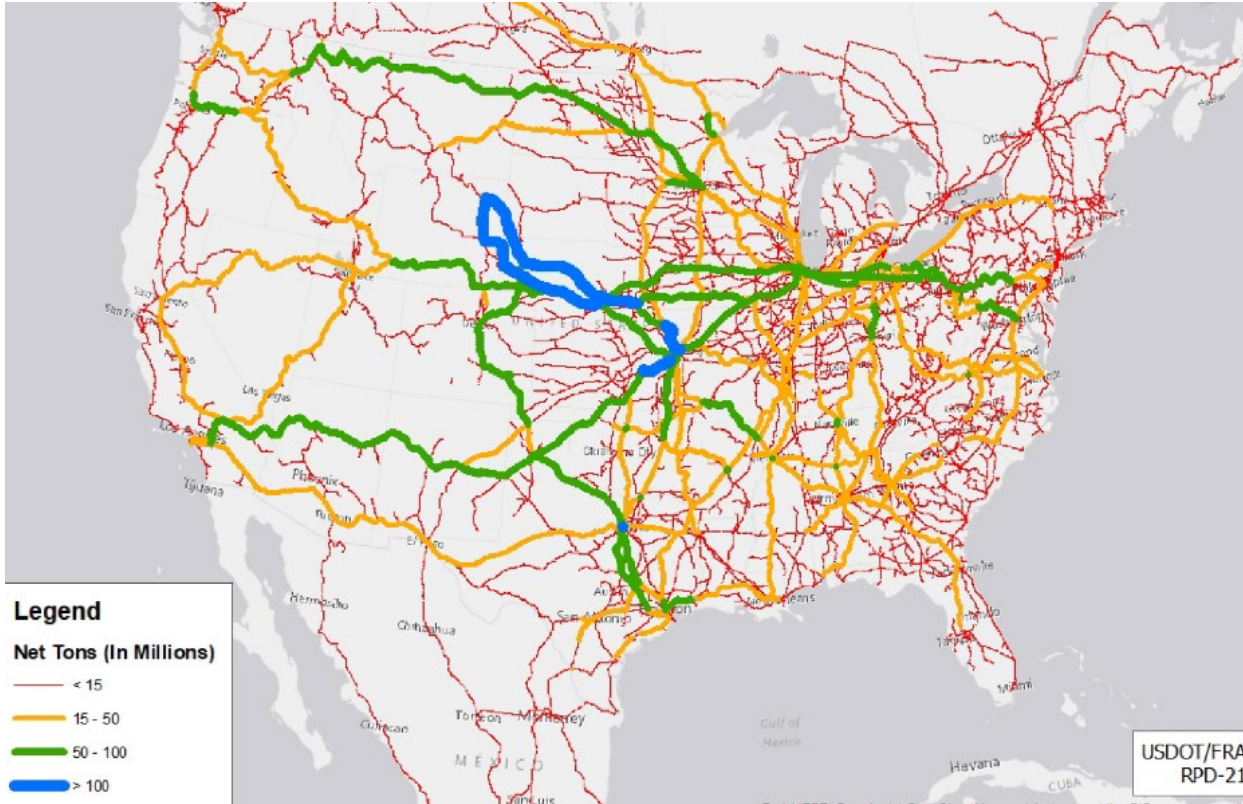


1980: Staggers Rail Act



# Rail Infrastructure

## Freight Network with Commodity Weighting



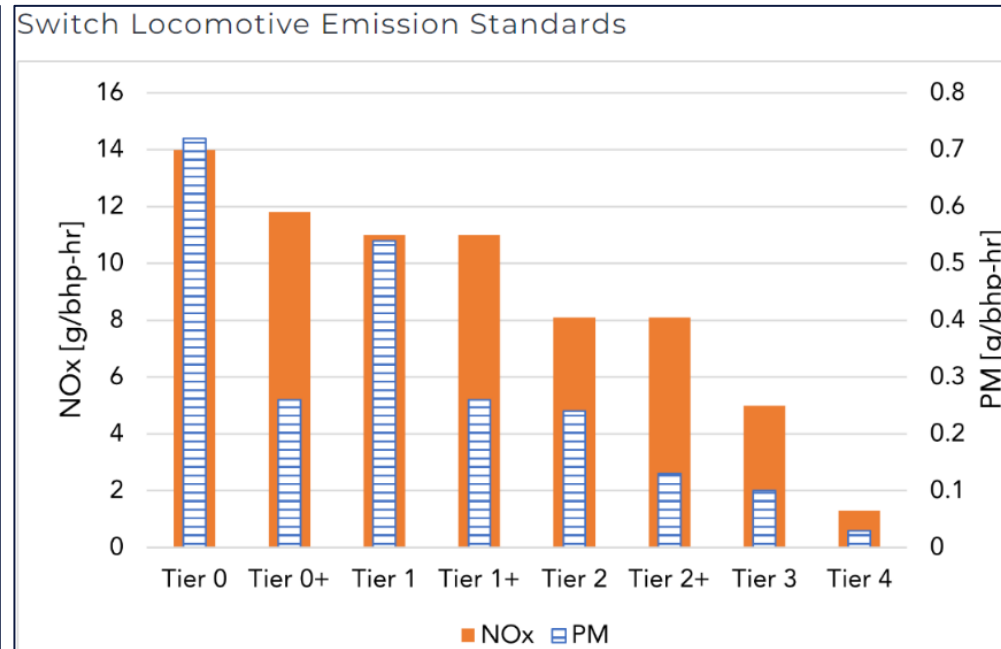
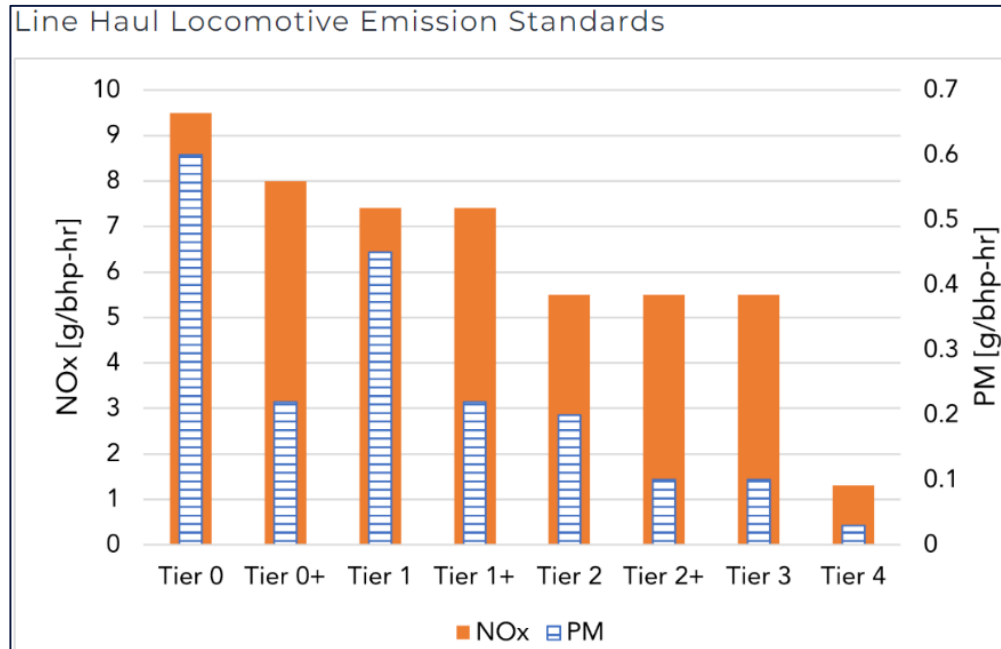
Freight Rail Overview | FRA (dot.gov). Image created by FRA, Office of Railroad Policy and Development, based on Surface Transportation Board's 2018 Carload Waybill Sample.

## 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



- ✗ ultrafine particle (<100 nm diameter) standards
- ✗ 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

Operational CO2 Emissions by Route (w/ Last Mile)

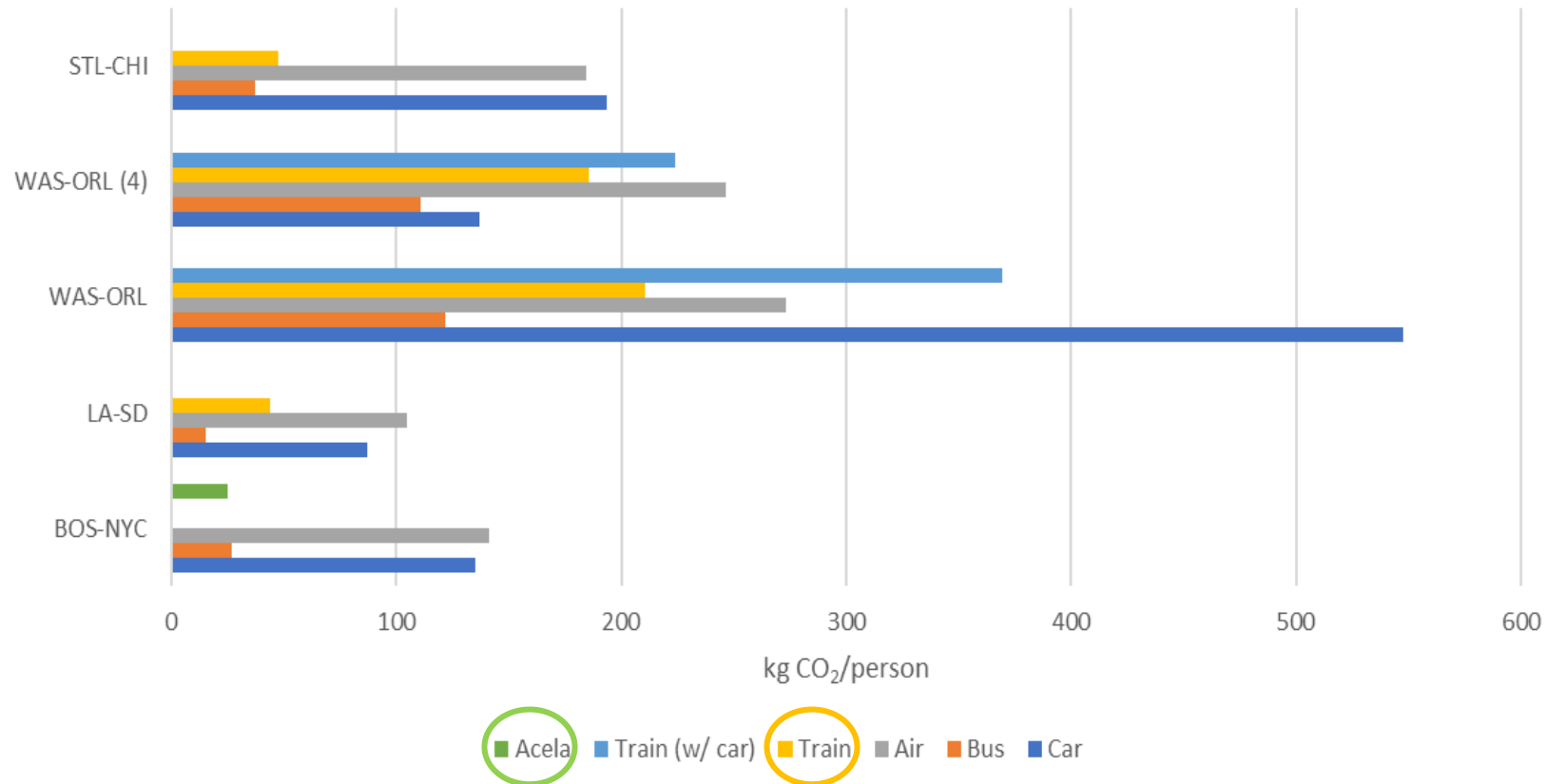


Figure from: [Carbon Dioxide Emissions from Four Real World Inter-City Passenger Trips: A Comparison of Rail, Air, and Road Travel Modes by City Pair | FRA \(2022\)](#)

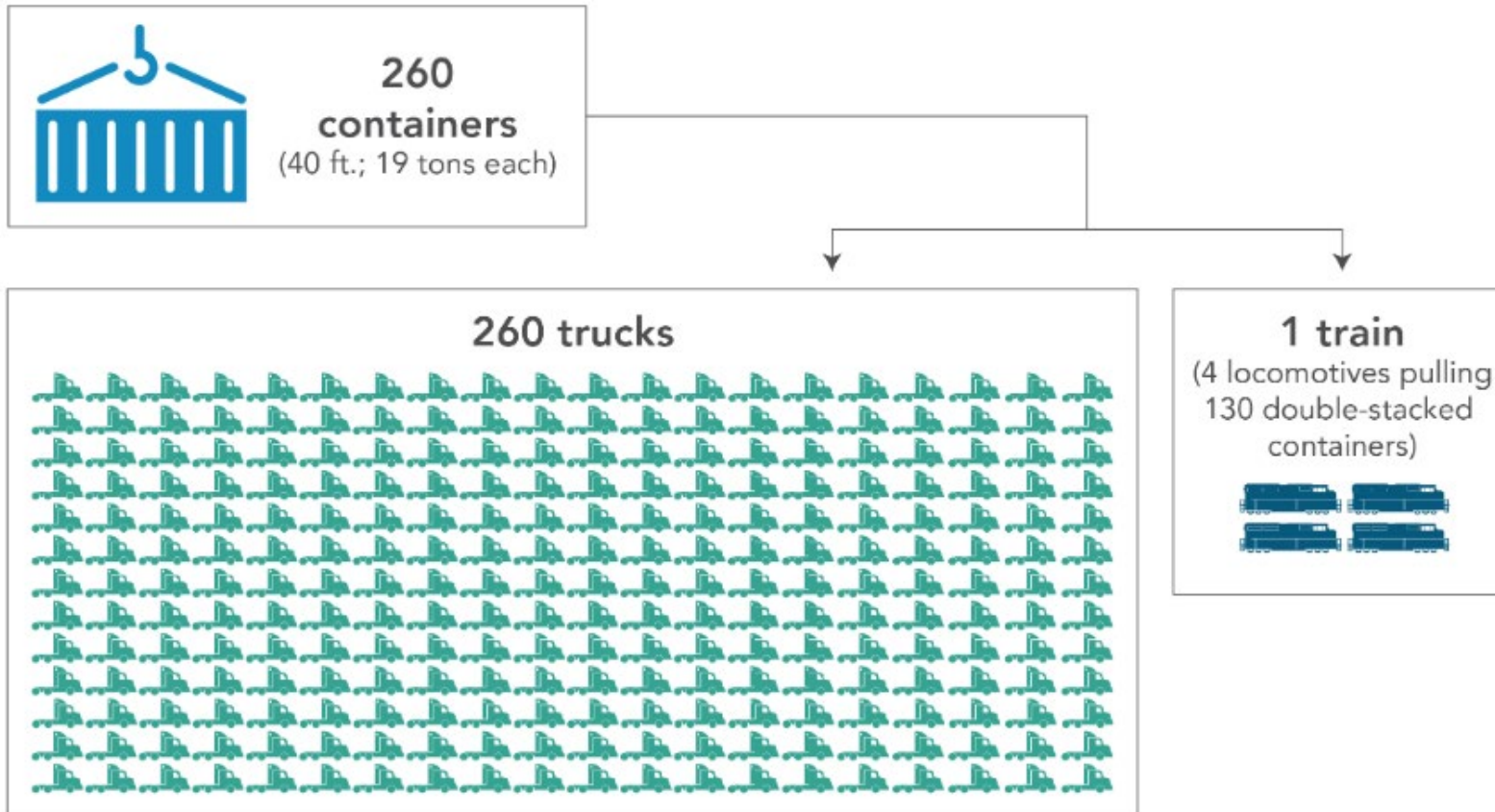
In brief\*:

- **69% reduction in CO<sub>2</sub> operational emissions** when going from single-occupancy vehicle to diesel passenger rail
- **85% reduction in CO<sub>2</sub> 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&AVMA, 71(12), 1458–147.



# Big Picture Benefits of Rail – Freight



## Fuel Efficiency by Mode

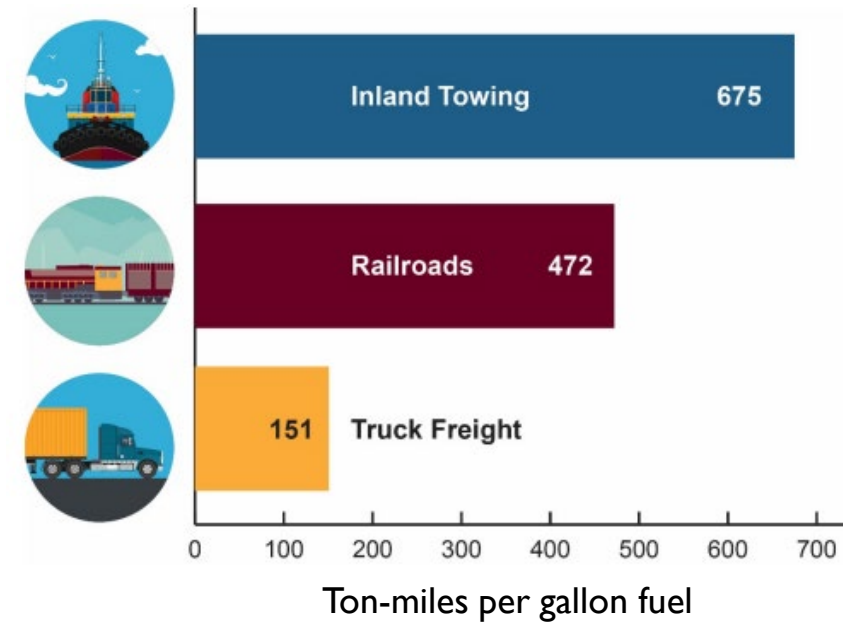
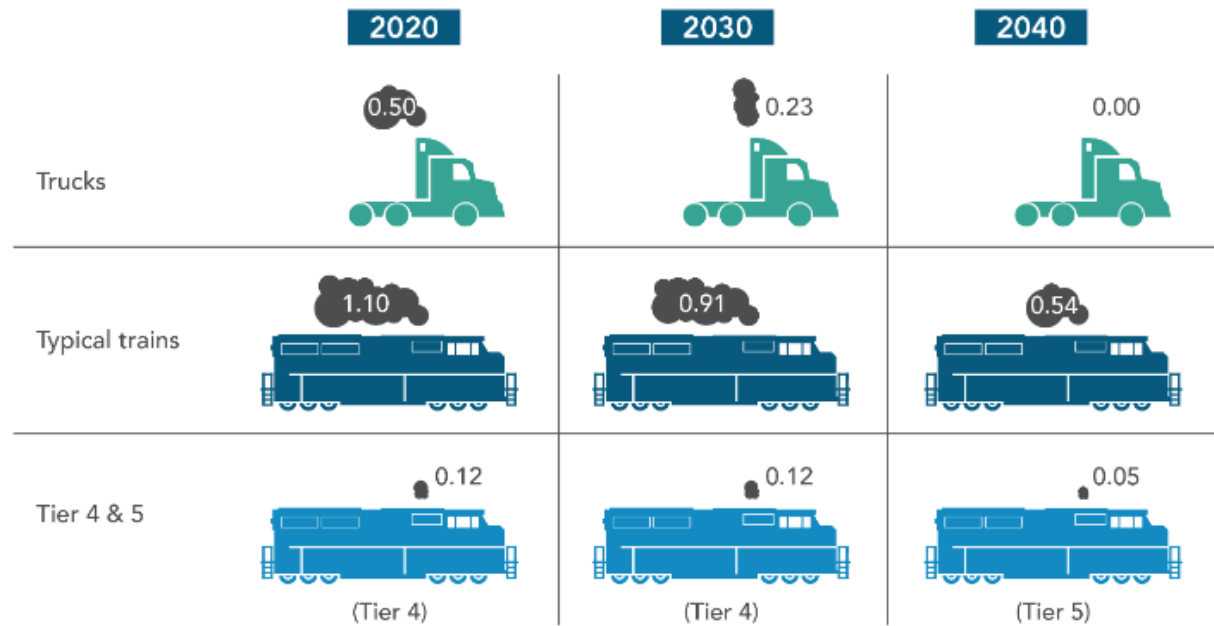


Diagram from: [Truck vs. Train Emissions Analysis](#) | California Air Resources Board.

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

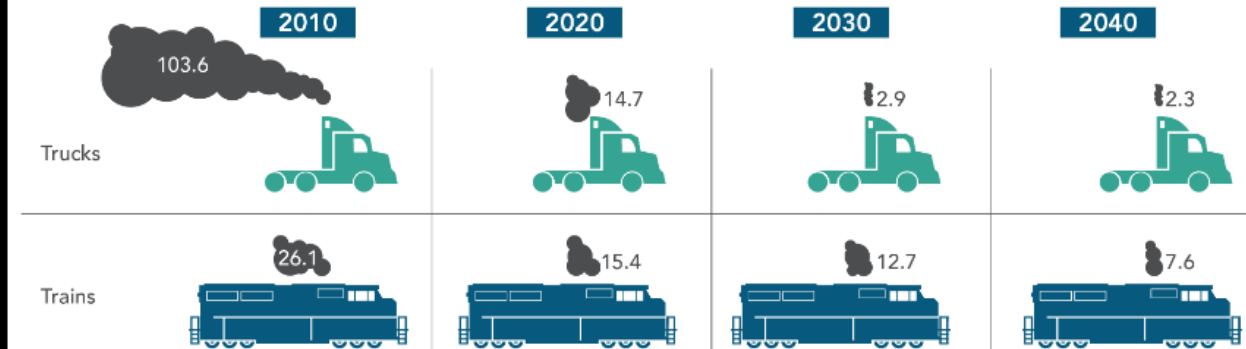
# CARB Analysis – Truck vs. Train Emissions

Total PM<sub>2.5</sub> Emissions in Communities within 20 Miles of the Ports



All emissions are in pounds

Total PM<sub>2.5</sub> Emissions in Communities 20-300 Miles from the Ports



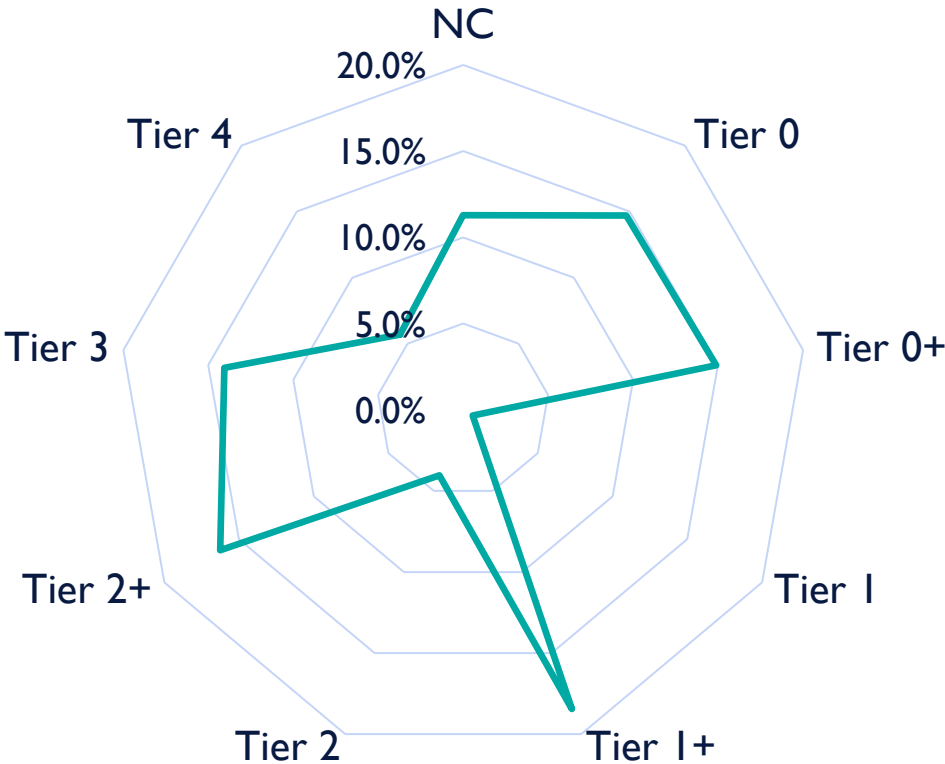
All emissions are in pounds

From: [Truck vs. Train Emissions Analysis](#) | California Air Resources Board

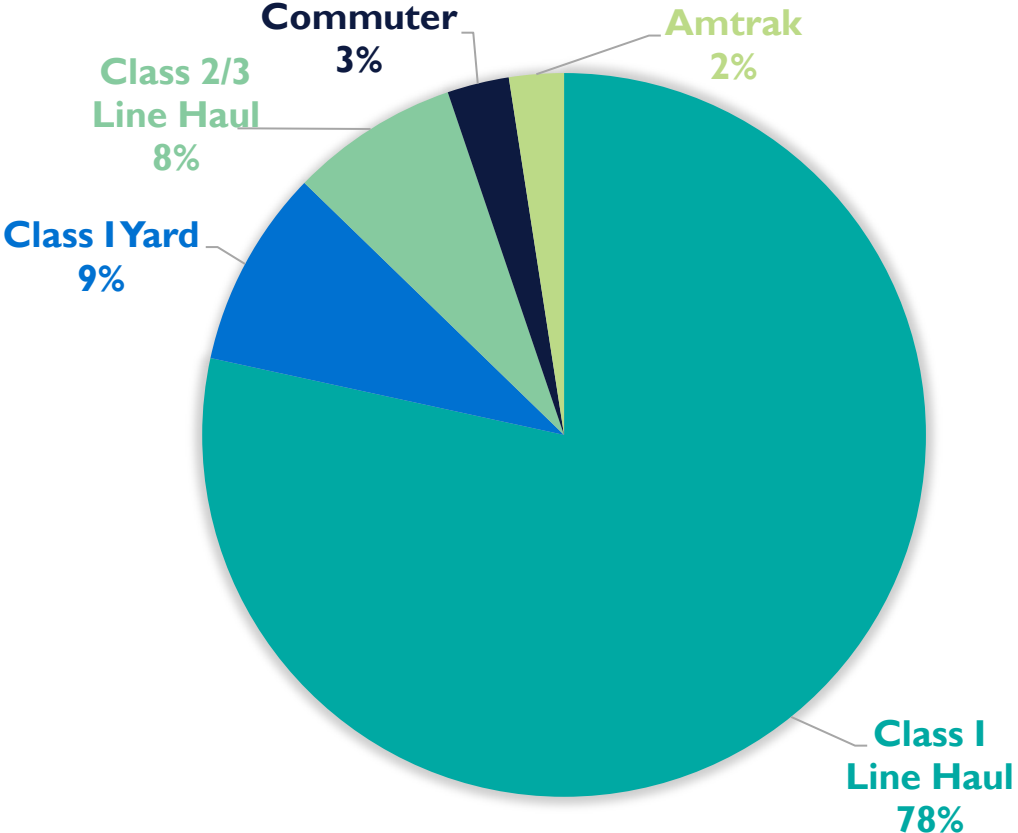
CARB = California Air Resources Board

# U.S. 2020 Locomotive Fleet

Fleet Mix by EPA Emissions Tier



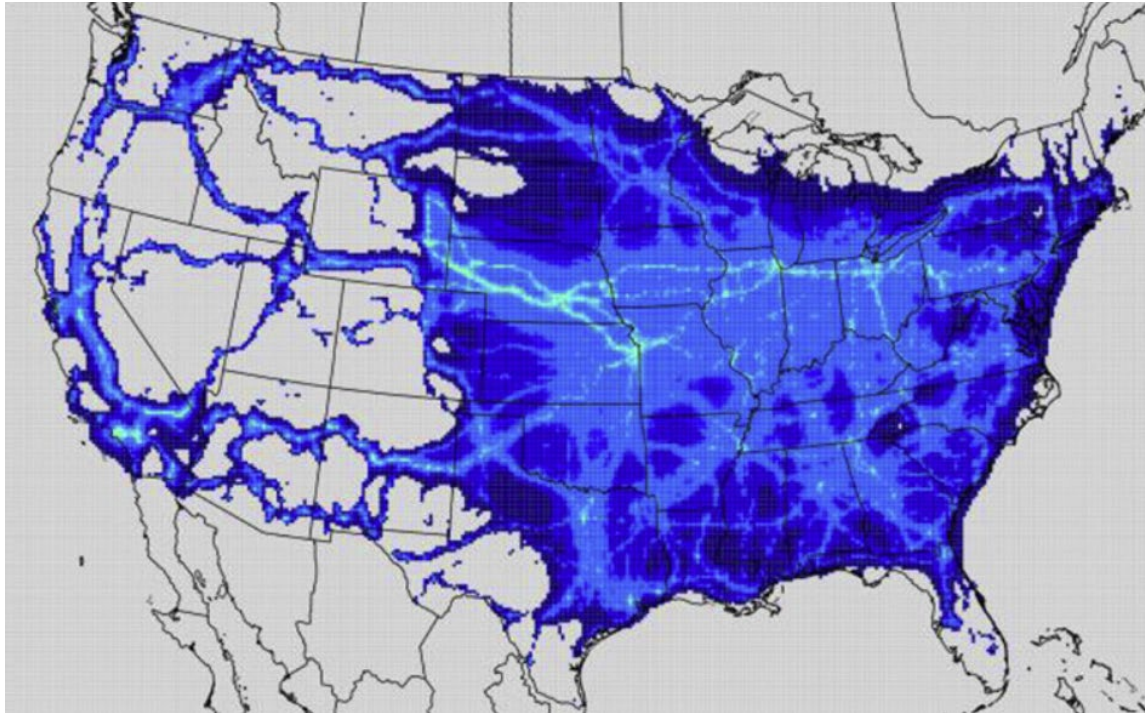
PM<sub>2.5</sub> Direct Emissions



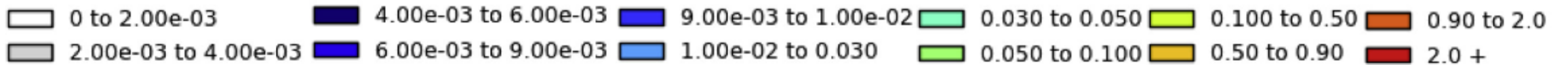
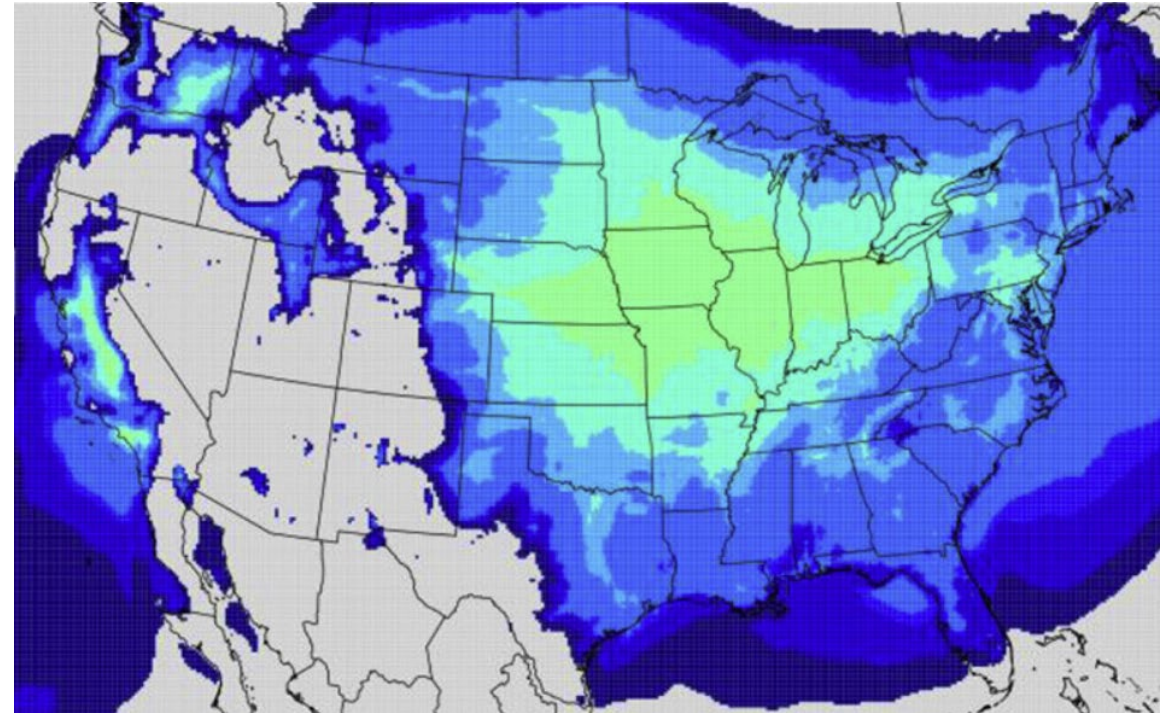
Plots created with data from [2020 National Emissions Inventory: Locomotive Component \(epa.gov\)](https://www.epa.gov/2020-national-emissions-inventory-locomotive-component)

# PM<sub>2.5</sub> Impacts of Rail

Projected primary PM<sub>2.5</sub> from rail in 2025 (μg/m<sup>3</sup>)



Projected secondary PM<sub>2.5</sub> from rail in 2025 (μg/m<sup>3</sup>)

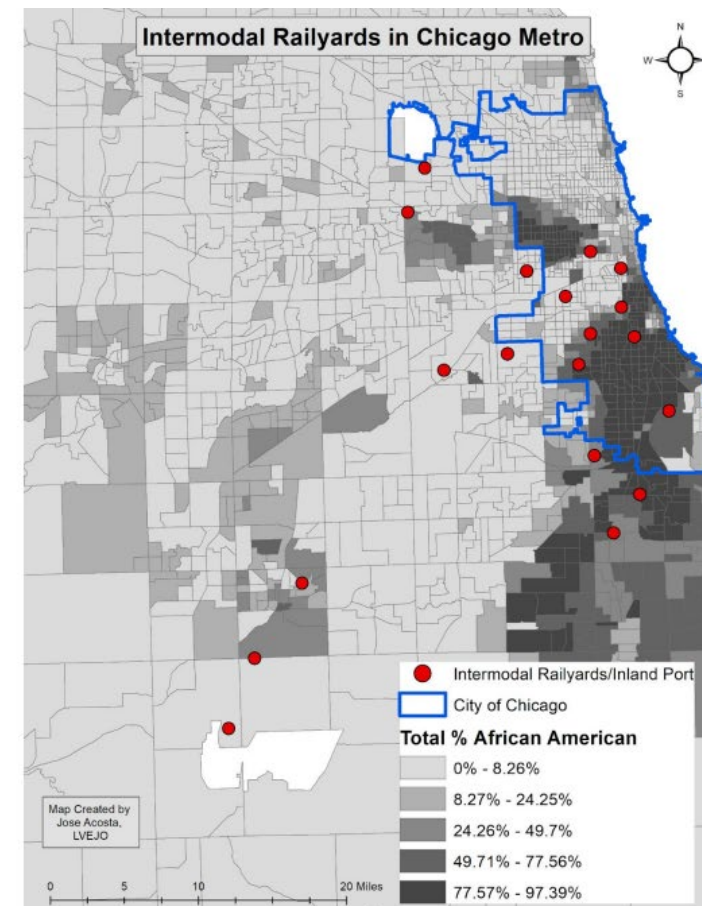
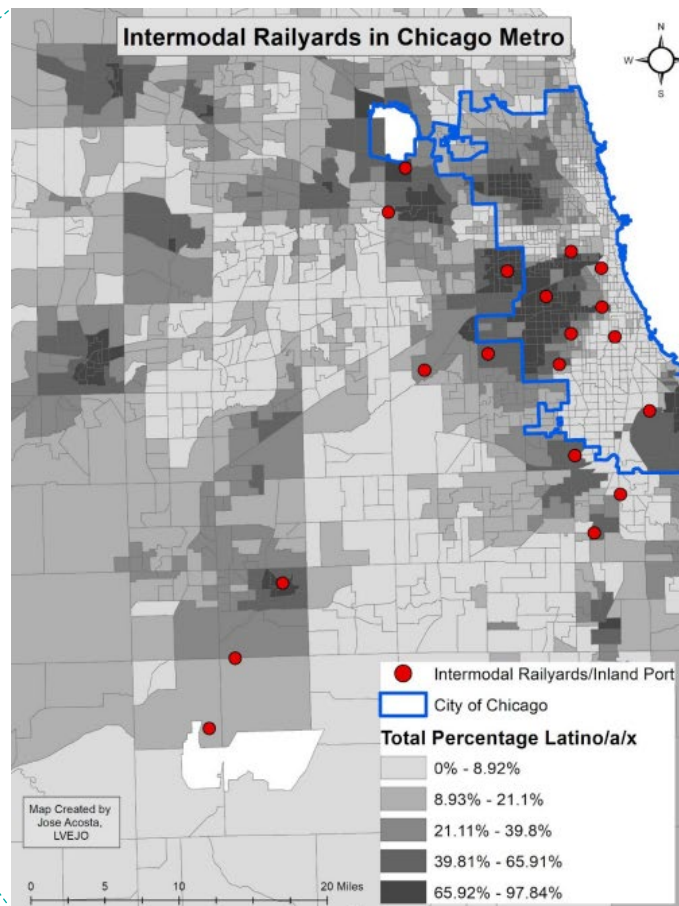


Zawacki et al. (2018) *Atmos. Environ.* <https://doi.org/10.1016/j.atmosenv.2018.04.057>

# Justice40 Rail Explorer – Railyard Emissions



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



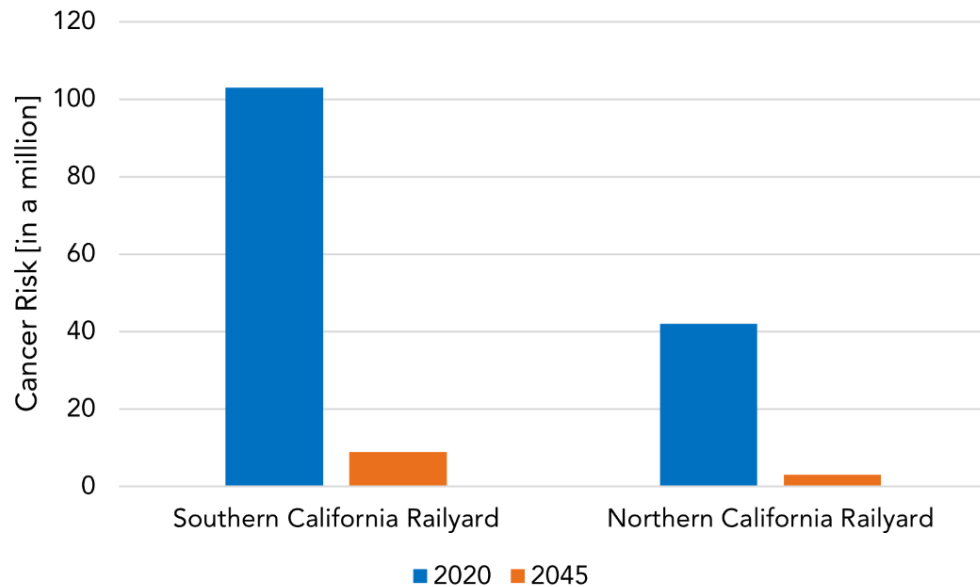
From [Presentation by the Moving Forward Network for the Spring 2023 MSTRS Meeting \(epa.gov\)](#). Maps created by Jose Acosta, Little Village Environmental Justice Organization.

Justice40 Rail Explorer

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

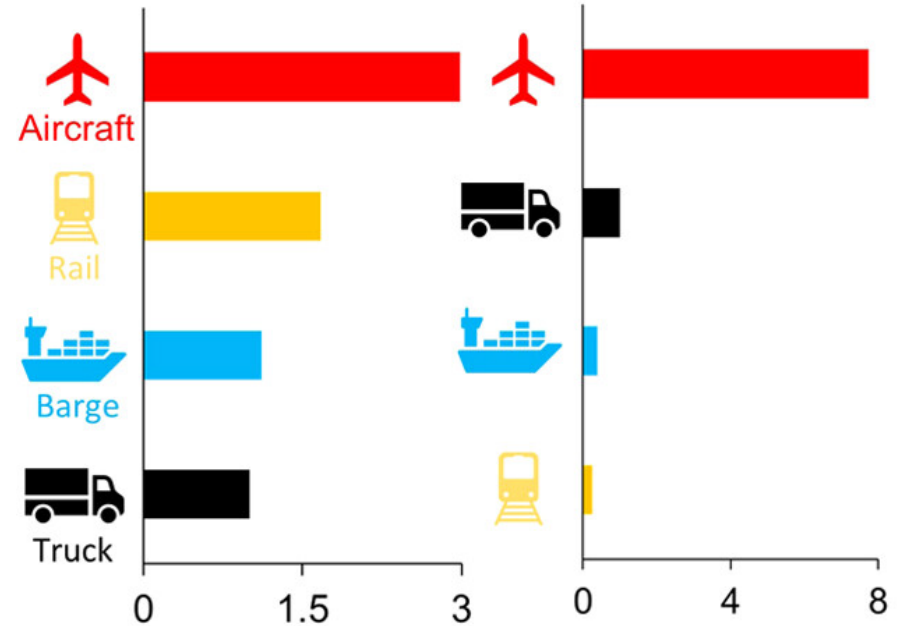
# (Select) Health Impacts of Rail

Decrease in Cancer Risk from Transition to Tier 4 Locomotives



PM<sub>2.5</sub> health impacts

Climate impacts



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 3<sup>rd</sup> 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**

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.

(2) What is the baseline equipment?  Baseline equipment is assumed to operate on diesel fuel.

(3) What emission standards tier is the baseline equipment currently held to?  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 Question 6.

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?  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.

Pollutant	Emission Factor (g/bhp-hr)
NOx	0.75
PM <sub>10</sub>	0.01
PM <sub>2.5</sub>	0.01
HC	0.04
CO	1

(6) What emissions tier will the replacement equipment be held to?  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 efficiency gains for replacement equipment. Refer to the User Guide for detail.

Before  gal/yr

After  gal/yr Fuel use for all-electric locomotives is assumed to be 0.

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

- 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>

## OUTPUT

Tool version: 12/2023

REDUCTIONS (LOCOMOTIVE OPERATION)		Upstream Emissions (metric tons/year)	
		Baseline	Replacement
<b>Reductions in Air Pollutants (short tons/year)</b>			
Carbon Monoxide (CO)	3.016		
Nitrogen Oxides (NO <sub>x</sub> )	33.615		
Particulate Matter ≤2.5 μm (PM <sub>2.5</sub> )	1.172		
Particulate Matter ≤10 μm (PM <sub>10</sub> )	1.208		
Volatile Organic Compounds (VOC)	2.882		
<b>Reductions in Greenhouse Gases (metric tons/year)</b>			
Carbon Dioxide (CO <sub>2</sub> )	133.328	277.014	207.763
Carbon Dioxide Equivalents (CO <sub>2</sub> e)	137.390	349.447	262.088
Methane (CH <sub>4</sub> )	0.033	2.343	1.757
Nitrous Oxide (N <sub>2</sub> O)	0.011	0.005	0.004
<small>*Note: emissions, not emissions reductions</small>			
<b>Energy Consumption (kWh)</b>			
		Baseline	Replacement
Upstream		7,451,592.150	5,588,750.000
Operational		2,261,397.558	1,696,065.129
<small>*Note: energy consumption, not energy reductions</small>			



# Other Relevant Emissions Calculator Tools

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

U.S. Department of Transportation  
Federal Highway Administration

About Programs Resources Briefing Room Contact Search FHWA

Office of Planning, Environment, & Realty (HEP)

Planning Environment Real Estate

HEP Events Guidance Publications Glossary Awards Contacts

### AIR QUALITY

Congestion Mitigation and Air Quality Improvement (CMAQ) Program

Air Toxics CMAQ Conformity It All Adds Up

Laws and Regulations  
Policy and Guidance  
Reference Materials  
Performance Measures  
Emissions Calculator Toolkit  
CMAQ Input Data Dictionary  
Research  
Training  
Reporting  
Other Links

#### Air Quality Contacts

For more information, please contact:

- Mark Glaze (202-366-4053)
- Karen Perritt (202-366-9066)
- Edward Dancausse (919-747-7026)

## CMAQ Emissions Calculator Toolkit

### Introduction to the CMAQ Toolkit

The Federal Highway Administration (FHWA) Office of Natural Environment developed a series of tools to provide technical support and resources for the implementation of the Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

CMAQ project justification as well as annual reporting require the development of reliable air quality benefit estimates. Realizing that every potential project sponsor may not have the capacity for developing independent air quality benefit estimates, the FHWA has undertaken the initiative of developing a series of spreadsheet based tools to facilitate the calculation of representative air quality benefit data.

This CMAQ Emissions Calculator Toolkit (in Microsoft Excel format) is only offered as an additional resource to assist DOTs, MPOs and project sponsors in the project justification process. Agencies and individuals using a preferred methodology to generate air quality benefit information are welcome to continue their current practice. The tool kit will be released in modules by project type.

**CMAQ Toolkit Video Series:** FHWA is developing short 3-4-minute videos for each tool or set of related tools in the CMAQ Toolkit. See an overview video [here](#) and tool-specific videos on the cards below. New videos will be added as they are completed.

#### Available Tools

- Adaptive Traffic Control Systems (ATCS)
- Alternative Fuel Vehicles and Infrastructure
- Bicycle, Pedestrian, and Shared Micromobility
- Carpooling and Vanpooling
- Congestion Reduction and Traffic Flow Improvements
- Construction and Intermodal Equipment
- Diesel Idle Reduction Strategies
- Diesel Truck and Engine Retrofit & Replacement
- Dust Mitigation
- Electronic Open-Road Tolling (EORT)
- Electric Vehicles and EV Charging Infrastructure
- Freight Modal Shift
- Locomotive & Marine Engine Retrofit and Replacement Tool
- Managed Lanes
- Telework Tool
- Transit Bus Upgrades & System Improvements
- Transit Bus Service and Fleet Expansion
- Travel Advisories

### 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

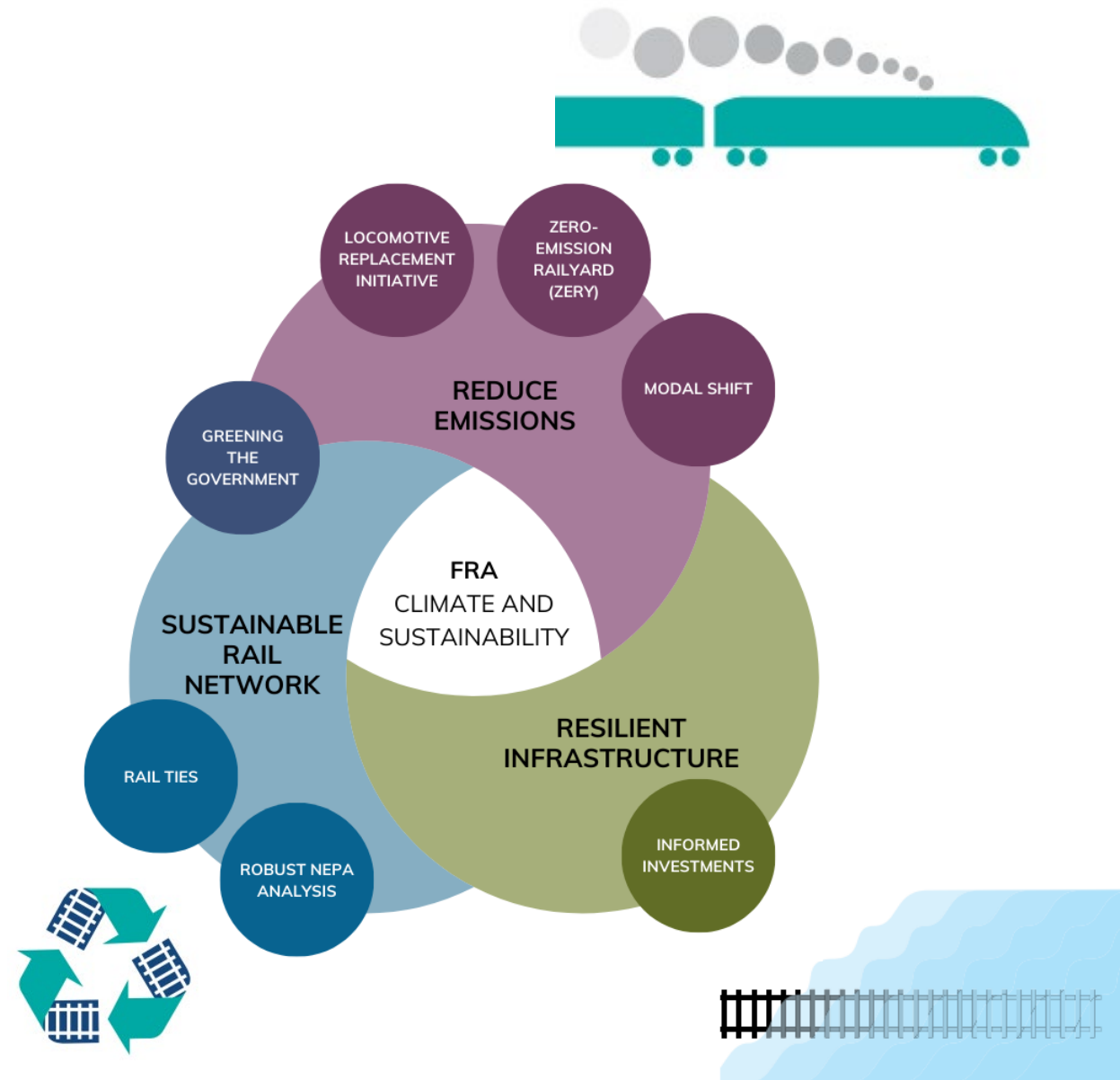
- >40 locomotives upgraded to Tier 2 and better
- 15 battery-powered switchers

## 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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## FRA Climate & Sustainability Program Team

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**Volpe Center:** Anjuliee Mittelman, PhD, Billy Chupp, Briana Litchholt, Agnes Li, Travis Mast



### Our Purpose

Advancing transportation innovation for the public good.

### OUR CORE VALUES



Public Service



Innovative Solutions



Collaboration and Partnering



Professional Excellence



Employee Well-Being

[www.volpe.dot.gov](http://www.volpe.dot.gov)