Reducing Energy Use in Excavators with Biodiesel

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In assessing the life-cycle cost of a building, the operation energy and construction energy are considered. The operation energy constitutes 90 to 95 percent of the lifetime energy use of a building. Concern over reducing operation energy has led to advancements where many buildings can now be considered net zero. While considerable advancements were made in achieving net zero in the operation, construction energy use has largely remained the same. To achieve net zero for the entire life-cycle of the building, construction energy consumption needs to be reduced. Excavators are one of the most popular pieces of construction equipment. They are primarily run off diesel fuel which is a nonrenewable resource. Biodiesel is currently offered on the market in different blends. These blends combine alcohol with vegetable or animal oils to create a renewable fuel source. This report will examine if biodiesel can be a viable replacement to traditional diesel used in excavators, and ultimately reduce construction energy.

Keywords: Biodiesel, Excavators, Construction Energy

History of Early Heavy Equipment

Before heavy equipment was established in the construction industry, all work on a project would require an immense labor force. Thousands of men would be called upon to perform the work that several pieces of heavy equipment could accomplish. Once the first piece of heavy equipment, the steam shovel designed by William S. Otis in 1838, made its way on to projects, the use of heavy equipment started to boom. However, the first steam shovels were large and cumbersome. But with the foundation laid by Otis, advancements could start to be made, and human ingenuity could shine. (Haycraft, 2011)

Otis had not designed a propulsion system for the original steam shovel, so it needed somewhere to be mounted. At the time of its inception, the only place to mount them were on top of rail cars. This meant that the steam shovel could only be effectively used on rail construction projects, or projects close to a railroad. With restricted mobility and reliable steam engines still a few decades away, something needed to be done in the interim. Bucryus and Marion had developed steam shovels that could pivot up to one hundred eighty degrees. With this expanded flexibility, the steam shovel got to see its use on one of the largest heavy civil projects of the time, the Panama Canal. A project of that magnitude could have taken a generation to complete solely with human labor, but the success of the steam shovel on the canal demonstrated how beneficial heavy equipment is in construction. (Haycraft, 2011)

The success of the heavy equipment on large scale projects was proven. There still needed to be more development in order to see the technology trickle down for use on smaller projects. Lack of mobility was still that largest obstacle of early construction equipment. As early as the mid-19th century, J.D. Adam debuted a wheeled grader that was equipped with a steam engine. While the grader was able to move under its own power, it struggled off-road. This was a problem due to the undeveloped nature of most construction sites. However, a few decades later, Benjamin Holt solved the mobility issue. Holt's first prototype involved combining a steam engine and a tractor on tracks to create a crawler tractor. He was quick to replace the steam engine with an internal combustion engine, which were rising quickly in popularity. The increased mobility that the tracks offered in off-road scenarios proved to be a winning combination. In 1910 Holt trademarked the name Caterpillar. The company has grown to become a well renowned manufacturer that continues to make heavy equipment today. (Haycraft, 2011)

Hydraulic Excavators

The hydraulic excavator built off the successes of early designs in order to become one of the most popular pieces of heavy equipment. Excavators can be found on many different sites. They are primarily used to excavate earth, but they can also find them being used in other industries such as logging. Excavators are split up into three different parts that work together. These parts are the undercarriage, upper structure and the front attachment.

At the bottom of the excavator is where the undercarriage is located. This is the base of the excavator where you will find its drivetrain and contact patch to the ground. Most excavators use a track, like the one from Holts original design, since they provide superior use in slippery low traction environments. Excavators are primarily used off-road, so a track provides the grip it needs. Excavators can also be found in wheeled configurations instead of tracks, but these are only viable in limited applications.

The next part of the excavator is the upper structure. This incorporates the cab, powertrain and counter weight. The cab is mounted directly behind or next to the front attachment and is where the operator sits. With a large see through panel separating the operator and the front structure, and the ability to pivot the upper structure a full 360 degrees, an operator is given a clean view of the work in front of them and can maneuver with ease. Early designs of excavators were exclusively controlled by levers and switches. This combination could be tricky to learn. That control scheme has been more recently supplanted by joysticks as the primary control unit. Operators prefer the extra dexterity that the joysticks provide. An excavator would be useless without its powertrain. The powertrain provides the power to physically move the excavator and power its many hydraulic systems. The most common engine found in excavators are diesel engines. (Haycraft, 2011) The last remaining crucial component of the upper structure is the counterweight. An excavator is expected to be handling heavy loads. Without the counterweight to balance the weight from the front attachment, an excavator would topple over.

Up front is where the business end of an excavator is located, the front attachment. The front attachment can be described by comparing it to the human arm. The boom, the first major part that connects to the upper structure, is like the upper arm between the shoulder and the elbow. Next on the front attachment is the arm of the excavator. This mimics the forearm. Closing out the front is the bucket, like a human hand. These components can move on an excavator thanks to the hydraulic cylinders found connecting these three pieces. The engine moves hydraulic fluid adjusting the pressures thus moving the boom, arm and bucket.

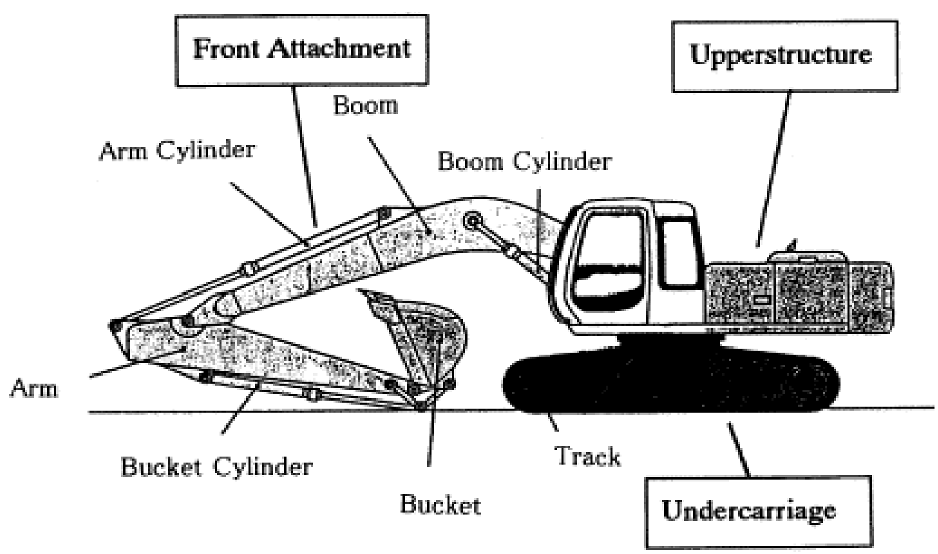

Figure 1-Hydraulic Excavator Constitution
Source: Haga M., Hiroshi W., & Fujishima K.(2001)

Diesel

Diesel fuel is the most common fuel type used in excavators. The history of diesel dates back to 1890 when Rudolf Diesel invented the diesel engine. The primary difference between diesel engines and gasoline engines is in the way they ignite the fuel. Both use the same four stroke engine cycle, but spark plugs are required in gasoline engines to create combustion. In diesel engines, the fuel is ignited by compression alone. This can be accomplished by compressing the air first then mixing gas. Since the air is compressed, it heats up. Fuel is injected right before the compression cycle is complete providing the necessary heat to ignite the fuel and push the piston back down.

Gasoline engines can handle the demand of excavators, but there are several reasons why diesel became the primary power source. The primary advantage diesel engines offer is its ability to generate large amounts of torque directly off idle. Torque is more beneficial than horsepower in heavy equipment such as excavators because torque is driving force used most in low speed and high load situations. Excavators are used only in these types of environment so having the torque outputs provided by diesel engines is valuable. Another benefit of diesel is its overall fuel efficiency. Diesel fuel has a higher energy density than gasoline, so less fuel is required in its operation. For a piece of equipment which sees long consistent run times, even a small efficiency advantage can realize a large amount of savings. (Marshall, 2014)

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. 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. (Biodiesel Production and Distribution, 2018)

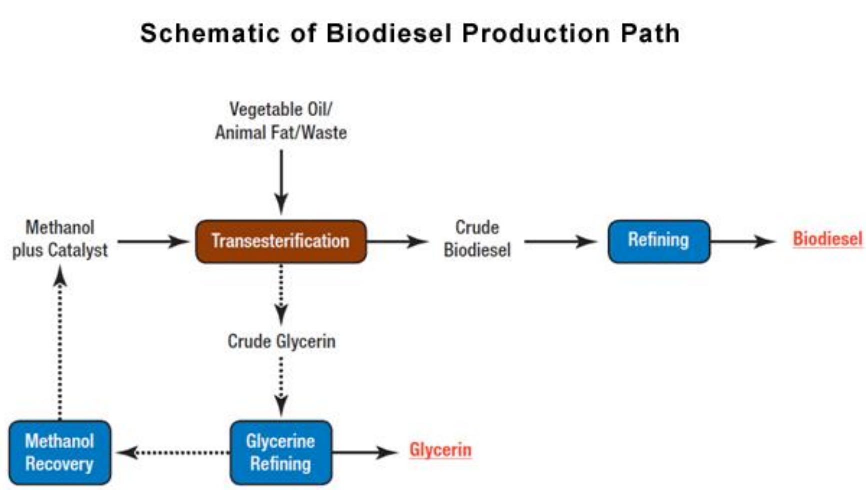

Figure 2-Biodiesel Production and Distribution
Source: AFDC. (2018)

Methodology

This report will examine quantitative data regarding the environmental effects and costs of using biodiesel in lieu of diesel on excavators, and if it can reduce total construction energy. The data explored will compare the percent of particulates released by either fuel, the costs to run them, and biodiesel's availability. The information presented here will help contractors looking to reduce their construction energy understand if biodiesel is a path they could take.

The objectives for this report are as follows:

- To report the emissions differences of biodiesel and diesel.
- Examine if there is potential fuel savings
- What modifications need to be made to an excavator to run on biodiesel.
- Analyze and report if biodiesel can be an effective means of reducing emissions.

Research

This first step in analyzing biodiesel's viability is to compare the emissions of the two fuels. If biodiesel does not have a significant enough reduction in emissions, its use in reducing construction energy is lost. The United States Department of Energy Alternative Fuels Data Center has reported and analyzed the data comparing the emissions of both types of fuel.

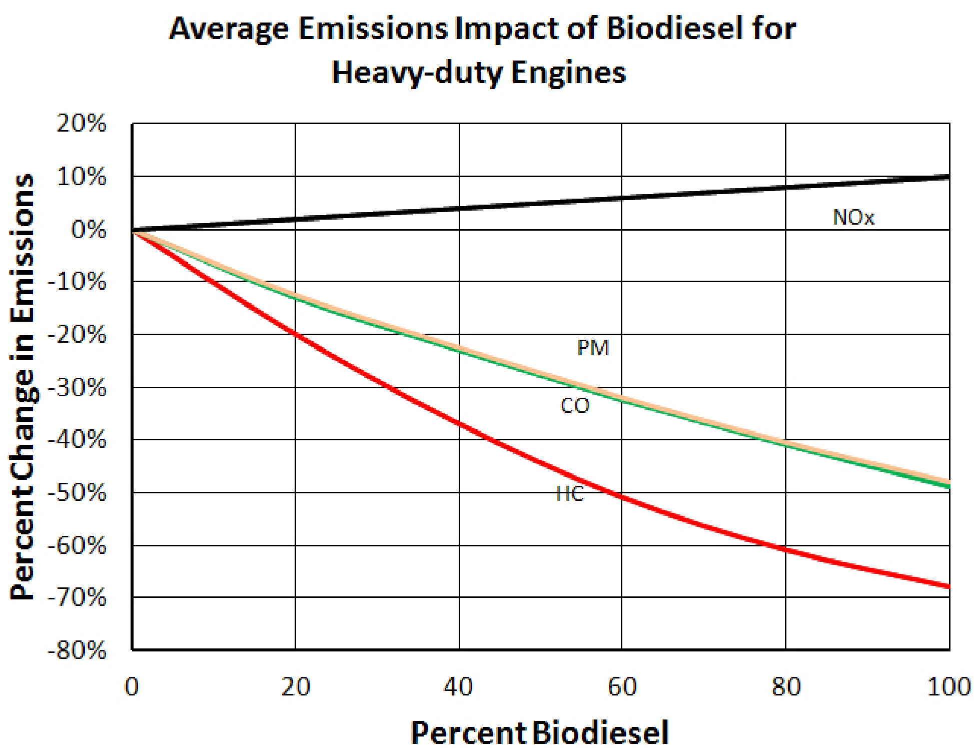

Figure 3-Biodiesel Vehicle Emissions
Source: AFDC. (2018)

Figure 3 shows that as you increase the percent of biodiesel, the percent change in emissions gets lower. However, this is not true across the board. 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 slightly higher. Even with the higher NOx emissions, the AFDC found that B100 biodiesel emissions are still 74% lower than those from petroleum diesel. (Biodiesel Vehicle Emissions, 2018)

With evidence to show that biodiesel can lower emissions, operating an excavator on biodiesel needs to be examined. It is reported that no modifications need to be done to operate an excavator on the alternative fuel. If an engine is rated to withstand operating on normal diesel, then it can withstand running on biodiesel. Biodiesel is a solvent, so it will clean an engines fuel system and release the deposits from when it was operated on petroleum-based diesel. For that reason, 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. This result can be more apparent if a higher blend of biodiesel is ran. (Biodiesel Blends, 2018)

The operating cost of using biodiesel needs to be examined if a contractor is going to make the switch. If the costs are too high, then it may not be a viable solution in reducing energy usage. The Alternative Fuels Data Center has also been tracking the costs of different alternative fuels since 2000.

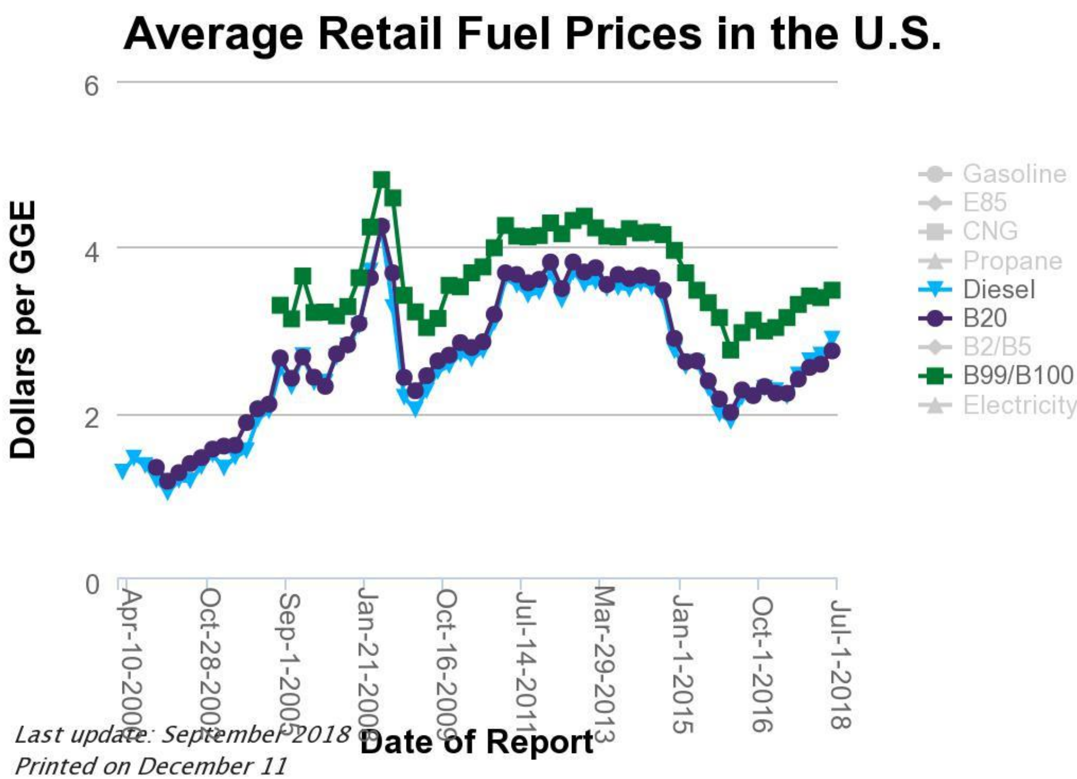

Figure 4-Alternative Fuel Price Report
Source: AFDC. (2018)

Figure 4 shows the price history of diesel with biodiesel blends B20 and B100. The average retail price of diesel in July 2018 was $3.24/gallon, B20 biodiesel was reported at $3.06/gallon, and B100 was reported at $3.55/gallon. Looking at the trends in the graph, diesel and B20 prices fluctuate the same, and their prices are always quite similar. B100 tends to be more expensive. B20 receives greater government incentives which is likely the reason why its price has remained close to diesels. (Fuel Prices, 2018)

With emissions that are lower, and a price that is comparable with diesel, what remains to be examined is biodiesels availability. If there is not enough access to the fuel, then its use is compromised. The AFDC keeps a map of 199 different biodiesel fueling locations across the United States.

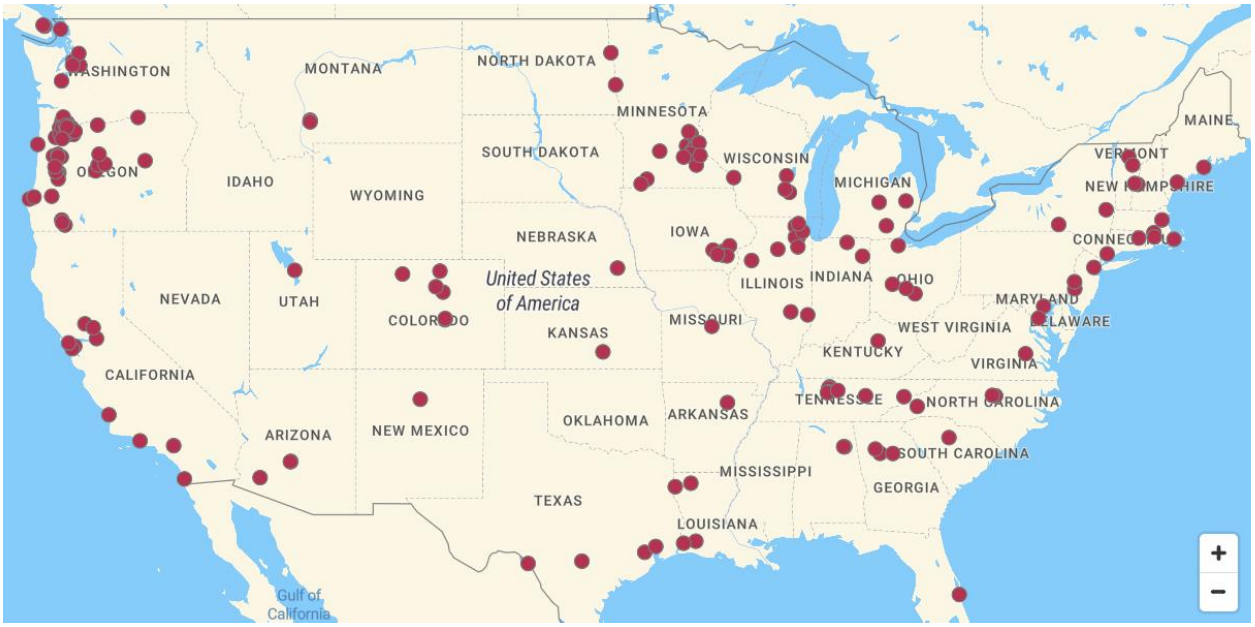

Figure 5-Biodiesel Fueling Station Locations
Source: AFDC. (2018)

Examining the map closer reveals a few things. While diesel fuel is available virtually everywhere, biodiesel is restricted to these 199 locations. In Southern California for example, there are only 3 viable biodiesel fueling stations for a significant area. A team of excavators can use thousands of gallons of fuel a day, so it will make it difficult to keep a steady supply of biodiesel. There are fuel depots that will deliver biodiesel regularly mitigating that issue, but that is not the norm. Biodiesel is not even available in some states at all meaning they will not even have the option of running the fuel. This stands to be the biggest hurdle for the adoption of the fuel. (Biodiesel Fueling Locations, 2018)

Conclusion and Future Research

After examining the differences between petroleum-based diesel and biodiesel for use in excavators, I think biodiesel can be an effective means of reducing construction energy usage. There is one caveat, however. The site where the excavators are running need to be close to a biodiesel fueling station in order to be an effective fuel source. With how current fueling stations are so spread out, that means the fuel can only effectively be used by sites near a station that dispenses it. This limits the fuel in becoming a new standard for excavator use but does leave it as an option for reducing construction energy.

As time moves forward, the benefits of biodiesel can continue to be realized by a greater amount of the population. Many are still unaware of the fuel’s existence. While this report primarily examined the usage of biodiesel in excavators, there is no reason why it may not be used in other diesel construction equipment to expand its use. To increase the adoption of alternative fuels, organizations such as LEED can possibly incorporate the use of alternative fuels when determining their scores.

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