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Sustainable Goods Movement

Environmental Implications of Trucks, Trains, Ships, and Planes

by **James Corbett**
and **James Winebrake**

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Consumers today have a hard time

avoiding products manufactured and transported overseas, as economic globalization moves more goods from factories to major markets throughout the world. For example, in 2005, imports and exports represented approximately 25% of the U.S. economy, up from 15% in 1990.¹ Increased goods movements to and from international markets generate increased domestic freight transport, as products are shipped to and from a nation's ports within a domestic freight transportation infrastructure that includes trucks, trains, ships, and planes.

Freight's increasing economic role implies a proportional increase in energy use and emissions from freight transport modes, contributing significantly to global, regional, and local air pollution problems. Global and domestic trends suggest that freight transportation will become even more important, an emerging leviathan threatening both climate change mitigation and air quality goals across other sectors.

Regulators, environmental managers, and decision-makers need to better understand these trends to address problems of emissions, climate change, and energy conservation associated with goods movement. This article considers emerging environmental issues that affect global freight movement and identifies some of the challenges to improve freight mobility and sustainability.

FREIGHT TRANSPORT OVERVIEW

The global freight transportation system includes ocean and coastal routes, inland waterways, railways, roads, and airways, and consists of both mono-modal and multi-modal networks (see Figure 1). In a mono-modal scenario, freight is moved from one location to another using a single mode of transport (e.g., truck). In a multi-modal scenario, freight is moved using combinations of transport modes (e.g., truck to barge to ocean-going vessel). International freight transportation commonly incorporates multiple transport modes via an "intermodal network," providing efficient transfers—often in the form of containerized cargo—among modes.

The choice of transport mode (especially for containerized cargo movement) involves balancing tradeoffs to facilitate trade among global corporations and nations. In the current global economy, competing factors have been time, cost, and delivery reliability. Low-cost transport modes may be less preferred than faster modes for time-sensitive cargo; however, slower, lower cost modes often carry more per trip. With proper planning, these modes can reliably deliver larger quantities to meet just-in-time inventory needs. Analogous to a relay race, multiple modes are needed to deliver cargo from the starting line to the finish line (i.e., origin to destination).

Cargo ton-kilometers (tkm) represent one common measure of the work done to compare mode share in freight transportation. In 2002, more than 4600 billion tkm (Gtkm) of freight moved domestically in the United States, amounting to a value of over US\$8.3 trillion.³ Single-mode journeys were the most common for U.S. domestic transport, representing more than 91% of the total freight movement (in tkm); multi-modal transport constituted approximately 7% of domestic transport. Of the single-mode transport

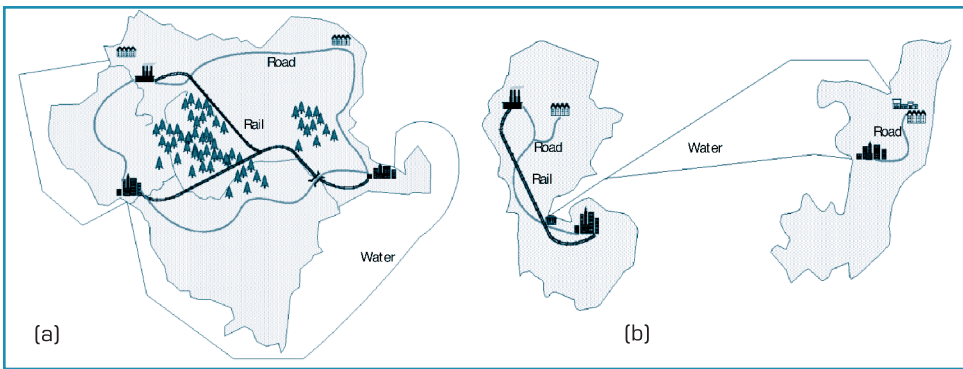


Figure 1. Illustration of freight movement as (a) several mono-modal approaches and (b) multi-modal approach.

Source: International Maritime Organization Study of Greenhouse Gases from Ships.²

modes, truck and rail were dominant, each moving 40% of the total tkm in the United States. Marine shipping moved 9% and air moved 0.2%. Total tkm for each mode are shown in Figure 2. Domestic multi-modal movements were led by rail-water combinations representing approximately 4% of the total freight movement.

The European Union (EU) has a similar mode share for trucking, approximately 45% of total freight transport work. However, European waterborne freight, meaning inland river and shortsea combined, is second in mode share, moving 40–44% of the cargo tkm in recent years (“shortsea” utilizes inland and coastal waterways instead of land-routes to move commercial freight from among domestic or regional ports without ocean). Like estimates for truck and rail, neither U.S. nor EU data include ocean shipping or airfreight outside their national domains. These summaries also ignore the

FREIGHT TRENDS, AIR QUALITY, AND CLIMATE CHANGE

The United States spends approximately 6–7% of its gross domestic product (GDP) on freight transport annually, while freight goods and services provide significantly greater economic value. Moreover, U.S. economic reliance on the freight transportation system nearly doubled since 1990, with approximately 23% of GDP attributed to imports and exports in 2006.⁷ When characterized in terms of today’s global economy, these goods movement trends may not be surprising.

In fact, containerized cargoes delivered by ships are driving multi-modal freight growth; international containerized cargoes are increasing more than seven times faster than growth in bulk trades. Growing numbers of containers loaded on or discharged from ships serve as trip-generators for trucking (primarily), rail, and parcel shipments (air and ground). Indeed, a single containerized ship may carry enough boxed cargo to generate more than 10,000 truck trips—not counting empty container returns, noncargo trips, or partial loads. Freight energy use and emissions are coupled with this recent shift to the most energy-intensive freight modes (e.g., faster containerized ships, long-haul trucks, aircraft), often motivated by “just-in-time” business models taking advantage of inexpensive transportation energy and available labor.

46,000 Gtkm of seaborne trade moving cargoes among all trading nations from distances outside the domains from which national statistics are reported. For context, world seaborne trade volume is more than 10 times greater than all freight tkm in the United States, as shown in Figure 2.^{4,5} More than two-thirds (by weight) and more than 40% (by value) of U.S. consumer products are delivered by ships connecting the United States to the global freight network.⁶

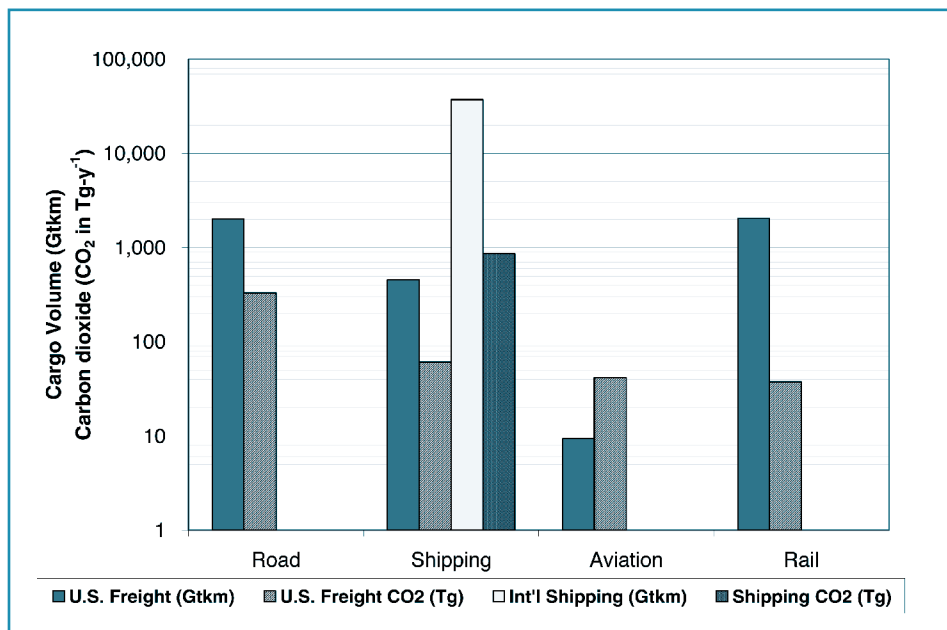


Figure 2. Comparison of freight mode shares (Gtkm and CO₂) for the United States (2003), with global cargo Gtkm and CO₂ estimates for international seaborne trade.

Note: Units are on a log scale.^{4,5}

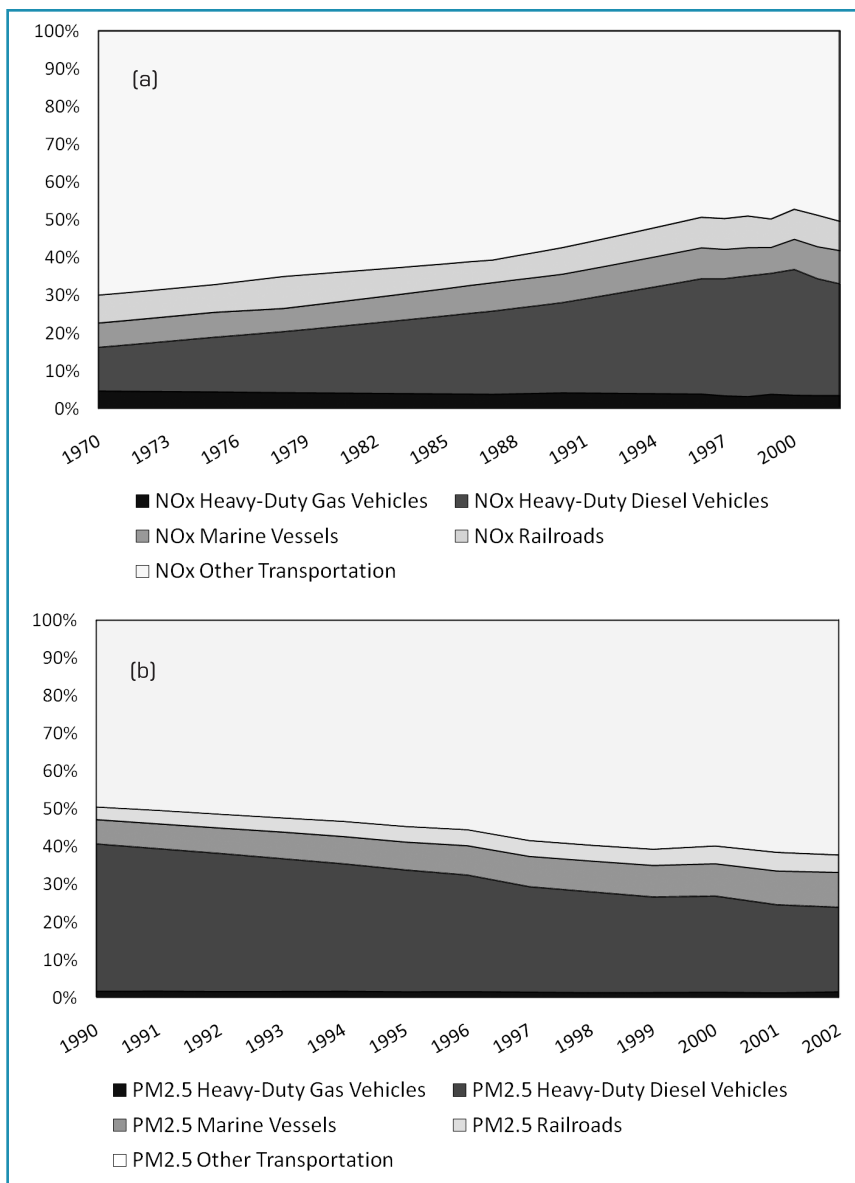


Figure 3. U.S. emissions trends from multimodal freight modes as a percent of total (on- and off-road) mobile source emissions for (a) NO_x and (b) PM_{2.5}.⁸

greenhouse gases, namely carbon dioxide (CO₂), oxides of nitrogen (NO_x), particulate matter (PM), sulfur oxides (SO_x), and air toxics. As a percentage of all mobile source emissions, heavy-duty truck, rail, and water transport together account for more than 25% of CO₂ emissions, approximately 50% of NO_x emissions, and nearly 40% of PM emissions in the United States. In Europe, these modes generate more than 30% of the transportation sector's CO₂ emissions.^{4,8}

Some transport modes are less pollution intensive. For example, along with Gtkm data, Figure 2 also contains data on CO₂ emissions by mode for the United States (in teragrams/yr, Tg/yr⁻¹). Using both sets of data, one can identify CO₂/tkm ratios useful in evaluating climate change trends in freight transportation. For example, rail and coastal shipping offer the lowest carbon intensity, while aviation is highest.

Figure 3 illustrates U.S. trends from a local and regional pollution perspective, revealing two important insights.⁸ First, as environmental policy action controlled automobile emissions, freight has become a more dominant source of NO_x and PM_{2.5}. Second, emissions regulations applied successfully to heavy-duty trucks has prevented their share of freight emissions from being a greater contribution to mobile source pollution, leveling trends in NO_x and reducing their share of PM emissions by more than 20% despite growth in goods movement.

Nonetheless, freight transport will continue to challenge environmental policy-makers as growth overcomes technology-induced emissions reductions. Global freight transportation and energy use continue to grow faster than the global economy, estimated to range between 3.6% and 5.9% per year over the past two decades; we forecast that world average freight growth will continue at 4% or more per year through 2020. This more than doubles overall transportation growth reported by the Intergovernmental Panel on Climate Change (IPCC).⁹

Air pollution from freight transportation has direct effects on human health and the environment. Besides air quality impacts on ozone and PM concentrations from all freight modes, high-sulfur fuels used by ships contributes to acidification of some coastal regions. Some of these impacts are now being controlled in various ways: (1) emissions control targets have included medium- and heavy-duty trucking (and to lesser degrees rail and water modes); (2) cleaner distillate fuels have been implemented for on-road

diesels, often extending to nonroad fuel distribution, and even ships are beginning to switch to low-sulfur fuels during operation in some regions; and (3) in-mode improvements in energy efficiency (and CO₂ emissions reductions) may occur during engine recapitalization and fleet turnover.

Transportation and environmental professionals are working to put freight onto the "high road" of environmental performance. Examples of such methods include reducing highway speeds, restricting engine idling time, improving rail connections on-dock and among transfer facilities, and utilizing new technologies and fuels. However, trade growth and just-in-time preferences for faster, more energy-intensive transport modes (i.e., truck and air vs. ship and rail) mean that freight emissions are increasing. Growth in freight transportation presents an enormous challenge for setting technology targets,

Moving Freight to the High Road

Environmental performance is motivating new models of selecting intermodal freight routes. One example is the Geospatial Intermodal Freight Transportation (GIFT) model under joint development at the University of Delaware and the Rochester Institute of Technology.¹² A GIS-based model evaluating the intermodal transportation network (highway, rail, and marine), GIFT lets users explore optimal routing for competing logistics constraints, including minimization of time-of-delivery, costs, distance, energy, CO₂ emissions, and other environmental parameters. GIFT routes freight along mode segments and through intermodal transfers, with appropriate energy, cost, time, and emissions “penalties” applied for such transfers.

Graphical output from GIFT, illustrated in Figure 4 for a case of freight moving from an origin in New York City to a destination in Tallahassee, shows three routes: shortest time (dominated by trucking), lowest CO₂ (dominated by rail), and least cost (dominated by ship). Comparing network attributes (i.e., cost, time, energy, emissions) allows users to better understand tradeoffs associated with route and modal choices.

GIFT can evaluate freight performance responses to highway congestion, infrastructure development (e.g., constructing new ports, expanding highways, improving intermodal transfer facilities), and even natural and man-made disasters.

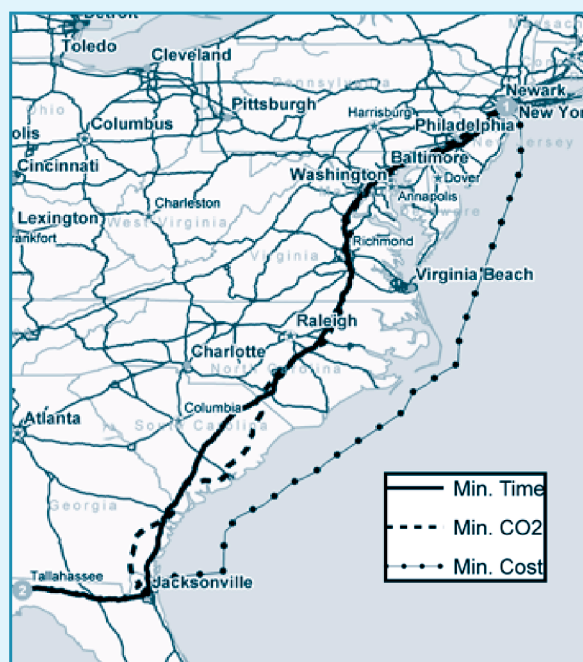


Figure 4. Example GIFT model graphical output. Routes shown by minimum time (primarily truck), minimum CO₂ (primarily rail), minimum cost (primarily ship).

especially when jointly addressing air quality and greenhouse gas concerns. At 4% annual growth in activity, fleet-wide controls would have to exceed 85% just to hold 2002 emissions constant through 2025; new-engine emissions controls alone may not achieve these targets, at least not without advanced alternative fuels. New attention focuses on evaluating strategies to reduce overall pollution by changing how trucks, trains, planes, and ships operate within a transportation infrastructure that is attracting reinvestment.

For freight transportation, mitigating CO₂ and criteria pollutants together may require improved freight logistics and shifting from higher to lower pollution-intensive modes. Adjusting freight transport modal shares can significantly address regional mobility, congestion, and environmental problems. The European Commission recently emphasized the role of shortsea shipping in maintaining an efficient transport system in Europe,¹⁰ and the U.S. Department of Transportation’s Maritime Administration is pursuing the expansion of shortsea shipping to aid in the reduction of growing freight congestion on U.S. rail and highway systems.¹¹

One could argue that pollution reductions in the freight sector may be more difficult to achieve than in other sectors. The recent IPCC Working Group III summary for policy-makers suggests that even mitigation alternatives such as a modal shift from road to rail and shipping could be “counteracted by growth in the sector,” and that implementation gaps include market barriers and a lack of policy frameworks to address them.⁹ However, without

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freight sector participation, other combustion sources may need more stringent controls, including conservation, demand-side constraints, and fuel switching, to offset goods movement emissions.

ADDRESSING ANALYTICAL GAPS

A sustainable freight transportation network incorporates necessary strategies for air quality and climate change mitigation within the context of transportation infrastructure investment, traffic safety, cargo security, and congestion. Transportation and environmental professionals need to provide policy-makers with integrated analytic tools and data that can (1) quantify costs, time-of-delivery, energy use, and emissions from intermodal freight transport; (2) evaluate tradeoffs among these criteria; (3) identify optimal routes and modal combinations within a network of travel paths that would lead to either minimum emissions, minimum costs, minimum travel time, or other objectives; and (4) evaluate modifications to the network, such as highway capacity expansion, intermodal transfer facility improvements, natural or human-caused disasters, infrastructure improvements to anticipate future freight transportation needs, or the impact of taxes or other policies.

Integrated freight activity models are showing potential for logistics to improve freight environmental performance more significantly than many transportation

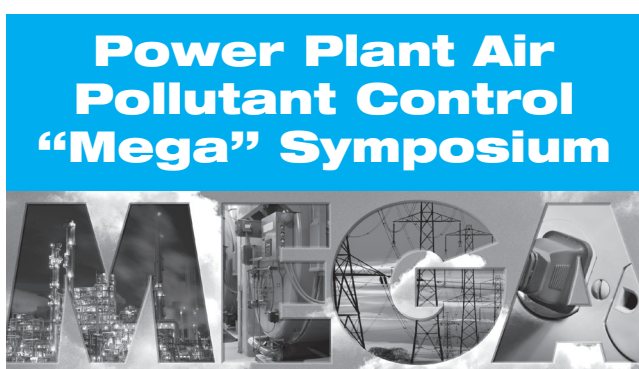
technology options (see sidebar “Moving Freight to the High Road” on page 11).

CONCLUSION

Policy-makers concerned about air quality and climate change are recognizing freight transportation as a significant and growing concern. Research and analysis of goods movement will help clarify the role of technology and policy in developing a freight transportation system that continues to serve economic needs in a sustainable fashion. With better information, infrastructure investments may be identified that reduce market barriers to more sustainable mode shares that deliver goods reliably to their intermediate and final destinations. Improved environmental performance in freight transport may also provide synergistic benefits to passenger mobility by reducing congestion and improving road safety. Avoided emissions will reduce health-risk exposure in metropolitan freight transportation corridors and cities, and energy savings will reduce greenhouse gas emissions. Together with leading retail businesses, logistics providers, and multimodal freight carriers, the freight transport sector may help make mobility more environmentally sustainable as it continues to carry the raw, intermediate, and finished products that serve society. **em**

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