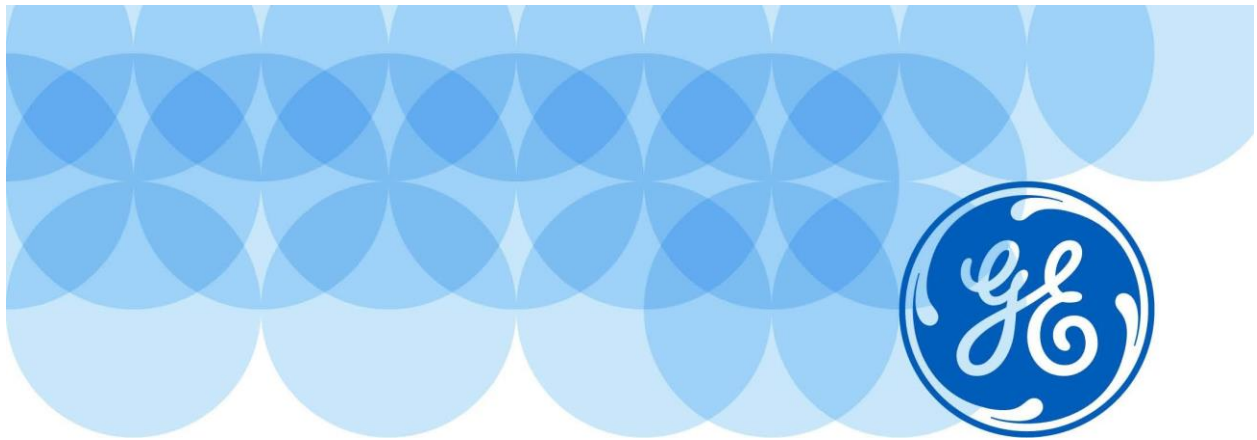


**The Pennsylvania State University
University Park Campus**

Freight, Fuel, & Emissions

**GE Transportation
EDSGN 100**



**Design Team 3
Purple Cobras
Fall 2015**

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SECTION 1 EXECUTIVE SUMMARY

General Electric has been looking for solution to cut emissions from transportation in Pittsadelphia. Each team is required to research and prove which method could provide the most efficiency while maintaining cargo and speed standards. GE would like the best locomotive option to improve the transportation in the area. The report that follows will be used to prove the type of delivery method that should be used.

SECTION 2 INTRODUCTION

2.1 Project Objectives.

Pittsadelphia is looking for the design of a cost-effective solution for its freight that reduces smog and meets EPA requirements, while maintaining or increasing freight capacity into and out of this important port city.

2.2 Project Background.

Every day into and out of the port city of Pittsadelphia, approx. 165,000 tons of freight or minerals (coal, etc.) per day travel via rail. Smog from locomotive emissions is a key complaint of city residents. Smog is generated from engine-emitted NO_x. Tier 2 locomotives used to haul freight are approaching age for overhaul, at which time investments will be required to meet EPA Tier 3 (or higher) requirements.

Some Suggestions have been

- 1) Upgrade the locomotive fleet to meet more recent emissions guidelines set by the EPA.
 - a) Sell existing fleet and purchase new locomotives
 - b) Upgrade fleet with exhaust after-treatment hardware
 - c) Utilize alternative fuels (Biodiesel, CNG, LNG, etc.) which may produce less NO_x
- 2) Alternate freight shipping methods:
 - a) By sea
 - b) By air
 - c) By ground, i.e., trucking

2.3 Project Sponsor Background.

GE Transportation, a unit of GE (NYSE: GE), solves the world's toughest transportation challenges. GE Transportation builds equipment that moves the rail, mining, and marine industries. GE's fuel-efficient and lower-emissions freight and passenger locomotives; diesel engines for rail; marine and stationary power applications; signaling and software solutions; drive systems for mining trucks; and value-added services help customers grow. GE Transportation is headquartered in Chicago, IL, and employs approximately 13,000 employees worldwide.

2.4 Project Description.

Each design team should research and evaluate the suggestions made for fleet upgrade or alternate shipping methods. For upgrades, consider physical constraints of new hardware, as well as fuel storage requirements. Provide your recommendations, commenting on impact to:

- 1) Emissions/Regulatory requirements
- 2) Costs: fuel, infrastructure, etc.
- 3) Freight throughput/capacity
- 4) Public opinion
- 5) On time delivery

2.5 Project Freight Requirements.

Approximately 165,000-tons of freight or minerals (coal, etc) per day travel in or out of the port city of Pittsadelphia via rail. Pittsadelphia must continue to meet EPA requirements, but is looking for a cost effective solution which reduces smog, while maintaining or increasing freight capacity.

2.6 Transportation Mode Comparisons.

a. Trucks. Roads are publicly owned and many trucking companies exist. Travel is quick, but the capacity in trucks is very small. Trucks can provide door-to-door service which no other can do. (Figure 1,9)

b. Barges. Waterways are publicly owned but the speed of transportation is very slow at 5-10 mph. Barges are very large and can haul large objects. Disruptions in weather can have an impact on transportation, for instance drought or flood. (Figure 2,9)

c. Railroad. Privately owned railroads lead to mergers and fewer very large railroads. The speed of transportation is about 20-25 mph with 80% of time being spent loading, unloading and waiting. Many cars hooked together can transport a mass amount of goods to the destination. (Figure 3,9)

SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

3.1 Introduction

Pennsylvania Sections of the American Society of Civil Engineers (ASCE) provide a Report Card on Pennsylvania's Infrastructure so that citizens can understand how Pennsylvania's infrastructure is doing. Over 55 experts evaluated different types of infrastructure by assigning them letter grades. The grades were developed considering each of the following eight criteria: capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation.

3.2 Pennsylvania Roads and Bridges.

Roads were given a grade of a "D-" meaning the overall roadway is between poor and deteriorating condition. Statewide, the amount of poor-condition roadways has risen seven percent (2,800 miles), bringing the total for poor condition roadways to 23 percent (9,800 miles). Vehicle travel through Pennsylvania has remained constant since 2009, however, by 2030 vehicle travel in Pennsylvania is projected to increase by 15%. Bridges received a slightly better grade of "D+" meaning bridges throughout the state are overall between mediocre and poor condition. Nearly one in every four bridges is categorized as structurally deficient (Figure 4) and one in every five bridges is categorized as functionally obsolete. On average more than 16 million vehicles cross Pennsylvania's structurally deficient bridges every day. In addition, at current and projected levels of state funding, more than 95 percent of transportation dollars are exhausted in keeping the existing system functional, leaving very little funding for new bridges and roads.

3.3 Pennsylvania Inland Waterways.

The heart of the Pennsylvanian inland waterways are its dams and locks. Seven dams received a Fair N.I.D. (National Inventory of Dams) rating, seven received poor, and three received unsatisfactory; none received a satisfactory rating. The locks fared slightly better, three locks received a satisfactory rating, four received a fair rating, four received a poor rating, and six received an unsatisfactory rating. The waterways have much more capacity than is being utilized as overall commercial activity along them is at an historic low as seen in figure .

3.4 Pennsylvania Freight Rail System.

Privately owned railroads get the service that they need while short line railroads are harder to find investments. PA has the 5th largest rail system in the U.S. \$1 million is needed for each bridge in disrepair. This information comes from multiple sources put together by ASCE.

SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity.

In Figure 4, comparisons are shown for different modes of transportation. One barge holds about 1,500 tons, a 15 barge tow holds about 22,500 tons, a jumbo hopper car can hold about 100 tons, a 100 car train unit can hold 10,500 tons, and a large semi truck can hold 26 tons.

4.2 Equivalent Units.

One barge can hold as much as 15 jumbo hopper cars and as much as 58 large semi trucks. A barge tow can hold as much as 2.25 train units and 870 large semi trucks. (Figure 4)

4.3 Equivalent Lengths.

One barge tow is .25 miles which is equivalent to 2.75 miles of train which is equivalent to 11.5 miles of large semi trucks. (Figure 4)

SECTION 5 TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)

5.1 Trucks.

Transportation costs for trucks is \$5.35 per ton mile and in terms of fuel efficiency trucks average 155 ton miles per gallon of fuel (Figure 7). Environmental quality for trucks in pounds per ton-mile is 0.0063 hydrocarbons, 0.0190 carbon monoxide, and 0.1017 nitrous oxide. (Figure 8)

5.2 Barges.

Transportation costs for barges is \$0.97 per ton mile and in terms of fuel efficiency barges average 576 ton miles per gallon of fuel (Figure 7). Environmental quality for barges in pounds per ton-mile is 0.0009 hydrocarbons, 0.0020 carbon monoxide, and 0.0053 nitrous oxide. (Figure 8)

5.3 Railroad.

Transportation costs for rails is \$2.53 per ton mile and in terms of fuel efficiency rails average 413 ton miles per gallon of fuel (Figure 7). Environmental quality for rail in pounds per ton-mile is 0.0046 hydrocarbons, 0.0064 carbon monoxide, and 0.0183 nitrous oxide. (Figure 8)

5.4 Most Economical Transportation Solution.

Waterborne transportation requires significantly less fuel than rail or trucks and also costs less money. Also, the barge releases the least number of emissions from every category compared to the other modes of transportation. Freight transportation is often measured in ton-miles. A ton-mile is equivalent to a ton of freight moved one mile. The barge is simply the most economical in terms of moving freight therefore.

5.5 Concept of Operations (ConOps).

a. General Description. The proposed transportation system is by barge. A barge is a flat-bottomed boat, built mainly for river and canal transport of heavy goods. Although most barges are self-propelled, some barges need to be towed or pushed by towboats.

b. Operational Policies and Constraints. There isn't really a space constraint for barge as it travels through waterways. Railroads will need more space for the construction of rails for it to transport goods while trucks mainly depend on roads for transportation. Compared to trucks and railroads, barge will need more workers as there are more goods transported at a certain time.

c. Performance characteristics. The standard barge is 195 feet long, 35 feet wide, and can be used to a 9-foot draft. The standard capacity is 1500 tons. Some of the newer barges today are 290 feet by 50 feet, double the capacity of earlier barges. Their maximum speed is seldom much more than 12 kilometres per hour, but the average cruising speed is normally 6 km/h or less. Compared to railroad and trucks, transporting goods via barge will take a longer time. Piracy and sea robbery are problems that might occur.

d. Operational Impacts. Other than diesel emission, oil spills may occur affect the aquatic ecosystem.

e. Continuity of Operations. Varying weather patterns can affect river levels, contribute to fog delays and cause ice to form in certain river areas. For example, the Upper Mississippi River closes annually from approximately mid-December to mid-March, and ice conditions can hamper navigation on the upper reaches of the Illinois River during the winter months. During hurricane season in the summer and early fall, revenue loss, business interruptions and equipment and facilities damage may occur.

SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background. Standards were made in two sets to ensure that emissions were not out of control.

6.2 Tier 0-2 Standards.

Duty Cycle	HC*	CO	NOx	PM
Tier 0 (1973 - 2001)				
Line-haul	1.0	5.0	9.5	0.60
Switch	2.1	8.0	14.0	0.72
Tier 1 (2002 - 2004)				
Line-haul	0.55	2.2	7.4	0.45

Switch	1.2	2.5	11.0	0.54
Tier 2 (2005 and later)				
Line-haul	0.3	1.5	5.5	0.20
Switch	0.6	2.4	8.1	0.24

- Tier 0—The first set of standards applies (effective 2000) to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured.
- Tier 1 - These standards apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines are required to meet the Tier 1 standards at the time of the manufacture and each subsequent remanufacture.
- Tier 2 - This set of standards applies to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines are required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

6.3 Tier 3-4 Standards.

Tier	Year	Date	HC	CO	NOx	PM
Line-Haul						
Tier 3 ^b	2012-2014	2012	0.30	1.5	5.5	0.10
Tier 4	2015 or later	2015	0.14 ^f	1.5	1.3 ^f	0.03

Switch Locomotive

Tier 3	2011-2014	2011	0.60	2.4	5.0	0.10
Tier 4	2015 or later	2015	0.14 ^d	2.4	1.3 ^d	0.03

- Tier 3 standards - Near-term engine-out emission standards for newly-built and remanufactured locomotives. Tier 3 standards are to be met using engine technology.
- Tier 4 standards - Longer-term standards for newly-built and remanufactured locomotives. Tier 4 standards are expected to require the use of exhaust gas aftertreatment technologies, such as particulate filters for PM control, and urea-SCR for NO_x emission control.

SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry.

a. NO_x

- has the highest proportion in the diesel pollutant emission (>50%)
- NO_x (NO + NO₂) is formed when air (oxygen and nitrogen) is heated
- NO_x formation is exponential with temperature (Higher T → much higher NO_x)

b. Particulate Matter (PM)

- has the second highest second proportion in the diesel pollutant emission
- can be divided into 3 main components:soot, soluble organic fraction (SOF) and inorganic fraction

c. CO₂

- CO₂ is formed in direct proportional to fuel consumed (Reduce fuel consumption → reduce CO₂)
- about 12% of the diesel exhaust gas

d. Hydrocarbons (HC).

- hydrocarbon emissions are composed of unburned fuels as a result of insufficient temperature which occurs near the cylinder wall
- diesel engines normally emit low levels of hydrocarbons

7.2 Diesel Emission Reduction Strategies.

A few strategies can be taken to reduce diesel emission, such as:

- switching to other forms of fuel where possible, eg gas or electric
- replacing old engines with newer versions with lower emissions
- making sure that engines are maintained properly – especially fuel delivery systems
- making sure diesel engine exhausts have filters
- using 'local exhaust ventilation' and good general ventilation in fixed or enclosed workplaces
- using forced ventilation to draw fresh air into the workplace
- using connecting extraction pipes for vehicle exhausts in workshops
- filtering air in vehicle cabs
- making sure that engines are turned off when they're not needed - if engines have to be left running, making sure the vehicle or equipment is moved outside (checking that no-one else is then exposed)
- making sure cold engines are warmed up in spaces with good ventilation
- keeping building doors and windows open if it's practical
- rotating jobs between different employees to minimise exposure

7.3 Alternate Fuels.

Biodiesel

Biodiesel is a renewable, biodegradable fuel that can be manufactured domestically from vegetable oils, animal fats, or recycled restaurant grease. It is a cleaner-burning replacement for petroleum diesel fuel.

Electricity

Electricity is considered an alternative fuel under the Energy Policy Act of 1992. Electricity can be produced from a variety of energy sources, including oil, coal, nuclear energy, hydropower, natural gas, wind energy, solar energy, and stored hydrogen. Plug-in vehicles are capable of drawing electricity from off-board electrical power sources (generally the electricity grid) and storing it in batteries. Though not yet widely available, fuel cell vehicles use hydrogen to generate electricity onboard the vehicle.

Ethanol

Ethanol is a renewable fuel made from various plant materials collectively known as "biomass." More than 95% of U.S. gasoline contains ethanol, typically E10 (10% ethanol, 90% gasoline), to oxygenate the fuel and reduce air pollution. Ethanol is also available as E85, or high-level ethanol blends. This fuel can be used in flexible fuel vehicles, which can run on high-level ethanol blends, gasoline, or any blend of these. Another blend, E15, has been approved for use in newer vehicles, and is slowly becoming available.

Hydrogen

Hydrogen (H₂) is an alternative fuel that can be produced from domestic resources. Although in its market infancy as a transportation fuel, government and industry are working towards clean, economical, and safe hydrogen production and distribution for use in fuel cell vehicles. Fuel cell vehicles are beginning to enter the consumer market in localized regions domestically and around the world. The market is also developing for buses, material handling equipment, ground support equipment, medium and heavy duty vehicles, and stationary applications. The National Aeronautics and Space Administration has used hydrogen for space flight since the 1950s. For more information, see fuel properties and the Hydrogen Analysis Resource Center.

Natural Gas

Natural gas is an odorless, gaseous mixture of hydrocarbons—predominantly methane (CH₄). It accounts for about a quarter of the energy used in the United States. About one-third goes to residential and commercial uses, such as heating and cooking; one-third to industrial uses; and one-third to electric power production. Although natural gas is a clean-burning alternative fuel that has long been used to power natural gas vehicles, only about one-tenth of 1% is used for transportation fuel.

Propane

Propane is also known as liquefied petroleum gas (LPG) or propane autogas, propane is a clean-burning, high-energy alternative fuel that's been used for decades to power light-, medium- and heavy-duty ¹propane vehicles.

7.4 Human Health Issues.

Breathing in diesel fumes can affect your health, and exposure to the fumes can cause irritation of your eyes or respiratory tract. These effects are generally short term and should disappear when you are away from the source of exposure. However, prolonged exposure to diesel fumes, in particular to any blue or black smoke, could lead to coughing, chestiness and breathlessness. There is some evidence that repeated exposure to diesel fumes over a period of about 20 years may increase the risk of lung cancer. Exposure to petrol engine exhaust emissions does not have the same risk.

SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives.

- i. Sell existing fleet and purchase new locomotives
- ii. Upgrade fleet with exhaust after-treatment hardware
- iii. Utilize alternative fuels (Biodiesel, CNG, LNG, etc.) which may produce less NOx.

8.2 Existing Fleet Make-Up.

No. of Existing Locomotives	Locomotive Group Designation	Assumed Existing Locomotive Mileage Range	Assumed Existing Diesel Type
10	A	<150,000	Tier 2
10	B	>150,000 and <300,000	Tier 2
10	C	>300,000 and <450,000	Tier 2
10	D	>450,000 and < 600,000	Tier 2
10	E	>600,000 and <750,000	Tier 2

8.3 Investment Data.

Diesel Locomotive Upgrade

Tier II -> Tier III \$750k

After-treatment \$100k

New Locomotive

Tier III Locomotive \$3M

Tier IV Locomotive \$4M

Alternative Fuels

Locomotive Upgrade \$1M

Fueling Station \$1B

8.4 Upgrade Strategy. The NextFuel kit by GE is a very good option for getting locomotives A,B and C up to Tier 3 standards. Fuel costs are cut by 50%. No negative effects on performance come from this. This upgrade makes a substitution of up to 80% of fuel with natural gas.² The D and E locomotives should be replaced.

8.5 Upgrade Schedule and Costs. For the alternative fuels to be upgraded to the locomotives, the cost will be around \$1 million for each locomotive, totaling \$30 million for upgrades plus \$1 billion for a fueling station. To replace the other locomotives to Tier III will take around \$60 million. The upgrades will be monthly projects to put on the locomotives while a fueling station will take about 3 months to put in. The new locomotives will also take about 3 months to receive.

² "Locomotives & Services | GE Transportation." 2014. 13 Nov. 2015
<<http://www.getransportation.com/locomotives>>

SECTION 9 SUMMARY

In summary, the barge is chosen as the proposed transportation system as it is cheaper and emits significantly less fuel and emissions than rail or trucks. A few suggestions that can further improve barge transportation are that Congress should shape and promote effective WRRDA legislation to fund operation, maintenance and rehabilitation of the waterway system appropriately. This is of great importance to the continued viability of the State's inland waterway infrastructure. Congress should also enable additional financing for inland waterway projects, e.g., by increasing the barge fuel tax and/or implementing user fees. They should also develop a coherent set of principles to prioritize capital projects, with consideration of risk, reliability, and economic benefits.

SECTION 10 REFERENCES

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FIGURES



Figure 1. Typical Diesel Truck and Trailer.

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<NOTE: All Figures must have a Figure Number and Title and be referenced from a Section of the Report. Only one Figure per page.>






Figure 2. Typical Diesel-Electric locomotive.



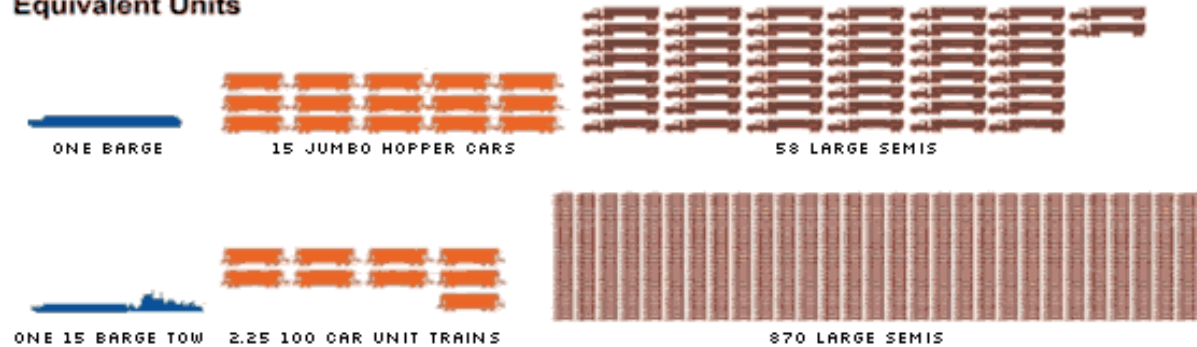
Figure 3. Typical Inland Water Ways Barge and Tug.

Compare...

Cargo Capacity

				
ONE BARGE	ONE 15 BARGE TOW	JUMBO HOPPER CAR	100 CAR TRAIN UNIT	LARGE SEMI
1,500 TON	22,500 TON	100 TON	10,500 TON	26 TON
52,500 BUSHELS	787,500 BUSHELS	3,500 BUSHELS	350,000 BUSHELS	910 BUSHELS
453,600 GALLONS	6,804,000 GALLONS	30,240 GALLONS	3,024,000 GALLONS	7,865 GALLONS

Equivalent Units



Equivalent Lengths



Figure 4. Comparison of transportation methods

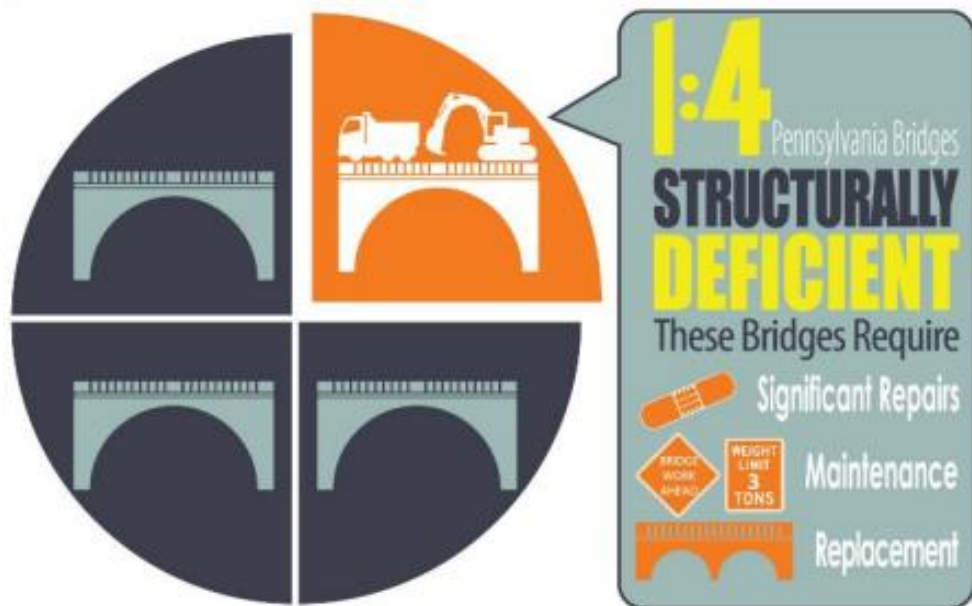


Figure 5. A very high amount of bridges need repair however the lack of funding is worrisome.

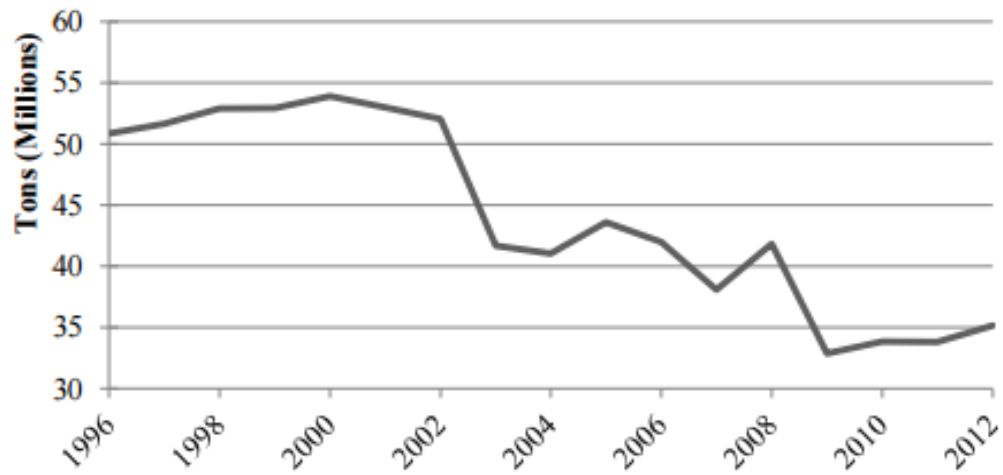


Figure 6. Graph that showcases the decrease in commercial goods along Pennsylvania inland waterways

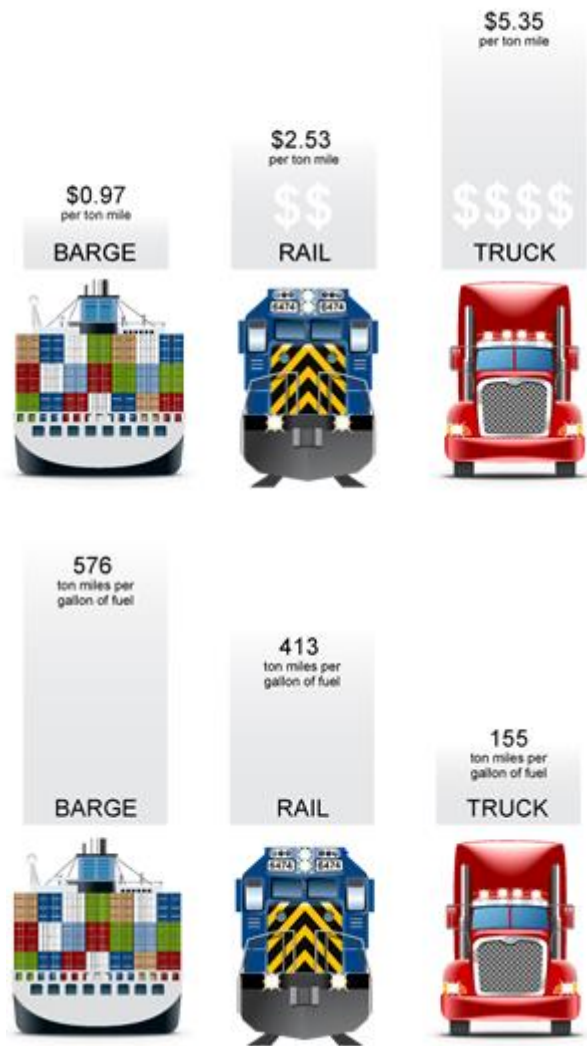





Figure 7. Cost comparison of transportation methods.

Energy Efficiency of Shipping Methods

Number of miles one ton can be carried per gallon of fuel
(Adapted from U.S. DOT Maritime Administration)

Mode of Transportation	Number of Miles/Gallon Carrying One Ton of Cargo
	514 miles/gallon
	202 miles/gallon
	59 miles/gallon

Environmental Quality of Shipping Methods

Comparison of the emissions of different gases into the atmosphere from different shipping methods
(Source: C. Jake Haulk Ph.D. - Inland Waterways as Vital National Infrastructure: Refuting "Corporate Welfare" Attacks)




Mode of Transportation	Hydrocarbons Emitted (lbs/ton-mile)	Carbon Monoxide Emitted (lbs/ton-mile)	Nitrous Oxide Emitted (lbs/ton-mile)
	0.0009	0.0020	0.0053
	0.0046	0.0064	0.0183
	0.0063	0.0190	0.1017

Figure 8. Showing energy efficiency and environmental quality

Mode Comparison

Mode	Relative Price	Delivery Time	Product Value	Damage
Water	1	4	1	1
Railroad	3.5	3	2	4
Truck	35	2	3	3
Air	80	1	4	2

1=fastest

1=least

1=least

Figure 9. Comparing modes of transportation value and speed.