Reducing NOx and Particulate Matter in Locomotives

EDSGN 100 section 4

Submitted to Wallace Catanach 12/10/2015
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Executive summary

As a group, team 4 of Engineering design class 100 section 003, has determined a way to reduce gas emissions in the shipping of mineral and coal locomotives over a 500 mineral radius. Smog has been plaguing the city of Pittsadelphia, and to counteract this problem. Additionally, the EPA has been raising the strictness and importance of reducing NO\textsubscript{X} emissions. The reduction of gases needs to be apprehended through the most efficient, cost efficient solution. Also the time that goods are transferred needs to stay the same, if not sped up.

Through the development process, we decided to upgrade the locomotive fleet instead of searching for an ulterior means of delivery. We conducted initial research on the EPA requirements for different tiers of efficiency as well as searched for locomotives that currently met the most efficient standards. Our group of three came to a decision to solve the issue, and reduce the emissions. We were able to narrow it down to having the locomotives be powered by B20 biodiesel. With the B20 biodiesel, the trains would also be upgraded to tier four EPA requirements, which greatly reduce the amount of nitrous oxide and other particulate into the environment. These two paired together would virtually eradicate the emission of carbon dioxide due to the exhaust recirculation technology implemented in the tier four design.

The prototype has a few risks involved with it. The tier four trains are already built meaning there is no risk with building and discovering that technology, nor is
there risk with using the biodiesel. However, there is risk with taking on this major renovation. The risk that is perceived is purely financial. The upgrading cost will be 1.5 million dollars per train, and with fifty trains, the total cost would be around 75 million dollars. The EPA set new standards from previously marked tier three to current mark tier four in just three years. This sets a risk because we do not know when there will new requirements and if it possible to effectively upgrade the tier four trains to the new requirement. With this being brought forward, the benefits and cuts to emission that these trains will have on the environment will be greatly observed and well worth the risk as well as the cost. The prototype of the train will be presented on December 9th, 2015.

Introduction

Our project was to find a suitable replacement for the freight locomotives in a theoretical city. The customer needs came from the Tier 4 EPA emission regulations and finding the lowest cost but keeping the efficiency of the original system. The customer also required that the freight capacity of the trains also not be reduced.
Customer Needs

<table>
<thead>
<tr>
<th>Customer Needs</th>
<th>Need Statement</th>
</tr>
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<tbody>
<tr>
<td>Reduce the gaseous emissions produced</td>
<td>The trains will produce a decreased amount of harmful gaseous products than before.</td>
</tr>
<tr>
<td>Keep the cost low to maintain a large profit margin</td>
<td>The total cost of the project will be taken into account by looking at the average years of technology improvements and EPA requirements.</td>
</tr>
<tr>
<td>Maintain or improve the freight capacity</td>
<td>The freight capacity of each train will not reduce.</td>
</tr>
<tr>
<td>Increase the public opinion of General Electric</td>
<td>The opinion of General electric through the eyes of the public will improve because of its awareness to harmful pollutants and gaseous products.</td>
</tr>
<tr>
<td>Maintain or increase the promptness of delivery</td>
<td>The time needed for each train to travel 500 miles will not increase.</td>
</tr>
</tbody>
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Research

We researched three potential options. The first was the SCR (selective catalytic reduction). Using multiple studies we found that the SCR can potentially eliminate 70-90% of NOx emissions. However these systems need to be replaced or cleaned and can be very costly. The particular ones we were investigating could cost 1000$ per ton of NOx removed which would be far too costly on this scale. Our second topic of research was Nuclear power and electrical trains. This system would eliminate all harmful waste. However, it would cost millions to develop and all of the current locomotives would need to be replaced with newer electrical ones. Our final topic of research is the already developed and available Tier 4 GE locomotives.
These locomotives proved to be affordable, efficient, and very environmentally friendly meeting all the standards required by the customer.

**Concept Generation and Selection**

The concepts we decided to judge were SCR, nuclear, and Tier 4 GE.

<table>
<thead>
<tr>
<th></th>
<th>SCR</th>
<th>Nuclear</th>
<th>Tier 4</th>
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<tr>
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<tr>
<td><strong>Cost</strong></td>
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<td>3</td>
</tr>
<tr>
<td><strong>Development</strong></td>
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<td>3</td>
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<tr>
<td><strong>Total</strong></td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
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Cost Model

The total cost of the design turned out to be 75 million dollars. We arrived at this number based on the price incurred by upgrading an individual train which is 1.5 million dollars, and multiplying this number by the number of trains in each fleet which is 50. After this calculation is made, the final price is indeed 75 million dollars. The second part of our solution is to use B20 biodiesel which would not affect the price at all. In today’s market the price of B20 fuel is very similar to the price of regular diesel fuel. However, this may in fact change over time based on the supply and demand of each fuel. For the time being, the cost incurred would be a fixed total of 75 million with a variable cost of the price difference between regular and B20 diesel fuel.
0.0429 <---- interest
1.0429 <---- Interest plus 1
3 <---- time period

1.134300184 single payment (future worth)
0.048661478 (Denominator of Uniform Series)
0.134300184

2.75988707 Uniform series (annuity)
0.881600845 single payment (present worth)
64.33303193

2.68262321 arithmetic gradient

75000000 Cost to upgrade 50 Locomotives
To Tier 4
66120063.35

Design
• “More than 70 percent reduction in emissions from Tier 3 locomotive technology;

• Reduced maintenance costs compared to GE’s Tier 3 locomotive;

• Advanced air-to-air cooling system for better performance and lower emissions;

• Increased cooling capacity by 25 percent to help eliminate engine deration in high ambient temperatures or during tunnel operation;

• AC individual-axle traction control for greater hauling power along with reduced slippage on startups, grades and suboptimal track conditions;

• Dynamic braking technology to help reduce wheel and brake wear by 20-40 percent; and

• Computer controlled architecture for improved diagnostics and simplified operation.

Exhaust Gas Recirculation (EGR)

Developed a new system to meet Tier 4 Nitrogen Oxide (NOx) standards.
A larger casting (+8”) and increased weight (+7,000 pounds) allows for larger bearings and crank with increased overall cylinder pressure capability for better reliability and performance.

Platform

Increased the length (16”) and increased the weight (8,000 pounds)

Cooling System

A two-stage charged air system featuring enhanced heat exchangers (allowing for 50 percent more heat rejection and 25 percent capacity increase compared to GE’s Tier 3 locomotive), an additional rad fan and 9,000 pounds of added weight.

Variable Speed Auxiliaries

The Tier 4 design adds auxiliary inverters/motors and six panels while eliminating the need for an auxiliary alternator, contactors and cycle skippers. These improvements allow for better fuel efficiency and reliability compared to GE’s Tier 3 locomotive.

Base Engine Improvements
Base engine reliability and performance improvements include:

Increased bearing size, longer induction-hardened crankshaft, top feed fuel injectors for easier removal and simplified fuel lines

Turbochargers

Two-stage turbocharging allows for a higher compression ratio, fuel efficiency, reduced thermal stress and a nearly 10 percent improvement in speed through tunnels compared to GE’s Tier 3 locomotive.

Fuel System

Increased reliability as a result of new double wall fuel lines, gear driven pumps and lower pump pulsation. Improved ease of maintenance by positioning the injector on top of the power assy.

Engine Control Unit (ECU) & Power Supply

A new ECU with 50 percent more sensors and a separate power supply come together to help provide improved reliability, performance and diagnostics.”

-GE on their new Tier 4 locomotives
Conclusion

Overall, we found our solution to the project to be a success. As a group we weighed the pros and cons of different ideas, and, after taking the customer needs into account, we found upgrading the trains and replacing the fuel with B20 biodiesel to be the best solution. The pros of this solution being a major reduction in particulate and NOx emissions. Another pro would be that length that this technology will be valid for. The EPA set a regulation of tier 4 ten years after they set the standards for tier two which is the tier that the current train meet. Based on a validity of ten years, the cost would come out to be 7.5 million dollars per year, with a major benefit of preserving the environment and lowering harmful gaseous products. The only con to this solution would be the uncertain time table. If the technology I sonly valid for a couple of years, it would appear to be a mistake to go this route, but if the time that this solution is valid goes on to be much longer, this is a fantastic, cost effective, and earth changing solution.


