Ge Pittsadelphia Proposal

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Executive Summary

The problem given to us by GE was to come up with a cost effective freight shipping system that both reduces smog and meets EPA requirements. The system was expected to maintain or improve upon the current freight capacity into and out of the city of Pittsadelphia. We generated twelve concepts after researching methods of freight transportation. Each concept reflects, to some degree, the customer’s needs, which include smog reduction, fast travel time, and cost efficient. Using the concept selection method, we weighed each option on criteria we determined to be essential to the solution. The heaviest criteria were smog reduction, price, and fuel efficiency. From there, we determined our best option was using diesel locomotives adding a before treatment method that involves greatly reducing the nitrogen in the air resulting in an aftertreatment method that burns more efficiently. These methods directly affect the combustion of fuel in the engine of the locomotives, thereby producing less smog to begin with.

Introduction

GE has given us the task of inventing a method to solve Pittsadelphia’s current pollution problem. The city’s current method of freight transportation produces too much NOx and PM emissions and that takes a toll on the citizens health as well as the environmental conditions in and around Pittsadelphia. To fix this problem, a solution must be able to effectively reduce the amount of NOx and PM produced by freight transportation. The method must also be able to keep up with the freight capacity of the current locomotives, or improve it. Designs must also be cost efficient in order to maintain the good economic conditions of Pittsadelphia. Lastly, the solutions must be visually appealing, meet the current space constraints of the city and must be
able to transport freight within a reasonable amount of time. All of these factors will contribute to increasing the happiness of the residents of Pittsadelphia and meeting the customer’s needs.

**Problem Statement**

NOx gases are formed whenever combustion occurs in the presence of nitrogen, and so they are responsible for a large amount of air pollution for producing Smog and even acid rain. Currently in Pittsadelphia, Smog is one of the main complaints of the city residents because the large movement of locomotives near or into the city produces high levels of air pollution and PM, which is the term used for a mixture of solid particles and liquid droplets found in the air. They are too small to be seen by the naked eye yet dramatically affect human health by entering the respiratory system and cause the lungs and heart complications. The burning of fossil fuels used to power locomotive engines is the main source of air pollution in Pittsadelphia, because approx. 165,000 tons of freight and minerals are driven into the city daily and so the amount of power locomotors need is too large to please environmentally-friendly standards.

This project will involve systematically looking into all solutions to the problem that we can envision as reasonable options. To do so, we will use concept generation to evaluate the different options that we come with. This will allow us to weigh our options on essential criteria that we feel are absolutely necessary to include in our final design. Once we rate each of the options based on this criteria, we will be able to easily conclude which solutions would be the most capable of meeting the needs of our customer. Our team will have narrowed our choices down to a few potential solutions. From there, we will heavily research these options and how each will affect Pittsadelphia’s overall pollution, the health of its citizens, and the freight transportation of the city.

**Research**

The research we obtained for this project gave us a variety of information about different types of locomotives, alternate sources of fuel and other methods of transportation. Our research also gave us some broad information about NOx and PM emissions.

**The Before Treatment**

Some of the benefits we found through our research:

The concentration of oxygen can be varied - At times when the trains need more power, the conductor could use more oxygen than normal to generate more power.

Lower NOx - taking out Nitrogen in the air intake leads to a direct reduction of nox
High engine temperature - Noxs form due to high temperature combustions. Since there a significantly less amount of nitrogen, the fuel can be combusted at hotter temperatures.

Less PM and more horsepower - With the hotter combustion temperatures, the engine will burn more of the fuel and produce less PM

Commercial products are already available

Some pre-existing companies with years of research and experience offer custom parts

Some negatives

The filter require space. More space than most add on treatments

requires a third party contract

What is this device?
The device is a bigger and more commercial version of a oxygen concentration. The system use a mechanical process rather and chemical one. A chemical process of would result is the highest concentration possible( 99% - 100%) but it would require expensive materials and it is also slow. This mechanical process is called Pressure Swing Absorption, which use materials to filter out the nitrogen. This process can create 88% -93% concentration of oxygen. With different variations of PSA( Pressure Swing Absorption) technology, the concentration can go up to as much a 99%.

This graph shows how efficient the the generator are. The bigger the machine gets the more constant the oxygen purity will be.
There are two variations that are used in the process of purifying the air. One is Double Stage and the other Rapid PSA. The Double is stage, stage repeats the purifying process twice. This increases the oxygen purity. Like the name implies, the Rapid PSA make high purity oxygen very quickly. They have two tanks that work to give continuous flow.
For this project.
We will be implementing a widely common technology, double tank production (Rapid PSA). This will allow a continuous flow of oxygen. While one tank is absorbing oxygen the other will be releasing the oxygen absorbed on the previous cycle. We would hire a third party, since it’s cheaper than buying two prefabricated parts, to create custom parts that give almost 100% oxygen flow to the engine.
We would require the company to design the part to fit in the width and height of a shipping freight, since they are universal and fit on trains. Part can be fitted on the back of the engine with trailers, which the rail company already has.

Some of the commercially available products:
A small commercially available oxygen generator

**Fuel research**

<table>
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<tr>
<th>Fuel type</th>
<th>Cost</th>
<th>Energy</th>
<th>External cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>$3.00 per gallon</td>
<td>128,288 BTU</td>
<td>Very low</td>
</tr>
<tr>
<td>LNG</td>
<td>$0.40 per gallon</td>
<td>82,644 BTU</td>
<td>Very High</td>
</tr>
<tr>
<td>CNG</td>
<td>$0.01 per gallon</td>
<td>121 BTU</td>
<td>Very High</td>
</tr>
</tbody>
</table>

The cost of LNG and CNG is so much cheaper per gallon than Diesel, but they don’t have the same concentration of energy. LNG and CNG will require more refueling during the trip or a big tank to hold more. There is an inherent problem with that. The Company will have to invest in more fueling station and new infrastructure, causing a huge financial burden on the company. The diesel external are low because they had many year to perfect it. They have suppliers and infrastructure already in place. Sticking to the diesel for the now is the most cost efficient.

**Combustion**

When our guest speaker came in to talk to us about combustion, we learned that there are many ways to decrease the reduce NOx.
We learned that one the way to reduce nox and soot is to play around with the combustion temperature. Since we decrease the amount of Nitrogen entering into the engine with the pre treatment. We can burn at hotter temperatures and reduce the amount of PM. I would recommend burning at the point indicated below.

We also learned that increasing the combustion temperature increases power. With hotter temperatures in the engine, the fuel is much efficiently burned to produce more more. Since Nitrogen is out of the equation, we don’t have to worry about burning to hot.

**Silencing**

Some of the citizens are complaining that the trains are keeping them awake. The company need a solution so the citizens can sleep and have a good impression on the company. We created a solution that doesn’t involve in extra costs. We would only run the trains during the day. If the company had to run it during the night, then they would coast the train. They will reduce speed, so the engine and the tracks will produce less sound.

<table>
<thead>
<tr>
<th>Start normal routine</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
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<td></td>
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<td>7:30 A.M</td>
<td>7:30 A.M</td>
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<td>7:30 A.M</td>
<td>10 A.M</td>
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<tr>
<td>Stop</td>
<td>9:00 P.M</td>
<td>9:00 P.M</td>
<td>9:00 P.M</td>
<td>9:00 P.M</td>
<td>12 P.M</td>
<td>12 P.M</td>
<td>9 P.M</td>
</tr>
</tbody>
</table>
After our presentation in class, there were concerns about safety. Storing high concentration of oxygen that is pressurized is dangerous. A leak and spark is all you need to make things explode. We aren’t storing the oxygen in tanks. The generators produce to meet demand. If the engine is shut off then the generator will stop producing too. Even if there were leaks, we have generator away from the engine and fuel. The chance of a disaster happening is very low.

REFS:
the GE slide
https://en.wikipedia.org/wiki/Pressure_swing_adsorption
http://patentimages.storage.googleapis.com/pages/US5395427-1.png

Calculations:

Facts:

1. 15 freight trains with 2 locomotives each and 5 coal trains with 3 locomotives equaling 45 per day.
2. 50 Locomotive engines in fleet but 45 are used everyday
3. Tier 2 fuel efficiency: 470 miles with one gallon of diesel to move one ton
4. Tier 2 standard horsepower: 4500 hp
5. Tier 2 emission: Particulate matter (P.M) = 0.2 g/hp-hr and Nox = 5.5 g/hp-hr
6. 500 miles of track to the city, so 1000 miles for a all around trip
7. Average speed is 50 miles per hour so one way is 10 hours
8. Freight leave the city with 5,000 tons per train
9. Diesel - $2.50 per gallon
10. total tons to the city is 165,000 tons
11. Coal trains go the to city with 12,000 tons and come back with 1,000 tons

Baseline (current setup)

Coal trains
To the city: 12,000 tons to the city
12,000 tons * 1 gallons / (1 ton * 470 miles) = 12,000 gallons of diesel / 470 miles
12,000 gallons / 470 miles = x gallons / 500 miles
x gallons = 12,766 gallons for 500 trip
Price of trip = 12,766 gallons of diesel * $2.50/per gallon of diesel
Price = $31,915

Exiting the City: 1,000 tons
1,000 tons * 1 gallons / (1 ton * 470 miles) = 1,000 gallons of diesel / 470 miles
1,000 gallons / 470 miles = x gallons / 500 miles
x gallons = 1,064 gallons for 500 trip
Price of trip = 1,064 gallons of diesel * $2.50/per gallon of diesel
Price = $2,660

Total price of one coal train making a round trip:
$31,915 + $2,660 = $34,575

Total price of 5 coal trains making a round trip in a day:
$34,575 per coal train for one round trip * 5 coal train * one trip per day
Total price = $172,875 per day

Freight trains
To the city: need to find the tons going into the city
165,000 total tons into the city – 12 tons per coal train * 5 coal trains
= 105,000 tons left for freight trains
105,000 tons / 15 freight trains = 7,000 tons per freight train

7,000 tons * 1 gallons / (1 ton * 470 miles) = 7,000 gallons of diesel / 470 miles
7,000 gallons / 470 miles = x gallons / 500 miles
x gallons = 7,447 gallons for 500 trip
Price of trip = 7,447 gallons of diesel * $2.50/per gallon of diesel
Price = $18,618

Exiting the city: 5,000 tons
5,000 tons * 1 gallons / (1 ton * 470 miles) = 5,000 gallons of diesel / 470 miles
5,000 gallons / 470 miles = x gallons / 500 miles
\[
x \text{gallons} = 5,319 \text{ gallons for 500 trip} \\
Price \text{ of trip} = 5,319 \text{ gallons of diesel} \times 2.50/\text{per gallon of diesel} \\
Price = 13,298 \\
\]
Total price of one coal train making a round trip: 
\[
18,618 + 13,298 = 31,916 \\
\]
Total price of 15 freight trains making one round trip: 
\[
31,916 \times 15 = 478,740 \text{ per day} \\
\]
Total cost of operation per day: 
\[
172,875 + 478,740 = 651,615 \text{ cost per day} \\
\]
Emissions: 
\[
\text{Particulate matter: } 0.2 \text{ g/hp-hr} \\
0.2 \text{ g/hp-hr} \times 4500 \text{ hp} \times 20 \text{ hr trip} = 18 \text{ kg of per loco per round trip} \\
18 \text{ kg} \times 45 \text{ trains in use per day} = 810 \text{ kg per 45 trains per day} \\
\text{Nox: } 5.5 \text{ g/hp-hr} \\
5.5 \text{ g/hp-hr} \times 4500 \text{ hp} \times 20 \text{ hr trip} = 495 \text{ kg per loco per round trip} \\
495 \text{ kg} \times 45 \text{ trains in use per day} = 22,275 \text{ kg per 45 loco per day} \\
\]
Case one: if we can give the engine air with 50\% reduced nitrogen content 
\[
\text{Operation cost per day still the same: } 651,615 \text{ cost per day} \\
\text{Emission:} \\
\text{PM is still the same: } 810 \text{ kg per 45 trains per day} \\
\text{Nox: } 2.75 \text{ g/hp-hr} \\
2.75 \text{ g/hp-hr} \times 4500 \text{ hp} \times 20 \text{ hr trip} = 247.5 \text{ kg per loco per round trip} \\
247.5 \text{ kg} \times 45 \text{ trains in use per day} = 11,137.5 \text{ kg per 45 loco per day} \\
\]
Case one: if we can give the engine air with 100\% reduced nitrogen content 
\[
\text{Operation cost per day still the same: } 651,615 \text{ cost per day} \\
\text{Emission:} \\
\text{PM is still the same: } 810 \text{ kg per 45 trains per day} \\
\text{Nox: } 0 \text{ g/hp-hr} \\
0 \text{ kg of PM} \\
\]
To meet Tier 3 standards for Nox: We are already there 
To meet Tier 4 standards for Nox: Find the percent of nitrogen reduction 
\[
\text{Tier 4 Standard} = 1.3 \text{ g/hp-hr} \\
(5.5 \text{ g/hp-hr} - 1.3 \text{ g/hp-hr}) \times 5.5 \text{ g/hp-hr} \times 100 \\
= 76\% \text{ reduction of nitrogen content} \\
\]
The cost of upgrade for 50\% reduction of nitrogen: Commercially available 
\[
est. \text{ cost of one oxygen generator + installation} \\
= 100,000 + 10,000 = 110,000 \text{ per engine} \\
110,000 \text{ per train} \times 50 \text{ trains} = 5.5 \text{ million for whole fleet} \\
\]
The cost of upgrade for 100\% reduction of nitrogen: Custom parts or double 50\% reduction
double 50% reduction machine= 2 * 5.5 million for the whole fleet
= 11 million for the whole fleet

Custom parts: From American companies
No cost of research
Cost of third party contract est. =
$150,000 per 100% oxygen generator + $10,000 install
= $160,000 per engine
= $160,000 * 50 engines
= $8 million for whole fleet

Concept Generation

Instead of thinking of one solution as a group, our group decided to use concept generation as a method of brainstorming ideas. Each member came up with four feasible solutions that were all different, ranging from locomotives, to ships, to zeppelins. As a group, we aimed for our concepts to meet the most essential customer needs, which included, low NOx and PM emissions, high power efficiency, fast delivery and a generally low cost. After we individually researched the best methods, we each picked four potential solutions that we’d enter into our concept selection matrix. Descriptions for each of our ideas can be found below.

Valentina -

1. Change the current fuels used in trains for biodiesel fuel: "Fueling with biodiesel blends reduced particulate matter (PM), total hydrocarbons (THC), and carbon monoxide (CO), while increasing oxides of nitrogen (NOx). Retarded fuel injection timing reduced NOx emissions while maintaining the other emissions reductions."

2. Implement wind turbines and solar panels on cargo ships: Due to the amount of breeze at sea, wind turbines would serve as a sail propulsion system and save 60% of energy waste while solar panels would fill in for the energy gaps that there might be. Making
the ship have a hull form would optimize propulsion efficiency and adding fuel cell utilization (which would extract the hydrogen from the water) would reduce a large percentage of CO₂ while producing no greenhouse gases. In the rare case there might not be enough wind or sun to produce enough energy to propel the ship forward, there would be an emergency power system that would use LNG fuel to power the ship. As an extra power system, the skysail technology would also help propel the ship forward when needed. The ships would function from port to port and the distribution of goods would be made through battery-electric and hydrogen fuel-cell-electric vehicles (trucks). This solution would be expensive to introduce at the beginning but once all the systems are put in motion, the savings in fuel would be dramatic for the following years.

3. Solar-powered/battery-electric trains: “a train using solar power can reduce diesel consumption by up to 90,000 litres per year and also bring down the carbon dioxide emission by over 200 tonnes.” so by slowly replacing the current amount of trains by solar-powered ones, we could run tests for the first year and see how much freight these trains could pull and what distances they could cover.

4. Fuel-cell powered trucks and airplanes: Fuel-cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. If implemented on a cargo aircraft for half of the amount of energy it requires, LNG fuels would complete the other half required and “save at least $100 billion in fuel over the next 50 years.”

Vig -

John -
1) A diesel engine train would be a possible solution to the problem at hand. Diesel engines are strong and durable and have been being used for a while. It is able to withstand greater stresses and strains than most other engines. However, diesel engines produce lots of pollution. In terms of NOx, diesel engines release 50-2,500 vppm (volumetric parts per million) and .1-.25 g/cm^3 in terms of pm emissions. In-cylinder, engine based design for the aftertreatment.

2) Gas-turbine electric powered locomotive. This would be a somewhat reasonable solution to our problem. These trains have few moving parts so they would require little maintenance and tend to have a high power output. Problems would be that the train would run on gasoline and oil prices are inconsistent and would be expensive for such a large scale operation. NOx emission data is not known at this time, but can be expected to be less than diesel emission.

3) Finding a fuel efficient freight truck would be another option. This would be used for somewhat short deliveries (300 miles or less.) Trucks would have a large storage capacity and would have a great power output. The problem would be gasoline fuel prices and finding something that is hybrid-like and fuel efficient.

4) The last option is the use of a super zeppelin to carry cargo. The super zeppelin is currently being designed by Aeroscraft and is a practical way to transport cargo. The giant zeppelin can carry up to 500 tons. It might not be as fast as other methods but is very efficient in terms of cargo capacity. Fuel emissions would not affect the city people directly because it is up in the sky.

Concept Selection

After we each had our four methods, we entered them into a concept selection matrix. The point of this matrix was to narrow down our options by weeding out the less effective solutions. We did so by creating criteria that reflected the customer needs and weighted that criteria based on which factors/features were most important to the design. Our conclusion was that we best solutions were Val 1, switching to biodiesel fuel; Vig 2, combination of a before and after treatment of a diesel engine; and John 4, the super zeppelin. We ultimately decided to go with Vig 2 because of its originality, high rating, and because he was so excited about it.

<table>
<thead>
<tr>
<th>Category</th>
<th>Wt.</th>
<th>Val 1</th>
<th>Val 2</th>
<th>Val 3</th>
<th>Val 4</th>
<th>Vig 1</th>
<th>Vig 2</th>
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<td>John 3</td>
<td>John 4</td>
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**Final Description:**

The before treatment was meant to take nitrogen out of the air. Since nitrogen causes the noxs, we decide to decrease the amount of Nitrogen we supply the engine. Though a 90% - 100% oxygen concentration is ideal for reducing Nox to almost Zero, commercially available seem to have a limit on how much they can produce quickly. As solution, we must mix in normal air with the high concentration of oxygen. Another more attractive option is Custom parts. There are companies that make custom parts to meet demands. This would we the best option because we increase our capacity to make more oxygen quickly and create a part that fits on the train.

The power input and cost will be outweighed by the high efficiency and the reduction of nox. The filters will use a fraction, if not negligible, of the power produced by the diesel electric motor and in turn be able to make more power and reduce nox. Using a turbocharger, running off exhaust gases, will give the filter the necessary pressure to work. Then using on board electrical system to power the filters onboard computer and pressure would solve our power input and decrease our cost.

**Systems diagram:**
Environmental analysis:

Before we implemented our solution, the system of locomotives used was the standard tier 2 diesel engine locomotives. This system caused the city of Pittsadelphia to become heavily polluted, leading to health problems of the citizens. The old locomotive system released from .2-.45 g/hp-hr of PM and 6-7 g/hp-hr of NOx. With the implementation of our before and after treatment, these emissions will be reduced to about 1.3 g/hp-hr of NOx (0 g/hp-hr if we could reach 100% oxygen content) and less than .03 g/hp-hr of PM.

Feasibility study:

The additional modifications done on the trains will have a generally positive opinion from the citizens of Pittsadelphia. Train noise will be reduced by $\frac{1}{5}$ of what the health regulations require, reducing the amount of stressed and hyperintense citizens. Additionally, the amount of pollution in and around of the city will be dramatically reduced. This will have a positive impact on the citizens who will have less health issues due to the pollution. The city of Pittsadelphia will be clean and bright once again, and with time, more innovations will be added to our systems to help improve the quality of the city ever more.

Conclusion:

This project was about learning how to envision and materialize our ideas as engineers. The ability to do so is beyond important because our job is to solve problems in an innovative and effective manner. As future engineers, we learned how to work properly and effectively as a team by clearly defining our roles and responsibilities. We were able to work on completing a list of concepts that eventually led us to formulating a proper and useful solution.

The goal of this project was to meet EPA requirements and reduce the amount of NOx produced while shipping freight into the city of Pittsadelphia. Our research of the possible options led us to conclude that the application of a before-treatment (where Nitrogen is taken out of the air to pollute less) would be the most effective solution for this issue. Once the
double tanks are inserted on a determined amount of trains, the amount of pollution produced will be reduced by half as the trains retake their usual routine. We can use the same types of fuel for the trains, such as diesel and biodiesel because we aren’t changing engines, and saving a lot. Once LNG fuel is further developed and more commonly used, we think the implementation of it on the trains would further reduce the amount of pollution the trains produce. We are hesitant to do this immediately because LNG technology is still new and fuel costs could be expensive. Once this changes, and LNG becomes commonly used, or at least more marketable, we would make the switch. Our before and after treatment would make LNG an even more effective alternate fuel source. Overall, our solution will have lasting, positive effects on the environment in and around Pittsadelphia.

Additional references:

http://www.atlascopco.com/nitrogenus/products/oxygen_generators/
https://erengineering.wordpress.com/2013/01/02/engineers-without-borders-reflections-on-the-2012-northeast-conference/