A Cost Benefit Analysis of Diesel and Liquid Natural Gas for Locomotive Engines

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Abstract

The booming fracking industry has led to rapid and sustainable growth of the supply of liquid natural gas (LNG), which has significantly lowered its cost, leaving transportation companies to consider switching from expensive diesel fuel to LNG. This analysis is based on the problems associated with fuel use in the freight locomotive industry. There are various ways of defining these problems, but this report identifies the problems as economic costs specific to these fuels, as rail companies look to costs in decision-making. From the combination of economic costs, a scoring matrix was devised to accurately represent the stakeholder's needs and determine whether LNG locomotives are more beneficial than diesel locomotives under current economic conditions or vice versa. A cost-benefit analysis was used to prove that diesel fuel locomotives are more cost efficient at this point in time, but with further research and governmental regulations, the current conditions are subject to change.

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1.0 Executive Summary

1.1 The Problem

Upon continual use of diesel fuel for U.S. locomotives, it was discovered that these large engines are guzzling up money as they release harmful emissions into the air. Compounding the issue, the U.S. is fuel dependent on other countries for diesel which creates a state of instability during times of international conflict. As such, liquid natural gas is at the forefront of alternative energy for locomotive engines. Why now? In a word, price. Liquid natural gas is much cheaper and more easily obtained as there are large shale deposits in the U.S.; but, integrating the natural gas into the current infrastructure proves challenging. An in-depth analysis investigating the economic impacts of liquid natural gas and diesel fuel was conducted to solve this dilemma of determining the optimal fuel for the locomotive industry.

1.2 Resolution Proposed

Both diesel and liquid natural gas were evaluated based on a solely economic framework. As large rail companies are profit maximizing, they seek to lower operating costs as well as improve efficiency. Any decision made revolves around economics—harmful emissions alone fail to sway a company to switch fuel sources, unless the government establishes more regulations. To understand the costs and benefits of each respective fuel for locomotives, they were scored in six areas:

1. Locomotive Investment Cost
2. Infrastructure Investment Cost
3. Operations and Maintenance Cost
4. Fuel Costs
5. Payback Period
6. Service Life

Each of these categories was scored equally on a one point basis. The type of locomotive that had the least cost associated with it for a single category was awarded one point, and the other received zero for that category. In the event of an indeterminate outcome which indicated that the costs associated with the specific category were comparable for both diesel and liquid natural gas, one point was awarded to both locomotive types. The locomotive with the greatest total points was regarded as the optimal option for rail companies under current economic conditions.

1.3 Success

The in-depth economic analysis of both fuels as it relates to the locomotive industry allows for the determination of the optimal fuel for rail companies within the U.S. The synthesis of the weighing mechanism responds to the needs and inquiries of GE, rail companies, and other stakeholders while justifying the basis for the determination of the better fuel option without delving into public opinions or environmental impacts. Solely from an economic perspective, the diesel fuel remains advantageous for rail companies, but LNG fuel is still worth looking into as an alternative. Because of the advancements with fracking and lowering gas costs, the LNG locomotives are a viable option for future locomotives.

2.0 Introduction

2.1 Client and Stakeholders

GE

Looking to reduce costs and still meet EPA requirements, GE is investigating their course of action as it relates to changing their current locomotives models. The company presented potential options including selling the existing fleet and purchasing new locomotives, upgrading their fleet with exhaust and after-treatment hardware, and utilizing alternative fuels (Bunce). With the switch to liquid natural gas as the fuel type, GE must compare the costs of LNG with the costs of their current diesel engines. If the costs outweigh the benefits for liquid natural gas, GE will proceed to evaluate their other options.

Rail Companies

Rail companies are interested in investigating the potential switch to liquid natural gas locomotives; however, safe, reliable, and cost-effective engines that can be fueled by LNG have not yet been developed. Consequently, regulatory and safety requirements for these locomotives across the industry are not set in place. Large rail companies, such as Amtrak, BNSF Railway, Union Pacific Railroad, and CSX Transportation are considering the necessary adjustments to railroad operations with the potential switch in fuel which includes the interchanges with connecting railroads as well as the investments required to integrate refueling stations into existing infrastructure. The rail companies are dependent on the locomotive manufacturers as well as the fuel tank and LNG suppliers. Union Pacific is planning to test LNG as a fuel source for their locomotives in 2016 (Union Pacific).

Locomotive Manufactures

GE's competitors in the locomotive manufacturing industry are also affected by the potential change in fuels. While the EPA continues to raise standards regarding locomotive emissions and energy efficiency, manufacturing companies continue to develop environmentally friendly generator sets. Most of these companies are either looking into liquid natural gas or are in the prototyping phase, as Electro-Motive Diesel Inc. is currently testing a Tier 4 prototype. Their locomotive should be available for purchase during the second half of 2016 (Michael Popke). These companies will continue their research and development as long as the economic incentive remains.

Government Agencies

To regulate liquid natural gas within the locomotive industry, both the Federal Railroad Administration (FRA) and Environmental Protection Agency (EPA) have to approve the locomotives and set standards to maintain safety. In the last couple of years, the FRA has received many requests from rail companies, manufactures, and other interested parties to meet and discuss LNG in the industry. Any locomotive that carries LNG is subject to FRA's statuary authority under 49 U.S.C. Chapter 207, Locomotives, formerly known as the Locomotive Inspection Act (Fronczak, Streicher, Sanders). As more prototypes are produced, the FRA will have to approve designs and monitor testing for the rail companies. The EPA continues to regulate the rail industry with their exhaust emission standards, which currently stand at Tier 4 (see Table 1). LNG locomotives are more favorable to the EPA, as the emissions are significantly less.

Table 1

	Duty-Cycle[b]	Tier	Year[c]	HC[i](g/hp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Smoke (percentage)[m]	Minimum Useful Life (hours / years / miles)[n]	Warranty Period (hours / years / miles)[n]
Federal[a]	Line-haul	Tier 0	1973-1992[d,e]	1.00	9.5 [ABT]	0.22 [ABT]	5.0	30 / 40 / 50	(7.5 x hp) / 10 / 750,000[o]	1/3 * Useful Life
		Tier 1	1993-2004[d,e]	0.55	7.4 [ABT]	0.22 [ABT]	2.2	25 / 40 / 50	(7.5 x hp) / 10 / 750,000[o]	
									(7.5 x hp) / 10 / –	
		Tier 2	2005-2011[d]	0.30	5.5 [ABT]	0.10[k][ABT]	1.5	20 / 40 / 50	(7.5 x hp) / 10 / –	
		Tier 3	2012-2014[f]	0.30	5.5 [ABT]	0.10 [ABT]	1.5	20 / 40 / 50	(7.5 x hp) / 10 / –	
		Tier 4	2015+[g]	0.14	1.3 [ABT]	0.03 [ABT]	1.5	–	(7.5 x hp) / 10 / –	
	Switch	Tier 0	1973-2001	2.10	11.8 [ABT]	0.26 [ABT]	8.0	30 / 40 / 50	(7.5 x hp) / 10 / 750,000[o]	
		Tier 1	2002-2004[h]	1.20	11.0 [ABT]	0.26 [ABT]	2.5	25 / 40 / 50	(7.5 x hp) / 10 / –	
		Tier 2	2005-2010[h]	0.60	8.1 [ABT]	0.13[l][ABT]	2.4	20 / 40 / 50	(7.5 x hp) / 10 / –	
		Tier 3	2011-2014	0.60	5.0 [ABT]	0.10 [ABT]	2.4	20 / 40 / 50	(7.5 x hp) / 10 / –	
		Tier 4	2015+	0.14[j]	1.3[j][ABT]	0.03 [ABT]	2.4	–	(7.5 x hp) / 10 / –	

2.2 Existing Conditions

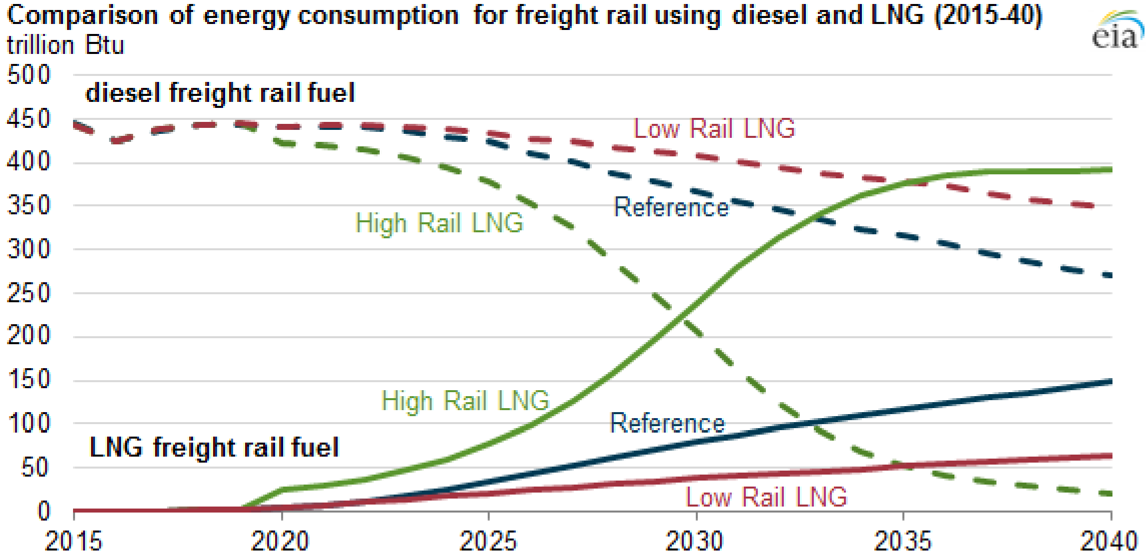
Diesel Locomotives

Currently, there are 561 freight railroads in the U.S. and the seven largest, known as Class 1 railroads, operate about 140,000 miles of track and consume about 7% of total diesel used in the U.S. On average, fuel accounts for about 23% of freight railroad operating costs (AFV Intelligence LLC). These locomotives must now comply with the EPA Tier 4 standards, which necessitates altered locomotive designs and after-treatment hardware. While the diesel locomotive works well within the current economic conditions and current infrastructure within the U.S., diesel is projected to cost more than three times as much as natural gas through 2020, according to the EIA, providing a powerful incentive to switch. The fuel savings could be more than $1.5 million per engine (GE Reports). If LNG locomotives become more cost efficient, companies will begin to switch from diesel to LNG for fuel.

Liquid Natural Gas Locomotives

Locomotive companies have investigated liquid natural gas for decades, but recent advances in drilling have led to rapid, sustainable growth in the supply of gas and resulted in the price of gas decreasing quickly compared to the price of oil. The economics of powering locomotives by natural gas are now very attractive given the significantly lower cost per unit of energy. In addition to fuel cost savings, emissions including NOx and particular matter (PM) are typically lower with natural gas compared to the emission levels of diesel engines, making it easier for companies to reach EPA standards. While LNG is a viable fuel alternative for locomotives, the lack of refueling stations and other infrastructure is stalling LNG locomotive production. The U.S. Energy Administration predicts an increase in LNG locomotives through 2040 (see Figure 1).

Figure 1



2.3 Preferred Conditions

Regulation

To allow companies to proceed with LNG locomotive production, the FRA must establish regulations and testing specifications. Currently, the FRA requires a safety analysis of the locomotive prototype prior to meeting with the company to approve of the design. Once the FRA creates standards for safety, crashworthiness, environmental protection, and fuel tender design, manufactures and rail companies can work together to create a safe and reliable LNG locomotive.

Cost

As rail companies continually seek to cut costs, fuel is the central focus; it is the largest cost in the industry at billions of dollars. Now that LNG is readily available, savings in fuel costs are possible with the switch to liquid natural gas; but, there are a few preclusions. The LNG locomotives cannot operate fully without the refueling stations. Rail companies and locomotive manufacturers need to overcome the additional costs of tender cars for LNG locomotives as well as the infrastructure costs of adding refueling stations. More investment in infrastructure and tender cars will allow these companies to make the fuel switch. The analysis included in this report discloses the costs associated with each locomotive to determine the optimal fuel under current economic conditions.

3.0 Methods, Assumptions, and Procedures

3.1 Assumptions

Within the bounds of our research, there are certain variables that must remain constant to reach a conclusion for the economic scope. While comparing diesel and LNG solely on economic grounds, output and delivery time for the locomotive fleets will exist outside of the scope. In addition, each fuel is fundamentally different in their energy capacities; the energy required to complete the same task for both systems is noted but not calculated in the analysis. This study also ignores public opinion and environmental impacts regarding a fuel choice, as these variables do not directly contribute to empirical cost calculations; however, the EPA and most public opinions sway in favor of LNG locomotives. Lastly, both systems are assumed to comply with any current regulation requirements and meet standards necessary to be legal within the U.S. With these variables held constant, an isolated analysis with respect to the economic costs of each fuel can be conducted.

3.2 Identification of Stakeholders

In an assessment and evaluation of the needs of the people associated with the locomotive industry, it is necessary to take into account the desires of those parties affected. This study focuses on the most economically beneficial method of fueling a locomotive between LNG and diesel. Consequently, the central stakeholders are those who are responsible for purchasing locomotives to run across the country, specifically the rail companies. Beyond the rail companies, other points of view are also taken into account. The manufacturers' ability to make these locomotives with reasonable costs is the largest factor in addition to the need for government agencies to create the legal standards. Cooperation of taxpayers and cities is also necessary for large infrastructure alterations such as the addition of refueling stations.

3.3 Specifications Defined

With stakeholders' conditions considered, the research is broken down into categories of costs that are essential and sufficient in evaluating which type of fuel is more beneficial for current freight locomotive use. Utilizing the School of Energy and Power Engineering's review on multi-criteria decision analysis aid in decision-making (Wang), it was possible to draw a conclusion within the scope. The largest costs to rail companies are substantial enough to represent the existing and preferred conditions of the stakeholders and provide a framework for determining the optimal fuel.

3.4 Grading Criteria

The breakdown of stakeholder needs necessitated a cost-benefit analysis of each fuel type as it applies to current economic conditions. To evaluate the fuel types directly, criteria was established based on largest costs to rail companies divided into six areas:

1. Locomotive Investment Cost
2. Infrastructure Investment Cost
3. Operation and Maintenance Cost
4. Fuel Costs
5. Payback Period
6. Service Life

These categories were determined to be equally important and are weighted accordingly. Each category is scored on a one point basis. If one fuel system had an advantage over the other, it was awarded one point, and the other was given no points. All points were tabulated at the end of the analysis to declare one locomotive as more economically beneficial currently.

4.0 Results and Discussion

4.1 Locomotive Investment Cost

One issue that railroad companies address is the investment in new locomotives. Currently, investment goes toward strictly diesel locomotives, as functioning LNG locomotives have not been developed and approved. In congruence with current EPA standards at Tier 4, both locomotives were held to their standards when considering the investment costs. Most rail companies will have to purchase Tier 4 locomotives if they haven't already. A tier 4 GE locomotive will cost an estimated $4 million (Bunce).

The alternate form of locomotive a railroad company can invest in is a liquid natural gas locomotive. Along with the locomotive itself, an auxiliary tender is required to carry fuel. The total cost of the two combined is $5 million (Slavin and Bunce).

Taking into consideration that the seven largest railroad companies operate approximately 25,000 locomotives, the investment required for liquid natural gas locomotives is $ 25 billion greater than the investment in diesel locomotives nationwide (See Table 2).

Table 2 – Investment Cost Comparison

Type of Locomotive	Initial Cost	Average number of Locomotives Operating	Investment Cost	Comparative Savings
Ge Tier 4 Diesel	$4 Million	25,000	$100 Billion	$25 Billion
Liquid Natural Gas (Locomotive + Auxiliary Fuel Tender)	$5 Million	25,000	$125 Billion	$0

4.2 Infrastructure Investment Cost

Another major issue with upgrading to natural gas locomotives is the investment in infrastructure. This mainly deals with investing in a brand new natural gas fueling station infrastructure. At this point in time, the amount of natural gas produced does not meet estimates that railroads would need to fuel even one quarter of their locomotives (Slavin). Current estimates suggest that natural gas production would have to be seven times its current output to fuel one quarter of the 25,000 class 1 locomotives in operation (Slavin). Building a small scale natural gas fueling infrastructure, approximately 25% of locomotives, is estimated to cost $1.9 billion (Slavin).

Put this figure together with one quarter of our estimated liquid natural gas locomotive investment cost, $31.25 billion, and railroad companies are looking at a $33.15 billion total investment. Given the comparatively small fuel savings with liquid natural gas, it is not likely that railroad companies will upgrade to liquid natural gas locomotives under current economic conditions.

4.3 Operation and Maintenance Cost

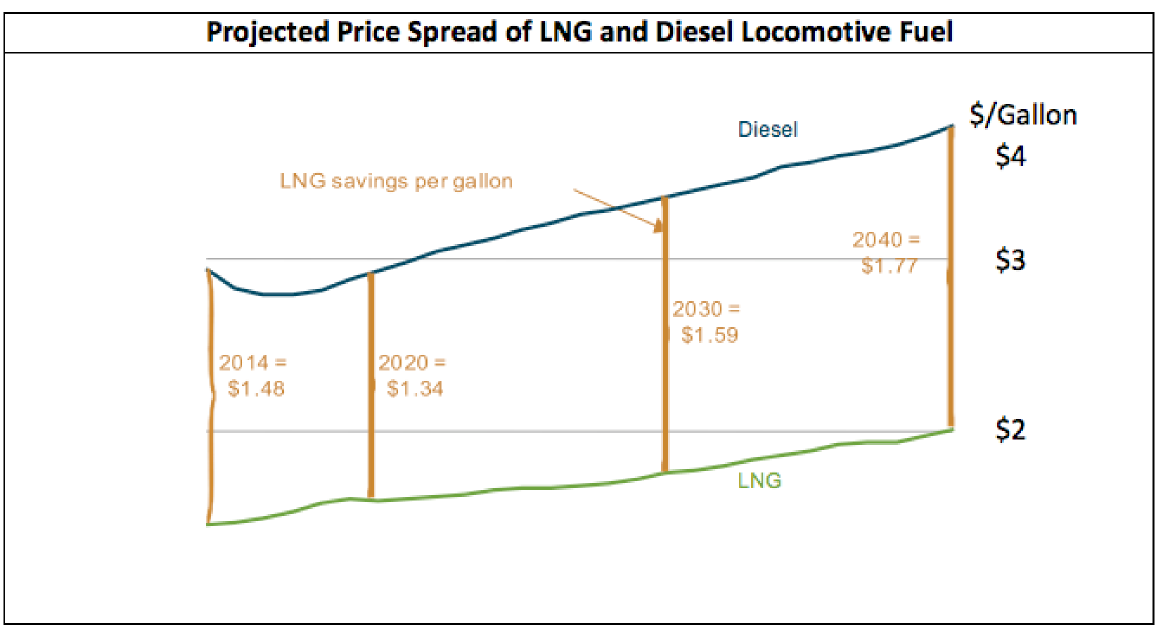
Fuel accounts for about 20% of railway operation expenses (Wesport). The majority of the operational costs revolve around infrastructure necessary to fuel the fleet with LNG. A fueling station large enough to refuel locomotives would cost between $1.4 and $1.8 million (U.S. Department of Energy). In addition, LNG locomotives require an exterior fuel tank (tender car) that is carried along with the locomotive. According to the EPA Alternative Fuel Research Development "LNG can already be delivered at a cost significantly less than diesel which, in high fuel use applications such as locomotives and off-road vehicles, could deliver substantial economic benefits over the life of the vehicle." (Alternative Fuel Data) Though LNG requires more operational costs upfront, the fuel savings will increase over time.

The U.S Department of Energy has conducted studies looking into savings that may be made by converting different percentages of the fleet onto LNG. That direction may have greater returns due to the fewer amount of fueling stations and infrastructure needed. Though the LNG savings won’t occur for several years, the savings can be made over the service life of the locomotives life. Looking at current economic standings, neither locomotive has a significantly greater advantage over the other in terms of the maintenance.

4.4 Fuel Cost

When comparing diesel fuel to liquid natural gas locomotives, the fuel cost is at the center of analysis. In 2014 LNG savings per gallon were $1.48, and with trends represented in Figure 2, fuel savings could potentially reach up to $1.77 per gallon in the next 25 years. Though the LNG fuel itself costs less, the vehicle range is compromised because the volumetric density of LNG is just over half that of diesel fuel (Lee), meaning more LNG is required to power the LNG locomotive the same amount as the diesel locomotive. But even still, the fuel cost savings are much greater for LNG locomotives, and so abundant are U.S. recoverable natural gas reserves that if freight railroads were to convert 95% of their rail energy to LNG from diesel, the price of natural gas would rise by only about 1% and possibly less. EIA projects that over a 20-year period, each new LNG locomotive could produce net costs savings of about $750,000 compared to operating the same locomotive on diesel over the same period. If the 25,000 locomotives are accounted for, the total fuel savings would total $18.75 billion over that same 20-year period (AFV Intelligence LLC).

Figure 2



4.5 Payback Period

From a 2014 study, the total potential LNG demand across the eastern region of the U.S. was calculated to reach 1 billion gallons annually by 2029, which equates to approximately seven times current LNG fuel use for transportation in the United States. This large-scale transition to natural gas would allow users to collectively save $575 million in fuel costs. With regards to the rail industry specifically, if the railroads converted one third of their operations to dual fuel liquid natural gas operations, they would be able to save approximately $2.6 million each day (Gladstein, Neandross). Though the savings overtime substantially increase for LNG locomotives per year, the payback period is still too long to sway most corporations to make the switch to LNG now. Based on fuel cost savings, payback for LNG is approximately 7 years for long haul freight locomotives (Gladstein, Neandross).

4.6 Service Life

In terms of the locomotives themselves, LNG and diesel models are comparable. Most locomotives have an asset life of 20 – 40 years (Gladstein, Neandross); however, most of the diesel engines are being retrofit with after-treatment systems to reach EPA's Tier 4 standards. Once the investment costs decrease along with the payback period, more companies will continue to consider the switch to LNG. For now, the service life is not a significant game-changer for either locomotives. Some companies are considering retrofitting LNG burning designs into current diesel locomotive engines, but even this modification does not have a considerable effect on service life.

5.0 Conclusion

5.1 Evaluation

After analyzing the six economic categories as they applied to diesel and LNG locomotives, the diesel locomotive proved more advantageous for rail companies under current economic conditions by a 33.3% margin (See Table 3).

Table 3

Grading Matrix	GE Tier 4 Diesel	Liquid Natural Gas Locomotive
Locomotive Investment Costs	1 / 1 points	0 / 1 points
Infrastructure Investment Costs	1 / 1 points	0 / 1 points
Operation and Maintenance Costs	1 / 1 points	1 / 1 points
Fuel Costs	0 / 1 points	1 / 1 points
Payback Period	1 / 1 points	0 / 1 points
Service Life	1 / 1 points	1 / 1 points
Total	5 / 6 points	3 / 6 points

While diesel locomotives came out on top after the in-depth economic analysis with a 5 / 6 score, LNG locomotives will be continually researched and prototyped. Rail companies will be more likely to switch fuels once investment costs and payback periods decrease for LNG locomotives and government regulating agencies provide more LNG safety requirements. Once the prototyping and design proposals are submitted and reviewed by the FRA, LNG locomotives will become a fuel option that extends beyond the cost predictions and operational theories. For now, the LNG locomotives exist as an idea and a subject for research and development within the rail industry.

5.2 Further Research and Solutions

Though the comprehensive cost-benefit analysis determined the best locomotive fuel option for rail companies today, the analysis excluded information regarding environmental impacts and the viewpoints of taxpayers, local governments, and other parties outside of the rail industry. The cost of pollution from diesel locomotives becomes a complicated algorithm that accounts for externalities, such as health implications for local residents and damage to property. Additionally, not all Tier 4 diesel locomotives cost the same, as some manufacturers include the after-treatment equipment while others utilize exhaust gas recirculation methods to lower the cost of the locomotives. Overall, both LNG and diesel are beneficial fuel options for locomotives as of now. The 33.3% margin separating the LNG and diesel economic costs will decrease overtime especially as the FRA begins to approve the LNG locomotive designs.

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