Dual Fuel Diesel-LNG Locomotive Engine Redesign

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Abstract

Pittsadelphia is looking to reinnovate the freight industry into a cost-effective shipping system, that helps to reduce smog and meet EPA requirements while at the same time, maintaining freight capacity into and out of the city and also, reduce the time of loading and unloading. The major cause for smog is the emissions of NOx which has become a source of nuisance for the people living in the city. Methods to reducing the amount of smog have been proposed by using alternate fuels or by improving the freight system by other modes of transport like, water, air etc. The question at hand is how can the operating fleet in Pittsadelphia be upgraded to be cleaner and more efficient fuel source. The problem has been solved to some extent by using the dual-fuel engine comprising of diesel and LNG which is seen to be fuel-efficient and also is efficient in terms of cost, maintenance, energy process, temperature and pressure.

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Executive Summary

Problem: Pittsadelphia is investigating a way to transport its freight through a cost-effective system that also meets EPA requirements and has a reduced carbon footprint, while also maintaining efficient freight capacity, freight transportation timing and maintenance of locomotive.

Foundation for proposal:

- Optimizing the use of dual fuel operation using LNG and Diesel
- Cost analysis of converting strictly diesel systems to a dual fuel system
- Environmental advantages and disadvantages of the hybrid fuel system compared to the traditional diesel system
- LNG/Diesel engine emissions being brought down to EPA standards
    - Utilizing the employment of catalytic converters
- Maintenance required for LNG/Diesel hybrid engine compared to a strictly diesel engine

Background Information:

Liquified natural gas (LNG) is a fuel option that is a liquid in its base form that must be stored at extremely low, cryogenic temperatures and upon utilization it is evaporated. One of the benefits of LNG that will be most publicly noticeable is the extreme decrease in smog producing NOx emissions. LNG is an inexpensive, clean, and effective counterpart fuel option that can efficiently cooperate with diesel to make for an overall better system through the use of both fuels. Albeit there are still certain problems that must be addressed and there are many differences existing between diesel and LNG. However, there are ways to simultaneously make use of these energy sources together.

Main Conclusion:

We discovered from our research that the dual fuel engine comprising of diesel and LNG is the most effective source to meet EPA requirements and is a long-term solution to reduce smog emissions and provide a better atmosphere of air for all the citizens living around the city. The cost of running and maintaining the dual-fuel system is quite efficient as LNG is cheaper than diesel and has a higher storage capacity.

Detailed Introduction

Client

The client that approached us to solve the stated problem was General Electric (GE). They are the manufacturers of the freight cars and locomotives being used by Pitts Adelphia for freight transport. The EPA has told them to reduce NOx emissions to tier 4 level and to do this, GE has approached us to find a way to achieve this while also maintaining or increasing freight transportation and efficiency.

Stakeholders

- *Current conditions*
  - Citizens: Residents frequently complain about the massive output of smog occurring in their city. The prevalent smog is a danger to citizens, as many Pitts Adelphians find it to be harmful to their health.
  - Freight manufacturers: They are experiencing a steady amount of freight being bought from them and thus are making a significant amount of their revenue through the purchasing of mass produced resources.
  - Municipal Government: Government officials recognize that there is a detrimental effect of the emissions from the NOx and but are also experiencing a stable expansion in revenue and movement of resources via freight.

- Railroad Workers/Maintenance Crew: Working with diesel engines proves to be a trouble for employees in the railroad system. Currently the diesel used in freight engines corrodes the inside compartments of the rather quickly, meaning that the maintenance crew is constantly at work.

- *Preferred conditions*

  - Citizens of Pittsadelphia: Denizens of Pittsadelphia wish to live in a city in which industries are more environmentally oriented, along with an increase in overall health. This means reduced NOx causing smog and other harmful gases being emitted.
  - Freight manufacturers: They would prefer to have timely perhaps quicker delivery of freight and also undamaged freight. They would want the freight transportation company to follow EPA requirements otherwise there may be unexpected halts to transportation and thus severe effects on their business. They would also want the freight to be cost-effective.
  - Municipal Government: Government would prefer to have much more habitable city and see a noticeable decrease in smog output from the freight industry while maintaining transportation revenue
  - Railroad Workers/Maintenance Crew: Workers in the freight industry would like to avoid the constant cleaning and repair of self-corroding diesel engines.

Product's benefits to stakeholders:

By investigating the fuel efficiency of different fuel sources being used in the engine and looking at the most efficient engine design, we will be able to significantly increase the fuel economy of the engine to allow for greater mileage. This will lead to the decrease in NOx levels

to within EPA requirements while also minimizing visible smog, thus addressing the needs of the citizens of Philadelphia and increasing health standards in the long-run.

For freight operators, the increase in mileage would allow for less time spent refueling the locomotive and thus more time spent transporting freight which will have increase in resource mobility and induce an increase in their revenues due to faster delivery and rate of freight transport.

For the municipal government the decrease in fuel emissions to required standards by the EPA will decrease pressure being put by the EPA on fuel emissions. This will also lead to the municipal government having to cover less costs of the city's citizens being affected by medical by problems as the reduction in emissions will increase overall health and thus decrease medical costs for doctor hiring and maintenance of equipment by the city.

For the rail yard workers, maintenance crews, track and rolling stock power crews, the use of LNG will allow for less engine repair and less fuel cleaning and oil change time. This will also reduce costs of engine maintenance. Also the increased fuel economy will allow for railyard workers to spend less time tending to the engine and will have more time to be able to address other problems on the locomotive and also more time loading and unloading thus allowing for faster freight transport.

<u>Problems to be addressed:</u>

- Incorporating the LNG into the traditional diesel fuel engine design
- Creating a new engine design that could use both diesel and LNG fuel in the most efficient way
- Maintaining the freight delivery speed when the engine is being run on different fuel

- Decreasing the freight delivery time by increasing the power output and horsepower of the engine.
- Reducing implementation costs of engine redesign and also costs of maintenance and repair of the new engine.

Focus of investigation: How to efficiently convert the standard diesel freight engine to a dual engine system that operates on a combination of liquified natural gas as well as diesel.

Research Question: How effectively can the change of fuel system from diesel to hybrid LNG-diesel engine decrease harmful gas emissions while maintaining its stable fuel economy?

Methods, Assumptions and Procedures

Scope of study: The scope of this investigation involves mainly the use of the engine already present in locomotives, a new engine that may be more efficient than the current diesel engine, LNG fuel in place of diesel fuel in a hybrid diesel-LNG locomotive engine.

Stakeholder specific needs: Product must be employed among the fleets in Pittsadelphia to produce much less NOx and CO2 emissions while maintaining the amount of freight/cargo being transported at the same rate it is delivered or even faster. Based on all the needs detailed by each of the stakeholders, the following list of specifications has been created:

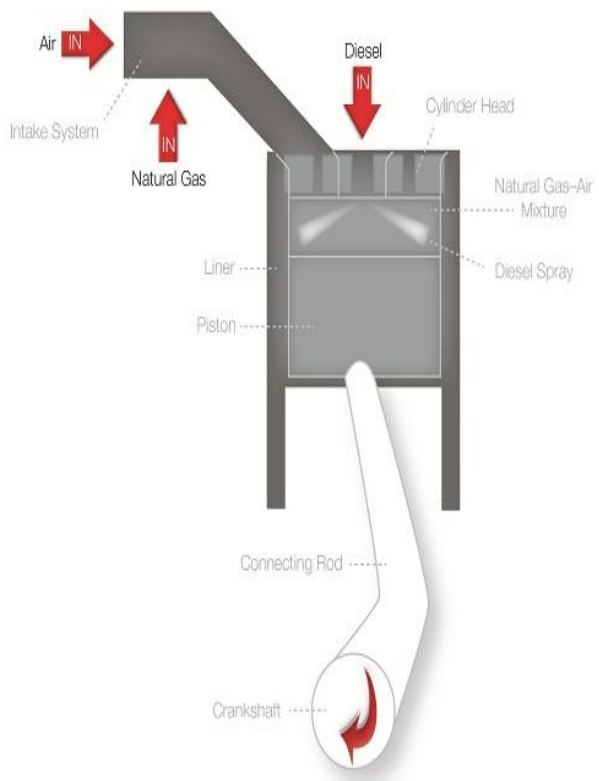
- Solution must be able to lower the amount of harmful gas emissions of NOx and CO2
- Must have capacity to decrease delivery time in various way
- The product must reduce the cost of internal maintenance
- Product must be able to increase mileage of locomotive and therefore decrease amount of time spent refueling
- The new engine redesign has to be safe and viable to use so as to not be an environmental or civil hazard.

Choice of product/process: Arriving to this idea was not something that happened instantaneously. Before deciding that to develop upon the diesel and LNG based dual engine, a few aspects came into consideration. Whether we would choose compressed natural gas or LNG was a big concern during research for this problem; CNG had certain advantages that warranted our attention and the same could be said for LNG. Finally, we analyzed the facts to discern which one would work best with diesel. (LLC, "Why Liquefied Natural Gas")

- Pressure: LNG systems operate at low pressure 25-200 PSI vs 3600 PSI for CNG and can store as much as 2.5 times the fuel in the same space as conventional CNG systems.
- Storage: LNG can store as much as 2.5 times the fuel in the same space as conventional CNG systems, increasing fuel efficiencies and range.
- Horse Power: LNG offers engines that are above 400 HP. Heavy loads must be pulled by LNG. This is because CNG is compressed gas under high pressure and with increased work by the engine, the CNG would explode due to container being unable to handle the pressure due to the gas. LNG on the other hand will not have such a pressure limit as it can be contained under lower pressure conditions and is kept in a very cool temperature.
- Fuel Economy: LNG offers better fuel economy vs CNG who historically tested is 12%-18% less efficient. This means the LNG fuel will provide more distance covered with the same unit amount of fuel than if CNG was used.
- Density: LNG is more dense so you can store more fuel in smaller, lighter tanks that increase efficiencies.
- Fueling Speed: LNG fuels as fast as Diesel at 40 gallons per minute, which is much more efficient compared to other natural gas resources.

Results and Discussion

Details final proposed product/process: Dual fuel engines will have several beneficial applications in the freight industry and especially in Pittsadelphia. The final product is the dual-fuel engine which is supposed to run on diesel and LNG accompanied by a re-gasifying vaporizer. Diesel is used to trigger combustion by pressure combustion but the engine has been optimized to also run on natural gas. The mechanisms of the engine that controls the compression rate is adapted so that the mean effective pressure in the chamber becomes lower. This allows for perfect setting for the injection of a carefully selected natural gas. The overall process takes place as follows: (Cummins Dual Fuel Engines)



1. LNG vaporizer mixes the regasified fuel source with intake air.
2. Diesel provides ignition source, therefore spark plugs are not required
    a. Due to the fragile nature of diesel, the pressurized heat in the chamber of the engine is enough to ignite the diesel fuel, meaning no spark plugs are required.
3. Gas replaces diesel at at 50-70% substitution rate (optimal range for best results).
4. LNG and diesel are combusted as the crankshaft begins to push the piston.

Proposed product/process versus existing: The existing Tier 2 fleet engines run strictly on diesel. This means that these engines are extremely vulnerable to internal corrosion due to this fuel

source and maintenance must constantly be done. Diesel engines also produce high amount of NOx, the compound responsible for the smog that has Pittsadelphia citizens complaining. Although the energy density of diesel is high and it is easily accessible, there are ways to reduce the recoil that is presented by using diesel. Our LNG/Diesel based product delivers the same amount of work as a standard diesel engine while also providing many benefits. LNG is a cleaner burning fuel than diesel, meaning less maintenance and increased fuel economy. Dual-fuel engines are more tempting than liquefied natural gas–only engines, because drivers can revert to diesel if natural gas pumps aren't available or if the price of natural gas goes back up. This is because the dual-fuel diesel LNG engine can use the same traditional diesel engine only with separate fuel intakes. The table below more specifically summarizes the differences between the existing fuel type used in fleets versus the suggested additive of LNG.

	Diesel	**LNG**
Energy content	128,488 Btu/gal	21,240 Btu/lb
Emissions	Heavy NOx output, producing visible smog	60% reduction in NOx compared to diesel usage
Price	$0.97/Liter	$0.11/Liter
Maintenance	Diesel engines requires fine tuning and checking up due to its corrosive nature when in proximity with water	Lower pressure in tank must be maintained. Clean
Resourcefulness	50% of oil used to make diesel is *imported* crude oil	more than twenty underground reserves found all across United States Of America
Autoignition temperature	600°F	1,004°F
Autoignition pressure	Extremely high pressure	Very low Pressure

("Fuel Properties Comparison", US Dept. of Energy)

Due to the extreme differences in pressure and the temperature, strictly diesel or strictly LNG engines will be highly inefficient. Sustaining high pressures along with a lower temperature for ignition is difficult in terms of cost and also require more fine tuned instruments. Diesel engines also require regular check up and cleaning due to excessive corrosion over time.

On the other hand, LNG requires a relatively much lower pressure and also a very high temperature which is also hard to sustain in an engine. The low pressure tank must also be maintained and this will take regular checks of pressure and also a pressure gauge attached and an inspector separately checking the pressure.

However, if we can incorporate both the LNG and Diesel into one dual-fuel engine we will simultaneously be able to reduce the pressure to an average amount of pressure and also bring the temperature to an average between 600□ and 1,004□ ("Why Liquefied Natural Gas", REVLNG). This average pressure along with average temperature will be much easier to maintain. Also, the differences among prices is noticeable, as diesel costs approximately $0.97 per liter in the U.S. while LNG runs for about $0.11 per liter ("Why Liquefied Natural Gas", REVLNG). This dual fuel will have the added benefits of reduced NOx and CO2 emissions and also the LNG will be more readily available in domestic deposits of natural gas.

With LNG, NOx and particulate matter (PM) emissions are lower, thus providing an alternate path to attain Tier 4 standards set by the federal government. The estimated fuel savings for dual-fuel locomotives running on diesel piloted NG could be as high as $300,000/year/locomotive—a substantial figure that's sure to benefit customers in a meaningful way. The cost of operating the dual engine is also estimated to be about 30% less than that of a diesel engine. ("Dual Fuel Engine Conversion.")

Needs/Specifications/Performance: Storage of LNG is an issue that must be addressed if it is to be integrated into the engines of the next tier. The storage type we have focused our attention on is most often referred to as full containment tanks in the professional field of natural gas. These tanks are comprised of a main refrigerated inner tank made of steel surrounded by a secondary concrete tank. The outer tank's purpose is to prevent the escape of vapors while also acting as a liquid containment unit for any runoff ("LNG Storage Tanks").

Firstly, the nature of natural gas, or methane (CH4), is such that the boiling point of the gas is -162 degrees Celsius at standard temperature and pressure (1 atm and 25 Celsius). This would mean that a cooling tank and some form of source providing power for cooling would be needed as well to maintain the liquid state of the natural gas (LNG Storage Tanks, CB&I). In that way, costs will be incurred for making the cooling tank to store the LNG in such a way that it is released into the combustion engine in the state it is kept in. The LNG is kept at its boiling point as any lower will not be cost effective. It is kept there since most of the natural gas is still in liquid form and the refrigeration unit also does not need to use more power to decrease temperature. The gas is also kept at constant pressure which helps to keep the temperature constant. Also the insulation of the tank is done by a concrete outer insulating wall followed by a hard and near pure nickel and steel inner wall to maintain temperature and pressure. Inevitably there is some heat leakage causing the LNG to boil off causing trapped natural gas. However that is used up in the phase change of the surface molecules reduces the overall temperature of the gas causing auto refrigeration. However this excess gas that is collected will need to be investigated and thus for our design we will be fitting a pipeline to a gas tank that will store this excess gas. This surplus of gas will also act as a recyclable source that can also be utilized (*Building Natural Gas Locomotives, O'Connor*).

Advantages of LNG/Diesel over diesel can be found everywhere, such as it could save shippers a whole lot of money and bring down the cost of shipped goods as LNG is considered to be a boom in the United States since it is cheaper than diesel and much more accessible. Another acknowledged benefit is that Engine maintenance will no longer be an immediate issue This is due to the fact that the engines will not be operating on the corrosive diesel fuel. This also means that railyard workers can allot much more time to manage other significant parts of the engine.

Diagrams and process:

Figure 2 shows ("Dual Fuel Engine Conversion") shows the conversion of the diesel combustion engine for locomotives to diesel-LNG dual-fuel engine. In this conversion, the parts circled above are changed in the diesel engine. The exhaust system that is modified to be able to handle the emission of waste products from used LNG and diesel. The air/gas intake system has been modified to reutilize the boil off gas from the LNG in the system and auto-refrigeration. The new fuel injection system is modified to allow for the actual use of the LNG in place of pure diesel fuel ignition. The cylinder head piston connecting rod is modified to provide more efficient compression of the diesel and LNG and limiting waste fuel droplets and unused fuel ("*Cryogenic Fuel for Sustainable Development*", Kumar, Kwon).

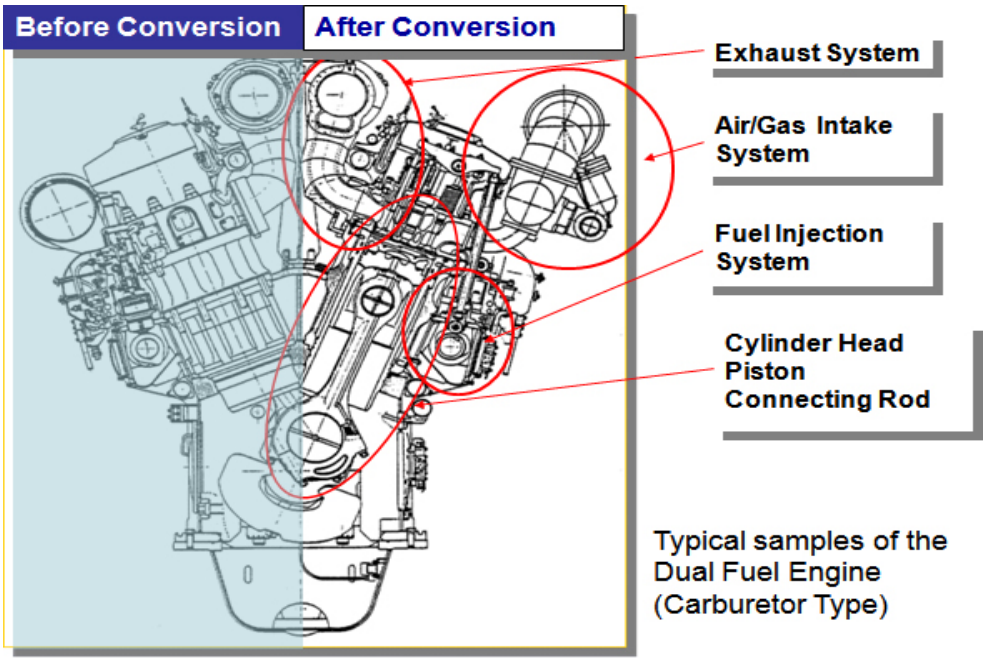
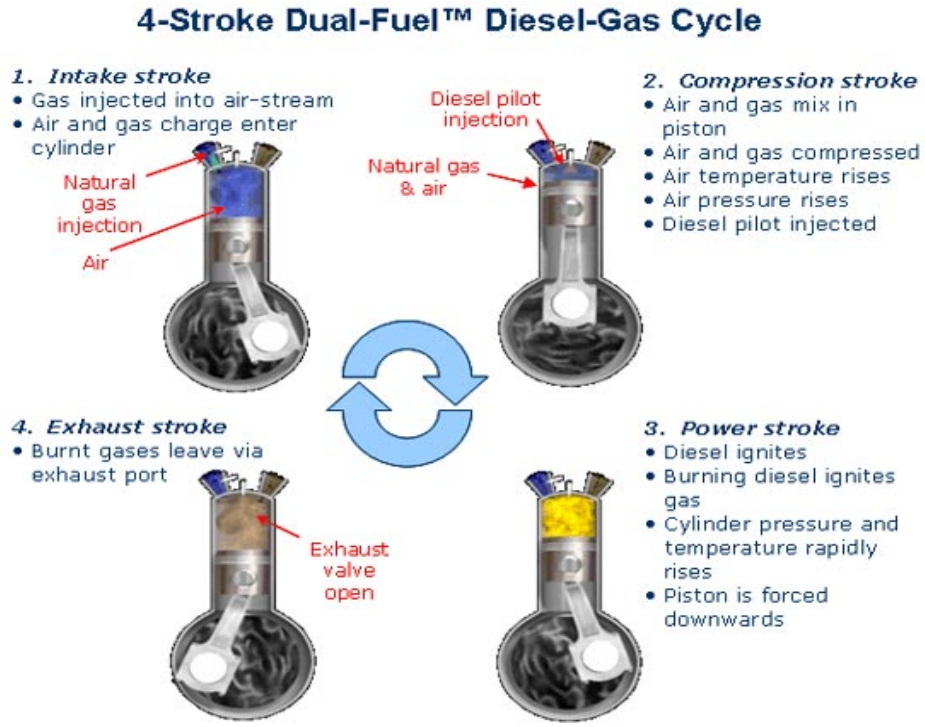


Figure 3; Process of fuel usage in dual fuel engine:



("Clean Air Technology to Power Volvo Truck Engines")

Future research: More research should be done in pertinence to finding the perfect substitution ratio for LNG and diesel in a dual fuel engine. Future research must also be done in finding more efficient storage units for LNG and ways to prevent boil off gas from occurring. Also improvements must be made in finding ways to make the LNG have increased efficiency so that diesel can be used to a lesser amount. This is in part due to the declining amount of oil reserves in the world that are set to run out in the next few decades. Also for further research, ways of implementing finer fuels such as unleaded and oil must be found in order to reduce the use of diesel. This is because diesel takes greater crude oil by kilogram than unleaded fuel or oil.

Conclusions

The research was effective as a solution was found to the problem. The dual engine reduces smog and also involves the use of a much cheaper, cleaner, accessible, and feasible fuel. There was much attention paid to finding a method to reduce smog while also being economic. LNG also uses less amount of fuel per mile travelled by the locomotive making it more fuel efficient in terms of economics, as it will endure longer distances. We are confident that our product will reinnovate the freight industry in Pittsadelphia.

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