# How the U.S. Moves Hazardous Materials

A side-by-side comparison of transportation methods for critically needed materials


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# About Aii

The Alliance for Innovation and Infrastructure (Aii) is an independent, national research and educational organization that explores the intersection of economics, law, and public policy in the areas of climate, damage prevention, energy, infrastructure, innovation, technology, and transportation.

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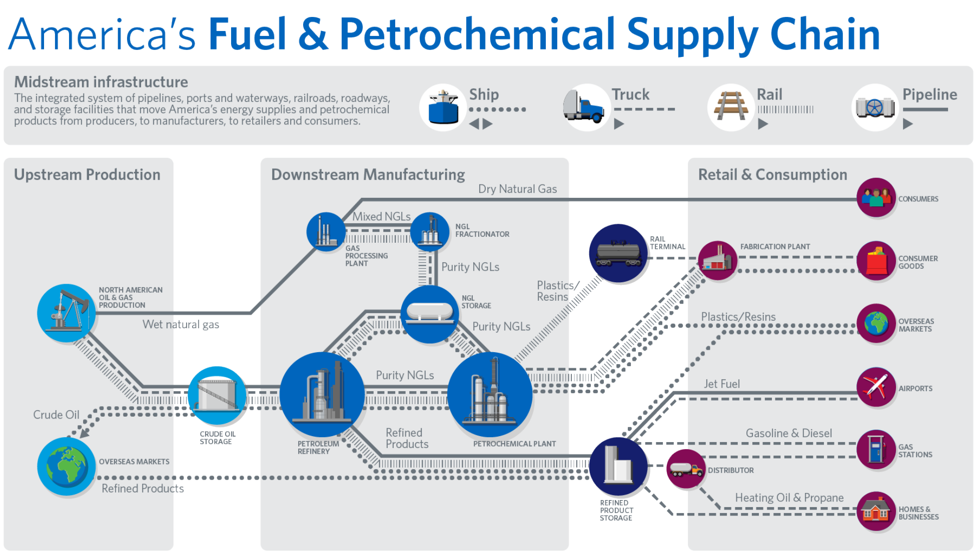
## Introduction

The U.S. consumes massive volumes of hazardous material in the form of natural gas and petroleum products, industrial chemicals, various gases, and other raw materials. While much of it is used to generate energy, these resources also go on to serve as cleaners, additives, or the building blocks of medicines, fabrics, plastics, and technological components. In fact, it is virtually impossible not to interact on a daily basis with a product using or derived from petroleum, natural gas, or other hazardous material.

Whether or not public policy favors transitioning to new forms of energy, given their importance for modern life beyond generating power, these hazardous materials ***must*** be transported. In order to get them where they are needed most effectively, there are several factors to explore. Policymakers must know the relative safety record and effectiveness, the relative carbon-intensity, the speed and efficiency of delivery, and the economic costs associated with their transportation.

The available transportation methods are pipelines, trains, trucks, and ships. This report surveys the safety and efficacy of each method for policymakers to better understand how to allocate resources and shape regulatory policy. This report does not rank the transportation methods but provides a side-by-side comparison for more informed decision making.




*This graphic provided courtesy of the American Fuel & Petrochemical Manufacturers.*

## Pipelines

According to the U.S. Department of Transportation (DOT) and the Pipeline and Hazardous Materials Safety Administration (PHMSA), there are over 2.8 million miles of natural gas and petroleum pipelines across the country.[1] This total mileage includes all gathering, feeder, transmission, and distribution infrastructure for both gases and liquids. With so much infrastructure in place, understanding its overall impact on the economy, environment, and communities is critical.

**Safety & Effectiveness**

Product loaded into one end of a pipeline arrives at its destination 99.999 percent of the time.[2] This leak, spill, or accident rate below 0.001 percent makes pipeline the most effective in-land transportation method currently available anywhere in the world. Industry estimates place the effectiveness record for natural gas high as 99.999997 percent.[3] Given the vast quantities moved through pipelines every year – 64 percent of all U.S. energy commodities[4] – even this nearly perfect effective rate still means that incidents occur. The U.S. pipeline network transports over 28 billion cubic feet of natural gas[5] and, over 16 billion barrels of crude and refined petroleum products each year.[6, 7]

Additionally, few deaths and injuries are attributed to pipeline operation. As few as 1.7 fatalities per year are estimated to occur due to pipeline issues, accounting for operators, pipeline personnel, and the general public.[8] The 10-year average across all pipelines and storage facilities is 13 fatalities, and among this number around half are the result of third-party excavation damage, not from pipeline operation or product handling.[9]

**Climate Impact**

In terms of carbon intensity, pipelines have two major sources of greenhouse gas emissions (GHGs).[10] Pump or compressor stations along oil and natural gas pipelines generate emissions to maintain pressure inside the pipeline that allow fuel to flow efficiently. The other source of emissions are leaks from maintenance operations, excavation damage, or deficiencies in the pipeline itself. Methane leaks from pipelines are more serious than certain oil leaks, as methane acutely impacts ozone.[11] However, pipelines emit 61 to 77 percent less[12] GHG – at only half the overall air pollution and greenhouse gas costs – than the next most efficient on-land transportation method.[13] Overall, significantly less direct emissions occur from pipeline transmission than other industry segments.[14] It is also estimated that the majority of leaks occur at facilities rather than line pipe, making oil and petroleum products contained, recoverable, or subject to secondary safety and cleanup measures.[15]

Importantly, this analysis does not consider end-use emissions from burning the fuel, as that impact is a feature of the fuel itself and would be applied to all transportation methods. When considering the entire lifecycle of the infrastructure, from material sourcing and production to construction and operation, pipelines are the only transportation method that allows for environmental restoration above ground, whereas rail tracks and roadways are permanent fixtures. This is one advantage of new pipeline projects relative to adding capacity to rail or building new roads. Once trenching and construction are completed, land is restored allowing wildlife, grass, and brush to retake the area, with a minimal easement retained by the operator for future maintenance and inspections.

**Efficiency**

Pipelines are extremely efficient in transporting hazardous liquids and gases. In terms of energy cost, pipelines use the least amount of energy when transporting hazardous materials, but the speed of transportation varies over distance and by diameter. A smaller pipeline like the Overland Pass Pipeline can transport 140,000 barrels a day across 760 miles from Opal, Wyoming to Conway, Kansas.[16] A larger pipeline like the 5,500-mile Colonial Pipeline can transport 3 million barrels per day between Texas and New York.[17] Depending on the viscosity of petroleum being moved through the pipeline, speeds range from 3 to 8 miles per hour, which moving around the clock in a direct path would take "14-22 days to move oil from Houston to New York City."[18]

Ultimately, pipelines operate in virtually straight lines, with relatively direct service from point A to point B. For natural gas, this allows for higher speed and greater efficiency up to 30 miles per hour.[19] Pipelines make the logistics of moving high volumes of natural gas or petroleum from place to place quick, efficient, and extremely safe, as pipelines can operate continuously and are monitored around the clock by pressure sensors, remote monitoring technology, and personnel.[20] Pipelines are ultimately not the fastest transportation method but are capable of moving the most volume with the greatest effectiveness.

**Cost**

The cost of transporting product through existing pipelines varies depending on distance travelled and the grade of the petroleum being transported.[21] The average cost for all pipelines rounds up to around five dollars per barrel[22] and two to four dollars per thousand cubic feet of natural gas.[23]

Of note, while pipelines transport the most volume of hazardous liquids and gases, and do so with great safety and efficiency, they often rely on secondary transportation methods to get products to end users. Rail is a needed partner to take on additional production capacity, trucks often take short distribution routes, and ships are critical for imports and exports.

## Rail

America's freight rail infrastructure consists of a 140,000-route-mile network, with nearly 100,000 additional miles of sidings, rail yards, and parallel tracks. According to the Federal Railroad Administration, "it is widely considered the largest, safest, and most cost-efficient freight system in the world." With fully integrated Positive Train Control (PTC) technology, rail is now a cutting-edge technological transportation industry utilizing computers and software to ensure safer delivery of all products.

**Safety & Effectiveness**

Hazardous products transported by rail tanker car arrive at the destination over 99.99 percent of the time without a release caused by a train accident.[24] The leak, spill, or accident rate below 0.01 percent makes rail the second safest in-land transportation method[25] with rail spilling the least volume of hazardous material of any in-land method.[26] Overall, in comparison to other forms of transportation, oil is spilled from railroad transports more frequently than pipelines, however rail loses significantly less oil from accidents in comparison to pipelines, given the larger volumes moved by pipe.[27] Rail effectively transports between 100 million and 200 million barrels of crude and petroleum products each year.[28, 29]

Each year, an estimated 2.4 fatalities occur as a result of moving crude and other products by rail. In the last five years, a total of 25 fatalities occurred across all passenger and freight rail in the U.S., of which only three were a result of derailment and eight from collisions.[30] Fatalities attributed to the movement of crude are incredibly rare, and in the last 10 years, only one rail death has been attributable to hazardous material.[31]

**Climate Impact**

The carbon intensity of rail is impacted by many factors, including freight load, car type, distance traveled, and time to deliver a product. Freight rail relies primarily on diesel-powered locomotives, which like other vehicle engines utilizes internal combustion to burn fuel and generate power. While creating emissions to power the train, on average, rail is able to move a ton of freight over 480 miles on a single gallon of fuel[32] making it very fuel efficient. Still, the total amount of GHGs released by railroad transporters of crude was found to be almost twice as much as pipelines.[33] Total carbon intensity is still dependent on scale: small-scale transportation of less than 50,000 barrels a day is extremely carbon efficient by rail (more so than pipeline), while larger scale rail operations produce up to four times more GHG emissions than pipeline when moving crude longer distances.[34]

Crude oil is not the only hazardous material moved by freight rail. In fact, rail moves many additional products and hazardous materials that pipelines do not or cannot move, including explosives, flammable gases and liquids, corrosives, chemical inputs, and certain radioactive material.[35, 36] Accounting for the additional payloads, the crude-transport carbon intensity of rail is relatively low. The total emissions per ton-mile of freight for rail is 0.048 pounds of $CO_2$, which is lower than any other freight method.[37] While producing a total of 38 million metric tons of GHGs, rail moved 1,729,638 million ton-miles in 2018.[38] When considering the carbon intensity to move hazardous materials by rail, the crude-specific transportation GHG emission are only a share of that total rail impact.

**Efficiency**

The overall effectiveness and speed advantages of railroad transport comes down to the flexibility of rail transport to adapt to changes in the oil and gas markets.[39] If a steep drop or increase in the price of oil or gas occurs, railroads can easily account for increased market demand in specific regions of the country very quickly.[40] Railroads are also more cost-effective when pipeline infrastructure is not available for utilization, as the existing rail network in North America is much more extensive than the pipeline transmission network.[41] Trains can also switch tracks and complete different routes than pipelines, which are fixed in the ground.

Trains can travel very quickly and are able to transport crude oil faster than pipelines. Depending on the type of hazardous material, number of carloads, and surrounding population density, trains can travel up to 50 mile per hour and can move from North Dakota to the Gulf Coast within a week.[42, 43] Trains may have to stop or utilize siding or rail yards to allow other trains to pass or react to track blockages or deficiencies. These add time costs to delivery, even when the ultimate destination is a straight line.

**Cost**

Overall costs for shipping oil and gas by rail fluctuate depending on the market. However, even during times when production has outstripped capacity, transporting oil and gas via rail remains twice as expensive as pipeline transportation.[44] The average cost to move crude by rail is estimated at between $10 and $15 per barrel, but is variable.[45] Additionally, choosing to transport oil by rail means that producers may have to compete for rail space with other commodities and products being shipped by rail and a higher number of high-hazard rail cars means a slower travel speed.[46]

# Truck

An estimated 100,000 tank trucks and trailers deliver oil, gas, and other hazardous materials around the country on a daily basis. These specialized trucks differ from other tractor trailers, box trucks, or flatbeds for intermodal payloads, and instead carry specialized tanks. They primarily undertake short routes to move products between facilities or distribute fuel to gas station, fulfilling a vital role in the supply chain that pipelines and rail lack the flexibility to accomplish. Despite largely fulfilling shorter routes, tank trucks deliver around 9 billion barrels each year of diesel, gasoline, aviation fuel, and chemicals.[47]

**Safety & Effectiveness**

The U.S. Department of Transportation has not traditionally tracked data regarding trucks transporting oil and gas.[48] However, one report from PHMSA shows that trucks carrying crude were estimated to safely transport 99.99 percent of product.[49] While spills are much more common for trucks during on-loading and offloading and in vehicle accidents, the quantity lost is far lower.

Notably, trucks travel far lesser distances with hazardous material, as they are primarily a distribution or short-route option, whereas pipelines and rail are used for long haul transmission. The shorter distance reduces the potential for an incident but takes place in a much more dynamic setting. That makes transport by truck less safe than rail and pipeline, as accidents occur from a variety of sources, including outdated infrastructure, traffic, driver error, driving collisions, mismatched truck designs, and unpredictable weather and road conditions.[50] Truck transports also have the highest number of injury or deaths per method of transportation, with an estimated 10.2 fatalities per year.[51, 52] In the last 10 years, 93 highway deaths have been attributable to hazardous materials.[53] Road-based casualties are usually compounded by other traffic risks and lead to direct human impact given road congestion in urban settings, which may be contrasted with leak or spill incidents by rail or pipe along remote transmission routes.

**Climate Impact**

Carbon intensity from the road transportation sector already accounts for the fastest growing source of GHGs. Commercial vehicles most often utilize internal combustion engines, primarily burning diesel fuel. The average tanker truck in the U.S. emits 161.8 grams of $CO_2$ per ton-mile and weighs six tons.[55] For the distance from the Bakken oil fields in North Dakota to the refineries in Houston, Texas of 1,369 miles, a single truck would emit 1.33 metric tons of $CO_2$ in a single one-way journey.[56] This calculation does not take into account potential accidents, delays on the road, or time spent loading and unloading product, where there is potential for additional emissions.

While leaks and spills are more common with trucks, they primarily take place at the on-loading or offloading stage, where there is little environmental impact and the quantity lost is minimal. When incidents occur on the road or in a vehicle collision, it may result in leaked material, fires, explosions, and greater emissions from traffic and emergency responses.

## Efficiency

The effectiveness and speed of trucking crude oil and gas is limited both by the trucks capacity and factors including traffic patterns and the distance needed to travel. Most tank trucks can only transport 200-250 barrels of oil.[57] This makes the cost of transporting crude or gas medium and long distances costly, both for fuel costs and the time it takes to navigate from a source to a refinery.[58] Transporting crude from North Dakota to Texas in a truck would take a shorter amount of time than rail or pipeline, but could carry only a small amount of product and cost far more per barrel.[59] Trucks are the fastest method of transport, able to reach or exceed speeds of 55 miles per hour on the Interstate Highway System, and therefore make very efficient short distribution deliveries. While pipelines offer 300,000 miles of transmission routes, and rail has a fixed 140,000-mile track network, trucks can utilize nearly all of America's four million miles of roadways to make deliveries and reroute as needed.

## Cost

Trucking oil and gas is "usually cost-prohibitive" for transmission routes, and most companies avoid trucking oil and gas except for very short journeys to distribute product to consumers.[60] It costs an estimated $20 per barrel of crude moved by truck, which is twice as much as by rail, and an estimated four times as expensive as pipelines.[61] This is mainly due to inability to reach economies of scale with limited tank sizes, the price of diesel, and relatively low fuel efficiency of trucks.

Overall, the primary function of tanker trucks has been limited to distributing refined crude to gas stations, distribution centers, or individual service locations. Trucks are a vital transportation form and in no danger of being replaced, as no alternative distribution method exists to rival it. Trucks are the most versatile, capable of rerouting and reaching destinations across a wide geographic area, not restricted to pipeline or rail track infrastructure.

## Ships and Barges

Maritime vessels have the ability to transport large amounts of cargo across the world's oceans and global markets. While their utilization is mainly kept to strictly international travel, tanker ships serve a crucial role in global trade, with maritime trade and shipping making up over 80 percent of global trade by volume.[62] Tankers are normally used to transport massive amounts of fuel, chemicals, and other raw materials to different foreign markets or to different ports across a single country. Within the nation's 12,000 miles of waterways, nearly 4,000 barges also offer safe and fuel-efficient means of transporting hazardous materials including crude, natural gas liquids, and ethanol.

**Safety & Effectiveness**

Tanker ship transport has the lowest number of accidents per million barrels of oil transported.[63] Overall safety has improved dramatically over the last three decades. Roughly 60 percent of the world's oil travels by tanker ship and since 1970 there has been a 98 percent reduction in the oil spilled from tankers worldwide.[64] Over the past decade, over 99.9997 percent of oil delivered to the U.S. reached its destination without an accident.[65] Advancements in maritime technology have streamlined the number of contingency options for tankers should an incident arise and increased safety standards and training time for tanker crews have resulted in a massive downturn in accidents.[66]

Within the navigable waters of the U.S., barges also boast an impressive safety record, transporting a greater volume than rail with no significant releases in the last 10 years.[67] Barges alone transport around 200 million barrels of crude oil around the U.S. each year. From 1995 to 2015, only three major incidents occurred by barge, which together released around 100,000 barrels total. In a typical year, barges release less than 5,000 barrels of oil, leading to an estimated 99.99975 percent effective rate for crude.[68] In the last 10 years, there have been no reported leaks of ethanol or natural gas liquids by barge.[69]

**Climate Impact**

Tanker ships make up a still-increasing share of world shipping emissions. The largest class of container and oil ships have increased their base operating speeds within the last decade, resulting in higher levels of emissions.[70] The total carbon intensity of these massive ships as a class of ship "actually decreased (became more efficient), but the largest of these already massive ships became more intensive (less efficient)."[71] The burning of "bunker fuel"[72] (high hydrocarbon fuel) for large tanker ships is unique to the shipping industry and is polluting enough to put the net emissions from international shipping on par with some standalone country emissions.[73] Currently, the single largest determinant of the amount of emissions from a ship is speed; if ships travel at a slower pace with their large cargoes, less partially burned pollutants like black carbon are emitted.[74]

In contrast, barges traveling in-land waterways are incredibly carbon-efficient, producing less carbon monoxide, nitrous oxide, and particulate matter than rail or trucks.[75] In emissions per ton-mile of freight moved, water transport produces 0.080 pounds of $CO_2$, second only to rail.[76] When rare leaks or spills do occur, they happen in incredibly sensitive environments, whereas trucks, trains, and pipelines often spill in more containable settings or less ecologically vulnerable areas.

**Efficiency**

One obvious drawback of tankers is that they are not available for most inland transport. With the exception of major rivers or Great Lakes, these are limited to coastal routes or large ports situated in import-export markets that can handle large ships. For those areas that have significant waterways, tankers have the capacity to carry tens of millions of gallons of oil and even smaller barges have significantly more carrying capacity than trucks or railroad cars.[77] Tankers provide the massive capacity and speed to deliver large quantities of crude and gas over long distances, but can be impeded by inclement weather, frozen waterways, or backlogs in major ports that can delay shipments.[78]

Barges are limited by the availability of waterways, restricting the routes and dynamism of deliveries to navigable rivers, streams, and canals. They can, however, move quickly on the water and do not often encounter congestion like rail and roadways. With a capacity of up to 90,000 barrels, river barges move at four to five miles per hour.[79]

**Cost**

Due to the scale of tanker ships, measuring costs is solely based on the cost per barrel of oil. Relative to other forms of long-distance oil and gas transportation, tankers are extremely cost-effective.[80] Lower oil prices internationally mean that shipping rates for tankers will be similarly affected; potentially opening the door to other means of transportation to compensate for the loss in profit for bulk shipments of crude.[81] Overall, in comparison to long-distance pipelines or railroad journeys, tanker ships offer a cheaper, more cost-effective, and more flexible way to ship massive quantities of oil internationally.[82]

The cost to move oil and other liquids by water depends on certain factors, including starting and end points, though not necessarily distance. The Merchant Marine Act of 1920, also known as the Jones Act, requires ships entering consecutive U.S. ports to meet certain U.S.-made and U.S.-crewed standards. This leads to higher costs. For oil shipped within the U.S., the price may be $5 to $6 per barrel, while shipping oil from the U.S. to Canada or using a foreign vessel may cost $2 per barrel.[83] Barges do vary by distance, but at an estimated $5 to $7, is cheaper than rail and more expensive than pipeline.

## Conclusion

The U.S. consumes over 6.63 billion barrels of petroleum[84] and 30.5 trillion cubic feet of natural gas[85] each year in addition to other hazardous liquids and gases used directly or as derivative inputs for necessary products. The nation, communities, and individuals need these resources to be productive, and in many cases, to survive. That means that public policy must allow these resources to be developed and transported. The methods of transport demands attention.

Rather than focus on the energy density, economic value, or climate impact of the fuels and resources themselves, we must focus on safe and effective ways to move them. This is not a question of wind and solar versus pipelines and fossil fuels, rather it is a question of how to get critically needed raw materials to fulfill energy, manufacturing, pharmaceutical, and even agricultural needs.

The four available methods of transporting these gases and liquids are pipelines, rail, trucks, and ships. Each of these are necessary and important for moving resources. In many instances, rather than competitors or substitutes, these often serve as compliments. Where substitution is feasible, knowing the relative differences in safety and effectiveness, climate impact, efficiency, and cost is important.

The key takeaway from this survey is that high volumes of oil, gas, chemicals, and other resources are needed by the U.S. population, and every year, enormous quantities are safely moved around the country. Underneath our feet, alongside our communities, sharing our roadways, and along the water, energy resources are moving every day. No method of transportation is perfect, although all four have over 99.99 percent safety and effectiveness, where leaks and spills are rare. Moreover, due to advances in innovative technology and best practices, all four methods of transportation are safer and more efficient than they have ever been. Incorporating technological assistance and remote monitoring within pipelines, locomotives, vehicles, and water vessels has led to safer environments and fewer casualties.

Based on the available data, policymakers should have no concerns about utilizing pipelines and approving new constructions to increase pipeline capacity. The minimal climate impact and efficiency of rail make it a needed compliment for additional oil and gas capacity as well as other hazardous materials and freight. Trucks are needed for distribution routes and added flexibility. Tanker ships are vital for international and costal transports, and barges carry high volumes efficiently through the nation’s waterways.

As legislators, policymakers, and industry continue to focus on improving safety and minimizing the climate impact of our transportation sector, they should recognize the vast improvements made in the last decades. Future marginal safety, climate, and efficiency gains will be important, and incorporating new and innovative technologies will be critical to achieve it.

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The Alliance for Innovation and Infrastructure (Aii) is an independent, national research and educational organization dedicated to identifying our nation's infrastructure needs, creating awareness of those needs, and finding solutions to critical public policy challenges. Aii strives to promote proven, innovative technology and higher safety standards in a non-partisan manner to achieve excellence nationwide.

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# About Aii

The Alliance for Innovation and Infrastructure (Aii) is an independent, national research and educational organization that explores the intersection of economics, law, and public policy in the areas of climate, damage prevention, energy, infrastructure, innovation, technology, and transportation.

The Alliance is a think tank consisting of two non-profits: the National Infrastructure Safety Foundation (NISF), a 501(c)(4) social welfare organization, and the Public Institute for Facility Safety (PIFS), a 501(c)(3) educational organization. Both non-profits are legally governed by volunteer boards of directors. These work in conjunction with the Alliance's own volunteer Advisory Council.