ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

Commercial Truck Fuel Economy and Emissions Technology Assessment

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Introduction

The current political administration in the United States has created the first ever fuel economy and efficiency program with the goal of reducing Heavy Duty Truck Emissions [1]. Commercial trucks currently account for 4% of the total traffic on the road however; they contribute to nearly 20% of all fuel usage and a total 20% of the emissions produced by all vehicular products used on the roadway [2]. Although emission reduction and efficiency requirement increases are common place in the consumer vehicle market they have not been applied to the Commercial Truck segment before the recent implementation of performance standard. In the transportation market Commercial trucks, also known as Heavy Duty Trucks represent the fastest growing contributors to greenhouse gas emissions. This fact can be attributed to the fact that other transportation sectors, such as light vehicles such as cars, and pick-up trucks have had GHG targets to meet due to the oil crisis of 1973. Having first implemented these standards in 1975, the goals of these requirements are to reduce energy consumption by dictating energy efficiency in automotive products[7].

The problem with this approach of improvement is that Commercial Trucks are the primary method of shipping within the United States, accounting for nearly 60% of all intra-county transportation [2]. Therefore any increases of costs that shipping companies bare would therefore be felt in the costs of products and ultimately financed by end item consumer. Additionally, this program could potentially drive down the sales of new Heavy Duty Truck, therefore influencing companies to repair current fleet vehicles instead of replacing them with new efficient products. Some of the emissions that this standard is aimed at reducing are listed in the following table; additionally a description of the elements is also included [8].

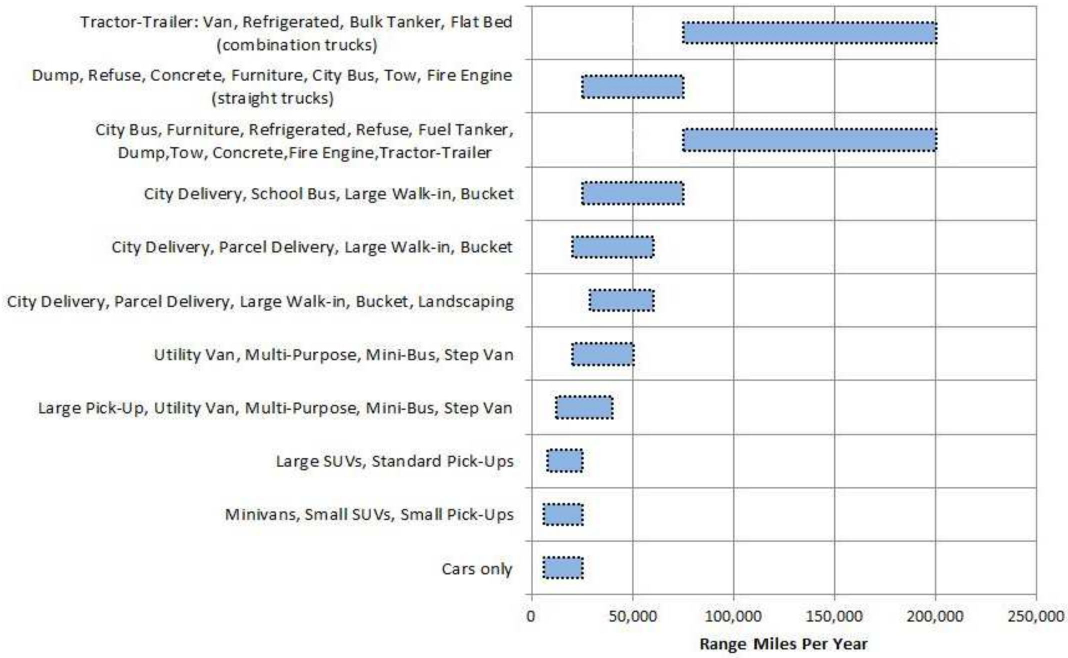
Table #1: Emission Elements and their Descriptions

Element	Description
Carbon Dioxide [3]	CO2 Occurs naturally in the carbon cycle, being emitted from combustion and the exhalation process. In this cycle Carbon Dioxide is removed from the air naturally by the oceans and growing plants. The concern about this element revolves around the fact that its presence is 35% higher than the pre-industrial revolution levels.
Methane [4]	CH4 is a greenhouse gas that is produced naturally in the environment through the decomposition of matter in landfills, and by the partial combustion of hydrocarbons. Methane will remain in the atmosphere for approximately 9-15 years, and is 20 times more effective at trapping heat in the atmosphere as carbon Dioxide.
Nitrous Oxide [5]	NO2 is an element that originates from many sources such microbial action in wetland, and

	though soil management processes, however 8% of all Nitrous Oxide produced by non-natural means comes from combustion purposes. As compared to carbon dioxide, Nitrous Oxide is 120 times more effective at trapping in atmospheric heat.
Hydro fluorocarbons [6]	Also known as HFC's, they are hydrocarbon elements that contain only Hydrogen, Fluorine, and Carbon atoms. They do not deplete the ozone layer as other fluorocarbons do however; they contribute to greenhouse gas build up.

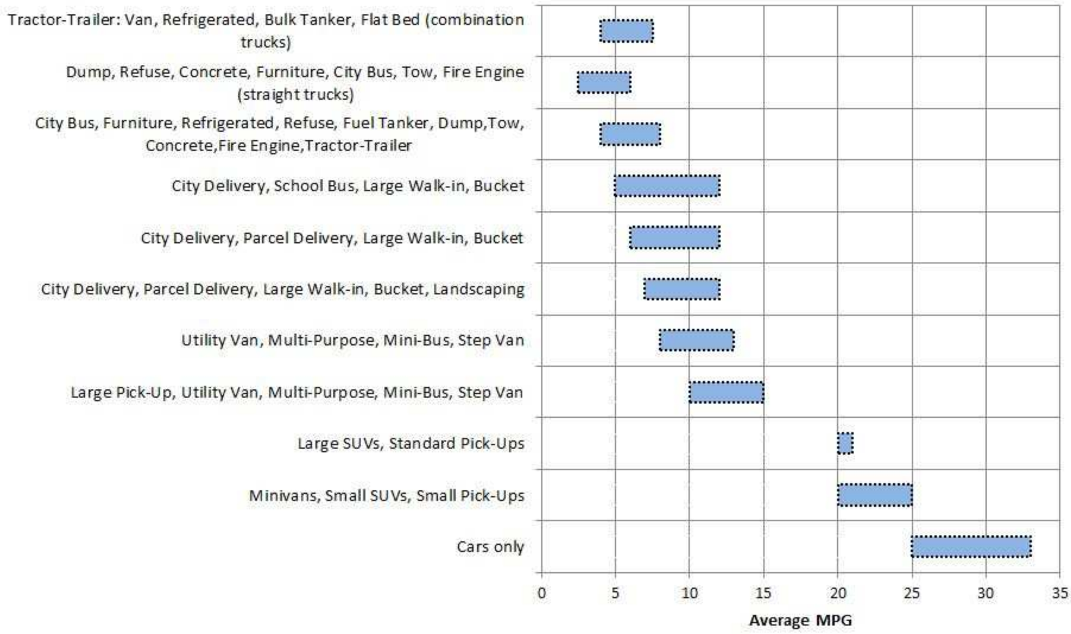
There are several topics that need to be discussed in order to understand the problem of efficiency with respect to the Commercial Truck segment. Since the purpose of trucks is typically the delivery of products, the miles driven per year of the market segment is of importance. As indicated by the following figure the miles driven per year in this market are nearly five times greater for the segment Commercial Trucks with tractor trailers, as passenger cars [8].

Figure #1: Miles Driven per Year by Vehicle segment



Another important element of discussion the miles per gallon (MPG) of the different segments of vehicular transportation. This element is of importance since there are different functions for each of the segments and the differences should be understood in order to analyze the market effectively. As indicated by the following figure, heavy duty trucks have a range of 4 and 6 MPG, whereas the passenger cars are between 25 and 32 MPG [9]. Therefore Heavy Duty Trucks consume approximately 500% as much fuel as much as the passenger vehicle segment per mile traveled.

Figure #2: Miles per gallon of different vehicles segments



In summary, the problem that the Commercial Truck industry faces revolves around the fact that vehicles operate more miles than any other on road vehicle, and get the worst MPG of any other segment. Much of this problem points to the function of the equipment, however the combination of these elements has created the need for the NHTSA and EPA to combine efforts and put together a program that requires the reduction of GHG emissions resulting from the Heavy Truck industry. Therefore, the industry may require commercialization of technologies that solve the problem of GHG reduction. The goal of this paper is to identify the technology that is most widely accepted by the industry as the tool that can be utilized to reduce GHG and increase fuel efficiency.

Market Analysis

The analysis methodology that was utilized to determine the technology that could be utilized to reduce GHG emissions while concurrently increasing fuel economy was the application of Linstone's perspective analysis [28]. The perspectives that are analyzed below are technical, organizational, and personal. The areas of analysis are broken down into three separate areas which are the identification of needs, capabilities, and the defining on technological gaps.

Identification of Needs

The following table identifies the current needs that future implementations in the Commercial Truck market must accomplish in order to reduce fuel usage and increase efficiency. Ultimately, these needs must be addressed in order for new technology to be commercialized.

Table #2: TOP analysis of Needs

Technical	Organizational	Personal
Reliable & dependable Efficient Use of Fuel	Technology must incorporate into the existing trucks Reduced emissions of atmospheric pollutants (EPA Regulation) Reduction of carbon dioxide emissions Not dependent on petroleum	Safe to use and operate Operation and use should be similar to current system Reduced Purchase Price for the Consumer

As indicated by the above table many of the needs of the new systems are organizational in nature since they are being driven by performance standards that are enforced by the governmental organizations. It should be noted that whatever technology is commercialized, the system has several personal items that must be addressed. These items indicate that the system must be as good as or better than the current diesel technology utilized in the market, and that consumers have the expectations that new product will perform better than the current products.

Identification of Capabilities

The following table identifies the current capabilities in the Commercial truck market. The capabilities as listed indicate the products are being introduced or researched in order to accomplish the goal of reducing GHG emissions and increasing fuel efficiency.

Table #3: TOP analysis of Capabilities

Technical	Organizational	Personal
Advance power train implementation - Battery Electric Vehicles - Hydrogen Fuel Cell - Partially Hybrid Electric - Improvements to the Internal Combustion Diesel Engine	Environmental regulations are driving development in the market Current technology is tied to support infrastructure	Electric energy is based on cleanliness of energy type in region New technology implementation of fuel cell usage

As indicated by the above table the capabilities of the new technologies being introduced are in the technical areas based on electric systems, fuel cells, and improvements to the current diesel system by utilizing alternative fuels such as bio-diesel or addition of system controls. Additionally, the organization perspective indicates that the solutions that are being developed need to be supported by the current infrastructure in order to refuel and operate efficiently.

Identification of Gaps

The following table identifies the current gaps that future implementations in the truck market must accomplish. The gaps are identified by linking the current needs with the current capabilities in the market.

Table #4: TOP analysis of Gaps

Technical	Organizational	Personal
Scaling of Technology to bring cost down Durability of Systems Size of the implementation Tolerance of sub-zero conditions with fast start-up from subzero condition Storage capacity Limits	Market segmentation and the creation of niche customer based in regional areas where the infrastructure exists Major Player customers Infrastructure & distribution	Exposure to fuel cell technology and the solutions that the technology can provide to the current market Cost of complete system needs to be reduced.

Limited operation range		

As indicated by the above table the technology gaps exist primarily on the technical side revolving the application of the technology into the current packaging space and the operating conditions and the performance of the technology. From the organizational perspective technology commercialization can be achieved through market segmentation in niche regions where the infrastructure exists or through the involvement of a larger player or trucking company to help push commercialization.

Potential Technologies

As indicated by the current capabilities identified above, the technologies that will be analyzed are Diesel Internal Combustion Engine, Battery Electric, Hybrid, and Fuel Fell Technologies. Each of the items will be discussed individually below.

Diesel Internal Combustion

Diesel Internal Combustion Engines (ICE) has been dominating in the commercial market since its introduction in the mid-1850s. In internal combustion engines high-pressure and high-temperature gases are produced by combustion of fuel with an oxidizer in a combustion chamber [14]. The force generated by these high-pressure and high-temperature gases moves components of the engine to create useful mechanical energy. Diesel ICE are primarily used in commercial trucks, where the low-stress, high-efficiency cycle leads to much longer engine life and lower operational cost that are around $0.72 per mile [15].

On the performance side, most of the highway commercial trucks are equipped with large diesel engines ranging from 127 to 448kW with respect to power generation[17]. Even though the capacity of the engine contributes to a high performance, the downside of it is that it consumes large amounts of diesel fuel and emits large amounts of greenhouse gases. With the increased government EPA standards and demand for fossil fuel, it is clear that now it is the time to find alternative fuel types to power the commercial truck market.

Battery Electric

Rechargeable batteries have been around since 1859 when they were invented by Gaston Plante, a French physicist. This original technology was created utilizing a lead anode, a lead dioxide cathode and a sulfuric acid electrolyte. A rechargeable battery works in the same fashion as a regular battery, in which the anode material is consumed and transferred to the cathode, only the process in a rechargeable battery is reversible [11]. The discussion of battery technology points to the use of Lithium Ion Batteries in the application of vehicular products. This direction is based on the higher energy density of lithium ion as compared to other rechargeable batteries, meaning that they can store the most energy per unit size or weight of the battery pack [12]. It has been determined that in passenger vehicles with larger battery packs perform better than others due to the extended range of the system [10].

An important discussion regarding battery technology is the valuation of the total emissions of the system, including the GHG produced from the manufacturing of the battery and from power plant emissions resulting from the creation of electricity. Essentially, the total cost to the owner was lowest for battery electric vehicles in regions where the primary source of energy is from green sources such as hydro-power and the gas price is estimated to be high [13].

Battery Electric vehicle can be used for the Heavy Duty trucking industry to meet the requirements of being zero GHG emitting however, this element depends on the source of the energy that is used to charge the battery system. Therefore, the owner/operator would need to know what type of electrical source was utilized in the community in order to realistically achieve zero GHG emissions.

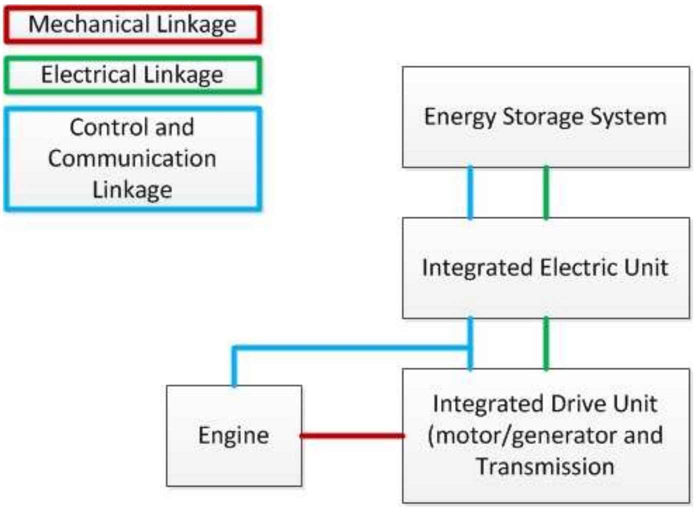
In terms of capabilities, Battery Electric Vehicle has an operation range between 40 and 100 miles of and a top speed of approximately 90 mph [16]. Fully loaded with (60,000-lb) the Battery Electric Truck would have a reduced range of operation in the window 30 to 60 miles total using 2kW-h/mile [16]. Some of the negative aspects of this technology are also the charge time, which can be 8 hours plus, depending on the electric hook-up voltage, and are relatively expensive to produce the batteries. Additionally the charge and discharge of batteries is only 60% efficiency in, therefore, energy is lost during operation.

Hybrid Electric Vehicle Technology

A hybrid electric truck uses the hybrid electric vehicle (HEV) technology that combines an electric motor with an internal combustion diesel engine. As the global economy is slowly boosting, heavy duty and light duty truck manufactures are now paying more interest in looking for new technologies that could provide alternatives for rising cost of diesel fuel while keep up with the increasing EPA emission standards. Plug-in hybrid

(PHEV) and hybrid electric (HEV) are the two most popular types of technologies that truck manufactures are currently using for heavy duty commercial trucks. HEV technology is a good alternative to avoid increasing demands for fossil fuels and its cost.

Figure #4: Hybrid drive Parallel Propulsion System [29]



In terms of performance, hybrid electric vehicle emits 20-70% less greenhouse gases compared to the diesel internal combustion engines and can save up to 30% of the total fuel consumption [19]. The recent test also found that HEV increase the total fuel efficiency by 10% as compared to current diesel ICEs [21]. Even though hybrid electric trucks have many technological advantages over conventional trucks, the biggest challenge for hybrid truck commercialization is its high cost. These trucks can cost 40-70% more than the fuel only models [22]. Apart from that, currently batteries cost roughly $800-$1000 per kilowatt-hour, but to transport heavy loads trucks requires 100-150kilowatt-hour batteries which can be very expensive [22]. After all, the operating cost of HEV is $0.60 per mile and that is $0.12 less per mile compared to conventional diesel engines [23].

Hydrogen Fuel Cell

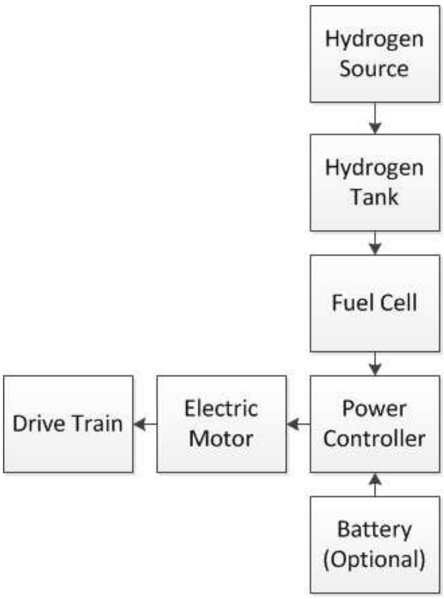
A fuel cell is an electrochemical device that combines hydrogen fuel with oxygen to produce electric power, water and heat. The difference between a battery and fuel cell is that fuel cell needs a continuous supply of hydrogen and oxygen to run and it can produce electricity as long as it receives inputs. Currently, there are several types of fuel cell systems under development with their own advantages and limitations.

Polymer Electrolyte Membrane (PEM) fuel cell is the cost common system that has been developed over the last few years. Alkaline, Molten Carbonate, Phosphoric Acid, Solid

Oxide, Direct Methanol, and Regenerative fuel cells are the other types of fuel cell systems that are being developed for different type of purposes.

One of the main advantages of fuel cells is that since it generates energy through an electrochemical process it produces no harmful emissions. In fact, the water produced by the systems is so clean that humans can consume it. Another advantage is that since Hydrogen is widely available in the universe it can be used to produce almost unlimited amount of energy at a relatively low cost. Some of the other advantages of fuel cell technology are that it can perform well under all weather conditions and is highly fuel efficient. It is 25% better than the conventional spark-ignition engines and the maximum output is 15% higher than gasoline engines [24].

Figure #5: 2010 Hydrogen Fuel Cell Powertrains [30]



Even though fuel cells have many advantages, one of its biggest disadvantages of the technology is its high cost. According to the 2010 DOE data, manufacturing cost of 1 kW is $51, however DOE assumes the cost will go down to $30/kW by 2012, making it possible to apply the technology to commercial vehicles [25]. Another issue is that the service life of fuel cells is still 7,300 hours; however this has to reach the target of 30,000 hours before the technology will be applied on heavy duty trucks [25]. Currently the distance of a fuel cell vehicle with one full Hydrogen fuel tank is about 250 miles. However, according to DOE, this will increase to 350 miles by 2015 [26]. The initial cost to purchase a fuel cell truck is currently about $270,000, but there are government incentive programs that will reduce the price up to $130,000 [27].

Table #5: Technology Comparison Matrix

Candidate Technologies	Efficiency	Environmental Emission	System Durability	Sustainability	Purchase Price	Reliability	Maintenance Requirement
	Requirements						
Diesel Engine Technology	3.9	340-440 g/mile	Yes	Yes	$65k-$95k	High	Low
Battery Electric Vehicle Technology	2.8	120-220 g/mile	Yes	Yes	$189k-$208k	High	Low
Hybrid Electric Vehicle Technology	1.8	330-230 g/mile	Yes	Yes	$502k	High	Low
Hydrogen Fuel Cell Technology	1.8	0 g/mile	Limited (100,000 miles)	No	$270k	Low	Low

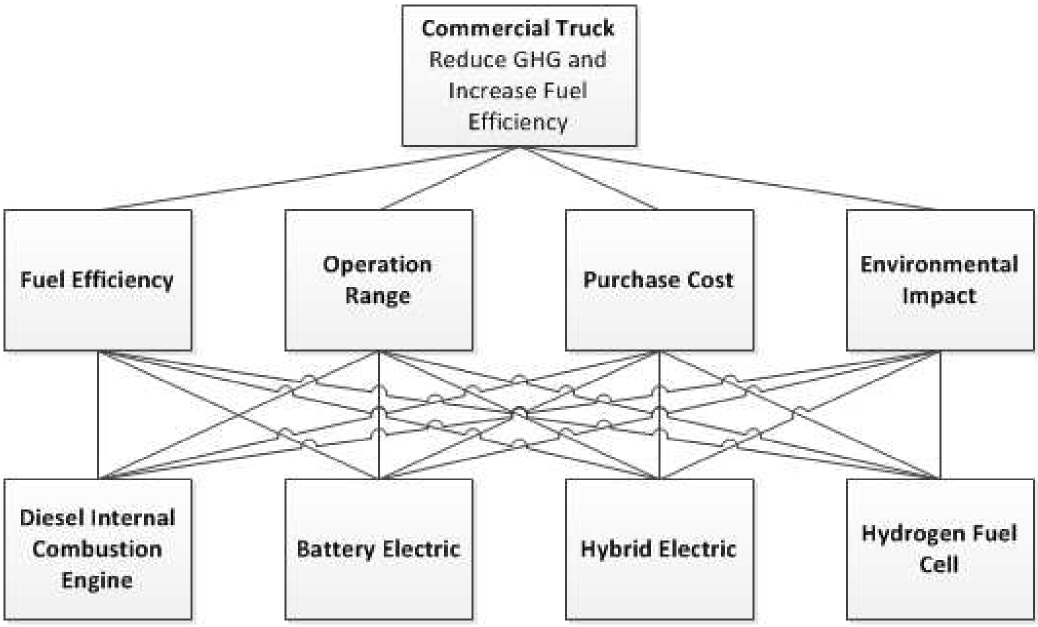
Selection Framework

The framework of this analysis that was utilized was an AHP Model, which allows us to fully identify key areas and to effectively select the most suitable alternative commercial truck based on our selection criteria's. The AHP model in Figure below, represents the analytical process used to fully evaluate our selections and alternatives chosen.

The selection criteria's that was selected was most looked at from a managerial perspective when it comes to the designing and producing of a commercial truck for owner operators and fleet use. Once our selections and alternatives have been selected, we conducted a pair-wise comparison among selection criteria's in respective to the alternatives.

A survey was created to have managers and engineers compare the selection criteria and alternatives using the provided information as a guideline. Once we collected the surveys we analyzed using the pair-wise comparison method to weight them all together. We've split the survey questions up to identify what analysis we are using for our overall calculation. We are using the information from the manager's comparison to only analyze the selection criteria in respect to the goal, and engineer's comparison was used to only analyze the alternatives with respect to the selection criteria's. The final results for our analysis are shown in Figures 7 and 8, which represents the weighted percentage of the selection criteria and alternatives from the conducted surveys.

Figure #6: AHP Model



Results

Figure #7: Selection Criteria Weights

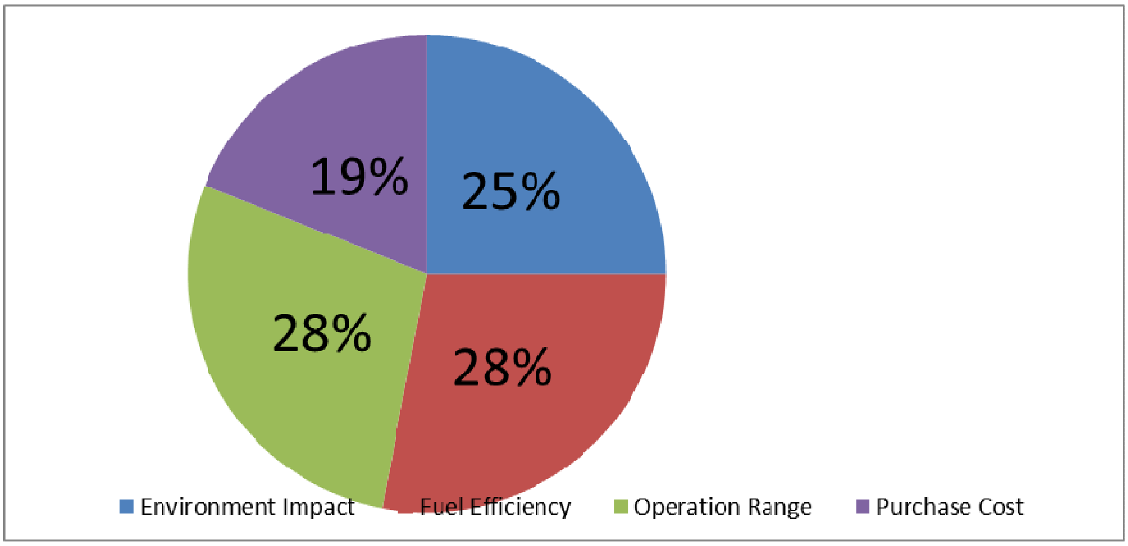
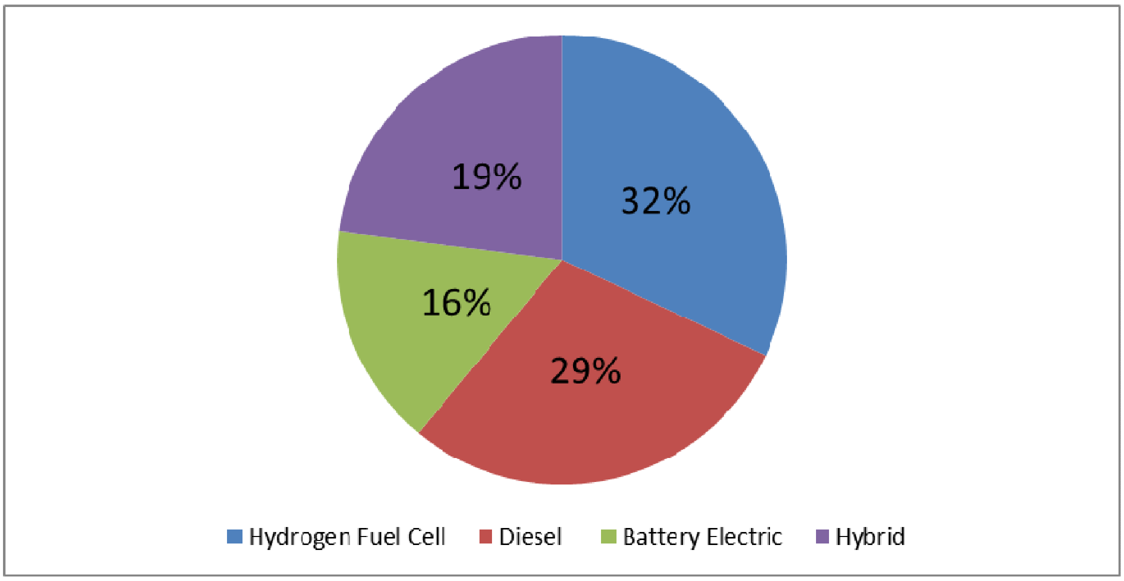


Figure #8: Alternative Commercial Truck Candidates



Conclusion & Recommendation

This paper examined the Commercial Truck technologies that are available today for the transportation markets and to find a candidate alternative that reduces or solves environmental GHG problem while concurrently increasing fuel efficiency. The paper applied the AHP methodology in conjunction with the evaluation of four technology alternatives. The results indicate that the Hydrogen Fuel Cell came out on top, followed by Diesel ICE, Hybrid, and Battery Electric. Our analysis also reveals that under the four criteria evaluated, Fuel Efficiency was the most important, but most came relatively close to each other. So the Hydrogen Fuel Cell Commercial Truck alternative may likely be the technology within the landscape in 25-30 years, once the infrastructure has been fully analyzed.

Our recommendation is that the infrastructure development may not be as bad in terms to technical and economical impacted as often stated. The infrastructure is well understood, but requires driving force to become the status quo of consumers. The demonstration of hydrogen refueling should be in parallel of Fuel Cell demonstration. R&D in small scale steam reformers may be something to look into. The production of hydrogen, delivery, storage, safety, codes, & standards, validation, fuel cell productions, and education of the process is something to address when it becomes fully understood and analyzed.

Lessons Learned

There are several things that we learned and could have done better. One of the lessons learned in this project was the case of selecting the criteria's that was used for the AHP model. We chose these criteria's based from what the managers and business look for when designing or producing a truck. There could have been more to include, so that it can be more in depth on top of what was selected. There were several different types of alternatives we could have included, but we narrowed it down to just 4, so that it would be achievable in the amount of time that was available. Also in our evaluation, there were inconsistencies on some of the collected data when using the pair-wise comparison method. These in terms affected the output in some sort of way, but we included it anyway to have a more accurate analysis overall.

Some of the challenges that we encounter were, of course getting feedback from manager's and engineers for the survey that we provided. We send out a total of 10 surveys and received only 5 back, so we used those for our data analysis. Another part was that by choosing the AHP model, we didn't know if it was going to turn out how we wanted, but in most cases, it actually turned out just fine. The data analysis showed that most important to their perception was somewhat in line of what our goal was, so it gave a really good outcome result.

Appendix 1: Survey

Objective Goal: To reduce Greenhouse Gases & increase fuel efficiency.

- Fundamental scale is scored in the range of 1-99.
- (1 being lowest importance & 99 being highest importance)
- With respect to each comparison, it must add up to 100. (ex. 40 vs. 60)
- **Acronyms:**
    - Diesel ICE = Diesel Internal Combustion Engine
    - BEV = Battery Electrical Vehicle
    - HEV = Hybrid Electrical Vehicle
    - FUEL CELL = Hydrogen Fuel Cell Electrical Vehicle

Summary of each alternative selection criteria's are on the next page as specified.

Alternatives compared with respect to **Wells-to-Wheels**

Diesel ICE		BEV	
Diesel ICE		HEV	
Diesel ICE		FUEL CELL	
BEV		HEV	
BEV		FUEL CELL	
HEV		FUEL CELL	

Alternatives compared with respect to **Operational Range**

Diesel ICE		BEV	
Diesel ICE		HEV	
Diesel ICE		FUEL CELL	
BEV		HEV	
BEV		FUEL CELL	
HEV		FUEL CELL	

Alternatives compared with respect to **Purchase Cost**

Diesel ICE		BEV	
Diesel ICE		HEV	
Diesel ICE		FUEL CELL	
BEV		HEV	
BEV		FUEL CELL	
HEV		FUEL CELL	

Alternatives compared with respect to **Environment**

Diesel ICE		BEV	
Diesel ICE		HEV	
Diesel ICE		FUEL CELL	
BEV		HEV	
BEV		FUEL CELL	
HEV		FUEL CELL	

Criteria compared with respect to reaching the **Objective Goal**

Wells-to-Wheels		Operation Range	
Wells-to-Wheels		Purchase Cost	
Wells-to-Wheels		Environment	
Operation Range		Purchase Cost	
Operation Range		Environment	
Purchase Cost		Environment	

Wells-to-wheels (Efficiency of complete system)

- Fuel/propulsion system requirements for a complete vehicle fuel-cycle analysis.

- **Diesel Internal Combustion Engine** – 3.9% WTW
- **Battery Electrical Vehicle** – 2.8% WTW
- **Hybrid Electrical Vehicle** – 1.8% WTW
- **Hydrogen Fuel Cell** – 1.8% WTW

Operational Range

-The amount of travel range that a commercial truck gets under a full tank of fuel/charge.

- **Diesel Internal Combustion Engine** – 400-800 miles (based on fuel tank capacity)
- **Battery Electrical Vehicle** – 60 mile & (not fully loaded) 30miles (fully loaded)
- **Hybrid Electrical Vehicle** – 720-1200 miles (average of 12 mpg based on fuel tank capacity)
- **Hydrogen Fuel Cell** – 300 miles (based from per full tank)

Purchase Cost

-The commercial truck cost in terms of price.

- **Diesel Internal Combustion Engine** – $65k-$95k
- **Battery Electrical Vehicle** – $189.95k-$208.5k
- **Hybrid Electrical Vehicle** – $502k
- **Hydrogen Fuel Cell** – $130k-$230k (based on government incentive)

Environment

-The amount of greenhouse gases that are emitted per mile (grams) measured from wells-to-wheel.

- **Diesel Internal Combustion Engine** – 340-440g/mile (WTW GHG)

- **Battery Electrical Vehicle** – 120-220g/mile (WTW GHG)
- **Hybrid Electrical Vehicle** – 130-230g/mile (WTW GHG)
- **Hydrogen Fuel Cell** – 0g/mile (WTW GHG) from 100% renewable energy

Appendix 2: Results and Data

1. Senior Engineer Evaluation

Wells-to-Wheels	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.67	0.82	0.72	0.193387	0.050386
BEV	1.50	1.00	1.50	1.50	0.331568	0.086388
HEV	1.22	0.67	1.00	0.67	0.209988	0.054711
FUEL CELL	1.38	0.67	1.50	1.00	0.265057	0.069059

C.I.=0.00798428

Operational Range	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	9.00	0.67	4.00	0.448437	0.138328
BEV	0.11	1.00	0.43	0.67	0.08498	0.026213
HEV	2.33	2.33	1.00	2.33	0.348225	0.107416
FUEL CELL	0.25	1.50	0.43	1.00	0.118358	0.03651

C.I.=0.0938441

Purchase Cost	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	2.33	1.50	2.33	0.380699	0.107368
BEV	0.43	1.00	0.67	0.43	0.13881	0.039148
HEV	0.67	1.50	1.00	2.33	0.287734	0.081149
FUEL CELL	0.43	2.33	0.43	1.00	0.192758	0.054363

C.I.=0.0543364

Environment	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.11	0.25	0.01	0.004002	0.000596
BEV	9.00	1.00	4.00	0.01	0.022384	0.003334
HEV	4.00	0.25	1.00	0.01	0.008707	0.001297
FUEL CELL	99.00	99.00	99.00	1.00	0.964907	0.143734

C.I.=0.200202

Criteria	WTW	Range	Cost	GHG	WEIGHTS	
WTW	1.00	0.43	2.33	1.00	0.260545	0.296678
Range	2.33	1.00	1.00	1.50	0.308467	0.155084
Cost	0.43	1.00	1.00	4.00	0.282028	0.244573
GHG	1.00	0.67	0.25	1.00	0.148961	0.303665

C.I.=0.20098

2. Senior Engineer Evaluation

Wells-to-Wheels	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	3.00	3.00	19.00	0.543726	0.021753
BEV	0.33	1.00	0.67	9.00	0.172981	0.006921
HEV	0.33	1.50	1.00	19.00	0.263407	0.010538
FUEL CELL	0.05	0.11	0.05	1.00	0.019886	0.000796

C.I.=0.0342227

Operational Range	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	9.00	0.67	3.00	0.403082	0.120162
BEV	0.11	1.00	0.33	0.33	0.067874	0.020234
HEV	1.50	3.00	1.00	3.00	0.384211	0.114536
FUEL CELL	0.33	3.00	0.33	1.00	0.144833	0.043176

C.I.=0.0773521

Purchase Cost	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	1.50	1.50	1.50	0.331813	0.185592
BEV	0.67	1.00	1.00	1.50	0.243693	0.136304
HEV	0.67	1.00	1.00	1.50	0.243693	0.136304
FUEL CELL	0.67	0.67	0.67	1.00	0.180801	0.101127

C.I.=0.0068734

Environment	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.67	0.33	0.05	0.031738	0.003255
BEV	1.50	1.00	1.50	0.05	0.055586	0.005701
HEV	3.00	0.67	1.00	0.05	0.055861	0.005729
FUEL CELL	19.00	19.00	19.00	1.00	0.856815	0.087872

C.I.=0.0583839

Criteria	WTW	Range	Cost	GHG	WEIGHTS	
WTW	1.00	0.05	0.05	1.00	0.040008	0.330762
Range	19.00	1.00	0.33	1.50	0.298107	0.169159
Cost	19.00	3.00	1.00	4.00	0.559328	0.267108
GHG	1.00	0.67	0.25	1.00	0.102557	0.232971

C.I.=0.230464

3. Engineer Evaluation

Wells-to-Wheels	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	1.50	2.33	4.00	0.432132	0.159976
BEV	0.67	1.00	1.50	2.33	0.275192	0.101876
HEV	0.43	0.67	1.00	1.00	0.164034	0.060726
FUEL CELL	0.25	0.43	1.00	1.00	0.128642	0.047623

C.I.=0.0342227

Operational Range	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	9.00	0.67	3.00	0.390318	0.055839
BEV	0.11	1.00	0.43	0.25	0.071568	0.010239
HEV	1.50	2.33	1.00	4.00	0.389525	0.055726
FUEL CELL	0.33	4.00	0.25	1.00	0.148589	0.021257

C.I.=0.152535

Purchase Cost	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.67	0.67	0.54	0.16964	0.031762
BEV	1.50	1.00	0.67	0.67	0.219466	0.04109
HEV	1.50	1.50	1.00	0.82	0.282648	0.05292
FUEL CELL	1.86	1.50	1.25	1.00	0.328245	0.061457

C.I.=0.00504758

Environment	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.43	0.25	0.01	0.005735	0.001718
BEV	2.33	1.00	1.22	0.01	0.012306	0.003686
HEV	4.00	0.82	1.00	0.01	0.013341	0.003996
FUEL CELL	99.00	99.00	99.00	1.00	0.968618	0.29011

C.I.=0.0691455

Criteria	WTW	Range	Cost	GHG	WEIGHTS	
WTW	1.00	4.00	1.50	1.00	0.370201	0.249294
Range	0.25	1.00	0.82	0.67	0.143061	0.156891
Cost	0.67	1.22	1.00	0.54	0.187229	0.173367
GHG	1.00	1.50	1.86	1.00	0.299509	0.420447

C.I.=0.0378123

4. Manager Evaluation

Wells-to-Wheels	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	1.50	2.33	9.00	0.512023	0.112016
BEV	0.01	1.00	0.67	0.67	0.162716	0.035598
HEV	0.43	1.50	1.00	2.33	0.211626	0.046298
FUEL CELL	0.11	1.50	0.43	1.00	0.113635	0.02486

C.I.=0.145705

Operational Range	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	99.00	9.00	2.33	0.805329	0.193906
BEV	0.01	1.00	0.43	0.67	0.025653	0.006177
HEV	0.11	2.33	1.00	1.00	0.061732	0.014864
FUEL CELL	0.43	1.50	1.00	1.00	0.107286	0.025832

C.I.=0.384628

Purchase Cost	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	4.00	2.33	4.00	0.521409	0.189472
BEV	0.25	1.00	0.67	1.00	0.13492	0.049028
HEV	0.43	1.50	1.00	1.50	0.20893	0.07592
FUEL CELL	0.25	1.00	0.67	1.00	0.13475	0.048965

C.I.=0.00078833

Environment	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.01	0.11	0.67	0.023884	0.004229
BEV	99.00	1.00	2.33	2.33	0.709888	0.125698
HEV	9.00	0.43	1.00	1.00	0.150436	0.026637
FUEL CELL	1.50	0.43	1.00	1.00	0.115791	0.020503

C.I.=0.412762

Criteria	WTW	Range	Cost	GHG	WEIGHTS	
WTW	1.00	1.00	0.67	1.00	0.218771	0.499622
Range	1.00	1.00	0.67	1.50	0.240778	0.2165
Cost	1.50	1.50	1.00	2.33	0.363384	0.163719
GHG	1.00	0.67	0.43	1.00	0.177067	0.120159

C.I.=0.00761964

5. Manager Evaluation

Wells-to-Wheels	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	1.50	2.03	2.03	0.370241	0.132083
BEV	0.67	1.00	2.03	2.03	0.30199	0.107735
HEV	0.49	0.49	1.00	1.00	0.163884	0.058466
FUEL CELL	0.49	0.49	1.00	1.00	0.163884	0.058466

C.I.=0.0068734

Operational Range	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	9.00	0.49	1.50	0.264927	0.036384
BEV	0.11	1.00	0.05	3.00	0.078779	0.010819
HEV	2.03	19.00	1.00	3.00	0.564129	0.077475
FUEL CELL	0.67	0.33	0.33	1.00	0.092166	0.012658

C.I.=0.413829

Purchase Cost	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	2.03	9.00	3.00	0.533661	0.100413
BEV	0.49	1.00	3.00	1.00	0.216256	0.040691
HEV	0.11	0.33	1.00	0.49	0.071979	0.013543
FUEL CELL	0.33	1.00	2.03	1.00	0.178105	0.033512

C.I.=0.0125801

Environment	Diesel ICE	BEV	HEV	FUEL CELL	WEIGHTS	
Diesel ICE	1.00	0.33	0.67	0.01	0.006739	0.002141
BEV	3.00	1.00	1.00	0.01	0.013018	0.004137
HEV	1.50	1.00	1.00	0.01	0.010503	0.003337
FUEL CELL	99.00	99.00	99.00	1.00	0.969739	0.308139

C.I.=0.0401624

Criteria	WTW	Range	Cost	GHG	WEIGHTS	
WTW	1.00	3.00	1.86	1.00	0.35675	0.271022
Range	0.33	1.00	0.67	0.54	0.137336	0.163381
Cost	0.54	1.50	1.00	0.54	0.188159	0.152822
GHG	1.00	1.86	1.86	1.00	0.317755	0.412775

C.I.=0.0083654

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