

# AMOD Energy



GE  
Transportation

**Kyle Dougherty, Mohammad Hajib Bin Ali,  
Rebecca Might, Jesse Opiyo  
EDSGN 100  
The Pennsylvania State University  
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## **Executive Summary**

AMOD Energy was challenged to come up with an alternative shipping system for Pittsadelphia, an important port city. The city is becoming thick with smog, and the people demand a change. For this reason, the new system must reduce NO<sub>x</sub> and PM emissions. While doing this, the new system should also be cost effective, not decrease freight capacity, maintain on-time delivery, and improve public opinion. Our team did research, and came up with four ideas each. We then compiled them together to compare the different plans using a concept matrix. The winning concept involves selling all of the locomotives, and replacing them with CNG trucks and cargo planes. We did further research about planes and their effect the five main criteria for the system. We found that our system will most likely not be reasonable for Pittsadelphia, merely because the cost is so great.

## **Introduction**

The purpose of this project is to develop a shipping system that will reduce the NO<sub>x</sub> and PM emissions while being cost efficient, maximizing freight capacity, and delivering on time. Columbus, OH was chosen to represent Pittsadelphia, and the coal will be shipped from Gilberton, PA. These cities are roughly 450 miles apart. The proposed shipping system must transport at least 165,000 tons of freight from Gilberton into Pittsadelphia every day.

## **Problem Statement**

Pittsadelphia wishes to reduce the amount of smog that is in their city from the NO<sub>x</sub> and PM emissions of locomotives. Currently, about 165,000 tons of freight travels in or out of Pittsadelphia's ports every day. Smog is a constant complaint from the residents. This project will investigate ways to reduce NO<sub>x</sub> and PM emissions while being cost conscientious without decreasing freight capacity.

## **Research**

We did research on different types of fuels, different types of locomotives and planes. We got the information from various websites, and from our classmates.

CNG is a fuel made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure. It consists of mostly methane drawn from natural gas wells. It costs about 50% less than gasoline or diesel. There is an abundant supply here in America. CNG is nontoxic, so it is not a threat to the land or water if some is released. There is no concern about storage time. The US only has about 500 fueling stations. The time it takes to fill the locomotive with CNG is long. It reduces NO<sub>x</sub> emissions by approximately 50%, reduces up to 95% of PM emissions, reduces CO<sub>2</sub> emissions by 20% to 30%, and reduces CO emissions by up to 75%. CNG is a good alternative fuel.

Low sulfur diesel is a fuel that is refined in order to reduce the sulfur content to 15 ppm. This reduces soot production, which will then reduce  $\text{NO}_x$  and PM emissions. Diesel engines using Low S Diesel fuel are 20-40% more efficient than gasoline vehicles. Low Sulfur Diesel engines absorb water from the atmosphere, which can cause corrosion and failure in metal components in the locomotive. Smoke emissions are reduced by 60%. Sulfur dioxide emissions are cut by 90%. PM emissions are cut by 20%, and  $\text{NO}_x$  emissions are cut by 80%. Low sulfur diesel is also a good alternative fuel.

A type of train that we researched is the maglev locomotive. Maglev is short for magnetic levitation. The magnet replaces the wheels and track trains, and it does not have a motor. There are no moving parts, so maintenance cost is reduced. Its speed can exceed 200 mph because there is no friction between the track. Because there is no internal combustion, it is very environmentally friendly. However, because it can not run on existing tracks, it requires new tracks to be built which will be very expensive.

Another train that we researched is the solar locomotive. Solar panels are put on the top of the train to power it. This cuts down on coal consumption, and if enough panels are used, no additional fuel is needed.  $\text{NO}_x$  and PM emissions are reduced, if not totally gotten rid of. However, solar panels cost a lot. Also, if energy is not stored on a grid, train may not have enough energy to run at night.

Cargo aircraft is an airplane designed to carry cargo rather than passengers. They have a fuselage that is much taller and wider than a typical passenger aircraft. They have at least one very large door to allow the plane to be loaded easier. They have a strengthened cabin floor to help hold the mass of the cargo. They have many wheels on the bottom to accommodate landing the extra weight. Today, they are mainly used to transport military machines, such as tanks.

## **Calculations**

The calculations are made so that the solution made to this problem are cost effective and does not release too much emissions. Some of the factors that needed to be computed were

- the cost of each type of fuel
- the amount of emissions
- the total cost of transportation

We gathered the information from a variety of internet sources regarding the alternative fuel that can replace diesel. The factor that was taken into action is the cost of fuel, amount of emission it produces and the energy value. The amount of  $\text{NO}_x$  and PM is needed in choosing the best type of fuel since it was the main problem of people from Pittsburgh. The list of fuel that we looked into is included below in Table 1.

<b>Fuels</b>	<b>Costs</b>
Biodiesel (B20)	\$2.92/gallon
Biodiesel (B99-B100)	\$3.77/gallon
Electricity (E85)	\$0.12/kWh
Natural Gas (CNG)	\$2.09/GGE
Propane	\$2.92/ gallon
Gasoline	\$2.32/gallon
Diesel	\$3.06/gallon
Aviation Gasoline	\$5.00-\$6.00
Ethanol	\$2.47/gallon

Table 1

From the table, we found out that Aviation Gasoline fuel was the highest cost among other fuel. which is around \$5.00/gallon while the lowest price was the Compressed Natural Gas Fuel. The diesel has around average cost which was \$3.06/gallon while others fuel were around 3.00/gallon.

The amount of NO<sub>x</sub>,PM,CO and CO<sub>2</sub> emissions by planes,locomotives and truck/freightliner has been recorded. We found out that planes emits much more pollutants than we had originally expected.

#### Planes :

- 1193 grams/ton-mile of CO<sub>2</sub>
- 3944 grams/ton-mile of NO<sub>x</sub>
- 0.119 grams/ton-mile of PM
- 92 kg CO<sub>2</sub>/hour emissions

#### Locomotives emissions (Based on Tier 4 Line Overhaul emissions factors)

PM : 0.015 g/bhp-hr

NO<sub>x</sub> : 1.00 g/bhp-hr

CO : 1.28 g/bhp-hr

In order to compare the emissions emit by those transportation, we standardized the units as it was hard to compare the emissions with different unit.

$$\begin{aligned} \text{PM} &= \frac{0.015 \text{ g}}{\text{hp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 0.312 \text{ g/gallon (Conversion factor is 20.8 for large line haul \& passenger)} \\ &= 0.312 \text{ g/gallon} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 7.8 \times 10^{-4} \text{ g/ton-miles (divided by 400 ton-miles/gal)} \end{aligned}$$

$$\begin{aligned} \text{NOx} &= \frac{1.00 \text{ g}}{\text{bhp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 20.8 \text{ g/gal (conversion factor is 20.8)} \\ &= 20.8 \text{ g/gal} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 0.052 \text{ g/ton-miles (divided by 400 ton-miles/gal)} \end{aligned}$$

$$\begin{aligned} \text{CO} &= \frac{1.28 \text{ g}}{\text{bhp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 26.62 \text{ g/gal (conversion factor of 20.8)} \\ &= \frac{26.62 \text{ g}}{\text{gal}} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 0.067 \text{ g/ton-miles} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &= 0.1048 \text{ kg/ton-miles} \\ &= \frac{0.1048 \text{ kg}}{\text{ton-miles}} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 104.8 \text{ g/ton-miles} \end{aligned}$$

#### Truck/ Freightliner

$$\begin{aligned} \text{CO}_2 &= 0.163 \text{ kg/ton-miles} \\ &= \frac{0.163 \text{ kg}}{\text{ton-miles}} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 163 \text{ g/ton-miles} \end{aligned}$$

$$\begin{aligned} \text{PM} &= 0.01 \text{ g/bhp-hr} = \frac{0.01 \text{ g}}{\text{bhp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 0.208 \text{ g/gal} \\ &= 0.208 \text{ g/gal} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 5.2 \times 10^{-4} \text{ g/ton-miles} \end{aligned}$$

$$\begin{aligned} \text{NOx} &= 0.02 \text{ g/bhp-hr} = \frac{0.02 \text{ g}}{\text{bhp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 0.416 \text{ g/gal} \\ &= 0.416 \text{ g/gal} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 1.04 \times 10^{-3} \text{ g/ton-miles} \end{aligned}$$

$$\begin{aligned} \text{CO} &= 15.5 \text{ g/bhp-hr} = \frac{15.5 \text{ g}}{\text{bhp-hr}} \times \frac{20.8 \text{ bhp-hr}}{\text{gal}} = 322.4 \text{ g/gal} \\ &= 322.4 \text{ g/gal} \times \frac{1 \text{ gal}}{400 \text{ ton-miles}} = 0.806 \text{ g/ton-miles} \end{aligned}$$

#### Total cost

For the total cost of the project, we decided sell all 50 trains for \$1.5 million each:  
 $50 \times \$1.5 \text{ million} = \$75 \text{ million}$

Buy 3 cargo planes at \$20 million each, and 60 CNG trucks at \$78,500 each

Total cost:  $3(\$20 \text{ million}) + 40(\$78,500) = \$64,710,000$

## Customer Needs and Target Specifications

Target specifications were created in order to understand what was necessary for customer satisfaction. Specifics varied from environmental friendly to producing a cost effective product. These specifications were found in the customer's report and briefings as well as the engineering team's intuitive senses. Parameters chosen here helped to give direction and focus to the multitude of possible designs for the problem. A list of customer needs and their related metrics are shown below in Table 2.

Needs	Acceptable	Ideal
1. Reduce emission of NOx and PM	Meet tier 3 of EPA requirements	Meet tier 4 of EPA requirements
2. Increase the freight capacity	15 trains per day 16500 tons	20 trains per day 200000 tons
3. Use alternative fuel that reduces amount of NOx and PM	Use biodiesel fuel, compressed natural gas, and liquefied natural gas.	Use Biodiesel fuel that have low amount of NOx or low Sulphur fuel as alternative fuel
4. After treatment of exhaust	Use cyanuric acid(chemical after treatment)	Use devices such as selective catalytic reduction (SCR) which uses reducing agent to reduce emission of NOx.
5. Exact time delivery	Maintain the efficiency of the train and make sure the train did not have problems that can cause late delivery.	Increase the efficiency of the train and make sure the train did not have problems that can cause late delivery.
6. Cost fuel	Do not increase costs from where they are now	Reduce costs from where they are now
7. Public opinion	Get the public to stop complaining	Make the public like the new system

Table 2

## Concept Generation

Instead of simply developing a single design, each member of our team generated four concepts, so we had a total of sixteen concepts. Some of our ideas were nearly the same, so in the end we had twelve different system designs to choose from. These twelve ideas included concepts using different fuels for locomotives, such as CNG and biodiesel, and using different forms of transportation, such as a plane and a ship. Each idea is in the “concept” column of the table below.

### Concept Selection

Each concept was placed into a concept selection matrix, where each concept was compared to the Low Sulfur Diesel Locomotive. Each concept was given a score of -2, -1, 0, 1, or 2 compared to the Low Sulfur Diesel Locomotive. A score of 0 was given if it was the same as a Low Sulfur Diesel Locomotive. A positive score was given if it is better, and a negative score was given if it is worse. The matrix was done below in Table 3.

Concept	Emissions	Costs	Capacity	Public Opinion	Time	TOTAL
Low Sulfur Diesel Locomotive	0	0	0	0	0	0
Biodiesel Locomotive	-2	2	0	0	0	0
CNG Freightliner and Cargo Plane	0	-2	1	1	2	2
Gasoline Locomotive with exhaust after treatment and cargo ship	-1	-2	2	-1	0	-2
LNG Locomotive	1	1	0	-1	0	1
Low Sulfur diesel locomotive with solar panels	1	-1	0	1	0	1
Diesel electric locomotive	-1	1	0	0	0	0
Maglev	2	-2	-1	2	0	1

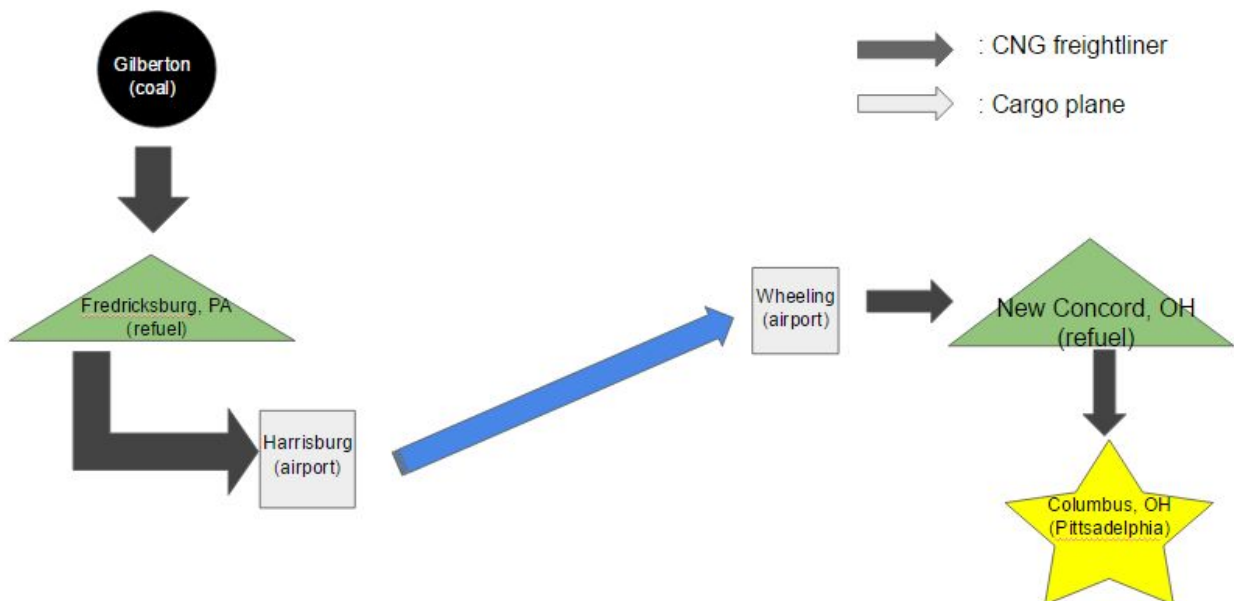
<b>Locomotive</b>						
<b>Freight truck to cargo ship</b>	-1	1	1	1	-1	1
<b>CNG Locomotive</b>	1	-1	0	0	0	0
<b>Truck to CNG locomotive</b>	0	1	-1	0	-1	-1

Table 3

## Final Description

After putting all the concepts through the concept selection matrix, the cargo plane to CNG freightliner system was found to be the best option. In order to transfer the coal to Pittsadelphia, the coal is first picked up at a coal company in Gilberton, PA by 30 CNG freightliners. These trucks then travel to Fredricksburg, PA to refuel at the CNG refueling station in that town. Once refueled, the trucks will continue to Harrisburg International Airport, where the coal will be unloaded from the trucks and put on to 3 cargo planes. These planes will then fly non-stop to Wheeling airport, where the coal will again be unloaded and loaded onto 30 new CNG freightliners. These freightliners will stop over in New Concord, OH to refuel and then continue to Columbus, OH (Pittsadelohia).

## Systems Diagram



## Concept of Operations



The cargo plane/CNG freightliner system involves coal being transported by CNG trucks to Harrisburg, where the coal will be loaded onto cargo planes. The planes then travel to Wheeling, where the coal is loaded onto more CNG freightliners. The CNG trucks will then finish the journey to Columbus, where the coal will be unloaded. The use of CNG trucks will cut NO<sub>x</sub> emissions in Pittsadelphia by 50%, reducing the smog in Pittsadelphia.

### **Environmental Analysis**

The use of cargo planes in the system makes the environmental impact much higher than anticipated. The cargo planes would produce 92 kg CO<sub>2</sub>/hr and 3.944 grams NO<sub>x</sub>/ton-mile. These emissions would add up over time and affect the environment in severe ways. The CNG freightliners would decrease the emissions, but not enough to cover for the emissions coming from the planes.

### **Economic Viability**

In order to make the system work, the cargo planes would have to travel back and forth from Harrisburg and Wheeling. This would increase the cost to maintain the planes by an extremely high amount. Gas for cargo planes is extremely expensive and would increase the cost of the system by a large amount. The CNG freightliners would reduce costs due to inexpensive fuel. This would help to reduce the cost brought on by the high cost of the cargo planes, however the system is still too expensive to maintain.

### **Feasibility Study**

After reviewing the system, it was found that the inclusion of cargo planes would be incredibly difficult to incorporate without severe consequences. The planes produce too much NO<sub>x</sub> and PM emissions, and are extremely expensive to maintain. Also, the planes would be affected more by severe weather conditions than ground transportation options. Another downside to the system is that the use of so many trucks could lead to disastrous traffic jams in Pittsadelphia, thus decreasing public opinion. The fueling stations would also be overflowing with trucks due to there being 30 trucks per station on the route. All in all, the system is extremely difficult to implement with the current transportation options being used.

### **Conclusions**

We have been working on this project for nearly two months. Over these two months, there were many lessons learned. Working with others is a skill that all people need, including engineers, so getting to work with a team of peers for an extended period of time has improved our teamwork skills. We were challenged to come up with a solution to a real problem that GE is facing. We all hope to someday be working in a similar field, and possibly being asked to do something very similar. Research is a key part to many fields, and this project forced us to do real research to come up with a solution. Practicing using our resources to obtain information was another great bonus to doing this project.

We chose our final concept based on our concept selection matrix. It was the highest scoring option, so we discussed it and decided it would be the best. In theory, our plan was great. It started off seeming like a very good solution to Pittsdelphia's problem. However, in the end it was not a feasible choice. The costs and emissions were higher than we had originally believed. Other practical problems also came up, such as traffic and troubles when there are poor weather conditions.

If we were to do this project over again, we would definitely not choose a cargo plane. We all agreed that we would choose locomotives to transport the freight. Some ideas that we discussed and agreed upon involved low sulfur diesel fuel, selling half of the fleet to buy tier 4 locomotives, and doing an aftertreatment on the old ones. As of today, trains really are the best option for transporting mass amounts of freight. Hopefully soon GE and other engineers will come up with a reasonable way to eliminate train emissions, and be able to implement it.

One of the most important lessons that we learned as a group is that failing is alright. When it became clear that we chose wrong, it was very devastating, and we did not have enough time to start over with a new concept. We had to admit that we came with a solution that would not work. We learned that knowing what will not work is sometimes just as important as knowing what will work.

#### **Appendix A Concepts from the first generation**

1. **Low Sulfur Diesel Locomotive**- Low Sulfur Diesel is a fuel that has reduced sulfur contents. This will reduce PM and NOx emissions.
2. **Biodiesel Locomotive**- Biodiesel is a fuel that does not require an engine. It can burn nearly any material to run, and is generally environmentally friendly. However, it increases NOx and is expensive.
3. **CNG Freightliner and Cargo Plane**- CNG is a fuel made from compressing natural gas. It is less expensive than diesel fuel, and more environmentally friendly. A plane has many advantages, such as speed.
4. **Gasoline Locomotive with Exhaust Aftertreatment and Cargo Ship**- An exhaust aftertreatment will reduce emissions from the locomotive. Cargo ships have many advantages, such as capacity and reducing traffic.
5. **LNG Locomotive**- LNG is a fuel made from liquefying natural gas. It will reduce the PM and NOx emissions.
6. **Low Sulfur Diesel Locomotive with Solar Panels**- Solar panels create no emissions. Low sulfur diesel will be there as a backup in case the solar panels do not generate enough energy to power the locomotive.
7. **Diesel Electric Locomotive**-This locomotive runs partly on electricity and partly on diesel fuel. This reduces the emissions a great deal.

8. **Maglev Locomotive-** A maglev locomotive is a train powered by magnets. It creates no emissions because it needs to fuel.
9. **Freight Truck to Cargo Ship-** A freight truck will bring coal to and from a cargo ship. Cargo ships have many advantages, such as capacity and reducing road traffic.
10. **CNG Locomotive-** CNG is a fuel made from compressing natural gas. If used in a locomotive, the emissions would be substantially reduced.
11. **Truck to CNG Locomotive-** A freight truck will transfer freight to and from a CNG Locomotive. The locomotive will have low emissions because it runs on CNG fuel.

#### Solidworks Model



#### References

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