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EDSGN 100
Introduction to Engineering Design
Section 009, Team #4

Natural Gas Locomotive
Sponsored by: GE

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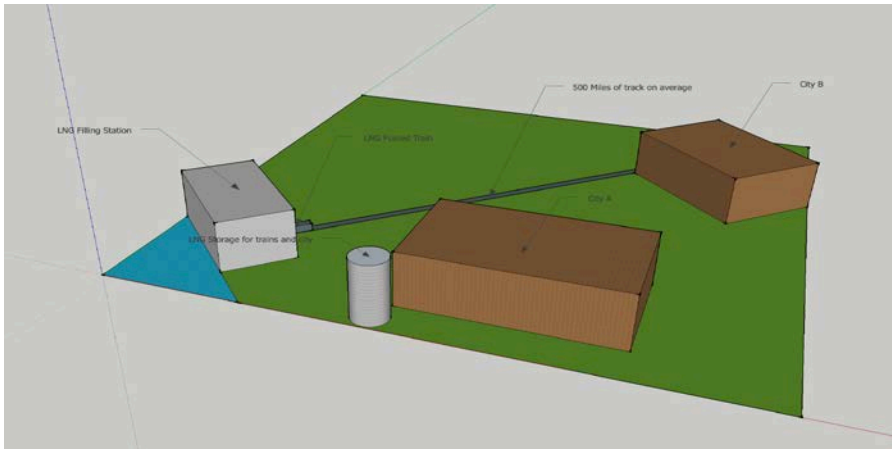
Submitted to: Xinli Wu

Fall 2015



Abstract

In this project, the team analyzed the information provided by GE to find the most cost efficient way of transportation while reducing emissions. After analyzing each method of transportation and the after treatments, the preferred solution turned out to use liquefied natural gas.

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Introduction

The proposed project looks to find a solution to reduce smog emissions from locomotives that transport freight in and out of a port city without decreasing efficiency. Current Tier 2 locomotives are approaching the age of overhaul, and investments are required to meet EPA Tier 3 requirements. There are two options in solving this problem, either by upgrading the current locomotive fleet by upgrading trains to Tier 4, use after treatment to reach Tier 4, or use alternative fuel (LNG), or by using alternate freight shipping. In order to carry out the project, the options were evaluated, several concepts were generated by brainstorming, and upon selecting the best concept using the design concept matrix, Alternate Fuel (LNG) was chosen. The design was assessed to make sure it is feasible and affordable. In order to ensure that the design was cost effective, the team calculated the net cost to upgrade, cost of fuel per year, potential for profit, and timeframe for money recuperation. A prototype and design drawings were also provided to best represent the idea to the audience.

Description of the Design Task

Problem Statement

The current level of emissions produced by locomotives is too high (Tier 2.) We need to reduce this by either upgrading the locomotives to reach at least tier 3 standards, purchasing new locomotives with technology that reduces emissions (Tier 3 and 4), or switch to a different method of transport.

Mission Statement

We are to analyze the data provided from GE about upgrading/replacing locomotives. From this data we will select the best option that reduces emissions most effectively and has the lowest cost.

Design Specifications

The city of Pittsdelphia is looking for a cost-effective method to reduce emissions that meet EPA requirements, but at the same time maintain or increase freight capacity into and out of the city.

Design Approach – Design Matrix

Project Management – Gantt Chart

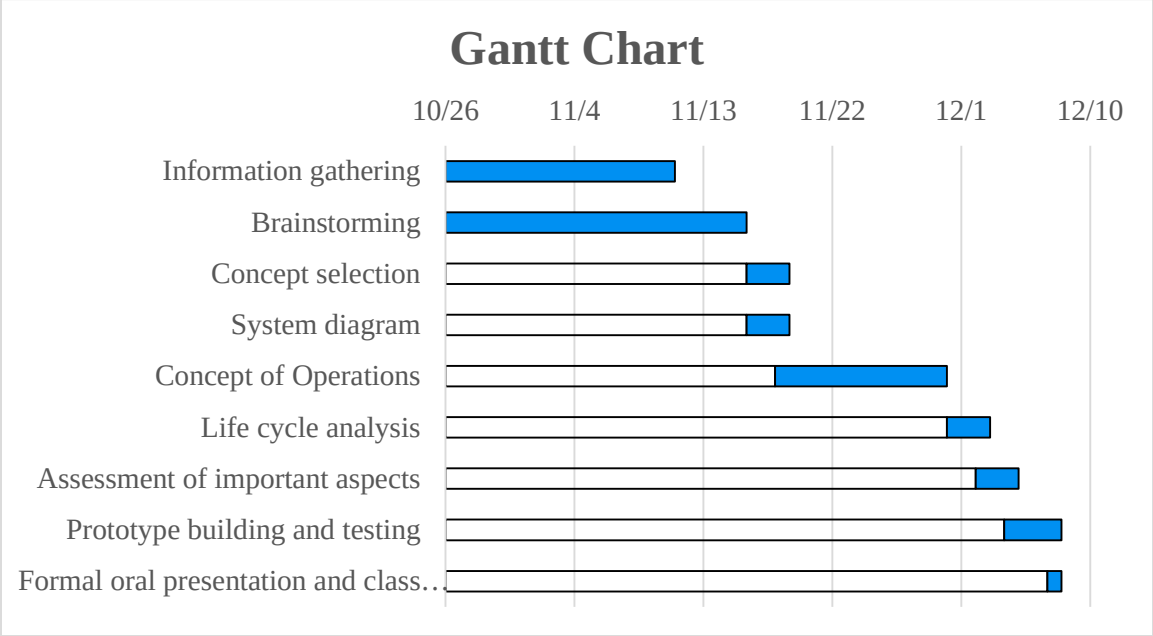


Chart 1. This chart shows the team's progress throughout the design process.

Concept Generation – Brainstorming

Air Transportation – Antonov AN-225

Time-
- Speed: up to 850 km/h
- Altitude: up to 12,000 m

Environmental-
- Engine: D-18T turbofan
- Low specific fuel consumption
- Low noise and pollutant
- Meets ICAO emission regulations

Cost-
- $20 million per plane
- Cost of operation: about $400 per hour

Capacity-
- 250 tons of freight

Sea

Time-

- About 10-12 hours to fully unload
- Transportation time: average: 21-25 knots (38.9-46.3 km/h)
- Biggest ship: 23 knots (26.5 mi/h)

Environmental-

- Fuel: waste oil (cheapest but pollutes the most)
- All shipping in Europe: 2.3 million tonnes SOx and 3.3 million tonnes of NOx
- One large ship generates 5,200 tonnes of sulphur oxide pollution in a year
- 15 of the largest ships emit the same SOx as 760 million cars
- One large ship pollutes the same as 50 million cars
- Shipping is responsible for 18-30% of the world's NOx and 9% of SOx
- Every 140-150 million of fuel consumption releases 10 million NOx

Capacity-

- Maximum: 200,000 tons
- Ultra large container vessel – 18, 270 TEU

Cost-

- Cost of ship: average for a 500 ton container ship : $10 million
- 12,000 TEU average price: $74-105 million
- Cost of operation: standard panamax: about $9 million/year
- Fuel 46%, port charges 21%
- Post-panamax (6,000 TEU): $12 million
- Post-panamax Plus (10,000 TEU): $14.5 million

Freight Truck Estimates

Time to go 500 miles – Approximately 7 hrs 30 mins

Emissions – All numbers in Tg CO_2 Equivalent (1 Tg = 1 million metric tons) in 2011
388.3 CO_2, 0.1 CH_4, 1.0 N_2O, 11.7 HFCs, Total = 401.1

Cost – Cabs cost $100,000+ and each trailer costs approximately $50,000

Cost of Operation - $180,000 per truck, largest cost is diesel fuel and second largest is driver salary

Capacity – Maximum capacity is approximately 200,000 pounds or 10 tons per truck

Design Concept Selection – Design Matrix

	Upgrade trains to tier 4	Use aftertreatment to reach tier 4	Alternative fuel(LNG)
Net cost to upgrade	$125,000,000	$4,250,000	$1,050,000,000
Cost of fuel per year	$196,050,573	$196,050,573	$98,025,287
Potential for profit	No	No	Yes
Timeframe for money recouperation	N/A	N/A	10.2 years(neglecting profit from LNG sales)
Pros:	Brand new locomotives	Cheapest initial investment	Provides city with a nearby source of LNG
	No new infrastructure	-	Provides a source of profit for the rail company
	Easy to meet future regulation changes	-	Significant pollution reduction
	-	-	Will easily meet future regulations
	-	-	Large reserves and local production ensure steady prices
	-	-	Large savings on fuel
Cons:	Large fuel cost	Large fuel cost	Extremely high initial investment
	Fuel cost subject to increases	Fuel cost subject to increases	Not brand new locomotive
	More foreign dependency for fuel	More foreign dependency for fuel	-
	-	Not brand new locomotive	-
	-	Will be harded to reach future regulations	-

Table 1. This table compares the current and different systems that could be used.

Selection Criteria	A (current system)	B	C	D	E (trucks)
Cost of initial investment	0	0	+	-	-
Cost of fuel per year	0	-	-	+	-
Potential for profit	0	-	-	+	-
Timeframe for money recuperation	0	0	0	+	-
Easy to meet future regulations	0	+	-	+	+
Fuel cost subject to increases	0	0	0	+	0

Sum +'s	0	1	1	5	1
Sum 0's	6	3	2	0	1
Sum -'s	0	2	3	1	4

Net score	0	-1	-2	4	-3
Rank	2	3	4	1	5
Continue?	no	no	no	yes	no

Table 2. Design Matrix. This table compares the designs mentioned above.

Description of the Best Design Selected

After taking into account travel time, emissions produced, cost of operations, upgrade cost, capacity, and return on investment upgrading to natural gas and diesel mixture (80% natural gas and 20% diesel) locomotives proved to be the best option. This design involves upgrading the existing locomotive fleet so that the locomotives are able to run on LNG (liquid natural gas) as well as diesel. In order for this to work a natural gas filling station must be added. This station will include a compressor to change the gas from gas to liquid. The gas will then be pumped into the trains, transferred to storage, or sold from here.

Assumptions and Calculations

Customer is the city we are implementing the change in
500 miles per train per day
Price of diesel: $3.06/gal
Savings for LNG is 50% of diesel cost
Trains do not leave empty
165,000 tons of freight per day
175,531 gallons of diesel for the entire fleet per day
Excess LNG can be sold to city for a profit
Fleet of 50 trains

Prototype/Model

Relative Design Drawings/System Diagram

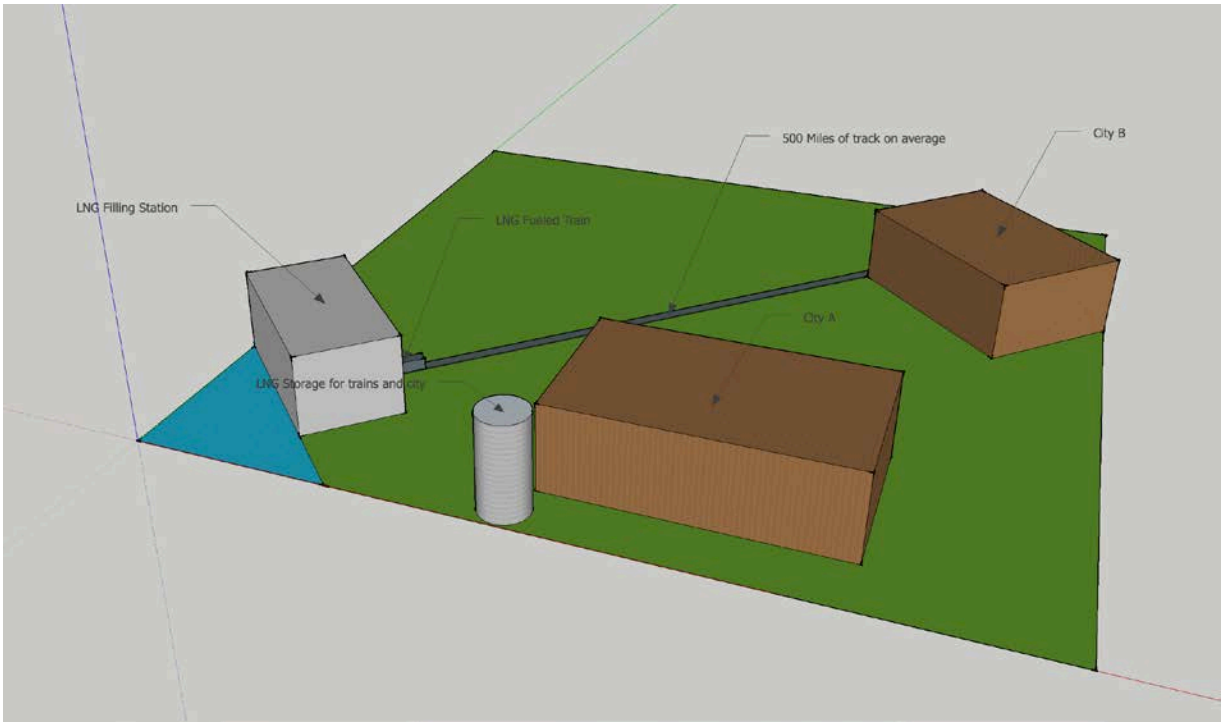


FIG 1. This figure is the CAD design drawing that represents the system.

Prototype Scale

Distance between cities are representative of the average distance but is not to scale and the sizes of the machines and trains are relative.

Digital Image of Prototype

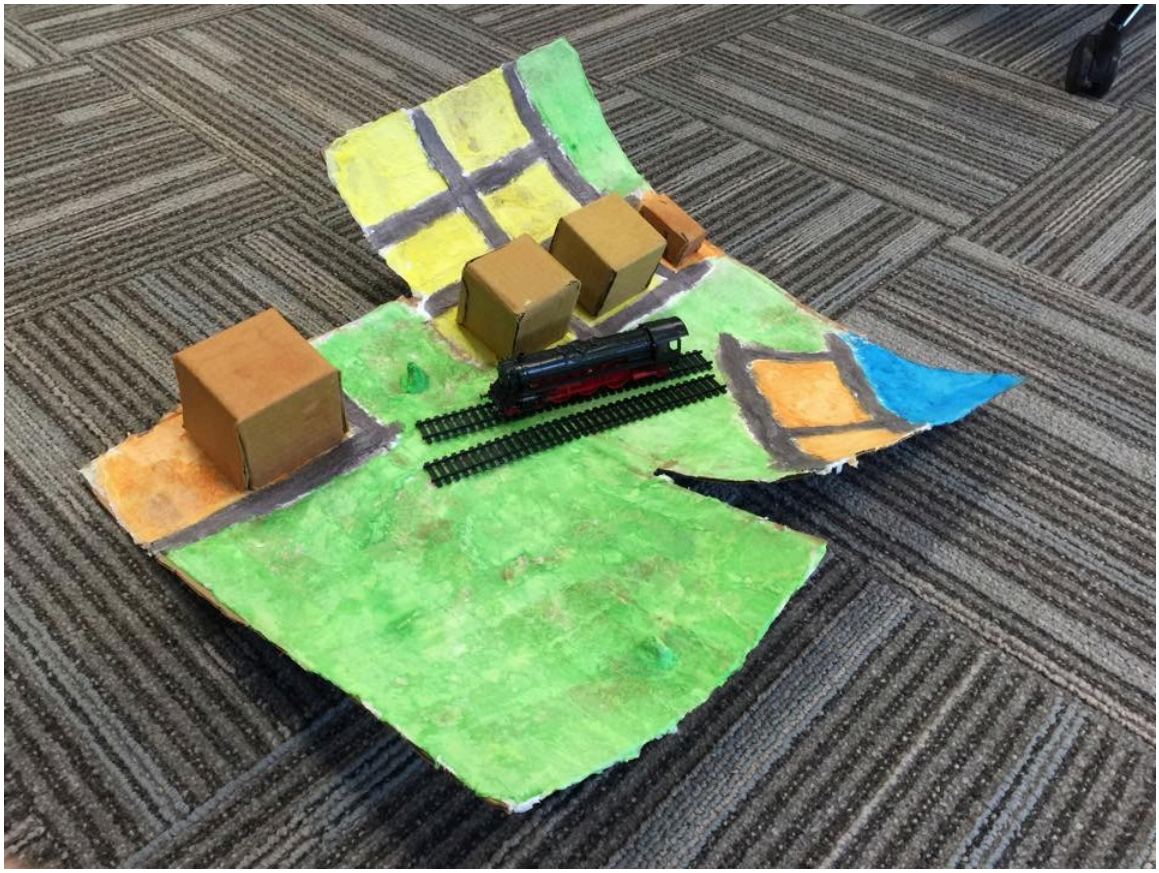


FIG 2. Prototype

Design Features

Since the main fuel source will be the liquefied natural gas so building a liquefaction planet next to the old train fuelling station will be the easiest approach to save the money. And each part of the facility will be separated due to the safety thought. After the cargo comes through the sea is loaded to the train, the train will be fueled by 20% of diesel and 80% of natural gas, which will be enough for the train across the 500 miles between two cities.

Analysis

Rationale for the Selection

The switch to natural gas will allow for a large reduction in the emissions produced by the locomotives. The biggest advantage of the switch to natural gas is the potential for the return on investment. With the other options there will be no money saved or extra money made since they are just simple upgrades to the existing fleet. With natural gas the fuel will be cheaper so a large amount of money will be saved by using that as fuel and will eventually exceed the difference in costs. The facility in the plan is also large enough to produce excess natural gas that could be used to expand the shipping potential or to sell to the city for a profit.

Concept of Operations

Goals and Objectives:

The goal of this system is to update the current tier 2 locomotives to reduce amount of emissions produced. In the process of doing this cost and efficiency were also taken into account. The upgrade will take place in the form of converting the engine from diesel to a diesel and natural gas mix (80% natural gas and 20% diesel). This process will also require a natural gas station to fuel the locomotive. The natural gas station must be capable of compressing the natural gas from gas to liquid form. The gas station must be able to compress and distribute 175, 531 gallons of fuel a day. By changing from diesel to a natural gas and diesel mixture, the locomotives will reduce emissions and reduce price of fuel by as much as 50 percent. Excess natural gas can be sold as well for extra profit.

Constraints:

The main constraint that will come with upgrading the locomotives is land and environment. The natural gas filling station that is needed in order to fill the locomotives will take up a significant amount of land. The tracks that are already in place for the tier 2 locomotives should be sufficient for the new locomotives and therefore will not take up more land. Overall the increase in land needed for the natural gas locomotives should not affect the environment at any level of concern.

Responsibilities and Authorities:

The customer, who is the city, must be able to operate the trains and also operate the fueling station. The existing crew from the tier 2 locomotives will not need to be replaced since their job will remain relatively the same. However, the city must hire employees who are capable of running the natural gas station. This crew includes people capable of running the machinery that compresses the natural gas, and also those who actually fuel the trains.

Operational Processes:

In order to change from diesel to a mixture, several processes must occur. First, the trains must be retrofitted to allow it to be fueled by natural gas as well as diesel. Meaning new locomotives do not need to be purchased, but the current ones must be upgraded. The city must also build a new fueling station that compresses natural gas and fuels the trains. Extra natural gas storage facilities may also need to be built for backup fuel reserves. New workers must be hired in order to operate the new fueling station. Finally, a steady source of natural gas must be established.

Maintenance:

The city will be in charge of constant maintenance. The maintenance on the locomotives should remain approximately constant through the change from tier 2. The change in maintenance will come from the new fueling station that must have constant maintenance considering the high flammability of natural gas. It will require more maintenance than the average diesel fueling station because of the more complicated processes that are happening such as the compression as well. Overall, more maintenance will be required and the cost of maintenance should increase a significant amount. However, the lower price of natural gas compared to diesel should counteract the increased price of maintenance.

Life Cycle Analysis

Natural gas is obtained from a well, and then it is liquefied in a facility. The acquired LNG goes through regasification after it is shipped to one of the five export markets. Finally, it is "transported to a local power plant for gas-fired electric generation" (Pace Global, 2015).

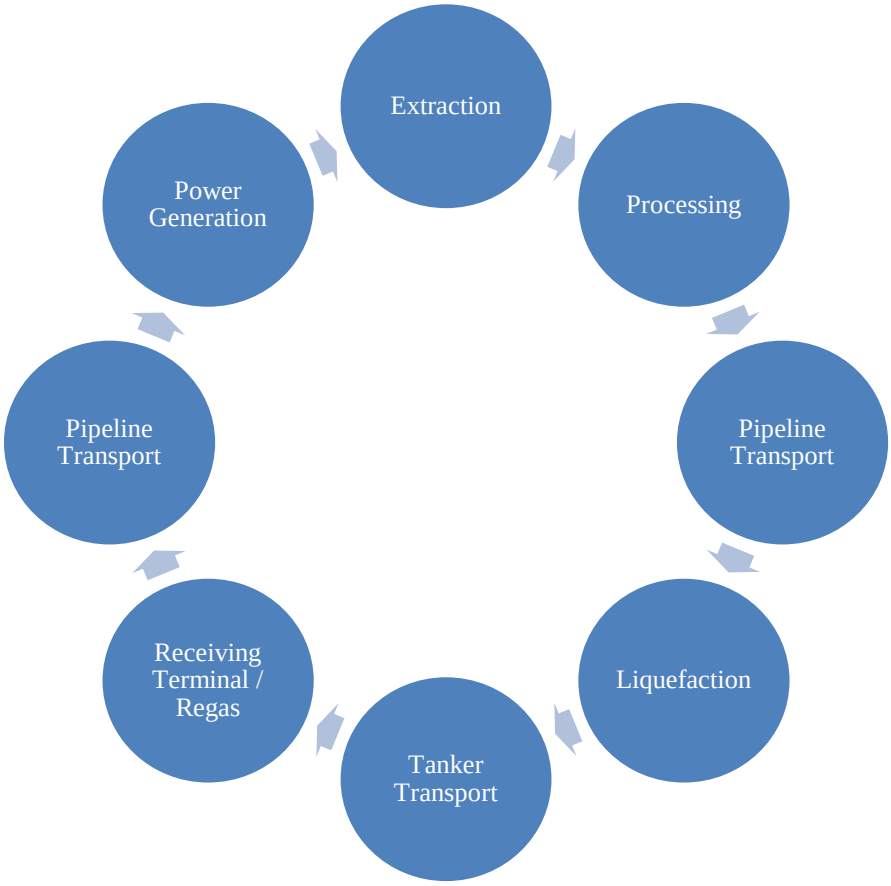


FIG. 3 Diagram of Life Cycle Analysis. Source: Pace Global.

Assessment of Important Aspects

One of the biggest changes with the switch to liquefied natural gas is the need for a plant that can liquefy natural gas. This plan includes a plant large enough that there will be an excess of liquefied natural gas, which will allow for expansion and can be sold to the city for a profit. This will allow the city to have a source of nearby liquefied natural gas if they chose to switch their public transportation to that. Also, The standard fuel capacity of the current diesel engines will not be big enough so each train will need to

have a tank car to store the liquefied natural gas. However, this will allow the train to have a much greater range and require fewer stops for fueling.

Economic Viability of the System

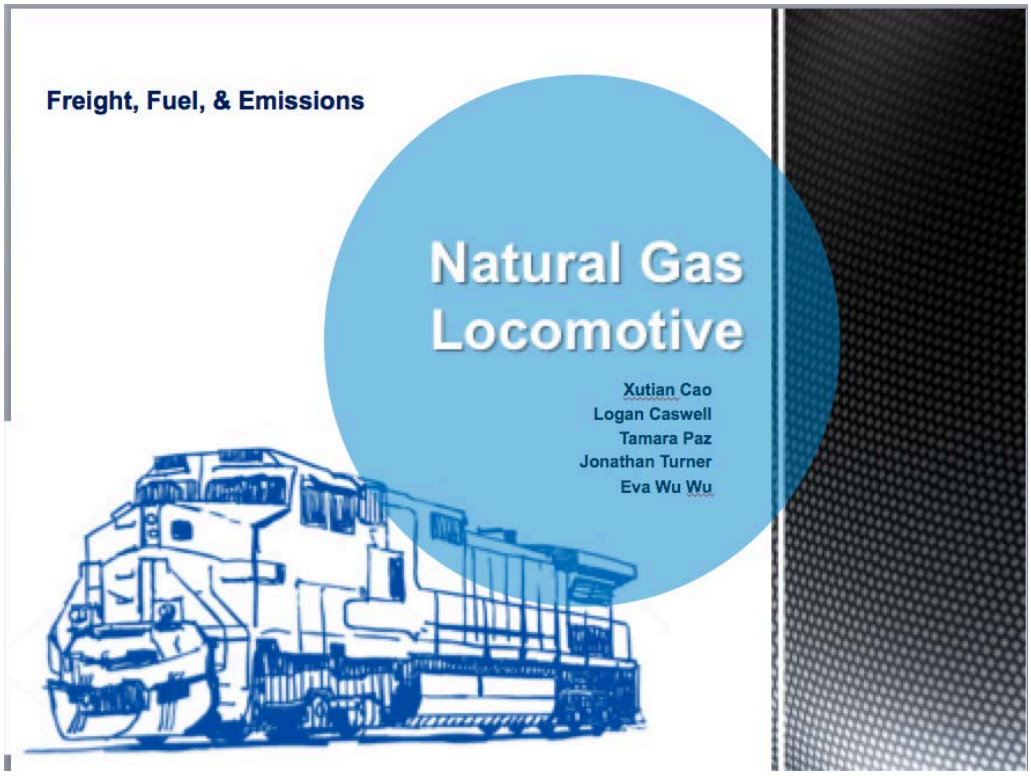
The original startup cost for the liquefied natural gas plant is much higher than other options but the money will eventually pay off. Natural gas is far cheaper than diesel and in just 10 years the savings will have paid for the difference in cost of the alternatives. With the natural gas plant so close to the city any excess can be sold to the city for a profit for the company. The city can use this natural gas to further reduce emissions in the city by switch public transportation to liquefied natural gas as well.

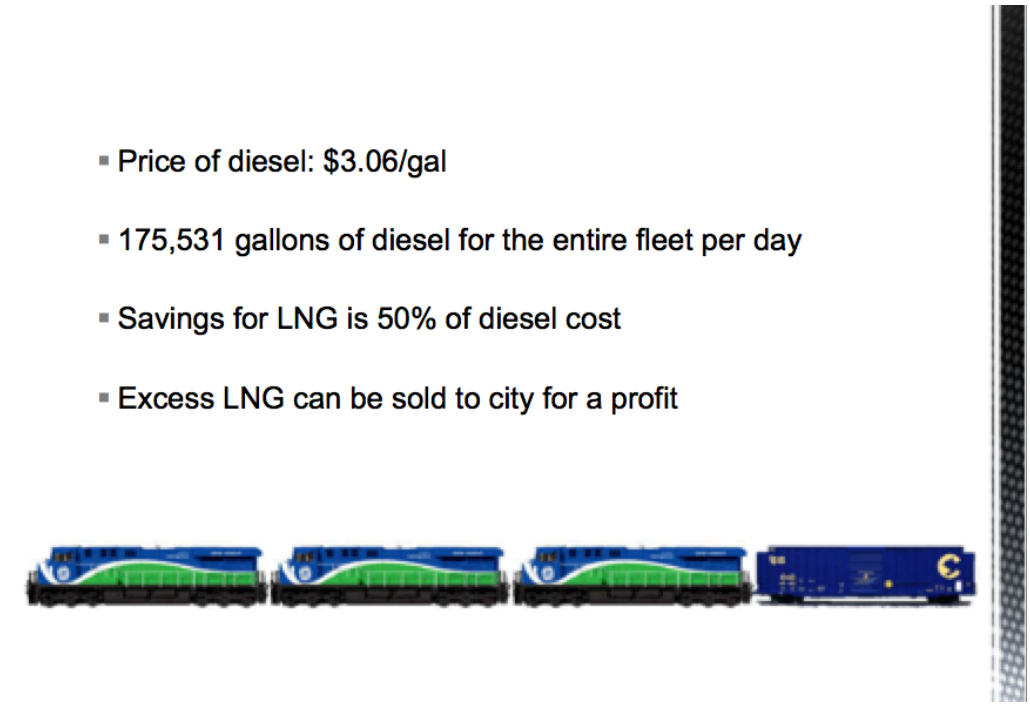
Summary and Conclusions

The main purpose for the team was to find a system that would reduce emissions in the future, while reducing losses in cost. With the change from diesel to natural gas, it will take about ten years to recover from losses. In the long run, this is better because even though it has a huge amount of investment, the money will be recuperated while reducing emissions significantly. Liquefied natural gas does not pollute as much as diesel does. Using liquefied natural gas will provide the city with a nearby source of LNG, significant pollution reduction, large savings on fuel, and will easily meet new regulations from the future.

While working on this project, the team learned how engines worked, the regulations set for pollution in society, and how a team of engineers would work when solving a real life problem like this one. Moreover, the team can conclude that this project was very helpful in introducing how engineers solve problems in a cost efficient way for companies.

Powerpoint Presentations





The customer: the city

We are implementing the change in

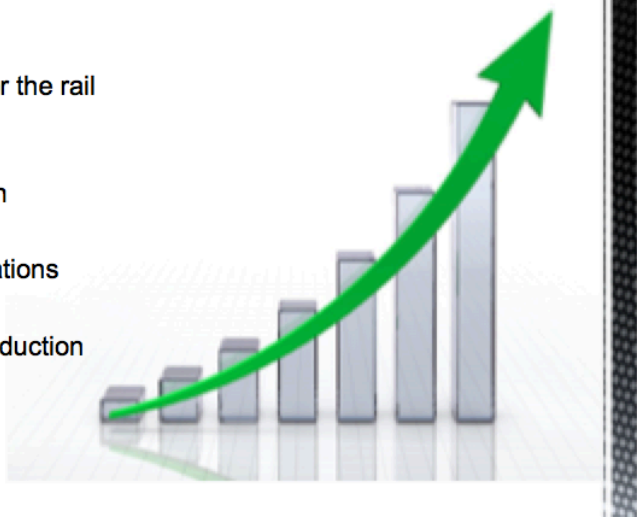
- 500 miles per train per day
- Fleet of 50 trains
- 165,000 tons of freight per day
- Trains do not leave empty

Alternate fuel (LNG)

- **Net cost to upgrade:** $1,050,000,000
- **Cost of fuel per year:** $98,025,287
- **Potential of profit?** Yes
- **Timeframe for money recuperation:**
  - 10.2 years(neglecting profit from LNG sales)

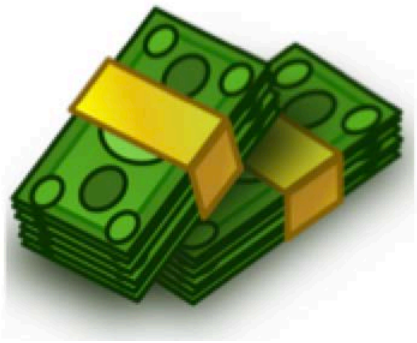
PROS

- Provides city with a nearby source of LNG
- Provides a source of profit for the rail company
- Significant pollution reduction
- Will easily meet future regulations
- Large reserves and local production ensure steady prices



CONS

- Extremely high initial investment
- Not brand new locomotive



	Upgrade trains to Tier 4	Use aftertreatment to reach Tier 4	Alternative fuel (LNG)
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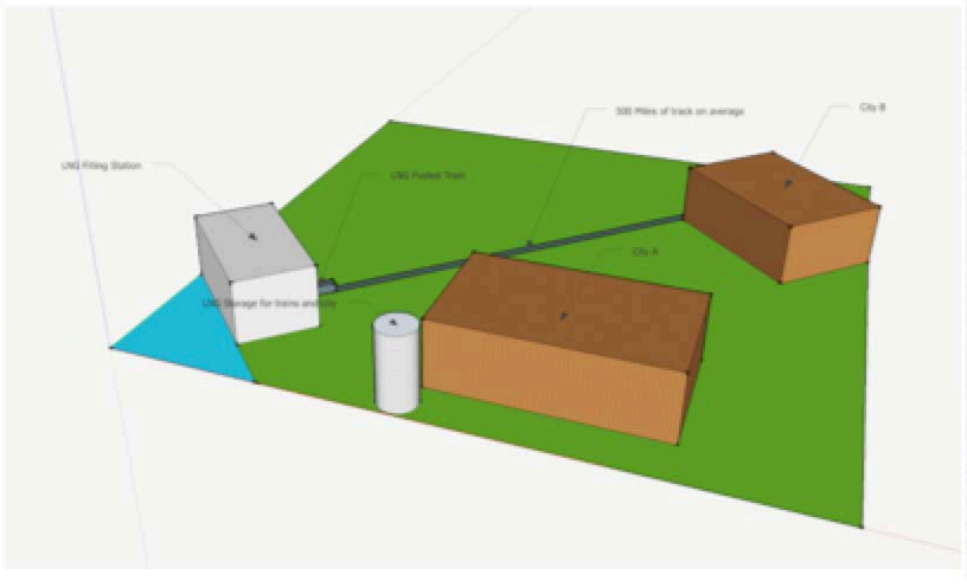
Cost of fuel per year	$196,050,573	$196,050,573	$98,025,287
Potential for profit	No	No	Yes
Timeframe for money recuperation	N/A	N/A	10.2 years(neglecting profit from LNG sales)
Pros:	Brand new locomotives	Cheapest initial investment	Provides city with a nearby source of LNG
	No new infrastructure	-	Provides a source of profit for the rail company
	Easy to meet future regulation changes	-	Significant pollution reduction
	-	-	Will easily meet future regulations
	-	-	Large reserves and local production ensure steady prices
	-	-	Large savings on fuel
Cons:	Large fuel cost	Large fuel cost	Extremely high initial investment
	Fuel cost subject to increases	Fuel cost subject to increases	Not brand new locomotive
	More foreign dependency for fuel	More foreign dependency for fuel	-
	-	Not brand new locomotive	-
	-	Will be harder to reach future regulations	-

Design Matrix Selection

	Concepts				
Selection Criteria	A (current system)	B (Upgrade trains to Tier 4)	C (Use aftertreatment)	**D (Alternate Fuel (LNG))**	E (trucks)
Cost of initial investment	0	0	+	-	-
Cost of fuel per year	0	-	-	+	-
Potential for profit	0	-	-	+	-
Timeframe for money recuperation	0	0	0	+	-
Easy to meet future regulations	0	+	-	+	+
Fuel cost subject to increases	0	0	0	+	0
Sum +'s	0	1	1	**5**	1
Sum 0's	6	3	2	**0**	1
Sum -'s	0	2	3	**1**	4
Net score	0	-1	-2	**4**	-3
Rank	2	3	4	**1**	5
Continue?	no	no	no	**yes**	no

CAD design drawing



NATURAL GAS LOCOMOTIVE

- Does not reduce efficiency and capacity

- Although more expensive at first,
  - Capacity to generate profits
  - Reduced amount of pollution
  - Ability to recuperate the money invested in the long run

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