The Biodiesel of Tomorrow

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Pennsylvania State University
Introduction to Engineering Design Class

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Abstract

The purpose of this research is to find a more efficient and environmentally friendly fuel for the newly introduced Tier 4 Locomotives. One of the goals is to satisfy GE, the business client, by reducing the cost of operating locomotives. In addition, the fuel is required to meet EPA regulations, another client in the environment sector. One significant way to meet its regulations is by reducing the amount of pollution emitted to the ecosystem. Biodiesel has been found to meet EPA regulations the most. This research mainly focuses on a specific type of biodiesel called Algae Biodiesel, which is yet to be researched on. Algae was chosen due to the simplicity of producing and extracting oil from it, along with its reasonable price and efficient use when 20 percent of it is used when mixed with other alternative kinds of diesel, not to mention the likeliness of increase in conventional diesel prices in the upcoming years as it becomes scarcer. Moreover, the governments have begun to encourage locomotive companies to use renewable energy by establishing tax incentives.
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1.0 SUMMARY

1.1 Problem
The two problems are to satisfy the citizens and government by reducing smog and to follow the
EPA regulations. The objective is to find a cheaper, innovative, and more efficient solution for
locomotives that can help the business.

1.2 Solutions
Algae biodiesel was used because of how easy it is to produce and extract oil as compared to
other plants and biodiesel forms. B20 (20 percent of biodiesel integrated with 80 percent of
diesel) releases 15 % less CO2, than using 100 percent diesel, all for the same price per gallon
and energy output. There is a tax incentive on renewable energy such as biodiesel which can
reduce the price of fueling locomotives. Lastly, the transition from diesel to its best alternative,
biodiesel, can be achieved without changing the locomotive or engine as biodiesel runs on the
same engine as diesel.

1.3 Conclusion
The Energy Department announced on July 9th, 2015, that six projects will receive up to $18
million dollars in funding to reduce the modeled price of algae-based biofuels. If these projects
prove to be successful, prices of biodiesel algae can be expected to fall down. Moreover, due to
the fact that algae reproduces quickly and grows in huge amounts rapidly, economists can
assume that, with high supply, prices of algae biodiesel will drop down. In addition, algae plants
can help reduce CO2 levels in the atmosphere.

1.4 Recommendation
More professional and technical studies need to be conducted in regards to algae biodiesel as
there aren't a lot of researches conducted on it so no further results can be deduced.
2.0 INTRODUCTION

2.1 Subject
The term biodiesel refers to diesel fuels that are composed of unrefined vegetable oils and animal fats. Extensive research of all of the variations of biodiesel concludes that algae biodiesel is the most favorable solution to the problem presented. In relation to compliance of EPA and governmental regulations, algae biodiesel is environmentally preferable over many other biodiesel fuels. Furthermore, algae biodiesel is economically superior for GE. One may ask, "Why Algae biodiesel?" Algae biodiesel is categorized as an alternative fuel. In comparison to other forms of fuel, this classification can be interpreted to mean that the fuel emits fewer amounts of harmful pollutants into the environment. Moreover, algae biodiesel is cost effective due to the incentives enacted by the United States Government to encourage the use of renewable energy.

2.2 Purpose
The purpose of this research is to discover an efficient and environmentally friendly solution for Tier 4 locomotives. However, the proposed solution must assure two main clients. The first client, GE, necessitates for there to be a reduction in the cost to operate locomotives. The second client is the United States Government and society, who are synergistic. The U.S. Government and the citizens of the United States demand for a reduction in fuel contaminants and a secure compliance of EPA regulations. Furthermore, this research will target and resolve both of the client's issues by using biodiesel. There are many reasons why biodiesel can resolve the issues present. For example, 20 percent of biodiesel integrated with 80 percent of regular diesel emits 15 percent less carbon dioxide than 100 percent diesel. Biodiesel fuel achieves this percentage at the same price per gallon as regular diesel. Also, there are tax incentives on multiple forms of renewable energy. This includes a tax incentive on biodiesel that can reduce the price of fueling locomotives. Lastly, the process of transitioning from diesel to biodiesel will need to be as frictionless as possible due to the high public demand in train transportation. However, ensuring a smooth operation is inevitable. Since biodiesel operates on the same type of engine as diesel, there is no need to manipulate the locomotive or engine.

2.3 Scope
Unfortunately, there is a small amount of professional study performed on algae biodiesel. This limits the amount of potential research that could have been collected for this project. However, the research that has been compiled for this project is based on specific algae biodiesel results of biodiesel extracted from plants. Hopefully, the research portrayed in this project will trigger the beginning of further studies in this particular field.
3.0 Cost, Emission and Energy for diesel

3.1 Cost
As the number of vehicles dependent on diesel is increasing, its demand is increasing as well, especially in the United States. The use of diesel has been significantly higher than various other forms of energy, as it produces a decent amount of torque for its low price, in addition to its engines withstanding high amounts of pressure compared to other fuel engines. In general, the price of diesel has fluctuated regularly in the past. Recently, as of July 2015, diesel prices have dropped to $2.93 per gallon. Throughout the past decade, Ultra Low Sulfur Diesel (ULSD), a new form of diesel was introduced as a more environmentally friendly fuel. As the name implies, the fuel emits significantly lower amounts of sulfur pollutants as one of the ways to contribute in reducing air pollution. Nevertheless, it costs 10 cents per gallon higher than the conventional diesel due to higher refining costs. In fact, prices of conventional diesel will most likely increase in the upcoming years due to its scarcity, turning biofuel into a greatly cheaper choice. Considering the costs, the new GE Tier 4 locomotives may store up to 5300 gallons of fuel using 4800 of them.

3.2 Energy
Compared to all alternative fuels, diesel is likely to release more energy for the same amount of weight. In Tier 4, diesel uses energy that ranges from 4,000 to 4,400 horsepower. In fact, diesel engines may be transformed into turbo-charging pressures with no barrier which can release more energy output at no additional cost.

3.3 Emission
There are a number of advantages of using diesel such as its successful fuel economy and low cost. On the contrary, there are outweighing disadvantages of using diesel. In comparison to other fuels, these disadvantages include a number of dangerous pollutants emitted, such as Particulate Matter (PM), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Hydrocarbons (HC), Sulfur Dioxide (SO2) and Volatile Organic Compounds (VOCs). Nonetheless, due to the EPA regulation standards that being updated every few years, companies were in need to find new ways in order to reduce emissions. That is how ULSD was introduced making sulfur not a significant factor in the current air pollution.
<table>
<thead>
<tr>
<th>Load (%)</th>
<th>Temp(°C)</th>
<th>O₂(%)</th>
<th>CO₂(%)</th>
<th>CO (ppm)</th>
<th>NO(ppm)</th>
<th>NO₂ (ppm)</th>
<th>NOₓ(ppm)</th>
<th>Efficiency (%)</th>
<th>λᵃ</th>
</tr>
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<tbody>
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<td>2.3 (idling)</td>
<td></td>
<td></td>
<td></td>
<td>110</td>
<td>201</td>
<td>33</td>
<td>234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.2 (notch 2)</td>
<td>174</td>
<td>17.4</td>
<td>2.6</td>
<td>147</td>
<td>329</td>
<td>30</td>
<td>359</td>
<td>69.1</td>
<td>5.94</td>
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<td>33.0 (notch 4)</td>
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<td>15.2</td>
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<td>257</td>
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<td>630</td>
<td>69.0</td>
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<td>59.1 (notch 6)</td>
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<td>13.1</td>
<td>5.8</td>
<td>1069</td>
<td>839</td>
<td>18</td>
<td>857</td>
<td>67.7</td>
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</tr>
<tr>
<td>100 (notch 8)</td>
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<td>13.0</td>
<td>5.9</td>
<td>412</td>
<td>1150</td>
<td>32</td>
<td>1282</td>
<td>67.5</td>
<td>2.62</td>
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</table>
4.0 Cost, Emission and Energy for biodiesel

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Biodiesel Percentage</th>
<th>Diesel percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>B20</td>
<td>20%</td>
<td>80%</td>
</tr>
<tr>
<td>B100</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

4.1 Subject
With oil scarcity becoming more of a reality every passing day, the US transportation system might be severely affected if reforms are not made to transition the country into one that relies more on renewable energy. Regardless of how simple this process may seem, this transition may not be instant as it will be unnecessarily expensive. Instead, using biodiesel that can run on diesel engines which will waive locomotive companies’ requirements of replacing engines with more sophisticated ones. Although refueling locomotives costs millions of dollars more than the price of locomotives themselves, it is considered a smoother transitioning process for the short and long run and will most likely become efficient with the establishment of tax incentives.

Figure 1

What Biodiesel Is Made From:

Source: Biodiesel.org
4.2 Cost
The price of biodiesel depends on the amount being used in its mixture with other fuels. If 20 percent of Biodiesel (B20) is mixed with 80 percent of conventional diesel, it costs as much as the regular diesel price, which is $2.93 per gallon (as of July 2015). When using 100 percent of biodiesel (B100), however, the price is $3.55 dollars per gallon (as of July 2015). Nevertheless, the cost of biodiesel may be cheaper than $2.93 a gallon in countries enforcing tax incentives on renewable energy for up to $10 million in tax credit annually, such as the US.

4.3 Energy
While it is widely known that no other renewable energy may release the same amount of energy as diesel, biodiesel energy is rather very close depending on its percentage in the mixture. For instance, when B20 is consumed, the difference in the amount of energy is considered negligible making its use very similar to the use of full conventional diesel. However, when B100 is used, there is approximately 5 to 7 percent less output energy compared to diesel.

4.4 Emissions
Governments are currently encouraging companies and citizens to use renewable energy due to their low amounts of harmful emissions. Biodiesel is a great example of a renewable energy given its low pollution emission compared to diesel. B20 releases approximately 15 percent less Carbon Dioxide (CO2) than conventional diesel with the percentages of NOx and Hydrocarbons (HC) being the same. Moreover, B100 releases 75 percent less CO2. While the reduction in CO2 is considered extremely high, B100 also releases approximately 7 percent more Hydrocarbon pollutants and slightly more NOx.
5.0 Discussion and Expectation of Biodiesel using Algae

5.1 Discussion
Compared to other alternative fuels, biodiesel has a number of unique traits relative to its competitors. Unlike any other alternative fuel, it has successfully satisfied the health effects testing requirements in order to meet the standards of the 1990 Clean Air Act Amendments. This research will focus not only on biodiesel but also using algae plants as they consist of one of the highest amount of oil in liters per hectare reaching to 1,000,000 liters (graph below).

Table 2
Yield of various plant oils.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil in liters per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Castor</td>
<td>1413</td>
</tr>
<tr>
<td>Coconut</td>
<td>2689</td>
</tr>
<tr>
<td>Palm</td>
<td>5950</td>
</tr>
<tr>
<td>Safflower</td>
<td>779</td>
</tr>
<tr>
<td>Soy</td>
<td>446</td>
</tr>
<tr>
<td>Sunflower</td>
<td>952</td>
</tr>
</tbody>
</table>

In addition, it has a fast growth rate making it simpler to grow compared to other plants, with the utilization of habitats not used for food agriculture. Algae plants may additionally decrease CO2 and contribute to combatting global warming. The process of extracting biodiesel from algae is in fact simpler than it seems depending on the method used. One way to extract oil works almost similar to the technique used in an oil press. This is considered the simplest and most common method for extracting. The result would contain 75 percent of total oil in algae plant.

Figure 2
Another common method that may be used with the first method is the Hexane Solvent Method. When combined with the oil press method, this step can gather up to 99 percent of available oil from algae. It utilizes a two-step process. The first step is to utilize the oil press method. However, rather than getting rid of the leftover algae, it is mixed with hexane, filtered and cleaned thoroughly to remove all traces of chemical in the oil.

**Figure 3**

5.2 Expectations
Due to the fact that algae grows in massive amounts rapidly, it can be assumed that prices of algae biodiesel will decrease in response to an increase in supply. Moreover, there are incentives imposed by the US government to rely on renewable forms of energy. Finally, The Energy Department announced on July 9th 2015, that six projects will receive up to $18 million in funding to reduce the modeled price of algae-based biofuels, which may help in decreasing prices.
6.0 Conclusion

The problem General Electric implements in respect to this research project is to discover an efficient and environmentally-safe method of fuel utilization for Tier four locomotives that can surpass the current method proposed by General Electric. A solution to this issue is alternative fuels, specifically algae biodiesel. However, there are conflicts present in regards to the specifications of fuel emissions and pollution. These conflicts include a satisfaction of EPA regulations and society’s demands for a reduction in smog. Despite a lack of professional and clinical study, the research collected in this report promotes a potentially fruitful future for algae biodiesel, a future that comprehensively abides the conflicts stated above. This alternative fuel [algae biodiesel] distinguishes itself from other alternative fuels by being one of the only fuels to comply with the Clean Air Act Amendments of 1990. Likewise, the process of producing and extracting oil from algae is remarkably simple. Also, the United States Government hopes to incite many firms that do not particularly work with renewable energy to initiate and convert to utilizing renewable energy in their everyday practices by establishing tax incentives.
References


- Figure 3: Gallagher, Brian J. "The economics of producing biodiesel from algae." Renewable Energy 36.1 (2011): 158-162. flow chart

- Table 2: Demirbas, Ayhan, and M. Fatih Demirbas. "Importance of algae oil as a source of biodiesel." Energy conversion and management 52.1 (2011): 163-170. 1,000,000 litres
8.0 List of symbols, abbreviations and acronyms

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B20</td>
<td>20% Biodiesel</td>
</tr>
<tr>
<td>B100</td>
<td>100% Biodiesel</td>
</tr>
<tr>
<td>ULSD</td>
<td>Ultra-Low Sulfur Diesel</td>
</tr>
</tbody>
</table>