Figure 1. GE Train, showing are final design of upgrading to Tier III and using aftertreatment to reach Tier IV emissions. Chapa, Jorge. "TRANSPORTATION TUESDAY: GE Evolution Hybrid." Inhabitat Sustainable Design Innovation Eco Architecture Green Building. N.p., 27 Nov. 2007. Web. 11 Dec. 2015.
Abstract/executive summary:  
The city of Pittsadelphia has a major problem with smog. This problem is mainly attributed to their older, less efficient Tier II locomotives. For the benefit of their citizens as well as the environment, the city of Pittsadelphia looks to implement a new, more efficient system of delivering freight, lowering emissions while still looking to make a profit and not interrupt service. In looking into a solution for their issue our team looked into many different possible solutions including upgrading to Tier III locomotives with after treatment, buying new Tier III locomotives and buying new Tier IV locomotives. After doing a concept selection matrix it was still difficult to deduce which was the best option. This led to a financial analysis of each of these solutions. This showed us that there was no benefit of purchasing new Tier III locomotives over simply upgrading. It also showed us that upgrading to Tier III was more cost effective in the short term as it led to a faster recuperation of the initial investment. Purchasing new Tier IV locomotives looked to be more cost efficient in the long term but over the next few years it would be significantly more cost effective simply upgrading Pittsadelphia’s fleet. This would also allow us to be more flexible down the road and maybe further upgrade when the cost of the technology lowers.

Problem Statement:  
The city of Pittsadelphia wants to reduce the amount of smog in its city. The city of Pittsadelphia plans to fix this by updating their current train fleet by making them more fuel efficient and reduce emissions. Currently, there is a large amount of smog emitted by the transportation of freight due to the fact that the city utilizes trains and locomotives that are not within the current EPA regulations of Tier III. This Project will fix this problem by investigating
the current system which is in place and by looking further into overhauling the current freight transportation methods so that the city can be more environmentally friendly.

**Background:**
The port city of Pittsadelphina is a bustling industrial town. Although it is a port city, Pittsadelphina sends and receives approximately 165,000 tons of freight or minerals such as coal through the railroad alone. However the Smog produced from these locomotives is one of the main complaints of the residents. The main cause of this Smog is the out of date engines in the Tier 2 locomotives that are currently being used to transport these goods, these outdated engines generate large amounts of NOx (NO and NO₂) and Particulate Matter (PM). The amount of NOx and PM produced by these engines is more than should be put into the local atmosphere. At such levels NOx and PM can be considered air pollutants and can react in the atmosphere to cause Smog or acid rain.[1] Partly due to this, the Tier 2 locomotives that are currently used to transport goods will soon need to be overhauled in order to meet at least the EPA’s Tier III emissions requirements.

**Customer Needs**
Table 1. List of Customer Needs with metrics

<table>
<thead>
<tr>
<th>Needs</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight Capacity</td>
<td>165,000 tons/day</td>
<td>200,000 tons/day</td>
</tr>
<tr>
<td>Lower smog</td>
<td>Tier 3 or higher</td>
<td>No smog</td>
</tr>
<tr>
<td>Long term solution</td>
<td>Last 5 years</td>
<td>10+ years</td>
</tr>
<tr>
<td>Economically feasible</td>
<td>Total cost of $150 mil</td>
<td>Total cost of $100 mil</td>
</tr>
<tr>
<td>Return on investment</td>
<td>5 year return on investment</td>
<td>2 years</td>
</tr>
<tr>
<td>Space constraints</td>
<td>Fits current clearance requirements</td>
<td>Reduction in size of trains</td>
</tr>
</tbody>
</table>
Table 1 gives our customer needs for the project, and as shown in the AHP matrix depicted in figure 2, our highest ranked criteria were capacity, lower smog, and fuel efficiency. Capacity was deemed important because the city of Pittsdelphia did not want to lower their freight capacity, as that would reduce freight, minerals, and revenue coming into the city. Both lowering smog and fuel efficiency are important because the main problem of this project is to reduce the emission of smog in the region near Pittsdelphia. Obviously lowering smog would reduce emissions, also reducing fuel consumption would lower emissions simply because it reduces the amount of fuel being burned. Other important needs were how economically feasible the design was, as well as how soon the investment would be returned. These were considered due the fact that if a design cost billions of dollars, it would not effectively solve the problem because it would be difficult to pay for as well as not start turning a profit for decades. Another considered need was how long the solution would last, as it would not be logical to provide a solution that would turn into a problem in only a few short years. The lowest rated needs were the train occurrence rate and space constraints. High train occurrence was a complaint of citizens of Pittsdelphia, though we deemed it was not as important to the design as other aforementioned needs.
needs. Similarly, the train fitting into existing tunnels and such was low on the list because none of our designs interfered with existing dimensions.

**Concept Generation:** For our concept generation, we brainstormed by drawing any and all ideas we could come up with. Shown in figures 3 and 4 are a few of the ideas we came up with. For this part of the assignment, every group member came up with ideas for the projects, and we then proceeded to discuss and evaluate each idea as a team. Each group member came up with approximately 4-5 ideas, and then presented their favorite ones to the group. From there, we chose our favorite ideas a group, and proceeded to evaluate our top 4 ideas through the use of AHP and concept selection matrices in order to choose the best one.
**Concept Selection:**

For our concept selection, we decided to look for solutions starting at a very broad Before we got to the possible solutions we had to figure out what we were looking to accomplish. We looked at several aspects including freight capacity, smog reduction, economic feasibility, fuel efficiency and more. With the use of the AHP matrix shown by figure 2, we were able to decide upon the aspects we needed to focus on and from there added in our ideal changes, as well as what was simply acceptable. With our aspects to focus on decided upon, we went on to generate ideas. We started with a very broad outlook. We even included obscure ideas like that of changing our fleet of trains into a fleet of camels. We felt as if the idea of starting at a very diverse point would allow us to consider more realistic opportunities. After our initial ideas we limited it to upgrading the current fleet to Tier III & aftertreatment, selling it all off and buying new Tier IV trains, a hybrid including the use of boats, or upgrading the trains to run on alternative fuel. From there we used the information in table 2 to determine which design met the customer needs the best.

Table 2. Comparison of three concepts to solve problem

<table>
<thead>
<tr>
<th>Design: Economic/Technical feasibility</th>
<th>Trains (upgrade/buy new)</th>
<th>New Fuel (upgrade/use biofuel)</th>
<th>Train &amp; Boat (sell old fleet &amp; upgrade to new trains)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Upgrade 10 tier II to tier IV ($65 Million)</td>
<td>-$1 billion cost to build alternative fueling station</td>
<td>-More costly than rail only</td>
<td>-Lower capacity</td>
</tr>
<tr>
<td>Cost-benefit analysis</td>
<td>See Figure 5</td>
<td></td>
<td></td>
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<tr>
<td>-----------------------</td>
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**Economic/Technical Feasibility:**

The economic feasibility of our design is very high, as the initial cost is only $42.5 million, which is much less than all other options we considered. Additionally, our design offers the opportunity for fuel savings over the course of the trains’ use. This is where the return on investment comes into play. As further elaborated within the Cost-Benefit Analysis section, the reduction in fuel cost essentially pays for itself after a short period of time, after which it simply turns into savings. Thus, this solution not only fixes the cities problem with smog, but it also goes further to help save the city money and pay for itself in the long run. As far as technicality, the process of upgrading and installing aftertreatment would not be too difficult. There could be a relatively quick turnover, upgrading the five extra trains, which are out of service, at a time.
From there, we simply need to upgrade all of them which would be quite feasible based on the fact that they are already in line to be upgraded. No changes would need to be made to the overall structure of the train there would just need to be change the interior parts. Thus, there would be no need for any infrastructural changes and thus the work would be minimal and not disrupt service.

Figure 5. Cost-benefit analysis graph showing two year return on investment
Figure 6 Graph comparing fuel costs of tier II trains (in blue) and tier III trains (orange) over a two year period.

**Cost-Benefit Analysis:**

The initial cost of the overall upgrade is $43 million including all of the upgrades and the after treatments. From there we went on to evaluate the savings that would come over the next couple of years. We calculated the cost of operating the fleet over a year by assuming the average mileage of a cart was approximately 600 miles. From there we deduced multiplied that by the average daily tonnage and divided it by 500 mile-tons per gallon, the approximate fuel consumption of a Tier 2 locomotive per day. [2] When multiplying that by 365 (days in a year) and $3.06 (cost of diesel) we found the annual cost to fuel the fleet. [3] Lastly, we found 11% of that total to be the average savings on fuel spending per year due to the fact that Tier 3 locomotives are 11% more efficient than Tier 2. [4] This gave us an annual savings of about $24 million and, as shown by figures 5 and 6, leading to a recuperation of initial costs within a two year period.
Design Review:
After presenting our initial design to our classmates, we received lots of helpful feedback. The most common feedback received was that our design would meet customer needs, all our requirements made sense, and that our main advantage was that our design had a very short return on investment timeframe. Some things we were told we needed to improve included improving our prototype, creating a more detailed systems diagram, and adjusting all costs to improve our estimates. One of our biggest challenges was cost estimates. With costs that can vary so greatly, it was difficult to make an accurate estimate for certain prices, which gave us trouble estimating things such as fuel cost per trip, or difference in efficiency between tier II and Tier III trains. Without exact numbers for fuel efficiency of each type of train, we had to do our best to estimate what we believe the fuel consumption for each type of locomotive is.

Description of Final Design:
For our final design, we decided to proceed with the Tier II to Tier III upgrade, as well as the aftertreatment upgrade for each locomotive. The initial cost of upgrading our entire fleet of locomotives would come out to $750k for the Tier II to Tier III upgrade per locomotive, along with an additional $100k per locomotive for an aftertreatment upgrade, which would make the emissions equivalent to that of a Tier IV locomotive. This initial cost, multiplied by 50, which is the size of the current fleet of locomotives, would come out to $42.5 million dollars. Due to the 11% reduction in fuel costs, this design would have a two year return on investment, and from then on produce profit. The upgrade and aftertreatment also reduce emissions greatly, NOx by 76% and PM by 85% which in turn will garner positive public opinion from the citizens of Pittsadelphia because one of their largest complaints is being fixed. Since the size of the fleet is...
not changing, Pittsadelphia will still be able to move 165,000 tons of freight a day. The timeframe for the upgrade would be fairly quick, as GE has told us it is able to build multiple locomotives in 2 weeks, thus upgrading existing locomotives should not take longer. Therefore, since there are five spare locomotives in the fleet, those can be upgraded while the freight capacity of the city remains untouched during the upgrade process.

**Systems Diagram:**

For our systems diagram, we will be putting in freight, minerals and fuel into our system, and will have reduced emissions, delivered freight and delivered minerals coming out of the system. The system would have minimal changes after our upgrade, as we are not changing anything besides the emissions produced by the locomotives. This means that the city of Pittsadelphia will not suffer major downtime from the delivery of freight and minerals, as the only change made to the current system will be upgrading the trains themselves. Aspects such as freight capacity, train occurrence rate, and infrastructure will not be affected. Although our system is not complex, it is efficient and will not have a major negative impact on the city of Pittsadelphia.
For our CONOPS, we decided to show two separate models. These models are essentially identical in their process but simply differ in what they are transporting. The first model shows the process used for mineral trains and the second shows the process for freight. Both conops begin with the loading of the specific type of freight onto the train. This is a short process, but it is the start of the whole occurrence. After this is done, the trains will travel to the Pittsadelphia. The average distance of a travel is approximately 600 miles. This means that it would take about 1.2 gallons per ton to make this journey. From there, they enter the city of Pittsadelphia and are later unloaded of their freight.
Conclusion:
In conclusion, our project was very successful. We not only designed a system that would allow us to have a two year return on the initial investment of $42.5 million dollars, but also managed to please the residents near/in the area. We managed to achieve the two year return on investment mainly due to the 11% reduction in fuel costs. The upgrade to Tier III along with the aftertreatment not only reduces NOx by 76%, but also reduces PM by 85%. Aside from the upgrade to engine itself, we minimized changes to freight capacity, train occurrence rate, and infrastructure. These are efforts we took to satisfy the residents in the area. We believe that little to no construction and roadwork will help relationships with the local citizens. Implementing this system is the first step towards making Pittsadelphia a more efficient and eco-friendly city.

References