GE Design Project

Group Name: Outside Philly

Group Members:
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Executive summary:
The city of Pittsadelphia’s is trying to reduce locomotives’ NO\textsubscript{x} and PM emissions. The current level of emission does not meet the EPA standards. Outside of Philly Incorporated’s goal is to develop an idea to reduce emissions while still being cost efficient, and energy efficient. The team developed several target specifications and customer needs. Then, the team took these requirements and each team member came up with concept based on their research. After, the team combined these ideas and came up with a final selection. The final conclusion was to use liquified natural gas (LNG) to reduce NO\textsubscript{x} and PM emissions in Pittsadelphia.

Introduction:
About 165,000 tons of freight is traveling in and out of Pittsadelphia. The engine on the locomotives emit PM and NO\textsubscript{x} emissions which do not meet the EPA requirements. Currently, the locomotives that the city of Pittsadelphia uses are tier II locomotives. GE’s goals to solve this problem in Pittsadelphia is to either maintain or upgrade current locomotives. Our goal is to try to upgrade these locomotives or buy new locomotives, which are finacially efficient, environmentally efficient, that uses mainly tier three or tier four locomotives.

Research:
Our research consisted of comparing the different types of fuels that could be used, the price of those fuels in the long term, breaking down a locomotive into its parts, breaking down the drives towards using locomotives, and the details of aftertreatment for each type of locomotive.

First we compared fuel sources. We compared gasoline, diesel, LNG, CNG, Biodiesel, and Low S diesel locomotives. Biodiesel is manufactured from new and used vegetable oils and animal fats. It is safe, biodegradable, and reduces air pollutants but increases the amount of NO\textsubscript{x} emissions. Biodiesel can be used in pure form but will require certain engine modifications to avoid problems. LNG is a compressed natural gas that is cooled to -260 degrees fahrenheit. CNG consists mainly of methane and is drawn from wells and from crude oil production. Both natural gases will require modifications to infrastructure and maintenance facilities. LNG and CNG are currently used for tractors, forklifts, and loaders. Low S Diesel has the lower the amount of sulfur, the lower amount of PM. Diesel contains harmful emissions and air toxics, which the EPA has tried to reduce in the last several years to improve health. They have lowered the sulfur levels to make this change.

The U.S. Energy Information Administration projects that LNG will be used more in the next 35 years for locomotives because of its low price compared to crude oil prices. The difference in price between LNG and diesel is supposed to result in $1 million in savings.

Communication/Electronics are located in the front of the engine and they serve as the main control for the entire locomotive. There are communication devices there for the engineers to communicate with maintenance on and off the train. The electric controls can have data downloaded to them via a laptop or other portable device. The engine is located right in the middle of the locomotive. It is the main power source that not only drives the locomotive but also powers the electricity generator. The cooling/radiator (the cooling system for a locomotive)
works just as it would for a car: water surrounds the engine, keeping it at optimum temperature, and is cooled by a fan powered by the engine. Controls/Power Management are also located at the front of the locomotive and they are generally to the left side of the engineer (in the US). They are the same as the electronics in that you can download information onto them. There are two different alternators, the main alternator and the auxiliary alternator. The main alternator is the machine that provides the power to move the train. It provides power in AC electricity which is then used by the traction motors to move the train. The auxiliary alternator is used for passenger trains to provide lighting, heating, air conditioning, etc. Traction Motors give the final drive that initiates the moving of the locomotive. There are typically anywhere between 4 and 6 motors on the locomotive at once.

Here are the drivers of locomotive technology in the order of most to least important:

1. **Performance**
   - must be able to accelerate and decelerate smoothly
   - horsepower must be strong enough to withstand heavy loads

2. **Regulatory (crashworthiness)**
   - also ties into performance: must be able to react timely in a dangerous situation while also taking into account the safety of workers on board and the load

3. **Customer Need**
   - locomotives with consumer demand are of high priority for production

4. **Cost**
   - consumer demand will increase if locomotives are both cost-effective and efficient

5. **Competition**
   - all of the above components will be compared to the company’s competitors in order to be considered the best model for the consumer

After treatment techniques are as follows:

1. **Diesel particulate filter**
   - This filter catches soot from the exhaust pipes
   - $10,000 to $20,000
   - size of filter depends on the type of filter

2. **Selective Catalytic Reduction (SCR) Catalyst**
   - Converts NO\textsubscript{X} to water vapor and nitrogen gas
   - 10,000 $/m\textsuperscript{3}$
   - 25 to 800 MW

3. **Decomposition Reaction Tube(DRT)**
   - urea is injected and the exhaust gas breaks the urea into ammonia particles

4. **Diesel oxidation catalyst(DOC)**
   - Platinum group metals catalyze the hydrocarbons to CO\textsubscript{2}

5. **Exhaust gas recirculation(EGR)**
   - cools the engine therefore decreasing the amount of NO\textsubscript{X}

**Calculations:**
We calculated the cost efficiency by finding the cost of fuel needed to move freight into and out of the city and adding it to the cost of fuel needed to move coal into and out of the city. We know that diesel costs $3.06 per gallon and liquid natural gas costs $2.09/gallon gas equivalent(GGE). By using 90% LNG and 10% diesel, we calculated that the cost of our
combination is $2.19 per GGE. To determine the cost of fuel to carry coal, we used the following calculation:

\[
\frac{12,000 \text{ tons into the city} + 1,000 \text{ tons out of the city}}{470 \text{ miles}} = \frac{(x \text{ gallons})}{(500 \text{ miles})} = \frac{13,830 \text{ gallons}}{(5 \text{ trains})} = $151,438.50
\]

To determine the cost of fuel to carry freight:

\[
\text{Tons of freight per train: } \frac{(165,000 - 5(12,000))/15 = 7,000 \text{ tons into the city}}{470 \text{ miles}} = \frac{(x \text{ gallons})}{(500 \text{ miles})} = \frac{12,766 \text{ gallons}}{(15 \text{ trains})} = $419,363.10
\]

**Table 1: Costs for LNG vs diesel**

<table>
<thead>
<tr>
<th></th>
<th>LNG/diesel combination</th>
<th>100% diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>$151,439</td>
<td>$537,128</td>
</tr>
<tr>
<td>Freight</td>
<td>$419,363</td>
<td>$260,426</td>
</tr>
<tr>
<td>Total</td>
<td>$570,802</td>
<td>$797,554</td>
</tr>
</tbody>
</table>

We also determined the energy efficiency of our fleet by calculating the fleet’s NOX and PM emissions. Since our locomotives are up to tier four standards, we used the tier four emissions criteria: 1.3 g NOx/(horsepower)(hour) and .03 g PM/(horsepower)(hour). We determined the NOx emissions through this equation:

\[
(1.3 \text{ g NOx/(horsepower)(hour)})(4500 \text{ horsepower})(20 \text{ hours}) = 117 \text{ kg NOx per day}
\]

We determined the PM emissions through this equation:

\[
(0.03 \text{ g NOx/(horsepower)(hour)})(4500 \text{ horsepower})(20 \text{ hours}) = 2.7 \text{ kg PM per day}
\]

**Table 2: NOx and PM emissions info**

<table>
<thead>
<tr>
<th></th>
<th>Tier 2</th>
<th>Tier 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>495 kg</td>
<td>117 kg</td>
</tr>
<tr>
<td>PM</td>
<td>18 kg</td>
<td>2.7 kg</td>
</tr>
</tbody>
</table>

**Customer Needs and target specifications:**

Before deciding on what type of transportation to implement or what characteristics our locomotives need, we examined our customer needs. We made statements based on what we
thought our customers would say about the transportation of their products. These can be seen in the table below.

**Table 3: Customer Needs:**

<table>
<thead>
<tr>
<th>Statements</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I want my products delivered on time.</td>
<td>Effective travel time</td>
</tr>
<tr>
<td>I want the cost of shipping to stay the same or be lower.</td>
<td>Cost Efficient</td>
</tr>
<tr>
<td>I want the same amount of product or more in each delivery.</td>
<td>Sizable</td>
</tr>
<tr>
<td>I want pollution kept to a minimum.</td>
<td>Energy Efficient</td>
</tr>
<tr>
<td>I want my item to not be broken in transport</td>
<td>Safe</td>
</tr>
<tr>
<td>I want the train to be quieter (if it runs through a neighborhood)</td>
<td>Noise-canceling</td>
</tr>
<tr>
<td>Need a lot of power to charge batteries</td>
<td>Power Output</td>
</tr>
</tbody>
</table>

After considering our customer needs, we formulated our target specifications for our locomotive. For each customer need, we came up with an idea that would satisfy their need and another idea that would exceed their expectations. They can be seen in the table below.
Table 4: Target Specifications:

<table>
<thead>
<tr>
<th>Need (daily basis)</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective travel time</td>
<td>Using same railroad tracks</td>
<td>Using quicker paths using more trains to transport</td>
</tr>
<tr>
<td>Cost Efficient</td>
<td>buying all tier 4 locomotives</td>
<td>buying half tier 4 and upgrading the other half to tier 3</td>
</tr>
<tr>
<td></td>
<td>50% diesel (@ $3.06/gallon) 50% LNG (@$2.09/GGE)</td>
<td>$2.09/GGE for LNG</td>
</tr>
<tr>
<td>Sizable</td>
<td>50’ standard box car</td>
<td>86’ box car</td>
</tr>
<tr>
<td>Energy Efficient</td>
<td>Tier 3 50% less PM 26% less NOx</td>
<td>Tier 4 70% less PM 76% less NOx</td>
</tr>
<tr>
<td>Safe</td>
<td>Reinforcement</td>
<td>Methane detectors; spillage prevention</td>
</tr>
<tr>
<td>Noise-canceling</td>
<td>Use same railroad tracks</td>
<td>Find a more secluded path, but one that is still roughly the same distance</td>
</tr>
<tr>
<td>Power Output</td>
<td>Production meets consumption</td>
<td>Production exceeds consumption</td>
</tr>
</tbody>
</table>

Concept Generation:

We each generated our own concepts based off of prior individual research, target specifications, and customer needs. After creating our own ideas, we all came together to present them to each other. We found that using LNG to power the locomotives was a common idea between all of us. Implementing solar panels was also discussed but we concluded that it would be too costly. Our final decision: we decided to use the common idea between our concepts and use LNG to fuel the locomotives. We would then conduct extensive research on LNG locomotives and become very familiar with them.

Here were our individual concepts:

Dora: I think that our team should upgrade some locomotives to about half LNG and half using solar power. Efficient use of after treatment for LNG will be
necessary to remove NOX and PM emissions. For the solar powered locomotives we should use some of the locomotives that we own and for the LNG we should buy new locomotives. We should try to make our locomotives to at least tier three or four standards. Pittsadelphia should be located close to Philadelphia so exporting or importing materials could be easier to move materials by a sea or air. Therefore Pittsadelphia would be the center of transportation. The city should be close to the Wyomissing PA which has an LNG production facility.

Amanda: I think we should use LNG to upgrade to Tier 4, reduce cost of energy, and decrease NOx and PM emissions. While after-treatment is not necessary for LNG locomotives, I think it would be advantageous to invest in SCR after-treatment to reduce the complexity of engine combustion and completely eliminate NOx emissions. We could potentially use trucks to transport materials within the state in order to save time and import more materials into Pittsadelphia than if we just used locomotives. Pittsadelphia should be located in the center of Pennsylvania so importing from (and exporting to) Pittsburgh and Philadelphia will be the same distance. Our natural gas should come from Washington county, PA because it contains the most amount of natural gas wells in Pennsylvania.

Chris: I think that upgrading locomotives to use LNG will reduce the cost of transportation and make locomotives more environmentally friendly. LNG will reduce NOx emissions and will completely eliminate them with aftertreatment, which I feel is necessary to invest in. The cost of getting all brand new locomotives would expensive and just upgrading them to tier 4 standards would be more cost efficient. I think that using locomotives is the most effective transportation in terms of cost and energy. Pittsadelphia is located in the middle of Pennsylvania, between Pittsburgh and Philadelphia. Our natural gas could come from Wyomissing, PA in Berks County.

Aaron: I believe the best approach is to upgrade existing locomotives to higher tier, more energy efficient locomotives. The cost to completely discontinue current locomotives and create brand new ones, in my opinion, would be far too great as opposed to just upgrading the current locomotives to be more energy efficient. I still believe that using locomotives will be more cost and time efficient than using other modes of transportation. LNG locomotives could be very beneficial to energy efficiency, and that would be what I would upgrade the current locomotives to. Pittsadelphia is located directly in between Pittsburgh and Philadelphia, in the middle of Pennsylvania. The natural gas for the LNG locomotive would come from Meshoppen, PA.

Concept Selection:
We used a concept selection matrix to decide which factors were the most important to us. To make the matrix, we used the criteria from target specifications and customer needs and rated them from 0-2, neutral to most important. All of the criteria were somewhat important so we decided to make the lowest rating possible a 0 instead of a negative integer, which would have stood for “not important”. In the end, we found that cost and energy efficiency were the most important to us.

Table 5: Concept Selection

<table>
<thead>
<tr>
<th></th>
<th>Amanda</th>
<th>Dora</th>
<th>Aaron</th>
<th>Chris</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Travel Time</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cost Efficient</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Sizable</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Energy Efficient</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Safe</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Noise-Canceling</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Power Output</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>24</td>
</tr>
</tbody>
</table>

Final description:

Our final decision was that we would use all LNG locomotives. We will minimize costs by purchasing half and upgrading half of the locomotives to tier 4 so they can be LNG. Also see concept selection for more details.
Environmental analysis:

By using liquid natural gas, the energy saved and the amount of smog emissions reduced allows tier three locomotives to be upgraded to tier four. Therefore, we calculated the NOx and particulate matter (PM) emissions based off of the tier four criteria. Tier four locomotives emit 1.3 grams of NOx per horsepower per hour, and .03 grams of PM per horsepower per hour. One tier two locomotives that only runs on diesel emits 495 kg of NOx and 18 kg of P. Our tier four fleet emits 117 kg of NOx per locomotive and 2.7 kg of PM per locomotive. By using liquid natural gas to run our fleet, we reduce NOx emissions by 76.4% and particulate matter emissions by 85%.

Economic viability:

One issue our team needed to discuss was the cost of running our fleet. We discussed selling all of our tier two locomotives and buying brand new tier four locomotives, but we decided that approach was too costly. We also considered upgrading all of our locomotives to tier three and allow the LNG addition to upgrade them to tier four, but we were concerned that the old locomotives would not be as durable as new ones. Therefore, we decided to sell half of our old tier two locomotives, buy 25 tier four locomotives, and upgrade the other half to tier four. This decision is more costly that simply upgrading every locomotive, but we decided that the extra durability was worth the money, especially because using LNG is expected to save us more money than using just diesel. Overall, the cost of this process is $101.25 million.

As for shipping methods, we only decided to use locomotives. Whereas planes and boats might be easier to transport larger amounts of freight at a faster time, Pittsburgh isn’t necessarily in a place where air and seas transportation are useful. In our scenario,
Pittsadelphia is in the middle of Pennsylvania so transportation by train or truck would be best, but we figured that trains could get freight to its destination much faster and in larger bulk than in trucks. As for fueling stations, LNG locomotives are already in use, so there are already some fueling stations for LNG. They might not be very common but they exist, like the one in Meshoppen, PA. This is and LNG fueling station that could be used for locomotives in the future.

Currently, there is only one other company that produces LNG locomotives other than GE: GM’s Electro-Motive Division (EMD)(Vantuono). GM uses a 60%/40% LNG/diesel combination with a 710 power plant, while GE uses a 80%/20% in conjunction with a GEVO power plant equipped with a NextFuel™ Natural Gas Retrofit Kit (Vantuono). Although GE already surpasses GM by using a LNG/diesel combination with a higher LNG composition, we want to push the boundaries one step further and develop a locomotive that runs on 90% LNG and 10% diesel. The cost of diesel is $3.09 per gallon, and liquid natural gas costs $2.09 per GGE. We calculated our LNG/diesel combination to cost $2.19/GGE. If we were to use only diesel as our source of energy, we would be spending $797,554 on energy per day. With the LNG/diesel combination, we would be spending $570,016. Therefore, substituting a majority of diesel fuel for liquid natural gas allows us to save $227,537 per day, or $11,377 per train per day.

Feasibility study:
Assess the important aspects of your system for feasibility and adoption. Include public opinion. This includes residents of Pittsadelphia, residents along your travel route and fueling station. Add any other considerations.

Currently, only GE and GM are the only companies producing LNG locomotives. However, based on its cheap price per GGE, low greenhouse gas emissions, and potential for economic savings, the U.S. Energy Information Administration predicts that the popularity of LNG locomotives to increase within the next 35 years. They also predict that companies that use LNG locomotives will save about $200,000 per year. Based on our calculations, this hypothesis seems to be true.

Conclusions:
As discussed earlier we came up with the final decision of using all LNG locomotives. We will be minimizing the costs by purchasing half and upgrading half of the locomotives to tier 4 so they can be LNG. Through this project we learned that locomotives do actually harm the environment as they are currently used. By researching about all of these alternative fueling methods, we can not only reduce coal consumption, but reduce the emissions that harm the environment. For the future, it honestly depends on what the technological advances are between now and then. The overall concept of our approach is not necessarily hard to do or expensive to make (like hydrogen fuel cells), and it is much more environmentally friendly than using coal. LNG locomotives are already in use too, which makes it that much easier for
refueling and convenience. LNG locomotives, at least for this generation, are the future of environmentally efficient modes of transportation.

References:


