Alternative Options to Diesel Fuel in Construction Equipment

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The construction industry is a major contributor to the environmental emissions due to the extensive use of construction equipment, which is responsible for greenhouse gas emissions and harmful substances such as carbon monoxide, nitrogen oxide and particulate matter emissions. The goal of this paper is to analyze the current equipment and fuel used and to compare to the new fuels that are said to be better for the environment. There have been studies in which companies have employed a portable emission measurement system (PEMS) for real time measurement of emissions from construction equipment including carbon dioxide (CO2), carbon monoxide (CO), as well as nitrous oxide (NO). The alternative fuel options were analyzed based on differences in costs and emissions while also examining the costs and benefits of Tier 4 engines. An interview with a construction professional lead to more insight on Tier 4 engines and their use in the industry. Biofuel is indeed better in terms of cost and emissions when compared to standard diesel. Tier 4 is an option that can greatly reduce emissions by 95 percent. The reduction of these emissions and pollutants is necessary to reduce the impact of the construction industry on our precious planet.

Key Words: Construction Energy, Energy Reduction, Biodiesel, Equipment, Heavy Civil

Introduction

For an internal combustion engine to move a vehicle down the road, it must convert the energy stored in the fuel into mechanical energy to drive the wheels. This process produces carbon dioxide (CO2). Burning 1 gallon of gasoline produces approximately 8.71 kg of CO2 (Resources Canada, 2014). In 2019, according to the US Energy Information Administration (USEIA), “Americans used 142 billion gallons of gasoline, or about 390 million gallons per day”. That means approximately 125 billion kg of carbon dioxide was released into the air in 2019, just from Americans. Diesel fuel releases more carbon dioxide into the air after combustion than regular gasoline. Some fuels are more efficient and can be used in construction equipment, which lower emissions and help to slow the effect of climate change (see Fig. 1). Through advances in engine technology, reduced equipment weight, and even some hybrid technologies, equipment manufacturers are offering more fuel-efficient new equipment. Also, by using low carbon fuels, trucks and equipment will emit less carbon-based emissions. In the United States, approximately 89% of biodiesel is currently derived from soybeans, with less than 9% of production from recycled vegetable oils or tallow. Diesel generators may consume as much fuel as a piece of construction equipment per hour and are generally operated over a longer period. For example, a large (500- kilowatt) generator that consumes 15 gallons of diesel per hour emits about 346 lbs of CO2 (0.16 metric tons) at an average cost of $35.30 per hour (U.S. EPA, 2007).
This paper will examine quantitative data regarding the comparative environmental effects of using biodiesel, or a tier 4 engine, in place of standard diesel use in construction equipment. The data explored will compare the proportion of emissions of each fuel type, the cost to use them, and other related data that will help contractors decide which form of energy can help to reduce emissions as well as construction energy on the construction site.

The objectives of this paper are as follows:

- Inform on alternative fuel and power forms for construction equipment.
- To report the difference in emissions between diesel, biodiesel, and electricity.
- Examine the costs allocated with each fuel type.
- List and explain some potential modifications to equipment for use of different fuels.
- Analyze and report if biodiesel or electricity are an effective means of reducing emissions, costs, and overall construction energy.
- Inform on an interview for tier 4 engines and their use in the construction industry.
- Inform on future developments on fuel and engine upgrades.

**Literature Review**

There are many different options when it comes to powering construction equipment including diesel fuel, biofuel, and Tier 4 engines. This section aims to explain the history and development of current forms of fuel and power for construction equipment.

**Diesel**

The first oil refinery was built in 1851 in Scotland and used primarily to extract paraffin for oil lamps. Eventually, kerosene was a common by-product that replaced paraffin. Diesel was also a common byproduct but was frequently discarded because there was no use for it. In fact, it was not given its name until 1894 when Rudolph Diesel invented the first engine that could use it. Before that, it was called distillate. (Kendrick, 2019)

Diesel fuel was a revolution because it was the first fuel that did not need to be externally ignited (i.e., did not have to light it on fire like coal). The diesel engine design, which is still used today,
compresses the liquid to extreme pressures to cause it to ignite. The combustion moves the piston and causes the motor to activate. The engine could be used for smaller vehicles like cars and trucks, but eventually, it was increased in size to accommodate large loads. Tractors, trains, and ships were using diesel engines within 20 years. (Kendrick, 2019)

Diesel fuel is derived from crude oil, which is extracted from the ground through wells and offshore rigs. The crude oil is sent to refineries, where it is turned into gasoline, diesel, kerosene, and other extracts. This resource is created through the distillation process. The oil is heated, and the vapors are captured in another tank to condense into a new liquid. The different vapors heat at varying temperatures and are caught in separate tanks, resulting in different types of fuel. This process continues as various distillates are captured and cooled. (Kendrick, 2019)

U.S. petroleum refineries produce an average of 11 to 12 gallons of diesel fuel from each 42-gallon (U.S.) barrel of crude oil (USEIA, 2020).

Diesel fuel is the most commonly used fuel in the construction industry. In the construction sector 98 percent of all energy use comes from diesel. (Diesel Technology Forum, 2019)

**Biodiesel**

Rudolf Diesel had envisioned that diesel engines could run off a multitude of different fuel types. Variations include using vegetable oil or even coal dust. While these other fuel types can work, engine performance and efficiency will be reduced. However, blends have been developed where alcohol is mixed with vegetable oil to produce biodiesel. Biodiesel is typically a blend of twenty percent vegetable oil with the remaining eighty percent coming from alcohol. This blend is known as B20. (Alternative Fuels Data Center, 2018a)

B100 and other high-level biodiesel blends are less common than B20 and lower blends due to a lack of regulatory incentives and pricing. Biodiesel-compatible material for certain parts, such as hoses and gaskets, allow B100 to be used in some engines built since 1994. B100 has a solvent effect; it can clean a vehicle's fuel system and release deposits accumulated from petroleum diesel use. The release of these deposits may initially clog filters and require frequent filter replacement in the first few tanks of high-level blends. B100 requires special handling and may require equipment modifications. (Alternative Fuels Data Center, 2018a)

Biodiesel provides comparable power to traditional diesel fuel. The process of creating it is not as simple as mixing the two together. To create the mixture, a process known as transesterification needs to take place. The process of converting to biodiesel is shown in Figure 2. (Alternative Fuels Data Center, 2018a)
Tier 4 Engines

Tier 4 refers to the latest emission milestone established by the U.S. Environmental Protection Agency and the California Air Resources Board applicable to new engines found in off-road equipment including construction, mining and agricultural equipment, marine vessels and workboats, locomotives and stationary engines found in industrial and power generation applications. As of January 1, 2014, these emissions standards apply to new engines that power equipment commonly found in most construction and agricultural applications while new engines manufactured for much larger applications including marine, locomotives must have met the standard by January 1, 2015. These emissions standards apply to new and remanufactured engines and do not apply to older engines. (Diesel Technology Forum, 2018)

Tier 4 compliant engines significantly reduce emissions of particulate matter (PM) and oxides of nitrogen (NOx) to near zero levels. Relative to previous emissions standards, Tier 4 compliant engines reduce emissions by over 95 percent for most agricultural and construction equipment and just over 86 percent for much larger applications like locomotives and marine vessels (See Figure 3). (Diesel Technology Forum, 2018)
Despite the seemingly endless permutation of emission reduction technologies found in Tier 4 engines and equipment, most manufacturers also incorporate fuel savings capabilities and productivity enhancing features. Light-weight materials, fuel sipping engines, hybridization, advanced energy storage capabilities and the use of global positioning systems and telematics developed to make the most of expensive equipment are increasingly found in off-road equipment that help equipment owners reduce fuel use to control costs but also conserve energy resources and reduce greenhouse gas emissions, and, more importantly, improve air quality for everyone. (Diesel Technology Forum, 2018)

Equipment owners considering acquiring older/used engines and equipment should be aware that future construction projects and bids may include consideration of the ages and or emissions performance of the fleet of machines used on the prospective project. Emissions performance of both new and existing equipment should be evaluated together as contractors consider trade and resale options (Diesel Technology Forum, 2018).

**Methodology**

When conducting the methodology, the alternative fuel options were analyzed based on differences in costs and emissions. The Alternative Fuel Data Center website had a lot of information and graphs on the emission differences between the fuel types, so a lot of the data was retrieved from there. Most of the research is comparing diesel to biodiesel in order to find the better option in terms of emissions and costs. The goal of this research is to inform contractors about which fuel option is better for both the environment and the company. Additional research was done on Tier 4 engines for the purpose of informing contractors on the benefits and costs associated with them.

The information retrieved from an interview with Jilk Heavy Construction, Inc. helped to understand Tier 4 engines in the construction industry from the standpoint of a business owner and senior project manager. The questions asked aimed to gain information on the cost of Tier 4 upgrades, potential...
performance changes, and any other information regarding Tier 4 engines. The final question asked the contractor if it was worth it to them to upgrade their equipment to Tier 4 standards. (see Appendix A)

**Results and Analysis**

The first step in analyzing the alternative options is to compare their emissions to that of diesel fuel. Figure 4 shows that as you increase the percent of biodiesel, the percent change in emissions gets lower. However, this is not true for nitrous oxide. While hydrocarbons, carbon monoxide, and particulate matter all were reduced as a greater blend of biodiesel was used, nitrogen oxide emissions were found to be higher; up to 10% higher in the case of B100 biofuel. Even with the higher NOx emissions, the AFDC found that B100 biodiesel emissions are still 74% lower than those from petroleum diesel (Alternative Fuel Data Center, 2018b).

![Figure 4. Biodiesel Emissions compared to Diesel (Alternative Fuels Data Center, 2018b)](image)

With evidence to show that biodiesel can lower emissions, operating construction equipment on biodiesel needs to be examined. It is reported that no modifications need to be done to operate most equipment on the alternative fuel. Before switching to biodiesel, it is important to check the manufacturer’s recommendations and the product data to see if the engine can use biodiesel. Biodiesel is a solvent, so it will clean the fuel system and release the deposits from when it was operated on petroleum-based diesel. The only thing to check for when operating on biodiesel is that the fuel filter does not get clogged in the first few uses of the fuel, which can be more apparent if a higher blend of biodiesel is used (Alternative Fuel Data Center, 2018c).

Figure 5 shows the difference in emissions between different tiers of engines. As the engines are upgraded from Tier 1 to Tier 4 Final, there is a decrease in overall emissions. The greatest change that this upgrade exhibits is that there is a decrease in particulate matter. For engines that produce at least 750 horsepower, Tier 4 Final engines have 90% less emissions in particulate matter, as well as a 69% decrease in nitrous oxide and carbon monoxide emissions than Tier 1 engines. This demonstrates the importance of upgrading to Tier 4 because of the overall drastic decrease in emissions.
The second step in analyzing the alternative options is to compare the costs associated with each option. Table 1 shows the average fuel prices as of January 2021. Compared to Diesel fuel, B20 is cheaper on average by $0.22 per gallon, as of January. The prices for fuel are always changing because of the market’s supply and demand for it. Of course, the main culprit is the high price of oil. After staying comfortably below $20 per barrel throughout most the 1990s, the cost of crude ballooned to $56 in 2005, and currently sits at $62.17. Each dollar-per-barrel rise translates into roughly 2.5 cents more per gallon. Strong global demand is the primary cause of the increase (Lieberman, 2006). Typically, the prices are all proportionate to the others. Basically, this means that when the market for fuel increases, all of the fuel types, typically, will increase. Generally, B20 biodiesel costs less than regular diesel, which is due to the government incentives that go along with biodiesel. This means that a contractor can spend less by switching to B20 from regular diesel fuel as well as reduce the emissions of the construction equipment.

Table 1

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Price (USD)</th>
<th>Units of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>$2.32</td>
<td>per gallon</td>
</tr>
<tr>
<td>Diesel</td>
<td>$2.64</td>
<td>per gallon</td>
</tr>
<tr>
<td>Biodiesel (B20)</td>
<td>$2.42</td>
<td>per gallon</td>
</tr>
<tr>
<td>Biodiesel (B99/B100)</td>
<td>$3.18</td>
<td>per gallon</td>
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</table>

When it comes to tier 4 engines, there are new costs that are associated. Used equipment has a grandfather clause associated with it, which means that if the machine was manufactured before Tier 4, it does not need to be brought up to current standards. However, used equipment still needs to meet the standards that were in place when the machine was manufactured. But updating equipment has a
cost allocated with it. Buying Tier 4 equipment costs 15-20% more on average than other equipment (Independent Equipment Dealers Association, 2021).

Example

In an interview conducted with Joshua Jilk, a senior project manager and partial owner of Jilk Heavy Construction Company, Inc., a lot of information on Tier 4 engines was obtained. The company is a general contractor based in Brea, California and specializes in heavy civil and marine construction. The equipment the company upgraded is shown in Table 2 below.

Table 2

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Equipment Model</th>
<th>Engine Upgrade</th>
<th>Source: Personal interview with Sr. Project Manager of Jilk Heavy Construction, May 27, 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crawler Crane</td>
<td>Manitowoc 3900W</td>
<td>Cummins QSL9.380</td>
<td></td>
</tr>
<tr>
<td>Truck Crane</td>
<td>P&amp;H 440TC</td>
<td>Carrier: Cummins B6.7</td>
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<tr>
<td></td>
<td></td>
<td>Upstairs: Cummins QSF 3.8</td>
<td></td>
</tr>
<tr>
<td>Excavator</td>
<td>Caterpillar 335FL</td>
<td>CAT C7.1</td>
<td></td>
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<tr>
<td>Reach Forklift</td>
<td>Caterpillar TL1255C</td>
<td>CAT C4.4</td>
<td></td>
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<tr>
<td>Vibratory Hammer Powerpack</td>
<td>HPSI 300</td>
<td>CAT C13</td>
<td></td>
</tr>
<tr>
<td>50 kW Generator</td>
<td>Caterpillar XQ60</td>
<td>CAT upgrade</td>
<td></td>
</tr>
</tbody>
</table>

According to Joshua Jilk, it cost approximately $415,000 to upgrade the Manitowoc 3900W crawler crane. When asked about fuel costs, the response was that the company did not track the cost for a single piece of equipment as they track costs for the entire fleet. The costs fluctuate depending on the amount of work that is done. Further investigation would be needed to see if fuel consumption decreases, and the costs allocated to fueling one piece of equipment. The company and the operators have not noticed a difference in the performance of the equipment since the upgrade.

When asked if the upgrade was worth it, the Joshua Jilk responded with:

“From a bottom-line standpoint, it is a mixed bag. If the regulations were not in place, we could have utilized the money we spent to upgrade working engines with Tier 4 engines on other new Tier 4 equipment instead. That might have had a bigger impact on profitability. As far as the environment goes, it was worth it. We, as a company and an industry have to be working towards a cleaner, more environmentally friendly operation.”

Conclusion and Future Research

After examining the differences between biodiesel and petroleum-based diesel, as well as looking into the use of tier 4 engines, I believe using B20 biodiesel in all construction equipment in lieu of regular diesel will help save the contractor money while simultaneously reducing emissions. With current regulations in place, I believe it is worth it to the contractor to purchase equipment with tier 4 engines, as they are only 15-20% more expensive, but have reduced operating costs and are considerably better for the environment.

Tier 4 regulations are still relatively new and yet many are wondering whether stricter Tier 5 regulations are just over the horizon. As European Stage V regulations go into effect, engine
manufacturers in the United States are making preparations to build machines that comply with ever more stringent requirements. This is spawning speculation that regulators may use this as an opportunity to create Tier 5 regulations that mirror European standards. These standards would set emissions levels to absolute zero.

References and Appendix


Appendix A - Questions from Interview with Jilk Heavy Construction, Inc.

1. Which equipment have you upgraded to tier 4 engines? (model numbers are appreciated)

2. How much did it cost to upgrade ____________? (Select one from above)

3. How many gallons of diesel fuel per month (avg) did you purchase prior to upgrading to tier 4 engines?

4. How many gallons of diesel fuel per month (avg) did you purchase after upgrading to tier 4 engines?

5. Has there been a change in the time required to fuel these engines?

6. Do you have an efficiency factor associated with your equipment when estimating? If so, what is it?

7. Has your efficiency factor changed since upgrading to the tier 4 engine?

8. Do you notice a difference in the performance of the equipment after upgrading?

9. In general, do you think upgrading was worth it to the company? To the environment?