

Optimized Locomotive Alternative General Electric (GE)



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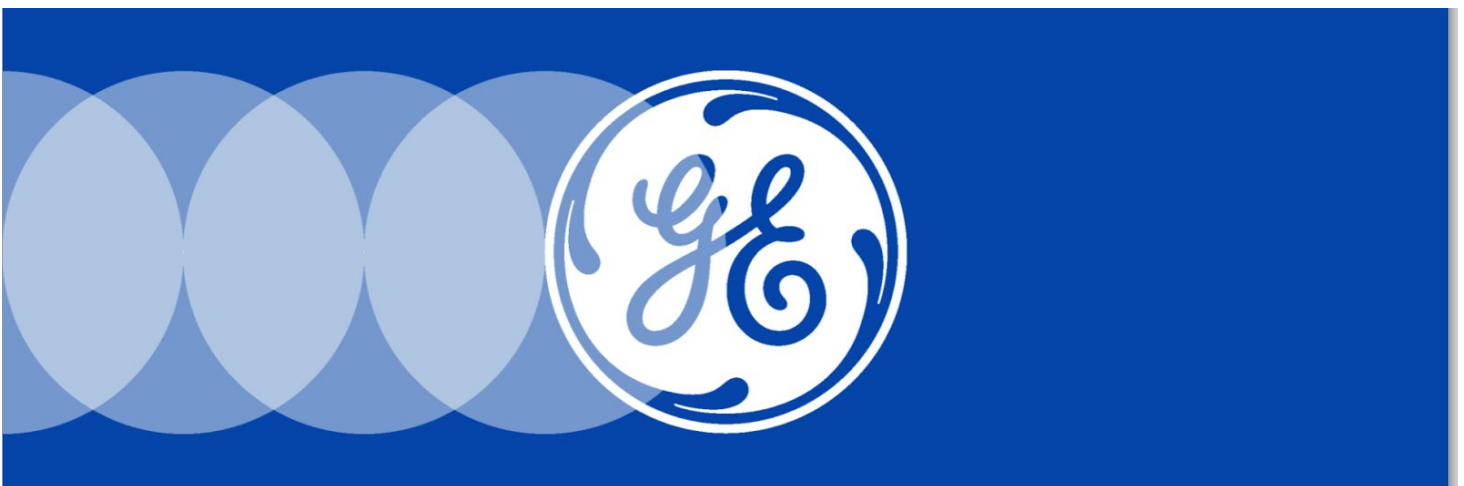
**EDSGN100
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EXECUTIVE SUMMARY:

General Electric has introduced a problem statement for an imaginary city named Pittsadelphia. Our goal is to introduce a solution to hauling 165,000 tons of freight per day while reducing the overall smog emissions. Both fuel types and transportation types were researched in order to find the best options. Twelve concepts were generated incorporating multiple transportation options based on the customer needs assessment. Concepts were then scored in a concept selection matrix and narrowed the selection to the top four concepts. Our group then discussed the pros and cons of each idea and chose a hydrogen fuel cell system based on emissions and practicality in the future. In this design, emissions, freight throughput, public opinion, and on-time delivery are considered. With respect to cost, our group decided that the best option was one that could survive in years to come while continuing to meet EPA standards.

INTRODUCTION:

The purpose of this project is to implement a solution to the problem statement through the modification or total reconstruction of train transportation to reduce NOx emissions while maintaining or increasing freight capacity. In this situation, Pittsadelphia has twenty trains at its disposal which includes five mineral trains and fifteen freight trains. Our team must consider the short-term and long-term effects of the proposed solution. The proposed solution must pay respect to factors such as emissions, costs, freight throughput, public opinion and on-time delivery. In addition, each solution must take into account the space constraints each locomotive has for any additional parts as well as any alternative shipping options. Finally, the solution should be possible to implement within the given constraints of General Electric for Pittsadelphia.



PROBLEM STATEMENT:

1.) Vision

Our vision is to find an acceptable solution to the locomotive problem while attempting to meet as many customers needs and target specifications as possible

2.) Where are we now?

WHO: Producers must meet changing EPA regulations and continuously improve transportation consumers are affected through both the price of transportation as well as indirectly paying for pollution

WHAT: The issue is that EPA standards are getting harder and harder to fulfill as well as emissions must be reduced for the sustainability of society. If we do not solve the problem then most forms of transportation will be banned

WHEN: This is a continuous issue that needs to be fixed as soon as possible. Society understands that the problem cannot be solved in one day but must strive for success in the reduction of emissions and a sustainable source of energy

WHERE: This issue occurs in our energy sector, specifically transportation because of the necessity of moving materials from one place to another

WHY: It is important to fix this problem in order to extend the existence of the human race as much as possible

Employers: increase in bills, decrease in salaries for employees

Suppliers: need to recognize which fuels employers want

Customers: increase in price paid for transportation

Stakeholders: dependent on the success of new technologies

3.) How are we going to get there?

1. We can look at different fuels for the locomotives. With this we need to look at the cost of fuel, the energy output of the fuel and the cost to convert the locomotives and the fueling stations to the new fuel.

2. We can look at the different shipping methods such as by train, by truck, by air, or by sea. With the different shipping methods we have to look at the time it takes to ship in this way, the cost, capacity of the transport, and efficiency of the technology.
 3. We can upgrade the current technology that we have to meet tier 3 or tier 4 emission regulations. This includes exhaust after treatments and are also available for other types of fuel technology.
 4. We will come up with multiple concepts and construct a concept selection matrix to narrow down our results. Then, with the remaining concepts, a more in depth concept selection matrix will help select the best alternative.
- Individually we can split up the research on the different fueling options and the different shipping options to come up with the best solution utilizing one or more technique mentioned above.

RESEARCH:

The research in the following slides includes NO_x and PM emissions for multiple fuel types as well as additional information gathered on each fuel. There are also examples and graphs that compare to fuel types to each other in relation to cost, power output, advantage and disadvantages, and investments in order to change fuel types. For some fuel types including gasoline, diesel, Liquefied Natural Gas (LNG), and Compressed Natural Gas (CNG), aftertreatment options are considered with concern directed towards size and cost in order to meet EPA standards.

Multiple studies were found that compared fuel types to each other with respect to NO_x emissions, PM emissions, power output, and many other factors. The most important factor in our study relates to emissions. In Figure 1, the EPA describes their current Tier III standards as well as the looming Tier IV standards in the approaching years. This gave us a baseline to find the best solutions for GE in the required amount of time while meeting the needs of Pittsadelphia.

In Figure 2, the graph describes the overall U.S. fuel consumption in all areas of energy. Although not specific to locomotives, the graph clearly represents what types of fuel options are readily available and used by the masses. Some of these fuel types are in danger of succumbing to EPA standards as well as continuously becoming more scarce in our environment. These discoveries urged our team to come up with a viable option that will last for years to come.

In Figure 3, our research led us to actual percentages of fuel used in the transportation sector to further refine our search. The conclusions from the graph shows that petroleum based fuels are used much more than any other type of fuel. To our surprised, natural gas only makes up 3% of fuel in the U.S. transportation sector while having a much larger impact in the total U.S. energy consumption. Although not the most widely available or used fuel, natural gas seems to have an increasing impact on the energy sector. For this reason, our group furthered our research into this field as well as looking for ways to efficiently make diesel meet EPA standards.

In Figure 4, our concerns as to which fuel produces the most amount of energy was investigated. Despite the lack of concern by GE in their problem statement, our team knows that power output is crucial in the locomotive industry due to fuel consumption and ability to perform while hauling cars. In our findings, we found that Diesel significantly outweighs any other fuel type in energy output. However, our team needed an alternative to diesel that would not deprive locomotives of their necessary horsepower. The closest alternative came from liquefied natural gas, or LNG, which is a type of natural gas stored in cryogenic tanks before combustion. As research continued, we deemed this as a viable fuel type to substitute existing diesel locomotives.

In Figure 5, our team addressed the need for our fuel type to meet EPA requirements with respect to particulate matter, or PM. Before researching, it was apparent that gasoline and diesel would have the largest PM emissions. However, after researching different fuel types, it was necessary to understand the PM impact of other fuels. The most important fuel we wanted to research was LNG because of the data mentioned above. Although not researched as thoroughly, hydrogen fuel cell and railroad electrification were also considered at this point due to lack of emission. In the graph, it is apparent that the best option for emissions in order is railroad electrification, hydrogen fuel cell, and then LNG. In relation to gasoline and diesel, all of our considered alternatives have enormous jumps in PM emissions that would easily meet EPA tier

In Figure 6, diesel alternatives were considered before fully eliminating the option. The only way to make diesel locomotives meet Tier III standards currently is to implement an aftertreatment system. However, we thought that the aftertreatment may not help enough. In our research, we discovered a biodiesel option. Although seemingly viable, research confirms that the fuel type will not be able to meet GE's needs and specifications. While biodiesel significantly decreases PM emissions, the side-effect is the increase of NOx emissions. In our study, both PM and especially NOx must be reduced in order to meet EPA requirements.

Figure 1 - Current EPA Standards

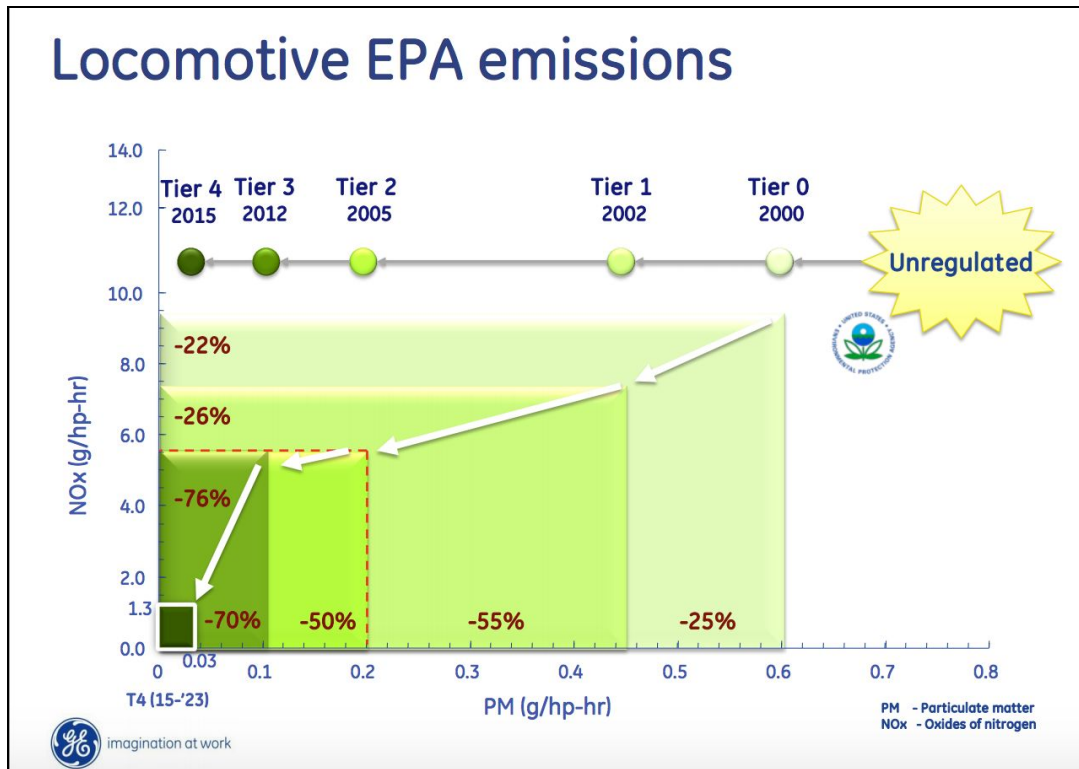


Figure 2 - Current Fuel

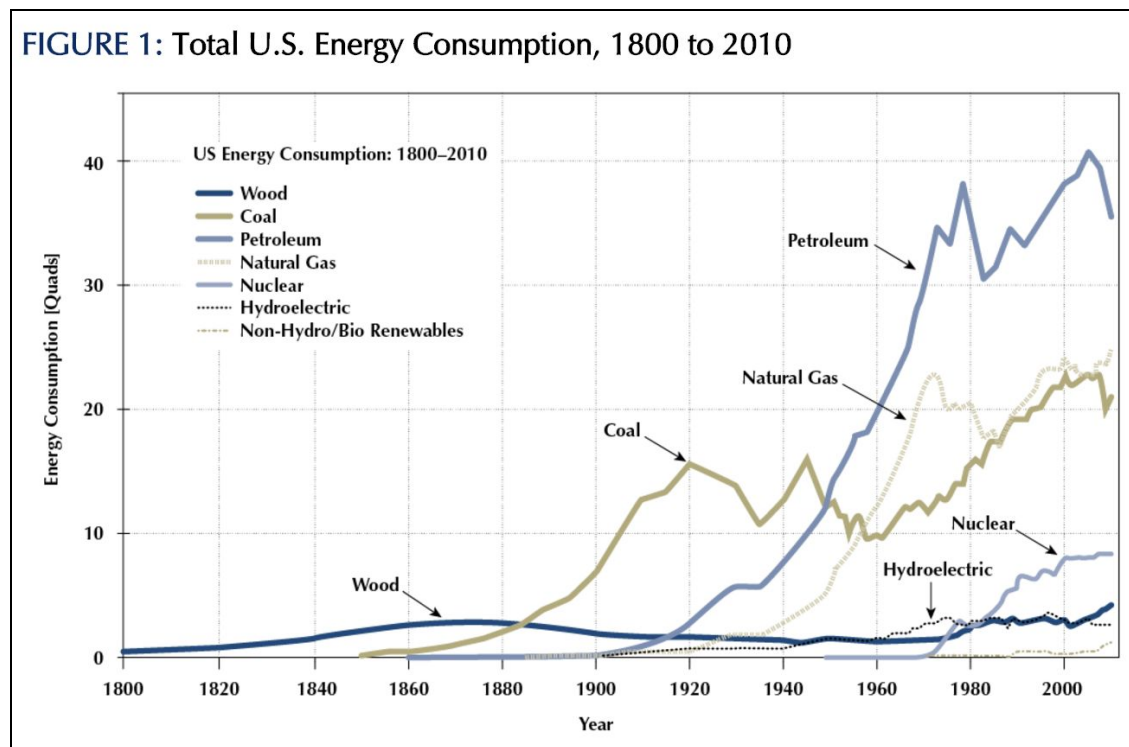


Figure 3 - Current Fuel 2

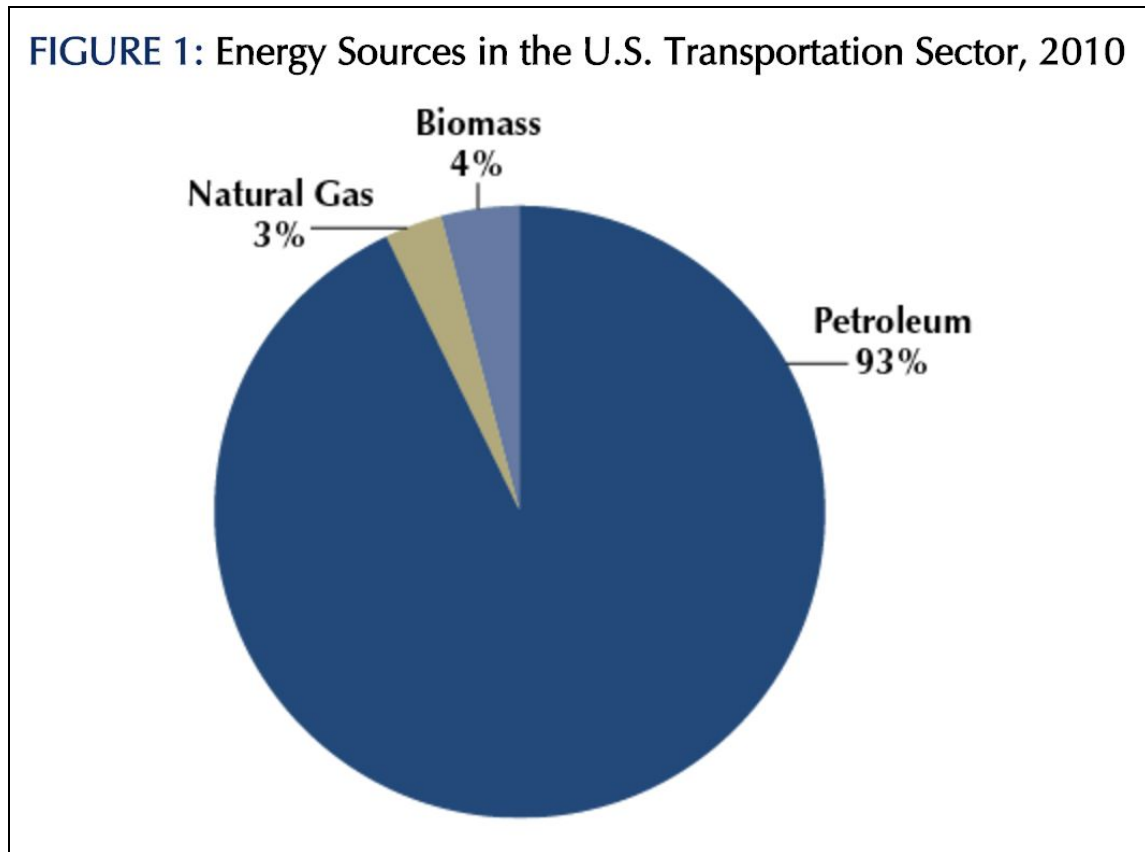


Figure 4 - Energy Density of Fuels

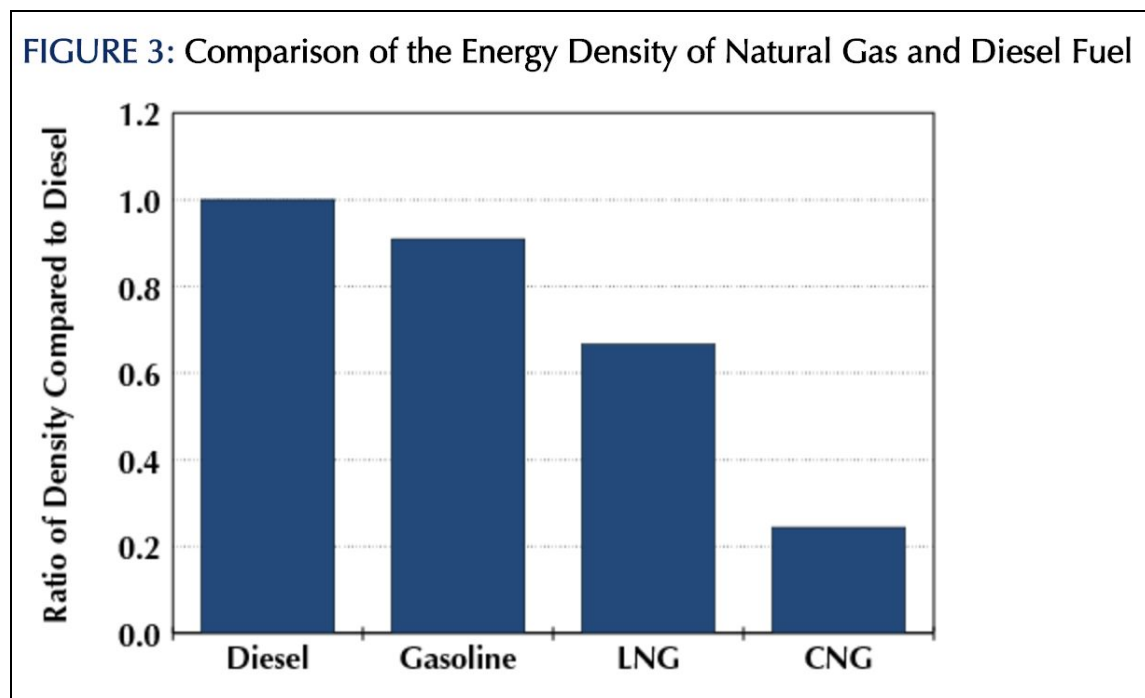


Figure 5 - Reduction of Hydrocarbons

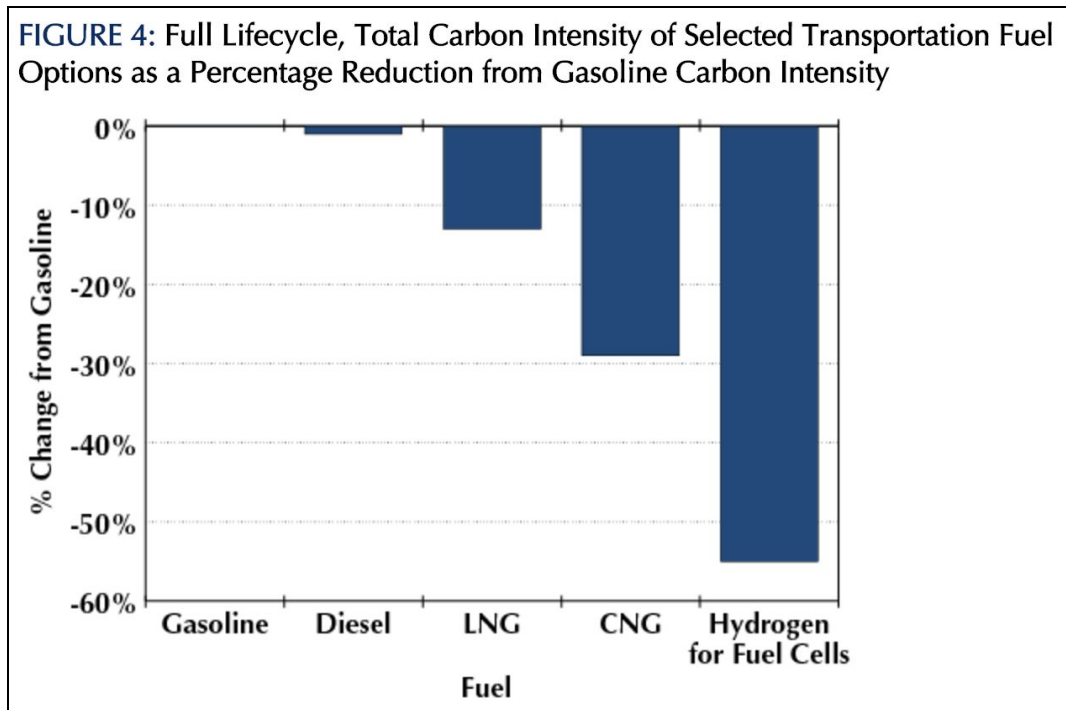
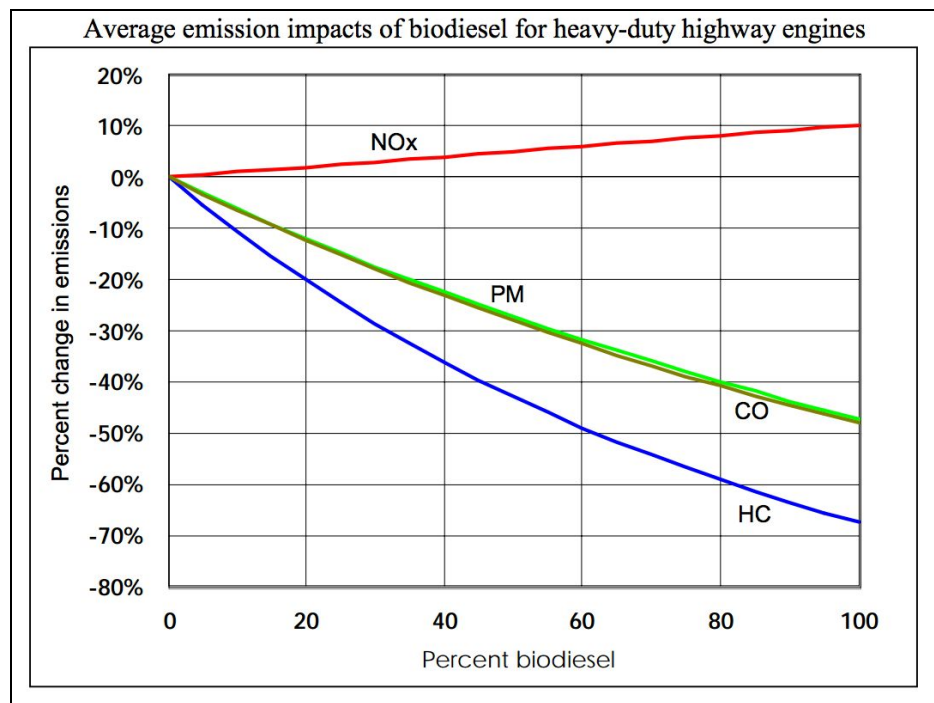


Figure 6 - Average Biodiesel Emissions



CUSTOMER NEEDS AND TARGET SPECIFICATIONS:

Before continuing with our report, a customer needs assessment was generated with the help of our research to narrow the scope of the project and eliminate some ideas based on the necessary requirements. Our customer needs assessment linked ideas to concrete numbers and also shows conditions that are either acceptable or ideal. This gives the project finite numbers to work off of that cannot be ignored.

Statement	Need	Acceptable	Ideal
should be cost effective	best alternative to existing locomotives	buy new locomotives with new technology	retrofit existing locomotives
Less harmful to environment	meet current and future EPA requirements	Tier 3	Tier 4
Reduce the smog production	reduce NOx and PM emissions		
	NOx (g/hp-hr)	<5.5	<1.3
	PM (g/hp-hr)	<0.1	<0.03
Comparable to existing locomotives	Engine output	4,500 HP	>4,500 HP
Accessibility	close but not too close	outskirts of city (45 minute drive)	industrial district of city (<30 minute drive)
Locomotive may weigh more after modifications	weight increase	425,000-430,000lbs	<425,000lbs
possible after treatment	space requirements	<60" x 41.36" x 29.33"	no ideal
cost effective	budget	TBA depending on	TBA depending on

	(should pay for itself in 10 years or less)	modifications	modifications
should not be off the tracks a lot	maintainability/reliability	minimal maintenance for 20 years	minimal maintenance for 30 years
calculate distance for fueling ports	optimum range	no acceptable	5,000 gallon fuel tank
	safety	99% success in testing and research	100% success in testing and research
who are the main customers of locomotives	cater to industry first then to passenger and commuter		over 90% of locomotives are used for freight
look at annual mileage degradation	new		100k miles
	after 15 years		>75k miles
	after 20 years		>60k miles

CONCEPT GENERATION:

Without any actual funds from GE to physically design a concept, all of our concepts are based off research and data available to our team. We began to narrow down our concept generation research in the areas of fuel, aftertreatment, and a customer needs assessment. Introduce your methodology. Our multiple concepts include fuels such as LNG, rail electrification, hydrogen fuel cell, and a biodiesel paired with aftertreatment.

CONCEPT SELECTION:

Each group member came up with four concepts that catered to their own specific research and ideas. Concepts included in the matrix follow all the guidelines of the customer needs assessments while combining transportation types to maximize efficiency for Pittsadelphia. After the concept matrix was constructed, the top four scores were kept and discussed by our group. The concept selection helped narrow down the concepts but we did not pick our concept based on the highest score. While discussing the remaining concepts, advantages and disadvantage were discussed more in-depth to solidify our decision.

Initial Concept Selection Matrix												
	LOGAN				SAM				MICHAEL			
	1	2	3	4	5	6	7	8	9	10	11	12
Regulatory	--	-	+++	---	++	+	---	+	+	---	+	--
Cost of fuel	+	--	0	0	+++	++	+	0	++	-	+	++
Overall Cost	+++	+	----	++	-----	-	++	0	-	--	----	-
Consumer need	+++	++ +	+++	+++	+++	++ +	+++	+++	+++	-	+++	++ +
Competition	-	-	++	---	+++	+	--	+	+	0	0	-
Shipping Time	0	0	0	0	0	0	0	0	0	0	0	0
Emissions Reduction	--	++	+++	--	+++ ++	++ +	+	+++ +	+++	--	+++	++
Integration	++	0	-	++	+	--	++	0	--	-	-	++ +
Power Generation	++	++	0	++	++	++ +	++	0	+++	0	0	++
Durability/Main tenance	-	+	++	-	++	-	0	++	-	-	0	-
Size	--	-	+	--	+	--	-	0	--	-	0	-
Aftertreatment	---	--	+++	---	0	++ +	0	0	+++	0	+++	--
Return on Investment	+	++	--	+++ +	0	+	+++	++	+	-	+	++ +
TOTAL	1	4	10	-1	17	11	8	13	11	-13	7	7

PRELIMINARY CONCEPTS:

After narrowing down our concepts from twelve to five, a new selection was created that includes the most important aspects needed for the concept. The most important metrics are given higher weights in order to give a more accurate representation of the best option. After calculating each concepts score, a hydrogen fuel cell concept made by both Michael and Sam was selected due to its adherence to all standards and customer needs while providing a long-term solution to the given problem.

Final Concept Selection Matrix												
<u>Metrics</u>	<u>Weight</u>		<u>#3</u>		<u>#5</u>		<u>#6</u>		<u>#8</u>		<u>#9</u>	
Cost	5		5	25	2	10	3	15	4	20	3	15
Upkeep	6		2	12	4	24	3	18	4	24	3	18
Weight	4		2	8	3	12	3	12	5	20	3	12
NOx Emissions	10		2	20	4	40	6	60	4	40	6	60
PM Emissions	9		2	18	4	36	5	45	4	36	5	45
Works with existing systems	6		5	30	1	6	2	12	4	24	2	12
Added Material	4		3	12	2	8	3	12	1	4	3	12
Aftertreatment	5		5	25	0	0	0	0	0	0	0	0
Cost of Fuel	8		4	32	5	40	4	32	0	0	4	32
Power Generation	6		4	24	5	30	4	24	0	0	4	24
Competition	4		1	4	2	8	3	12	3	12	3	12
Tier III or Tier IV	6		2	12	0	0	0	0	0	0	0	0
Long Term Solution	7		0	0	4	28	6	42	3	21	6	42

Totals				222		242		284		201		284
Screening Range (1-6)												

#3 - LNG

Our LNG concept includes in-depth thought into a long term solution for GE. Although not the most fuel efficient, LNG seemed like a good idea due to its interchangeability with diesel. For our concept, the implementation of new LNG engines would slowly replace diesel engines. Some of the existing diesel engines would be equipped with aftertreatment to meet EPA standards. Also, the new LNG engines will have the ability to run on up to 80% LNG and at least 20% diesel. This specification is meant for the early stages of the transition as the new LNG engines will also be able to run on 100% diesel if necessary until new LNG fueling stations are created. Although this is a long-term solution, the amount of waste when applying new aftertreatment to existing diesel engines and making LNG engines that cannot run on solely LNG is not a viable solution to the problem statement proposed by GE.

#5 - Railroad electrification

Rail electrification is an important part of the Department's carbon strategy. Typically, an electric train emits between 20% and 35% less carbon per passenger mile than a diesel train. This benefit will only improve as the electricity generation industry reduces its carbon levels. Electric trains also have zero emissions at the point of use, of particular benefit for air quality in pollution hotspots like city centres and mainline stations such as London Paddington.

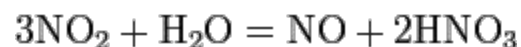
#6 and #9 - H₂ Fuel Cell

It is the generic term denoting all forms of rail vehicles, large or small, which use on-board hydrogen as a source of energy to power the traction motors, or the auxiliaries, or both. It converts the chemical energy of hydrogen to mechanical energy, either by burning hydrogen in a hydrogen internal combustion engine vehicle, or by reacting hydrogen with oxygen in a fuel cell to run electric motors. Widespread use of hydrogen for fueling rail transportation is a basic element of the proposed hydrogen economy.

#8 - Water Box Aftertreatment

This was an original idea that was discussed that employs a volume of water in which the exhaust is run through that traps the NO_x and PM. When NO_x is run through water it goes through a chemical reaction that produces nitric acid in liquid form. It was decided that it would be too difficult to store large quantities of nitric acid on a locomotive and the nitric acid would be a serious safety hazard in the case of an accident.

For example:



ADDITIONAL H₂ FUEL CELL RESEARCH

How do we get Hydrogen fuel ?

There are three main methods to produce hydrogen so far:

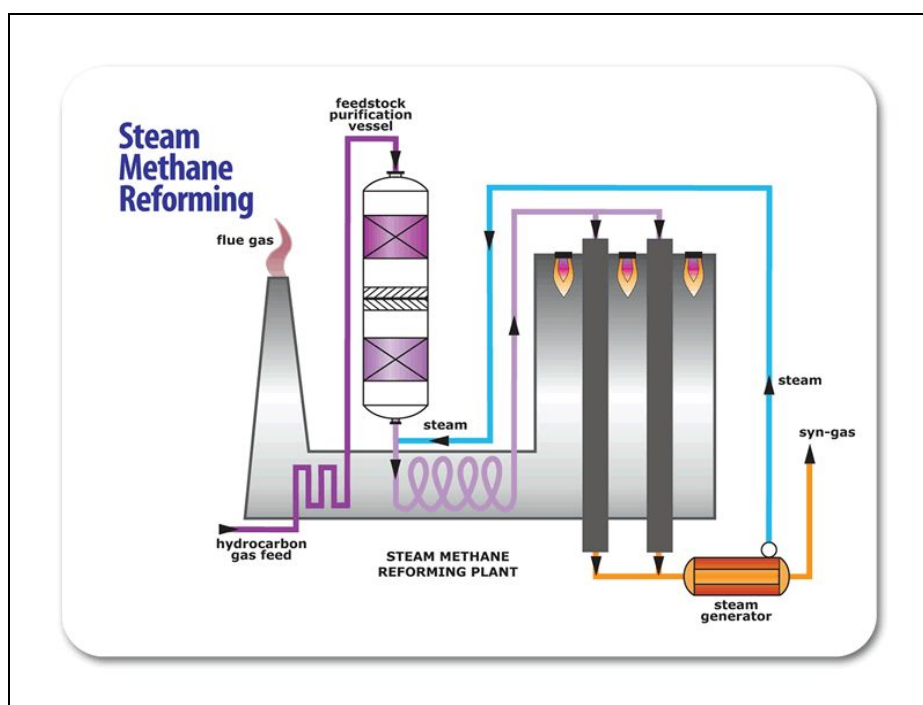
1. Electrolysis: Electrolysis consists in using electricity to split water into hydrogen and oxygen. This source of hydrogen is by far the most expensive since the energy input required for water splitting is higher than the energy that could be obtained from the produced hydrogen. According to the research, the energy it needs is 1.4 times than it produces. Therefore, this is not an efficient way to produce hydrogen.

2. Steam reforming: The production of hydrogen from natural gas is the cheapest source of hydrogen nowadays. This process consists of heating the gas in the presence of steam and a nickel catalyst. The resulting exothermic reaction breaks up the methane molecules and forms carbon monoxide CO and hydrogen H₂. The carbon monoxide gas can then be passed with steam over iron oxide or other oxides and undergo a water-gas shift reaction. This last reaction produces even more H₂.

3. Pyrolysis: It can be used as traditional fuel or nuclear power. Using nuclear power to produce hydrogen: The current interest in nontraditional methods for the generation of hydrogen has prompted a revisit of radiolytic splitting of water, where the interaction of various types of ionizing radiation (α , β , and γ) with water produces molecular hydrogen. This reevaluation was further prompted by the current availability of large amounts of radiation sources contained in the fuel discharged from nuclear reactors. This spent fuel is usually stored in water pools, awaiting permanent disposal or reprocessing. The yield of hydrogen resulting from the

irradiation of water with β and γ radiation is low (G-values = <1 molecule per 100 electronvolts of absorbed energy) but this is largely due to the rapid reassociation of the species arising during the initial radiolysis. If impurities are present or if physical conditions are created that prevent the establishment of a chemical equilibrium, the net production of hydrogen can be greatly enhanced. Another approach uses radioactive waste as an energy source for regeneration of spent fuel by converting sodium borate to sodium borohydride. By applying the proper combination of controls, stable borohydride compounds may be produced and used as hydrogen fuel storage medium. However, in the future, scientists are eager to find the way to produce hydrogen with nuclear power stably, and it will still need about a decade to produce amount of hydrogen.

Figure 7 - Steam Methane Reforming



CALCULATIONS:

12,000 tons into city

1,000 tons out of city

can take 2 tons 1,050 miles of 15 gallons of fuel

efficiency: 70 miles per gallon (car terms)

average car horsepower: 220

train horsepower: 4,500

Initial Costs:

Replacement of 50 trains: \$4 million x 50 = \$200 million

Creation of Fueling Stations:

# of Fueling Stations	Cost	Range Between Stations
1	\$1 billion	1,500 mile
7	\$7 billion	1,000 miles
17	\$17 billion	500 miles

Total Initial Costs:

(\$200 million + optimized fueling stations [7 initial]) = \$200 million + \$7 billion = **\$7,200,000,000**

5 Mineral Trains:

$4,500/220 = y/70 = 1,431$ miles per gallon

$1,000/1,431 = y/500 = 349$ gallons of fuel x \$3 = \$1,047 out of city

$12,000/1,431 = y/500 = 4,193$ gallons of fuel x \$3 = \$12,597 into city

$(\$1,047 + \$12,597) \times 5 = \$68,220$

15 Freight Trains:

$700/1,431 = y/500 = 244$ gallons of fuel x \$3 = \$732 out of city

$7,000/1,431 = y/500 = 2,445$ gallons of fuel x \$3 = \$7,335 into city

$(\$732 + \$7,335) \times 15 = \$121,005$

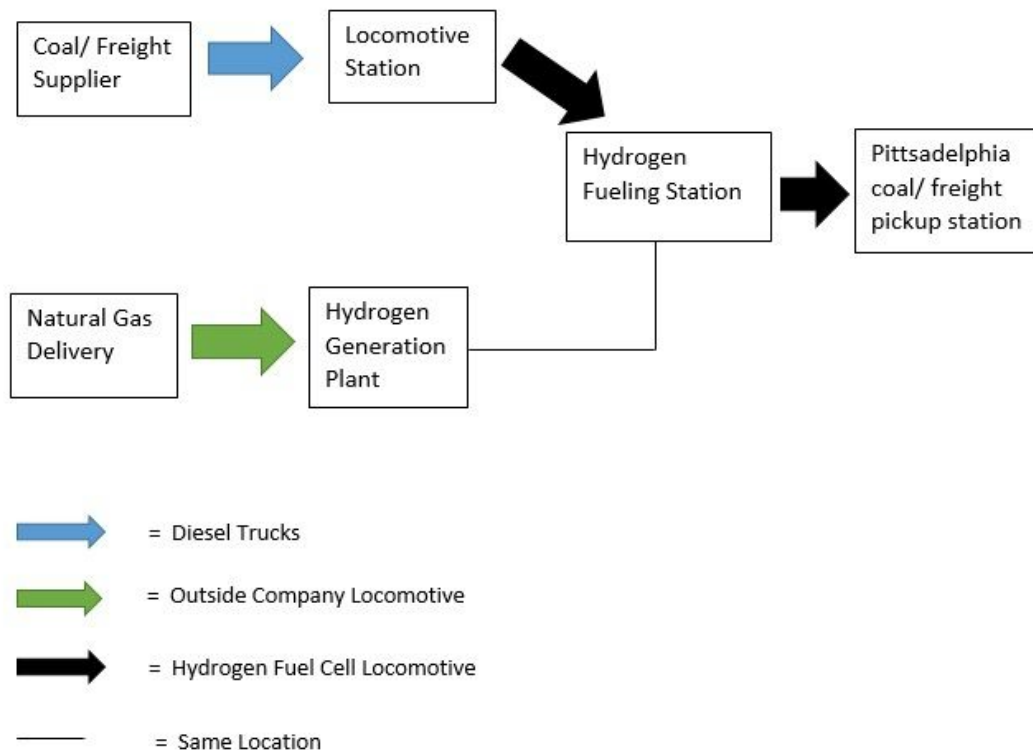
Total Shipping Cost Per Day:

$(\$68,220 + \$121,005) = \textbf{\$189,225 per day}$

FINAL DESCRIPTION:

As we know that the production of the hydrogen nowadays is not completely efficient, but we still believe that the hydrogen fuel cell will be the solution in the long run. According to the report from EIA, about a decade, the production of the hydrogen will be widespread. Therefore, we need to take our time to improve the two big problem: How to storage more hydrogen on the locomotive? How to convert hydrogen fuel into power more efficient? To the first concern, scientists have found some way to develop by BN-methylcyclopentane or magnesium-base alloy to storage the hydrogen. These elements have good ability to absorb hydrogen. Also, when the locomotive needs the hydrogen, we just need to use the system's heat to rise the temperature of the element. To the second problem, we don't need to concern so much because the efficiency have improved year by year. However, somebody will says that hydrogen is a burning quality gas, so it is dangerous to use as energy. In fact, hydrogen fuel is much safer than the diesel fuel which people use today. When the hydrogen burns, it will not produce the ash, and its radiation of heat is low. Also, when the hydrogen unfortunately explode, it will vitalize into the air and have not enough time to burn. Therefore, in the conclusion, we believe that hydrogen fuel cell locomotive is the best solution.

SYSTEMS DIAGRAM:



CONCEPT OF OPERATIONS:

Our proposed transportation concept for the coal and freight that is being shipped to Pittsadelphia uses hydrogen fuel cell powered locomotives. We will build a hydrogen generation plant that doubles as a fueling station for the locomotives. At the plant, hydrogen will be produced using steam-methane reforming and an after treatment to reduce greenhouse gas and NOx emissions that are a result of this process. The use of hydrogen fuel cells to power the locomotives results in no NOx or PM emissions at the location of the locomotive thereby reducing smog in the city of Pittsadelphia.

ENVIRONMENTAL ANALYSIS:

Using hydrogen fuel cells as power for the locomotive produces zero NOx emissions at the location of the locomotive. In the production of the hydrogen there is little to no NOx emissions, even using the steam-methane reforming method. In comparison to the production of hydrogen using this process, the NOx emissions range from 50-100 ppmv. This is significantly less than that of the diesel engines that are currently being used by almost all companies today and it can be contained away from the city where the smog is a problem. Also there is a good amount of research being done to enhance the ability to efficiently make hydrogen from water, which is a renewable process. The hydrogen fuel cell will meet EPA regulations for many years to come because of its low emission on site and the advancement of hydrogen production processes.

ECONOMIC VIABILITY:

In our alternative to current GE diesel locomotives, the viability must be considered. Throughout the whole shipment process, cargo will largely be transported by hydrogen fuel cell locomotives. Initially, the cost for new locomotives with this technology, fueling stations, and plants, the cost is extraordinarily high compared to a diesel aftertreatment alternative. Although one of the most expensive alternatives initially, the switch over from diesel to hydrogen fuel cell now may prove vital to the sustainability of the environment and the danger of not meeting EPA standards. With little to no NOx and PM emissions, GE will not have to worry about EPA standards for decades to come. The opportunity to implement new technology gives GE an edge over customers and a friendly relationship with the government that could provide additional funding to supplement expenditures.

In research from hydrail.org, it is discussed that there are currently around 923 fueling stations and over 100,000 miles of rail. Contrary to popular belief, it will not be necessary to construct 923 new hydrogen fueling stations. Instead, fueling stations can be strategically placed around the country to maximize efficiency. For instance, if only 7 fueling stations are constructed, the distance between two fueling stations would only be 1,000 miles. Increasing to 17 fueling stations will result in a 500 mile range and so on. If a 5,000 gallon train carries around 20,000 tons, it can travel about 1,500 miles on one tank of gas. Therefore, very few fueling stations will need to be constructed. For our problem statement, only three new fueling stations will be constructed: one at Pittsadelphia and one at both the coal and freight supplier. Also, all 50 locomotives will need to be replaced at the cost of \$4 million each. Therefore, the final cost will be around three billion two hundred million dollars (\$3,200,000,000). In comparison to GE's net worth of \$40 billion, the cost of such a system would be around 10% of the company. However, with the help of government subsidies, GE will be able to regain most of its funds while continuing to meet EPA standards and transportation needs.

FEASIBILITY STUDY:

In discussing the feasibility of our plan, multiple factors were considered. Firstly, the relationship of GE and the EPA must be preserved. By adopting a hydrogen fuel cell alternative, emission standards will be met for years to come due to the low output of emissions from the fuel cells. For the adoption of our plan, GE must make a move that influences other locomotive companies and/or the government to support the same concept in order to make a widespread web of the new locomotive. However, GE will be able to meet the requirements of Pittsadelphia with their own revenue. With over \$40 billion in company worth, GE only needs to contribute about \$2-3 billion in order to meet the needs of the EPA and Pittsadelphia. Lastly, public opinion plays a large role in the adoption of a new concept. Pittsadelphia residents expect stable delivery rates with current transportation, reduced smog, and an alternative that is appealing to the majority. Delivery rates will stay up to date with current times as proven by the average speed of a hydrogen fuel cell locomotive. Also, the new type of fuel will almost completely eliminate emissions directly from the locomotive. Lastly, due to the environmental craze, a new type of fuel that drastically cuts emissions will be favored within the city. According to GE, the main concern of public opinion is the smog emissions. However, Pittsadelphia will also consider the cost of plan implementation. Although costly initially, hydrogen fuel cell locomotives will pay off in the long run by meeting EPA standard for decades to come while finding a fuel that has a comparable price to gasoline and diesel.

CONCLUSIONS:

Our final concept has developed through multiple stages of deduction that include individual efforts, research, and refinement. The decision to reinvent the locomotive industry towards hydrogen fuel cells will push others towards the same conclusion. Within our final concept, the logistics have been mapped out in order to display our concept's feasibility. Large-scale production of hydrogen fuel cell locomotives readily meet EPA standards and will pay off in years to come. Also, GE will benefit by not having to worry about EPA standards for a long time due to little to no emissions coming from the locomotives.

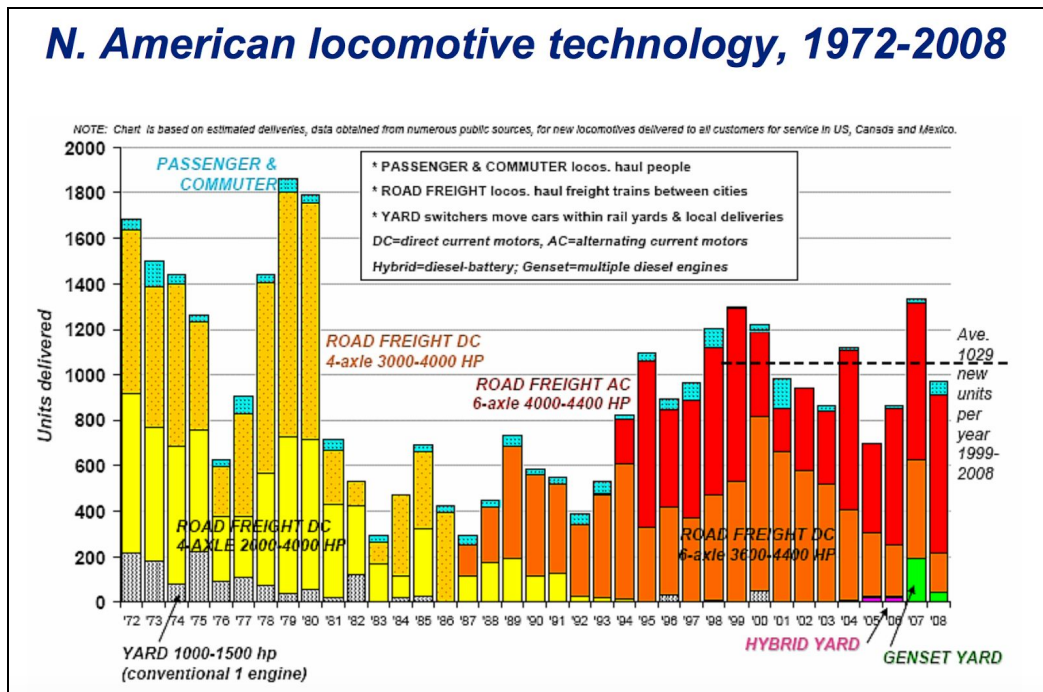
Overall, our team learned the positive and negative aspects of multiple fuel types and shipping methods including emissions, costs, and time management. We would like to pursue our concept in more depth to ensure the financial stability of the plan as well as GE's opinion on our plan for the future. Now, the next step is to continuously increase public opinion and support for hydrogen fuel cell locomotives in order to cause a widespread shift in train transportation. Although not a requirement for the problem statement, our solution includes a plan to expand hydrogen fuel cell locomotives throughout the entirety of the United States and possibly other countries. With increased research and decreasing prices with regards to hydrogen fuel cells, the change over may prove to be a crucial decision in the sustainment of the environment and U.S. innovation.

APPENDICES:

Appendix A - Gas Price Comparison

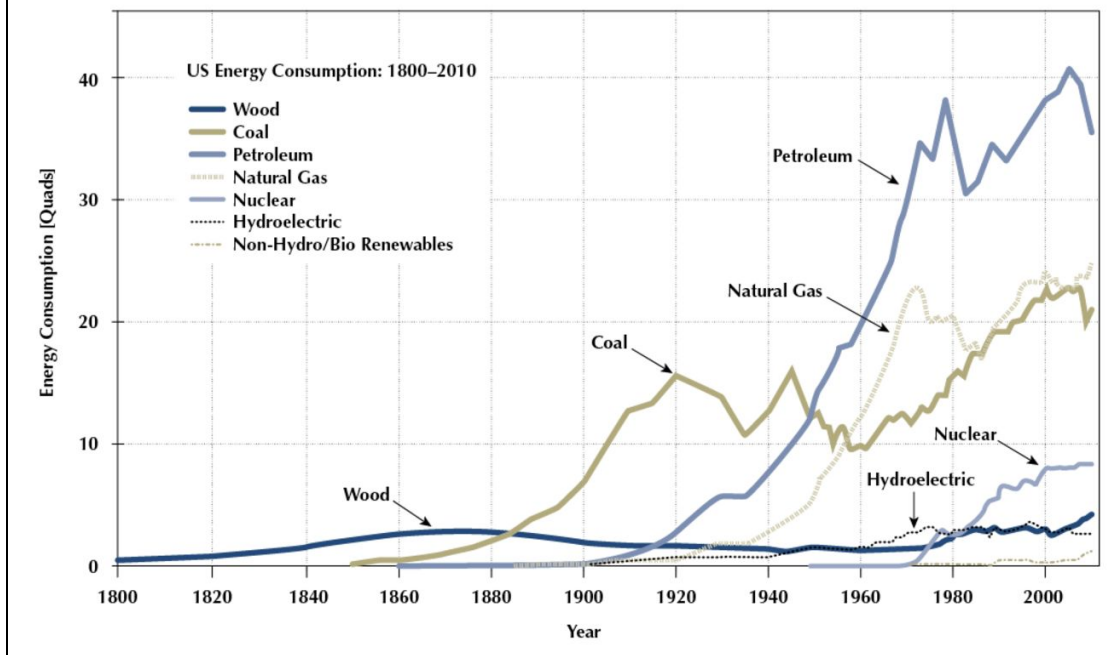
Fuel Type	Price
Gasoline (Gas Turbine)	\$2.42/gallon
Diesel	\$3.06/gallon
LNG (Liquefied Natural Gas)	\$2.92/gallon
CNG (Compressed Natural Gas)	\$2.09/CGE
Biodiesel	\$2.92/gallon (B20) OR \$3.77/gallon (B99-B100)
Low S Diesel	\$3.83/gallon
Hydrogen Fuel	\$3.00/gallon

Appendix B - Current Train Workforce

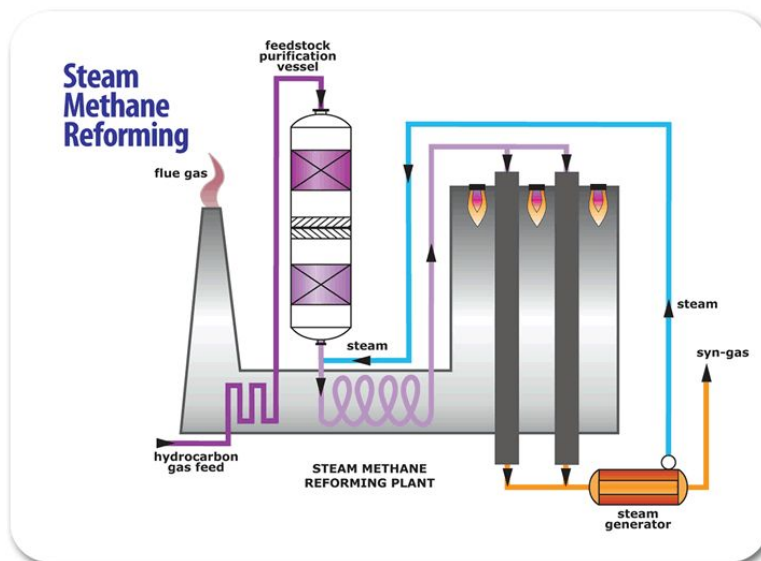


Appendix C - Current Fuel Consumption

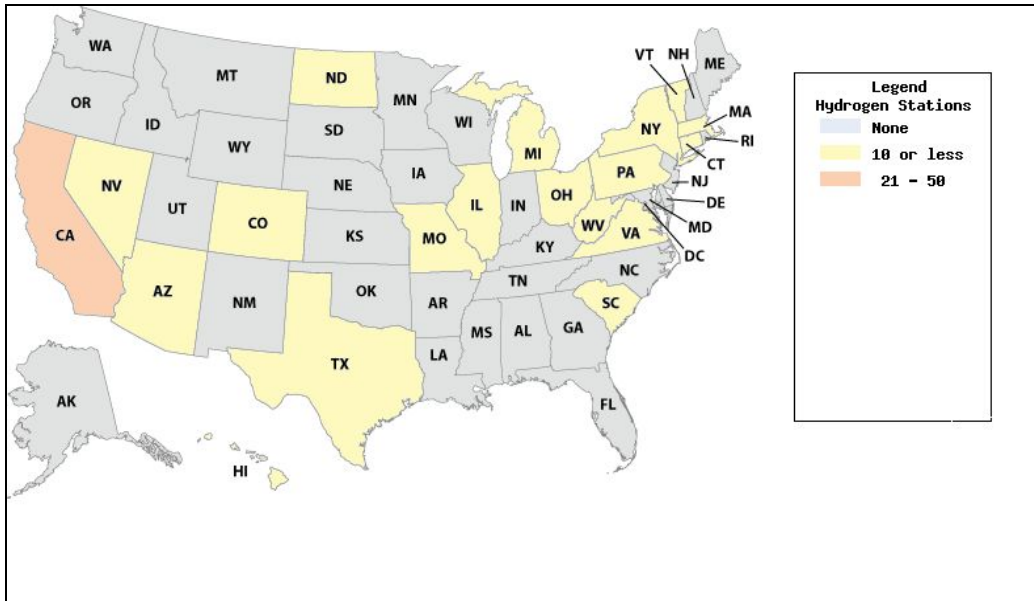
FIGURE 1: Total U.S. Energy Consumption, 1800 to 2010



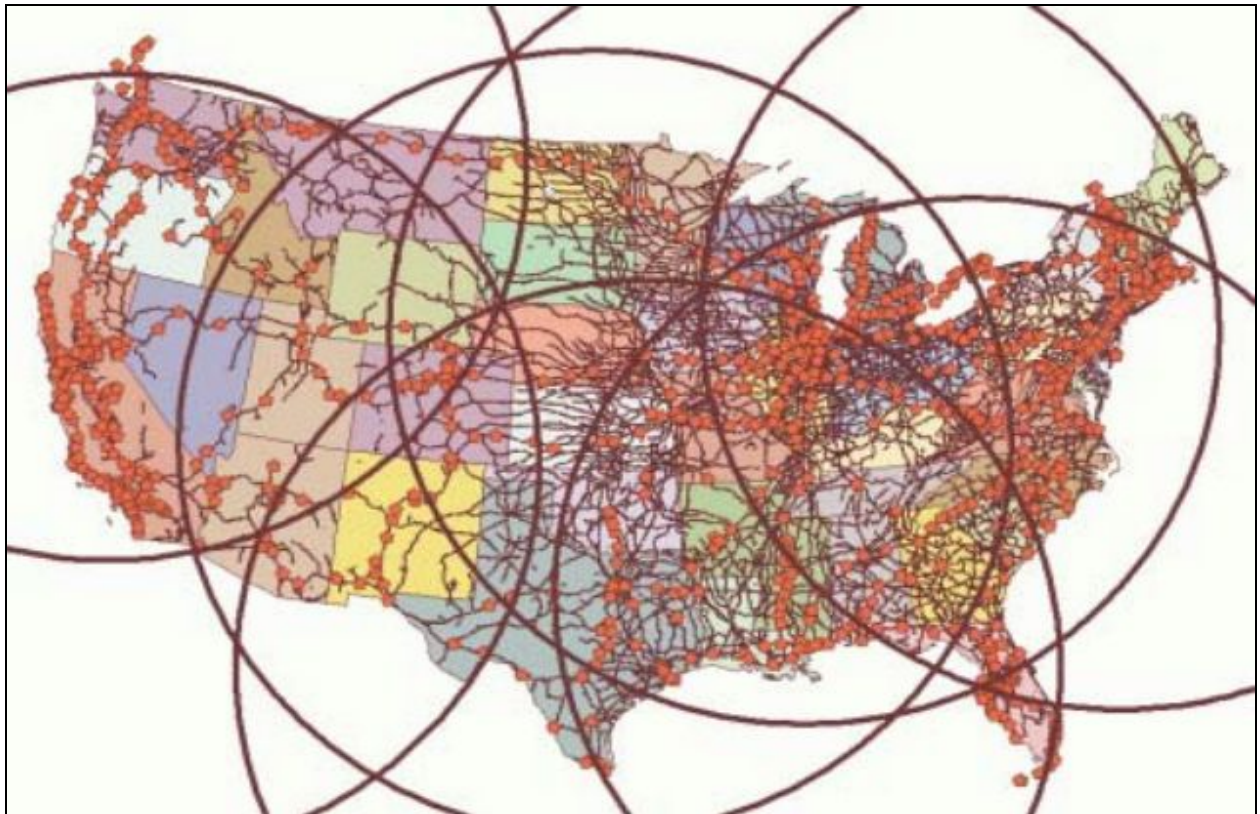
Appendix D - Methane Reforming



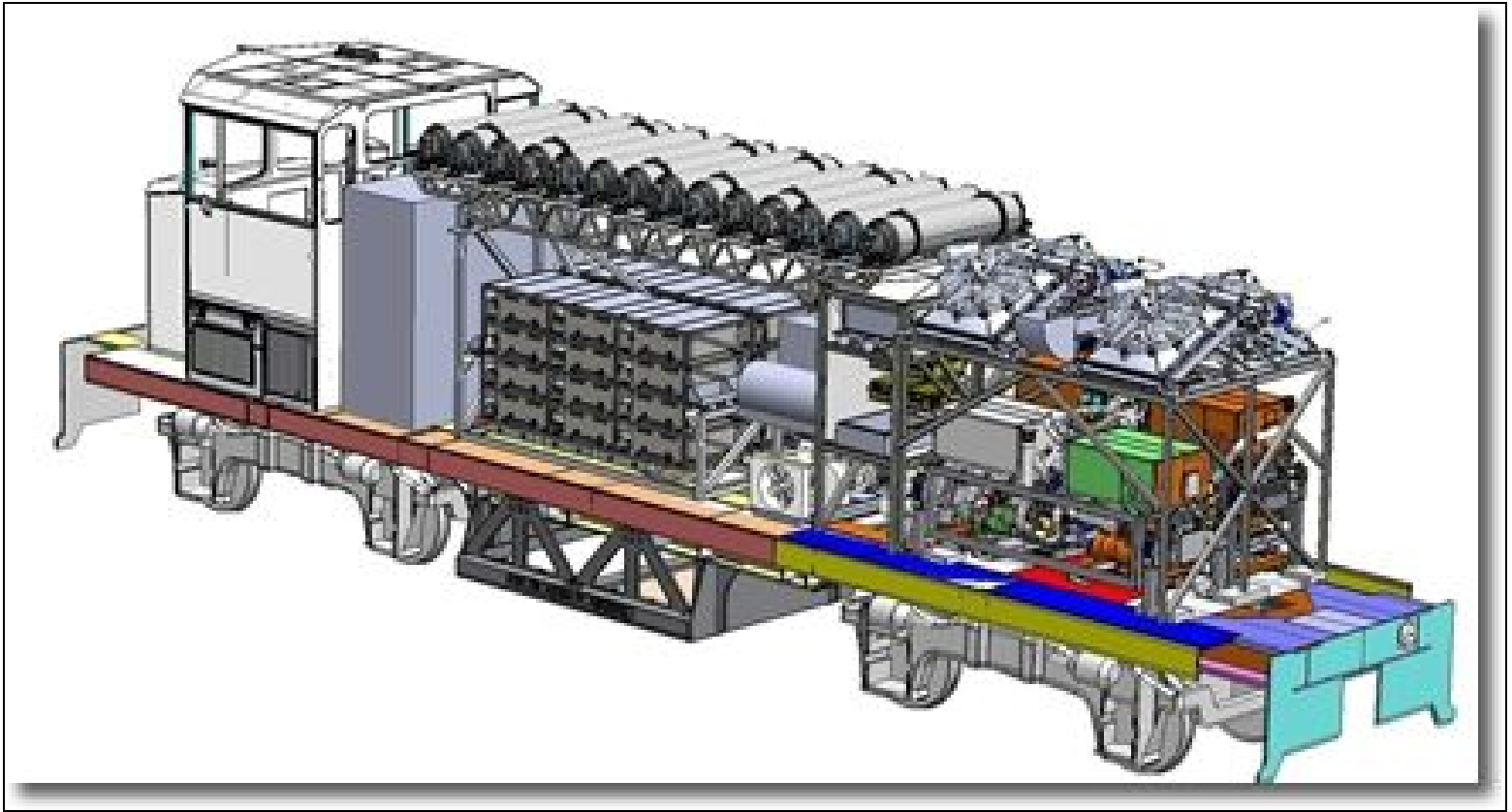
Appendix E - Existing Hydrogen Car Stations



Appendix F - Conceptual Fueling Station Range



Appendix G - Hydrogen Fuel Cell Locomotive



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