Alternative Fuel Vehicles in Heavy Duty Transportation

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CSU- EPA Summer Internship

July 31st, 2015

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Acknowledgements

This project was made possible through the 2013 Memorandum of Understanding between the

U.S. Environmental Protection Agency Region IX and the California State University.

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Introduction

Currently in the United States diesel heavy duty vehicles dominate the transportation sector. Although they are the workhorses of our economy when it comes to overland transportation of goods, the use of heavy duty diesel vehicles poses serious environmental and health risks. There is alternative energy heavy duty transportation available, but they are not widely implemented. Although diesel technologies are well developed and very adaptable, there are alternative technologies that could fit particular niches very well. The goal of this project is to assess and quantify benefits of 3 specific applications of alternative technology vehicles which are, battery electric school buses, and short haul trucks and LNG long haul trucks.

Objectives

The goal of this project is to quantify the benefits of electric and other alternative technology vehicles in terms of economic feasibility and CO_2 emissions compared to traditional diesel technologies. There are two objectives that will aid in this goal. First I will refine and update documents and an excel model John Mikulin has developed to assist fleet operators of medium duty vehicles in determining the benefits of implementing battery electric vehicles (BEV) in their fleet. Then, information from these documents will be used to develop similar documents for liquefied natural gas long haul trucks. John Mikulin will serve as the EPA mentor for this project. The goal of this project is to make accessible tools and information for fleet operators to determine the feasibility in implementing alternative technology vehicles.

For the first part of the project two documents have been updated that John Mikulin has made for assisting fleet operators in determining whether it is cost effective to implement BEV short haul trucks (between 10,001-26,000 lbs.) and school busses in Southern California. These are short documents (2-3 pages) that are meant to have very accessible information for people trying to learn about and implement these alternative technologies. These tools have been made in 2012 and need to be updated to reflect the current market and technologies. An excel model was used to calculate the payback period for BEVs, which has been updated with current information as well.

The next part of the project entails taking that information and tools that were refined in the previous part and adapting them to determine the feasibility of implementing liquefied natural gas (LNG) long haul trucks. This technology was chosen because currently LNG is the only alternative fuel that is really feasible for the long haul trucking application.

The project focuses on the fuel and cost savings, along with air quality improvements. The project is focused around on Southern California, where air quality is a large issue.

Literature Review

Electric Vehicles

Short Haul electric trucks

The trucks that we will be exploring are short haul electric trucks that have gross vehicle weight rating-GVWR of 10,001 to 26,000 lbs. These trucks are classes 3-6. We are looking at short haul electric trucks because electric vehicles are well suited for inter-city short delivery routes. Traditional diesel vehicles do well on the highway where they are going a constant speed where electric vehicles do a lot better with frequent acceleration. Although the main limitation of electric vehicles is short range, trucks that are within the range of a battery charge are excellent candidates for battery electric implementation (U.S. Department of Energy, 2011). Currently there are quite a few large companies in Southern California that have implemented short haul electric trucks into their fleet, including Fedex, Staples, and Coca-Cola. Some manufactures that produce electric trucks are Smith Electric, EVI, AMP Electric Vehicles, Hino Motors, and Zenith Motors. These manufactures produce nine electric trucks between the 10,000 and 26,000 lbs. GVWR that are eligible for HVIP vouchers, which will be discussed later in the incentives section (California Air Resources Board, 2012).

Battery Electric School Busses

School busses are an excellent application for battery electric vehicles because of the nature of the routes they take and the proposed emission reduction. The electric school busses currently in production have a range of 80 to 100 miles and in most cases this is within routes city school busses take. Electric school busses would excel in the acceleration heavy route of a city route. Also electric vehicles are less energy intensive when idling, which is something school busses do a lot (Clements, 2013). Emission reduction would be another huge advantage, especially when transporting younger children.

Currently there is only one school bus that is eligible for a HVIP voucher. This bus is manufactured by Motiv Power. There is two sizes, 14,500 and 22,000 lbs. (California Air Resources Board, 2015). This bus has been implemented by the Kings Canyon Unified School District and has been in use for the 2014-2015 school year. The

Kings Canyon School District has published a preliminary report about the process of implementing the electric bus, but they have not published a full report on their findings (Clements, 2013).

Costs

Initial Purchase costs

Currently the costs of electric medium duty vehicles are quite high. Electric school busses and trucks are in their early stages, meaning low production volume. Cost quotes for traditional diesel vehicles compared to their EV counterparts are shown in table 1. The price estimates for the technologies are significantly higher, on average about 1.5 times more expensive. The electric school bus price is from the Kings Canyon School District and the bus they purchased from Motiv Power and quotes for trucks were found on the CALSTART website.

Table 1- shows sale prices of traditional diesel technologies compared to their electric Vehicle counterpart. (Commercial Truck Trade, 2015), (CALSTART, 2015), (Clements, 2013)

	Diesel Internal Combustion	Battery Electric Counterpart
Class 3-4 truck	$77,000	$144,000
Class 4-5 truck	$102,000	$159,000
School bus	$149,000	$221,000

Another cost associated with implementing an electric vehicle is charging infrastructure. The cost to set up a charging station was estimated to be between $5,000 and $10,000 based on the amount of infrastructure that needs to be installed (CALSTART, 2013).

Maintenance and Operational Costs

Maintenance and operational costs of fleet vehicles are an important consideration, Electric vehicle operational costs are estimated to be lower for a number of reasons. First, the price of electricity for charging electric vehicles, especially during off peak times are very low. For the applications we are exploring the off peak rate of electricity is $0.055/kWh. Estimated efficiency for electric trucks are 1 kWh/mi and 0.7 kWh/mi for class 3-4 and 5-6 trucks respectively (CALSTART, 2015). For the Electric school bus we are exploring the estimate is 1 kWh/mi (Clements, 2013). Comparing the traditional diesel counterparts, trucks get 8-12 mpg and school busses get 5-10 mpg (CALSTART 2015) (Clements, 2013).

Maintenance costs are also projected to be lower than traditional internal combustion engine technology. Electric vehicles require less maintenance items. The electric school bus produced by Motiv Power does not require engine oil, transmission fluid, and engine air and oil filters. Additionally, more costs are saved by having less oil to dispose of and less frequent brake pad changes because of regenerative braking (Clements, 2013).

Electricity rate

Electricity cost for Electric vehicles implementation is important to determine the feasibility of the technology. Southern California Edison has two rate plans that are relevant to this project. TOU-EV-3 and TOU-EV-4. TOUR-EV-3 is for smaller commercial electric vehicle charging infrastructure and TUO-EV-4 is for larger commercial operations. Both of these rate plans are specifically for charging electric vehicles and are metered separately. The difference is in the load capacity. in the TOU-EV-3 plan vehicle load cannot exceed 20 kW maximum capacity and in TOU-EV-4 vehicle load must operate between 20 kW and 500 kW. The rate prices for these two schedules are significantly different also. The rates for TOU-EV-3 and 4 are shown in tables 3 and 4.

Table 2 - Electricity Rates for TOU-EV-3

	Summer	Winter
Peak	$0.36/kWh	$0.16/kWh
Mid-Peak	$0.17/kWh	$0.14/kWh
Off-Peak	$0.09/kWh	$0.10/kWh

Table 3 - Electricity Rates for TOU-EV- 4

	Summer	Winter
Peak	$0.29/kWh	$0.11/kWh
Mid-Peak	$0.12/kWh	$0.09/kWh
Off-Peak	$0.05/kWh	$0.06/kWh

Clearly it is significantly more economical to charge in off peak hours, especially during the summer where the difference in peak hour is about $0.25 for both rate plans.

Emissions

Emission reduction is a very important benefit from electric vehicles that will be taken into account. Although cost savings is a significant motivation for implementing electric vehicles, emission reduction is very important in Southern California where this project is focused. Electric vehicles are considered zero emission by the EPA because there is no point emissions from the vehicle. This is important because air quality in Southern California is a big concern because of all the vehicles on the road and the applications that these vehicles are used. Emissions from electric vehicles come from the power plants in the area, and are generally lower than emissions associated with diesel internal combustion engines. The EPA accepted numbers for CO_2 is 22.5 lbs/gal and 0.661 lbs. /kWh for diesel fuel and California grid electricity respectively. Using the fuel efficiencies of electric school busses discussed in the prior section, diesel internal combustion engines have a rating of 3.7lbs/mi and .661 lbs./mi. So not only is there a huge reduction of point emissions from these vehicles, but the CO_2 emissions for the electric vehicles are still significantly less (CARB, Low Carbon Fuel, 2015).

Incentives

Incentives are important to the implementation of electric vehicles in order to bring down the cost of implementing new technologies. Electric Vehicles are a new technology and will be more expensive than traditional established technology especially in the technology’s early years of production. The big incentives for Electric vehicles are from the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).

CARB and HIVP

The most significant incentive program is initiated by California Air Resources Board (CARB) and is called California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). The objective of the program is to speed the implementation and development of low emission hybrid and electric trucks and busses. They seek to achieve this goal by lowering the cost of buying a hybrid or electric vehicle through a voucher at the time of purchase. The voucher values range from $20,000 and $110,000.

GVWR (lbs)	Base Vehicle Incentive		
	1 to 100 vehicles[1]		101 to 200 vehicles
	Outside DC[2]	Within DC[2]	
5,001 – 8,500	$20,000	$25,000	$12,000
8,501 – 10,000	$25,000	$30,000	$18,000
10,001 – 14,000[3]	$50,000	$55,000	$30,000
14,001 – 19,500	$80,000	$90,000	$35,000
19,501 – 26,000	$90,000	$100,000	$40,000
> 26,000	$95,000	$110,000	$45,000

1 - The first three vouchers received by a fleet, inclusive of previous funding years, are eligible for the following additional funding amount: $2,000/vehicle if below 8,501 lbs; $5,000/vehicle if 8,501 to 10,000 lbs; and $10,000/vehicle if over 10,000 lbs.
2 – 'DC' refers to a disadvantaged community.
3 - This weight range is not intended for vehicles utilizing a pick-up truck chassis/platform typically found in vehicles below 10,001 lbs GVWR. Vehicles at the lower end of the 10,001 to 14,000 lbs weight range will be evaluated on a case-by-case basis to determine eligibility for the full Base Vehicle Incentive.

Table 4 - Shows voucher amounts for weight classes, whether technology is inside disadvantaged community, and number of vehicles purchased (HVIP, 2015).

The voucher amounts depend on gross vehicle weight rating (GVWR) and whether the technology will be implemented inside a disadvantaged community. Table 4 shows a incentive levels for different weight classes of vehicles. Right now there is 19 eligible vehicles for this program. They are delivery trucks and vans, school and transit busses, and a utility truck with a lift (HVIP, 2015). The program is operated on a first come first serve basis and is targeted to fleet operators of all sizes, it is possible to order 1 to 200 vouchers.

The electric school bus model that is eligible for a voucher worth $80,000 for the smaller 14,500 lbs. size and $90,000 for the 22,000 lbs. model. This significant savings puts electric school busses at a very competitive price compared to its diesel equivalent. The trucks within the weight classes we are looking at have voucher values that range from $50,000 to $95,000 (HVIP, 2015).

Natural Gas Long Haul Trucks

Technologies

We will be focusing on liquefied natural gas (LNG) long haul trucks for this part of our analysis. LNG is better suited for our application because it has a higher energy density than compressed natural gas. LNG is produced by purifying and cooling natural gas to -260 F. This process is energy intensive, which increases the cost of the fuel however it makes the fuel a lot more energy dense. The onboard fuel tanks also need to be insulated and stronger than compressed natural gas, which increases the cost. However in the long haul trucking application the increased range of LNG necessitates the extra costs of production and storage.

There are two different technologies for natural gas combustion engines used in long haul trucks, all which can be used with liquid or compressed natural gas tanks. First there is dedicated natural gas engines, which run solely on natural gas. These engines use a spark plug to ignite the fuel in the piston, much like conventional gasoline engines. Unfortunately the spark plugs do not last long in this kind of cycle, so there is higher maintenance cost for these engines. The other option is a dual fuel engine. These engines inject diesel fuel during each compression cycle and compress the natural gas, diesel, and air mix. The diesel then ignites, much like in a conventional diesel engine, then ignites the rest of the fuel in the piston. This eliminates the need for a spark plug in the piston. However these vehicles need a fuel tank for the diesel, thus increasing the weight and complexity of the vehicle (Natural Gas Basics, 2015).

A few different manufacturers make LNG long haul trucks. Cummins Westport is a leading manufacturer of LNG trucks, and is the source of engines for two case studies used in the project. This company is a partnership between two larger truck companies. Cummins, which is well known for their diesel engines, and Westport, which is a leading long haul truck manufacturer. Their engine utilizes a dual fuel cycle, and is a modified version of a Cummins diesel engine. Natural gas engines are also manufactured by Volvo, and Freightliner (J.B. Hunt, 2014)

Costs

The estimate for the cost of a LNG long haul truck came from a couple of different sources. The issue being that most long haul trucks are custom and finding published price quotes for them was difficult. First, there was a LNG truck listed on commercial truck trader for 189,000, with its diesel equivalent priced at 149,000. The second important source was a paper on natural gas in transportation by J.B. Hunt. The paper quoted the incremental cost of natural gas vehicles from $50,000 - $90,000. The cost range is attributed to different packages, including the addition of a LNG tank, which is more expensive than a CNG tank (J.B. Hunt, 2014).

Emissions

The emissions from LNG for CO_2e and criteria pollutants were explored in this project. The CO_2 emissions from combusting natural gas are lower than diesel because is less carbon dense, however sometimes this is offset by the lower energy density of natural gas. The emission factor we found for LNG was 4.46 kg of CO_2 per gallon of LNG. Although this is significantly lower than diesel fuel, other greenhouse gas emissions have higher levels for LNG. CH_4 and N_2O being the significant other GHG investigated in this project, have emission factors of 1.9660, and 0.1750 g/mile respectively (EPA Emission Factors, 2014). LNG has a high CH_4 emission factor because the tanks have a limited storage time that they can hold LNG because it is kept at a cool temperature. As a result, some gas is lost to the venting needed, which is factored in the number given above. Alternatively, for diesel fuel the CO_2 emission factor used was 10.21 kg CO_2/gallon of diesel. The CH_4 and N_2O emission factors are 0.0051, and 0.0048 g/ mile respectively, which are magnitudes lower than the factors for LNG. To convert these numbers to CO_2e the global warming potential values of 25 and 298 were used for CH_4 and N_2O respectively (EPA Emissions Factors, 2014).

Next we looked at criteria pollutant levels. A study done by the California Energy Commission sites a 1-2% decrease in PM, 4% increase to 5% decrease in NOx, and a 70-71% decrease in VOC compared diesel emissions in comparable vehicles. These results are interesting and they point to LNG vehicle emissions not being significantly less than comparable diesel vehicles.

Methodology

In order to determine the economic viability of implementing an alternate fuel technology an excel model was created to calculate the incremental cost and payback period was created. Incremental cost was calculated for the initial purchase costs of the vehicle, and for the yearly operations and maintenance costs. This was used to calculate the payback period and the net present value at the first year. The simple payback period and the payback period with fuel inflation estimates were calculated. Once the excel model was made for the BEV model, it was simply altered for the LNG application. Most of the information used was taken from EPA reports and tools, but information was also taken from other government agencies, case studies and some web sites for market information.

Application

This section discusses the specific inputs used in the model to calculated payback period and incremental costs. Parameters that were used in the model for BEV school busses, Class 3-4 BEV trucks, Class 4-5 BEV trucks, and LNG long haul trucks are shown in Table 5. Costs, incentives, fuel economy, driving behavior and idling, fuel and maintenance costs, and CO_2 equivalence was researched and determined in order to run the model. These values were all taken from the sources discussed in the literature review. Although the information used was not totally comprehensive in all of the costs of ownership, it is a good starting point and guide on the costs of an alternative fuel vehicle. One item to note is that the analysis for LNG long haul trucks did not include any incentives. Although there are some programs in place they are mostly grant based, and the amounts not largely published.

Table 5- The input values used to run the payback period and emissions excel model.

	BEV School Bus	BEV Truck class 3-4	BEV truck class 4-5	LNG long haul truck
Sale Price	$221,000	$144,000	$159,346	$221,000
Registration Fees	$1,876	$1,374	$1,474	$1,876
Taxes	$19,890	$12,953	$14,341	$19,890
Incentives	$100,000	$60,000	$90,000	0
Fuel Economy	0.9 kWh/mi	0.7 kWh/mi	1.0 kWh/mi	5.3 mi/dge
Idling fuel	0.32 kWh/hr	0.233 kWh/hr	0.333 kWh/hr	.74 dge/mi
Miles traveled per year	13,000	19,8000	19,800	150,000
Idling Time	270	411	411	270
Fuel Costs	$0.055/kWh	$0.055/kWh	$0.055/kWh	$2.53/dge
Maintenance Costs	$0.0525/mi	$0.0525/mi	$0.0525/mi	0.150
CO_2 emissions	0.611 lbs/kWh	0.611 lbs/kWh	0.611 lbs/kWh	16.69 CO_2/dge
CH_4 emissions	7.123×10^{-4} lbs/kWh	7.123×10^{-4} lbs/kWh	7.123×10^{-4} lbs/kWh	.1084 lbs/mile
N_2O emissions	1.797×10^{-3} lbs/kWh	1.797×10^{-3} lbs/kWh	1.797×10^{-3} lbs/kWh	.1150 lbs/mile

Results and Discussion

Although Initial purchase costs are high, we found all technologies to be less expensive with incentives or have a payback period within the life expectancy of the vehicle. Table 6 shows the results of the excel model run for BEV school busses, BEV trucks, and LNG long haul trucks. BEV vehicles had a pretty solid economic incentive but LNG trucks did not have as great of results. For the BEV school bus and class 5-6 truck, the initial incremental cost was even lower than the traditional diesel. When you factor in the operational savings over the lifetime of the BEV vehicles, a large cost difference is clear. The largest net present value was for the class 3-4 trucks, which was $102,334. These values was much higher than anticipated, which indicates that these technologies are solid investments. For the LNG long haul trucks, the payback period was seems short but relative to the typical lifespan of these kinds of trucks, which is usually 4-6 years, the payback period of 3.1 years is pretty long. For these trucks there was a cost savings in the fuel price, however it wasn't that much of a difference so the total miles driven is really critical to determine if these technologies are economically viable.

Table 6 - Incremental costs with incentives and simple payback period for the alternative fuel vehicles discussed.

	BEV School Bus	BEV Truck Class 3-4	BEV Truck Class 5-6	LNG Long Haul Truck
Incremental Cost (*Traditional Diesel $ - alternative $*)	$-15,169	$19,446	$-21,216	$66,234
Payback Period	Immediate	2 years	Immediate	3.1
Net present Value	$59,095	$102,334	$89,055	$24,672

The reduction in CO_2e emissions were also pretty significant. The yearly savings based on fuel usage, emission intensity, and miles driven are shown in Table 7. Interestingly, the weight savings values for CO_2e are very close to each other considering the difference in mileage and use. Although the percent savings vary a little more drastically from the BEV to the LNG technologies where the LNG long haul trucks were only found to have a 6% reduction in CO_2e at the lower end and the BEV school bus had an 82% reduction in CO_2e.

Table 7 - CO_2e yearly emissions saving comparing alternative technologies to diesel. The values are given in lbs. savings per year and a percentage. Although the weights are strikingly similar the percentage difference is very drastic.

	BEV School Bus	BEV Class 3-4 Truck	BEV Class 5-6 Truck	LNG Long Haul Truck
CO_2 e (lbs.)	42,386 (82%)	43,373 (81%)	45,134 (75%)	36,506 (6%)

Conclusions

This project set out to quantify the benefits and determine the economic feasibility of various alternative technology medium and heavy duty vehicles. The technologies investigated were BEV school busses, BEV short haul trucks, and LNG long haul trucks. The results from the BEV busses and trucks were clear, there was a large reduction in CO_2e emissions and the costs with the current incentives is very low. For the LNG long haul trucks, we determined they had a payback period for the investment, however it was close to more expensive than the traditional diesel. In addition, the CO_2e difference was not that large for LNG trucks. If a fleet was looking to expand and needed a vehicle for in city use, it would be wise to investigate if battery electric or natural gas vehicles fit their usage.

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