



PennState
College of Engineering

**ENGINEERING DESIGN, TECHNOLOGY,
AND PROFESSIONAL PROGRAMS**

**The Pennsylvania State University
University Park Campus**

Freight, Fuel, & Emissions

GE Transportation

EDSGN 100

Section 001

**Design Team 4
Team Flying Wombat
Fall 2015**



Cody Heaton
Connor Hoover
Denis Pasic
Laura Cook

Submitted to:
Professor Berezniak

College of Engineering
School of Engineering Design, Technology and Professional Programs
Penn State University

08 Dec 2015

ACKNOWLEDGMENTS

Penn State University

- **Dean, College of Engineering**
Amr Salah Elnashai (Harold and Inge Marcus Dean of Engineering; Fellow of the UK Royal Academy of Engineering)
- **Department Head, SEDTAPP**
Sven Bilén (Professional Engineer; Head, School of Engineering Design, Technology, and Professional Programs)
- **Course Instructor**
John Berezniak (Professional Engineer; Instructor, Engineering Design)
- **Laboratory Assistants**
Morgan Gardner, Industrial Engineering
Matthew Sorna, Engineering Science
Sean Fitzpatrick, Mechanical Engineering

GE Transportation

- **James Bunce (Senior Manager, LNG Program)**
GE Transportation Erie
2901 East Lake Road
Erie, PA 16531
-



TABLE OF CONTENTS

SECTION 1. EXECUTIVE SUMMARY

SECTION 2. INTRODUCTION

- 2.1 PROJECT OBJECTIVES
- 2.2 PROJECT BACKGROUND
- 2.3 PROJECT SPONSOR BACKGROUND
- 2.4 PROJECT DESCRIPTION
- 2.5 PROJECT FREIGHT REQUIREMENTS
- 2.6 TRANSPORTATION MODE COMPARISONS

SECTION 3. TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

- 3.1 INTRODUCTION
- 3.2 PENNSYLVANIA ROADS AND BRIDGES
- 3.3 PENNSYLVANIA INLAND WATERWAY SYSTEM
- 3.4 PENNSYLVANIA FREIGHT RAIL SYSTEM

SECTION 4. STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

- 4.1 CARGO CAPACITY
- 4.2 EQUIVALENT UNITS
- 4.3 EQUIVALENT LENGTHS

SECTION 5. TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)

- 5.1 TRUCKS
- 5.2 BARGES
- 5.3 RAILROAD
- 5.4 MOST ECONOMICAL TRANSPORTATION SOLUTION
- 5.5 CONCEPT OF OPERATIONS (CONOPS)

SECTION 6. EPA DIESEL EMISSION STANDARDS

- 6.1 BACKGROUND
 - 6.2 TIER 0-2 STANDARDS
 - 6.3 TIER 3-4 STANDARDS
-



SECTION 7. DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

- 7.1 DIESEL EMISSION CHEMISTRY
- 7.2 DIESEL EMISSION REDUCTION STRATEGIES
- 7.3 ALTERNATE FUELS
- 7.4 HUMAN HEALTH ISSUES

SECTION 8. LOCOMOTIVE FLEET UPGRADE

- 8.1 ALTERNATIVES
- 8.2 EXISTING FLEET MAKE-UP
- 8.3 INVESTMENT DATA
- 8.4 UPGRADE STRATEGY
- 8.5 UPGRADE SCHEDULE AND COSTS

SECTION 9. SUMMARY

SECTION 10. REFERENCES



SECTION 1 EXECUTIVE SUMMARY

The client, GE Transportation, asked several EDSGN 100 design teams to develop an efficient method to upgrade their fleet of locomotives. The fleet consists of fifty different locomotives, each of which are at the current Tier 2 emission standards; the upgrades would be intended to bring the locomotives up to meet the more stringent Tier 3 emission standards. Locomotives emit several types of pollutants that can contribute to smog and other air and water pollution. Over a period of years, the United States has tightened the restrictions on pollutants emitted by locomotives' engines in an effort to become more environmentally efficient.

In order to develop a plan for the upgrade of the locomotive fleet, the group analyzed several different possibilities after researching engines, locomotives, alternate forms of transportation like barges and trucks, alternate fuels like compressed natural gas, port operations in Pittsburgh, the extent of the rail network in the United States, and the potential cost of the different options. The possibilities included upgrading all of the locomotives to Tier 3 standards, selling all of the locomotives and replacing them with new Tier 3 machines, and modifying all of the locomotives to utilize alternate fuels. Analysis of each was done to determine which method was the most economically and environmentally efficient. These possible solutions had varying costs, with the most expensive being around \$2.05B.

Ultimately, a combination of the above methods was selected as the best solution. The plan outlined in this report is to upgrade the newer locomotives, replace the oldest locomotives with their more efficient models, and fit the rest with exhaust after-treatment devices. The plan, which was economically analyzed, was determined to cost an approximate total of \$32M, far less than the other possible options.



SECTION 2 INTRODUCTION

2.1 Project Objectives.

Pittsburgh 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 Pittsburgh, approximately 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 NOx. 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.

Suggestions have been made to address locomotive emissions (i.e., smog) by:

1) Upgrading the locomotive fleet to meet more recent emissions guidelines set by the EPA. A few options may exist to meet the new guidelines:

- Sell existing fleet and purchase new locomotives

- Upgrade fleet with exhaust after-treatment hardware

- Utilize alternate fuels (Biodiesel, CNG, LNG, etc.) which may produce less NOx

2) Using alternate freight shipping methods:

- By sea

- By air

- 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 researched and evaluated the suggestions made for fleet upgrade or alternate shipping methods. For upgrades, they considered physical constraints of new hardware, as well as fuel storage requirements. Recommendations also consider 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.

There will be a total of 20 trains per day entering and exiting Pittsburgh, 15 of which are freight trains (7,000 ton freight/intermodal) with two locomotives. The others are mineral trains (12,000 ton coal trains) with three locomotives. The coal trains travel a round-trip distance of 500 miles; the freight trains, 1000 miles. Overall, the total amount of freight traveling through Pittsburgh per day is about 165,000 tons. This number must be maintained or improved with the new fleet of locomotives.

2.6 Transportation Mode Comparisons.

a. Trucks

Trucks come in several different classes or sizes, which are used for different types of hauling. "Light trucks" are smaller and often utilized for more local deliveries, while bigger, heavier "semis"--also known as "tractor trailers"--can travel for long distances and transport more cargo. (See Figures 1 and 2.) Tractor trailers are made up of a tractor unit, which acts like the locomotive on a train, and one or two semi-trailers attached to it. Shipping by truck is usually done by private commercial companies, so the drivers are private employees. Truck drivers obey strict regulations on how long they can drive at a time before they have to stop, eat, and sleep. This is done to minimize the risks of the road.

Trucks are a good option for small shipments or short hauls, as they are flexible and maneuverable, able to go wherever there are roads. For such restricted cargoes, they can even be cheaper than competing methods of transportation. In addition, trucks are faster to unload than most other modes of transportation. In situations where the distance or cargo is small and time and money are of the essence, trucks can be a viable option.

However, trucks can be a limited method of transporting cargo. Not all shipments will fit in a truck, and they can be expensive for longer distances or larger cargoes. Trucks are also strongly affected by the weather and road conditions, which can cause delays. The road can be a dangerous place; in Pennsylvania, an average of 332 reportable traffic crashes occurred per day in 2014 (about 14 crashes every hour). Trucks also run on diesel fuel, the use of which contributes to air pollution.

b. Barges

The inland waterway system of the United States consists of almost 12,000 miles of inland waterways and 13,000 miles of deep channels, making it a very good method for transporting goods and people from place to place. The primary vehicle for waterway transportation is the barge, which comes in several different types and are usually moved by towboats. Barges are large, flat boats that can be lashed together to form a "tow." (See Figures 3 and 4.) The benefits of transporting goods by barge include direct access to major U.S. cities and the ability to transport large volumes of cargo. Barges are especially useful for transporting raw materials and bulk items like coal.



Water transport has several other benefits. For instance, transporting cargo by barge can be more environmentally efficient than by either truck or rail. To transport one ton on one gallon of fuel, a barge can move 514 miles; a train, 202 miles; and a truck, 59 miles. This conserves fuel and therefore releases less harmful particulate matter into the atmosphere. Barges also carry less risk of injury than comparable methods of transportation.

However, there is a reason water transportation was mostly overtaken by rail when rail transportation was at its peak. Barges are slower than trucks or trains; there are many locks along inland water routes, which cause delays. In addition, similar to rail transportation, barges can only go where main rivers do. This results in a lack of “door-to-door” service available with road transportation.

c. Railroad

A train is a transport vehicle consisting of one or more locomotives and a line of cars carrying the cargo to be transported. Locomotives contain the engine and create the pulling force that moves the train as a whole. Each individual car carries some type of cargo, whether it be humans, minerals, goods, animals, or food. These cars are coupled to the locomotive and can stretch for over a mile. Different varieties of train car are used for different cargoes; for example, refrigerator cars exist to transport food and other goods that need to stay cold, and tank cars transport large amounts of liquids like oil. (See Figures 5 – 10.) Locomotives often run on diesel or gasoline, though newer electric ones are beginning to gain traction as a more environmentally friendly option. Emissions from locomotives are subject to rules and regulations set by the Environmental Protection Agency (EPA) and ranked by tier.

Rail transport can be an economical, efficient method of moving large or bulky cargoes, as trains can carry huge amounts of material and accommodate objects that would not fit in a truck. Locomotives can travel faster than trucks, and they provide fuller protection to the cargo from weather and other inclement conditions. In addition, since trains run on one specific route and schedule, rail transport is both more dependable and safer than driving.

On the other hand, cargo being transported by train can only go where there are railroads, which are less numerous than regular roads. There is no “door-to-door” transport with a train; cargo can only be unloaded at a station or railyard, from where it will have to be transported in some other manner. Building railyards, railroads, and new locomotives is an expensive process. Locomotives, when held to less stringent emissions standards like Tiers 0 through 2, can also be environmentally harmful, affecting human health and the atmosphere.



SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

3.1 Introduction.

The American Society of Civil Engineers (ASCE) was founded in 1852 and is globally comprised of over 145,000 civil engineers. It is America's oldest national engineering society. The Pennsylvania section of the ASCE publishes a report card on the state of the state's infrastructure annually. The most recent of these is the 2014 report, where the highest grade is a B (freight rail) and the lowest a D-minus (roads, wastewater). The report assesses the structural quality of the different types of infrastructure and notes the potential costs associated with fixing the deficiencies. Under the scope of this project, the categories of roads (D-minus), bridges (D-plus), inland waterways (D-plus), and rail (B) are of particular interest.

3.2 Pennsylvania Roads and Bridges.

Approximately 24.9% of America's bridges were considered deficient in 2013. This is a 13% increase in the number of deficient bridges from just two years before. Similarly, Pennsylvania was reported to have 22.6% of its bridges classified as structurally deficient in 2014. Bridge deficiencies can lead to traffic delays and detours that waste extra time for people on the move. (See Figure 11.)

32% of America's roads are labeled as being in poor condition, with over 47% of urban interstate and 15% of rural interstate vehicle miles traveled over poor roads. (See Figure 12.) In addition to the poor condition of the roads, as of 2013, approximately 42% of roadways being congested. This congestion led to a loss of 1.9 billion gallons of fuel as well as an average of 34 hours per driver in 2010.

3.3 Pennsylvania Inland Water Ways.

There are over 12,000 miles of inland waterways in the United States. In these waterways there are nearly 200 lock chambers, 17 of which are in western Pennsylvania alone. These waterways are able to transport approximately 51 million truck trips' worth of cargo a year. Unfortunately, due to increase in price of operation, there has been a drastic increase in the number of delays at each lock point. There are, on average, 52 delays per day for about 90% of the locks in the United States. There was a total of 25 years' worth of delays in 2011 alone. These delays have resulted in hundreds of millions of dollars annually to commercial traffic.



Pittsburgh is the origin of Federal Marine Highway Corridor M-70, which connects farther south with the Mississippi River and the IntraCoastal Waterway. The corridor includes the Ohio, Mississippi, and Missouri Rivers and spans several states, including Pennsylvania, Ohio, West Virginia, Kentucky, Indiana, Illinois, and Missouri. Pittsburgh, a city known for its many bridges and its three rivers, is a bustling port with a great volume of cargo moving in and out every day. (See Figure 13.)

3.4 Pennsylvania Freight Rail System.

There are 57 freight railroads over 5127 miles in the state; 246 million tons of cargo pass through each year. (See Figure 14.) Rails can handle about 286,000 load. It is predicted that freight traffic will increase by 22%, to approximately 15.3 billion tons a year, by 2035. Currently, there are multiple bottleneck zones in the freight system that cause the loss of approximately \$200 billion a year.



SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity.

On average one barge is able to carry a load of about 1,500 tons, and a tow of fifteen barges would be able to handle 22,500 tons of cargo. One jumper hopper car is able to sustain a load of around 100 tons and a train unit of one hundred cars would be able to carry around 10,500 tons of cargo. A large semi is capable of carrying the least, with about 26 tons on average. (See Figure 15.)

4.2 Equivalent Units.

One barge is the equivalent of fifteen jumbo hopper cars, which is the equivalent of 58 large semis. When taking a tow of fifteen barges into account, this is the equivalent of 2.25 units of 100 cars as well as 870 large semis. (See Figure 15.)

4.3 Equivalent Lengths.

Using the standards of the second comparison in Section 4.2 above, a tow of fifteen barges has the length of about a quarter of a mile, while 2.25 units of 100 cars is about 2.75 miles, and 870 large semis take up about 11.5 miles in length. (See Figure 15.)

SECTION 5 **TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)**

5.1 Trucks.

Of the three possible modes of transportation, trucks have the highest cost per ton mile at an average of \$5.35/ton mile nationwide. Trucks require a lot of money for costs such as gas, tolls, and additional equipment needed for operation. Trucks also carry the least amount of cargo per unit when compared to the other methods, which helps to explain why the cost per ton mile is so high; a truck carries the least amount of tons per mile. The number of ton-miles per gallon of fuel for trucks is only 59 miles on average, so it is the least efficient method in terms of how much fuel it burns. As a result, costs go up.

5.2 Barges.

The cost of transporting cargo with a barge is only \$.97/ton-mile. Compared to trucks, this is about one fifth of the cost; compared to railroads, this is less than half of the cost. The number of ton miles per gallon of fuel by barge is about 514 miles, which shows that transportation through waterways requires much less fuel than the other forms. This is one of the largest contributing factors to the low cost of transportation through waterways.

5.3 Railroad.

The cost of transportation on railways is \$2.53/ton-mile. Trains are in the middle of the pack in terms of cost when compared to barges and trucks. The number of ton miles per gallon of fuel for trains is around 202 miles which makes sense considering that it is capable of carrying the second most amount of cargo out of the three modes of transportation, so it is the second most efficient when it comes to fuel efficiency. This is obviously a large factor in determining the cost of transport through the railroad when compared to trucks and barges. While this is a lower cost than trucks by a significant margin, it is still not as cost efficient as barges.

5.4 Most Economical Transportation Solution.

It seems quite clear that the most economical transportation solution is waterways as it has the lowest cost per ton-mile. When considering all three modes of transportation from an economic standpoint, waterways stand out for the fact that barges can carry much more cargo while using less fuel, making water transport significantly more economically efficient than trucks and railroads. (See Figure 17.)

5.5 Concept of Operations (ConOps).

a. General Description

The operation of this system would be stationed on the Allegheny, Monongahela, and Ohio Rivers, all three of which flow through Pittsburgh. These rivers connect to the



Mississippi waterways, granting the barge routes access to the Upper and Lower Mississippi River, as well as the Gulf Intracoastal Waterways. Inland ports, or “dry ports,” such as the city of Pittsburgh, are often used by private companies who ship goods, materials, and people to and from the port with the help of the inland waterways.

A particular cargo like coal, which is commonly shipped by barge, may begin its journey at the coal mine from which it was extracted. After this, the coal is cleaned and prepared at a coal yard, where it is then transferred to tall silo towers so that it can be loaded onto a train. Trains have the open, large containers necessary to ship loose materials like coal.

From there, the coal is brought to a shipping facility at the port from where it will depart. It is transferred, often using a large conveyor belt, from the train to a barge owned by one of the aforementioned private companies. The barge then travels along inland waterways—of which there are many in the United States—to reach another port, the target of its cargo. (See Figure 16.) The barge may utilize numerous locks and navigate several rivers along the way. At the new port, the coal is once again loaded onto a train and brought to its final destination, which may be a power plant, a factory, a company, or another type of client. (See Figure 17.)

b. Operational Policies and Constraints

Many locks operate 24 hours a day. Loading and unloading procedures, which are handled by private companies that use the river for their barges, will follow their usual hours of operation, as will the non-24-hour locks.

Space constraints are laid out by the city of Pittsburgh. There are areas along the rivers allocated for shipping and trade, and this space must be balanced with space for the citizens of the city, especially those using the rivers for fun. With three rivers available for barge use, however, there should be plenty of space for numerous shipping companies to set up operations. Pittsburgh is well-situated to handle a large volume of river trade, which it already does.

c. Performance Characteristics

There are several reasons why inland waterways are very useful shipping routes. For example, river shipping has one of the lowest accident rates, and what accidents do occur tend to involve minimal loss of life or money. Contrast this to a plane crash, a train derailment, or a multicar pile-up; it is clear that rivers can be less dangerous than the roads or the rails, if navigated properly and carefully. Using rivers to ship goods instead of streets and roads can also relieve traffic congestion, making driving a safer activity for all.

Rivers also tend to be highly reliable networks for trade. While there are often numerous locks to be traversed, this process has a set procedure and is familiar and regular. There are no road closings or detours, and intersections with other modes of transportation (like a train track crossing a busy road) are rare.

Barges, as versatile cargo-carrying vessels, can accommodate many different sizes and types of shipments. Oddly shaped or abnormally large cargos can be transported easily on inland waterway routes. One barge can also carry a great deal more cargo than a single train or truck; this makes water shipping a very efficient method of moving goods from



place to place. Barges are especially effective at transporting minerals like coal, which are shipped in large quantities. Trucks would have to put the coal into smaller containers in order to transport it, and trains cannot handle the same volume of cargo as barges can.

One area where water transport may fall short is speed. There is no doubt that a train, truck, or airplane can move much faster than a barge can, and delays like locks can lengthen a journey beyond its original time frame. However, this drawback is inherent in the method of transportation. It is an accepted fact that shipping by barge will take longer, but other advantages like cost, safety, environmental friendliness, capacity, and reliability can make up for that negative aspect of the process.

d. Operational Impacts

Pittsburgh is one of the most active inland ports in the entire United States, already shipping an enormous amount of cargo regularly; companies shipped 12.7 million tons of goods on the Allegheny, Monongahela, and Ohio rivers in May 2013 alone, for example. Pittsburgh's location, at the intersection of three major rivers, enables it to control river trade in a way not many other cities can. With this unique advantage, it makes particular sense to expand and better utilize the river shipping system in Pittsburgh.

More local shipping means more local jobs, a definite plus as the country pulls itself out of the still-recent recession. These jobs would be close to home for many workers and would improve the city's economy, as well as cementing its reputation as a bustling port. Since barges and tows are comparatively much more environmentally friendly than rail or road, the city's environmental cleanliness—a point of issue due to the high-pollution steel mills that lent their name to the city's football team—would not be adversely affected. This change would also have the effect of moving traffic that would have been clogging the streets or the railways to the river, freeing up space and time for commuters in the city.

The rivers are not only home to fleets of barges, however; many city residents use smaller vessels to sail the waters for fun. Increasing the volume of shipping on these rivers could cause them to be taken over by trade vehicles, leaving less time or space for pleasure craft. The citizens of Pittsburgh would have to weigh this potential drawback against the benefits to the city's economy and status.

e. Continuity of Operations

River trade is susceptible to extreme weather conditions, especially regarding precipitation. Excessive rain may swell the river and render it too dangerous to traverse, or visibility may be too low to navigate a large craft along the water. Debris or silt buildup may also damage locks, which would then require repair.

Companies who use the rivers as transport routes will need to judge the danger associated with extreme weather events accordingly. If the rivers are deemed too dangerous, other methods of transportation, like rails and roads, are available for time-sensitive shipments. Buyers who wish to keep the economic benefit of shipping by water may want to wait out the weather. Either way, the river shipping system will run until it is determined too dangerous to do so. Safety of workers and cargo is paramount. This problem is especially prevalent during the winter, when rivers may freeze over, and during times of drought.

SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background.

Emissions are measured on “line-haul” and “switch” locomotives, but each locomotive, no matter which type, must meet both sets of standards. Switch locomotives involve a large amount of time spent in idle and at low power. Line-haul locomotives, on the other hand, involve a large amount of time spent at high power.

The first locomotive emissions standards were adopted on December 17, 1997, becoming effective from 2000 onward. They applied to locomotives manufactured in or after 1973, whether the locomotives were being manufactured for the first time or remanufactured. These first emissions standards created Tiers 0 through 2 and were to be met through engine design methods.

Tiers 3 and 4 were created in later regulation, which was signed on March 14, 2008. This new regulation also remodeled the original tiers, updating them with more stringent standards. The 2008 regulations became effective from 2011-2012 onward. Tier 3, like Tiers 0 through 2, was to be met through engine design methods, while meeting Tier 4 would require the use of exhaust after-treatments, as a more long-term measure.

To enable Tier 4 regulation involving these after-treatments, the Environmental Protection Agency (EPA) limited the availability of low-sulfur diesel fuel. As of June 2007, the limit was 500 parts per million (ppm). In June 2012, the limit was changed to 15 ppm.

6.2 Tier 0-2 Standards.

Each tier’s number refers to the year of manufacture of the locomotive in question. Tier 0 covers locomotives manufactured from 1973 to 2001; Tier 1, from 2002 to 2004; and Tier 2, from 2005 to 2011. The standards are most lenient for Tier 0, as the locomotives are older and may have been constructed during the years when there was no regulation on emissions.

These standards regulate the amount of each compound that can be found in gases emitted by the locomotive.

Emissions Standards

(in g/bhp-hr)	HC	CO	NO _x	PM
TIER 0				
LH	1.0	5.0	8.0	0.22
SW	2.1	8.0	11.8	0.26
TIER 1				

LH	0.55	2.2	7.4	0.22
SW	1.2	2.5	11.0	0.26
TIER 2				
LH	0.3	1.5	5.5	0.10
SW	0.6	2.4	8.1	0.13

Smoke Opacity

(in percentages)	Steady	30s	3s
Tier 0	30	40	50
Tier 1	25	40	50
Tiers 2 - 4	20	40	50

6.3 Tier 3-4 Standards.

Tier 3 consists of short-term standards that apply solely to newly built locomotives (from 2012 to 2014). This regulation will be met using engine technology in the design process. On the other hand, Tier 4 is a set of long-term standards, also for newly built locomotives, that require exhaust gas after-treatment.

All standards only apply to locomotives with greater than or equal to 750 kW (or 1006 hp). Line-haul locomotives usually have greater than 2300 hp, and switch locomotives have less than 2300 hp.

These standards regulate the amount of each compound that can be found in gases emitted by the locomotive.

Emissions Standards

(#s in g/bhp-hr)	HC	CO	NO _x	PM
TIER 3				
LH	0.30	1.5	5.5	0.10
SW	0.60	2.4	5.0	0.10
TIER 4				
LH	0.14	1.5	1.3	0.03
SW	0.14	2.4	1.3	0.03



SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry.

a. NO_x

NO_x is formed when the intake inhales oxygen and nitrogen (O₂ + N₂), then is put under pressure. It makes up remaining emissions (those not attributed to another type of pollutant below) and typically occurs at 50 – 2500 ppm. NO_x, a colorless and odorless gas, is an environmental hazard due to its role in smog production.

b. Particulate Matter

Made of sulfate and soot, particulate matter is a byproduct collected in filters and created by the combustion of lubrication, air, and fuel. Typical amounts range between 0.1 – 0.25 g/m³.

c. CO

Carbon monoxide (CO) is a byproduct of fuel and oxygen combustion. The amount produced is directly proportional to fuel consumption. Carbon monoxide is very hazardous to human health, especially in confined spaces. It is usually emitted in amounts around 5 – 1,500 ppm.

d. Hydrocarbons

Hydrocarbons are also byproducts of incomplete combustion of fuel. A large fraction of emitted hydrocarbons come from the engine lubrication as well. Emitted hydrocarbons (20 – 400 ppm) are an important component of smog.

7.2 Diesel Emission Reduction Strategies.

The website of the Manufacturers of Emission Controls Association (MECA) lists the numerous ways in which diesel emissions can be reduced. “Retrofitting” involves attaching an emission-control device to the exhaust of an engine, removing emissions from the air retroactively. Common types of retrofit devices include filters and catalysts of different kinds. The most popular retrofit device is the diesel oxidation catalyst, or DOC. DOCs often come in the form of a stainless steel canister. Inside, emitted pollutants are converted to harmless gases using chemical oxidation.

There are also several other methods of reducing emissions in diesel engines. “Repowering” involves replacing an old engine with a new one while keeping the rest of the machine intact. This method is useful for devices that can run well for longer than their engines can. The new engine put into the machinery could emit fewer harmful gases, or it could run on an alternative fuel like electricity or gas. “Rebuilding” an engine is to replace old parts with newer and more efficient ones while preserving the overall structure of the engine. “Refueling” modifies an engine so that it can run on alternative fuels. Common alternative fuels for diesel engines include biodiesel, compressed natural gas, and liquefied



natural gas. Some engines can run on electricity instead. Finally, “replacing” is to retire old, environmentally harmful equipment before its usual time so that it can be replaced with new, lower-emission engines.

In 2012, Cummins Power Generation promoted a prime example of diesel emissions reduction technology (see “Diesel Emissions Reduction Technology” in Section 10). Typically meant for diesel generators, this technology is meant to change the harmful substances released (hydrocarbons, PM, CO, and NO_x) into environmentally friendly matter like water, nitrogen, and carbon dioxide. This device has 3,500 hours of run-time before scheduled maintenance is required. One option could be to adapt the Cummins technology for locomotive use.

7.3 Alternate Fuels.

Possible fuel alternatives to diesel include biodiesel, a fuel based on vegetable oil or animal fat; compressed natural gas, which is methane stored at very high pressures; and liquefied natural gas, which is methane that has been converted to liquid form in order to take up less space. (See Figure 18.) Biodiesel has several different types, such as B100 and B20. The numbers indicate what percentage of the fuel is actual biodiesel; for instance, B100 is pure biodiesel, and B20 is 20% biodiesel and 80% petroleum diesel. B20, with more petroleum diesel, has the closest energy output to pure petroleum diesel, but B100 is not far behind, making it a decent contender for a viable alternative fuel. B20 can be used in many existing engines with few or no modifications. B100 requires some modifications to the machinery in order to use it, as it can adversely affect equipment like hoses and seals. Biodiesel has been shown to result in a reduction of harmful emissions when compared to ordinary diesel.

Compressed natural gas can match or exceed ordinary diesel in energy output. However, use of this fuel would require heavy modifications to existing machinery, and the high-pressure tanks in which it is stored would need to be inspected and certified periodically. Compressed natural gas is an environmentally friendly alternative to diesel, as it cuts down on some emissions and is also safer in the event of a spill.

A smaller amount of liquefied natural gas (6.06 lbs) has the same energy output as one gallon of diesel or 6.38 lbs of compressed natural gas. It takes up very little volume compared to diesel and also results in less emission of harmful gases. However, transport of the fuel is a concern; leaks or spills can be dangerous for the environment and for human health, and the liquid form of methane must be kept at very low temperatures to stop vaporization. Modifications would also need to be made to existing engines in order for them to be able to use liquefied natural gas as a fuel.

7.4 Human Health Issues.

Carbon monoxide can cause humans to experience dizziness, lethargy, and headaches. Hydrocarbons can create choking and eye irritation; bring out asthma, bronchitis, and emphysema; and weaken the heart. Death can occur with overexposure. Through exposure to air pollution, even a normally healthy person can experience temporary symptoms, like irritated eyes, nose, and throat; coughing; tightness in the chest; and trouble breathing.

SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives.

Options include selling the existing fleet and purchasing new locomotives; upgrading the current fleet with exhaust after-treatment hardware; and utilizing alternate fuels like biodiesel, CNG, and LNG, which may produce less NO_x. The goal is to bring all of the locomotives in the fleet to Tier 3 standards through any single one of these methods or a combination.

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 2 to Tier 3: \$750k

After-treatment: \$100k

New Locomotive

Tier 3 Locomotive: \$3M

Tier 4 Locomotive: \$4M

Alternative Fuels

Locomotive Upgrade: \$1M

Fueling Station: \$1B

8.4 Upgrade Strategy

Strategy	Cost per locomotive	Total cost
Upgrade all	\$750k x 50 trains	\$37.5M
Sell/replace all	\$1.5M x 50 trains	\$75M
Alternate fuel upgrade all	\$1M x 50 trains (+ two \$1B fueling stations)	\$2.05B
Our Solution	\$750k x 20 trains \$100k x 20 trains \$1.5M x 10 trains	\$32M

There are four possible options for upgrading the fleet of locomotives to Tier 3 standards: upgrading all of the locomotives (\$37.5M); selling all of the current locomotives and purchasing new ones, assuming each current locomotive can sell for about \$1.5 million (\$75M); upgrading all of the locomotives to utilize alternate fuels, as well as installing two new fueling stations (\$2.05B); and using a combination of the above methods (\$32M). The combination solution is the most cost-effective, so that will be the route through which Pittsburgh's fleet of locomotives will be brought to higher emissions standards.

The locomotives in the fleet vary in the amount of miles they have already traveled. There are some older machines nearing the end of their usefulness, as well as newer ones who have many miles left. Accordingly, not all of the locomotives can be treated the same; the final solution, therefore, has three levels.

The first level consists of locomotives in Groups A and B, which are newer and will be useful for years to follow. These locomotives will be upgraded to Tier 3 standards. This is more cost-effective than replacing them with all-new machines, and it seems wasteful to get rid of the new locomotives as well as the old.

The second level consists of locomotives in Groups C and D, which have a moderate number of miles on them. These locomotives will be fitted with exhaust after-treatment devices, as they will become old and need to be replaced sooner rather than later, making a full upgrade pointless; however, they are not at the end of their useful life yet, so replacing them entirely is also too pricy to make sense.

The third level consists of locomotives in Group E, which are old and nearing the end of their usefulness. These locomotives will be sold, and the money gained from this transaction can be put toward the purchase of new Tier 3 standard locomotives. It does not make sense to put money into prolonging the life of the older locomotives when a complete replacement might cost less in the long run.



8.5 Upgrade Schedule and Costs

The first level of the solution will cost \$750k per locomotive, or \$15M total; the second level, \$100k per locomotive, or \$2M total; the third level, \$1.5M per locomotive, or \$15M total. (See table in Section 8.4.) Overall, the combination of methods will cost \$32M, the least of any of the possible options.

Upgrading twenty locomotives will take a much longer time than fitting exhaust after-treatment devices or selling and buying locomotives. The team proposes a five-year plan to finish the upgrading of the entire fleet, with the possibility of completing the work sooner than expected. This five-year plan will allow for delays while still finishing in a timely manner. The selling of the old locomotives can begin immediately, as can the purchasing of new ones and the fitting of exhaust after-treatments. Upgrading the new trains can be allowed more time, as they have so few miles that they can run for a little while longer while they wait to be upgraded.



SECTION 9 **SUMMARY**

The client, GE Transportation, asked several EDSGN 100 design teams to develop an efficient method to upgrade their fleet of locomotives. The fleet consists of fifty different locomotives, each of which are at the current Tier 2 emission standards; the upgrades would be intended to bring the locomotives up to meet the more stringent Tier 3 emission standards.

In order to develop a plan for the upgrade of the locomotive fleet, the group analyzed several different possibilities after researching engines, locomotives, alternate forms of transportation like barges and trucks, alternate fuels like compressed natural gas, port operations in Pittsburgh, the extent of the rail network in the United States, and the potential cost of the different options. The possibilities included upgrading all of the locomotives to Tier 3 standards, selling all of the locomotives and replacing them with new Tier 3 machines, and modifying all of the locomotives to utilize alternate fuels. Analysis of each was done to determine which method was the most economically and environmentally efficient. These possible solutions had varying costs, with the most expensive being around \$2.05B.

When considering the transportation methods of locomotive, barge, and truck, inland waterway transportation seemed to be a clear winner. Although barges are slow compared to the other two methods, the economic benefits can outweigh the loss of speed. In addition, barges are safer and more efficient than trucks or trains, carrying more cargo and carrying it farther on just one gallon of fuel. If the cost of upgrading the fleet of trains is ultimately too prohibitive, perhaps transferring some of that shipping to barges would help keep costs low and trade high. Pittsburgh is, in fact, a city of rivers.

Alternate fuels like biofuel, compressed natural gas, and liquefied natural gas are an environmentally conscious solution, but using them in locomotives usually requires a modification of the locomotives, which can be expensive. In addition, the cost of installing a fueling station is extremely high, making this option not fiscally viable for now. Perhaps in the future, alternate fuels will become the cheaper alternative.

Ultimately, a combination of the various methods above was selected as the best solution. The plan outlined in this report is to upgrade the newer locomotives, replace the oldest locomotives with their more efficient models, and fit the rest with exhaust after-treatment devices. The plan was determined to cost an approximate total of \$32M, far less than the other possible options. The group's recommendation is to follow this plan for maximum efficiency.



SECTION 10 REFERENCES

Arney, Carol. Mississippi River Lock and Dam Number 19. Digital Image. *Wikimedia Commons*. Wikimedia Commons, 1 Sept. 1990. Web. 5 Dec. 2015.

"2013 Report Card for America's Infrastructure." *2013 Report Card for America's Infrastructure*. American Society of Civil Engineers, 2013. Web. 13 Nov. 2015.

"2014 Report Card for Pennsylvania's Infrastructure." *2014 Report Card for Pennsylvania's Infrastructure*. American Society of Civil Engineers, 2014. Web. 25 Nov. 2015.

Barge. Digital image. *Blogsdir.cms.rrcdn.com*. N.p., n.d. Web. 4 Dec. 2015.

Beach, Emily. "The Effects of Semi Trucks on the Environment." *LIVESTRONG.COM*. LIVESTRONG.COM, 27 Jan. 2015. Web. 18 Nov. 2015.

Beevers, S. "Gaseous Emissions." *Gaseous Emissions*. N.p., 2010. Web. 20 Nov. 2015.

Box Car. Digital image. *Midwest Railcar*. Midwest Railcar Corporation, n.d. Web. 4 Dec. 2015.

Bridge in Philadelphia, PA. Digital Image. *Trblmg*. N.p., n.d. Web. 4 Dec. 2015.

Cantrell, Terry. Intermodal Shipping Containers on a Railway Flat Car. Digital image. *Wikimedia Commons*. Wikimedia Commons, 25 Jan. 2008. Web. 4 Dec. 2015.

Comparison of Transportation Methods. Digital Image. *Energy Skeptic*. Peak Energy & Resources, Climate Change, and the Preservation of Knowledge, 16 Jun. 2015. Web. 4 Dec. 2015.

Curtain Side Tractor-Trailer. Digital image. *Cannonball Trucking*. Cannonball Trucking, Inc., n.d. Web. 4 Dec. 2015.

Diesel Emissions Reduction Technology. Dir. Cummins Power Generation. *YouTube*. YouTube, 24 Aug. 2012. Web. 25 Nov. 2015.

"Emission Standards: Locomotives." *DieselNet*. N.p., n.d. Web. 06 Nov. 2015.

"Federal Marine Highway Corridor M-70." *Port of Pittsburgh Commission*. The Port of Pittsburgh Commission, n.d. Web. 30 Nov. 2015.

Fontaine, Tom. "River Shipping Swells up to 62 Percent in Western Pa." *TribLive*. Trib Total Media, Inc., 22 July 2013. Web. 1 Dec. 2015.

Freight, Fuel, and Emissions. Erie: GE Transportation, 2015. Print.

Fuel Properties Comparison Results. Digital Image. *Alternative Fuels Data Center*. U.S. Department of Energy, n.d. Web. 25 Nov. 2015.

Harris, Patrick. SSW #87709 Bulkhead Flat Car on CSX Almonaster Avenue New Orleans 1997. Digital image. *Seaboard Coast*. N.p., n.d. Web. 4 Dec. 2015.

"Health Effects of Air Pollution." *Spare The Air*. Sacramento Metropolitan Air Quality Management District, n.d. Web. 18 Nov. 2015.

Henkelmann, Harvey. TILX290344. *Wikimedia Commons*. Wikimedia Commons, 03 Dec. 2007.

Hopper-Car. Digital image. *DynaGraphics*. DynaGraphics Inc., n.d. Web. 4 Dec. 2015.

"Industry Information." *Truck Transportation and Warehousing Industry*. CollegeGrad.com, n.d. Web. 18 Nov. 2015.

Light Truck. Digital image. *Bridgestone Tyres*. Bridgestone Australia Ltd., n.d. Web. 4 Dec. 2015.

Majewski, W. Addy. "What Are Diesel Emissions." *What Are Diesel Emissions*. N.p., 2011. Web. 20 Nov. 2015.

Map of Inland Waterways Near Pittsburgh. Digital Image. *Port of Pittsburgh Commission*. The Port of Pittsburgh Commission, n.d. Web. 4 Dec. 2015.

"Navigation." *US Army Corps of Engineers, Pittsburgh District*. US Army Corps of Engineers, n.d. Web. 1 Dec. 2015.

Office of Transportation and Air Quality (OTAQ). "Locomotives." *Transportation and Air Quality*. Environmental Protection Agency (EPA), n.d. Web. 06 Nov. 2015.

Pennsylvania Crash Facts & Statistics. Harrisburg: Bureau of Maintenance And Operations, Pennsylvania Department of Transportation, 2014. Web.

The Pennsylvania Railroad Regional Map. Digital Image. *Keystone Crossings*. N.p., n.d. Web. 4 Dec. 2015.

Pothole. Digital Image. *The Pittsburgh Post-Gazette*. PG Publishing Co., Inc., 11 Mar. 2015. Web. 4 Dec. 2015.

"The Port District and the Inland Waterway System." *Port of Pittsburgh Commission*. The Port of Pittsburgh Commission, n.d. Web. 1 Dec. 2015.

Refrigerator Car. Digital image. *Train Weather*. N.p., n.d. Web. 4 Dec. 2015.

Regatta5. Digital Image. *Brookline Connection*. N.p., n.d. Web. 4 Dec. 2015.

Schmitz, Jon. "Shippers Look to the Rivers to Move More Freight." *Pittsburgh Post-Gazette*. PG Publishing Co., Inc., 18 Apr. 2015. Web. 1 Dec. 2015.

"Shipping Comparisons." *For Business & Industry*. Tennessee-Tombigbee Waterway, n.d. Web. 20 Nov. 2015.

Smith, Casey. "Recent Rains' Impact 'Horrific' on Waterway Shipping for Navigation System, Tulsa Port of Catoosa." *Tulsa World*. BH Media Group Holdings, Inc., 5 July 2015. Web. 1 Dec. 2015.

"Water Transport Benefits." *Kentucky Association of Riverports*. Kentucky Association of Riverports, 2008. Web. 13 Nov. 2015.

"What Are Diesel Emissions?" *Nett Technologies*. N.p., 2014. Web. 20 Nov. 2015.

"What Is Retrofit?" *Diesel Retrofit*. MECA, n.d. Web. 25 Nov. 2015.

"Why Inland Waterways." *Naiades*. Platina II, n.d. Web. 01 Dec. 2015.

"Why Waterways?" *AWC*. Arkansas Waterways Commission, 2012. Web. 13 Nov. 2015.



Figure 1. Typical light truck.



Figure 2. Typical tractor-trailer.



Figure 3. Typical inland waterways barge and tug/towboat.



Figure 4. Typical inland waterway lock.



Figure 5. Typical hopper car.



Figure 6. Typical refrigerator car.



Figure 7. Typical box car.



Figure 8. Typical intermodal car.



Figure 9. Typical tanker car.



Figure 10. Typical flat car.

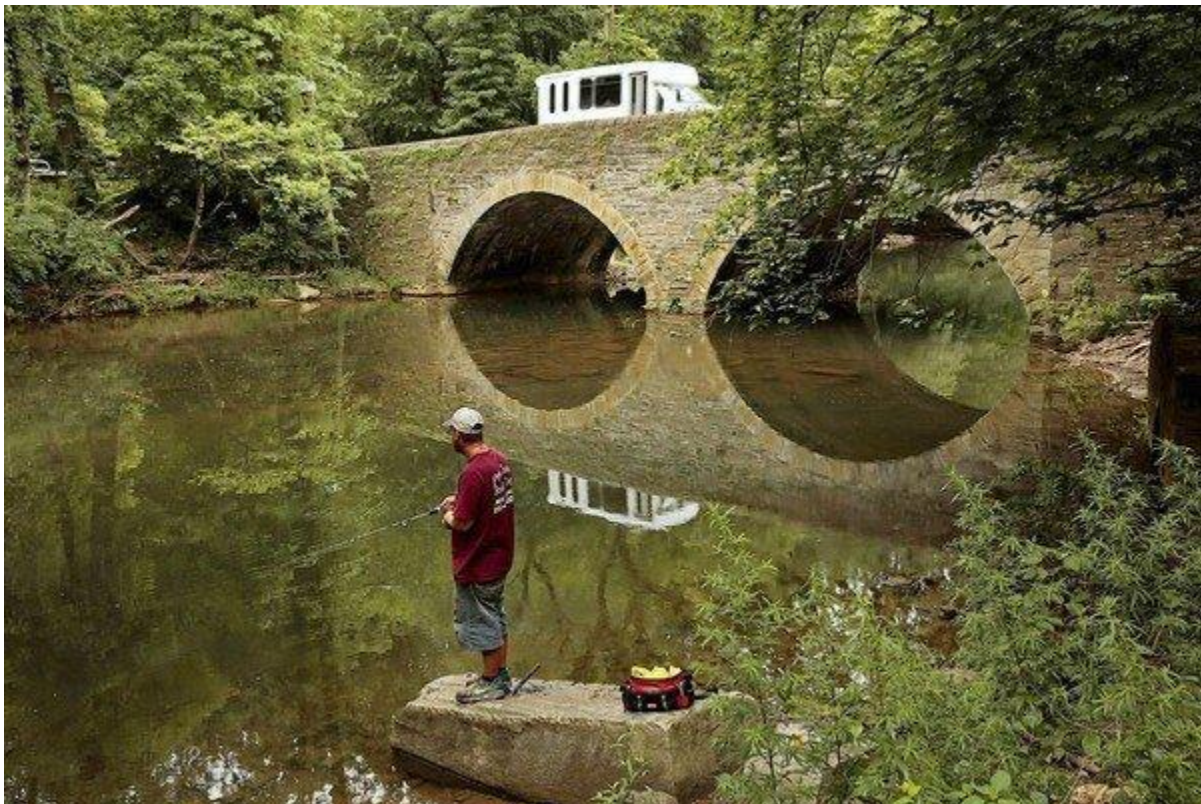


Figure 11. An old and locally historic bridge in Philadelphia, PA.



Figure 12. A familiar sight to PA residents: the common pothole.



Figure 13. The Point, Pittsburgh, PA.

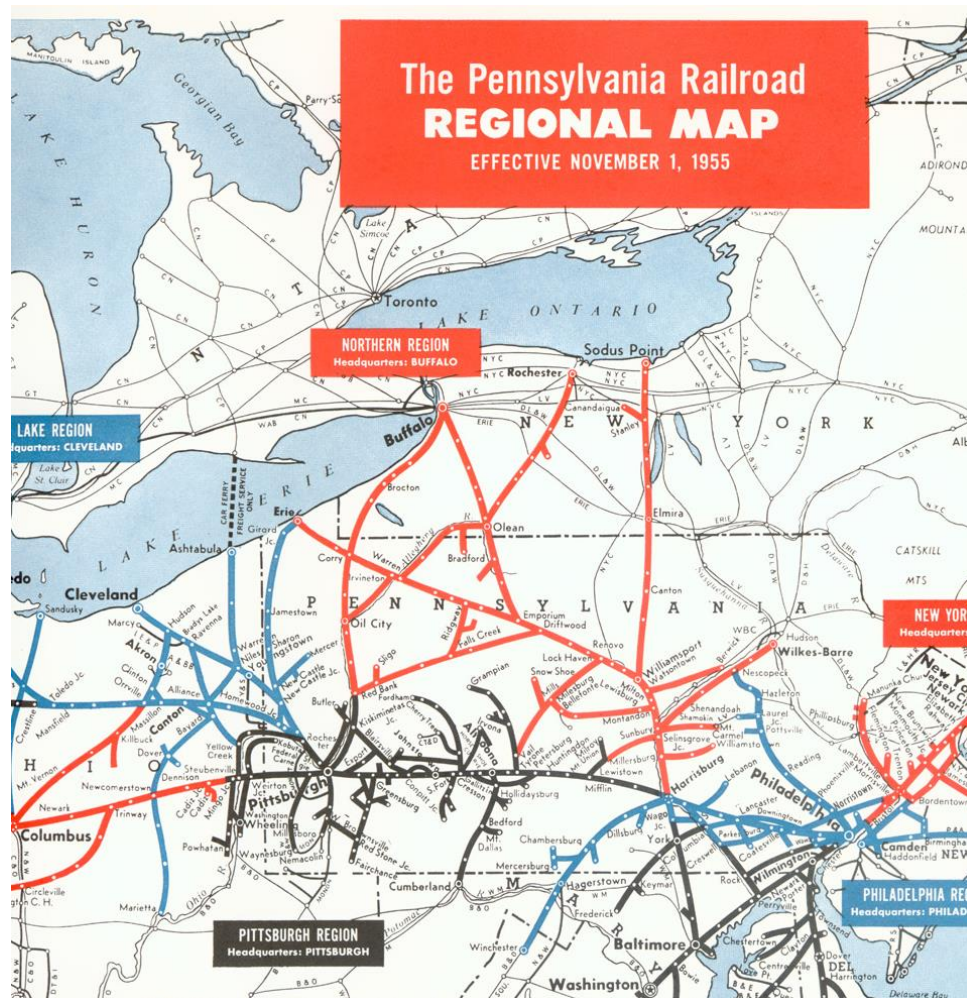


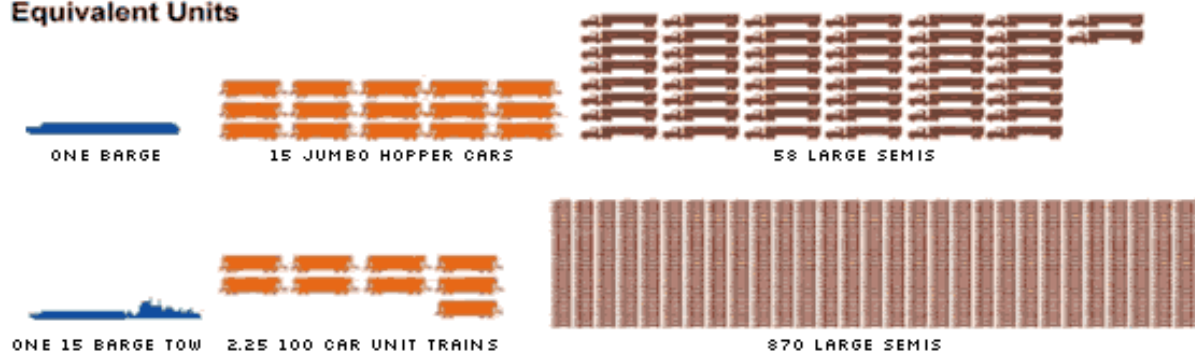
Figure 14. Railroads in the Pittsburgh area.

Compare...

Cargo Capacity



Equivalent Units



Equivalent Lengths



Figure 15. Cargo capacity, equivalent units, and equivalent lengths comparisons.

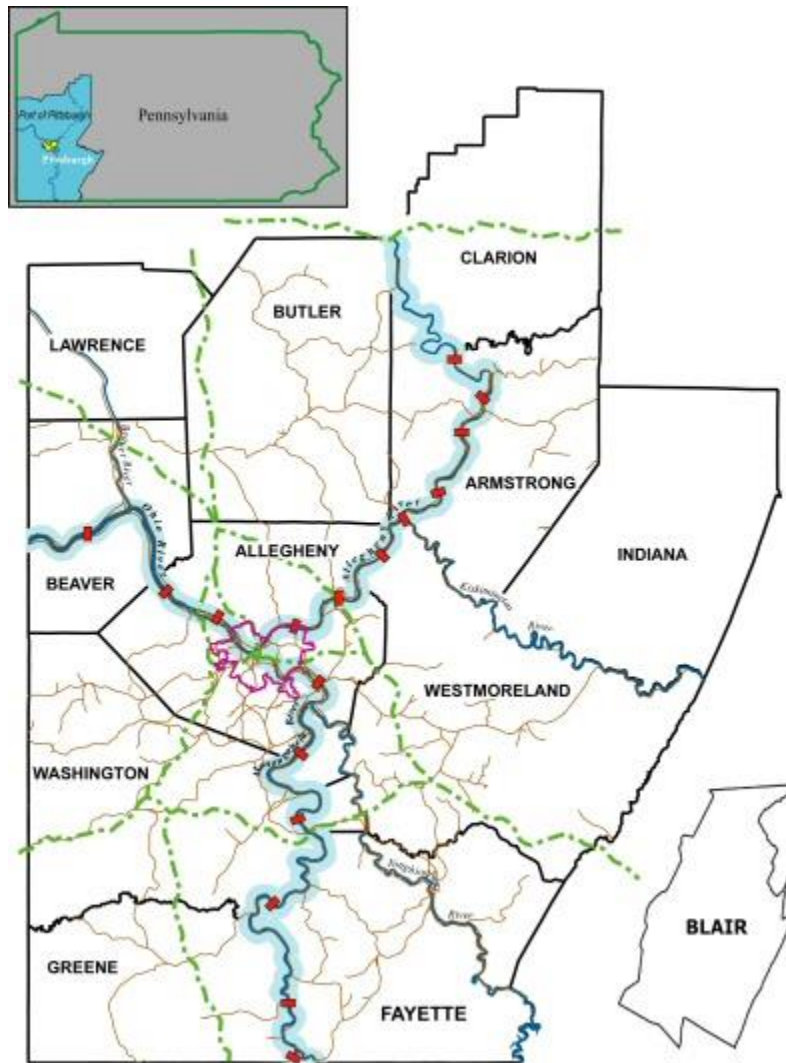


Figure 16. Map of inland waterway systems in and near Pittsburgh.

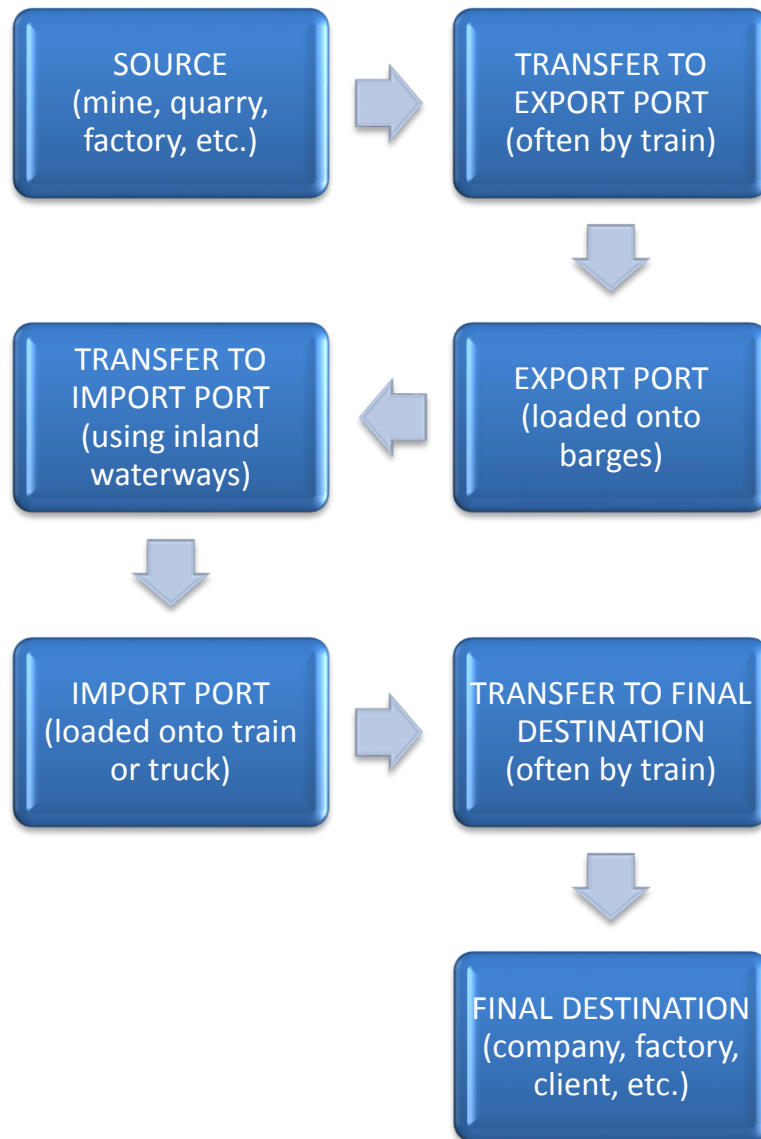


Figure 17. Systems model of barge shipping using inland waterways.



Property	Fuels				
	Gasoline/E10	Low Sulfur Diesel	Biodiesel	Compressed Natural Gas (CNG)	Liquefied Natural Gas (LNG)
Gasoline Gallon Equivalent [4]	97% - 100%	1 gallon of diesel has 113% of the energy of one gallon of gasoline.	B100 has 103% of the energy in one gallon of gasoline or 93% of the energy of one gallon of diesel. B20 has 109% of the energy of one gallon of gasoline or 99% of the energy of one gallon of diesel.	5.66 pounds or 123.57 cu ft. of CNG has 100% of the energy of one gallon of gasoline. [2][5](q) 6.38 pounds or 139.30 cu ft. of CNG has 100% of the energy content of one gallon of diesel [2][5](q)	5.38 pounds of LNG has 100% of one gallon of gasoline and 6.06 pounds of LNG has 100% of the energy of one gallon of diesel (r)
Energy Content (lower heating value)	112,114 - 116,090 Btu/gal (g)	128,488 Btu/gal (g)	119,550 Btu/gal for B100 (g)	20,160 Btu/lb [2](q)	21,240 Btu/lb (r)
Energy Content (higher heating value)	120,388 - 124,340 Btu/gal (g)	138,490 Btu/gal (g)	127,960 Btu/gal for B100 (g)	22,453 Btu/lb [1](g)	23,726 Btu/lb (g)
Physical State	Liquid	Liquid	Liquid	Compressed Gas	Cryogenic Liquid
Maintenance Issues			Hoses and seals may be affected by higher-percent blends, lubricity is improved over that of conventional diesel fuel.	High-pressure tanks require periodic inspection and certification.	LNG is stored in cryogenic tanks with a specific hold time before the pressure build is relieved, the vehicle should be operated on a schedule to maintain a lower pressure in the tank.

Figure 18. Alternative fuels comparison.