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Freight Rail for the 21st Century: Opportunities for Mode Shift to Improve Efficiency and Resiliency

A Route Map for Policymakers

Eno Center for Transportation

Author

Sohail Husain
Policy Analyst,
Eno Center for Transportation

Other Contributors

Patrick McKenna
President and CEO,
Eno Center for Transportation

Rebecca Higgins
Vice President of Policy,
Eno Center for Transportation

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American Short Line and Regional Railroad Association

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Clement Solomon
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The leader in its field for more than a century, Eno provides government and industry leaders with timely research and an independent voice on policy issues. Eno publishes rigorous, objective analyses on the problems facing transportation and provides ideas for, and a clear path toward possible solutions. In addition, for nearly two decades, Eno Transportation Weekly (ETW) has been the premier federal transportation policy publication for transportation leaders across the country.

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Introduction

Robust options for modal choice enable supply chains to be more resilient while also enhancing efficiency for shippers. Commercial shippers make mode choice decisions by considering the tradeoff between time and cost of each mode and the value of their products. Ideally these economic decisions could drive efficiency and value in the freight sector, however shippers may also face constraints in infrastructure availability and shipping capacity as well as friction between modes, which limits their modal choices and increases inefficiency. Supply chain disruptions can exacerbate inefficiency, as was demonstrated during and after the pandemic, when small deficiencies in the supply chain, such as availability of shipping containers, led to global-scale delays and increased shipping costs.

The current capacity of our freight network faces numerous constraints. The highway trucking network experiences significant bottlenecks and congestion constraints caused by highway capacity gaps as well as crash related congestion. Trucking workforce shortages pose further challenges for commercial trucking, and limited truck parking and work hour regulations constrain long haul shipping. In the freight rail network, shippers face constraints in intermodal terminal capacity and the shortage of commercial spurs to access freight terminals, industrial parks and distribution centers.

These constraints, which are already demonstrated on the existing freight networks, will become more severe as freight volumes grow. Future trends, per estimates from the Freight Analysis Framework (FAF), indicate that freight volumes are expected to increase to 8.2 trillion ton-miles by 2050, which would be a 58 percent increase from the 2020 figures.[1] Even if these estimates prove only half correct, this projected growth means that the freight network capacity will need to grow significantly. At the same time, disruptions related to natural disasters and extreme weather are also anticipated to increase over this period. Disasters that affect a specific geographic location can still result in cascading impacts throughout a network or supply chain. As natural disasters become more frequent and severe, it will become more urgent to strengthen the efficiency of the freight network and create a resilient, cross-modal network that sustains commerce by avoiding the risk of a single point of failure.

To accommodate the growth in freight shipping volumes, mitigate supply chain disruption risk, provide economic opportunity for businesses and consumers, and increase the efficiency of the freight network, this paper intends to examine ways to reduce areas of friction that may prevent modal shift, and identify the areas of greatest opportunity to facilitate that shift. Given the projected need for investment to expand freight network capacity, this paper will evaluate the costs and benefits of investments that would expand freight rail movements, including the significant fuel and cost savings.

As another factor, a significant portion of rail volumes today are composed of fossil fuel products including coal and natural gas. Weakening demand for coal in particular has the rail industry adapting to backfill this gap. Rather than allow this economic shift to undermine the economic resilience of freight rail, policy makers may consider how to support the use of that excess capacity for the movement of other goods.

Enabling shippers to more readily choose freight rail will also have benefits for transportation emissions and safety. The freight transportation sector's contribution to overall greenhouse gas (GHG) emissions has increased steadily over the last few decades, rising from 24 percent in 1990 to 32 percent within the transportation GHG emissions by 2020. However, among the freight modes, railroads contribute much lower levels of emissions. While medium and heavy-duty trucks emit nearly 24 percent of transportation emissions in the United States, railroads contribute only about two percent.[2] Today, rail is the most fuel-efficient form of surface transportation and as the industry continues to innovate, it can play a significant role in reducing the transportation sector's emissions. Therefore, as an available, sustainable surface transportation option, shifting freight to railroads presents a key opportunity to reduce carbon emissions, given that railroads are about four times more fuel-efficient and eight times more energy efficient than trucks.

As this paper shows, a robust and reliable freight rail system can play a vital role in addressing multiple policy goals—improve supply chain resilience, ensure that goods continue to move efficiently even in the face of increasingly regular climate disruptions, reduce transportation emissions within the freight sector, and expand efficient and economical choices for shippers. To achieve these goals, it is crucial to analyze the current state of freight transportation in the United States and explore the potential market growth for freight rail, particularly in shipment types and travel distances where railroads compete most directly with trucks.

The paper will begin with a section analyzing the current and future freight movements using the latest FAF dataset and the factors that influence mode choice for shippers. The following section examines opportunities to expand freight rail shipping, focusing on strategies in modal shift, infrastructure development, planning, and innovation efficiency. The final section evaluates the costs and benefits of modal shift, including impacts on emissions, fuel consumption, and safety.

The primary objective for this report is to bring together various proposals and ideas for improving freight rail policy with the intention of improving efficiency and resiliency, while also reducing carbon emissions and improving safety. This report is developed for policymakers and transportation professionals seeking a better understanding of the primary issues facing railroads in the 21st century, and practical advice on how to position freight rail to help address challenges of shipping costs, fuel consumption, safety, and emissions.

We reviewed freight data from various public and private sources, including a robust analysis of available freight data published by the Bureau of Transportation Statistics and Federal Highway Administration. We also conducted an extensive literature review of the past and existing freight policies implemented inside and outside the US to improve freight rail mode share and increase energy efficiency. Our research was supported by interviews with industry and issue area experts from diverse sectors. Finally, we relied heavily on the guidance of a panel of experts representing federal and state transportation agencies, railroad companies, shippers, and electric vehicle manufacturers.

Analysis of the Freight Sector

This section analyzes the size, nature, and location of freight movement in the United States. We look at historical trends of freight tonnage and ton-miles to study how freight has conventionally moved in the United States across different modes and distances.

Wherever data is available, we also look at the future estimates to see how these trends are going to evolve between now and 2050. The latest Freight Analysis Framework (FAF), which was released in 2020 by Bureau of Transportation Statistics (BTS), offers projections until 2050.

We also analyze how the top ten commodities, in terms of tonnage, are moved through different modes and across different distances. We use the waybill sample data published by the Surface Transportation Board to analyze the types of commodities moved over railroads. Comparing this sample data with historical waybill data allows us to assess changing trends in the types of commodities typically moved by railroads and future growth opportunities.

Freight Movement in the United States

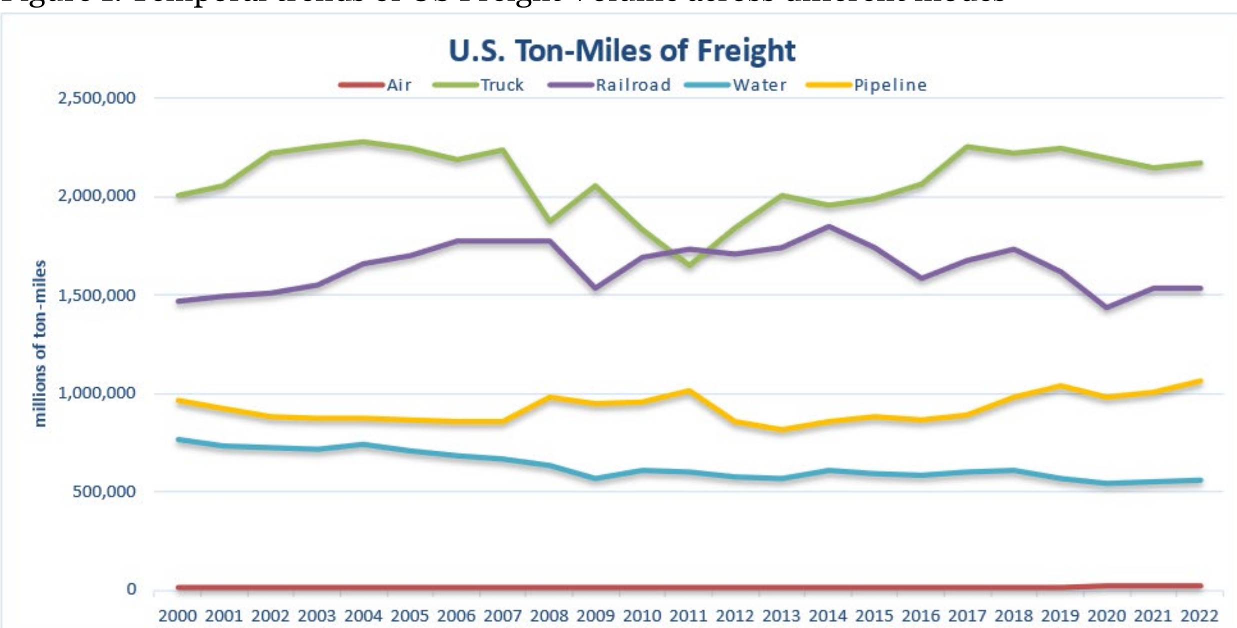
To some degree, the varying costs, infrastructure, and delivery speeds of each freight mode shape the types of goods for which that mode can provide competitive shipping options and determines the commodities and travel distances for which each mode is ideally suited. Freight carriers can be both cooperators for intermodal goods as well as competitors; over the long run, investments in infrastructure and technology combined with regulatory changes can serve either to increase competition or impede mode shift.

In this section, we analyze the scale of freight movement in the United States and role of each of the modes, both historically and in the current context. We also assess the typical distance of freight movement and commodity types for different modes with the intention to highlight opportunities where freight rail could be an increasingly attractive mode of shipping.

Volumes

In the United States, nearly 5.2 trillion ton-miles of freight is moved annually across all modes.[3] Trucks carry about 46 percent of total freight volume, amounting to about 2.4 trillion ton-miles every year. Railroads are the second most predominant mode by ton-miles carried, carrying about 28 percent of freight volume in 2022. This is similar to the typical freight mode split in other OECD (Organization for Economic Cooperation and Development) countries, where on average 40 percent of freight ton-miles is served by trucks and 24 percent by railroads.[4]

Figure 1. Temporal trends of US Freight Volume across different modes



Source: USDOT, Bureau of Transportation Statistics, "U.S. Ton-Miles of Freight."

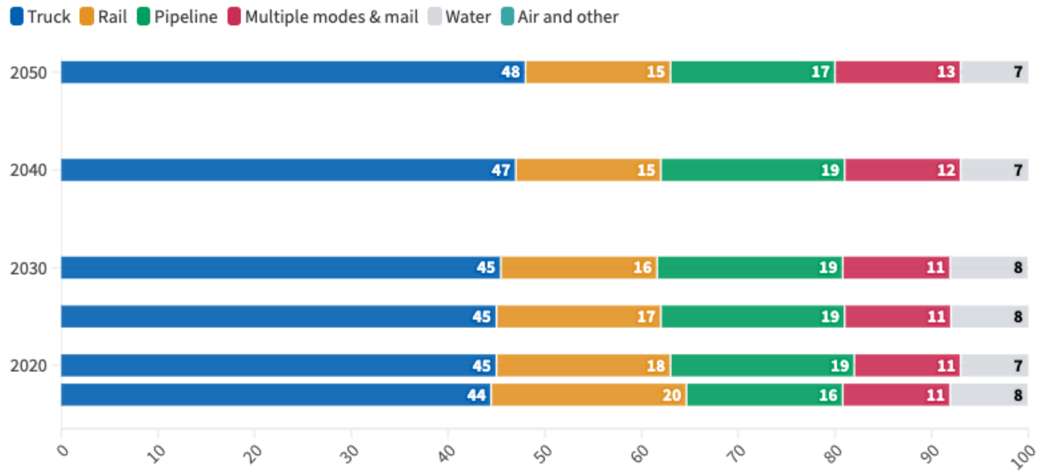
Figure 1 above shows that U.S. ton-miles of freight moved by rail increased between 2000 and 2008 and remained steady until 2013. The graph demonstrates that total freight volumes are largely dictated by the overall economic conditions, but in certain periods modes do gain or lose volume at the others' expense. Between 1998 and 2004, both trucks and rail increased their ton-miles carried year-on-year. Between 2008 and 2012, trucks and rail alternated between losing and gaining modal share.

While trucks and rail can compete for shipping volumes, they also cooperate in intermodal transport networks, in which largely containerized goods are carried by multiple modes from origin to destination, including water, rail, and/or trucks. The term "multiple modes and mail," refers to freight movements that involve more than one mode of transportation. This includes intermodal movements (container shipping by ship, rail, and truck for example) and parcel delivery (goods moved by UPS or FedEx that may be moved by air, rail, or any other means). Although FAF provides data on intermodal freight trips, it does not provide information on the ton-miles moved by each component mode of intermodal volumes. For example, while 11 percent of total ton-miles in 2017 was transported through "multiple modes and mail", it is unclear what percentage of each ton-miles was moved by truck versus rail.[5] Knowing the share of rail movement of intermodal traffic could help to quantify what role rail plays in intermodal traffic.

Despite this, it is clear from data on rail volumes that intermodal rail transport is growing. Measurements of rail traffic differentiate between intermodal units, which are capable of being transferred to trucks, and carloads, which include boxcars and other car types. Intermodal transport has been growing consistently over the past few decades since the adoption of the intermodal shipping containers in the 1950s, whereas carload traffic has been decreasing since 2000. Railroads have heavily invested in intermodal infrastructure at ports and inland facilities to enable the transfer of containers between rail and either ships or trucks. In 2023, intermodal freight movement accounted for 25 percent of the revenue for Class I railroads.[6]

As per estimates released by the BTS through their latest FAF, freight volume is expected to increase to 8.1 trillion ton-miles by 2050, which is a 56 percent increase from what it was in 2020.[7] Freight ton-miles are expected to increase 1.7 percent per year between now and 2050 on average.[8] But this increased freight demand is predicted to be served largely by intermodal and truck transportation, with rail losing its mode share through 2050. As shown in Figure 2, by 2050, rail is predicted to carry only about 15 percent of total freight ton-miles as compared to 20 percent in 2017.

Figure 2. Freight volume (ton-miles) by mode



Source: USDOT, Bureau of Transportation Statistics, "Moving Goods in the United States."

Distances

The mode share between trucks and rail looks quite different when "tons" is used as the unit of measurement instead of "ton-miles". In 2017, railroads carried only about 7 percent of the total freight weight. This is because railroads typically serve long-distance, heavy-density, and low-value freight movements, resulting in a higher share of ton-miles than tons. FAF data indicates that most freight tonnage is moved over short distances. About 74 percent of total freight weight is transported within 250 miles and about 36 percent is within 100 miles.[9] This typical nature of freight movement is not expected to change between now and 2050, as shown in Figure 3.

Figure 3. Percentage freight tonnage by distance moved (miles)

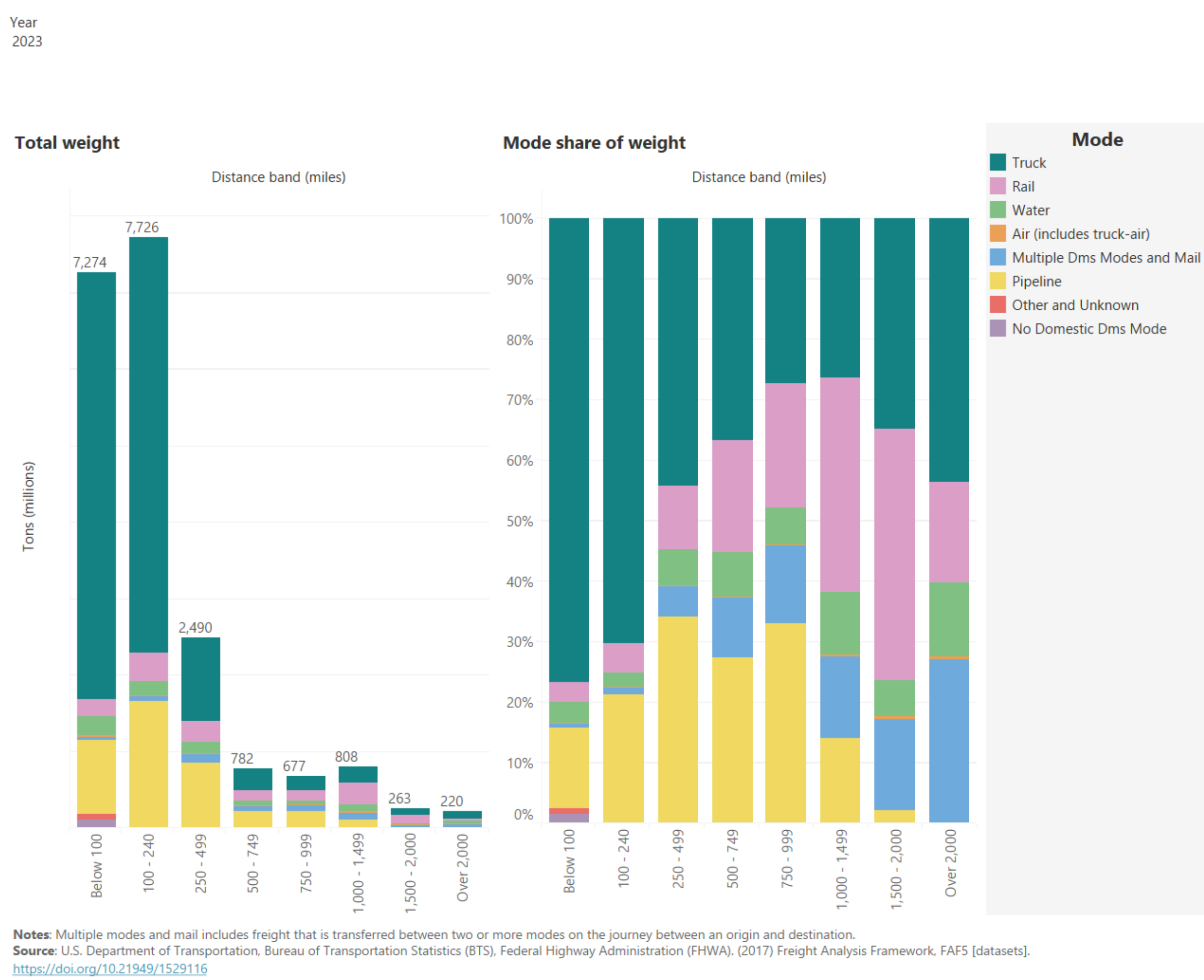
Year	Below 100	100-240	250-499	500-749	750-999	1,000-1,499	1,500-2,000	Over 2,000
2017	36.9%	37.0%	12.2%	3.8%	3.2%	4.3%	1.4%	1.2%
2023	35.9%	38.2%	12.3%	3.9%	3.3%	4.0%	1.3%	1.1%
2050	35.2%	37.9%	12.9%	3.8%	3.4%	3.9%	1.4%	1.5%

Source: USDOT, Bureau of Transportation Statistics, Freight Facts and Figures, "Moving Goods in the United States."

Currently, trucks are the predominant mode of transport for short-distance freight trips under 250 miles, which –as Figure 3 shows—represented 74.1 percent of all freight tonnage in 2023. More than 70 percent of freight weight in this distance range is moved by trucks. Further, FAF estimates indicate that this trend is likely to continue well into 2050.

Freight rail is more competitive for longer distance shipping. For freight tonnage that is moved more than 1,000 miles, railroads move the highest share of the weight; specifically 36 percent of weight is moved by rail in the distance band of 1,000 – 1,500 miles and 41 percent for 1,500 – 2,000 miles , shown in Figure 4.[10] While railroads clearly have an advantage in this distance range, trucks still carry about 25-30 percent of freight weight in the 1,000-2,000 miles distance range. The goods being carried by trucks at these distances may be most likely candidates for mode switching to rail, and assessing the types of commodities carried by trucks over those longer distances would improve the analysis on the potential for mode shift.

Figure 4. Mode share by weight along distance bands (miles)



Source: USDOT, Bureau of Transportation Statistics, Freight Facts and Figures, "Moving Goods in the United States."

As Figure 4 shows, the percentage of intermodal shipping increases significantly in the freight-trips above 2,000 miles category. While the mode split within the 'intermodal' category is unavailable, it is likely that these long-haul freight trips above 2,000 miles are largely served by a combination of water, rail, and trucks, whereas the medium-haul trips of between 500 and 2,000 miles are served by trucks and rail. More granular data on modes used for intermodal shipping would also provide more analysis for the opportunities for mode shift.

Commodities

To assess opportunities for rail to be competitive to trucking, it is important to explore how different commodity types are moved across the United States. The top 20 commodities comprise about 84 percent of the total freight weight moved in the U.S., based on both historical data and future estimates.[11] Certain commodities are better candidates for mode shift than others, so studying the current and historical mode share of commodities will help in identifying which commodity types and movements could be captured by rail. The latest FAF dataset shows that the top commodities moved in terms of total ton-miles today are petroleum and fuel products including natural gas, crude oil, and gasoline; gravel; non-metal mineral products; grain and agricultural products; coal; and foodstuffs.

Figure 5. Modal split of Top 11 commodities based on weight in 2023

Top Commodities	Truck	Rail	Water	Air	Intermodal	Pipeline	Other/unknown	Total Weight (thousand lbs.)
Natural Gas/Fossil Fuels	12%	7%	3%	0%	0.7%	77%	0%	3,135,356
Gravel	90%	5%	3%	0.01%	1%	0.01%	0.5%	2,075,021
Gasoline	62%	2%	5%	0.01%	2%	29%	0%	1,439,329
Cereal Grains	78%	14%	5%	0%	3%	0%	0%	1,343,053
Nonmetal mineral products	94%	3%	0.7%	0.4%	2%	0.01%	0%	1,199,802
Crude Petroleum	2%	2%	6%		0%	81%	0%	1,166,626
Fuel Oils	64%	3%	13%	0.01%	2%	18%	0%	960,839
Other agricultural products	82%	8%	7%	0.02%	2%	0%	0.01%	741,396
Natural sands	80%	14%	1%	0.01%	5%	0%	0%	709,856
Other foodstuffs	88%	5%	1%	0.01%	6%	0%	0%	693,723
Coal	20%	55%	12%	0.01%	3%	0%	9%	688,791

Source: USDOT, Bureau of Transportation Statistics, Top Commodities Moved by Mode, 2023.

- Petroleum fuel products are largely moved via pipelines and trucks. For crude petroleum and petroleum products, pipelines carry about 80 percent of ton-miles. For gasoline and fuel oils, pipelines carry only 29 percent and 18 percent of ton-miles, respectively, and trucks are the predominant mode, carrying about 62 percent of ton-miles of gasoline and 64 percent of ton-miles of fuel oil.

- Domestic transportation of natural gas occurs mainly by pipeline, but ships and tanker trucks also transport liquified natural gas where pipeline infrastructure doesn't exist.

- Rail carries around five percent of gravel and three percent of nonmetal mineral products. Trucking remains the predominant mode for transporting these commodities. These trends are expected to continue through 2050.

- Railroads have a majority share in carrying coal. In 2023, railroads moved 55 percent of total ton-weight of coal. However, total coal movement is on a downward trajectory and by 2050, coal is anticipated to no longer be among the top 10 commodities moved in terms of weight.

- Rail carries around 14 percent of cereal grains. Trucks account for the vast majority of cereal grain movements, but compared to other goods, rail contributes relatively more to cereal grain movements

- Rail carries around 14 percent of natural sands. Again, trucking accounts for the majority of these movements.

- Basic chemicals, plastics, rubber, and natural sands are moved by intermodal means. While granular public data is not available to show the modal composition of the "intermodal" category, it is likely that these commodities are carried by a combination of rail (for long-haul) and trucks (for first- and last-mile).

Freight volumes can also be examined based on the percentage of total rail movement they represent through analysis of waybill data published by the Surface Transportation Board (STB), which provides information on the top commodities carried by rail in terms of carloads, tonnage, and revenue.

The cost of coal relative to natural gas has led to declining demand for coal in energy production and as a result, coal consumption dropped from 1.13 billion tons in 2007 to 546 million in 2021.[12] Far from reversing, these trends are expected to accelerate and between 2020 and 2050, coal-based energy generation is expected to decline by more than 40 percent. In 2006, 23 percent of all rail carloads carried coal and coal comprised 41 percent of total rail freight tonnage[13] Due to reduction in total coal movement, these numbers are declining and in 2019, only 16 percent of carloads carried coal and coal comprised less than a third of tonnage. Despite declines in total volume, coal continues to be the top commodity carried by rail. It is also possible that decreasing demand for fossil fuels could affect demand for freight rail shipping of fuel oils, gasoline, and natural gas. The combined effect of declining volume of coal and other fossil fuels could result in significant underutilized capacity for railroads, which could enable rail to carry other commodities currently being carried by truck. Efficient distribution of shipping volumes to shipping capacity could help alleviate increasing congestion on roadways projected as a result of increasing freight volumes.

Capacity Constraints

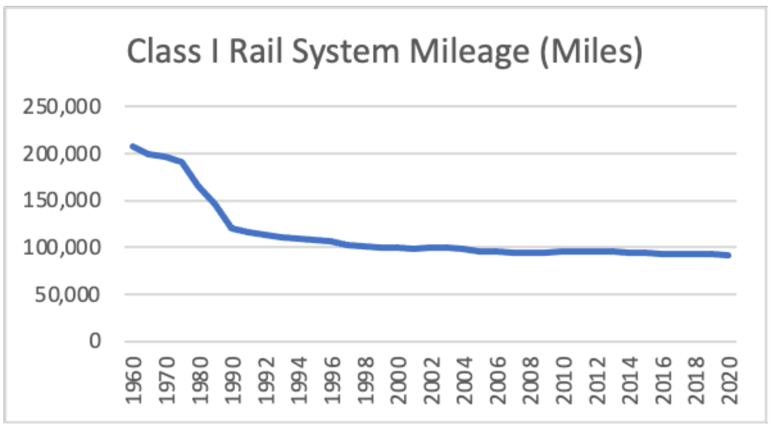
The United States has around four million miles of public roads, and total traffic volume for 2024 was around three trillion vehicle miles. Trucks accounted for around 10.5 percent of total traffic volume, at around 300 billion vehicle miles traveled in 2024.[14] The annual average daily traffic volume (AADT) is another data point that shows the average volume of traffic along the roads. In their annual report, the data collection company Replica visualizes AADT to show the level of traffic volume across the country. According to Replica, the median Interstate AADT for single and combination trucks moving freight is 4,000 AADT. The area with highest level of traffic volume is I-80 going south from Chicago, IL, at around 25,000 freight AADT trips. Generally, the higher freight volumes are located near major shipping hubs like Chicago, Memphis, St. Louis, and Los Angeles.

The U.S. freight rail system is the largest in the world, with 1.6 million rail cars, 28,000 locomotives, and 140,000 miles of rail lines.[15] Since 2014, the total freight volume moved by rail has declined accompanied by a corresponding growth in truck and intermodal freight volumes.[16] Some of this decrease may be attributable to precision scheduled railroading (PSR), a profit-maximizing business model which major Class I railroads have adopted by focusing on long-distance routes serving high volume shippers. This has essentially reduced rail mode share of freight as small shippers moved away from rail to other modes, including trucking and intermodal. As seen in Figure 6, the mileage of Class I rail has steadily decreased over the years. As per FAF estimates, the freight mode share of rail is expected to further decrease between now and 2050.

Expanding rail capacity by laying out new infrastructure, such as tracks, crossings, and signals can help railroads operate safely and increase their capacity. In particular, expanding rail capacity through new rail infrastructure can help short lines to serve small shippers, for whom rail could be a competitive, sustainable transportation option. Additional capacity gives the railroad the ability to move more goods and relieve congestion on roads by shifting some goods movement from trucking to rail.

New rail infrastructure, including double tracking, longer siding tracks, and improved signaling, are also part of building resiliency in the rail network. Additional trackage creates capacity that railroads can use in the event of disruptions and improved signaling keeps trains safe. A resilient rail network is one in which trains can be re-routed to other parts of the network. New tracks and improved signaling improve capacity and facilitate the need to re-route trains at times when one part of the network is disrupted.

Figure 6. Class I rail system Mileage



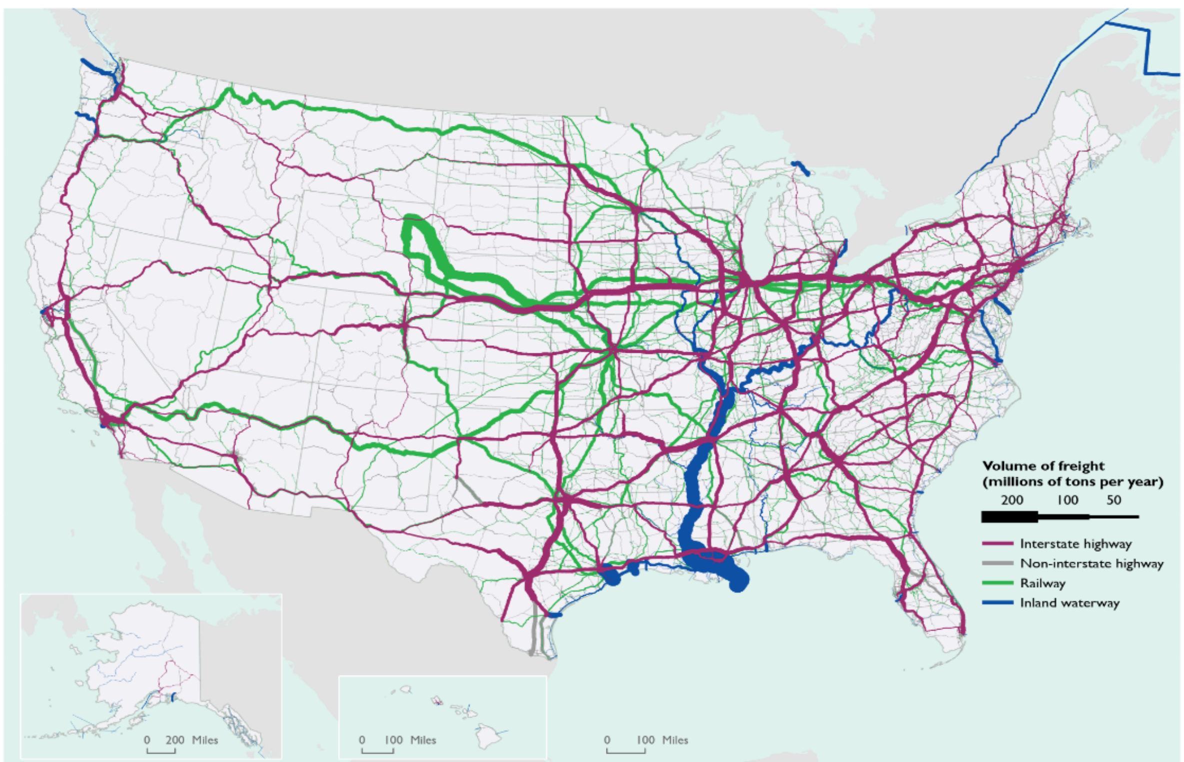
Source: Data taken from Bureau of Transportation Statistics, “Class I Railroad System Mileage and Ton-Miles of Freight 1960-2021.”

The private sector has been the primary developer and owner of freight rail assets in the United States. Class I railroads have cumulatively spent about $23 billion a year on average on capital expenditure and maintenance costs.[17] According to AAR, this is about six times the amount that the average U.S. manufacturer spends on capital expenditures. Class II and Class III railroads have comparatively smaller budgets to make capital investments in rail infrastructure and generally rely on support from federal, state, and local funding. Further, they face high maintenance costs as they typically own and operate rolling stock and rail tracks that may be aging and in poor condition. As per ASLRRA, short line railroads typically spend nearly 25 to 33 percent of their revenues on capital expenditures and maintenance of infrastructure.[18] Operating on these marginal profits, short line railroads must rely more heavily on tax credits. Since the creation of the Consolidated Rail Infrastructure Safety Improvement (CRISI) program in 2015, short lines have also received $2.7 billion in grants.[19]

The current and future capacity of the freight network is best captured in the following maps, shown in Figures 7 and 8. The freight flows in 2018 present highway data from 2015 and rail/waterway data from 2018. While not showing current data, the trend in the map indicates that highways in the Midwest and northeast carry close to 100 million tons of freight per year. To understand the future capacity, it is best to compare Figure 7 with Figure 8. Figure 7 shows the freight network carries a substantial amount of freight, concentrated in certain parts of the country. But when comparing with Figure 8, the volume of freight will increase by 2045 and cause strain on the freight network, specifically the highway system.

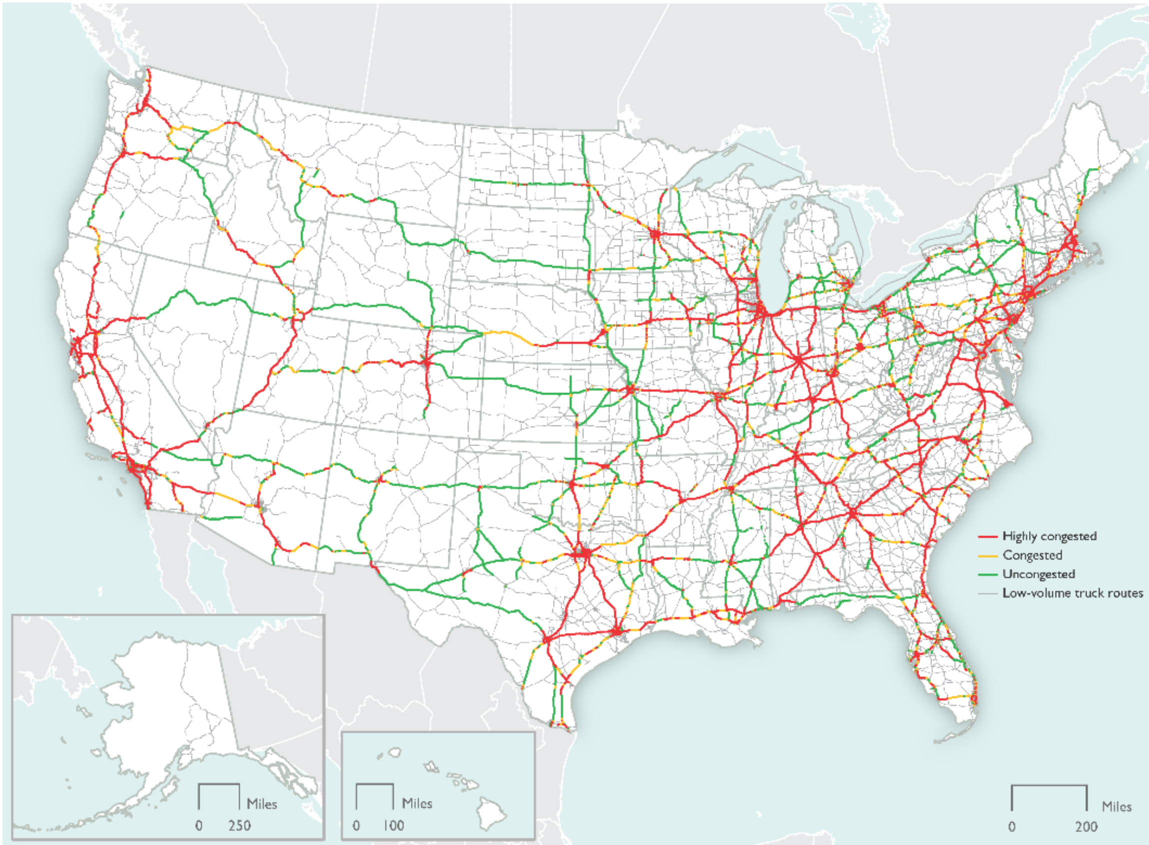
Figure 7. Freight Flows by Highway, Rail, and Waterway

Freight Flows by Highway, Railway, and Waterway: 2018



NOTE: Highway flows depicted in this map are based on the Freight Analysis Framework (FAF) data for 2015—the latest year for which the FAF network flow data is available.
SOURCES: Highway—U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework, version 4.3.1, 2015. Rail—Based on Surface Transportation Board, Annual Carload Waybill Sample and rail freight flow assignment done by Oakridge National Laboratory, 2018. Inland Waterways—U.S. Army Corps of Engineers, Institute of Water Resources, Annual Vessel Operating Activity and Lock Performance Monitoring System data, 2018.

Figure 8. 2045 peak period projected congestion on high volume truck portions of national highway system



Source: USDOT, Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework, version 4.5, 2019.

Currently, there is a concentration of freight volume around major shipping hubs, but the 2045 projection indicates high congestion around major shipping hubs along with significant portions of the highway network. As the volume of freight increases, if this volume is absorbed by the highway system it may lead to highly congested roads. Congestion is only one of the impacts that will result from the increase in freight traffic on highways; impacts will also include safety outcomes and the infrastructure quality of the roads themselves.

According to the American Society of Civil Engineers' infrastructure report card, the share of interstate highway pavements with poor ride quality rose from 15.8 percent of 22.6 percent between 2008 and 2018. Increasing freight traffic will result in more trucks on the roads, which increases the wear and tear of the road. Non-interstate roads, such as rural highways and arterial roads are also at risk for deterioration. The congestion on interstates may push trucks to use secondary roads, which do not have the same ability to handle large amounts of traffic, or the weights of commercial trucking. Poor roadway condition can also lead to unsafe conditions for drivers and can exacerbate congestion.

In all, the increase in congestion and damage to the roadway are liable to reduce the road's ability to move freight.

Longterm economic resilience of freight rail demands that railroads find opportunities and build their capacity to move other commodities to replace those sectors that are projected to decline. In the power generation space, coal has experienced decline over the years. In general, both U.S. coal consumption and production have declined between 2008 and 2018. According to AAR, coal averaged around a 52 percent share of electricity generation in the 1990s. By 2018, coal's share of electricity generation had dropped to 27 percent.[20]

Historically, coal has been the major commodity moved by rail in the United States. As mentioned previously, coal remains the largest single carload commodity moved by rail, accounting for 27 percent of non-intermodal shipments in January 2025. However, coal shipments decreased by around 2.3 percent in January 2025 compared to January 2024, continuing the downward trend of coal shipments by rail, which have been in general decline since their peak in 2008. In 2008, Class I railroads originated 7.71 million carloads of coal and moved 878.6 million tons of coal. By 2018, Class I railroads originated 4.44 million carloads of coal and moved 518.4 million tons of coal. Total carloads of coal decreased by almost 3 million cars and total coal moved fell by almost 300 million tons over ten years.

On the revenues side, railroads earned more revenue from coal than anything else. Railroads like the Norfolk & Western and Chesapeake & Ohio built their railroad's success on coal shipping. Coal traffic was also an important commodity for western railroads, namely the Burlington Northern, Chicago & Northwestern, and Union Pacific. Union Pacific averages 30 trains per day out of the Southern Powder River Basin, an area with large amounts of coal. Class I railroad revenue from coal was around $10 billion in 2018, which was down from $16.4 billion in 2011.[21] Even though coal production and consumption is down, coal remains a significant commodity moved by rail. Moreover, the Trump administration in early 2025 has encouraged and supported increased reliance on coal in the energy sector, which could mean that coal remains a major commodity moved by rail.

Railroads are also increasingly focusing on moving chemicals, and grain. To capture new market share, railroads should continue to explore opportunities to provide the safe, economical and reliable movement of agricultural produce, construction materials, waste/ scrap items, plastics, and paper-- all of which are moved predominantly by trucks.

Intermodal traffic remains an ever-growing part of the freight rail network. Intermodal traffic increased 10.3 percent, year-over-year in January 2025. This growth reflects robust consumer spending and increasing demand for containerized traffic. In 2024, US GDP grew by 2.8 percent, supported by consumer spending. The increase in consumer spending, by around six percent, fuels intermodal traffic. With more consumer spending and demand to move consumer goods in containerized traffic, there is an opportunity for rail to increase its movement of intermodal traffic. Already, the top ports in the country have on-dock rail facilities, providing railroads with the ability to better access container traffic coming from overseas and providing a connection to major shipping hubs across the country.

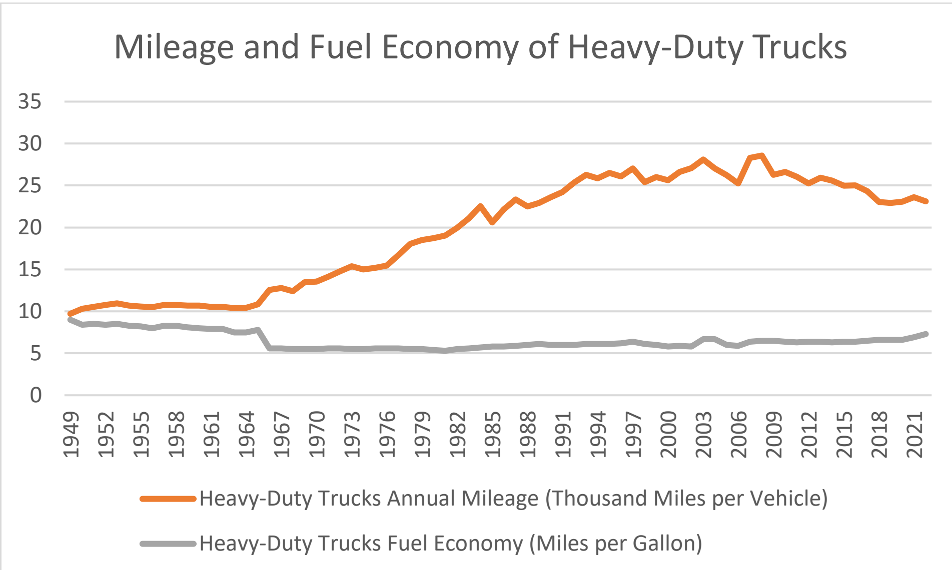
Recent tariff policies present a potential impact on intermodal and general freight movements. The Intermodal Association of North America, in a statement, addressed the tariff policy's impact on intermodal freight movements indicating that the rise in tariffs may lead to increased costs for consumer goods and an increase in costs for shippers.[22] Following the introduction of the tariff policy, the freight industry experienced a" tariff shockwave," where the amount of global container units booked fell by 49 percent and overall US exports and imports decreased.[23] As of the time of publication, booking volumes for container unit imports remain high, but the decline in late March and early April is an indication of uncertainty in international freight movements.

Tariffs that impact trade between the U.S., Mexico, and Canada are especially of concern. Increase in the cost of imported goods such as automobile parts and energy coming from Mexico and Canada can lead to a reduction in the movement of those goods across the borders. For rail and trucking, the reduction in imported goods from Canada and Mexico means trucks and trains that move across the border will move less freight. Tariff policies, while increasing costs of imported goods, may also boost domestic production. Rather than relying on imported automotive parts from Mexico, or natural gas from Canada, a concentrated focus on domestic production may increase domestic freight movement. The impact of the tariffs may be a shift in freight flows to stay more domestically and shift the supply chain to have goods sourced in the United States and moved within the United States. This does not mean that freight flows will decrease, only shift.

Fuel Consumption and Other costs

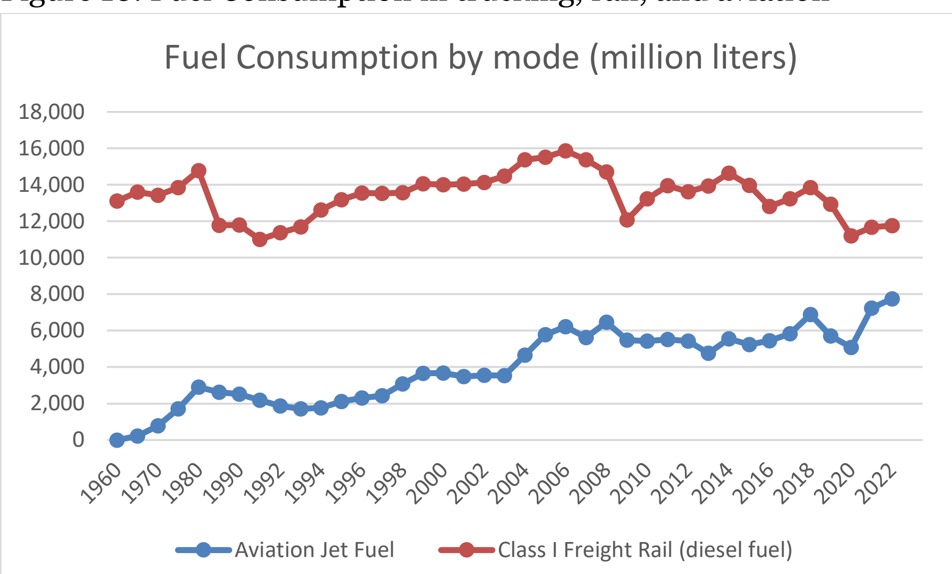
Fuel consumption data from the BTS indicates that trucks alone (which include single-unit, 2-axle, 6-tire or more combination trucks) consumed around 45 billion gallons of fuel in 2022.[24] In comparison, railroads and water-based transport consumed the least amount of fuel per year, around three billion gallons and six billion gallons, respectively.[25] Fuel consumption by trucks rapidly increased until 2008 except for minor dips in early 2000s; since 2008 total truck fuel consumption has held approximately steady. Total fuel consumption is a result of both fuel economy and total miles traveled; in the trucking sector, while truck fuel economy has remained essentially flat since 1970, total miles traveled have increased rapidly, as Figure 9 shows. Figure 10 shows fuel consumption between modes, truck and aviation jet fuel consumption has steadily increased over the years, while rail has remained relatively constant.

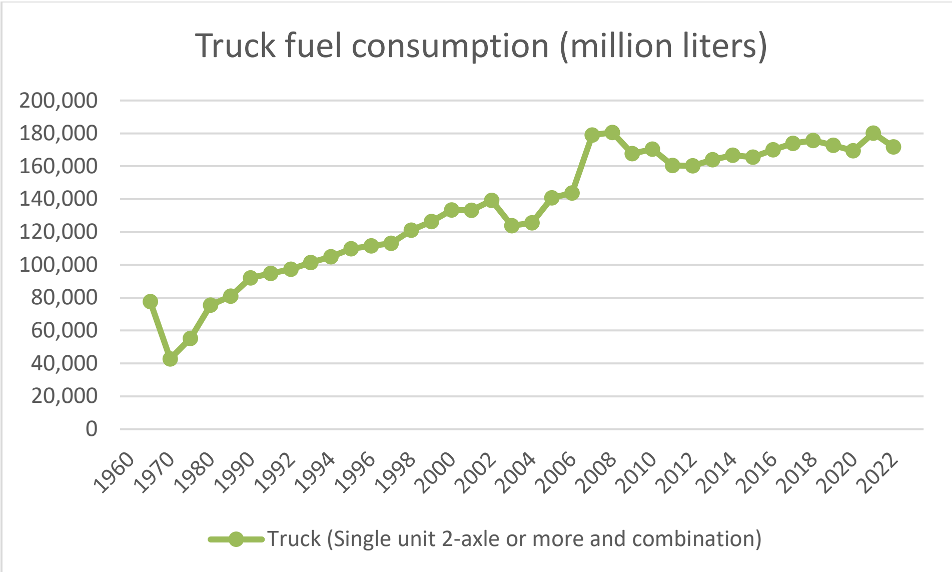
Figure 9. Trends in Heavy Duty Truck mileage and fuel economy



Source: U.S. Department of Energy, Energy Information Administration, "Monthly Energy Review" February 2025.

Figure 10. Fuel Consumption in trucking, rail, and aviation





Source: USDOT, Bureau of Transportation Statistics, "National Transportation Statistics 2023."

For the evaluation of efficient movement of goods, the measure of energy efficiency, e.g. the number of ton-miles of freight moved per gallon of fuel consumed, is a critical metric. A modal comparison of energy efficiency indicates that rail is currently the most sustainable land-based transportation option available for freight movement. Freight rail can move one ton of goods around 470 miles on a gallon of fuel, compared to trucking's 136 miles per gallon of fuel. As per an estimate by CSX, railroads are up to four times more fuel efficient than trucks.[26] Another study that looked at the relative fuel efficiencies of both the modes concluded that railroads are 1.9 to 5.5 times more fuel-efficient than trucks.[27]

Railroads have also made significant efficiency gains over the years as compared to trucks. A FRA study that analyzed past trends in truck and rail fuel efficiency cited changes in traffic mix, technical improvements, and changes in operating practices as three principal reasons behind the efficiency gains for railroads.[28] For example, fuel management systems used by railroads, which provide real-time guidance to engineers on how to most fuel-efficiently operate a train based on several factors can increase fuel efficiency by 14 percent.[29] Railroads are also reducing emissions in yards by anti-idling technologies.

In comparison, trucks have made marginal gains in fuel efficiency. As per the FRA study, fuel efficiency increased by eight percent for long-haul trucks and 11 percent for short-haul trucks between 1992 and 2002. This was calculated by multiplying fuel economy data for different model years (1992 and 2002) obtained from the U.S. Census Bureau by the average shipment weight.[30] The study attributes these increases to advancement in engine and non-engine technologies and operational improvements.

The costs of transportation come from the resources necessary to provide transportation services. These costs include fuel, labor, maintenance, and insurance. Fuel costs for roads (diesel and gasoline), rail (diesel), and aviation (jet fuel) have increased since 2020. Historically, rail and aviation fuel are lower than diesel and gasoline prices for roadway vehicles. In the trucking sector, the average marginal cost per mile for all cost elements increased since 2020, excluding permits and licenses. Labor, fuel, and truck lease/purchase payments were the largest costs for the trucking sector.

There is no question that trucking is and will remain a critical part of the freight network. Particularly as a last-mile or first-mile connection, trucks are a valuable component of the freight network that works with the freight rail to get goods where they need to go. It's clear though that the fuel-efficiency of railroads offers benefits to the freight supply chain in terms of resilience to fuel prices and makes mode shift to rail, where feasible and appropriate, an attractive and potentially low-cost means of reducing oil consumption as well as GHG emissions in the transportation sector.

With the potential for increased congestion on roadways and high fuel costs compared to non-road modes like rail and water, there is an opportunity for rail to take on capacity from the road, especially with long-distance traffic like intermodal container traffic. Freight movement is not slowing down, and the transportation network may not be able to accommodate future growth by road alone. Rail presents an opportunity to take on some freight traffic from roads. With declining coal shipments, there is potentially increased capacity on railroads to take on more intermodal traffic and take some of it off the roadway network. In turn, the road network will see less wear-and-tear on roads and reduced congestion, improving the ability of the roadway network to provide short-distance freight delivery, passenger movement, and emergency services. In this way, the shift towards rail would be not only a way to provide an economical method of moving long-distance freight for individual shippers but also a way to maximize well-being by improving infrastructure performance across multiple sectors. But mode choice of shippers is a complex issue driven by several factors as discussed in the next section.

Mode Choice

Shippers make mode choice decisions based on the type of commodities being moved, among other factors such as distance, value of goods, delivery time, weight of the shipment, infrastructure availability, reliability, and flexibility. Figure 11 below outlines a broader pattern of freight movement across different modes. Trucks are typically used to move lighter, high-value goods over short distances and mixed commodities. Rail is typically preferred by shippers when they want to move heavier, low-value bulk shipments, that are not time-sensitive, over long distances.

Figure 11. Freight Movement Across Modes of Transportation

	Distance	Value of Goods	Delivery Time	Weight
Truck	Short	High value	Time-sensitive	Light
Rail	Long	Low value	Less time-sensitive	Heavy
Barge	Long	Low value	Less time-sensitive	Heavy
Air	Long	High value	Time-sensitive	Light

Source: Information take from: USDOT, Bureau of Transportation Statistics, “Moving Goods in the United States,” and Riverside Logistics, “When Should I Consider using a different mode for my domestic freight.”

While barge and air mostly cater to specific shipment types, for which shippers do not have significant choice among different modes, rail and truck are two modes that generally compete for the same shipment types in some distance ranges. Particularly, movements involving low to medium value shipments that are not time-sensitive, rail and trucks can compete depending on the length of haulage, costs, and availability of infrastructure.

Shippers generally have a choice between moving their freight through trucks for the entire trip or through intermodal transport, comprising rail for the long-haul movement and trucks for the first- and last-mile connections. This is especially true for long-haul movements above 400 miles, for which intermodal becomes a better choice than trucks.[31] Shippers can justify the expensive (high fixed costs) drayage moves on either end of the trip if they can spread this cost over the length of the haul to reduce the average per mile costs of the haul. The choice among different modes for shippers is complex and depends on several factors. Reliability, transit time, safety, and availability of infrastructure (such as transloading facilities and sidings) are important considerations before cost becomes a determinant.

Mode Shift

One potential strategy to enhance the resilience and efficiency of the freight network is promoting mode shift from road to rail. Railroads carry about 27 percent of the total ton-miles of freight on average as compared to trucks, which carry about 46 percent of freight volume. In moving bulk commodities and intermodal traffic, railroads are generally more fuel efficient, being able to move more goods with less power compared to trucks. A greater reliance on rail can be a strategy to diversify and strengthen the freight network.

Energy efficiency in the freight network is important, and environmentally speaking, freight rail is a sustainable method of transporting goods that can aid in reducing overall greenhouse gas emissions. However, the rationale to promote mode shift is not just about environmental benefits; it is also about ensuring the long-term adaptability and robustness of freight transportation in the face of economic shifts, infrastructure constraints, and evolving policy landscapes.

Most trucks operating in the United States are fueled by diesel. Currently, while medium and heavy-duty trucks comprise only four percent of the vehicles on highways, they contribute to about 26 percent of total fuel consumed and about 30 percent of CO_2 emissions from highway vehicles.[32] The fuel economy and GHG emission standards introduced by NHTSA and EPA have nudged a transition toward fuel-efficient and low-emission technologies in the medium and heavy-duty trucking sector.[33]

The trend toward electrification and driverless trucks is going to reduce the cost of trucking over the coming decades.[34] As per a recent report released by the U.S. Department of Energy (DOE), heavy-duty trucks–including battery-electric trucks operating within the range of 500 miles and hydrogen fuel cell electric trucks operating above 500 miles–will become cost-competitive with diesel trucks by 2035.[35] During the previous administration, the DOE awarded $127 million across five teams for the SuperTruck 3 Program, which is aimed at developing solutions for electric and fuel-cell medium and heavy-duty trucks. The SuperTruck 3 program is set to run between 2023 and 2027. Its ongoing goals are a reduction in total cost of truck ownership, a 75 percent reduction in GHG emissions, and supporting companies in developing hydrogen fuel cell and battery electric power trucks.[36] The award from DOE provided support for companies like Volvo, PACCAR, and GM to work on zero emission projects, including developing new battery electric vehicles and next generation charging systems. The Volvo and PACCAR projects are currently in their design and project testing phases.[37]

Recent policy changes from the Trump Administration have frozen rules for tailpipe emissions reductions for trucks and limited California's zero emission truck regulations. Regardless of the outcome of the trucking sector energy transition, policies that can induce a mode-shift from truck to rail in the short term could have a positive impact on overall emission reductions because rail is currently more energy efficient compared to trucks. In the long-term, it may still be beneficial to shift freight volumes to rail if rail continues to be more energy efficient than trucks running on alternative fuels. To assess this, it is important to see how railroads compare with electric trucks and trucks running on alternative fuels on emissions per ton-mile moved, while also considering the negative externalities that electric trucks are likely to retain, such as traffic crashes and congestion.

Rail networks are less susceptible to congestion and infrastructure deterioration and can provide consistent, long-haul transport options that complement last-mile trucking solutions. However, to maintain a competitive edge over an increasingly efficient trucking sector, railroads must also innovate. This includes improving service reliability, infrastructure improvements, planning and the integration of data, along with exploring alternative energy sources.

Rail transportation is a safe mode of transportation. Between 1991 and 2019, the number of total incidents on railroads in the U.S. decreased from around 30,000 to around 12,000. There are still accidents and fatalities on railroads, particularly due to rail grade-crossings accidents and trespassing. However, in comparison to trucking, rail appears to be a safer mode of transportation. Between 2013 and 20223, there were a total of 8,917 railroad-related fatalities with an average of 810 fatalities per year.[38] In the same period, there were 53,813 trucking-related fatalities with an average of 4,892 fatalities per year.[39] In the movement of hazardous materials, hazardous materials accidents between 1994 and 2005 resulted in 14 fatalities on railroads. In the same period, hazardous materials accidents resulted in 116 fatalities on highways. According to the BTS, deaths from hazardous materials transportation have declined for both highways and rail, but highways retain the lion's share of hazardous materials accidents compared to rail.[40]

Public Policy Recommendations

Federal, state, and local policymakers interested in supporting this mode shift can implement targeted strategies that encourage rail use where it is most effective. These strategies should be assessed based on their feasibility, cost-effectiveness, and potential for short- and long-term impact. While this report does not compare specific policy options, it lays the foundation for understanding how a mode shift from road to rail can contribute to a more resilient freight transportation network.

- Introduce a new grant program for funding capital projects that can achieve "rail competitiveness" on critical freight corridors that are currently being served by trucks.

The USDOT should consider introducing a grant program that funds rail infrastructure investments on critical fright corridors that have the most potential to attract shippers that are currently being served by trucks. Applicants should be asked to outline how they anticipate the investments will improve mode share of rail and reduce freight trips that are made by trucks and the expected reduction in emissions. This would allow rail to be competitive with trucking on particular freight corridors, boosting redundancy in the network, thereby enhancing network resilience. A model of this for water-borne freight already exists in the Marine Highway Program, which designates Marine Highway Routes that provide congestion reduction benefits to highway routes and awards discretionary grants to promote transportation on these "marine highways". A rail alternative to highways could be similarly designated and funded in order to promote system wide efficiency.

An alternative to a new grant program could be to expand the existing Corridor ID program, with a part of the program for identifying potential corridors with a dual use for freight and passenger service. Freight and passenger rail share the U.S. rail network, with private freight rail companies owning most of the trackage and passenger service like Amtrak running trains on privately owned tracks. Understanding the relationship between freight and passenger rail in the context of improving efficiency is important because in most cases, freight and passenger rail operate on the same tracks. While this research focuses on freight rail primarily, there are opportunities for further discussion on the efficiency and resilience of the rail network including: the relationship between freight and passenger rail on shared tracks, particularly in high-density corridors. An overview of this relationship can provide a comprehensive view of the rail network's efficiency. Additionally, looking at how rail investments benefit passengers and freight services by improving reliability and efficiency for all rail users. Emphasizing the benefits of moving both freight and passenger traffic to rail presents a more holistic view of the advantages of rail.

There are other existing grant programs like MEGA and INFRA that provide eligibility for rail infrastructure investments on critical freight corridors that facilitate intermodal exchange. The BUILD (formerly TIGER) program awarded Norfolk Southern $105 million to assist in their Capital Crescent intermodal corridor improvements and $98 million for CSX's National Gateway intermodal corridor. Additional funding for existing grant programs like MEGA, INFRA, BUILD, or Corridor ID could be an alternative to a new grant program and still provide support for rail projects that encourage intermodal movement.

Resiliency in the Freight sector

According to a 2015 report from the National Infrastructure Advisory Council (NIAC), infrastructure resilience is defined as the "ability to reduce the magnitude or duration of disruptive events, by anticipating, adapting to and/or recovering from a potentially disruptive event."[41] A resilient piece of infrastructure can survive a natural disaster, man-made disruptive event (such as a terrorist or cyber-attack), or simply the process of natural wear-and-tear. A resilient infrastructure system can adapt and recover to ensure that the individual components of infrastructure remain strong and operational in the face of disruptive events. The NIAC was tasked to develop a report that evaluated infrastructure resiliency in the U.S. and provide recommendations based on its evaluation. With the increase in extreme weather events as a part of global climate change, building resilience in the freight rail sector is crucial, and there are several topics that can help explain resilience in the freight rail sector further. These topics include mode shift, infrastructure development, planning, and innovation.

At the time of the report, NIAC found that there were several key issues within the resilience of the nation's transportation infrastructure. A critical element of a resilient transportation system is the amount of redundancy in the system. In the freight transportation space, limited redundancy means there are few routes or modes to move goods from one place to another, without a substitute option. In a disruptive event where the transportation system cannot function, limited redundancy creates single points of failure. For example, if goods are moved between two cities by road, and there are no rail options to move goods between the same cities, there is no redundancy in the system. If trucks are unable to operate, the movement of freight between the two cities grinds to a halt. A system with redundancy might have a road network and a parallel rail network such that freight can be moved by rail in the event that the road network fails, and vice versa.

Building on redundancy, the report notes the importance of intermodal and cross-sector resilience coordination and notes the lack of it in the transportation sector.[42]. A good example of cross-sector resilience in the freight transportation space is ports, which are points of interaction between multiple modes. A resilient port can efficiently move goods from ship to rail or ship to truck and can adapt to changes in freight movements or to a disruptive event and continue to move freight from port to destination.

The Covid-19 pandemic was a substantial disruptive event for the freight transportation system. The lockdown measures affected factories, ports, mining, agricultural, and other sectors, impacting the movement of raw materials and finished goods alike. The global supply chain slowed dramatically, causing delays in shipping, congestion at ports, and rising costs for moving freight. In a situation where one port is too congested and cannot quickly move freight from port to a rail carrier, a resilient supply chain has built in redundancy, where another port can take on the extra congestion. In the context of freight rail, resiliency in the supply chain is critical. The rail system that has multiple routes and the ability to shift freight movements from one route to another in response to a disruptive event is strong. For example, the movement of finished goods from a factory to a rural area may be disrupted by flooding that damages a rail line. A resilient system would be able to shift the movement of those finished goods along a different route and possibly with a different mode to get goods where they are needed. It may take longer, but the supply chain remains intact and able to function.

An overarching issue in building resilience is what the NIAC report calls "short-sighted decision-making."[43] Building a resilient transportation system takes time and significant investment. Building redundancy and systems that can adapt, respond, and thrive to disruptions requires planning. The benefits of a resilient system may not be apparent or prioritized during annual public budget decision making. However, as seen during the pandemic, short-term disruptions in the supply chain can have significant and lasting economic consequences. Sound long-term planning and policy should prioritize resiliency in the freight transportation sector. Freight transportation, and freight rail specifically, are critical in the supply chain, and keep the economy running. A freight transportation system that can survive, adapt, and thrive for decades to come will require significant investments, research, and political willpower in prioritizing resilience.

Infrastructure

Federal programs that support rail infrastructure development

Though freight rail infrastructure is privately owned and maintained, public funding support for rail infrastructure has been made available through federal grant and loan programs as well as tax credits. The Qualified Railroad Track Maintenance Credit administered by the IRS offers eligible Class II and Class III railroads tax credits of up to 40 percent of the track maintenance expenditures.[44] This tax credit program has helped the short line and regional railroads to increase investments in rehabilitating and maintaining old tracks. The federal government also supports rail infrastructure investments through its competitive grant programs such as CRISI (Consolidated Rail Infrastructure Grants), administered by the FRA, INFRA, and BUILD. Total budget for federal highways, including funding from the IIJA, is around $72 billion. The IIJA represented a significant investment in rail, at around $66 billion between 2021 and 2026. Currently, CRISI, INFRA, and the rest of the FRA's discretionary grant programs are not accepting applications.

The CRISI grant program supports a wide range of freight and passenger rail projects aimed at improving safety, efficiency, and reliability of railroad operations. In total, the IIJA included $5 billion in advanced appropriations for CRISI, with up to $5 billion more potentially available through annual appropriations. In 2021, around $369 million was awarded to 46 projects led by short line railroads, state DOTs, and local governments.[45] In FY2022, the grant program awarded $1.4 billion across 70 different projects, with close to two thirds of the projects located in rural areas.[46] During the 2023-2024 fiscal year, the CRISI grant program awarded around $2.4 billion for 122 projects across the country, with many of the projects involving short lines and regional railroads.[47] For FY2025, the IIJA included $1 billion in advanced appropriations for the program, with an additional $100 in annual appropriations from Congress.[48]

The INFRA grant program supports highway projects as well as multimodal freight and rail projects, including critical rail infrastructure such as bridges, tracks, signaling, and crossings.[49] The IIJA made available around $8 billion for this discretionary grant program. One example of a project that was recently funded under the INFRA grant program is the Rockport Bridge Rehabilitation Project, for which the Ohio and Muhlenberg counties in Kentucky will receive about $17 million for upgrading a critical freight rail bridge.[50] The project will be implemented in partnership with a short line railroad. This investment would allow the state and the railroads to retain the freight rail traffic on the 280-mile track and remain competitive with the trucking sector. These improvements in track and bridge infrastructure not only prevent a short line from losing out to trucking business but also protect the resiliency of the freight network by retaining the freight rail option for freight movement. The 2025-2026 INFRA awards include $511 million across 7 projects with rail-elements.[51]

The BUILD grant program has supported a wide range of local and regional surface transportation priorities. The program, previously known as RAISE, was funded in the IIJA and provides nearly $9.5 billion until 2026 to state and local governments to implement multi-modal and multi-jurisdictional projects, which include building and repairing freight rail infrastructure, setting up of logistics facilities, and rail yards.[52] The state and local governments can partner with railroads for implementing the projects.

In addition to benefiting from grant programs, railroads can also access funding through loan programs such as Railroad Rehabilitation and Improvement Financing (RRIF) and Transportation Infrastructure Finance and Innovation Act (TIFIA).[53] As a recent example of a loan for a freight rail project, in FY24 the USDOT provided a $31.4 million RRIF loan to the Sierra Northern Railway and Mendocino Railway to finance nearly 100 percent of costs to expand and improve their rail infrastructure in California, including 6.7 miles of new track.[54]

In the past few years, there has been significant funding for rail, however, CRISI is the only dedicated rail program. While INFRA and BUILD have eligibility for rail, there is no requirement that any funds be used for rail projects. Under the INFRA program, support for non-highway projects is subject to a cap—no more than 30 percent of total funds can be used for freight rail, water, or other intermodal freight projects. This cap on certain rail/intermodal projects limits how much funding is available for rail from the federal government.

Intermodal infrastructure

Setting up rail access facilities at ports can also help enhance railroads' capacity of moving intermodal shipments, and ports play an important role in building such infrastructure. In the State of the Freight Report III published in 2018, AAPA port members projected an investment need of $20 billion in multi-modal port and rail access in the next decade.[55] Port members overwhelmingly said that rail access is important for meeting growing freight demands, securing new cargo, and improving throughput capacity. 67 percent of ports identified 'funding and financing options' as the biggest obstacle for initiating rail access projects, 37 percent of them said 'problematic at-grade crossings or heigh-restricted overpasses and tunnels constrain capacity', and 36 percent reported 'land acquisition' as an issue.

USDOT's Port Infrastructure Development Program (PIDP) offers competitive grant funding for improving, strengthening, and modernizing maritime systems and gateway ports. Figure 12 provides a breakdown of rail and non-rail funding from the grant program between 2021 and 2024.

Figure 12. Breakdown of Port Infrastructure Development Grant program funding by year

Port Infrastructure Development Grant Program Year	2021	2022	2023	2024
Total Rail Funding	$92M	$175M	$22.4M	$45.6M
Total Non-Rail Funding	$149M	$528M	$630.6M	$534.4M
Total Grant Funding	$241M	$703M	$653M	$580M

Source: USDOT, 2021 Port Infrastructure Development Program Grant Awards; USDOT, 2022 Port Infrastructure Development Program Grant Awards; USDOT, PIDP 2023 Awards Fact Sheets; USDOT, PIDP 2024 Project Descriptions.

Planning and Data

Although most freight rail infrastructure is privately owned in the U.S., federal state, and local government agencies play important roles in freight planning to ensure unimpeded flow of goods and minimize the external costs of freight. Systematic freight planning was largely absent in the United States until a report by U.S. Government Accountability Office (GAO) on freight transportation in 2008, which recommended a few strategies to improve freight mobility and tackle what GAO considered to be a funding bias toward projects benefiting passenger mobility, in both rail and roadway sectors. The report recommended that the federal government develop a national freight strategy to prioritize the freight network and allocate federal funding for freight system improvements.[56] The report also recommended that the freight strategy outline the role of the federal government in setting goals or objectives and allocating funding to advance the freight network.

Following the 2008 report, the federal government has assumed an increasing role in outlining a freight strategy and providing guidance to the states to create their own freight plans. The Moving Ahead for Progress in the 21st Century Act (MAP-21), enacted in 2012, required that the USDOT address the impacts of freight movement on communities through a national freight strategic plan. The law also required the Secretary to encourage states to form freight advisory committees, consisting of public and private stakeholders, and develop state freight plans with the inputs of such committees.[57]

The USDOT published a draft of the National Freight Strategic Plan in 2015. According to GAO, the goals of this plan were not exhaustive as it neither delineates the role of the federal government nor identifies goals and measurement metrics. Section 8001 of the FAST Act, enacted in December 2015, required the Under Secretary of Transportation to develop a final National Freight Strategic Plan (NFSP) and also required states to develop their own State Freight Plans to be able to access funds from the newly established National Highway Freight Program.[58].

The Department of Transportation published a final National Freight Strategic Plan in 2020 to better define the role of the federal agencies, states, local governments, and the private sector, in supporting and overseeing the freight system. The plan noted that freight systems would leverage federal funding through competitive grants aimed at enhancing capacity and optimizing existing capacity, to facilitate their being a resilient part of the freight supply chain.

The National Strategic Freight Plan released by the USDOT does not emphasize carbon emission reduction as a goal. The emphasis is largely on improving system efficiency and performance and reducing congestion, and the strategic goals identified by the plan are safety, infrastructure, and innovation. The plan has a small section on “reducing impacts on communities", in which reductions of environmental pollution from freight activities are discussed. As amended by the IIJA, the US Code requires USDOT to develop an updated 2025 NFSP. In July 2025, USDOT released a Request for Information, seeking input from the public, MPOs, local agencies, companies, trade groups, and other stakeholders to inform USDOT in the development of the updated NFSP.

A 2015 paper from the Transportation Research Board outlined a roadmap for adapting transportation to changing environmental pressures, including climate change. The researchers proposed a series of measures related to organization, technical options, legislative options. After presenting the list of measures, the researchers organized them based on their implementation cost and contribution to reducing transportation vulnerability.[59] This is a useful tool that policymakers can use to understand what policies are most effective towards improving the transportation system's ability to withstand increasing environmental pressures, such as climate change.

Data

One significant barrier that federal, state, and local transportation agencies face in implementing freight planning is the lack of data. Lack of publicly available data is a widely recognized issue across the freight sector. This is especially acute in the freight rail sector because the industry is largely privatized and therefore public statistical agencies have little leverage in obtaining data on rail shipments from private railroad companies.

Collecting and analyzing data on freight rail trips, including the types of commodities carried, train schedules, and real-time train locations can have significant benefits. Firstly, the data can be helpful for railroad companies to improve service quality by reducing shipment delays and congestion on the network and improving efficiency of operations. Making the data available to shippers can help them track their shipments better, thereby enhancing reliability, transparency, and overall customer experience. Further, if the data is made available to public agencies, it can significantly aid in integrated freight planning and decision-making.

Other data outside of freight volumes is also important for freight planning. For instance, historical and real-time weather data help rail operators anticipate and prepare for extreme conditions like floods, hurricanes, or wildfires. Data-driven simulations and models identify network vulnerabilities and suggest alternative routing options to minimize disruptions. Real-time data taken from sensors, locomotives, and freight cars help detect wear and tears, before accidents occur.

Even as data-sharing can offer many benefits, there is hesitancy from private railroad companies to make data available to public agencies. Some of the often-cited concerns that explain this wariness are the potential leakage of proprietary information of shippers and railroad companies that can impact their market competitiveness and high costs of investment in data collection and management systems. Railroads are also cautious about sharing data because they want to avoid inviting additional levels of scrutiny or potential new regulations from federal or state governments.

The public sector can and should play an enabling role in this regard by creating the right incentives and ecosystem for data sharing. Sharing data on freight rail trips can have mutual benefits for railroad companies and the public agencies as they can provide crucial information on how the freight network can be planned. Given the positive societal benefits, the costs of data collection and sharing could be borne partially by the public sector. Due care should be taken to ensure that such data does not reveal business or proprietary information about the shippers in a way that impacts their competitiveness. This could negatively impact the mode share of rail by pushing shippers away to other modes.

It is important to carefully balance the level and nature of data sharing to maximize the benefits and minimize the negative impacts from it. One level of data-sharing could be within the industry for improving service and operations. Railroad companies can create a secure platform where individual shippers can have access to their own trip level data which helps them track their shipments. For example, RailPulse is a coalition of railcar manufacturers, railroads, shippers, and lessors that are working toward location-based and telematic solutions for tracking and improving rail performance.[60] Funded partially by the CRISI grant through the State of Pennsylvania, this initiative will work on building a technology platform, which shippers, railroad companies, and switching companies can gain access for a fee. The platform commits to maintaining security and confidentiality of proprietary data.

Another level of data-sharing could be with public agencies. Railroad companies can share anonymized aggregate-level data with public agencies to aid freight planning. This could yield mutual benefits if the data is used by public agencies to plan infrastructure and service enhancements to rail with the objective of adding more freight capacity and maintaining freight rail competitiveness.

Innovation

The Staggers Act of 1980 deregulated the rail sector, leading to large-scale changes including market consolidation, growth of short line railroads, and increase in revenue for the private sector.[61] Deregulation also spurred innovation in the freight rail sector with railroad companies dedicating considerable amounts of capital resources to improving efficiency, safety, and performance of their services. Recent innovations in the freight rail sector have been directed toward advancing three primary goals. These goals are important elements of building resiliency into the freight rail network.

1. **Safety and maintenance:** Improving safety has been the primary objective for many of the innovations adopted by railroads. A great example of this is the positive train control (PTC), which was mandated by Congress as per the Rail Safety Improvement Act of 2008. The technology was quickly developed and fully implemented by 2020 on Class I rail to prevent train-to-train collisions and overspeed derailments, among other things. Further, automated track inspection (ATI) and predictive maintenance techniques have helped improve inspection and maintenance practices, reducing safety incidents.[62]

2. **Customer service and reliability:** Railroads also seek innovations to improve service and performance through customer-oriented tools and information platforms. Railinc, for example, is an information and performance tool developed by the Association of American Railroads (AAR) to assist entities in the freight value chain to improve operations and business performance.[63]

3. **Energy efficiency:** Railroad companies also innovate to increase energy efficiency and improve emissions performance through anti-idling systems, advanced fuel management systems to improve fuel efficiency, and testing alternative fuel locomotives. Short line railroads are also investing on this front with low-cost technologies such as improved lubrication techniques, fuel-saving injectors, among other measures.[64] These new technologies are setting rail on the path of competition with future trucking innovation trends such as automation and electrification.

There are also innovations in the freight handling and logistics sectors, which can reduce shipping time and costs and increase reliability, thereby increasing the competitiveness of rail. Yard automation technologies pioneered by companies such as RailComm in rail yards show promise to improve safety and efficiency. While some innovations, such as PTC, have been instigated by government regulations and supported by public funding, many were undertaken independently by the railroad companies using their own resources to achieve higher cost-efficiency.

One innovation in particular for building resilient transportation networks could be applied to the freight rail sector. Researchers in 2015 proposed an Infrastructure Planning Support System (IPSS). The IPSS is an engineering-based tool that uses stressor-response equations to analyze the impact of extreme weather events and incremental climate changes on roadway infrastructure.[65] According to the researchers, the IPSS-based analysis can assist in developing proactive or reactive transportation measures. The IPSS tool enhances the understanding of transportation infrastructure risks and vulnerabilities to climate change while offering potential solutions. It enables planners and policymakers to integrate quantitative data into their decision-making processes.

Promoting innovation in the rail sector is key to addressing the declining mode share of rail. Advancements in automation and fuel-efficient rail technologies will be important as these technological trends increasingly gain traction in the trucking sector. The longer life cycles of rail assets, as compared to trucks, makes it challenging for rail to test and implement new technologies. This would mean that there needs to be intentional public sector investment to foster innovation in the rail sector, which can help reduce costs, improve performance, and increase the attractiveness of rail as compared to other modes. Governments at the federal, state, and national level must, therefore, play an enhanced role by assisting railroads compete with other modes through innovation.

Public Policy Recommendations

Each of the federal grant programs discussed above have been crucial in building and maintaining freight rail infrastructure over the years. While these grant programs prioritize projects that promote environmental sustainability, they do not identify "mode shift from trucks to rail" as a key goal. Listed below are several proposed actions that the federal government could implement to achieve mode shift through infrastructural investments.

- Expand funding availability under existing grant programs for infrastructure improvements and prioritize resiliency in freight rail development.

  Expanding infrastructure grant programs can make it less expensive for short line and regional railroads to own the network and free up capital to gain additional market share by improving operations and customer service. Currently, there are very few grant programs that fund the purchase of rolling stock and those that do exist are largely administered by the EPA and limited to locomotives that run on alternative fuels and promise to reduce emissions. The USDOT can play a larger role in supporting such investments by recognizing the efficiency of railroads and the importance of promoting resiliency, through infrastructure investment, improved planning, and even mode shift when appropriate. This would necessitate "mode shift" to be seen as a viable strategy. CRISI grants administered by the USDOT do not recognize "mode share" as a strategy for reducing emissions. It primarily recognizes emission reduction projects that improve energy efficiency of rail operations, including locomotive upgrades and testing of alternative fuels.

- Spell out emission reduction as part of the goal to improve resilience in freight planning and drive alignment with rail planning and climate change mitigation planning

The National Freight Strategic Plan, released in 2020, outlines key planning and development priorities in the freight sector. The predominant focus of the plan is to improve and modernize the multi-modal freight network by adding capacity and carrying crucial enhancements needed to tackle the increase in freight demand in the coming years. The plan also outlines the need to improve safety and reliability of freight and support innovation, including in data, technologies, and workforce, to set up the freight network for the future. Among the stated objectives includes "protecting the freight system from natural and human-caused disasters and improve system resilience and recovery speed."

Emission reduction as an element of resilience-building should, therefore, be stated as an explicit goal in the National Freight Strategic Plan. Further, mode shift from emission-intensive modes to sustainable modes, such as rail, could be suggested as a strategy to reduce GHG emissions. Broadly, freight planning at the federal and state level should integrate strategies that will help achieve GHG emission reduction, driving a broader alignment between climate and freight planning.

State rail plans should also be updated and aligned with strategies presented in the freight plans. Although the plans discuss the environmental and other benefits of shifting freight traffic from trucks to rail through capacity enhancements, they don't present any strategies to achieve that.

Europe offers multiple examples of integrated planning in the freight sector. The European Union's Mobility Strategy and Action Plan aims to increase rail freight traffic by 50 percent by 2030 and double it by 2050 (as compared to 2015).[66] There is also an industry-led policy in the EU called "30 by 2030", which aims to achieve a rail mode share of 30 percent by 2030.[67] This ambition is laid out by a coalition of rail freight companies in Europe called Rail Freight Forward. Both these plans reference GHG emission reduction goals of the EU and how mode shift in the freight sector could help achieve those goals.

Further, freight plans published by a few member states in EU reciprocate the freight planning and mode shift goals of the European Commission. Germany's Freight Transport and Logistics Action Plan, launched in 2010, highlighted mode shift to rail as a key strategy to achieve its climate change mitigation goals.[68] The most recent coalition government in Germany released an agreement for government programs until 2025; this agreement mentions a goal of achieving a 25 percent mode share of rail freight by 2030.[69] Spain recently published its 'Freight 30 Initiative,' through which it aims to increase rail freight's market share from five percent to ten percent by 2030.[70]

In the United States, such an alignment between climate, freight, and rail policy goals exists, to some extent, at the state level. For example, the state freight plans of New York and California mention environmental sustainability as a goal and highlight mode shift from truck to rail as a strategy. These plans would be further strengthened by recognizing the sustainability benefits of building a resilient rail network that can withstand the dangers of climate change. Strategies such as infrastructure development, using data-driven policy making, and encourage mode shift could be valuable to think about as part of the alignment of freight and climate policy.

- Create requirements and specifications for anonymized aggregate-level data sharing

Sharing freight rail data can have significant mutual benefits for the public sector and the private railroad companies, as it can help with planning and decision-making that can improve mode share of rail. Lack of adequate data on freight is widely identified as a concern that limits freight planning at the national and state level.[71]

The Federal Highway Administration (FHWA) and Bureau of Transportation Statistics (BTS) jointly compile the freight analysis framework (FAF), which is the most extensive freight data and analysis tool at the federal level. FAF draws data and insights from the Commodity Flow Survey and trade statistics published by the Census Bureau. In addition to this, Carload Waybill Sample data collected by the Surface Transportation Board (STB) provides historical data on the commodity types moved by rail along with origin and destination, number of railcars, weight, and haulage length.[72] Data analyzed and presented through these above platforms are aggregated at a national or state level and often don't offer the granular insights needed for local planning. States largely use the FAF data published by BTS for developing the state freight plans while also depending on freight data purchased locally from private entities.

Overall, there is a need for a broader partnership between the public sector agencies, railroad companies, and shippers to enhance the collection and availability of data on freight car movements, weight, track conditions, and incidents, among other things. To that end, the FRA can play a leadership role in developing data sharing specifications and formats to enhance freight rail planning and decision-making. FRA could also mandate the railroad companies to share anonymized and aggregated data while taking the necessary steps to protect the proprietary information of shippers and railroad companies. In doing so, FRA should closely consult with the railroad companies and shippers to develop data standards that can drive mutual benefits for the industry and the public sector.

- Increase the organizational capacity for freight planning

Multimodal freight planning will require inter-agency coordination and collaboration with the private sector. The USDOT and agencies at the state and local level should build organizational capacity by hiring dedicated staff to coordinate freight planning.

A recent step in that direction is USDOT's efforts to set up a freight office (Office of Multimodal Freight Infrastructure and Policy), as a requirement of IIJA, to manage multimodal freight planning and federal grants in the freight sector.[73] This office will implement freight policy, administer grants in the freight sector, coordinate between the public and private sector for share information, conduct research on freight mobility, and offer guidance to cities and states. This new office could offer capacity and capabilities to expand the focus of freight planning in the United States, beyond highways, to rail. Having staff with expertise on freight rail could help delineate opportunities to expand the capacity of freight rail and collaborate with the private railroad companies and shippers.

Currently, most state and local governments do not have dedicated staff to carry out freight planning activities. In both state departments of transportation and regional metropolitan planning organizations (MPOs), freight planning is typically conducted by staff in the planning and policy teams whose primary focus and expertise is passenger transportation. This limits state and local capacities to develop comprehensive multimodal freight policies and plans and lead interventions with the private sector. So organizational capacities should also be developed at the state and the local level to aid in freight planning.

- Set up a freight innovation unit at the FRA

Innovation in the freight sector will be crucial for ensuring high levels of efficiency needed for accommodating future freight demand while minimizing the negative externalities. Some of these innovations can also flow back into the passenger rail sector, amplifying the public benefits.

To that end, the federal, state, and local governments must support the private sector with the right kind of regulatory and incentive structures. The federal government already has a few grant programs (INFRA and CRISI) that encourage innovation in the freight sector. However, these grant programs serve many purposes beyond promoting innovation, such as reducing congestion on the freight system and improving safety. Historically, most of the CRISI grant funding has been awarded to projects that improve the safety infrastructure of railroads (example: building railroad crossings). There is a need for a dedicated effort to improve innovation in the freight rail system through grants, regulatory assistance, and additional guidance.

The FRA conducts research and innovation activities through its Office of Research, Data, and Innovation. This office conducts safety research, performs economic analysis of regulations and grant programs, and leads training and workforce development activities, among other responsibilities. The office conducts many activities in collaboration with the private sector, including AAR. However, this office is highly focused on innovation that advances safety as it comes under the direct purview of the FRA, whereas other freight goals are given less priority.

Setting up a new freight innovation unit within the Office of Research, Data, and Innovation can help FRA expand its focus beyond safety to include improving freight's operating efficiency, performance, and resilience. The new unit should have the authority and funding to work with railroads and shippers to test new operational models and ideas that can improve railroad operations. This unit's remit could include anything that encourages greater mode shift as well as alternative fuels.

Freight railroads are interested in exploring train automation technologies that eliminate the need for two crew members in each locomotive. There are clear concerns about deploying this technology for safety and its implications on the railroad workforce. If FRA were directly involved with testing, monitoring, and measuring the outcomes of an automated train pilot on a US railroad, it could measure the effectiveness and address concerns in future regulations. Similar tests could be done for automated equipment inspection, automated track inspection, and deployment of alternative fuel technologies. The office could also work with shippers to fund equipment and test innovative ways to load and unload cargo that can increase the appeal of moving goods on the railroads.

- Support technology-agnostic solutions and identify opportunities for reducing regulatory burden or modernizing regulations

Regulations that prescribe a system-wide technological change without consideration of cost-effectiveness can hinder innovation and lead to socially suboptimal outcomes.

Let us consider the current efforts to advance energy efficiency and reduce emissions in the freight rail sector, for example. Currently, there is not a single technology or approach to increasing railroad efficiency that merits a federal mandate. Sometimes this is because technology is too immature to implement. For instance, hydrogen powered locomotives could offer a revolutionary low (or no) carbon way to power future locomotives. But hydrogen is notoriously tricky to store, is expensive (and sometimes carbon-intensive) to create and is largely untested at a large scale. Hydrogen would be perfect for pilot projects but mandating at this point would not be effective.

In some cases, proposed mandates are cost-prohibitive and carry significant unintended consequences. One example is the push by some policymakers for catenary electrification of the national railway network. While full overhead wire electrification would reduce carbon emissions, the estimated cost of electrifying the entire 140,000-mile network—including tracks and yards—exceeds $1 trillion. Even targeting primary corridors presents operational challenges, as locomotives are typically used interchangeably across the country. Electrifying only certain corridors could limit network flexibility and increase operating costs. However, this concept is well-suited for pilot programs in high-density, point-to-point corridors, where its effectiveness can be tested and evaluated before broader implementation.

Another important step is identifying areas within the rail sector where overregulation has hindered innovation and technological advancement. Easing unnecessary regulatory burdens can yield mutual benefits for both railroads and the public. First, it can stimulate the research and innovation necessary for rail to remain a vital component of the freight transportation system. Without such progress, future freight demand will increasingly shift to trucking—a mode with substantially higher negative externalities. Second, reducing regulatory costs can help railroads compete more effectively with trucks by enabling more affordable shipping options. However, to realize these benefits, railroads must reinvest the resulting savings into infrastructure improvements or lower shipping rates. The Federal Railroad Administration (FRA) faces a delicate task in this process: it must balance public priorities by ensuring that regulatory reform does not compromise safety or other essential protections, while still creating space for railroads to innovate and strengthen their competitive position.

Some of these changes are happening in the area of track inspection and maintenance. For example, FRA recently revised regulations on track safety to adopt a more performance-based approach, which is expected to save railroads and the public unnecessary costs. The final rule on Rail Integrity Amendments and Track Safety offers more flexibility to railroads by allowing continuous rail testing as a method of track inspection.[74] Another potential strategy for improving track inspections could be finalizing a rule allowing for automated track inspection. Automated track inspection uses sensors mounted on locomotives or railcars that monitor track conditions as a train moves along.[75] This modernization of federal regulation would improve rail capacity because using revenue service trains for track inspection would avoid the need to close a section of track so that a person can conduct a manual inspection. The FRA should work toward identifying similar opportunities for reducing the regulatory burden and modernizing regulations on railroads with the objective of spurring innovation and increasing the competitiveness of rail.

Efficiency in the Freight Sector

Railroads are a sustainable land-based mode of transport for freight movement. Various studies indicate that, as compared to trucks, railroads are between four times more fuel-efficient and about eight times more energy efficient. However, freight rail emissions are not non-existent and there are opportunities to minimize emissions from diesel locomotives through the usage of alternative fuels and fuel-efficiency technologies that can move the sector toward the goal of net zero emissions. These technologies and investments will provide benefit not only for emissions but also to reduce costs and vulnerability to spikes in diesel fuel prices and therefore can be an important strategy to keep railroads environmentally and economically sustainable for decades to come.

Many developed countries have been able to make their rail transportation greener through electrification and other fuel technologies, demonstrating rail's ability to adapt to changing trends towards innovative power. For example, more than 55 percent of the European rail network is electrified.[76] Such large-scale electrification has been made possible through capital investments from the national governments.

In the U.S., where the freight rail industry is privately owned and operated, the change is being led by railroad companies and locomotive manufacturers. A few railroads have set sustainability goals to reduce carbon emissions and are also running pilots to test alternative locomotive fuel technologies for line-haul and switching operations. For example, Union Pacific released a Climate Action Plan in 2021, committing to reducing well-to-wheel GHG emissions by 26 percent by 2030 from the 2018 baseline.[77] According to AAR, between 2000 and 2022, U.S. freight railroads emitted 133 million fewer tons of carbon emissions due to improvements in fuel efficiency.[78]

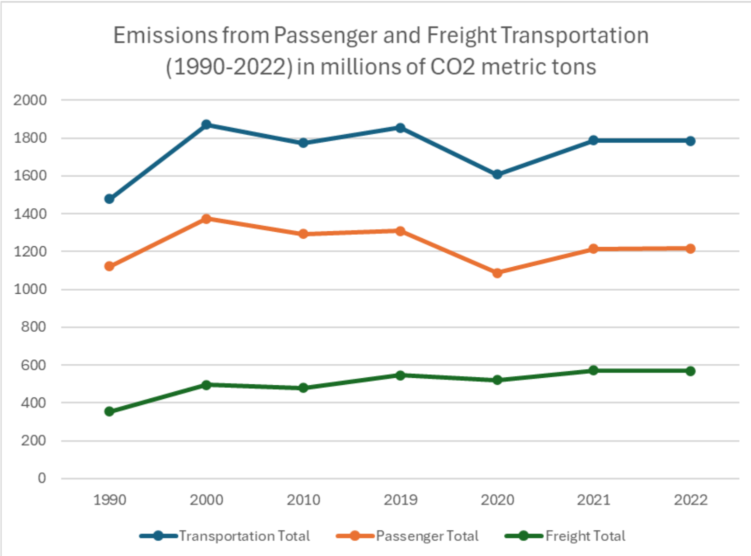
In addition to carbon emissions, railroad emissions include criteria pollutants that impact air quality. This is especially the case in rail yards, where diesel locomotive emissions can result in significant localized air quality and public health impacts.[79] Reducing overall emissions, including criteria pollutants, has been a federal priority, and railroads have invested in alternative fuel pilots and other technologies, with support from funding available from the EPA to reduce emissions from diesel fleets. The FAF projections of how the freight sector will grow and change between now and 2050, offer us some foresight on the likelihood of achieving net-zero emissions goals by 2050.

This section reviews some of the alternative fuels that can replace diesel locomotives, highlights the opportunities and barriers for their adoption in the short-term and long-term, and estimates the potential emission reduction benefits from these options. Further, it also discusses the considerations of safety, performance, and viability for different fuel options. Finally, this section identifies the need for future research to compare the emission reduction potential of each of these strategies against their costs, to help prioritize implementation and cost-effective emission reductions.

Emissions in the freight sector

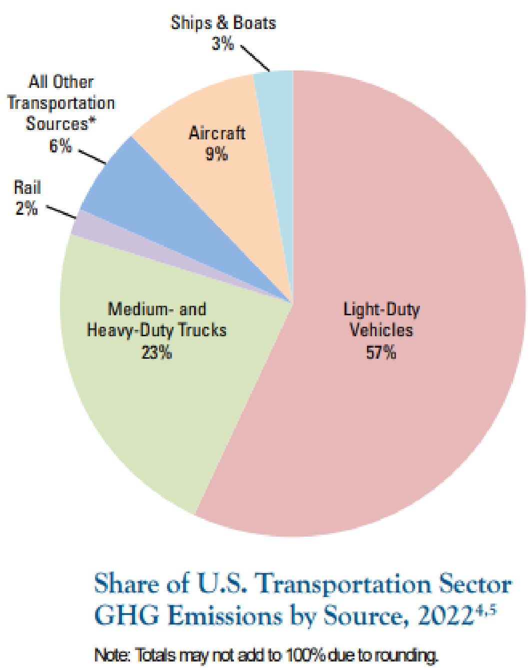
In 2022, the U.S. transportation sector contributed to about 1.8 billion metric tons of CO_2 equivalent emissions.[80] About 32 percent of these emissions came from freight transportation. Since the high point in transportation emissions in 2000, there has been significant emphasis on and some progress achieved in reducing carbon emissions from passenger transport, while freight emissions have grown somewhat. As shown in Figure 13, passenger emissions between 1990 and 2022 declined, while freight emissions have been growing, and as a result the percentage contribution of freight to total transportation emissions has steadily increased from 23 percent in 1990 to 32 percent in 2022.[81]

Figure 13. Emissions from Passenger and Freight Transportation, 1990-2022



Source: U.S. Department of Transportation, Bureau of Transportation Statistics, "U.S. Green House Gas Emissions from Domestic Freight Transportation"

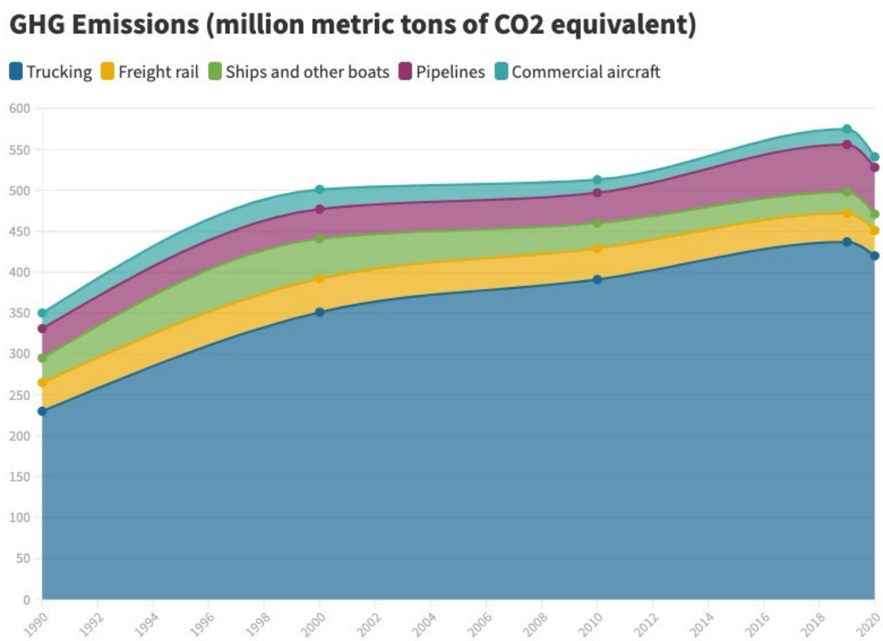
Figure 14. Share of U.S. Transportation Sector GHG Emissions by mode, 2022



Source: U.S. Environmental Protection Agency, U.S. Transportation Sector Greenhouse Gas Emissions, 1990-2022, 2024.

As shown in Figure 14, medium and heavy-duty trucks contribute to nearly 24 percent of transportation emissions in the United States as compared to railroads, which contribute only about two percent of transportation emissions.[82] Since 1990, trucks' contribution to emissions has increased, whereas railroads' has decreased. This is partially explained by the fact that railroad prominence in mode share has been decreasing in the past decade. The percentage share of truck emissions out of total freight emissions has increased from 66 percent in 1990 to 72 percent in 2022. Contrastingly, railroads' contribution to total freight emissions has decreased from around 10 percent in 1990 to around 6 percent in 2022.[83]

Figure 15. GHG Emissions (million metric tons of CO2)



Source: USDOT, Bureau of Transportation Statistics, "U.S. Greenhouse Gas Emissions from Domestic Freight Transportation."

The greater contribution of truck to total emissions is partly explained by the dominance of trucking as a mode of freight transport, but it is also the result of the fuel inefficiency and related emissions intensiveness of the mode. Air transportation is by far the most emission-intensive among all freight modes, however trucks are the second most emissions-intensive. The below figure shows the CO_2 emissions per ton-mile for all modes and relative fuel efficiencies of all modes in comparison to rail. As seen in Figure 16, truck emissions per ton-miles are nine times that of rail. Figure 15 illustrates each transportation mode's share of GHG emissions.

Figure 16. CO2 emissions per mode

Mode	CO2 emissions (grams/ ton-mile)	CO2 emissions (relative to rail)
Rail	15.7	1X
Truck	143.9	9X
Intermodal	52.9	3X
Barge	12	1X
Air	817	52X

Source: U.S. Environmental Protection Agency, *2019 Smart Way Shipper Company Partner Tool*, 2018.

Alternative Fuels for Locomotives

As noted above, railroads have made progress in reducing emissions and fuel consumption. If the fuel efficiency of railroads had remained at their 2000 level, it is estimated that railroads would have consumed 9.6 billion additional gallons of fuel and emitted 108 million additional tons of CO_2 by 2019.[84] Efforts to reduce emissions further often focus on alternative fuels to power locomotives; biofuel, natural gas, hydrogen, battery electric, and overhead catenary are some of the most common alternatives to a diesel-powered locomotive for reducing carbon emissions. These power sources vary based on emissions performance, investment and lifecycle costs, and safety. Weight and volume of the fuel, energy density, availability of fuel, refueling time, maintenance interval, and system life are a few technical and operational considerations that also influence fuel choice for railroads.[85] These factors collectively result in tradeoffs that railroads and locomotive manufacturers must consider in evaluating these options.

Biofuel: Biofuel (biodiesel and renewable diesel) is largely considered an operationally feasible intermediary fuel switching option that would not require any major modifications or new infrastructure.[86] There are a couple of prevailing biofuel types: B20 and B99/B100. B20 refers to a fuel blend with 20 percent biodiesel blended with regular petroleum diesel and is the most common blend type of biodiesel. B99/100 refers to a blend with 99 or 100 percent biodiesel. While not zero-emission, biofuel can partially reduce many GHG and particulate emissions; on the other hand, nitrous oxide (NOx) emissions actually increase with the usage of biofuel.[87] Usage of biofuel also increases fuel consumption and is not as efficient without additives to improve fuel performance. The Argonne National Laboratory, in partnership with the FRA and

Progress Rail, is conducting research on the how biodiesel and renewable diesel fuels can be sustainable methods of power for rail. The goal will be to use higher blends of biodiesel without compromising engine performance. The research will inform the industry on the value of higher blend biodiesel and important improvements in technology to build locomotives that can harness the sustainability potential of higher blend biodiesel fuels. This fuel is commercially available in various biodiesel blends, and the amount of emission reduction is positively correlated to the proportion of biofuel used in the blend.[88]

The cost of biofuel is comparable to that of diesel fuels or slightly higher in the case of purer blends.[89] As per the Department of Energy, the US has about one billion tons of biomass, municipal solid waste, and biosolids that can be used towards generating biofuel. The biodiesel plant production capacity in January 2024 was around 2,000 million gallons per year, which comes from 56 biodiesel production plants across the country.[90] but does not have sufficient quantities to power the rail sector; expanding production of biofuels can have additional upstream impacts of increasing GHG emissions.[91]

One additional barrier is that the locomotive manufacturers, except for Progress Rail and UP, have not approved the use of biofuel blends in their locomotives.[92] UP has increased their biofuel use from 1.2 percent of total fuel in 2018 to 6.1 percent of fuel in 2023 and has found that biofuels reduced their carbon footprint by 79 percent relative to diesel fuel; the railroad has announced a goal to use 20 percent biofuel by 2030.[93]

LNG and CNG: The combustion of Liquified Natural Gas (LNG) and Compressed Natural Gas (CNG) remains an alternative means to power locomotives and can replace the use of diesel through conversion and retrofitting of diesel engines; dual-fuel engines also exist that can run on a blend of diesel and renewable natural gas. Dual-fuel locomotives use a combination of diesel and natural gas, with natural gas serving as the primary fuel for operations, providing the bulk of the locomotive's power. Diesel is used as an ignition tool, with small amounts of diesel injected to ignite the natural gas air-mixture. Diesel is also used as a secondary source of fuel in case natural gas runs out or is not available.

Locomotives powered by natural gas release fewer emissions as compared to diesel-powered locomotives; however, natural gas can result in higher CO emissions as compared to diesel. The easy availability of natural gas in the United States makes it an attractive fuel option for railroads. A few downsides are that this is not a zero-emission mode since it still results in some tailpipe emissions. Safety is another concern because of the storage of these fuels in locomotives. The storage tanks need to be designed to withstand high pressure or very low temperatures, making them highly expensive compared to diesel storage tanks.[94]

Given these concerns, FRA has not made any regulatory changes to allow the large-scale adoption of LNG. CNG requires more storage space than diesel or LNG for the same amount of energy, requiring frequent refueling, which makes it more suitable for switching operations than for long hauls.[95] LNG is more suitable for long hauls as it can offer a range of 800 miles before refueling.[96] Further, usage of LNG would require a liquification facility closer to the operation of the railroad.[97] While the fuel costs are considerably lower, natural gas options require safe storage tanks and setting up of fuel infrastructure, which can drive up the costs.

Hydrogen: Interest has grown in the potential for hydrogen fuel cells to power rail locomotives. Electricity is generated by hydrogen fuel cells and must be stored in on-board batteries. While this fuel source has no tailpipe emissions, there can be source emissions from the production of hydrogen; hydrogen fuel has great potential to eliminate GHG and air pollution emissions if the fuel source used to produce hydrogen is clean.[98]

Unlike natural gas, hydrogen fuel cells cannot operate in dual-fuel locomotives. This means that there is a need for a new locomotive design for hydrogen fuel cells. Hydrogen is also stored at high pressure in storage tanks, and the pressure of the tank determines the fueling time.[99] During leakages the fuel tends to rise as opposed to staying closer to floor (as is the case with diesel and natural gas), and hydrogen also causes embrittlement of metals, affecting their mechanical performance and integrity. These factors introduce additional safety concerns which need to be tackled through specific locomotive design elements, such as ventilation, overhead placement of hydrogen fuel tanks, and usage of stainless steel or other metals that can better sustain exposure to hydrogen.

The BNSF pilot has shown that safety concerns of hydrogen fuel cell propulsion such as flammability and gas accumulation have to be addressed.[100] Smaller pilots or prototype operations might be needed before wider deployment can be considered. One major drawback is cost. The production of hydrogen fuel cells is currently expensive. DOE estimates that the production prices have to drop from $323 per kW to $80 per kW by 2030 for wider adoption of this technology.[101]

Battery Electric: Rail industry momentum is increasing for battery electric locomotives, which are being tested for line haul and switcher functions and also being studied for long haul applications. Studies have shown that battery tender cars can be effective at achieving the power and range requirements needed for a freight rail.[102]

Retrofitting existing diesel-electric locomotives with batteries provides the power needed to move a typical Class I rail over 150 miles and is an option for most diesel-powered locomotives, which typically are diesel-electric with the capacity to run on electric power.

Studies have shown that switching to battery electric can also yield high benefits in the long run. With declining battery costs and increasing energy density, trends which are expected to continue into the future, switching to battery-electric locomotive can create a 20-year net present value (NPV) of savings between $54 billion and $250 billion.[103] Another study shows that a 241-km range can be achieved by adding a box car that can carry a 14-MWh LFP (lithium ferrous phosphate) battery and an inverter.[104] This would result in savings of $94 billion over the next 20 years for the U.S. freight rail sector in terms of reduced criteria pollutants and GHG emissions. While the additional weight of the battery tender car increases the energy requirement by about 5 percent, it is significantly lower than the energy savings from running on a battery.[105] Battery-electric freight trains consume only half the energy as a diesel train.[106] To date, no electric line-haul locomotives have entered commercial main line service on a Class I railroad in the U.S. but internationally, there are numerous countries where freight rail relies on battery-electric locomotives.

Overhead Catenary: Switching the freight rail network to an overhead catenary power supply would require significant capital investment to lay out electric infrastructure along the length of the tracks. It is estimated that electrifying one mile of rail could cost anywhere between $3 million and $8 million, excluding the cost of locomotives and there are approximately 140,000 miles of freight rail track in the U.S.[107] AAR, in their report titled *Freight Railroads and Climate Change* released in February 2025 noted that while "technically feasible," construction of a rail network of overhead catenary would be cost between $870 billion to $1.1 trillion and would take decades to construct.[108] According to AAR, overhead catenary can also present resiliency issues because relying on overhead wires presents the scenario where trains could become stranded in the event of power disruption.[109] Some researchers and policymakers argue that rail electrification is viable on denser rail corridors, which are capable of offering the required return on investment.[110]

Comparison of alternatives

Emission Reduction Potential

The emission reduction potential of various fuel alternatives will depend on the quality of the fuel used, carbon content of the fuel, the operation of the locomotive, among other things, and will vary based on the type of locomotive application. For example, for battery-powered locomotives, emission reduction will depend on the battery technology used and the source of electric power. This section, therefore, discusses the emission reduction potential of various fuel alternatives based on the limited information gathered from pilots.

In terms of emission reduction, natural gas and biofuel don't offer significant benefits as compared to diesel alternatives. While usage of biofuels can help reduce particulate emissions, it has only marginal impacts on CO_2 reduction depending on the blend, or percentage, of biofuel used. Biofuels do not reduce locomotive stack emissions but reduce fuel source emissions because of the low carbon content of the fuel, which is made of agricultural waste. For example, a 20 percent biofuel blend (B20) can reduce CO_2 emissions by up to five percent.[111] A study of CNG locomotives for short line railroad applications shows that CNG could reduce annual CO_2 emissions by eight percent but can increase carbon monoxide (CO) emissions.[112] Canadian National's locomotive pilot involving an LNG-diesel hybrid (with 90 percent natural gas and 10 percent diesel) indicated that CO_2 emissions could be reduced by 30 percent with the usage of natural gas.[113]

Electric power and hydrogen demonstrate potential for achieving near zero carbon emissions and are, therefore, considered the most suitable fuel options in the long term for achieving emission reduction at the needed scale. While fully electric-powered rail will have zero exhaust emissions, battery-powered locomotives are currently being tested in conjunction with diesel locomotives to deliver the power needed for heavy-haul applications.

It is estimated that on-board batteries can help reduce fuel consumption and GHG emissions by up to 25 percent.[114] Wabtec's first 100 percent battery-electric locomotive, FLXdrive, is expected to reduce fuel usage and GHG emissions by 10-30 percent as compared to a traditional locomotive.[115] A three-month pilot of Wabtec's battery-electric locomotive with BNSF in San Joaquin Valley showed a 11 percent average reduction in GHG emissions.[116]

Hydrogen fuel cells have the potential to achieve near-zero carbon emissions depending on the production of hydrogen. Sierra Northern Railway, for example, is piloting a zero-emission hydrogen fuel-cell switching locomotive in West Sacramento, and Canadian Pacific is in the process of designing North America's first hydrogen-powered line-haul locomotive and zero-emission hydrogen production and fueling facilities.

Other Considerations

Beyond the potential to reduce greenhouse gas emissions, several other factors contribute to growing interest in shifting freight rail to alternative fuels. A major driver is the reduction of particulate emissions from locomotives, which would yield significant public health benefits—a longstanding priority for many state and local governments and a key focus of EPA regulations and funding initiatives. The various alternative fuels offer differing impacts on criteria pollutants. For instance, biofuels are expected to reduce some pollutants but may increase nitrogen oxide (NOx) emissions. In contrast, natural gas can lower most criteria pollutants while potentially increasing CO_2 emissions. Battery-electric and hydrogen fuel cell locomotives offer zero tailpipe emissions, effectively eliminating local pollutant emissions, though emissions may still occur at the point of energy generation.

Another critical factor for railroads is the cost of transitioning to alternative fuels, which includes both capital and operational expenses. Capital costs encompass the purchase of new locomotives, fueling infrastructure, maintenance facilities, and any necessary track modifications. Operational costs include fuel, labor, and ongoing maintenance. Biofuels and natural gas generally require lower capital investment, as they can be used with existing diesel locomotives or through dual-fuel conversion kits. However, natural gas locomotives necessitate specially designed tender cars to safely store fuel. In contrast, battery-electric, catenary-electric, and hydrogen fuel cell locomotives demand higher upfront investment, including new propulsion systems, safe fuel storage solutions, dedicated fueling or charging facilities, and potential track upgrades—contributing to significantly higher total costs.

The relative cost of alternative fuels as compared to diesel is also a determining factor given that fuel is the fourth largest expense for railroads after labor, purchase of services, and depreciation.[117] Fuel costs averaged between 10 and 20 percent of total operating expenses for major Class I railroads in 2021. The cost of biofuel is comparable to that of diesel, with purer blends costing slightly higher than diesel. The B20 blend of biodiesel costs around $3.53 per gallon. Compared to the national petroleum diesel cost per gallon of $3.64 in October 2024, B20 costs 11 cents less, making is a lower cost fuel option. On the other hand, B99/100 costs $4.04 per gallon, making it 41 cents more expensive than traditional petroleum diesel.[118] While the B99/100 blend has a greater impact on reducing greenhouse gas emissions compared to B20 and traditional diesel, B99 is more expensive, less commonly used, and may require engine modification when used.

Natural gas and electric power are significantly less expensive than diesel for generating the same amount of energy, making them attractive options for reducing long-term operational costs. Additionally, the prices of natural gas and electricity tend to be more stable than diesel, which is closely tied to crude oil prices and subject to fluctuations driven by global supply and demand, geopolitical events, and other market forces. While electric power—particularly battery-electric systems—is efficient and cost-effective in many applications, concerns remain regarding its energy density. Long-distance and heavy-haul freight rail operations require substantial power, which necessitates a large number of batteries. These batteries add considerable weight to the train, which can reduce overall efficiency and increase energy consumption. For high-power, long-haul freight applications, battery-electric propulsion is currently less efficient than diesel. Diesel fuel offers a higher energy density per unit of weight, making it a more practical and efficient energy source for heavy-duty rail transport under current technological constraints.

Presently, the cost of hydrogen fuel is higher than that of diesel. In the coming years, this cost differential is expected to shrink with the increase in production and supply of hydrogen and the high energy efficiency that can be obtained through hydrogen fuel cells.[119]

Switching to alternative fuels proves economical in the long run, especially when environmental costs are considered. In the case of LNG, it is estimated that the NPV of future fuel savings more than offsets the capital cost of approximately $1 million that is needed for switching to LNG locomotive and the tender.[120] The total cost of ownership of battery-electric locomotives, over a period of 20 years, is around $6.5 million as compared to $5.8 million for diesel. When environmental costs are included, the cost of owning and operating a battery-electric locomotive ($8 million) is much lower than that of diesel ($11.8 million).[121] In the case of hydrogen fuel cell locomotive, fuel cost may comprise up to 80 percent of the total cost of ownership. As per a study by Argonne National Laboratory, fuel cells locomotives are more suitable for switching operations and could be about 15 percent cheaper than diesel locomotives in terms of total cost of ownership if they are developed to meet the requirements of DOE.[122] The study also estimates that the cost of delivered hydrogen should be less than $2.20 per kg to achieve cost parity with diesel priced at $2.25 per gallon.

Safety of various fuel options is another determining factor. The FRA has regulatory oversight over the safety of locomotives.[123] The railroads are required to obtain permits from the FRA to test locomotives powered by alternative fuels to ensure that safety is maintained. Safety concerns largely arise from using fuels that are stored at low temperatures or high pressures.[124] Natural gas and hydrogen require both such storage conditions, increasing their safety risk as compared to other fuels. The locomotive, tender, and fuel storage tanks must be designed to minimize these risks. Usage of batteries for high power applications, such as powering a locomotive, introduces risks of thermal runaway (a condition where battery cells generate more heat than they can dissipate).[125] Each of these technologies, therefore, must be tested and safety standards must be developed before they can be approved for wide-scale adoption. AAR developed LNG and CNG tender standards in June 2021, which could be adapted for hydrogen locomotives. The standards for battery-powered and hydrogen locomotives are still in the developmental stage. Figure 17 below provides a comparison of alternative fuels.

Figure 17. Comparison of alternative fuels for rail applications

Fuel	Advantages	Disadvantages
Biofuel	Can use existing capital infrastructure and will not require large-scale investment in tracks and locomotives	Not 100% emissions free. Partially reduces GHG emissions and particulate emissions, but increases NOX emissions Not energy efficient; increases fuel consumption More common B20 blend: comparable to diesel. Higher B99/100 blends are higher cost than diesel. Don't have enough biofuel reserves to power the entire rail sector
LNG and CNG	Dual fuel locomotives can be used and would not require new locomotives Abundant availability of natural gas	Not 100% green since it still results in tailpipe emissions. Cleaner fuel than diesel as it reduces particulate emissions Safety issues related to storage of natural gas at low temperatures and at high pressures, increasing the cost of storage tanks Require setting up of new refueling infrastructure
Hydrogen	Near zero carbon emissions. Can be zero-emission if a clean power source is used for producing hydrogen	Requires new locomotive design and replacement or conversion of existing locomotives Production of hydrogen fuel cells is expensive Safety concerns given that Hydrogen is diffusive and also causes embrittlement of metals
Battery-Electric	Potential to achieve high emission reductions with new battery technologies Energy efficiency of fuel is high Low fuel costs	High capital costs in terms of fueling infrastructure Have to be used in conjunction with diesel as low energy density of batteries make them unsuitable for high-power rail applications
Catenary	Zero tailpipe emissions Energy efficiency of fuel is high Low fuel costs	High capital costs in terms of new track infrastructure

Source: Authors; developed using information provided in previous sections.

Existing Public Policy and Recommendations

There are a few major ways in which public policy interfaces with the objective of improving the efficiency of railroads. First are the standards that guide and permit the development of emission reduction technologies. Second is the regulations that govern locomotive emissions. Finally, grant funding has been available railroads and public agencies to support research and development of new technologies, conduct pilots, and purchase new equipment and infrastructure.

Safety

FRA regulates the safety of railroad operations including development and enforcement of standards. As fuels and power systems can have significant implications for rail safety and performance, railroads and locomotive manufacturers are required to obtain permits from FRA to pilot new technologies and deploy them for commercial operations.

At this stage, standards for alternative fuel locomotives and tenders are in various stages of development. For example, biofuels and natural gas have existing standards for on-board fuel handling and storage tanks, whereas standards for battery-powered and hydrogen locomotives are still in the developmental stage.[126] For battery-powered locomotives, an AAR and Wabtec-led task force is looking at safety concerns around yards and stationary charging. This effort will also look at standards for charging infrastructure for battery locomotives to allow interoperability across different regions in North America. In June 2021, AAR developed LNG and CNG tender standards.

Emissions Regulation

The Environmental Protection Agency (EPA) regulates all mobile sources of air quality emissions, which includes all types of locomotives, including those used for line-haul, switcher, and passenger applications. EPA standards have been in place since 1997 and initially included Tier 0-2 standards for existing locomotives to meet when remanufactured. These rules were updated in 2008 in a rule that aimed to reduce particulate emissions by 90 percent and nitrogen oxides (NO_x) emissions by about 80 percent.[127] This comprehensive program applies to locomotives that are newly manufactured as well as remanufactured locomotives and required that remanufacturing systems be made available for older locomotives. The 2008 rules established a Tier 3 standard, which requires usage of emission reduction technologies applicable for all newly built or remanufactured locomotives starting from 2012. It also added a long-term Tier 4 standard, which mandates the application of high-efficiency catalytic aftertreatment technologies to reduce emissions, took effect from 2015 and is applicable to all newly built or remanufactured locomotives. An EPA rule released in 2009 also mandated reporting of GHG emissions for locomotives, which first came into effect for the 2011 model year.[128]

Funding for emission reductions

Railroad companies have traditionally invested in technologies that enhance energy efficiency, lower fuel costs, and reduce emissions. In recent years, they have expanded these efforts by partnering with locomotive manufacturers and public sector agencies to explore alternative fuel options through pilot programs. While much of the funding for these initiatives originates from the private sector, public investment—particularly in the short line rail industry—has played a critical role in supporting and incentivizing innovation.

Several grant programs at the federal, state, and local levels have supported private-sector efforts to reduce emissions. Although most of these grants focus on reducing criteria pollutants, many also contribute—directly or indirectly—to broader goals of greenhouse gas (GHG) reduction. Furthermore, investments aimed at improving energy efficiency offer the added benefit of strengthening the resilience and sustainability of the freight rail network.

- **Diesel Emissions Reduction Act (DERA) National Grants Program**: This grant program administered by the EPA reduces diesel emissions resulting from fleet operations. EPA administers some of this funding directly to states in the formula funding. A portion of the DERA funding is also available as competitive grants to projects that can achieve significant diesel emission reductions, especially in areas that are designated as "poor air quality areas." The funding covers emission reduction technologies in locomotives, including alternative cleaner fuels, engine upgrades, replacements, and retrofits. Private fleet operators, including railroads, are not eligible to apply for these grants, but they can access these grants through other applicants, such as the state or local government and port authorities. For example, the recent battery-electric locomotive pilot by Union Pacific is being partially funded from a $2 million DERA grant which was secured by the Port of Los Angeles.

- **Targeted Airshed Funding Program** – This EPA grant program is directed toward reducing pollution in non-attainment areas that are considered the top five most polluted areas in terms ozone and $PM_{2.5}$ concentrations. As per the latest Notice of Funding Opportunity (NOFO), around $62 million is available in competitive funding for this purpose. As per EPA's assessment, most of these areas are in the state of California, making this grant a considerable funding source for railroads to implement pilots in the state. This grant funding could be used to invest in certified or verified technologies, vehicles, and engines that will be operated in the non-attainment area for a majority of the time during the project lifecycle. The funding supports both retrofits and upgrades to reduce emissions using existing technologies and demonstration projects for new experimental technologies. Between 2020 and 2021, this program supported two projects worth around $7 million to replace conventional locomotives with low-emission alternatives.[129]

- **CRISI Grants:** The Consolidated Rail Infrastructure Grants, administered by the FRA, support a wide range of projects aimed at improving safety, efficiency, and reliability of railroad operations. Funding can be directly accessed by a Class II and Class III railroad or a Class I railroad and rail equipment manufacturer in partnership with the state(s) or a public agency. In the most recent 2023-2024 NOFO, around $2.4 billion was available in funding under this grant opportunity.[130] Among other types of projects, CRISI grants fund research and testing of innovative rail projects and procurement or overhauling of locomotives for emission reduction.

- **CMAQ Grants:** USDOT's Congestion Mitigation and Air Quality (CMAQ) program funds projects aimed at reducing traffic congestion and the impacts of poor air quality on communities. The Bipartisan Infrastructure Law (BIL) continues the CMAQ program and provides about $2.5 million annually between 2022 and 2026, which is distributed as formula funds to State DOTs. Projects must demonstrate how they can achieve reduction in CO, ozone precursor emissions, and PM-10 pollution especially in non-attainment areas. The program provides significant flexibility to state and local governments to cover a wide range of projects aimed at reducing pollution, including conversion to alternative fuels fleets and experimental projects that can reduce vehicle miles traveled and fuel consumption. CMAQ funding can also be used to support purchase and retrofits of locomotives owned by the private sector if such projects are implemented through a public-private partnership.[131] An example of such a project, operationalized through a public-private partnership between CSX and Port Authority of New York and New Jersey (PANYNJ), is the diesel engine retrofit program to reduce particulate and GHG emissions. For this project, $1.8 million of CMAQ funding from NJPTA was matched with $600,000 funding each from PANYNJ and CSX.[132]

- **BUILD (previously RAISE) Grants:** Better Utilizing Investments to Leverage Development (BUILD) is a discretionary grant program from the USDOT supporting investments in road, rail, transit, and port projects of significant regional or local importance. These grants support multi-modal and multi-jurisdictional projects by transferring funds directly to a wide range of public entities. BUILD funds projects that reduce GHG emissions and incorporate electrification or zero emission vehicle infrastructure. Capital investments in passenger and freight rail infrastructure are eligible expenses under these grants.[133]

- **State and local funding:** In addition to the federal grants, a few states have funding available through their climate action plans and strategies. One example is California, where the funding collected through the cap-and-trade program is used for emission reduction. The state's Zero- and Near Zero-Emission Freight Facilities program provides competitive funding to public entities and local air districts, who may partner with the private sector, to run demonstrations of advanced engines and transportation systems that reduce emissions.[134] BNSF, in partnership with San Joaquin Valley Air Pollution Control District, has received around $22 million from the California Air Resources Board to pilot emission reduction technologies in and around railyards.[135] The grant covers about half of the total cost of the project. BNSF used this funding to develop its emission reduction technologies and to pilot a battery-diesel hybrid locomotive, in partnership with GE, on the Stockton-Barstow route.

Pilots

Most alternative fuel pilots led by railroads and locomotive manufacturers have been prompted by the EPA regulations limiting air pollution from locomotives.[136] These technologies, however, have carbon reduction benefits. Below is a list of pilots involving natural gas, battery-electric, and hydrogen fuel technologies that have been conducted by freight railroads. Most of these pilots are being led and funded by Class I railroads with the key drivers being reducing fuel costs, reduction in particulate and carbon emissions-- both to comply with the increasing government regulations and to better compete with trucks that are making technological advancements in these areas.

Investments in procuring new alternative-fuel locomotives and building the necessary infrastructure can be cost-prohibitive for short line rail. Short line railroads, therefore, largely focus on achieving emission reductions through measures that improve fuel efficiency, such as fuel additives and injector sets. Despite the existing cost barrier, a few short line railroads have been leading pilots through grants from the government. As seen in the table below, Indiana Harbor Beltway, Pacific Harbor Line, and Sierra Northern Railway have relied on federal and state funding for conducting these pilots. See Appendix for the full list of pilots.

Recommendations

The freight rail industry must remain competitive by embracing innovation and keeping pace with emerging trends in the trucking sector to maintain its relevance and market share in the evolving freight landscape. Emission reduction efforts can lower costs and strengthen the resilience of the freight rail network, ensuring it can continue to deliver goods efficiently and reliably. U.S. railroads have already acknowledged these priorities, directing capital and resources toward research, pilot programs, and alternative fuel testing. These investments are motivated by both regulatory requirements and the potential for operational savings in fuel and maintenance, while also reinforcing the industry's commitment to sustainability.

Reducing locomotive emissions offers substantial public benefits, both in terms of climate impact and public health. As such, the public sector has an important role to play in advancing these efforts—whether through regulation or targeted incentives. Federal agencies such as the U.S. Department of Transportation (USDOT), Department of Energy (DOE), and Environmental Protection Agency (EPA) each have a role in shaping and supporting this transition.

Currently, federal regulations related to locomotive emissions primarily address safety—regulated by the Federal Railroad Administration (FRA)—and criteria pollutants—regulated by the EPA. While USDOT and EPA administer competitive grant programs that support air quality, safety, operational performance, and technological advancement, most of these grants are not explicitly aimed expanding rail infrastructure or reducing GHG reduction. Federal, state, and local governments can play a stronger role in encouraging private-sector research and investment in alternative fuels—particularly when the long-term benefits outweigh associated costs. To further support innovation, the federal government should ensure a regulatory environment that enables the safe testing and deployment of new technologies by establishing clear standards and approving pilots.

- Tax credits for railroads that test alternative fuels

  Railroads are all interested in cutting their carbon emissions to meet sustainability goals and lower their own costs. But the market incentives for them to do so are not always there. Hydrogen, natural gas, biodiesel, and battery technologies all represent potential carbon efficiencies for railroads. Tax credits can provide flexibility and cost subsidies for large and small railroads to invest in the facilities and locomotives needed to test and deploy alternative fuels. It is unclear at this time which type of fuel has the greatest potential for long-term, large-scale applicability, so allowing an open-ended tax credit tied to carbon emission reduction provides flexibility to railroads to meet the broader objective without being tied to a specific technology.

- Update emissions ratings for locomotives to include carbon emissions

  The Environmental Protection Agency currently regulates the emission of locomotives based on a 2008 ruling.[137] This ruling, which is applied to line-haul, switching, and passenger rail locomotives, cuts particulate matter and nitrous oxide emissions by 90 and 80 percent, respectively. But implementing and adhering to this law in some cases has decreased the carbon efficiency of locomotives.

Conclusion

Railroads play a pivotal role in the U.S. freight transportation system, offering a fuel-efficient alternative to trucking, particularly for long-distance and bulk commodity shipments. As an energy-efficient land-based freight mode, railroads are uniquely positioned to contribute to the transition to a more sustainable economy. However, to fully realize this potential, significant challenges must be addressed, including improving infrastructure, expanding intermodal capabilities, and overcoming the dominance of trucking in short-haul freight. Policies geared towards safety, emissions reduction, and advanced rail technologies, such as fuel management systems or anti-idling solutions, are a handful of public policy levers that could further enhance the efficiency and environmental benefits of railroads.

Transitioning to alternative fuels for locomotives will provide significant benefits for reducing carbon emissions, improving air quality, and achieving sustainability goals in freight rail transportation. While biofuels and natural gas provide short-term solutions with moderate emission reductions, hydrogen and battery-electric technologies offer the greatest potential for near-zero emissions in the long term. However, significant barriers, including high capital costs, safety concerns, and infrastructure requirements, must be addressed to enable large-scale adoption. Strategic investments and regulatory advancements will be crucial in guiding railroads and policymakers toward implementing viable and sustainable fuel solutions for the future.

Ensuring resilience in the freight rail sector is not just about mitigating immediate disruptions but also about fostering a long-term, adaptable system that can sustain economic stability and growth. Encouraging a strategic mode shift from truck to rail can play a vital role in enhancing the resilience, efficiency, and sustainability of the freight transportation system. While advancements in trucking technology will continue to shape the industry, targeted investments, policy support, and infrastructure improvements can help ensure that rail remains a competitive and viable option for long-haul freight movement in the years to come.

Sustaining and expanding the U.S. freight rail network requires a balanced approach that includes private investment, public funding, and strategic infrastructure development. As freight rail competes with an evolving trucking industry, targeted policies, grant programs, and intermodal investments will be critical in enhancing rail's efficiency, accessibility, and resilience. Strengthening rail infrastructure not only supports economic competitiveness but also ensures a more sustainable and adaptable freight transportation system for the future. Effective freight rail planning requires collaboration between the public and private sectors to ensure a resilient, efficient, and sustainable transportation network. By fostering strategic investments, improving data-sharing frameworks, and balancing industry competitiveness with public interest, policymakers can enhance freight rail's role in meeting future transportation and environmental challenges.

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