General Electric
Final Report

PENNSTATE

Penn State Engineering
Team #1, The Logical Lions

Christopher Solis – cvs5703@psu.edu
Marisa Saliola – mjs6809@psu.edu

Jill Mascoli – jvm6104@psu.edu
Evan Klim - evk5244@psu.edu

Engineering Design 100, Section 005
Submitted to: Wallace Catanach
Date: 14 December 2015

Dear Professor Catanach:

We, the Logical Lions, are submitting to you the report, due December 14th, 2015, that was assigned as a project for Engineering Design 100, Section 005. The report is entitled General Electric Final Report. The purpose of the report is to inform you of our design decisions for the project, focusing most on the selection of the method of transportation we chose to use, as well as of the fuel it will be powered by. If you should have any questions concerning our project and/or paper please feel free to contact any of our team’s members using the Penn State emails provided on the cover of this report.

Sincerely,

The Logical Lions
## Index

1.0  Executive Summary ................................................................. 5
2.0  Introduction ........................................................................... 5
3.0  Customer Needs Analysis .......................................................... 5
   3.1.  Attractive Qualities ................................................................. 5
   3.2.  Must-be Qualities ................................................................. 6
   3.3.  Need Statements ................................................................. 6
4.0  External Research ................................................................. 6
   4.1.  Methods of Transportation ...................................................... 6
   4.2.  Fuel sources ......................................................................... 8
   4.3.  Benchmarking ................................................................. 9
   4.4.  Product Dissection ............................................................... 10
       4.4.1.  Cost Efficiency ............................................................... 10
           4.4.1.1.  Initial ................................................................. 10
           4.4.1.2.  Long Run ............................................................. 11
       4.4.2.  Environmental Impact .................................................... 12
5.0  Concept Generation ............................................................. 13
6.0  Concept Selection ............................................................... 15
7.0  Embodiment Design ............................................................. 16
8.0  Design Description ............................................................... 17
9.0  Conclusion ............................................................................. 17
10.0 References ............................................................................ 18
List of Figures

Figure 4.1.A
Rail Pros and Cons...........................................................................................................6
Figure 4.1.B
Truck Pros and Cons.......................................................................................................7
Figure 4.1.C
Sea Transportation Pros and Cons....................................................................................7
Figure 4.1.C
Air Transportation Pros and Cons....................................................................................7
Figure 4.2.A
Diesel Pros and Cons.......................................................................................................8
Figure 4.2.B
Hydrogen Pros and Cons................................................................................................8
Figure 4.2.C
Compressed Natural Gas Pros and Cons..........................................................................9
Figure 4.3.A
Fuel Cost: Tier 2 Locomotive.............................................................................................9
Figure 4.3.B
Tier 2 Emissions..............................................................................................................10
Figure 4.4.A
Fuel Cost: Hydrogen Fuel Cells.......................................................................................11
Figure 4.4.B
Accelerating Commercialization.....................................................................................11
Figure 4.4.C
Fuel Costs.........................................................................................................................12
Figure 4.4.D
Projected Fuel Cost: Hydrogen Fuel Cells......................................................................12
Figure 4.4.E
Environmental Impact.......................................................................................................13
Figure 5.A
Concept Generation Matrix..............................................................................................13
Figure 6.A
Concept Selection Matrix...............................................................................................15
Figure 6.B
Fuel Type Matrix..............................................................................................................16
Figure 7.A
Embodiment Design........................................................................................................16
1.0 - Executive Summary

The purpose of this project is to create a more environmentally efficient transportation system than General Electric’s tier two train currently in use. The updated system will maintain or surpass the capacity of the tier two system, 160,000 tons per day, while reducing the amount of NOx, particulate matter (PM), and other emissions released into the atmosphere. This project will serve as a model for the development of future transportation systems, progressing society to a more sustainable lifestyle.

During our initial design process, we took under consideration modeling ships to transport the cargo. However, the cargo must be transported from Wyoming to Pittsadelphia, two landlocked cities. For this reason, rather than designing an entirely new method of transport, we chose to update the current rail system. This allows us to easily access both destinations, and utilize the rail systems that are already in place.

We chose to keep the method of transport constant, however, we did introduce alternate energy sources to fuel it. Our main sources of power will be fuel cells and diesel oil. Although seemingly not cost effective in the short run, progressively introducing trains fueled by alternative energy sources will reduce both costs and energy in the long run.

2.0 - Introduction

This report was created by The Logical Lions, team one of Penn State Engineering’s introductory course Engineering Design 100 Section 005, to develop a method of transport for General Electric (GE) that is more environmentally efficient than the tier two train they currently have in use. Per the customer’s requirements, it must be able to maintain or surpass a carrying capacity of 165,000 tons of freight or minerals to and from the port city of Pittsadelphia. It also must reduce the amount of smog produced, so as to mollify the complaints of the residents of the city. It must reduce the amount of emissions it generates, at the minimal meeting the requirements set out by the Environmental Protection Agency (EPA), with especially in the emission of NOx and particulate matter. Finally, it must complete all deliveries on time.

3.0 - Customer Needs Analysis

The following were requested by the customer to be inarguable requirements of the method of transport:

3.1 - Attractive Qualities
   a) The transport must be viewed positively by the public.

3.2 - Must-be Qualities
   b) The transport must have the capacity to transport 165,000 tons per day.
   c) The transport must produce less smog than the current GE tier two train.
d) The transport must meet all EPA requirements.
e) The transport must complete all deliveries on time.

3.3 - Need Statements
The Following Bullets Correlate with the Above Customer Requirements
- The transport will reduce smog by cutting down on NOx it produces.
- The transport will be able to carry 165,000 tons of freight into and out of Pittsburgh each day.
- The transport will abide by all of the Environmental Protection Agency’s regulations.
- The transport will reduce the particulate matter it lets off.
- The transport will be able to complete all of its deliveries on time.

4.0 - External Research

4.1 - Methods of Transportation
The new method of transportation must be able to transport 165,000 tons of freight or minerals in the most efficient manner. The type of transport must have a good combination of cost effectiveness, efficiency, and performance. The following charts indicate the positive and negative attributes of the considered transportation:

Figure 4.1.A

<table>
<thead>
<tr>
<th>Rail</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pros</td>
<td>Ability to transport thousands of tons at a time; not reliant on waterways.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Existing infrastructure only requires a new train to be made.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>190.5 MPG on average which is relatively fuel efficient for motor powered shipping.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.1.B

<table>
<thead>
<tr>
<th>Truck</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pros</td>
<td>More possible routes to travel, which allows</td>
<td>One truck can only carry a few tons at a time.</td>
</tr>
</tbody>
</table>
for the utilization of alternate routes to better ensure on time delivery.  

<table>
<thead>
<tr>
<th>Higher risk of damage/maintenance while driving alongside ordinary people on the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent traffic issues</td>
</tr>
<tr>
<td>Inefficient use of fuel with an average of 32.2 MPG</td>
</tr>
<tr>
<td>More risk with hazards and dangerous driving conditions. Such risks can delay or prevent the shipment from arriving.</td>
</tr>
</tbody>
</table>

**Figure 4.1.C**

**Sea Transportation**

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of 340 MPG which is really fuel efficient.</td>
<td>Dependent on water access (limited locations it can deliver to).</td>
</tr>
<tr>
<td>Excellent efficiency for carrying heavy/bulky cargo.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.1.D**

**Air Transportation**

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed. Shipping only takes a matter of hours.</td>
<td>Lower fuel efficiency of about 42.6 MPG on average.</td>
</tr>
<tr>
<td>Little traffic/physical barriers.</td>
<td>Inability to pack tons of freight/minerals to keep transport in the air and due to lack of space.</td>
</tr>
<tr>
<td>No additional construction of tracks/roads.</td>
<td>Very dependent on weather conditions (consistent on time delivery would be unlikely).</td>
</tr>
<tr>
<td>Easy transport of light goods.</td>
<td>Prone to accidents; hijacking is easily possible.</td>
</tr>
</tbody>
</table>
After analyzing the pros and cons of each of the possible considered transportation methods as shown in the charts above, rail stood out as the best solution. Although a ship would have been a strong choice, GE’s coal trains will likely have to undergo frequent trips to Wyoming, the main coal producing state in the United States. Since Wyoming is a landlocked state, the use of a ship would be ill-advised. The use of railways would then be the best option, as it can effectively carry large amounts of cargo, and can utilize rail systems that are already in place.

### 4.2 - Fuel Sources

#### Figure 4.2.A

<table>
<thead>
<tr>
<th>Diesel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Easier to maintain, since most locomotives are currently fueled by diesel. (Maintenance is more available.)</td>
<td>Nonrenewable resource.</td>
</tr>
<tr>
<td>Relatively efficient, as it is energy dense and therefore contains significant usable energy.</td>
<td>Releases significant amounts of NOx and particulate matter, resulting in smog. Worsens public opinion.</td>
</tr>
<tr>
<td>Diesel engines can also accept biodiesel fuel.</td>
<td>Tends to produce more noise/vibration (disrupt residents).</td>
</tr>
<tr>
<td>More refueling stations readily available.</td>
<td>Expensive: $3.09 per gallon</td>
</tr>
</tbody>
</table>

#### Figure 4.2.B

<table>
<thead>
<tr>
<th>Hydrogen</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Cost-effective in a long run business model.</td>
<td>Will be a large initial investment.</td>
</tr>
<tr>
<td>Abundant resource (hydrogen is the most common element on the planet).</td>
<td>The process to create hydrogen fuel creates large amounts of CO2 emissions (although still 60% fewer “well-to-wheel” than gasoline produces).</td>
</tr>
</tbody>
</table>
### 4.2 - Compressed Natural Gas

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundant natural resource in the US</td>
<td>Few refueling stations already in place.</td>
</tr>
<tr>
<td>Relatively cheap ($.70 per gallon).</td>
<td>Refuels very slowly.</td>
</tr>
<tr>
<td>Burns much cleaner than diesel does.</td>
<td>Still releases harmful emissions.</td>
</tr>
</tbody>
</table>

### 4.3 - Benchmarking

**The Tier Two Model:**

To evaluate the efficiency and benefits of our hydrogen powered rail system, we calculated the costs and release of harmful emissions of the current system in use -- the tier two system -- to later compare to the projected costs and emissions of our design. Our aim was to improve the numbers on both counts.

![Figure 4.3.A](image)

**Fuel Costs: Tier 2 Locomotives**

**Mineral Train:**

\[
\frac{500 \text{ miles} \times 12900 \text{ gallons} \times $3.09}{470 \text{ miles/gallon}} = $39,446.80 \text{ per coal train}
\]

So all 5 coal trains: \(5 \times ($39,446.80) = $197,234.04\) every day.

**Freight Train:**

\[
\frac{500 \text{ miles} \times 11,748.25 \text{ gallons} \times $3.09}{470 \text{ miles/gallon}} = $38,619.25 \text{ per freight train}
\]

So all 15 freight trains: \(15 \times ($38,619.25) = $579,288.71\) every day.

Therefore the total fuel cost for tier 2 locomotives is $197,234.04 + $579,288.71 = $\textbf{776,522.75} \text{ in fuel costs every single day.}
Many factors must be considered when deciding the best method to maintain such a large capacity while reducing emissions. Our main considerations in concluding that a hydrogen powered rail system is the most beneficial method are shown in detail below.

**4.4.1 - Cost Efficiency**

**4.4.1.1 - Initial**

The greatest barrier we faced when designing our model was figuring out whether or not a hydrail would be too expensive to be realistically carried through with. Each locomotive would need to be upgraded to permit the use of a hydrogen fuel cell, rather than the diesel engine, which is a million dollar investment. Furthermore, General Electric would likely have to build a fueling station for the hydrail, an estimated billion dollar investment, causing the initial investment in the design to be extremely high.

Hydrogen, however, is marketed at a cheaper price than diesel currently is: $2.30 per gallon compared to diesel’s $3.09 per gallon. This is due to the fact that natural gas, which is currently the most common source of most hydrogen fuel, can be up to ⅓ cheaper than diesel per unit energy. Furthermore, hydrogen fuel cells can range to be up to two to three times more efficient than the typical diesel engine, driving down the overall price of hydrogen.

This seemingly minute saving in fuel cost compounds when considered for the train as a whole, saving a total of nearly $200,000 in fuel costs for just a 500 mile trip, the calculations for which are shown below.
4.4.1.2 - Long Run

The number of commercial technologies for the storage, production, and delivery of hydrogen is steadily increasing, along with the number of fuel cells in use, as shown in the chart below.

This increase in the availability and ease of producing hydrogen will cause hydrogen costs to fall over time, while other nonrenewable resources, such as diesel, will only become more expensive as they become more scarce, as shown in the chart below.
This means that, in the long run, relative fuel costs of a hydrogen powered rail versus a diesel run rail will differentiate even further. We calculated the expected long run fuel costs below, using the rate that hydrogen is expected to steady out at, $1.50 per gallon.

Projected Fuel Costs: Hydrogen Fuel Cells

Mineral Train:

\[
\frac{500 \text{ miles} \times 12000 \text{ gallons} \times $1.50}{470 \text{ miles/gallon}} = $19,148.94 \text{ per coal train}
\]

So all 5 coal trains: 5($19,148.94) = $95,744.68 every day.

Freight Train:

\[
\frac{500 \text{ miles} \times 11748.25 \text{ gallons} \times $1.50}{470 \text{ miles/gallon}} = $18,747.21 \text{ per freight train}
\]

So all 15 freight trains: 15($18,747.21) = $281,208.11 every day

Therefore the total fuel cost for hydrogen powered locomotives is $95,744.68 + $281,208.11 = $376,952.79 in fuel costs every day.

Therefore the fuel cost savings would be: $399,569.96 every single day.

4.4.2 - Environmental Impact

The primary goal of this project is to reduce the amount of harmful emissions produced by the transport. With only water vapor produced as a byproduct of hydrogen fuel cells, the amount of emissions prevented using hydrails cannot be beat, as shown in the figure below.
5.0 - Concept Generation

The process of concept generation uses the customer needs and target specifications to determine which concepts would work best in the final design. It includes the most important aspects of the design and is a key feature in the final design process.

The concept generation chart above shows the specific ideas for the design of the locomotive. The main specification of this design is fuel type. The fuel must reduce smog emissions, therefore becoming more environmentally friendly. While there is no specific budget, it is also beneficial to consider the cost efficiency of the fuel type, in this case, hydrogen fuel. Developing different ideas and providing a number of options is a key feature in the engineering design process. The 8 steps in concept generation are:
1. Identify the Problem
   To identify the problem, the customer needs and target specifications were used as guidelines. This made it possible to clarify the basic concepts of the locomotive design and fuel type.

2. Define the Problem
   When the necessary steps to design the locomotive were decided, it was time to decide how to go through with these steps. This required a lot of research on fuel types, materials, fuel costs, and other methods of transportation that use hydrogen fuel cells. A list of metrics was created based on this research.

3. Develop Possible Solutions
   Using the research from step 2, possible solutions were considered. Specific ideas were brought up on which fuel to use. Surveys were created and given out to other students, patents were researched, and a benchmark was put together.

4. Select the Best Possible Solutions
   The group considered all options and ideas and finally decided on the best fuel source to use for the train.

5. Model the Solutions
   A 3-dimensional model of the locomotive was built. It included the hydrogen tank, the engine, the fuel cells, and the storage batteries.

6. Test and Evaluate the Solutions
   Decided whether or not the design of the train met the original specifications that were created in step 3. In this case, the design did meet the right specifications and we were able to move forward.

7. Communicate Solutions
   Gave a presentation that described main ideas and steps of designing and developing the model of the hydrogen fuel cell locomotive.

8. Refine the Solutions
   We went back and reconsidered all of the possible solutions on how to decide the fuel type that is the most beneficial to the environment as possible. We also looked for and settled and minor issues that came up.
6.0 - Concept Selection

The following table is a specifications matrix displaying the customer needs and possible solutions. It shows the different ways certain needs can be reached by certain solutions.

Figure 6.A

<table>
<thead>
<tr>
<th>needs</th>
<th>metrics</th>
<th>50 locomotives</th>
<th>fuel cell emissions</th>
<th>keep old infrastructure</th>
<th>add jobs</th>
<th>reduction in weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>165,000 tons shipped per day</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduction in emissions</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost effective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>public opinion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>on time delivery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This table specifies which metrics account for which needs. It will better organize and ensure that all needs of the customer are met.

The following selection matrices were created in order to decide on more specific components of the locomotive. The plus sign (+) indicates that the detail is a good option, and the minus sign (-) indicates that the detail is not a good option.

Figure 6.B

**Fuel Type Matrix**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Diesel</th>
<th>Hydrogen</th>
<th>Compressed Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0</td>
<td>=</td>
<td>0</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Environmentally Friendly</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
7.0 - Embodiment Design

The following figure depicts a clearer image of the layout of our hydrogen powered train design. It highlights the fact that our infrastructure changes were minimal, only replacing the conventional diesel engine with a fuel cell and accounting for the addition of storage units that will be needed to hold the hydrogen fuel.

Figure 7.A

8.0 - Design Description

The objective of our locomotive design is to reduce NOx and PM emissions while still maintaining the ability to haul minerals and fleets at proper carrying capacity. In addition our design is to maintain speed during operation to assure on time arrival of the materials. The most effective way we found to do this cut emission completely out of our system during operation. To do so, we prepared a locomotive design essentially identical to that of a standard diesel engine locomotive with slight variation of some parts. Those parts in that were altered are listed above in bold text in Figure 7.A.

Changes made to our locomotive include; a change from a “Diesel Engine” to a “Fuel Cell Engine”, change from a “Fuel Tank” to a “Hydrogen Fuel Tank,” addition of “Storage Batteries,” and the removal of the “Turbo Charger.”

The change to a Fuel Cell Engine is our primary alteration to the locomotive, being the source of zero emissions but energy to operate the locomotive. Being that this engine is substantially smaller than a standard diesel engine, instead of using just one fuel cell, our locomotive using the extra space to fill with fuel cell stacks. These stacks of fuel cells are simply
multiple fuel cells operating at once; this process is identical to having multiple pistons within an engine to increase engine power. The **Hydrogen Fuel Tank** is the specific, compatible fuel source used to power the engine. Fuel cell technology utilizes hydrogen gas as fuel and oxygen from the Air Intake, reacting together to emit water as a byproduct. In case of emergency and simply as additional energy as reassurance for functioning, our locomotive is equipped with **Storage Batteries** on top. The purpose of these batteries is to provide excess energy during operation that can my be used to either increase energy output and movement speed, but also serves in case of emergency as it is conserved. In a sense, these **Storage Batteries** essentially replaced the Turbo Charger, which would normally be located next to the engine itself. The function of the Turbo Charger was to recycle the exhausted gas from a diesel engine to forcefully push additional air to the fans in the cylinder. This process would increase engine power, but with there being no exhaust gas produced from a **Fuel Cell Engine**, this component is inoperable.

**9.0 - Conclusion**

In conclusion, the Logical Lions have carefully considered many different types of transport and methods of powering them, but ultimately decided that a rail system that is fueled by hydrogen is the best way to maintain a capacity of 165,000 tons into and out of Pittsadelphia each day while reducing the amount of emissions released. This design will not only help the environment by eliminating all harmful emissions released while operating, but also grow to be more cost efficient for the company over time.

**10.0 - References**


