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GE Transportation

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SECTION 1 EXECUTIVE SUMMARY

Pittsburgh has approximately 165,000 tons of freight or minerals per day travel by railroads. A significant amount of smog is produced by locomotives and is becoming a large problem. Two suggestions have been given to address this problem. The first one is to upgrade the locomotives to meet more recent guidelines set by the EPA. The second suggestion is to use different freight shipping methods such as by barges or trucks. To evaluate the different suggestions we will consider emissions, cost, freight capacity, public opinion, and on time delivery.



SECTION 2 INTRODUCTION

2.1 Project Objectives. The project objective is to look for a cost effective solution, which reduces smog, while maintaining or increasing freight capacity. This project is for the transportation of freight in Pittsburgh under EPA requirements.

2.2 Project Background. Approximately 165,000 tons of freight or minerals per day travel in or out of the city of Pittsburgh. Smog from locomotive emissions is a key component of city residents. Smog is generated from engine emitted Nox. Tier 2 locomotive that are used to haul freight are approaching the age for overhaul, at which time investment will be required to meet EPA Tier 3 requirements.

2.3 Project Sponsor Background. The project sponsor is General Electric Transportation. A unit of GE solves the world's toughest transportation challenges. GE transportation builds equipment that moves the rail, mining, and marine industries. GE has fuel efficient and low emission freight and passenger locomotives, diesel engines for rails, marine and stationary power applications signaling and software solutions. They drive systems for mining trucks and valve- added services help customers grow.

2.4 Project Description. Evaluate the suggestions made for fleet upgrade or alternate shipping methods based on costs, EPA requirements, capacity, logistics and public opinion.

2.5 Project Freight Requirements. 15 Trains per day= 3 mineral trains and 12 freight trains. Fleet Make up: 50 Tier 11 Emission.

2.6 Transportation Mode Comparisons.

a. Trucks. The cost of a truck is high and the capacity is low. Comparing to rail and sea, it takes less time however, it is not environmentally friendly *[Figure 1]*

b. Barges. The cost of barges is the lowest and the capacity is high. It takes a long time but it is the most environmentally friendly. *[Figure 2]*

c. Railroad. The cost of railroads is low and the capacity is the highest. It takes relatively a long time but it is environmentally friendly. *[Figure 3]*



SECTION 3 **TRANSPORTATION INFRASTRUCTURE** **CONDITION AND CAPACITY**

3.1 Introduction. Pennsylvania is in need of major upgrades for all of their infrastructure. Almost every aspect of our infrastructure scored below a C, especially our roads and bridges.

3.2 Pennsylvania Roads and Bridges. Roads are in bad conditions, but so are ¼ of all bridges in Pennsylvania. The grade of the roads was a D- and it hasn't changed since 2010.

[Figure 4]

3.3 Pennsylvania Inland Water Ways. Not a single satisfactory rating for Navigation Dams. Capacity for inland waterways is bigger than what is used. The grade is only a D+. The M-70 goes from Pittsburgh to Kansas City and also connects with the Mississippi River.

[Figure 5]

3.4 Pennsylvania Freight Rail System. Railroads are the best way to travel long distances for large amounts of quantities. Short distance railroads are at risk of abandonment. The condition of the railroads isn't great and needs repair for bridges larger than \$170,000,000.00. Choke point & heavy load infrastructures need repair.

[Figure 6]



SECTION 4 **STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES**

4.1 Cargo Capacity. One barge weighs 1,500 tons; one 15-barge tow weighs 22,500 ton. One bulk type railroad car like a jumbo hopper car weighs 100 tons. One boxcar type railroad car like a 100-car train unit weighs 10,500 ton and a large semi weighs 26 ton, which has the lowest capacity comparing to the others. Moreover, among those transportation modes, the 15-barge tow has the highest cargo capacity.

[Figure 7]

4.2 Equivalent Units. The cargo capacity of one barge is equivalent to 15 jumbo hopper cars or 58 large semis. Moreover, the cargo capacity of one 15-barge tow is equivalent to 2.25 100 car unit trains or 870 large semis.

[Figure 7]

4.3 Equivalent Lengths. One 15-barge tow is about 0.25 miles long. The length of 2.25 100-car train unit is 2.75 miles and 870 large semis are about 11.5 miles long.

[Figure 7]



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

5.1 Trucks. A 5-Axle & 53' Truck has a payload up to 24.55 tons. It would take about 58 large trucks to equal one barge. The distance one-way from Cincinnati to Pittsburgh is 300 miles using ground transportation. The cost per vehicle mile is equal to \$1.09. The cost per ton-mile is equal to \$0.0513 and if you multiply that by the payload you get cost per loaded mile. Using this information and an average speed of about 50 miles per hour, you will find that the cost for traveling round trip is \$2,165.28. The total cost calculated for round trip will take around 12 hours

5.2 Barges. One barge has the carrying capacity of 1,500 tons. The distance to go from Cincinnati to Pittsburgh is around 500 miles if using waterways. The cost per ton-mile is equal to \$0.48. The operation cost per day is equal to \$3,109. We are also assuming the average speed of the barge is 8 miles per hour, so the total amount of time it takes to travel just one way is 2 full days & 14.5 hours. The total cost to go round trip is equal to \$736,193.

5.3 Railroad. One Jumbo Hopper Car has the carrying capacity of about 100 tons. It would take about 15 Jumbo Hopper Cars to have the carrying capacity equal to one barge. The distance one-way from Cincinnati to Pittsburgh is about 400 miles using railway transportation. The cost per ton-mile is equal to \$.41. Using this information you will find the average cost for one jumbo hopper car to travel round trip is \$32,800. The total time to go round trip is around 6 hours and 40 minutes if the train went 120 miles per hour.

5.4 Most Economical Transportation Solution. Our team has decided the best economical transportation for this problem is using a railroad system. One reason why is because Pennsylvania is the railroad state. They are famous for their railroads and have many different railroads throughout the state so it will be easy to transport anywhere bordering Pennsylvania. Another reason is that locomotives travel at 120 miles/hour, which is fifteen times faster than a barge and about 2 times as fast as a truck. Due to this speed, locomotives are able to travel round trip from Cincinnati to Pittsburgh in only 6 hours and 40 minutes, which is the fastest round trip time for any of the three transportation ideas. Locomotives are also environmentally better than trucks. Finally, locomotives are the best because they can carry up to 100 rail cars at once which almost 10,000 tons of supplies.



5.5 Concept of Operations (ConOps).

a. General Description.

We will use previous schedules and systems from past years when the railroad system was being used at a higher capacity.

b. Operational Policies and Constraints.

Hours of operation will be constant (24 hours and 7 days a week). Due constant operation, we will always have a conductor and engineer on the train. Though because a round trip from Cincinnati to Pittsburgh is roughly 7 hours, which is almost one work day, an engineer and conductor will only work one shift a day.

c. Performance characteristics.

The train will travel at a speed of 120 miles per hour. The safety of using a locomotive is 1.15 deaths per billion ton-miles.

d. Operational Impacts.

The railway system is great for transporting into local populations and big cities like Pittsburgh because the trains go right through the city without being the reason of congestion in the city. This is a perfect system unlike the use of trucks because trucks can delay the logistics of transporting goods and supplies to other cities due to the commonality of car accidents.

e. Continuity of Operations.

Railways are the best option in terms of extreme weather. Barges and trucks will have issues due to snow, but not a locomotive. Locomotives are able to transport through ice and even snow as high as ten feet with a snowplow on the front. Yes, the locomotive will travel slower in ice and snow, but at least it will be able to transport goods still in the same day for most locations in Pennsylvania.



SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background.

EPA proposed a three part program that will significantly reduce all types of diesel locomotives emissions in March 2008, which are line-haul, switch, and passenger rail. If fully implemented, it reduce the emission of PM by 90% and NOx by 80%. The standards are based on manufactured engines built in 2015 and later with high-efficiency catalytic after treatment technology. EPA standards can also be applied for existing locomotives to reduce idling for new and remanufactured locomotives.

6.2 Tier 0-2 Standards. See table below

6.3 Tier 3-4 Standards. See table below

	Duty-Cycle ^b	Tier	Year ^c	HC ^f (g/hp-hr)	NOx ^f (g/bhp-hr)	PM ^f (g/bhp-hr)	CO ^f (g/bhp-hr)	Smoke ^f (percentage) ^m	Minimum Useful Life ⁿ (hours / years / miles)	Warranty Period ⁿ (hours / years / miles)
Federal ^a	Line-haul	Tier 0	1973- ^{d,e} 1992	1.00	9.5 [ABT]	0.22 [ABT]	5.0	30 / 40 / 50	(7.5 x hp) / 10 / 750,000 ^o	1/3 * Useful Life
		Tier 1	1993- ^{d,e} 2004	0.55	7.4 [ABT]	0.22 [ABT]	2.2	25 / 40 / 50	(7.5 x hp) / 10 / 750,000 ^o	
									(7.5 x hp) / 10 / -	
		Tier 2	2005- ^d 2011	0.30	5.5 [ABT]	0.10 ^k [ABT]	1.5	20 / 40 / 50	(7.5 x hp) / 10 / -	
		Tier 3	2012- ^f 2014	0.30	5.5 [ABT]	0.10 [ABT]	1.5	20 / 40 / 50	(7.5 x hp) / 10 / -	
	Switch	Tier 4	2015+ ^g	0.14	1.3 [ABT]	0.03 [ABT]	1.5	-	(7.5 x hp) / 10 / -	
		Tier 0	1973- 2001	2.10	11.8 [ABT]	0.26 [ABT]	8.0	30 / 40 / 50	(7.5 x hp) / 10 / 750,000 ^o	
		Tier 1	2002- ^h 2004	1.20	11.0 [ABT]	0.26 [ABT]	2.5	25 / 40 / 50	(7.5 x hp) / 10 / -	
		Tier 2	2005- ^h 2010	0.60	8.1 [ABT]	0.13 ⁱ [ABT]	2.4	20 / 40 / 50	(7.5 x hp) / 10 / -	
		Tier 3	2011- 2014	0.60	5.0 [ABT]	0.10 [ABT]	2.4	20 / 40 / 50	(7.5 x hp) / 10 / -	
		Tier 4	2015+ ^j	0.14 ^j	1.3 ^j [ABT]	0.03 [ABT]	2.4	-	(7.5 x hp) / 10 / -	



SECTION 7 **DIESEL ENGINE EXHAUST EMISSIONS (DEEE)**

7.1 Diesel Emission Chemistry.

a. NO_x.

Diesel engines compresses hot air to ignite the fuel, and air is mostly composed of oxygen and nitrogen. When compressed air and fuel are injected to the combustion chamber, the fuel is burned and heat is released. High temperatures above 1600°C in the cylinder cause nitrogen to react with oxygen and generate NO_x.

b. Particulate Matter (PM).

Particulate matter emissions are resulted from combustion process. They come from the agglomeration of very small particles of burned fuel, burned lube oil, ash content of fuel oil, and cylinder lube oil or sulfates and water. Most PMs are from incomplete combustion.

c. CO₂.

Like most fossil fuels, diesel is consisted of carbon and hydrogen. The complete combustion of diesel would produce carbon dioxide and water. 12% of the emission is CO₂.

d. Hydrocarbons (HC).

Near the cylinder wall, where the temperature is significantly lower than the center of cylinder, insufficient temperature causes the emission of hydrocarbons. Hydrocarbons consist of thousands of species, such as alkanes, alkenes, and aromatics.

7.2 Diesel Emission Reduction Strategies.

1. Regulations

European countries has established Euro standards which have continuously been lowered since 1993 with Euro I to Euro VI.

2. Diesel oxidation catalyst (DOC)

DOC is to oxidize HC and CO emissions to CO₂ and H₂O. It decreases the mass of diesel particulates emissions by oxidizing some of the hydrocarbons that are absorbed onto the carbon particles. In the mean time, DOC also can be used in conjunction with SCR catalysts to oxidize NO into NO₂.

3. Diesel particulate filter (DPF)

DPF is mostly applied in the production of vehicles to remove PM emissions from the exhaust gas by physical filtration. It is made of either cordierite (2MgO–2Al₂O₃–5SiO₂) or silicon carbide (SiC) honeycomb structure monolith with the channels blocked at alternate ends.

4. Selective catalytic reduction (SCR)

SCR is a technology to reduce the emission of NO_x for high-duty vehicles. Nowadays, it is applied on light-duty vehicles as well. SCR utilizes ammonia in the exhaust gas as the reductant.



7.3 Alternate Fuels.

Alternate fuels of diesel include biodiesel, methyl alcohol can reduce or eliminate the pollutant. They have been used to prevent the sulfur damage.

7.4 Human Health Issues.

Diesel fumes can affect human health in two ways. First, breathing in diesel fumes is harmful to human body. Second, exposing in diesel fumes could cause irritation of eyes or respiratory tract. Even though these effects are short-term, and they could disappear when people are away from the exposure, pro-longed exposure in blue and black smoke could cause coughing, chestiness and breathlessness. Evidence shows that exposure to diesel fumes over a period of 20 years increases the risk of lung cancer, however, exposure to petrol engine emission does not have such a risk.



SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives. Sell existing fleet and purchase new locomotives

The new locomotive is usually a vehicle that combines new engine, power, or drivetrain systems to significantly improve fuel economy. This includes hybrid power systems and fuel cells, as well as some specialized electric vehicles.

i. Upgrade fleet with exhaust after-treatment hardware

A large portion of the operating expense of a large-bore diesel engine is fuel cost and the flow restriction of the after-treatment system is one of the influences on fuel consumption. The additional work that the engine has to perform in order to exhaust the combustion products from the engine translates into additional fuel used.

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

Utilize alternative fuels (Biodiesel, CNG, LNG, etc.) which may produce less NOx. Basically, there are alternate fuels like Biodiesel (B100), Natural gas, Propane (liquefied petroleum gas), Electricity, Hydrogen and ethanol etc.

8.2 Existing Fleet Make-Up. {NOTE: Assume: (i) fleet consists of the following locomotives and (ii) locomotives are rebuilt at 750,000 mile intervals.}

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.

There are three main ways for fleet upgrade. First is upgrading Tier 2 to Tier 3 locomotives. The Tier 3 program is part of a comprehensive approach to reducing the impacts of motor vehicles on air quality and public health. Its fuel as an integrated system, setting new vehicle emissions standards and lowering the sulfur content of gasoline beginning in 2017. The vehicle standards will reduce both tailpipe and evaporative emissions from passenger cars, light-duty trucks, medium-duty passenger vehicles, and some heavy-duty vehicles. The gasoline sulfur standard will make emissions control systems more effective. Also, we Upgrade fleet with exhaust after-treatment hardware. In an effort to keep this additional flow restriction to a minimum the maximum frontal area of the catalyst within the after-treatment system is needed. A catalyst is made up of the substrate or honeycomb and the washcoat where the chemical reactions take place. The substrate will influence the flow of the exhaust gas and provide surface area for washcoat. Last, upgrading locomotives to use alternative fuels. For example, biodiesel is a renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled cooking grease for use in diesel vehicles. Electricity can be used to power plug-in electric vehicles, which are increasingly available. Hybrids use electricity to boost efficiency. Ethanol is a widely used renewable fuel made from corn and other plant materials. It is blended with gasoline for use in vehicle. Hydrogen is a potentially emissions- free alternative fuel that can be produced from domestic resources for use in fuel cell vehicles. Natural gas is a domestically abundant gaseous fuel that can have significant fuel cost advantages over gasoline and diesel fuel. Propane is a readily available gaseous fuel that has been widely used in vehicles throughout the world for decades.



8.5 Upgrade Schedule and Costs.

If we upgrade the locomotives from tier 2 to tier 3, the cost per locomotive is \$750k+\$100k=\$850k. Therefore, the total cost for 10 locomotives is \$8500k. If we sell tier 2 locomotives and buy new tier 3 and tier 4 locomotives, the total costs will be $(\$3M - \$2.5M) \times 10 = \$5M$ and $(\$4M - \$2.5M) \times 10 = \$15M$. The third strategy is to use alternative fuels, and the fuels we choose are liquified natural gas and compressed natural gas. The cost table of 10 locomotives for different mileage range is

cost of different fuels	10 of A	10 of B	10 of C	10 of D	10 of E
Diesel	220M	440M	660M	880M	1100M
Liquified Natural Gas	46.6M	93.3M	139.9M	186.5M	233.1M
Compressed Nautural Gas	787.9M	1575.7M	2363.7M	3151.6M	3939.5M

From the cost analysis, it shows that upgrading the locomotives costs the least and change the fuel will be the most expensive, especially there is 1 billion extra cost for fueling station. But since the fuel is used everyday and liquified natural gas is much cheaper than diesel, the costs of building fueling station and locomotives upgrade will be made up in the long term.



SECTION 9 SUMMARY

For the transportation under EPA requirement of Pittsburgh for the company GE Transportation, the goal of this project is to maintain and increase the freight capacity and while reduce the emissions. In the process of developing the shipping method, our design team set trains as our project since it is the most efficient one among all of the options, and we evaluated the costs and emissions of this shipping method. Our goal is to upgrade the locomotives to meet the requirements set by EPA from Tier 2 to Tier 3-4. Some upgrade strategies include selling existing fleet and purchasing new fleet, upgrading fleet with exhaust after-treatment hardware, and utilizing alternative fuels such as biodiesels, CNG and LNG. Comparing these three strategies, utilizing alternative fuels, especially liquified natural gas, is the best solution because of the low cost and sustainability. Therefore, our suggestion is replacing the traditional fuel by liquified natural gas.



SECTION 10 REFERENCES

<List your References here>

<http://www3.epa.gov/otaq/locomotives.htm>

<http://pareportcard.org/index.php>

section 4: EDSGN100_DP2_GE Presentation_F2015.pdf

section 6: Locomotives, EPA <http://www3.epa.gov/otaq/locomotives.htm>

section 7: Ibrahim Aslan Res, itog~lu • Kemal Altinis, ik • Ali Keskin *The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems*

section 8: alternative fuels data center <http://www.afdc.energy.gov/fuels>

Section 5: Transport Fundamental.pdf

Estimating Transport Costs.pdf

Comparison of Different Shipping Methods – Barge, Truck, Rail.pdf



Figure 1. Typical Diesel Truck and Trailer.



Figure 2. Typical Diesel-Electric locomotive.



Figure 3. Typical Inland Water Ways Barge and Tug.

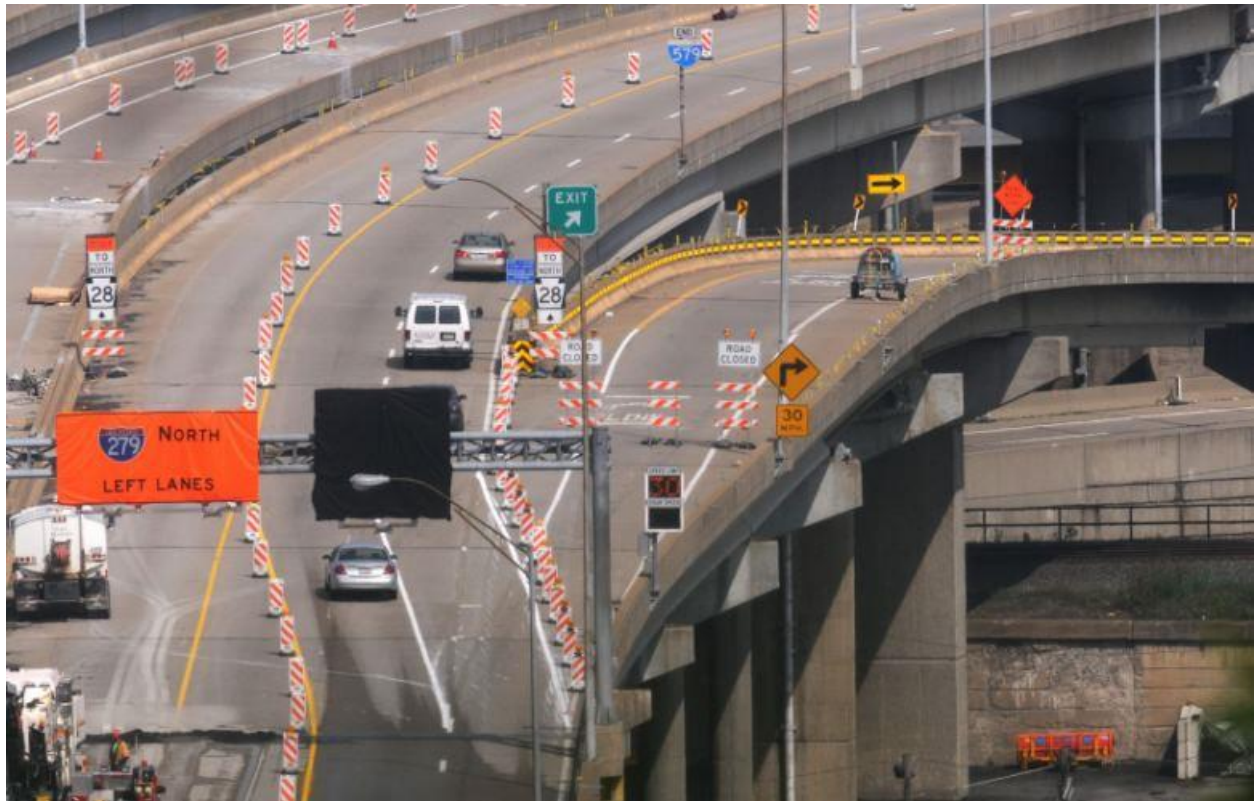


Figure 4. Pennsylvania Roads and Bridges

Inland Navigation Map

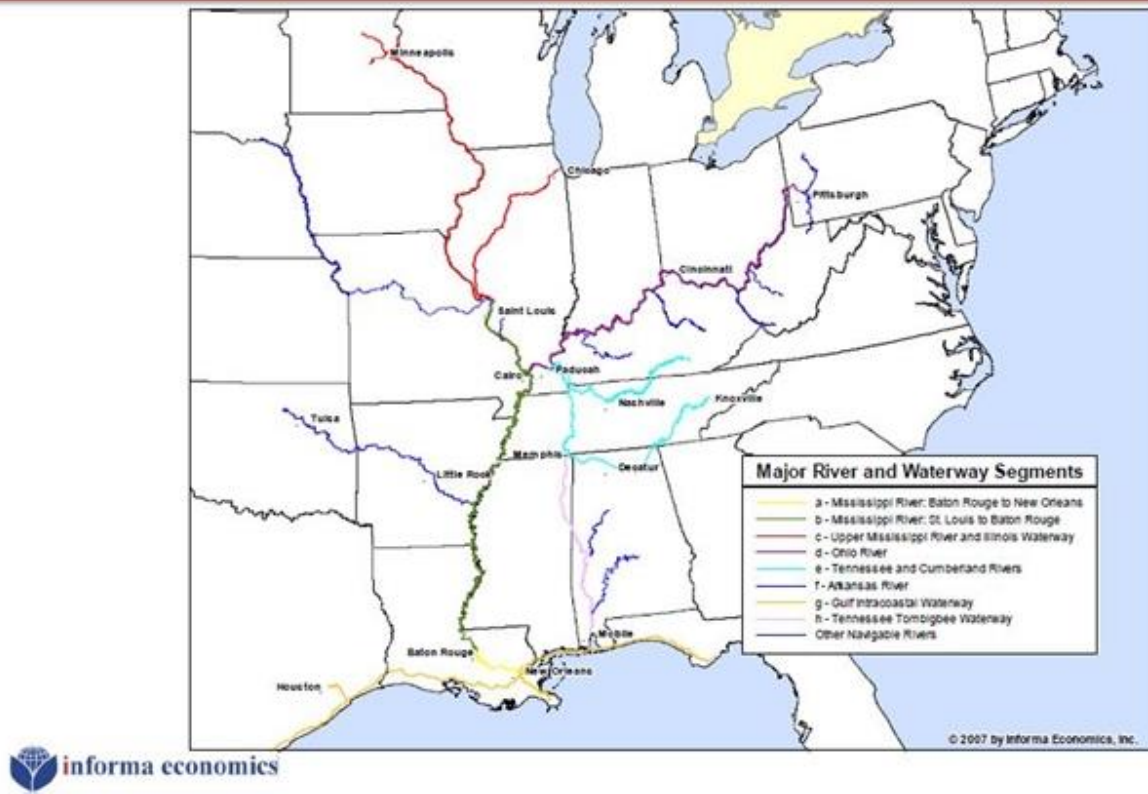
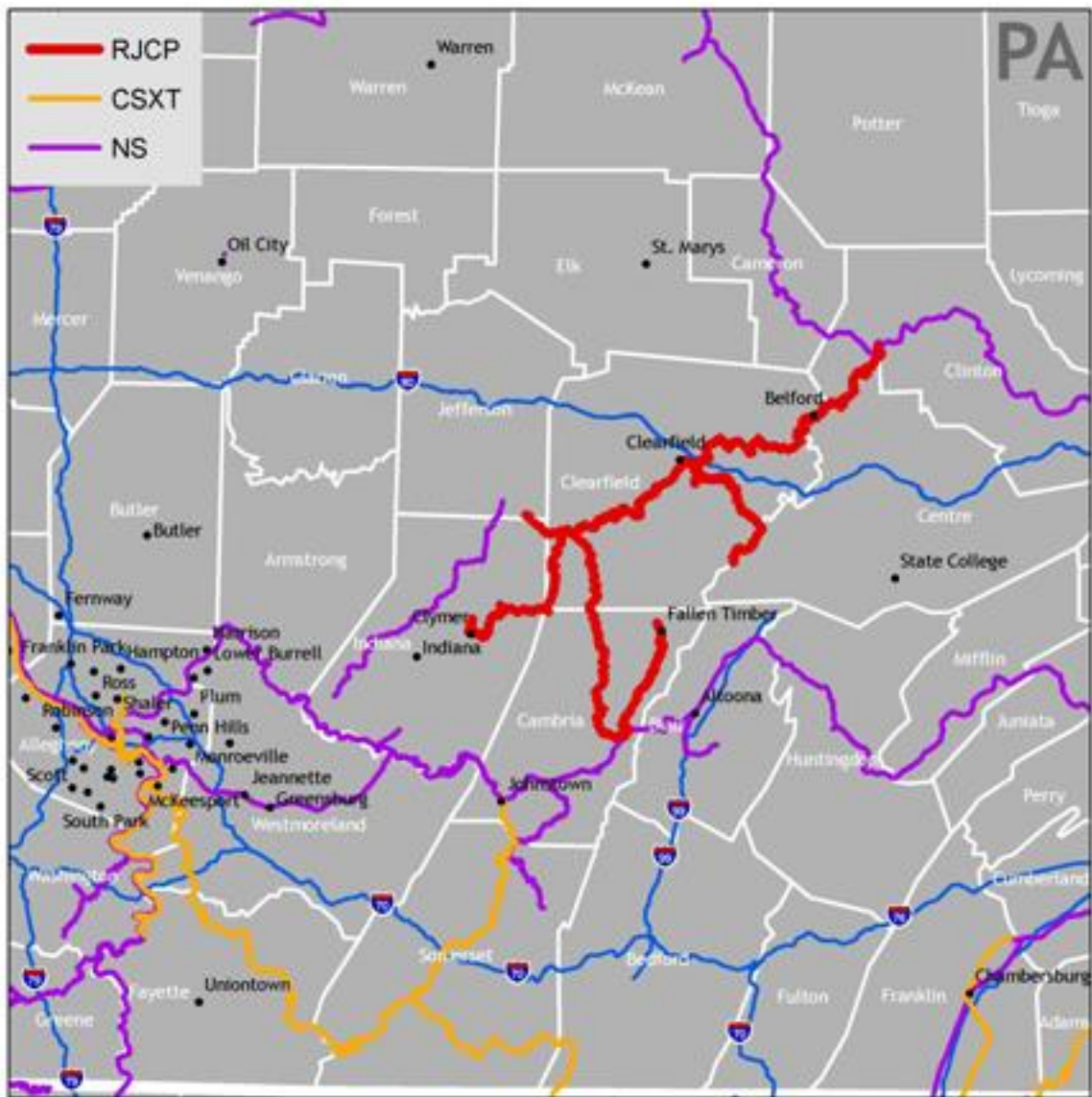
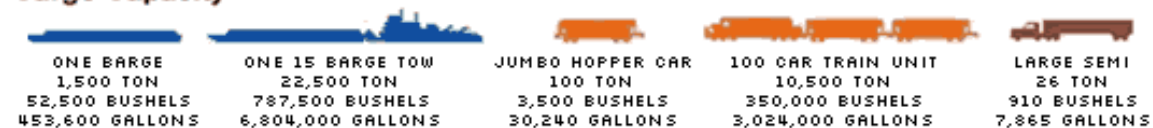


Figure 5. Inland Waterways

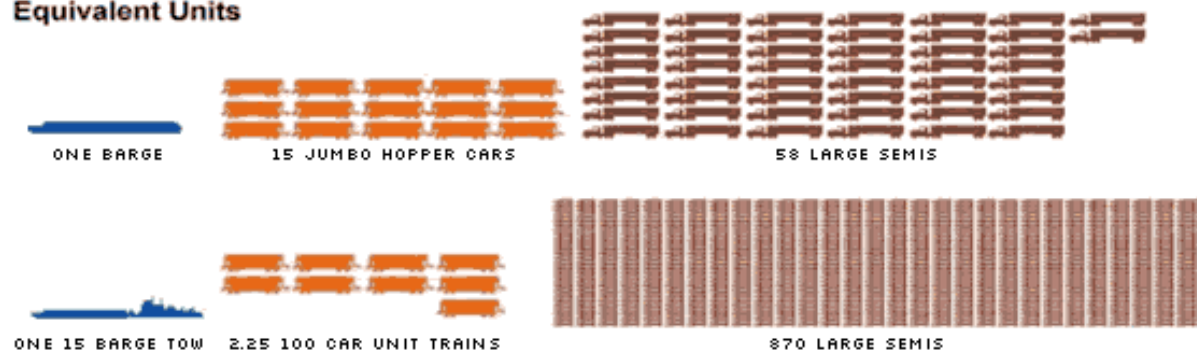


Compare...

Cargo Capacity



Equivalent Units



Equivalent Lengths



Figure 7. Cargo Capacity and Equivalent Costs and Lengths