METHODOLOGY

Addressing Freight Pollution at the Source

Air Pollution, Freight Facility Clusters, and the Role of Indirect Source Rules

HIGHLIGHTS

Nationwide, over 66 million people—nearly one in five people in the United States—live near freight facilities and corridors. Growth in e-commerce has driven the construction of larger, increasingly clustered warehouses, and UCS research shows that higher concentrations of nearby warehouses are associated with greater environmental and health impacts in freight-adjacent areas. Because the US freight system largely runs on fossil fuels that pollute the air, people living around freight facilities and corridors are often exposed to elevated levels of harmful pollutants. Public health issues resulting from exposure include chronic and lethal illnesses that disproportionately affect people of color and people with lower incomes.

But indirect source rules (ISRs) for freight hubs can reduce emissions in the near term and direct investments to the people most burdened by freight pollution. This policy tool requires facilities that are pollution sources to begin to address pollution attracted by their operations.

Sam Wilson

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Goals for Proximity Analysis

UCS designed spatial analysis methods to identify populations exposed to pollution from major components of the US freight system. Specifically, the analysis:

- Identified the locations of major freight facilities, including intermodal freight facilities, large warehouses, distribution centers, truck terminals, railyards, and primary freight corridors;
- Employed intermodal freight facilities as proxies for port locations, given that federal data on port locations were often displayed as regional port districts polygons rather than locations of primary port operations (e.g., as container terminals);
- Estimated the populations living in close proximity to these facilities and corridors;
- Evaluated disparities in exposure and associated socioeconomic and health indicators; and
- Identified and quantified populations experiencing cumulative exposure from multiple freight-related pollution sources.

The analysis excluded pipeline terminals. It captured major petroleum ports through data on co-located freight facilities.

The analysis looked at the contiguous United States. It excluded Hawaii and Alaska due to data limitations.

Spatial Methods and Sources

Examining Population Proximity to Freight Pollution Sources through Areal Apportionment and Dasymetric Mapping Methods

To estimate population counts in close proximity to freight facilities and corridors, and to examine sociodemographic characteristics of these populations, we applied spatial buffers and conducted areal apportionment analysis using ArcGIS Pro software. We allowed buffer radii to vary by source type to reflect likely differences in pollution concentrations.

Prior research showed that distance-decay gradients for traffic-related air pollution varied widely, reflecting not only differences in pollutant chemistry and emissions intensity but also meteorological conditions, background concentrations, sunlight, and topography (WHO Regional Office for Europe 2013). In response to this variability, we adopted source-specific buffer distances informed by meta-analyses and empirical studies, described in detail below.

Identifying Population and Locations of Sources of Indirect Pollution

Population, sociodemographic, pollution exposure, and public health data were obtained from the 2024 Environmental Justice Index of the Centers for Disease Control and Prevention (CDC) (CDC 2024). This is reported at the census tract level. Because census tracts vary widely in geographic size, relying on tract-level averages can obscure localized patterns of exposure near freight facilities.

To improve spatial precision, we employed dasymetric mapping methods to redistribute census tract populations using an ancillary high-resolution population dataset from WorldPop at 100 m^2 resolution. Following established approaches in the literature, we allocated population counts within each census tract based on the WorldPop distribution, producing a national grid of 100 m^2 polygons with weighted population estimates (Bondarenko et al. 2025; Chakraborty et al. 2011). Sociodemographic, pollution, and public health indicators from the CDC dataset were then population-weighted and assigned to these subdivided polygons, enabling more precise estimates of exposure for populations living near freight facilities and corridors.

We sourced locations of intermodal ports, terminals ports, railyards, and primary freight corridors from the federal Bureau of Transportation Statistics (BTS 2025a, 2025b, 2025c, 2025d, 2024). CoStar's proprietary property database provided locations of warehouses (including distribution centers and truck terminals).

We established inclusion thresholds for CoStar locations to focus the analysis on locations most relevant to freight-related pollution. We included only facilities that were currently in operation and leased more than 5 percent of their rentable space. Size thresholds were set at 20,000 square feet for distribution centers and truck terminals and 100,000 square feet for warehouses, consistent with thresholds used in recent peer-reviewed research and regulatory programs (Kerr et al. 2024; SCAQMD n.d.). A review of the CoStar data found that these thresholds effectively excluded facilities unlikely to generate significant goods-movement activity.

Buffered freight facilities and corridor features were merged into a single polygon (preserving a feature-type identification) and intersected with the subdivided polygons, leaving only those that overlapped with the buffers. This yielded a nationwide population estimate within the buffer areas and corresponding sociodemographic, pollution, and public health indicators for those populations.

Freight facility and Corridor Pollution Buffers

Buffer distances were selected to reflect differences in emissions intensity across freight source types. We applied larger buffers to facilities where idling, equipment use, and vehicle clustering were likely to produce elevated pollution concentrations.

In setting buffers of population proximity to sources of freight pollution, the analysis took a somewhat more protective and dynamic approach compared with existing literature. We relied on previously identified decay buffers for mobile source pollution from both meta-analyses and individual studies to set a buffer of 500 meters for primary freight corridors (Chakraborty et al. 2011; Levasseur et al. 2026; Maantay 2007; Samuels and Freemark 2022; Zhou and Levy 2007).

However, it is important to acknowledge that air pollution concentrations around large or clustered indirect sources are likely higher than near-roadway concentrations due to emissions from congregated idling trucks as well as off-road vehicles, such as locomotives, yard tractors, and cargo handling equipment (Brantley et al. 2019; Port of LA 2025; Port of LB

2025). Given this, we set buffers around intermodal port terminals, railyards, and clustered freight facilities at one kilometer to reflect the likely higher pollution concentrations of idling vehicles at these locations.

We determined clustered freight facilities to be those sited within 500 meters of one another. Freight facilities not falling into this category were assigned at a buffer of 500 meters. Each buffer included fenceline estimates to account for additional distance between the border of the facility or corridor and areas within the facility or corridor where vehicle and equipment operations and resulting emissions were likely to occur.

- 1 kilometer for large/clustered freight facilities:
    - Principle port terminals (including a 100 meter fenceline addition)
    - Clustered warehouses, distribution centers, truck terminals (>2 overlapping 500 meter radii) (including a 10 meter fenceline)
    - Railyards (including a 100 meter fenceline addition)
- 500 meters for freight corridors and single freight facilities:
    - Primary freight corridors (including a 50 meter fenceline)
    - Single warehouses, distribution centers, truck terminals (including a 10 meter fenceline)

Analysis of Cumulative Exposure from Clustered Hubs

Populations within freight buffer areas were grouped by the number of buffers overlapping their locations to create a count of population by increasing freight facility clusters. Weighted sociodemographic, pollution, and public health data were compared with national averages. The results suggested that average values for ambient diesel particulate matter, days with particulate matter and ground-level ozone exceeding National Ambient Air Quality Standards, cancer risk from air toxics exposure, share of people of color, and share of residents living below 200 percent of the federal poverty level were all significantly higher in areas near freight facilities.

UCS found relationships between the concentration of nearby freight facilities and multiple indicators of environmental and health burdens. Areas with more freight facilities had higher census tract percentiles for key air-quality impacts, including diesel particulate matter (R^2=0.10, p=0.024) and the number of days exceeding National Ambient Air Quality Standards for ground-level ozone (R^2=0.36, $p<0.001$) and $PM_{2.5}$ (R^2= 0.29, $p<0.001$). We also found a strong relationship between freight facility concentration and elevated cancer risk (R^2= 0.85, $p<0.001$). These environmental burdens intersected with social inequities: census tracts with greater freight facility concentrations were more likely to have higher shares of residents of color (R^2= 0.66, $p<.001$) and moderately higher shares of households living below 200 percent of the federal poverty level (R^2= 0.15, p=.004).

ISR Compliance Option Review

ISRs provide covered facilities with a flexible menu of options to meet their compliance obligations. Options can include pollution mitigation actions and investments that directly reduce the pollution associated with the covered facility's operations, prepare a facility to host or deploy zero-emission vehicles and equipment, and address existing exposure to pollution for nearby sensitive receptors.

We reviewed compliance options of existing ISR programs, as well as those proposed in recently considered legislation to describe anticipated high-level environmental, market, and economic impacts. The compliance options reviewed include:

- Currently Implemented and Proposed Compliance Options:
    - Clean on-road vehicle visits and deployments;
    - Installation and use of zero-emission charging and fueling infrastructure;
    - On-site renewable energy generation and battery storage;
    - Acquisition and use of zero-emission cargo handling equipment;
    - Acquisition and use of zero-emission locomotives and switchers;
    - Air pollution mitigation measures; and
    - Mitigation fees.
- Emerging and Innovative Compliance Options:
    - Software solutions to improve queuing at ports and reduce idling;
    - Leveraging air pollution from wastewater treatment for zero-emission power at ports; and
    - Measures to reduce commuter pollution.

Qualitative Framework for Reviewing Best-Practice Compliance Options

A qualitative analytical framework provided a structured basis for evaluating compliance options available under existing and new ISRs. We introduced each option with an overview describing its purpose, functional characteristics, and operational context, followed by an assessment of the facility types for which the option was applicable. This established the technical relevance of each action across diverse types of freight facility.

The framework then evaluated the pollution-reduction potential of each option, considering both its capacity to reduce exposure for nearby sensitive receptors and its contribution to broader regional air-quality improvements. This assessment also distinguished whether an option replaced existing emissions-intensive activities or was an additive mitigation measure, clarifying its incremental environmental benefit.

A further dimension of the framework assessed how well each option supported the transition to zero-emission freight systems. This included examining its role in preparing facilities for the deployment of zero-emission vehicles and equipment and its influence on broader market adoption of electrification technologies.

Finally, the framework evaluated cost-effectiveness by examining upfront capital requirements, expected changes in operational costs, and additional ancillary benefits. These included improvements in operational efficiency, reduced community exposure, and other co-benefits that enhanced the overall value of the compliance action.

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