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

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Design Team Name
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SECTION 1 EXECUTIVE SUMMARY

General Electric is trying to find cost efficient methods to reduce the amount of diesel emissions in the air to compare different forms of transportation to one another. Students are to critically analyze infrastructures in Pennsylvania, compare various forms of transportation to decide the most economically efficient choice; discuss emission requirements, come to a conclusion on an upgrade schedule for a calendar year and effectively explain diesel emission strategies. In the end, students will find different emission reduction strategies for General Electric to use in their business model.

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, 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 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) Upgrade 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 alternative fuels (Biodiesel, CNG, LNG, etc.) which may produce less NOx

2) Alternate freight shipping methods:

- By waterway
- 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 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.

Technical report containing the following elements

- o Rationale for the recommendation
- o Description of alternative concepts and their evaluation
- o Economic viability of the system

2.6 Transportation Mode Comparisons.

a. Trucks.

Features: Delivery of digital products can be handled in a fairly smooth way by allowing customers to access their purchase over the Internet.

Advantages include: Providing a complete door to door service, it can be cheaper than other modes of transportation for short distances, it is highly flexible, able to go wherever there are roads and streets and offers a wide variety of equipment, the freight can be loaded and unloaded quickly.

Disadvantages include: Dependence on weather, road conditions and traffic. It is more expensive for long hauls than some competing modes of transit.

Figures: Please reference Figure 1

b. Barges.

Features: Cargo distribution within the hull is not constrained by the requirements of propelling machinery or accommodations. Because tow speeds are quite low, barges have very full lines.

Advantages include: Barges are both economical and environmentally friendly (cleaner air and reduced emissions), can hold as much cargo as 15 rail cars or 60 semi trailer trucks, offers great fuel efficiency and you don't need a big crew.

Disadvantages include: Barges can be really slow and no part is completely free from rust.

Figures: Please reference Figure 3

c. Railroad.

Features: Railways provide an essential service to the public. It being a public utility service, requires protection and investments by government

Advantages include: It can facilitate long distance travel and transport of bulky goods which are not easily transported through motor vehicles. It is a quick and regular form of transport because it helps in the transportation of goods with speed and certainty. The carrying capacity of the railways is extremely large. Moreover, its capacity is elastic which can easily be increased by adding more wagons.

Disadvantages include: It involves much time and labor in booking and taking delivery of goods through railways as compared to motor transpor*t. it does not provide door to door service*s and Railway transport is unsuitable and uneconomical for short distances and small traffic of goods.

Figures: Please reference Figure 4

SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

3.1 Introduction.

Every few years the Pennsylvania Sections of the American Society of Civil Engineers (ASCE) provide a report card on how Pennsylvania's infrastructure is doing. This 2014 report card on Pennsylvania's infrastructure shows our leaders addressing the long term infrastructure needs of the commonwealth. From water to roads to waterways, their grades show that we should prioritize strategic assets and build infrastructure that protects our economic prosperity and our citizens.

3.2 Pennsylvania Roads and Bridges.

ROADS: The amount of poor-condition roadways has risen 7 percent (an additional 2,800 miles), bringing the total for poor condition roadways to 23 percent (nearly 9,800 miles). Over the prior decade (2000 – 2009), the condition discrepancy between the national average and Pennsylvania's roads had been reduced, even considering that Pennsylvania has some of the oldest highways in the nation. Since then, pavement condition has begun to worsen again, with the 2012 overall average condition rating equal to what it was in 2005. Pennsylvania has as many roadway miles as any state that experiences severe winters. Pavements are susceptible to cracking and expanding due to the temperature and weather changes (freeze/thaw cycles). Also, the chemicals used during snowy/icy conditions, while critical for safe travel, contribute to the decreased life of a pavement when compared to more temperate states.

The Commonwealth is the fourth state with the highest number of vehicles travelling on SD bridges in the nation. The total percentage of SD bridges has decreased by 4 percent since the 2010 report card, largely due to a short-term increase in funding.

Figures: Please reference Figure 5

BRIDGES: In Pennsylvania's more than 22,660 bridges, 23 percent are considered structurally deficient, which is the highest percentage in the nation. The Commonwealth's bridges are 10 years older than the national average and are in dire need of repair and modernization. it is estimated that approximately 40 percent of the needs for bridges in the Commonwealth will not be met in 2019. The Commonwealth's transportation system includes over 22,660 bridges, the third highest number of bridges in the nation, and over 114 million drivers pass over these bridges every day. Nearly one in four (23 percent) is categorized as SD. This is the highest percentage compared to the national average of 11 percent. In addition, nearly one in five (19 percent) of Pennsylvania's bridges is categorized as FO, compared with a national average of 14 percent. The total percentage of SD bridges has decreased by 4 percent since the 2010 report card, largely due to a short-term increase in funding. While on average, typical highway bridges were designed for a 50-year lifespan

when most of PA bridges were constructed (as opposed to 75-year lifespan for more modern bridges), the average Commonwealth is now approximately 54 years.

Figures: Please reference Figure 6

3.3 Pennsylvania Inland Water Ways.

Receiving an overall grade of a D+, of the 17 navigation dams in Western Pennsylvania; none of these dams are considered to be satisfactory under the guidelines of the U.S Army Corps of Engineers. The current condition assessment for the locks show that only 18 percent have a satisfactory rating. Commercial lockages have been relatively steady at about 37,000 annual lockages over the past four years, and recreational lockages averaging about 12,000 lockages per year.

Figures: Please reference Figure 2

3.4 Pennsylvania Freight Rail System.

Pennsylvania has 57 freight railroads covering 5127 miles across the state, ranking it 4th largest rail network by mileage in the U.S. By 2035, 246 million tons of freight is expected to pass through the Commonwealth of Pennsylvania, an increase of 22 percent over 2007 levels. Coal is 69 percent of the total tons originating in Pennsylvania and 35 percent of terminating tons. Other important commodities include primary metal products, petroleum, chemicals, and food products

SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity.

Of the five cargo capacities; the fifteen barge tow has the highest capacity with the ability to hold 787k bushels which requires 6.8M gallons, the 100-unit car train follows it with the ability to hold 350k bushels which requires 3M gallons and we have have the one barge tow which follows the car train with the ability to hold 52k bushels which requires 453,600 gallons. The jumbo hopper car train follows it with the ability to hold 3,500 bushels which requires 30k gallons and last but not least is the semi truck with the ability to hold 910 bushels which require 7,865 gallons.

4.2 Equivalent Units.

As shown in the diagram in figure 7, one barge equals 15 jumbo hopper cars which then equals 58 large semis. This is in proportion to one 15 Barge equation by multiplying everything by 15. Ex: 1 Barge = 55 Large Semis which also means that 15 Barges = (58x15) = 870 Large Semis

4.3 Equivalent Lengths.

With the proportion discussed in section 4.2, One 15 barge tow equals ¼ of a mile; a 2.25 100 Car Train Unit equals 234miles and the 870 Large semis equals 11.5 miles. Because all three of these units are equivalent in capacity, it is the best sense to use one 15 barge tow due to its size taking up the least amount of space.

Figures: Please refer to figure 7

SECTION 5 TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)

5.1 Trucks.

Transportation Costs:
Fuel costs range around $5.35 per ton mile (max: 26 tons)
Can get up to 155 ton miles/gallon of fuel
Equipment costs:
Vary whether you want to buy or lease a vehicle. These costs average around $6.52 per hour.
Repair and maintenance costs:
Average around $5.92 per hour.

5.2 Barges.

Transportation cost
Fuel costs range around $0.97 per ton mile (max: 1,500 tons)
Can get up to 576 ton miles/gallon of fuel
Equipment Costs: Vary whether you want to buy or lease the barge. These costs average around $15.30 per hour.
Repair and Maintenance Costs:
Average around $13.90 per hour.

5.3 Railroad.

Transportation Costs:
Fuel costs range around $2.53 per ton mile (max: 10,000 tons)
Can get up to 413 ton miles/gallon of fuel
Equipment costs:
Vary whether you own the locomotive and train cars or not. These costs average around $8.00 per hour.
Repair and maintenance costs:
average around $6.50 per hour.

5.4 Most Economical Transportation Solution.

The most economical transportation system available is railroad transport. Trucks are not from even considered being an option since the price per ton mile is way too expensive and not worth it since it can not transport more than 26 tons per truck. Trucks also take much longer to get from one place to the next and have to deal with stops and traffic. Although barge transport is more economically friendly than both railroad transport and trucks, it seems to have more flaws than these two. When it comes to barges you also have to take in consideration dealing with traffic, frozen rivers in the winter, water being too low sometimes, the slow speed, and many other imperfections. Railroad transportation is not perfect either but it seems to have the best outcome. Railroad transportation is the most economical transportation system since it is the fastest out of these three and can carry the most product for a decent price and does not have to deal with traffic or weather conditions.

5.5 Concept of Operations (ConOps).

a. General Description.

The railroad system seems to be an all rounded better system due to being the best economical, customer friendly, environmentally friendly and overall more efficient solution that meets the required needs. When it comes to price, the railroad system ranks second after the barge. When dealing with ease and availability to transport goods, it ranks first when you take into consideration possible environmental problems, it ranks in first When dealing with traffic, it ranks first by a long way. The railroad system will operate in the city of Pittsburgh. These are the major components we took into consideration when selecting the best transportation system.

b. Operational Policies and Constraints.

Maintenance hours are mainly during nighttime hours, off-peak hours, altering train schedules or routes. Currently, 36 cents out of every dollar spent to run the railroads goes to labor costs. As part of cost reduction initiatives, many railroads reduced their workforce, with most of the cuts in operating staff. the 3 main space constraints are topography, Hydrology and climate.

c. Performance characteristics

As of 2014, the operating speed of High-speed Rail systems in the world are running about all set at 300 km/h (190 mph). The most important safety measures to prevent accidents are strict operating rules, e.g. railway signaling and gates or grade separation at crossings. Train whistles, bells or horns warn of the presence of a train, while trackside signals maintain the distances between trains. In terms of cargo capacity combining speed and size being moved in a day:

Human – can carry 100 pounds (45 kg) for 20 miles (32 km) per day
Utility truck – can carry 20,000 tmi/day
Horse and Wheelbarrow – can carry 4 tmi/day

Most trains take 250–400 trucks off the road, thus making the road safer.

d. Operational Impacts.

The environmental impact of transport is significant because it is a major user of energy, and burns most of the world's petroleum. This creates air pollution, including nitrous oxides and particulates, and is a significant contributor to global warming through emission of carbon dioxide, for which transport is the fastest-growing emission sector. On average, commuter rail and subway trains emit 0.17 kg of CO_2 per passenger mile (0.26 kg/km per passenger), and long distance trains emit 0.19 kg of CO_2 per passenger mile (0.3 kg/km per passenger).

e. Continuity of Operations.

During extreme weather events the railroad system has the benefit of traveling on a rail, making it almost impossible to derail but most importantly safer for the transport of product. In the scenario of extreme weather events, the railroad is the best choice.

SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background.

Tier 0-2: Adopted December 17th, 1997 (Effective from 2,000)

- Applies to locomotives manufactured after 1973 and relies primarily on engine design methods

Tier 3-4: Signed March 2008
Tier 3 - Engine Design Standards
Tier 4: (required after 2015) - requires exhaust gas after treatment technologies

**Switch emissions standards follow the trend of generally having a greater emission freedom compared to Line-haul.*

Under the conditions of this report, we are assuming that Line-Haul Locomotives are used.

6.2 Tier 0-2 Standards.

0 - (Effective 2000) - (1973 - 2001)
1 - (Applicable to 2000-2004 models)
2 - (2005 models & above)

6.3 Tier 3-4 Standards.

*Stronger emission stands on locomotives when manufactured
3 - (2011 → 2014)
4 - (2015)

Under the Line Haul conditions; Tier 3 locomotives tend have the **exact** emission standard as Tier 2. This means that Tier 4 has the lowest emission standard with HC, Nox and PM emissions being reduced by at least 50%. The only distinct part to point out is that Carbon monoxide emission standard remained the same.

These emission standards are significant if we compare Tier 4 (the most recent Tier) compared to Tier 0 (the first). This set, has greatly decreased from the time the standards were first introduced (1973). This goes to show that as time passes, technology improves which results in enforcement of higher standards of emissions.

Figures: Please reference Figure 8 **Standards are explicitly shown in figures*

SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry.

a. NOx.

- (N2 + O2) → (NO, NO2)-NOx (NO + NO2) is formed when air (oxygen and nitrogen) is heated

- -NOx formation is exponential with temperature – Higher T → much higher No_x – More time at T→ much higher No_x

b. Particulate Matter (PM).

-PM - not a single substance - anything collected on test filter
-Delicate balance of compression, oil control & wear management

c. CO_2.

- (CxHy + O2) → (CO2 + H2O)-CO2 is formed in direct proportional to fuel consumed – Reduce fuel consumption → reduce CO2 – Increase fuel consumption → increase CO2

d. Hydrocarbons (HC).

- Hydrocarbons are chemical compounds that contain hydrogen and carbon. Pollution exists when unburned or partially burned fuel is emitted from the engine as an exhaust and the fuel goes directly into the atmosphere. The problem with hydrocarbon residues with its toxicity, as it can cause cancer and many other adverse health effects.

Figures: Please reference Figures 9 & 10

7.2 Diesel Emission Reduction Strategies.

A. Implementing new technology on old engines
B. Replacing old engines with newer ones
C. Having an incentive for the private sector

A. Tools such as oxidation filters or even oxidation catalysts help reduce diesel emissions in a cost efficient way. **This can only be a short-run solution as old engines cannot thrive in the long run and technology*

B. With this approach, costs can be considered the most expensive but the payoff to society is extremely high due to the dramatic reduction in diesel emission. **While this option seems the least doable, it only helps to begin and to continue with this option gradually*

C. If the government gives the private sector incentive to reduce emissions, it would be in the best interest for firms who emit significant amounts of diesel to begin to cut back. This could come to fruition with special programs that subsidize firms based on the change of diesel emissions that the firm produces on a regular basis. **The best case scenario is that firms will continue to follow this program and in turn, the development of diesel reducing emissions increases drastically.*

Conclusion: While all of the strategies discussed above are important; the most effective solution is to implement these strategies simultaneously. If filters are put on old engines, while the are gradually being replaced with new ones with a government program to encourage emission reduction; diesel emissions can be reduced greatly.

7.3 Alternate Fuels.

Biodiesel - Form of diesel fuel created from vegetable oils, animal fats and or recycled restaurant greases. It is considered safe, biodegradable and emits less air pollutants than petroleum based diesel.

CNG (Compressed Natural Gas) - Also known as methane stored at high pressure, CNG is made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure.

LNG (Liquefied Natural Gas) - As stated by its name, LNG is liquefied natural gas that is clear, colorless, and non toxic.

Propane - Approved as a clean fuel in the 1990 Clean Air act, propane is produced as part of natural gas processing and is the third most commonly used gas within the United States. Used around the world in light, medium and heavy-duty applications.

Hydrogen - Hydrogen does not produce harmful substances such as nitrogen oxides, hydrocarbons and other () particles. Instead, hydrogen emits water and and warm air which are harmless.

7.4 Human Health Issues.

As we breathe in oxygen, toxic gases and small particles of diesel are drawn into the lungs. Due to these very particles being very microscopic (one-fifth less than the thickness of human hair) they can infiltrate deep within the lungs.

Once these particles are within the lungs, they become benefactors in creating mutations in cells, thus developing cancer. In fact, long time exposure to diesel exhaust is the greatest health risk of any toxic air contaminant.

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

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.

Here are the Upgrading Strategy Options:

1. Do Nothing
2. Replace ALL 50Tier II locomotives with Tier II or IV locomotives
3. Upgrade ALL 50 Tier II locomotives for Tier III locomotives or after-treatment
4. Use alternative fuels
5. Combination of Option 2 and Option 3

Analysis of Upgrade Strategy Options

1. If we Do Nothing, the emissions stay they same and there is no innovation. (We want innovation!)
2. If we replace all Tier II locomotives with Tier II or IV, the cheapest investment is $150M (3M x 50) and the most expensive investment is $200M ($4 x 50) bringing the investment range between 150M - 200M.
3. If we Upgrade ALL 50 Tier II locomotives for Tier III locomotives or after-treatment the cheapest investment would be $5M and the most expensive investment would be $37.5M making the investment range from $5M - $37.5M
4. Using alternative fuels gives us the option of an upgrade of creating fuel stations. If we upgrade, the cost is $50M but if we create a fuel station the cost would be $1B, the most expensive out of all of the options.
5. Option 5 gives us the flexibility of using Options 2 and 3. This is significant because some locomotives are in condition to keep running rather than being upgraded.

Pros/Cons of Each Option

Option	Pros	Cons
1	No money is spent	No innovation
2	New locomotives will emit significantly less emissions	Not ideal to purchase all new Capital; 2nd most expensive
3	Investment range is cheaper than option 2	Not ideal to upgrade all New Capital
4	Significant reduction of Diesel emissions	Very expensive
5	Allows us to optimize price vs emissions	Investment strategy is not as straightforward as other 4 options

8.5 Upgrade Schedule and Costs.

Upgrade Schedule

Locomotive Group	Investment Strategy	Cost
E (Q1)	Purchase All New Tier 4	(10 x $4M) = 40M
D (Q2)	Purchase All New Tier 3	(10 x $3) = 30M
C (Q3)	Upgrade to Tier III	(10 x $750k) = 7.5M
B+A (Q4)	Upgrade After Treatment	(20 x $100k) = 2M
Total		$79.5M

Upgrade Strategy Conclusion

With the decision to go along with Investment 5, this allowed us to save at least $70.5M compared to option 2, save $920.5M compared to creating a fueling station and even though this option was not the cheapest, it allowed us to maximize both price and emissions that are released into the air by upgrading a few locomotives, and purchasing all new locomotives compared to the mileage on each.

SECTION 9 SUMMARY

I. Executive Summary Restated
II. Pennsylvania Infrastructure
III. Optimized Economical Solution
IV. Alternative Fuels
V. Upgrade Schedule

I. **Executive Summary Restated -** Students are to critically analyze infrastructure in Pennsylvania, compare various forms of transportation to another to decide the most economically efficient choice, discuss emission requirements, come to a conclusion on an upgrade schedule for a calendar year and effectively explain diesel emission strategies.

II. **Pennsylvania Infrastructure** - The amount of poor-condition roadways has risen 7 percent (an additional 2,800 miles), bringing the total for poor condition roadways to 23 percent (nearly 9,800 miles). In Pennsylvania's more than 22,660 bridges, 23 percent are considered structurally deficient, which is the highest percentage in the nation.

Pennsylvania has 57 freight railroads covering 5127 miles across the state, ranking it 4th largest rail network by mileage in the U.S. By 2035, 246 million tons of freight is expected to pass through the Commonwealth of Pennsylvania, an increase of 22 percent over 2007 levels.

III. **Optimized Economical Solution** - Earlier it was concluded that the most economical transportation system available is railroad transport. Trucks were eliminated due to price per ton and the amount of time it takes for it to get from point A to point B. At the same time, barges were highly economically efficient, but the complications are other risks that it can face on the waterway gave railroads the upper hand.

IV. **Alternative Fuels** - The five alternative fuels discussed are: Biodiesel, Compressed Natural Gas, Liquefied Natural Gas, Propane and Hydrogen. These fuels combined all use common resources while significantly minimizing the amount of pollutants that go into the atmosphere.

V. **Upgrade Schedule** - The upgrade strategy follows a combination of replacing and upgrading the locomotives based on the mileage of the locomotives. This is the most cost efficient which significantly reduces the amount of emissions.

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FIGURES

Figure 1. Typical Truck and Trailer

Figure 2. Waterway System for Barge Transportation Traffic

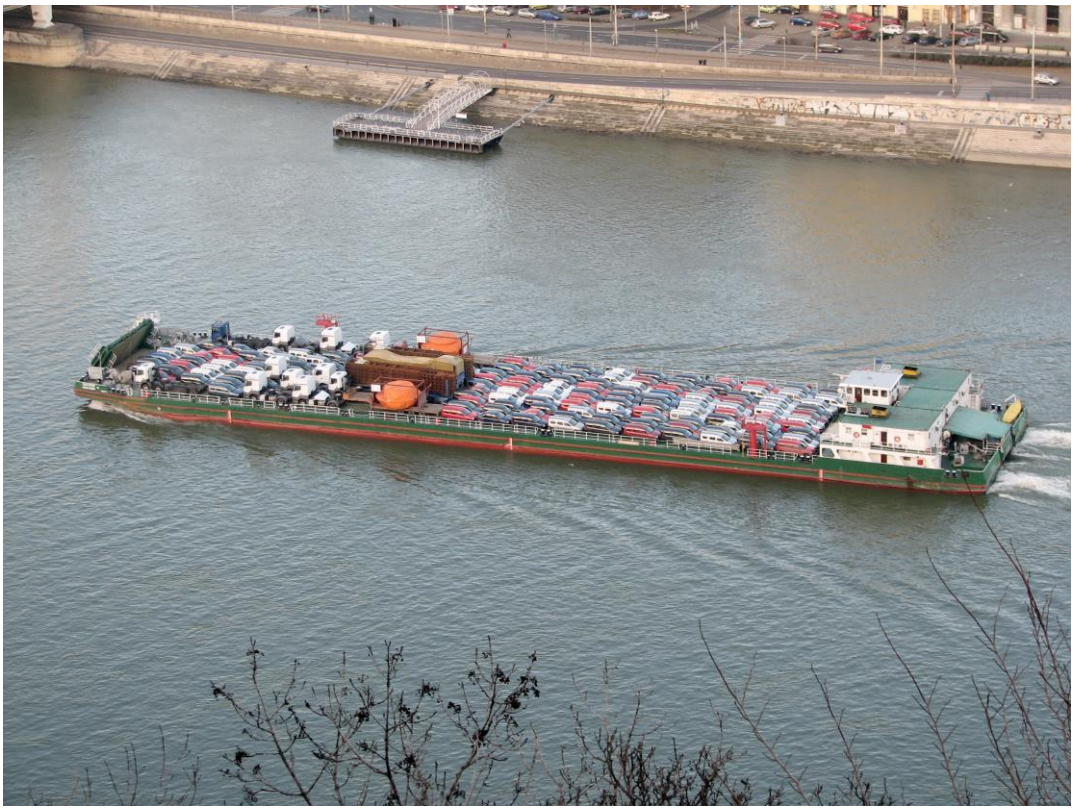

Figure 3. Typical Barge and Tug Transporting Across Water

Figure 4. Typical Diesel-Electric Locomotive

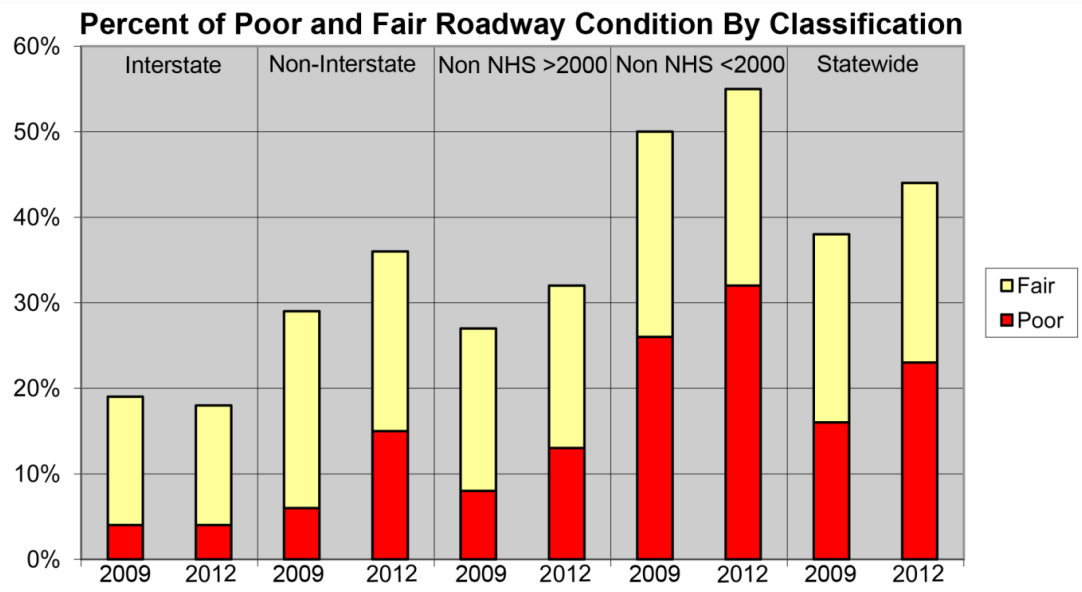

Figure 5. Conditions Reflected on Pennsylvania Roadways

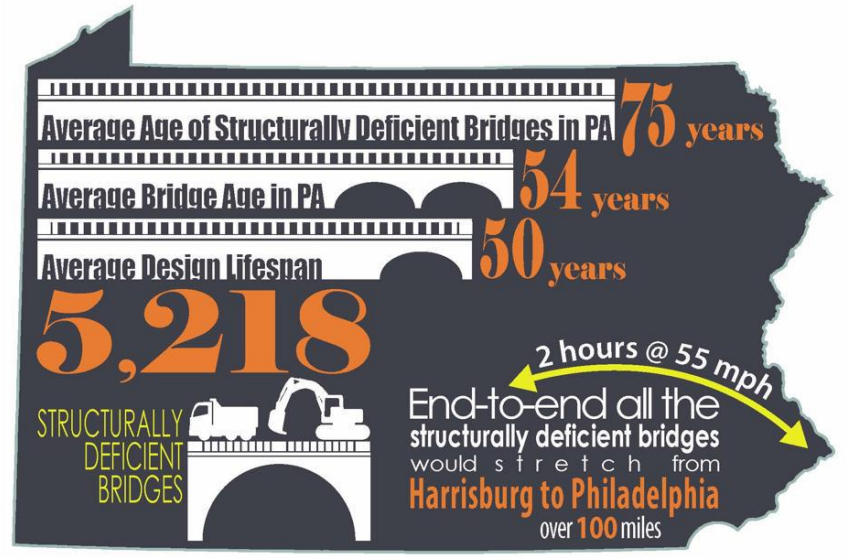

Figure 6. Graphic Depicting Structurally Deficient Bridges in Pennsylvania

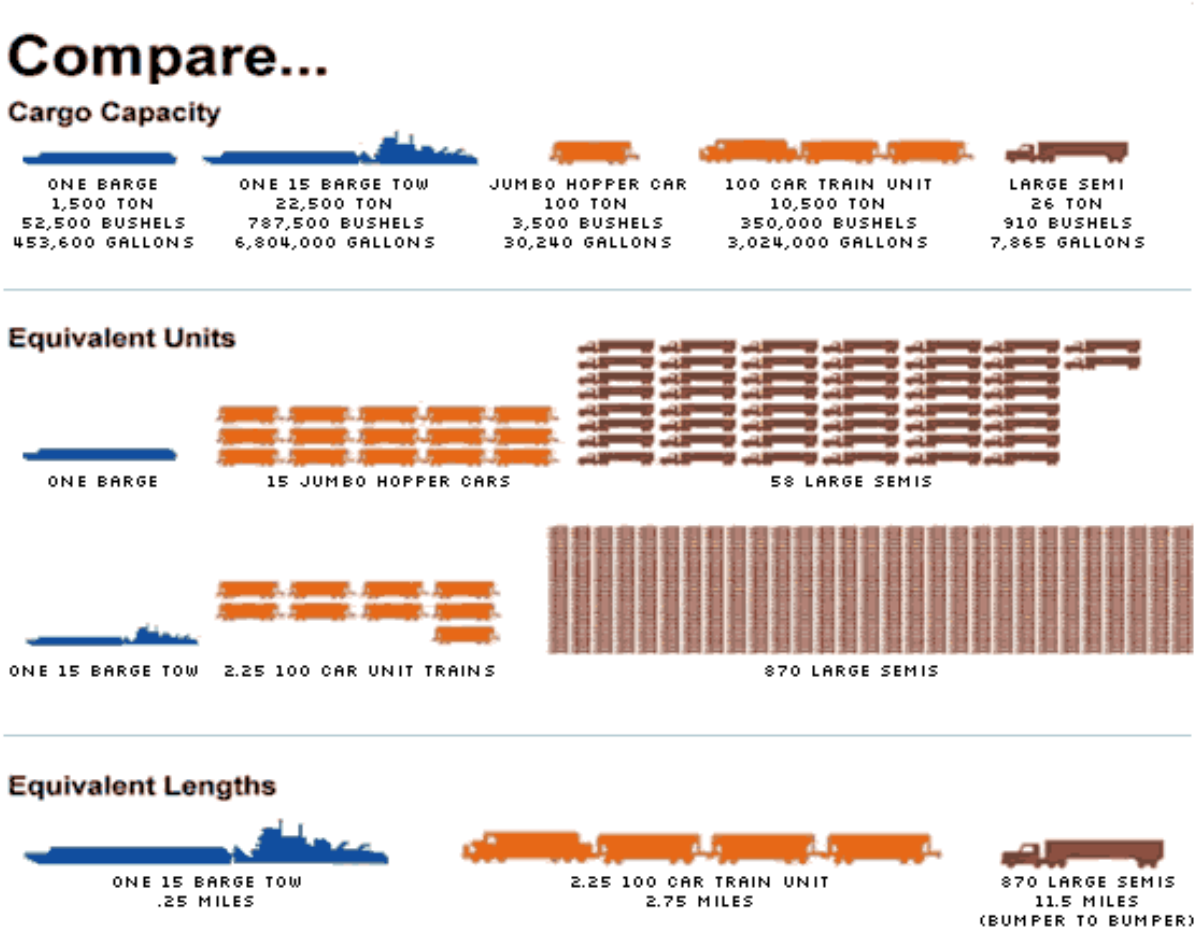

Figure 7. Capacity, Equivalent Units and Equivalent Lengths of various forms of Transportation

Table 1
Tier 0-2 Locomotive Emission Standards, g/bhp·hr

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
Non-Regulated Locomotives (1997 estimates)				
Line-haul	0.5	1.5	13.5	0.34
Switch	1.1	2.4	19.8	0.41
* HC standard is in the form of THC for diesel engines				

Table 3
Line-Haul Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0[a]	1973-1992[c]	2010[d]	1.00	5.0	8.0	0.22
Tier 1[a]	1993[c]-2004	2010[d]	0.55	2.2	7.4	0.22
Tier 2[a]	2005-2011	2010[d]	0.30	1.5	5.5	0.10[e]
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

a - Tier 0-2 line-haul locomotives must also meet switch standards of the same tier.
b - Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
c - 1993-2001 locomotive that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
d - As early as 2008 if approved engine upgrade kits become available.
e - 0.20 g/bhp-hr until January 1, 2013 (with some exceptions).
f - Manufacturers may elect to meet a combined NOx+HC standard of 1.4 g/bhp-hr.

Table 4
Switch Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0	1973-2001	2010[b]	2.10	8.0	11.8	0.26
Tier 1[a]	2002-2004	2010[b]	1.20	2.5	11.0	0.26
Tier 2[a]	2005-2010	2010[b]	0.60	2.4	8.1	0.13[c]
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

a - Tier 1-2 switch locomotives must also meet line-haul standards of the same tier.
b - As early as 2008 if approved engine upgrade kits become available.
c - 0.24 g/bhp-hr until January 1, 2013 (with some exceptions).
d - Manufacturers may elect to meet a combined NOx+HC standard of 1.3 g/bhp-hr.

Figure 8. Cumulative Tables defining Locomotive Emission Standards for Tier 0-4

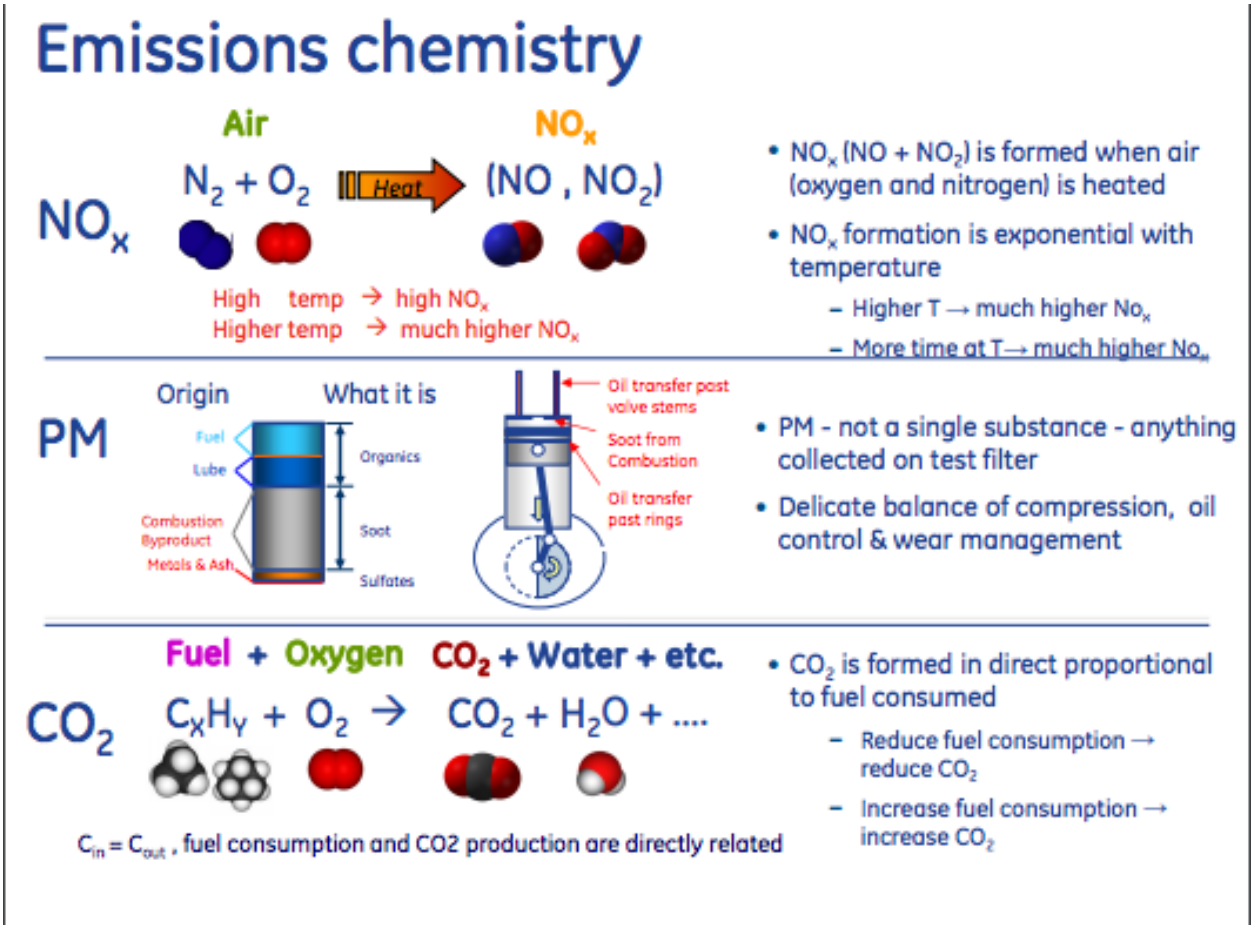

Figure 9. Graphical Representation of various Diesel Emissions

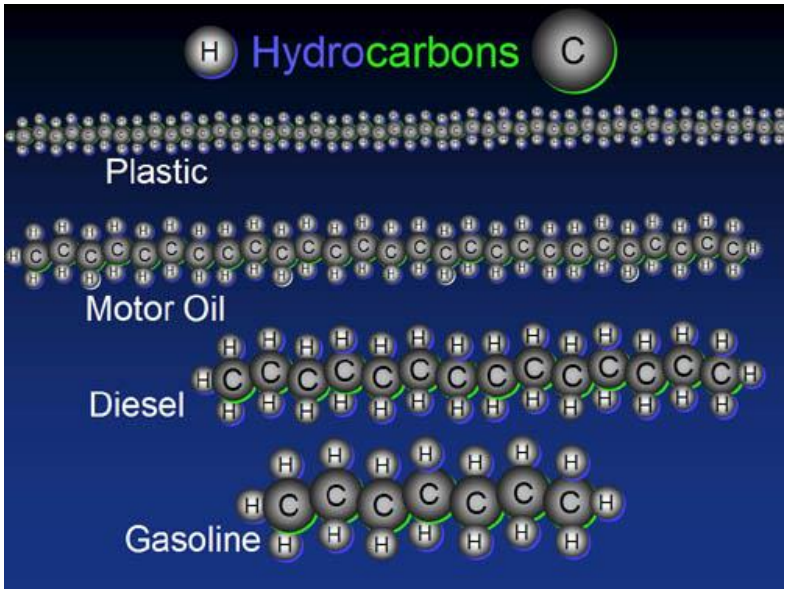

Figure 10. Graphical Representation Depicting Composition of various Gases