Manipulation of Biodiesel Precursor Components: Maximizing Energy Density and Cost Efficiency

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Abstract

Biodiesel is a potential, carbon-neutral alternative fuel source for petroleum diesel. While considered expensive in current synthetic approaches, further research into biodiesel can result in fuel that competes with the performance and pricing of diesel. We hypothesized that using canola oil in combination with potassium hydroxide and ethanol would result in a biodiesel with the highest energy to cost ratio (J/g/$) compared to other precursor component combinations. This study explored the relationship between precursor oil and biodiesel energy density; the energy to cost ratio between ethanol and methanol biodiesels; the percent yield and yield to dollar ratio of KOH and NaOH biodiesels; and if we could make a biodiesel that could compete with the energy to cost ratio to gasoline. We synthesized various batches of biodiesel and performed calorimetry on them. Our results refuted our hypothesis, instead suggesting that safflower, NaOH, and ethanol would produce the most energy dense biodiesel. Herein we propose additional pathways to further refine alkali-based biodiesel synthesis to maximize cost-to-energy ratios.

Introduction

Around the world, energy is required for society to function, powering its cars, engines, planes, and other technology. Currently, this energy is extracted from fossil fuels, which are natural fuels derived from the remains of living organisms. Examples of fossil fuels include petroleum, coal, and natural gas. The World Energy Council reports that 80% of the world's energy was from the use of fossil fuels in 2013 [1]. The fossil fuel of petroleum is what this report will be focusing on. It is commonly known by another name: diesel. Much of the technology in society burns this fuel, making petroleum a significant component of modern transportation and industry. The US Energy Information Administration (EIA) reports that in 2016, 95% of the energy used for transportation in the US came from fossil fuels [2]. Despite the world's reliance on fossil fuels, there is only a finite amount of it in existence. Since fossil fuels are taken from fossilized remains that take millions of years to form, they can be considered a nonrenewable resource. In 2014, BP (formerly British Petroleum) predicted that the world had only 53.3 years left until it is depleted of oil [3]. Despite this, the rate at which humans are consuming fossil fuels is projected to increase. The EIA predicts in its 2014 International Energy Outlook that by 2040 the world's liquid fuels consumption would have increased by 38% [4]. With humans increasing their petroleum consumption at a faster rate than it can form, there will be a net decrease of global liquid fuel supplies. Furthermore, the combustion and usage of fossil fuels emits pollutants which contribute to global climate change, namely carbon in the form of CO_2. This gas acts as a blanket over Earth's atmosphere, trapping in heat from the sun onto the surface. Since 1850, Earth's atmosphere's CO_2 levels have increased by 44%, from 280 ppm to 404.48 ppm [5,6]. Earth's temperature has risen 0.8ºC from 1880 to 2014 [7]. The diminishing supply of fossil fuels and the harmful effects of their usage on the environment has resulted in governments around the world creating policies aimed at countering global warming. All of these factors have prompted nations to seek alternative sources of fuel that are environmentally-friendly, renewable, and practical.

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In the wake of this search for new fuel sources, biodiesel has gained popularity as a replacement for petroleum diesel. Biodiesel is created through chemically combining natural oils or fats with an alcohol in the presence of a catalyst through transesterification. Commonly used oils include soybean, sunflower, rapeseed oil. Catalysts are usually, but not limited to, potassium hydroxide (KOH) and sodium hydroxide (NaOH). Methanol is the most commonly used alcohol for commercial biodiesel but ethanol is also an alternative. It mainly uses renewable resources from plants and animals in its creation as opposed to the nonrenewable fossil fuels. The combustion of biodiesel results in less CO_2, SO_2, CO, and HC being produced than conventional petroleum diesel. Soy biodiesel is reported to reduce CO_2 by 78% [8]. Biodiesel is able to do this by creating a closed cycle of carbon usage, recycling any carbon that is emitted. In this cycle, carbon emitted is absorbed by plants during photosynthesis. Then, those plants are used in the creation biodiesel which would go on to power diesel-burning technology. Carbon that is produced is reused. For fossil fuels, the sequence is more linear. Carbon from the fossils fuels are burned in diesel engines that emit carbon. Without any means to capture the emitted carbon, it is able to escape into the atmosphere and contribute to climate change.

However, biodiesel is not a flawless alternative for fuel. Its high detergency, or ability to lift debris off surfaces, results in it being able to clog fuel filters. At low temperatures, biodiesel has the tendency to thicken, reducing its performance. It is also more likely to oxidize than petroleum diesel due to its unstable double bond(s), which can degrade the fuel if left standing for an extended period of time [9]. The high oxygen content of biodiesel produces larger formations of nitrogen oxide (NOx) gas than petroleum, which is a highly-poisonous substance. In order to produce biodiesel, large amounts of agricultural land have to be dedicated to grow feedstock (crops for biodiesel production). This has led to deforestation to open more land for monoculture agriculture. Deforestation produces 20% of the world's greenhouse gas emissions so the environmental benefits of biodiesel can be outweighed by this [8]. Furthermore, more crops going towards biodiesel production leads to a lower food supply. A shortage of food can be detrimental to the health of those in some developing nations that struggle with food production. Another notable shortcoming of biodiesel is its monetary cost of production. The price of food is expected to rise as more crops are directed towards biodiesel. As demand increases but supply decreases, prices increase. This high production cost can translate into a high price for consumers, making this fuel less affordable. Some of the issues regarding biodiesel's properties can be reduced through additives or creating a biodiesel-petroleum blend while others require large systemic changes.

We hypothesized that using canola oil in combination with potassium hydroxide and ethanol would result in a biodiesel with the highest energy to cost ratio (J/g/$) compared to other precursor component combinations. Oils high in oleic acid are the most beneficial at increasing biodiesel performance due to their long molecules of unsaturated fats [9]. These unsaturated fats are favorable because while saturated fats contain more energy, they tend to transform into a gel-like state in cold weather. However, unsaturated fats are also more prone to oxidation, which degrades the biodiesel. This shortcoming can be fixed by combining the fuel with oxidation stabilizers. Oils consisting of monounsaturated fats are also favorable since these fats contain a single double bond. In these double bonds, electrons from atoms on both sides of it repel each

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other. These bonds are stronger than a single bond. On the other hand, the more bonds that are present, the stronger the electron repulsion and thus the molecule is more reactive. Having a long chain of these unstable double bonds means that there are multiple places where that bond could react, releasing energy in the process. Saturated fats (alkanes) are characterized by stable C-H bonds which make it more difficult for them to be broken. This means the energy within these fats can go unused. Polyunsaturated fats contain many double bonds that can make the molecules unstable. Their instability can make the molecules react before transesterification, resulting in wasted energy and decreased yield. Monounsaturated fats provides a good balance between the two with weak bonds but not so many weak bonds that make the molecule unstable. Canola oil consists of mainly monounsaturated fats in long chains (carbon atom to double bond ratio of 18:1), has an energy density of 39.64 to 39.8 MJ/kg, and contains 56% oleic acid [10, 11, 12]. This combination of high oleic acid content, high energy density relative to other natural oils, and stable molecule structure makes it a strong choice for a precursor oil. Furthermore, it is one of the cheapest precursor oils, at about $0.7 - $0.9 per fl oz [13]. A few oils, such as vegetable oil, are cheaper than canola oil but do not have the chemical properties suitable for biodiesel. However, it should be noted that prices fluctuate. The two tables positioned below show the composition of the various precursor oils and the percentage of fatty acid composition, respectively.

Table 1: Oil Composition by Fat Type

Oil	Saturated	Monounsaturated	Polyunsaturated
Canola oil	7%	62%	31%
Safflower oil	7%	14%	79%
Camelina oil	10%	33%	54%
Sunflower oil	10%	20%	66%
Corn oil	13%	24%	59%
Olive oil	14%	73%	11%
Soybean oil	16%	23%	58%
Peanut oil	17%	46%	32%
Chufa oil	20%	67%	12%
Cottonseed oil	26%	18%	52%
Lard	39%	45%	11%
Palm oil	49%	37%	9%
Butter	63%	26%	4%

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Coconut oil	90%	6%	2%

Table 2: Oil Composition by Fatty Acid Type

Fat or Oil	12:0	14:0	16:0	18:0	18:1	18:2	18:3	20:0	20:1	22:1
Soybean	.	.	6-10	2-5	20-30	50-60	5-11	.	.	.
Canola	.	.	4	7	61	21	11-13	.	.	.
Corn	.	1-2	8-12	2-5	19-49	34-62	.	.	.	.
Peanut	.	.	8-9	2-3	50-65	20-30	.	.	.	.
Olive	.	.	9-10	2-3	73-84	10-12	.	.	.	.
Cottonseed	.	0-2	20-25	1-2	23-35	40-50	.	.	.	.
Butter	.	7-10	24-26	10-13	28-31	1-2.5	.2-.5	.	.	.
Lard	.	1-2	28-30	12-18	40-50	7-13	0-1	.	.	.
Tallow	.	3-6	24-32	20-25	37-43	2-3	.	.	.	.
Linseed Oil	.	.	4-7	2-4	25-40	35-40	25-60	.	.	.
Coconut Oil	45-53	17-21	7-10	2-4	5-10	1-3	.	.	.	.
Palm oil	.	.	44	5	39	10	.	.	.	.
Pongamia pinnata oil	.	.	4-8	3-9	45-71	11-18	.	2-5	10-12	4-5

For the lye, potassium hydroxide takes less time to react with alcohols compared to sodium hydroxide [14, 15]. It also results in the creation of less solid soap, which could clog diesel engines and reduce yield. The price between sodium hydroxide and potassium hydroxide varies depending on the retailer but on average, potassium hydroxide costs $2.50/lb while sodium hydroxide costs $1.27/lb [16]. More potassium hydroxide than sodium hydroxide is usually needed to create a certain amount of biodiesel. However, the amount of soap that would be create using sodium hydroxide means that there is less biodiesel produced compared to potassium hydroxide. This means that our money for a sodium hydroxide biodiesel is not being used as efficiently and will translate into a higher cost for the fuel. For the alcohol, one gallon of E10 (ethanol fuel) contains 96.7% of the energy of a gallon of gasoline while one gallon of methanol fuel contains only 49% [17]. They cost about the same with methanol costing $6.25 per 500 mL and ethanol costing $6.65 per 500mL container. When taking into consideration the energy to cost ratio, ethanol has greater potential energy for a small increase in price. Theoretically, this makes it seem more cost efficient than methanol. To test our hypothesis, we asked these research questions:

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- Molecules consisting of many carbon atoms and double bonds have a long length with large amounts of potential energy. If this is the case, then do oils with a higher carbon atom to double bond ratio produce a more energy dense biodiesel (J/g)?
- Methanol costs less than ethanol yet provides less energy than it. As a result of this, will the energy to cost ratio (J/g/$) of ethanol-based biodiesel be significantly greater than the ratio for methanol-based biodiesel?
- A part of the cost efficiency calculations is the amount of biodiesel yielded compared to the cost of production. A study done by the Australian Journal of Crop Science concluded that sodium hydroxide biodiesels had a percent yield of 71.2% while potassium hydroxide biodiesels yielded 68.9% [18]. However, the byproducts of soap and glycerin can result in less usable biodiesel in the end. It is also mentioned above that potassium hydroxide on average costs more. Based on this, does potassium hydroxide result in a significantly higher percent yield of usable biodiesel compared to sodium hydroxide? Is the ratio of biodiesel produced to dollar of lye (g/$) for potassium hydroxide greater than that same ratio for sodium hydroxide?
- The average cost of gasoline in America according to American Automobile Association is around $2.28 per gallon with an average energy density of 44,000 J/g [19-20]. This calculates to 19298.25 J/g/$/gal. Since one of the main issues of biodiesel is the cost of the fuel, can we make a biodiesel recipe which is able to compete with the energy per dollar of a gallon of gasoline (J/g/$/gal)?

In this study, we synthesized six different biodiesels. For each one, we kept the lye and the alcohol consistent but changed the precursor oil used. The two different oils we used are canola oil and safflower oil. Canola oil was tested because it was in our hypothesis. Safflower oil contains 79% polyunsaturated fats, which are mentioned above to contain more potential energy but are also the most unstable out of the three fat types. We chose these two oils because one is mainly polyunsaturated fats while the other is mainly monounsaturated fats. After synthesizing 6 batches of biodiesel, we performed calorimetry tests in order to record the amount of energy (J) each fuel released to calculate energy density (J/g). Then, we calculated the cost of creating each biodiesel and mathematically calculated the amount of energy per dollar. In order to get all the data to adequately answer these questions, we collaborated with other groups that created different biodiesel recipes. In total, we were able to obtain a database of 69 biodiesel batches.

Methods

Materials

The materials used for 6 batches of 100 g of biodiesel were 144 g of anhydrous ethanol, 6 g of pure solid potassium hydroxide, 300 g of pure canola oil, and 300 g of pure safflower oil [21, 22]. At least 1200 mL of water was also needed to properly wash the biodiesel but more was required. If the biodiesel did not separate, 0.2 g of salt was needed for each unseparated batch. Tools used for this procedure were 1 hot plate, 1 digital thermometer capable of measuring at least 60ºC, 1 50 mL graduated glass cylinder, 2 400 mL graduated glass beakers, 13 4 oz or larger glass mason jars with lids, 1 scale capable of measuring mass in grams up to 0.01 significant figures and has a TARE button, 1 Sharpie marker, 1 roll of washing tape, 1 plastic

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weigh boat for measuring the potassium hydroxide, tweezers, at least 18 plastic 10 mL pipettes or 1 reusable 10 mL syringe with at least 12 needles, and a plastic stirring stick. It is important that these tools were clean and dry since outside substances, especially water, can affect the results of this experiment. Since some of the substances used were caustic, it was important to have 1 lab coat per person, 1 pair of safety goggles per person, and 1 pair of safety gloves per person.

Biodiesel Synthesis Process

This process is where the biodiesel was made. The reaction in which biodiesel is created is called transesterification. Natural oils are composed of molecules called triglycerides that are made of three fatty acid chains chemically bonded to one glycerol molecule. During transesterification, the fatty acid chains become connected to the alcohol molecules to form an ester. In this case, since ethanol is used, ethyl esters were formed with pure glycerine as a byproduct. These esters are what constitute biodiesel [23]. It is important that the oils undergo transesterification because it makes them suitable for use in diesel engines. Pure oils have too high of a viscosity to properly function inside a conventional diesel engine. Transesterification lowers the viscosity of the oils so they can flow inside an engine [41].

100 g of precursor oil was heated to a temperature between $55^{o}C$ and $60^{o}C$ with a hot plate. While it was heating, 23.15 g of ethanol (if the precursor oil was canola) or 23.33 g of ethanol (if the oil was safflower) was mixed with 0.8 g of pure potassium hydroxide tablets in a 50 mL graduated cylinder. This mixture was stirred until the potassium hydroxide was fully dissolved. Once the oil was at the appropriate temperature and the ethoxide was prepared, the ethoxide was poured into the precursor oil and the entire mixture was stirred for 5 minutes. During this step, heat was maintained between $55^{o}C$ and $60^{o}C$. After 5 minutes of stirring, the crude biodiesel was poured into a 4 oz mason jar and allowed to sit for 24 hours.

If the glycerol did not separate from the biodiesel within 24 hours, the biodiesel was reheated to $55^{o}C$ - $60^{o}C$ and 0.2 g of salt was poured into it. The salt was intended to attracted the glycerol molecules and initiate the buildup of a glycerol layer.

Glycerol Removal

Once transesterification was complete, pure glycerol molecules from the triglycerides settled on the bottom of the jars. The current combination of glycerol and biodiesel cannot be inputted into a diesel engine because the viscosity of the glycerol makes it difficult for the engine to function. Once the glycerol was removed, crude biodiesel remained.

A 10 mL pipette was used to extract the crude biodiesel from the glycerol layer. The crude biodiesel was placed in a separate 4 oz mason jar and the leftover glycerol was disposed of.

Biodiesel Washing and Drying Process [30]

The final step was to clean the crude biodiesel of impurities. Soap, excess ethanol, excess potassium hydroxide, unreacted oil, and small amounts of glycerin were still present inside the biodiesel. When water is introduced to the biodiesel, these impurities more readily dissolve in water than the biodiesel. Water is considered the “universal solvent” because its molecular

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structure consists of positively charged hydrogen atoms with one negatively charged oxygen atom. This polar arrangement makes it attract a variety of different molecules, including the ones that make up these impurities [31]. “Drying” refers to the process of removing the water. Water in diesel engines can potentially cause the fuel injector tip to explode or shorten the life of a diesel engine [34].The end result of this process was pure biodiesel that is ready for calorimetry.

At least 100 g of water heated to 35ºC was used to wash each batch of crude biodiesel. This water was used to bubble wash the biodiesel inside the mason jar, along with a pipette. Water was added until the jar was nearly full. After one round of bubble washing, the jar was allowed to sit for 5 hours. Then, the biodiesel was moved to another mason jar with a pipette. Bubble washing was repeated until the water used in the wash came out transparent. Once all the washing was complete, the pure biodiesel was poured into a mason jar and ready for calorimetry.

Calculating Percent Yield

Percent yield is a measure of the amount of biodiesel was created from the original 100 g of precursor oil. This is an important value to assess the efficiency and effectiveness of our biodiesel synthesizing procedures. Percent yield was calculated using this formula:

$$Percent\ yield = \frac{Actual\ yield}{Theoretical\ yield}\ x\ 100\ .$$

Calorimetry Procedures [36]

The First Law of Thermodynamics states that heat energy lost from one body is transferred into another body. When two bodies with different amounts of heat are placed next to each other, the particles of the warmer body are moving faster than the particles of the colder body. If these two bodies make contact with each other, the particles of the warmer body will transfer their energy to the particles in the colder body. The warmer body loses heat while the colder body gains heat. Eventually, they will reach the same temperature. This is the basis for calorimetry, which is the measurement of heat transfer. A calorie (cal) in this context is defined as the amount of energy needed to increase the heat of 1 g of water by 1ºC. In this lab, each biodiesel was burned under a soda can containing water, with the temperature change in the water being recorded. Once this value was recorded, a formula was used to calculate the amount of heat produced by each biodiesel. By knowing the heat produced, we could analyze the energy density of each biodiesel and either confirm or refute our hypothesis.

Materials

For the calorimetry lab, it was necessary to have the 6 biodiesel batches synthesized and cleaned. Other materials that were used include a laboratory ring stand consisting of an arm with clamps, a clean and dry 12 fl oz soda can, at least 1 3.81 cm aluminum candle holder with at least 6 wicks, a digital thermometer capable of measuring up to at least 60ºC, a 100 mL or larger graduated glass beaker, a 50 mL graduated cylinder, a 50 mL graduated beaker, a ruler measuring in cm, a scale with a TARE button capable of measuring up to 0.05 decimal places, a pair of scissors, a timer, and a lighter. All the tools for this lab were clean and dry so extra water did not affect the results of the lab. Similar to the biodiesel synthesis lab, every person had 1 lab coat, 1 pair of safety goggles, and 1 pair of safety gloves for safety purposes.

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Calorimetry Process

100 g of room temperature water was poured into a 12 fl oz soda can and secured into a ring stand's arm. Biodiesel was poured into a 3.81 cm candle holder until it was full and a 2 cm wick was placed in the center of it. The soda can was lowered until it was 2 cm above the wick. The mass of the candle holder with biodiesel was recorded. The wick was lit on fire and temperature of the water was monitored every 1 minute until 10 minutes passed. The height of the soda can was adjusted during the experiment to try to keep it 2 cm above the wick. The mass of the candle holder with biodiesel after the experiment was also recorded.

The energy of the biodiesel in Joules was calculated using the equation $Q = mC\Delta T$. m was the mass of biodiesel that was consumed by the combustion reaction. This was found by subtracting the initial mass of the candleholder and biodiesel with its final mass. It should be noted that since the experiment was not a closed system, some of the energy produced by the biodiesel escaped into the surroundings.

After Synthesis

Our biodiesel synthesis had some significant issues. The first was that the biodiesel failed to separate into biodiesel and glycerol. This is how we created the contingency plan in our methods about what to do if the biodiesel does not separate. We added salt to the biodiesel batch after it was heated to 55°C and waited for it to resettle. After it still failed to separate, we separated the biodiesel from the salt through a filter and washed the biodiesels. Some of the initial batches turned into soap, likely due to improper washing techniques or the formation of a large emulsion consuming the entire batch. Other batches gradually contained less and less biodiesel until there was almost none left. Eventually, all of our initial 6 batches were considered failures. Our chemistry teacher, Mr. Davey, recommended a new addition to our methods where the biodiesel is stirred and heated for 60 minutes and in addition to only pouring water, we bubble washed the biodiesel as well. We did this on two new batches of biodiesel that we made and the end result was collectable, usable, and washed biodiesel. These additions and fixes are added to the methods for a more effective procedure. In the end, we had no safflower batches and only two batches of canola biodiesel. We also had one canola biodiesel made from methanol that we made out of curiosity.

Results

We synthesized 100 g of canola or safflower oil with 0.8 g of KOH and 23.13 g or 23.33 g of ethanol depending on the precursor oil used respectively. We produced two canola batches and a canola batch with methanol. Our biodiesels yielded some results and in collaboration with other research groups, we had a large pool of data to analyze. In total, we analyzed 69 batches of biodiesels synthesized from a variety of recipes. When it comes to the composition of our data, 40 of the biodiesels used canola oil, 2 used corn oil, 17 used olive oil, 2 used peanut oil, 4 used safflower oil, 1 used soybean oil, and 3 used sunflower oil. 39 batches used KOH while 30 used NaOH. Furthermore, 5 batches used ethanol while 64 used methanol. The batch with the highest recorded percent yield from the database was a canola, KOH, and methanol batch with a percent yield of 82.5%. The lowest recorded percent yield was 6.75% from a sunflower oil, KOH, and methanol batch. For our own batches, one of batch of canola, KOH, and ethanol had a percent

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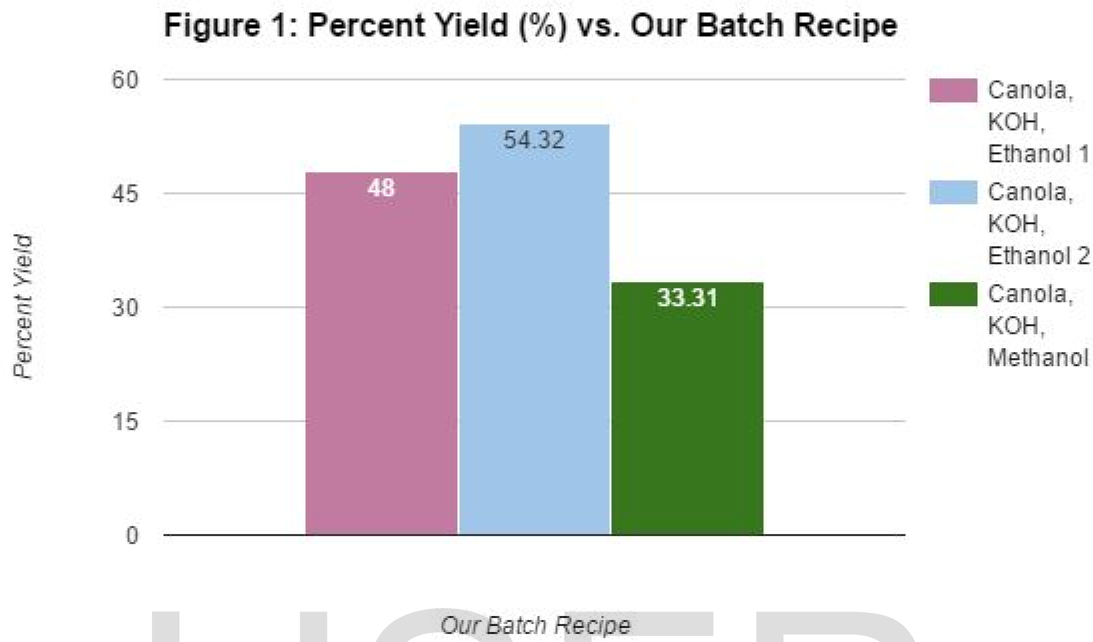
yield of 48% and the other was 54.32%. A third batch of the same oil and lye but with methanol had a percent yield of 33.31%. Figure 1 below illustrates the percent yield of our biodiesel.



We also analyzed the individual components of biodiesel (precursor oil, lye, and alcohol) in relation to the percent yield of the biodiesels they are in. Figure 2 shows the percent yield of all the canola batches (n=40) from the experiments, which was the oil from our hypothesis. Figure 3 shows the type of precursor oil used to make biodiesel compared to the average percent yield of all those biodiesels using the same oil. It also contains error bars to show the standard error of each precursor oil group. Table 3 displays the highest and lowest values for the data for each oil in regards to percent yield plus the standard error. Figure 4 shows a graphical representation of the data range.

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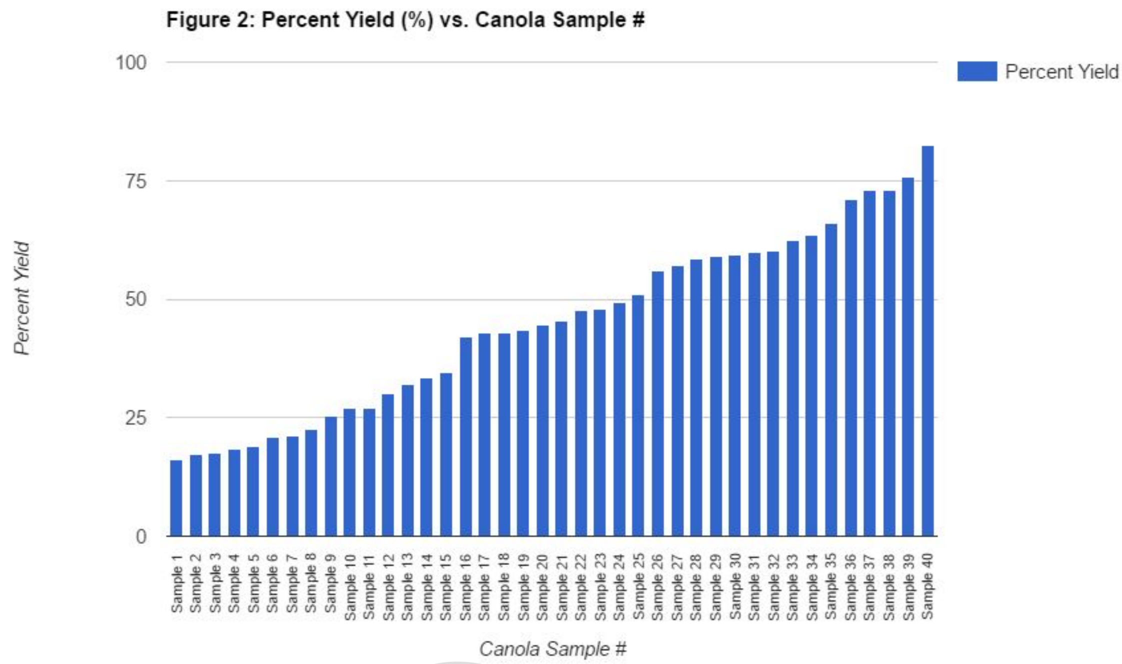

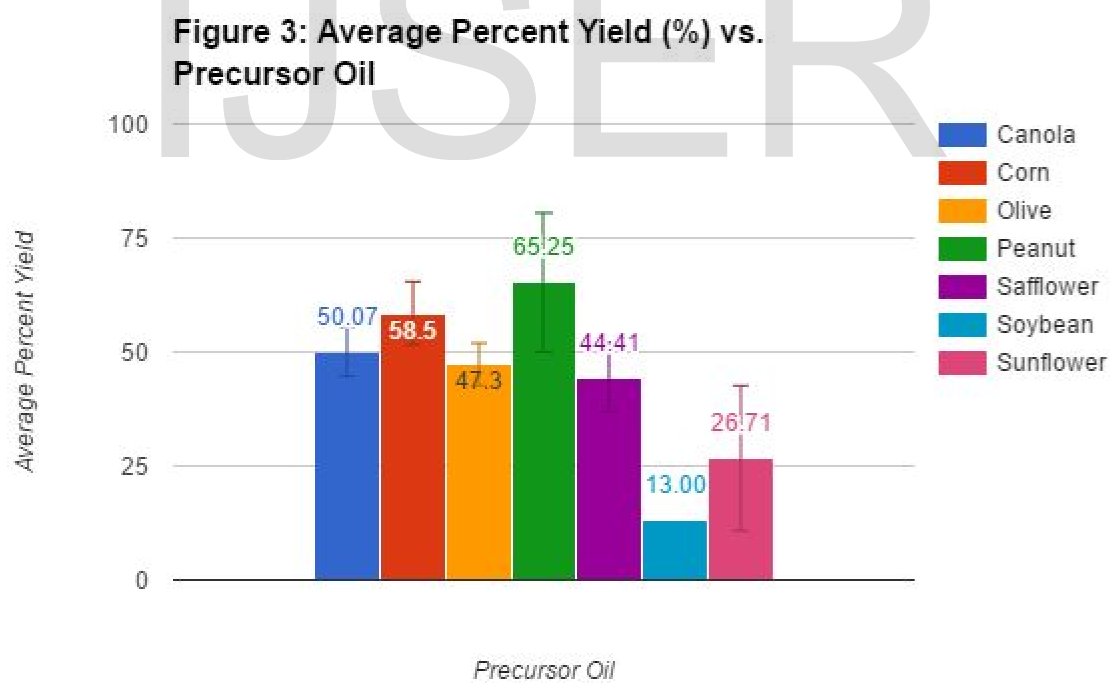

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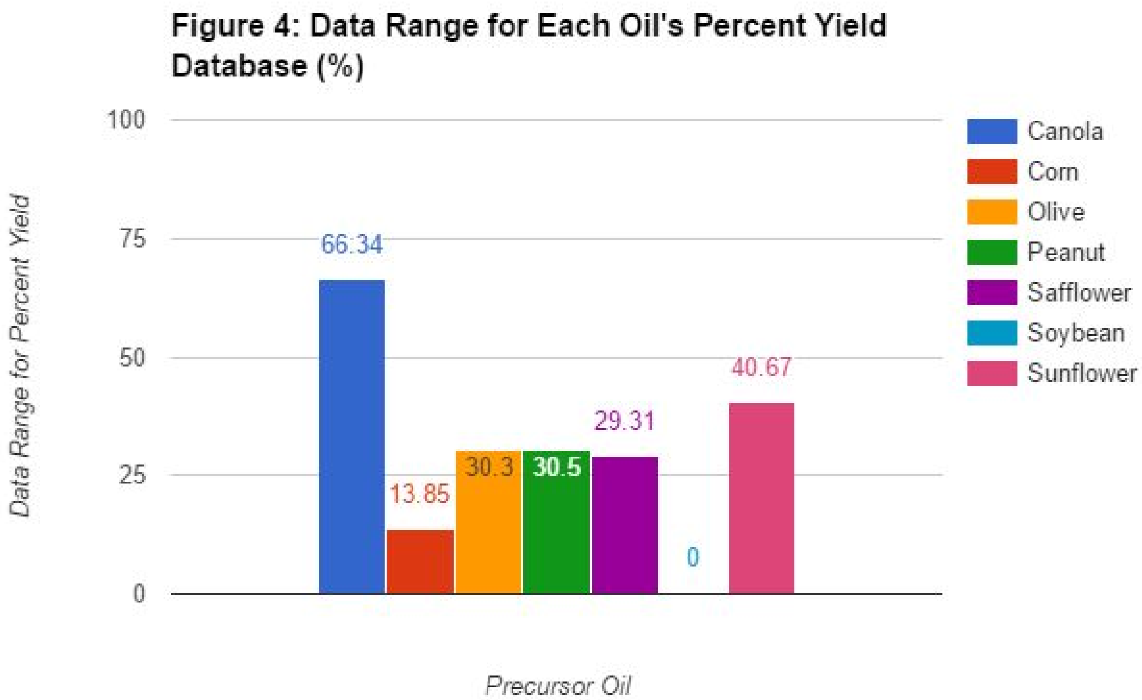

Table 3: Range and Standard Error Values for Percent Yield for Precursor Oil Data				
Oil	Lowest Value (%)	Highest Value (%)	Data Range (%)	Standard Error (%)
Canola	16.16	82.5	66.34	3.04
Corn	30.92	44.77	13.85	17.45
Olive	46.57	76.9	30.33	11.27
Peanut	50.0	80.5	30.5	23.89
Safflower	33.21	62.52	29.31	9.13
Soybean	13	13	0	0
Sunflower	25.43	66.10	40.67	13.95

The average percent yield for the canola oil biodiesels (n=40) was 50.07%, the average for corn oil biodiesels (n=2) was 37.85%, 47.30% for olive oil biodiesels (n=17), 65.25% for peanut oil biodiesels (n=2), 44.41% for safflower oil biodiesels (n=4), 13.00% for soybean oil biodiesels (n=1), and 26.71% for sunflower oil biodiesels (n=3). The lowest average percent yield was from the soybean oil biodiesel and the highest average came from the peanut oil biodiesels. The

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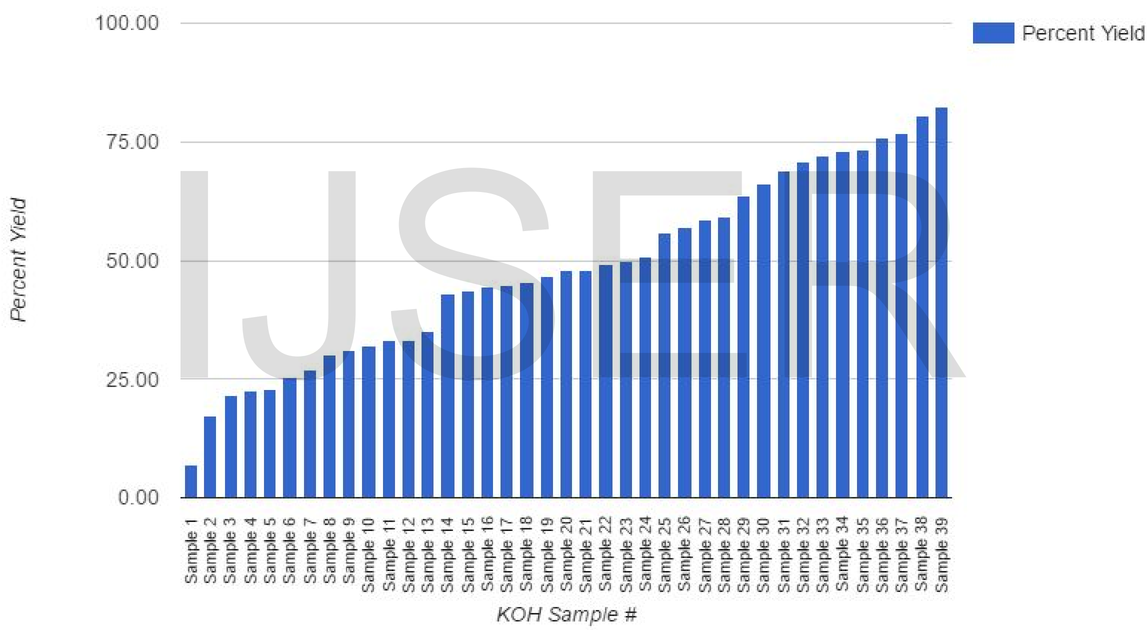
median was safflower oil biodiesel with 44.41%. The standard error for each oil group was 3.04% for canola oil biodiesels, 17.45% for corn oil biodiesels, 11.27% for olive oil biodiesels, 23.89% for peanut oil biodiesels, 9.13% for safflower oil biodiesels, 0% for soybean oil biodiesel (there was only one batch), and 13.95% for sunflower oil biodiesels. The range for canola biodiesels was 66.34%, for corn oil biodiesels was 13.85%, for olive oil biodiesels was 30.33%, for peanut oil biodiesels was 30.5%, for safflower oil biodiesels was 29.31%, for soybean oil biodiesels was 0%, and for sunflower oil biodiesels was 40.67%. The largest range was from the canola oil biodiesels and the lowest was from the safflower oil biodiesels. In addition, Figure 5 shows the percent yield for every KOH batch (n=39) in the database, the second component of our hypothesis. Figure 6 shows the average percent yield for biodiesel batches according to the type of lye used. Table 4 shows the lowest and highest values for each lye's percent yield database and the standard error. Figure 7 gives a graph of the data range.

Figure 5: Percent Yield (%) vs. KOH Sample #



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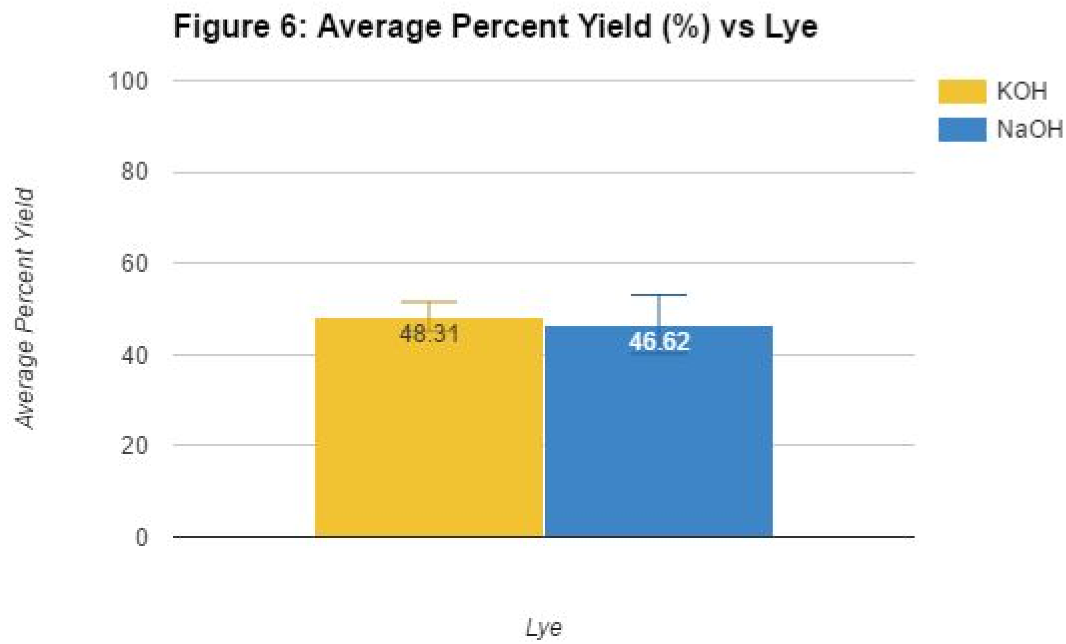

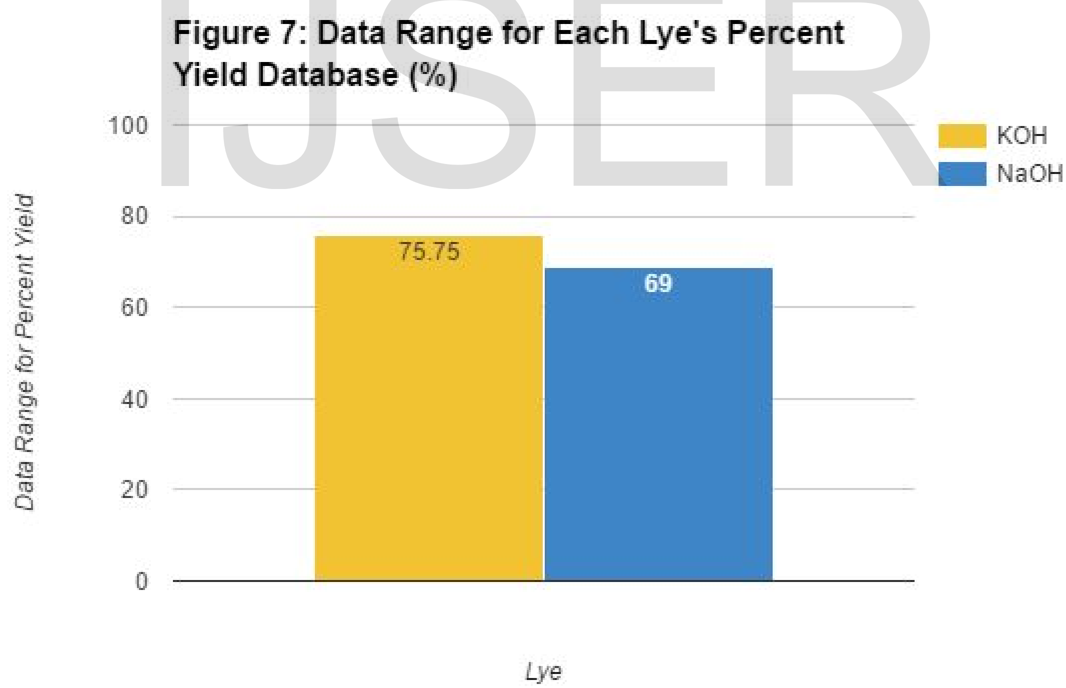

Table 4: Range and Standard Error Values for Percent Yield for Lye Data				
Lye	Lowest Value (%)	Highest Value (%)	Data Range (%)	Standard Error (%)

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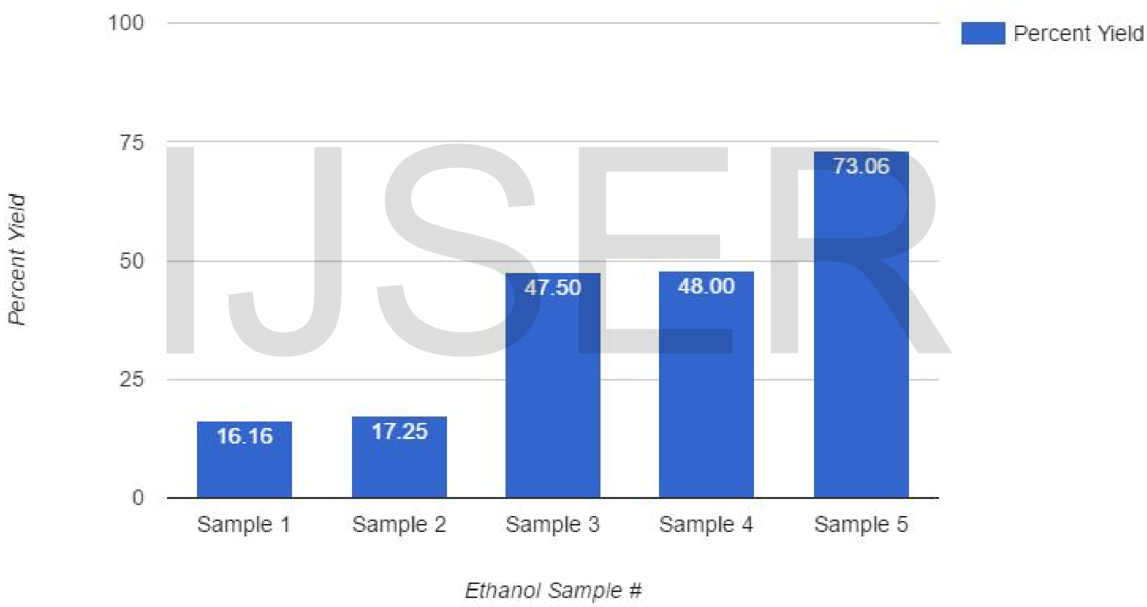
KOH	6.75	82.50	75.75	3.23
NaOH	13	82	69	6.43

According to Figure 6, KOH biodiesel (n=39) had an average percent yield of 48.31% while NaOH biodiesel (n=30) had an average of 46.62%. The standard error for the KOH biodiesel data was 3.23% and the standard error for NaOH biodiesel data was 6.43%. The range of the data of KOH biodiesel was 75.75%. The range for NaOH biodiesel data was 69%. Next, Figure 8 shows the percent yield for all our ethanol batches (n=5), the third component of our hypothesis. Figure 9 shows the average percent yield compared to the type of alcohol used to create biodiesel. Table 5 shows the data range in each alcohol's database along with the standard error values while Figure 10 shows the data range.

Figure 8: Percent Yield (%) vs. Ethanol Sample #



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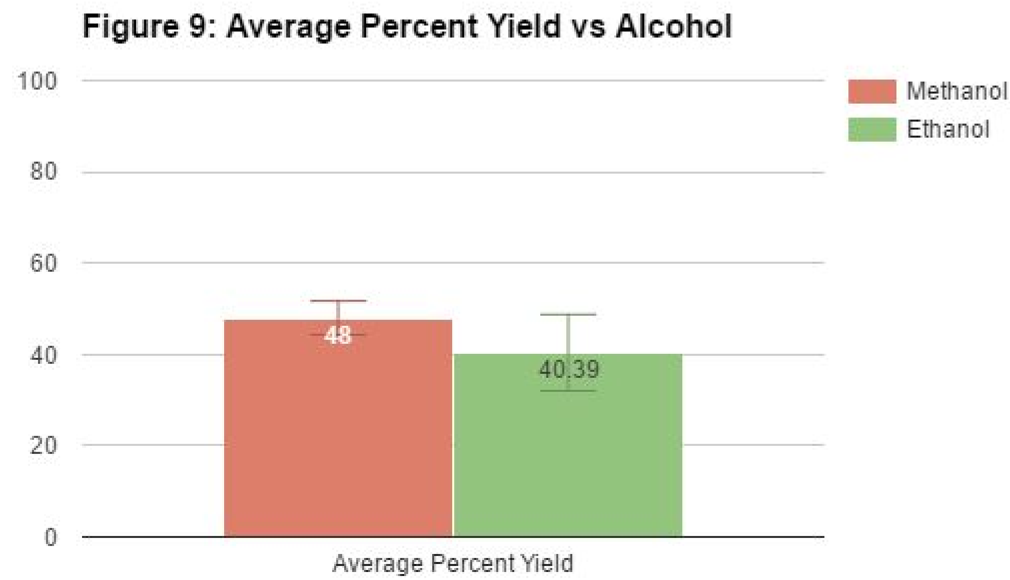


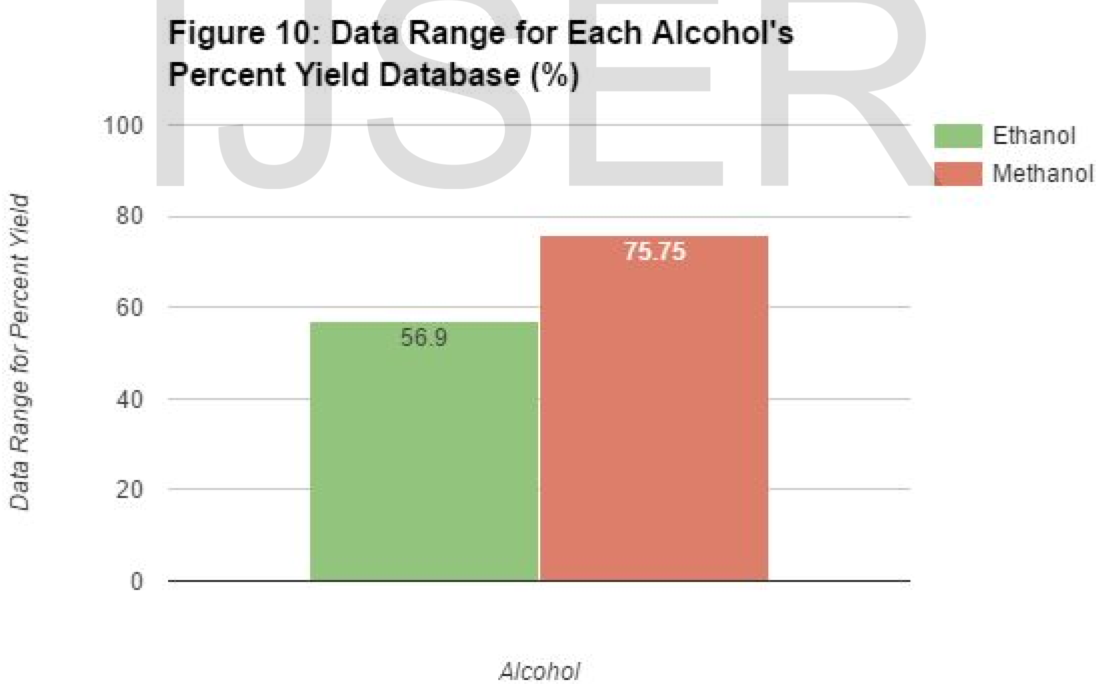


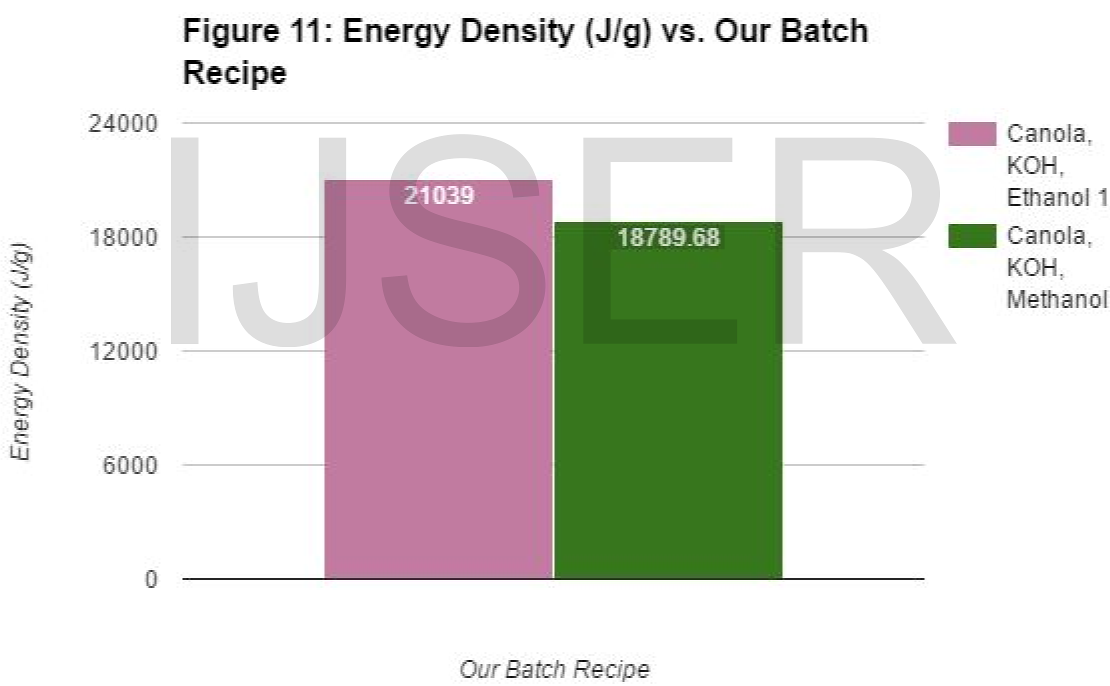
Table 5: Range and Standard Error Values for Percent Yield for Alcohol Data				
Alcohol	Lowest Value (%)	Highest Value (%)	Data Range (%)	Standard Error (%)

[1]*Department of Chemistry, Summit Public School: Shasta, Daly City, CA 94015, USA*

Ethanol	16.16	73.06	56.9	8.37
Methanol	6.75	82.50	75.75	3.7

Figure 5 shows the average percent yield for methanol biodiesels (n=64) was 48% and the average for ethanol biodiesel (n=5) was 40.39%. The standard error for the methanol biodiesel data was 3.70% while the standard error for ethanol biodiesel was 8.37%. The range for the ethanol batches was 56.9% and the range for the methanol batches was 75.75%.

The batch with the absolute highest energy density (J/g) in our data pool consisted of safflower, NaOH, and methanol with 43,890 J/g. The absolute lowest energy dense batch was a canola, NaOH, and methanol batch which contained 2034.3 J/g. We were able to perform calorimetry on one of our two canola, KOH, and ethanol batches, which had an energy density of 21039 J/g. Our canola, KOH, and methanol batch had an energy density of 18789.68 J/g. Figure 11 below shows the energy density of our own biodiesel batches.



Similar to the data on percent yield, we inspected the average energy density of biodiesels with common components. First, Figure 12 shows the energy density of all our canola biodiesels (n=40). Figure 13 shows average energy density compared to the type of precursor oil used to make biodiesel. Table 6 shows the data range values and standard error . Figure 14 shows the data range graphically.

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Figure 12: Energy Density (J/g) vs. Canola Sample #

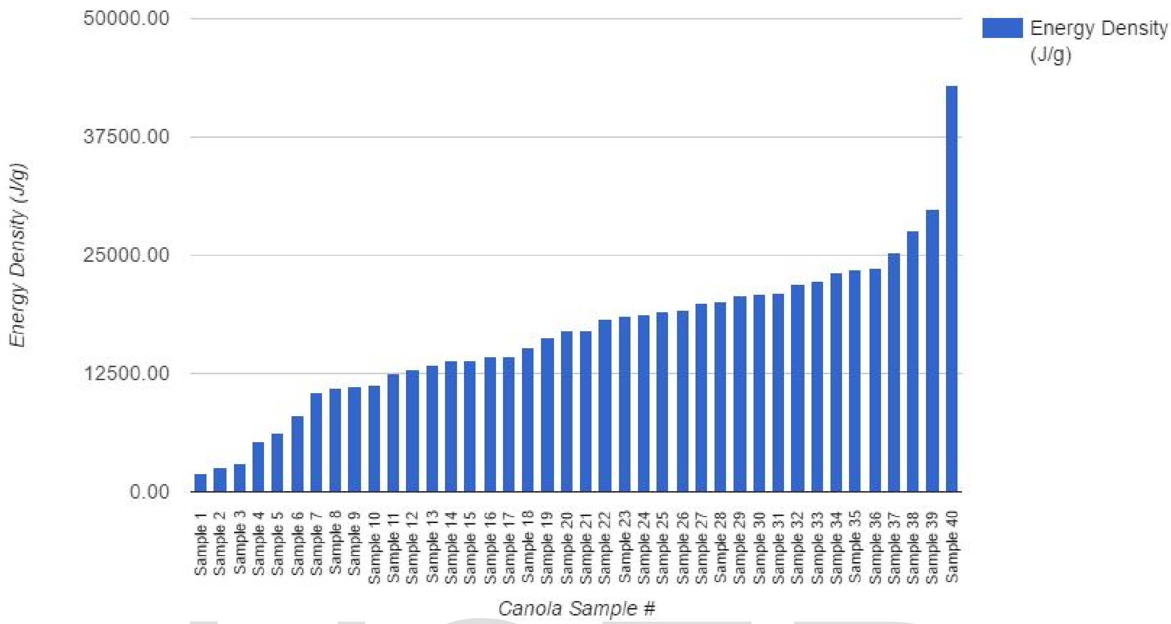
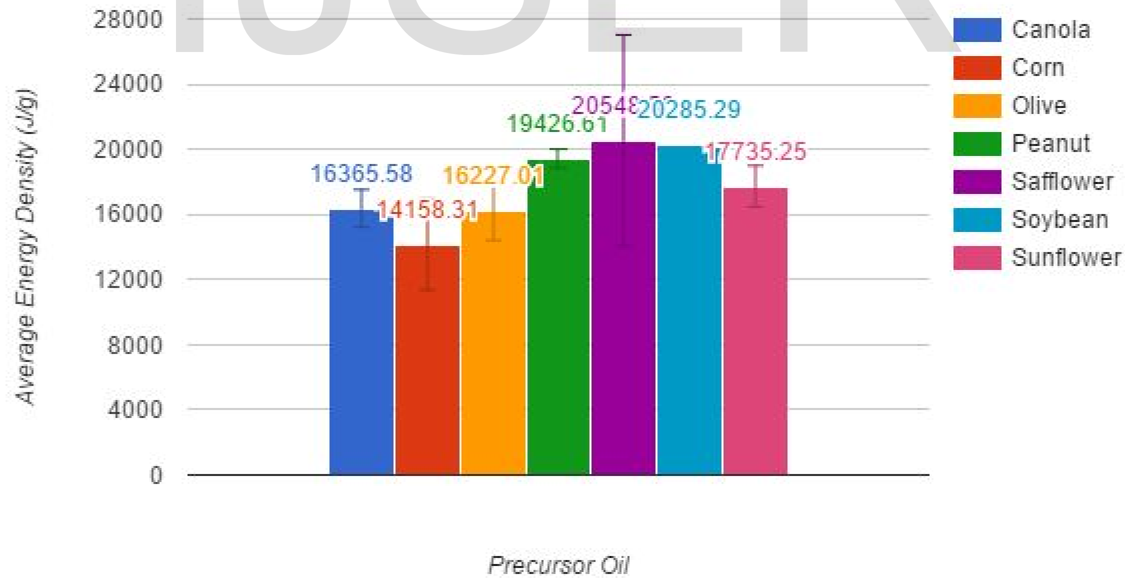


Figure 13: Average Energy Density (J/g) vs. Precursor Oil



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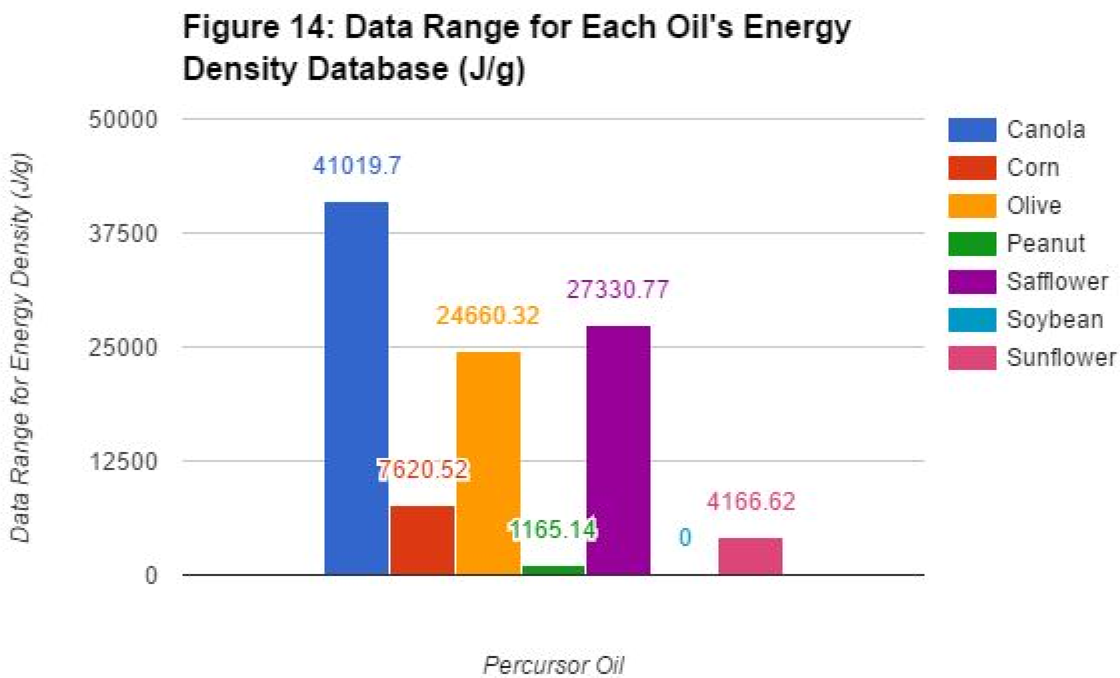

Table 6: Range and Standard Error Values for Energy Density for Precursor Oil Data				
Oil	Lowest Value (J/g)	Highest Value (J/g)	Data Range (J/g)	Standard Error (J/g)
Canola	2034.30	43054	41019.7	1218.58
Corn	10348.05	17968.57	7620.52	3810.26
Olive	5211.43	29871.75	24660.32	1494.45
Peanut	18844.04	20009.18	1165.14	582.57
Safflower	16559.23	43890.0	27330.77	6476.29
Soybean	4180.0	4180.0	0	0
Sunflower	16118.67	20285.29	4166.62	1262.39

The average energy density for canola oil biodiesel (n=40) was 16365.58 J/g, 14158.31 J/g for corn oil biodiesel (n=2), 16227.01 J/g for olive oil biodiesel (n=17), 19426.61 J/g for peanut oil biodiesel (n=2), 20548.58 J/g for safflower oil biodiesel (n=4), 20285.29 J/g for soybean oil biodiesel (n=1), and 17735.25 J/g for sunflower oil biodiesel (n=3). The highest average energy density came from the safflower oil batches and the lowest average came from the corn oil batches. The median average came from the sunflower oil biodiesels. The standard error for the canola oil biodiesel data was 1218.58 J/g, 3810.26 J/g for corn oil biodiesel, 1494.45 J/g for

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olive oil biodiesel, 582.57 J/g for peanut oil biodiesel, 6476.29 J/g for safflower oil biodiesel, 0 J/g for soybean oil biodiesel (there was only one batch), and 1262.39 J/g for sunflower oil biodiesel. The range for canola oil biodiesel data was 41019.7 J/g, for corn oil biodiesel was 7620.52 J/g, for olive oil biodiesel was 24660.32 J/g, for peanut oil biodiesel was 1165.14 J/g, for safflower oil biodiesel was 27330.77 J/g, for soybean oil biodiesel was 0 J/g, and for sunflower oil biodiesel was 4166.62 J/g. Furthermore, Figure 15 shows the energy density for all of the KOH batches (n=39) in the database. Figure 16 shows the average energy density of biodiesel compared to the lye used to make the biodiesel. Table 7 shows the data range values and standard error values. Figure 17 shows the range of the data for each lye group.

Figure 15: Energy Density (J/g) vs. KOH Sample #

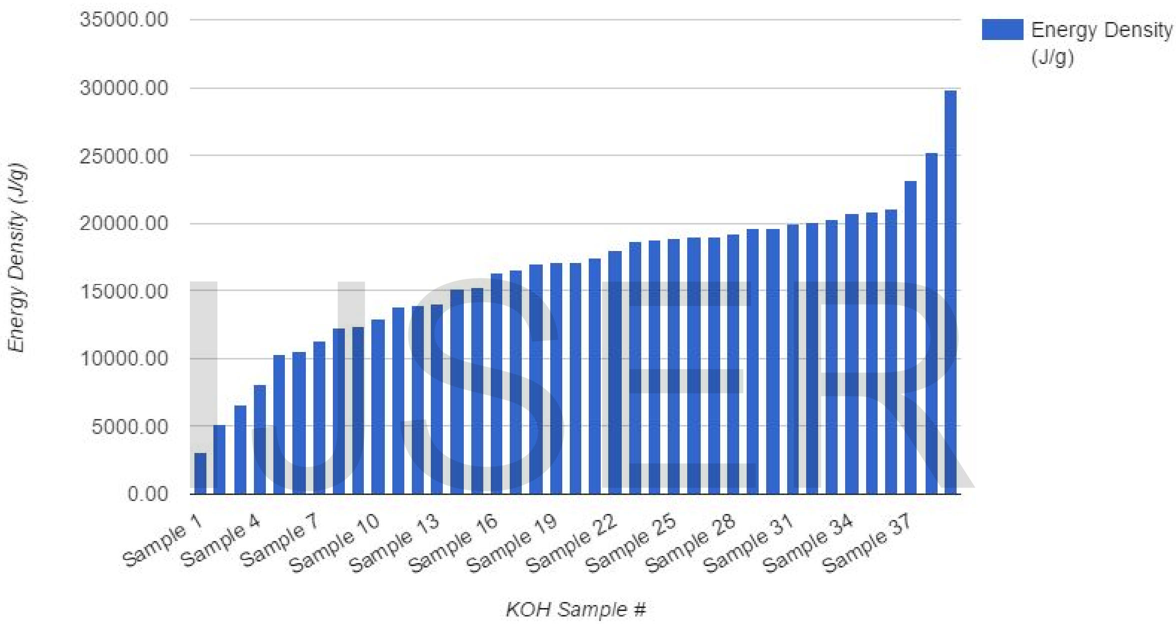

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Figure 16: Average Energy Density (J/g) vs. Lye

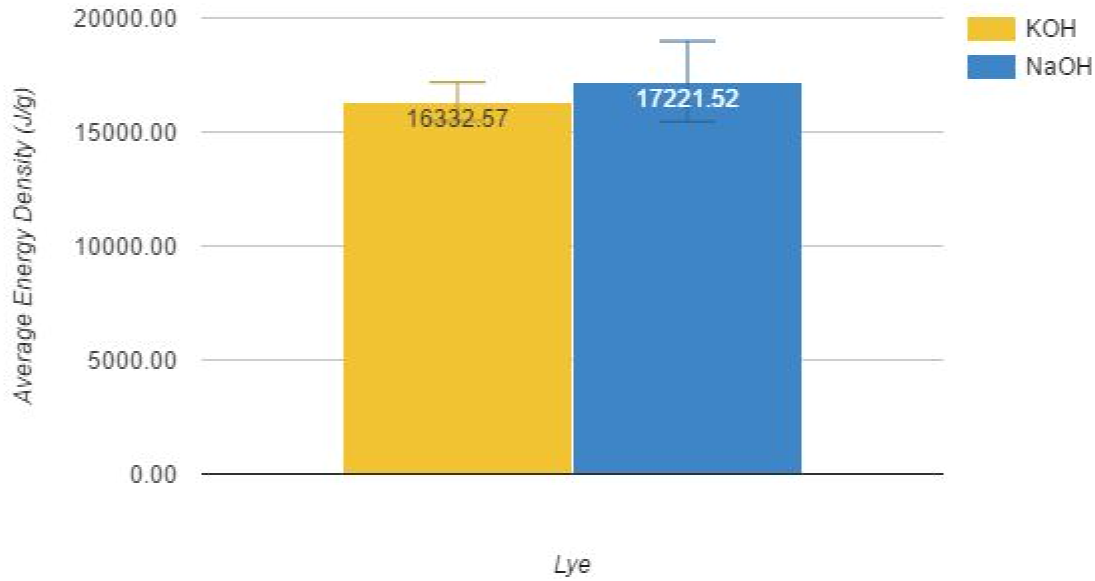

Figure 17: Data Range for Each Lye's Energy Density Database (J/g)

Table 7: Range and Standard Error Values for Energy Density for Lye Data				
Lye	Lowest Value (J/g)	Highest Value (J/g)	Difference Between Highest	Standard Error (J/g)

[1]*Department of Chemistry, Summit Public School: Shasta, Daly City, CA 94015, USA*

			and Lowest Values (J/g)	
KOH	3032.55	29871.75	26839.2	843.25
NaOH	2034.3	43890.0	41855.7	1765.64

According to Figure 9, the average energy density of the KOH batches (n=39) was 16332.57 J/g and the average of the NaOH batches (n=30) was 17221.52 J/g. The standard error for the KOH batch data 843.25 J/g while the standard error for the NaOH batches was 1765.64 J/g. The range of the KOH data was 26839.2 J/g and the range for the NaOH data was 41855.7 J/g. Lastly, Figure 18 contains the energy density of all the ethanol batches (n=5). Figure 19 illustrates the average energy density of biodiesel against the alcohol used in their recipe; Table 8 contains the standard error and data range values; and Figure 20 is a graph of the data range.

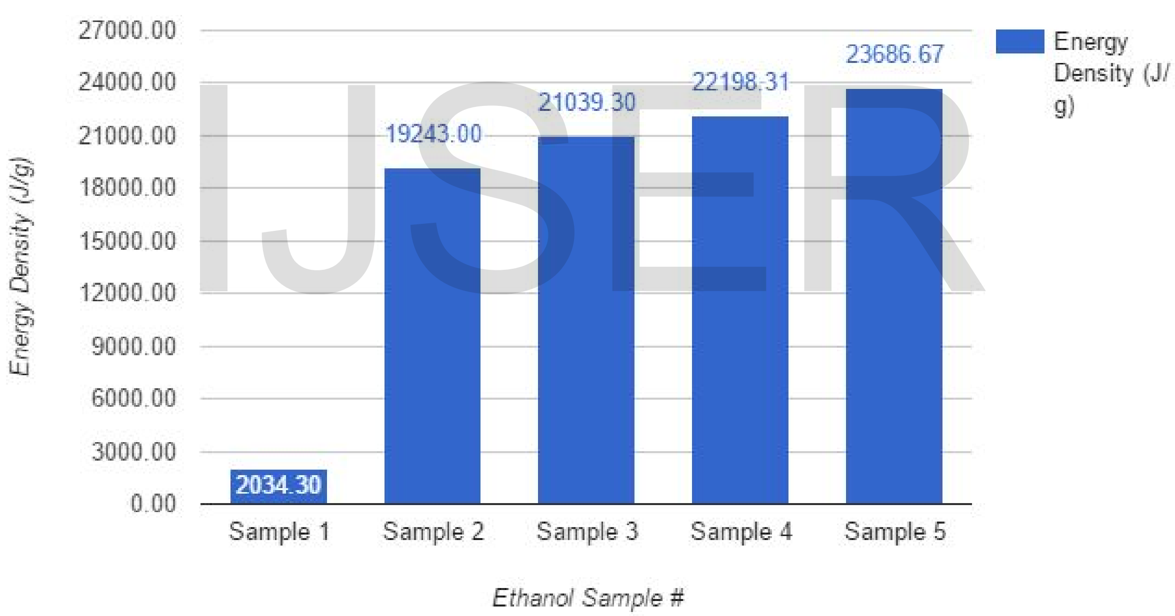

Figure 18: Energy Density (J/g) vs. Ethanol Sample #

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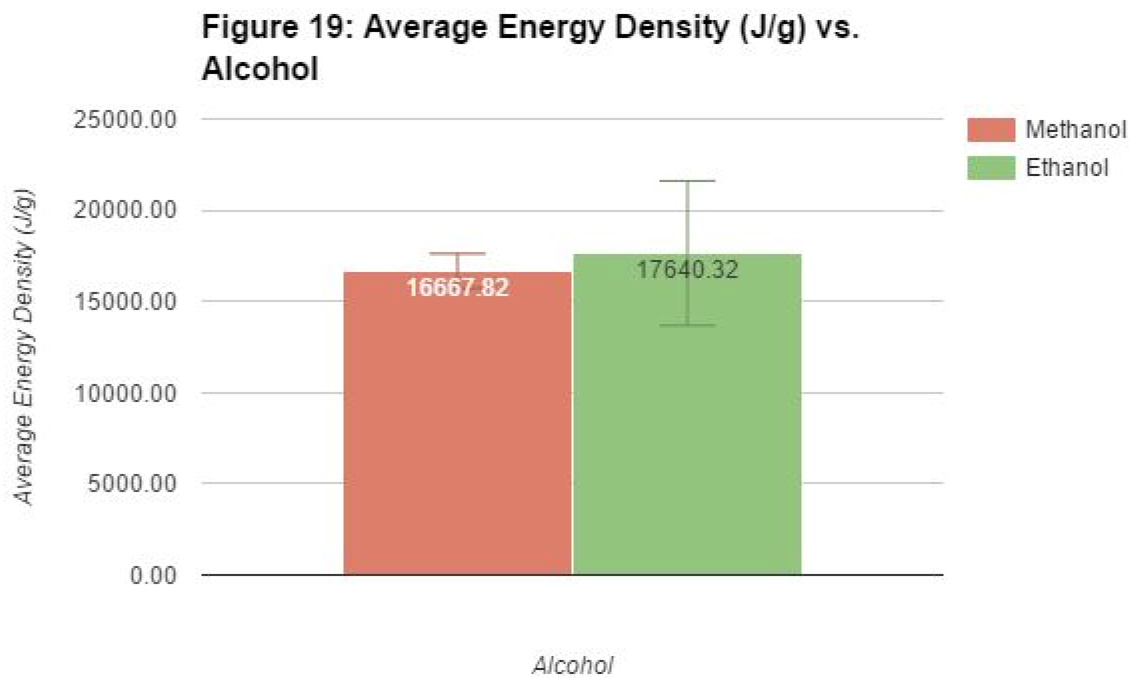


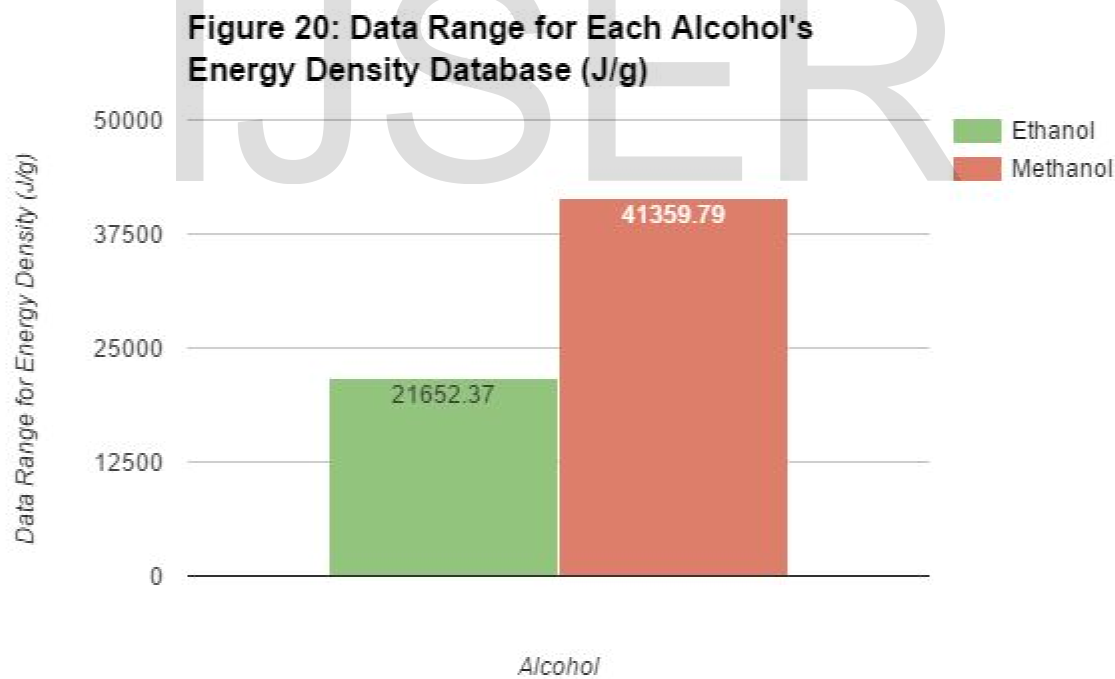


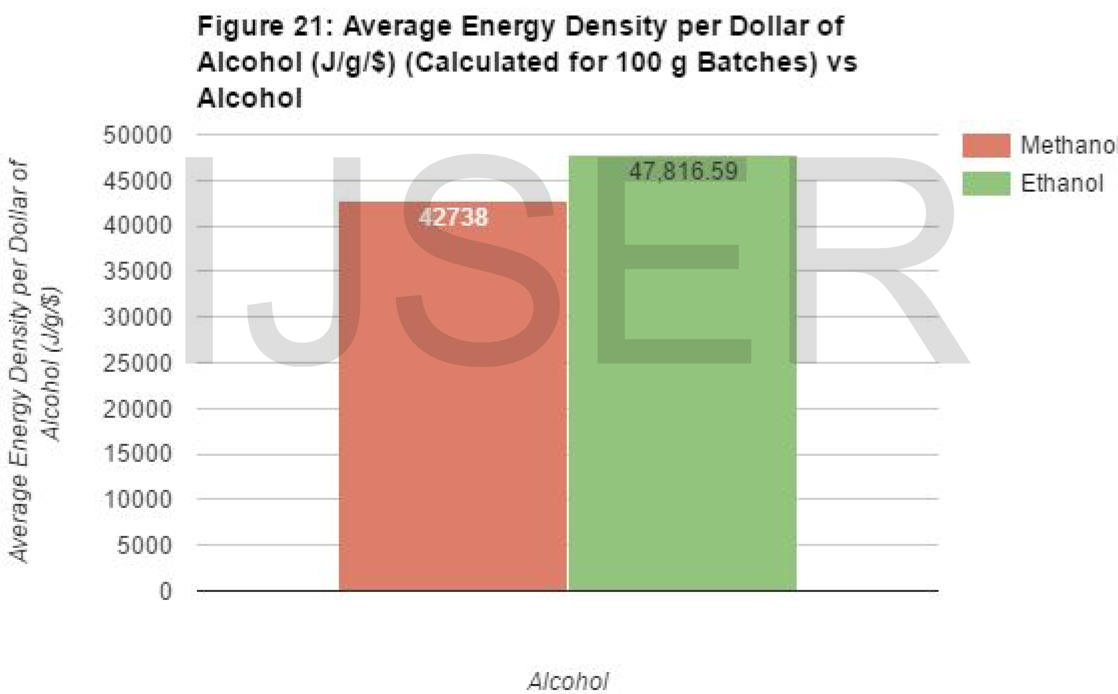
Table 8: Range and Standard Error Values for Energy Density of Alcohol Data				
Alcohol	Lowest Value (J/g)	Highest Value (J/g)	Difference Between Highest	Standard Error (J/g)

[1]Department of Chemistry, Summit Public School: Shasta, Daly City, CA 94015, USA

			and Lowest Values (J/g)	
Ethanol	2034.3	23686.67	21652.37	3968.65
Methanol	2530.21	43890.0	41359.79	948.20

The average energy density for our methanol batches (n=64) was 16667.82 J/g and the average for the ethanol batches (n=5) was 17640.32 J/g. The standard error for the methanol biodiesel data was 948.20 J/g and the standard error for ethanol biodiesel data was 3968.65 J/g. The range for the methanol biodiesel data was 41359.79 J/g while the range for ethanol biodiesel data was 21652.37 J/g.

For our research questions, we collected more data related to various cost ratios. Figure 21 shows the average energy density per dollar of alcohol (J/g/$) compared to the alcohol used to make it.



These values were calculated by dividing the average energy density of 100 g methanol (n=16) and ethanol batches (n=1) by the cost for 23 g of the alcohol, which is the amount of alcohol used to make 100 g batches according to our recipe. The average energy density per dollar of alcohol was 42738.00 J/g/$ for methanol and 47816.59 J/g/$ for ethanol. The standard error for the average energy density of the methanol batches was 2112.57 J/g and the standard error for ethanol was 0 J/g. The difference between these two ratios is 5078.59 J/g/$. Next, Figure 22 compares a similar ratio to the one shown above. It compares the average amount of biodiesel produced per dollar compared to the lye used.

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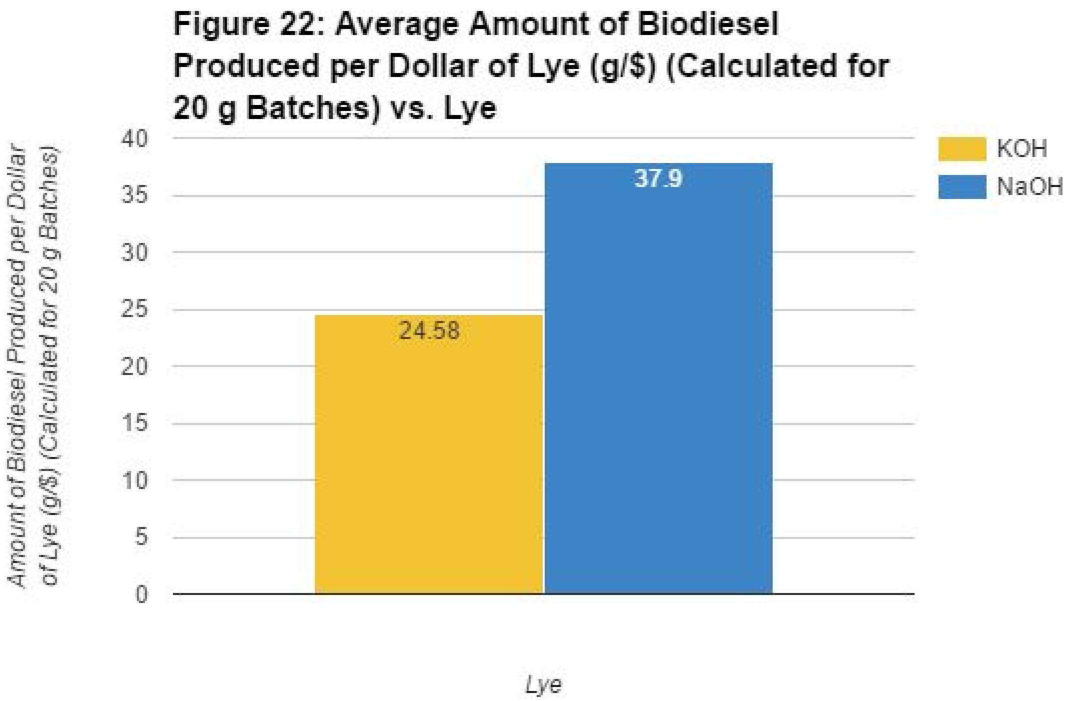

For these calculations, only batches made from 20 g of oil were analyzed for consistency. The average amount of biodiesel produced by the KOH (n=24) and NaOH (n=23) batches was calculated and then divided by the cost of 4.6 g of a lye, which is the amount our recipe calls for in a 20 g batch. The average amount of biodiesel produced per dollar of KOH was 24.58 g/$ and 37.9 g/$ for NaOH. The standard error for the average of KOH biodiesel produced was 5.75 g and the standard error for NaOH batches was 2.70 g. The difference between the two ratios is 13.32 g/$. Finally, Figure 23 shows the average energy per dollar per gallon of fuel compared to the biodiesel recipe. Only recipes with data were included.

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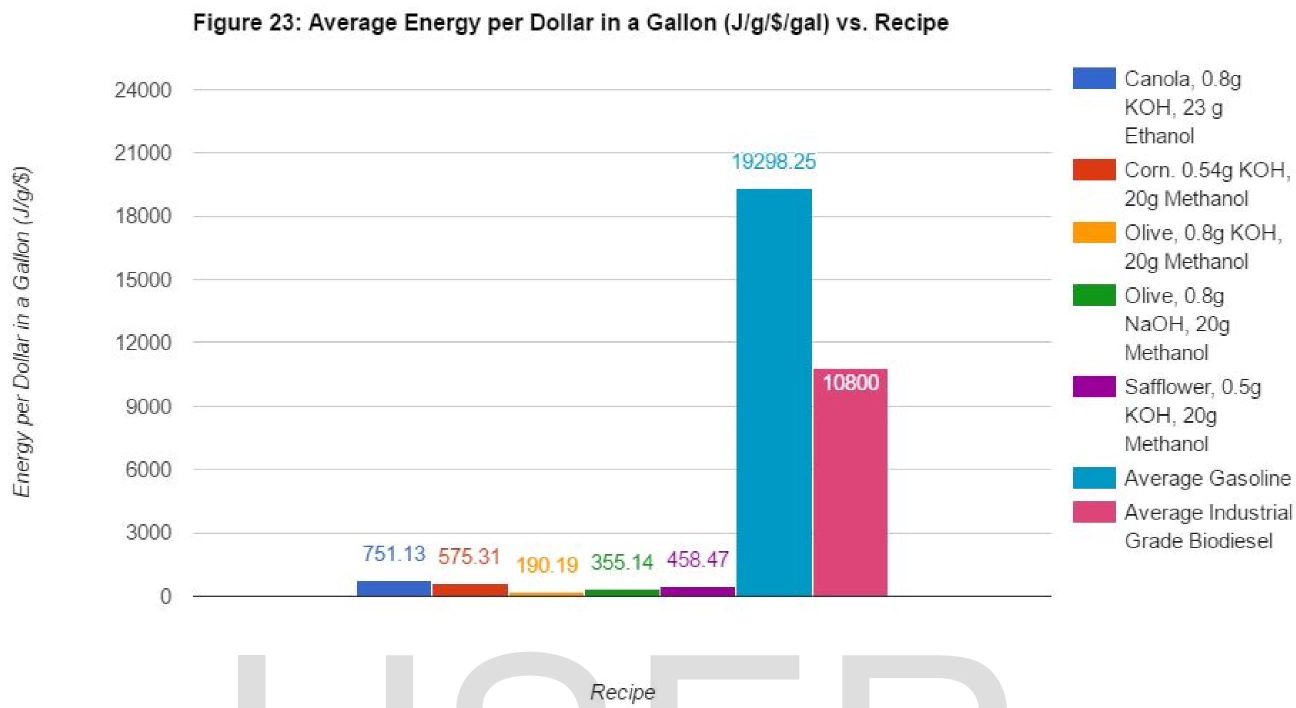

These values were calculated by first finding biodiesel recipes that had enough data about energy density and could be easily scaled to a 100 g batch (we focused on 20 g and 100 g batches only). Then, the cost of each ingredient of that 100 g recipe was calculated and added to find the cost of a 100 g batch. The cost of that batch was multiplied by 37.8541 because that scales the cost for 1 gal. Finally, the average energy density of a recipie was divided by the total cost of 1 gal. The canola, KOH, and ethanol batch (n=1) was 751.13 J/g/$/gal with the average energy calculation having a standard error of 0. The corn, KOH, and methanol batches (n=2) were 575.31 J/g/$/gal with a standard error of 5983.14 J/g in the average energy. The olive, KOH, and methanol batches (n=3) were 190.19 J/g/$/gal with a standard error of 2942.63 J/g/gal. The olive, NaOH, and methanol batch (n=1) was 355.14 J/g/$/gal with a standard error of 0 J/g. The safflower, KOH, and methanol recipes (n=2) were 458.47 J/g/$/gal with a standard error of 450.15 J/g. The average energy per dollar in a gallon of gasoline was calculated to be 19298.25 J/g/$/gal and the average for industrial grade biodiesel was 10800 J/g/$/gal [37].

Discussion

The production and mass usage of biodiesel is viewed as a potential method to significantly reduce humanity’s carbon footprints on the environment by lowering the amount of fossil fuels burned. However, research studies we have examined state that the majority of industrial-grade biodiesels cost significantly more than standard petroleum diesel [8]. We predicted that the widespread use of biodiesel would be hampered by its expense, thus meaning less people would be willing to use it. This way, regular diesel fuel remains popular and the environmental benefits of biodiesel are limited. Since affordability is important to the future success of biodiesel, we

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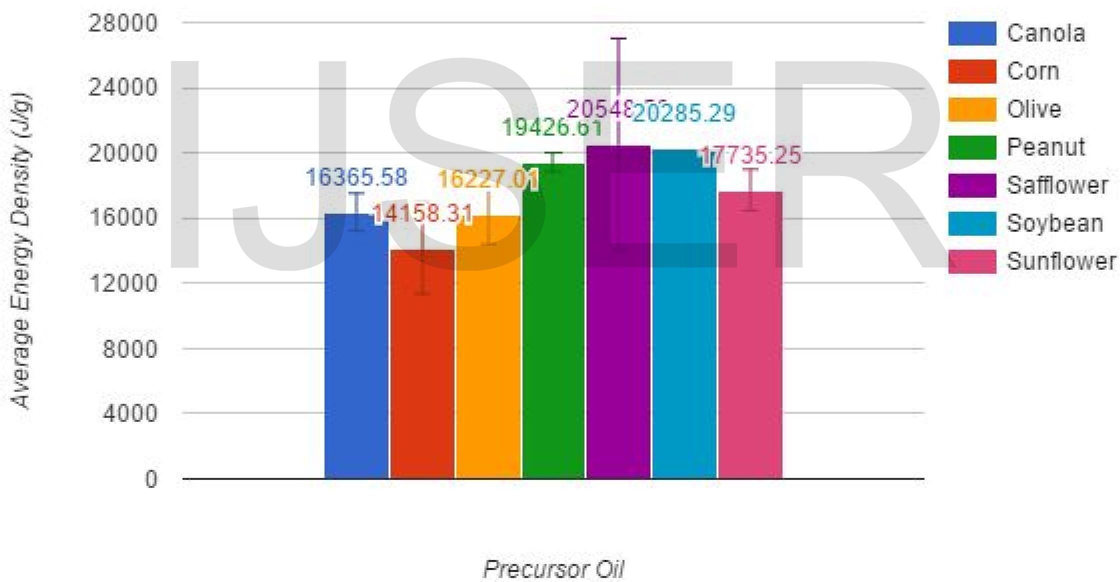
decided to focus on researching a biodiesel recipe which provides the most energy density per unit cost. At the beginning of our research inquiry, we hypothesized that a combination of canola oil, KOH, and ethanol would produce the most energy dense biodiesel per dollar (J/g/$) compared to other combinations of oil, lye, and alcohol. Canola oil's long length combined with its high oleic acid content of unsaturated fats was predicted to contain a significant amount of energy compared to other oils. KOH, while not hypothesized to have a drastic effect on biodiesel energy, was chosen because it would take less time to react with alcohols compared to NaOH and would produce less waste soap. Ethanol was favored over methanol because our research suggested that it contained more energy while only having a small increase in price [17].

After analyzing our data, we concluded that our initial hypothesis was refuted, with canola oil failing to produce the most energy dense biodiesel. Referring to Figure 13, the canola biodiesels (n=40) had an average energy density of 16365.58 J/g. In comparison, safflower biodiesels (n=4) had the highest average at 20548.58 J/g and the soybean biodiesel (n=1) had the second highest average at 20285.29 J/g.

Figure 13: Average Energy Density (J/g) vs. Precursor Oil



Based on this, canola oil is not the highest energy dense oil that could be used to make biodiesel, making part of our hypothesis incorrect. Instead, safflower oil should be used to create the most energy dense biodiesel in our experience. This is perhaps due to the composition of safflower oil. On average, safflower oil is composed of 79% polyunsaturated fats and 14% monounsaturated fats. It has the highest polyunsaturated fat content compared to the rest of the oils we tested. Polyunsaturated fats contain multiple double bonds as opposed to monounsaturated fats, which consist of only one double bond. The presence of multiple double bonds means that there are more areas where an oil molecule could be broken, releasing more energy. These polyunsaturated fats hold more potential energy than monounsaturated fats while also being easier to break than saturated fats. In comparison, canola oil is 62% monounsaturated and 31%

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polyunsaturated, meaning that it contains less potential energy than safflower. Since safflower contains the most amount of polyunsaturated fat, it makes sense for safflower biodiesels to produce the highest average energy density. The majority of safflower is also composed of linoleic acid, about 74-79% of it, which have a carbon atom to double bond ratio of 18:2 [38]. The second highest energy dense biodiesels, soybean biodiesels, are created with an oil composed of 50-60% linoleic acid [11]. Since the biodiesels with the most average energy density come from oils with the greatest carbon atom to double bond ratio, we also conclude that oils with a higher ratio would result in more energy dense biodiesel. While our evidence supports the conclusion above, it is not statistically significant. The standard error for the canola biodiesel average was 1218.58 J/g and 6476.29 J/g for the average of safflower biodiesel. Furthermore, the range for the data on canola biodiesel was 41019.7 J/g and the range for safflower biodiesel was 27330.77 J/g (Table 6).

Table 6: Range and Standard Error Values for Energy Density for Precursor Oil Data

Oil	Lowest Value (J/g)	Highest Value (J/g)	Data Range (J/g)	Standard Error (J/g)
Canola	2034.30	43054	41019.7	1218.58
Corn	10348.05	17968.57	7620.52	3810.26
Olive	5211.43	29871.75	24660.32	1494.45
Peanut	18844.04	20009.18	1165.14	582.57
Safflower	16559.23	43890.0	27330.77	6476.29
Soybean	4180.0	4180.0	0	0
Sunflower	16118.67	20285.29	4166.62	1262.39

While the averages shown from our experiments suggest that safflower oil would produce the most energy dense biodiesel, the high amount of standard error for both canola and safflower oil combined with the extremely high ranges means that there is a large amount of room for error. These high ranges indicate that there is a large spread of data for both canola and safflower biodiesels. Since averages take all the values into account, it can easily be skewed by outliers in the data. Furthermore, the high range can indicate a lack of consistency between biodiesels made from the same oil or between experiments. The high amount of standard error greatly expands the value of the average of the data. Rather than simply using a single number to represent the average energy density, the standard error creates a range that the energy density could fluctuate. On Figure 13, instances where standard error bars overlap mean that the interpretation of data shown above can change. In this case, the actual energy density of a canola biodiesel could increase to the maximum of the standard error bar while the energy density of a safflower biodiesel could decrease to its minimum. If this occurs, then the opposite is true and soybean biodiesel would seem to have the most energy density. The data for the energy density can also

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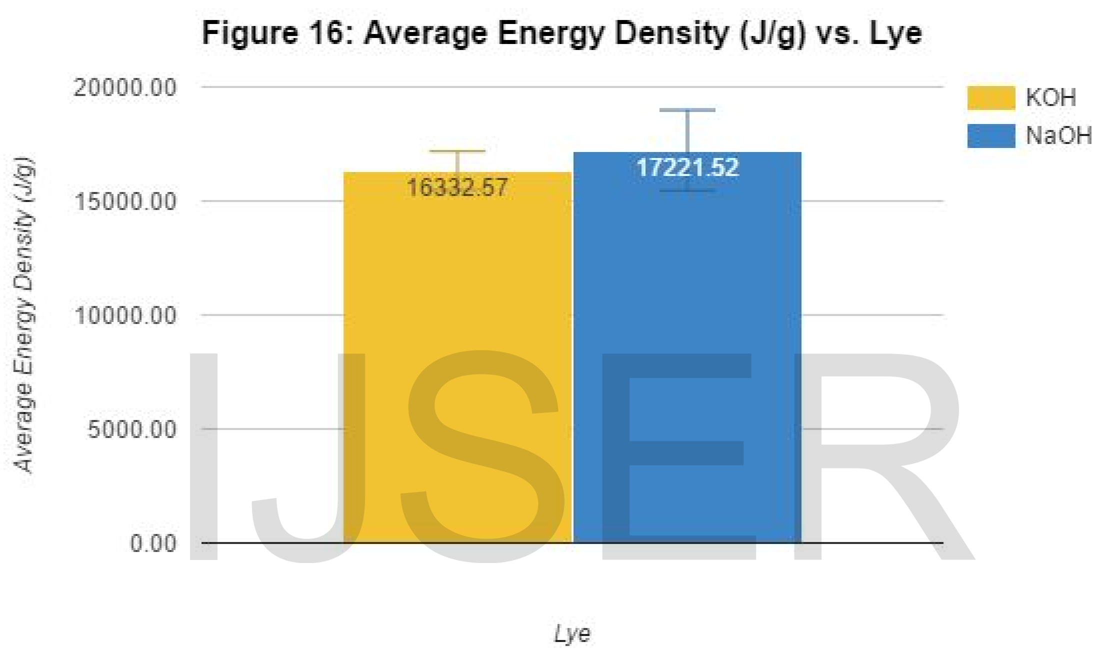
be skewed by the amount of biodiesels using each oil. Some oils, such as canola, were used significantly more than other oils, like peanut or soybean . More data for some of these oils would alter our findings.

Next, the second portion of our hypothesis about the better lye choice is refuted as well, since our findings indicate that NaOH produces a biodiesel with a greater energy density. Figure 16 shows the average energy density of biodiesel containing KOH or NaOH. KOH biodiesels (n=39) had an average energy density of 16332.57 J/g while NaOH biodiesels (n=30) had an average energy density of 17221.52 J/g.



Based off this, NaOH would be the better lye to use in order to create the most energy dense biodiesel. Furthermore, the cost of NaOH is less than KOH, although the actual prices can fluctuate. From our supplier, Flinn Scientific, KOH costed $0.09/g while NaOH costed $0.08/g. In both terms of energy density and cost, NaOH is the better option, thus making it the preferable choice for making biodiesel. While the averages do indicate this conclusion, a statistical look at the accuracy of the data indicates the presence of error. The standard error for the KOH data was 843.25 J/g while the standard error for the NaOH data was 1765.64 J/g. While not as high as the standard error for the oils, meaning the average is a better representation of the entire data, there is still overlap between error bars. On Figure 16, the entirety of the KOH error bar is overlapping with the NaOH error bar. Similar to the situation with the standard error for oil, there is a range for the average energy density. If, for example, the average energy density for NaOH biodiesel decreases near the bottom of its error bar and the KOH biodiesel increase to near the top of its error bar, then NaOH biodiesel would seem to have less energy density than KOH biodiesel. This would make part of our hypothesis true. Furthermore, the averages shown above can be greatly affected by outliers, which were present in data for both lyes. For the data relating to KOH biodiesel, the data range was from 3032.55 J/g to 29871.75 J/g. For NaOH biodiesel data,

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the range was from 2034.3 J/g to 43890 J/g (Table 7).

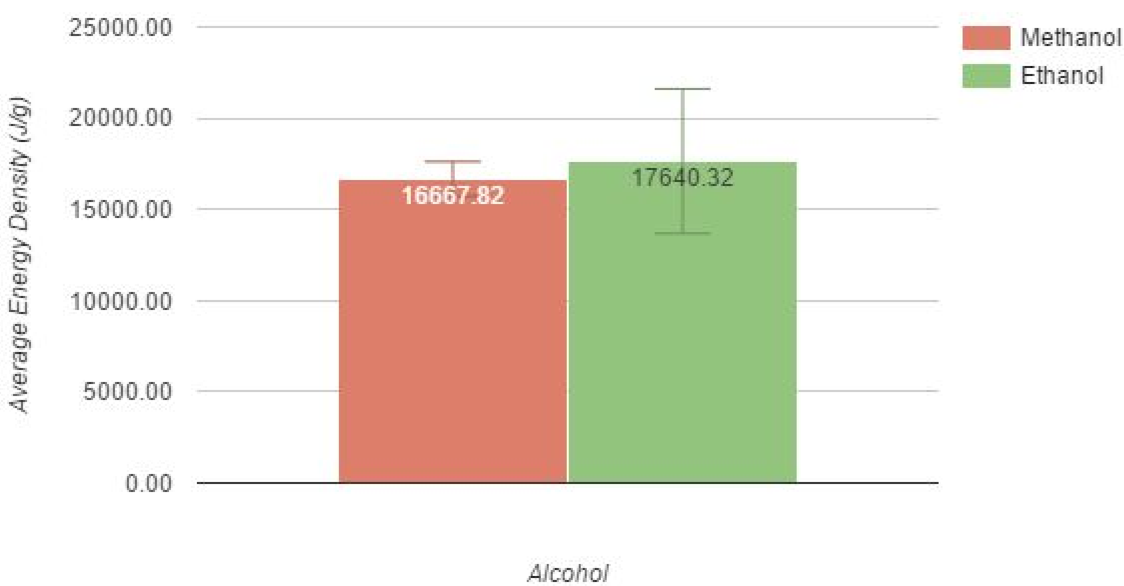
Table 7: Range and Standard Error Values for Energy Density for Lye Data

Lye	Lowest Value (J/g)	Highest Value (J/g)	Difference Between Highest and Lowest Values (J/g)	Standard Error (J/g)
KOH	3032.55	29871.75	26839.2	843.25
NaOH	2034.3	43890.0	41855.7	1765.64

These large ranges indicate a lack of consistency between all the biodiesels as the data was spread out. This gives room for outliers to occur and impact the averages shown above. It is possible these inconsistencies were a result of the difference in the number of batches analyzed, 39 batches of KOH biodiesel compared to 30 batches of NaOH biodiesel. While there is not as much of a significant difference in the number of batches analyzed compared to the situation with oils, this difference means that there is not an equal amount of data for both lyes. Perhaps with more data, the results we obtained would have been more consistent.

The third portion of our hypothesis states that ethanol would provide for a more energy dense biodiesel than methanol, which is supported by our results. Figure 19 shows that the average energy density of our methanol biodiesels (n=64) was 16667.82 J/g and the average energy density for our ethanol batches (n=5) was 17640.32 J/g.

Figure 19: Average Energy Density (J/g) vs. Alcohol



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Based on this, ethanol on average would yield biodiesel with the higher energy density than methanol would, making it the better option for creating the most energy dense biodiesel. This aligns with our previous research, which said that one gallon of E10 (ethanol fuel) contained 96.7% of the energy in a gallon of gasoline while one gallon of methanol fuel contained only 49% [17]. The structure of an ethanol molecule shows that there are more bonds present in it than in methanol, 8 covalent bonds compared to 5 covalent bonds. Since there are more bonds present in ethanol, there are more locations for the molecule to be broken, resulting in more energy being released [39]. Despite our results supporting the third piece of our hypothesis, the results are not statistically significant. The standard error for the methanol data was 948.20 J/g and the range for it was between 2530.21 J/g to 43890 J/g (Table 8). The large range of the data shows that there are some outliers on both the low end and high end of the data. However, the tight standard error bar indicates that the average can accurately represent the entirety of the data to an extent. The opposite holds true for the ethanol data, with a standard error of 3968.65 J/g and a range from 2034 J/g to 23686.67 J/g (Table 8).

Table 8: Range and Standard Error Values for Energy Density of Alcohol Data

Alcohol	Lowest Value (J/g)	Highest Value (J/g)	Difference Between Highest and Lowest Values (J/g)	Standard Error (J/g)
Ethanol	2034.3	23686.67	21652.37	3968.65
Methanol	2530.21	43890.0	41359.79	948.20

With a significantly higher standard error, the average is less representative of the actual average energy density of ethanol biodiesel. The smaller range can mean that while the average for the ethanol data is inaccurate compared to the methanol one, the endpoints of the data are closer together than methanol's data. However, this smaller range cannot be interpreted as more consistency because we only analyzed 5 ethanol batches compared to 64 methanol batches. Since the number of batches we analyzed is vastly different, we lack enough evidence to confirm that the ethanol batches yielded consistent findings. Similar to the analysis for the oil and lye data, the error bars on Figure 19 show an overlap, with the ethanol error bar completely overlapping the methanol one. With this overlap, there is potential that the actual average for the ethanol could dip below the average for the methanol, meaning this portion of our hypothesis would be refuted.

To average energy density per dollar of alcohol (J/g/$), these values were found by dividing the average energy density of 100 g methanol (n=16) and ethanol (n=1) batches by the cost for 23 g of alcohol, the amount of alcohol for 100 g of biodiesel according to our recipe. When it comes to price, Figure 21 shows the average energy density per dollar of alcohol (J/g/$) compared to the type of alcohol used to make biodiesel.

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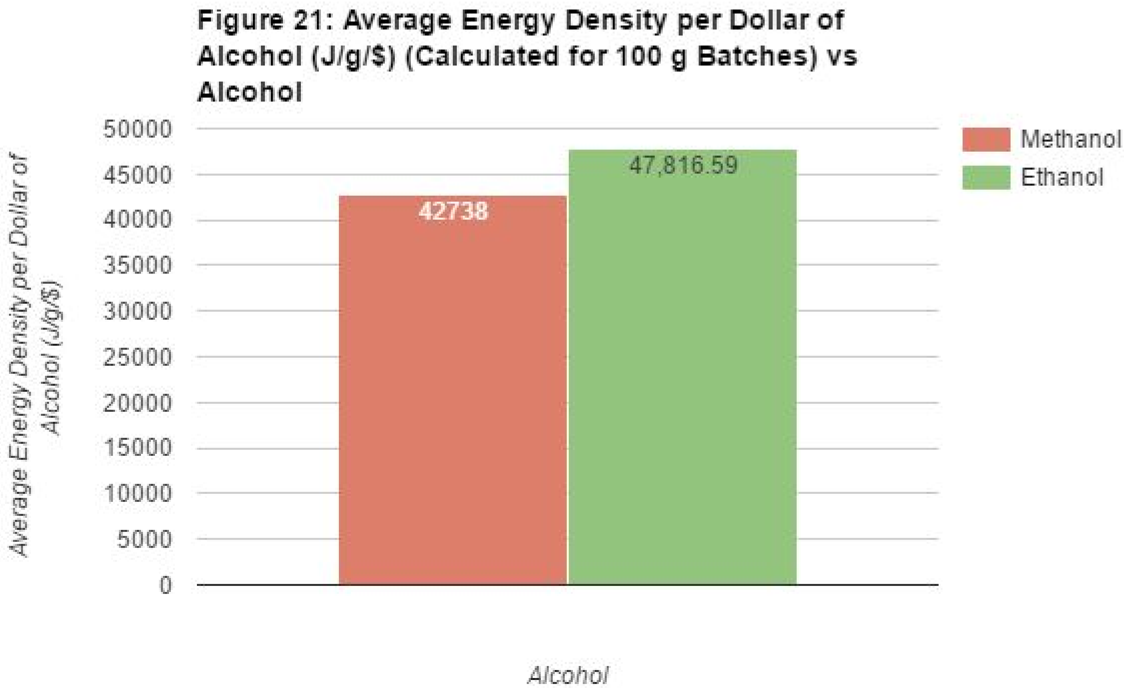

According to the graph, ethanol had a ratio of 47816.59 J/g/$ while methanol had one of 42738.00 J/g/$. The higher ratio from ethanol shows that on average, it provides more energy for one dollar compared to methanol, making it a more energy dense biodiesel for the same price. In terms of both energy and costs, ethanol would be the better choice. However, there are some weaknesses in our data collection. Since we divided the average energy densities by the price of 23 g of alcohol, that assumes that all of the batches we collected data from also used 23 g of alcohol. In reality, batches varied greatly in the amount of alcohol used, ranging from around 20 g to 23 g. This inconsistency, coupled with the low amount of ethanol batches analyzed, makes these results far from conclusive. Furthermore, the standard error for the averages used to calculate these values was high: 2112.57 J/g for methanol and 0 J/g for ethanol. The high standard error for methanol data means that the average used to calculate this data might not accurately represent the actual average of the data set. While a standard error of 0 J/g for ethanol data make its average seem statistically accurate, having only one ethanol biodiesel to analyze negates this.

The average percent yield of biodiesel does not seem to be affected greatly by the type of lye used. We defined a great impact on percent yield as in a difference of at least 10%. Figure 6 shows the average percent yield compared to the type of lye used. KOH biodiesels (n=39) had an average percent yield of 48.31% and NaOH biodiesel (n=30) had an average percent yield of 46.62%.

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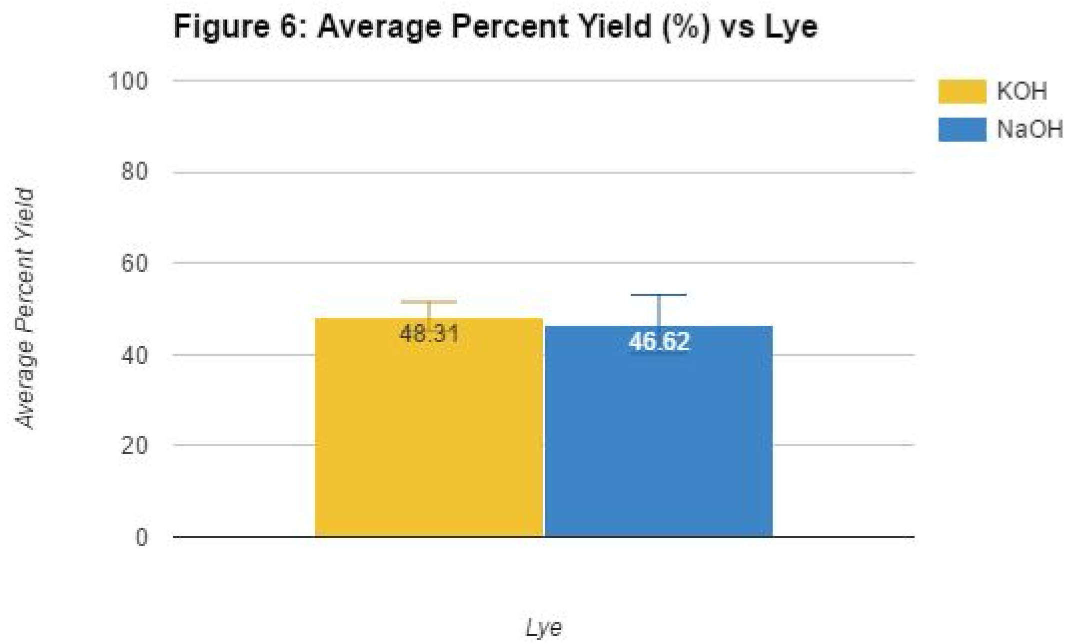

The very small difference between these two averages, while showing KOH biodiesels have a higher percent yield on average, is not significant enough to show that the type of lye used would greatly impact the amount of biodiesel yielded. The negligible difference is probably due to the role these lyes have in transesterification. They are meant to act as catalysts in the reaction, speeding up the process of it but not becoming a substance inside the biodiesel itself. The lyes are instead washed out during biodiesel synthesis. Since this occurs, the lyes do not greatly add to the volume of the biodiesel. Statistically, the KOH biodiesel data had a standard error of 3.32% while the NaOH biodiesel had a standard error of 6.43%. These values are small, meaning that the averages shown in Figure 6 are an accurate representation of the actual average of the data. However, averages can also be skewed by outliers. The KOH biodiesel data ranged from 6.75% to 82.50%. The NaOH biodiesel data ranged from 13% to 82% (Table 4).

Table 4: Range and Standard Error Values for Percent Yield for Lye Data

Lye	Lowest Value (%)	Highest Value (%)	Data Range (%)	Standard Error (%)
KOH	6.75	82.50	75.75	3.23
NaOH	13	82	69	6.43

These high ranges indicate that the endpoints of the data are greatly spread out. These endpoints could have skewed the average to be higher or lower than the rest of the data would suggest. The error bars on Figure 6 do overlap. The error bars on the KOH biodiesel portion of the graph make the average range between a minimum of 44.99% and a maximum of 51.63%. For NaOH

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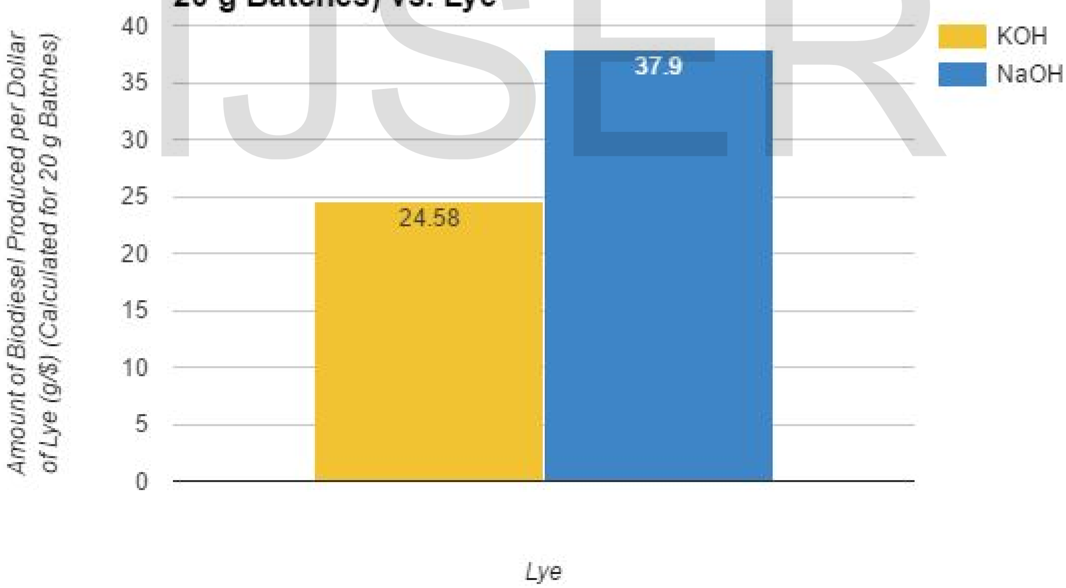
biodiesel, the average ranges between 40.19% and 53.05%. The largest difference between the KOH biodiesel average and the NaOH biodiesel average would be between the maximum of the NaOH data and the minimum of the KOH data, which would be 8.06%. Even with the overlapping standard error bars that could indicate a possibility of lye making a difference in percent yield, the largest possible difference between the averages was 8.06% based on our data. That is still not a significant difference in the percent yield of biodiesel and we still conclude that lye has a minimal impact on percent yield. With more data to give an equal amount of KOH and NaOH samples, these results may vary.

Despite the lye not making a significant difference in percent yield, NaOH is shown to have the higher average amount of biodiesel produced per dollar of lye (g/$), making it the more cost efficient option. Figure 22 contains the average amount of biodiesel produced per dollar of lye for both NaOH and KOH. These values were calculated by taking the average amount of biodiesel produced of all 20 g batches with KOH and NaOH. Then, those averages were divided by the cost of 4.6 g of lye, which is what our recipe calls for when scaled down for 20 g batches. We looked at 20 g batches because the majority of batches in our database were made for that size. KOH biodiesels (n=24) had a yield to dollar ratio of 24.58 g/$ and NaOH biodiesels (n=23) had a ratio of 37.90 g/$.

Figure 22: Average Amount of Biodiesel Produced per Dollar of Lye (g/$) (Calculated for 20 g Batches) vs. Lye



Since the ratio for NaOH biodiesels was greater than the one of KOH biodiesels, it produces more biodiesel for the same price, making it the more cost efficient option. As mentioned before, KOH costed $0.09/g for us while NaOH costed $0.08/g. Also, we concluded that the type of lyes used to make biodiesel does not great impact the amount of biodiesel produced. Since the amount of biodiesel does not change too much but the price gap slowly increases as more lye is used, it makes sense for NaOH to eventually be more cost efficient. When finding the average of the amount of biodiesel produced, the standard error for the KOH batches was 5.75 g and the

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standard error for the NaOH batches was 2.70 g. The calculated average yield for KOH biodiesel was 10.33 g and the average for NaOH biodiesel was 14.08 g. While these standard error values are small, indicating that these averages are an accurate representation of the data, they result in an error bar overlap. If the average of the KOH batches increases while the average for the NaOH batches decreases, then the average of the NaOH batches would be lower, affecting the final calculations. The calculations for the yield to dollar ratio also have the fault of using only our recipe's measurement for the amount of lye used. Similar to the energy density to price ratio for the alcohols, our data pool used a variety of different measurements for the batches, meaning 4.6 g of lye is not applicable to every batch analyzed. This inconsistency makes these results inconclusive to a degree.

All the analysis done above has the issue of only inspecting how one component of biodiesel affects the entire fuel. However, the presence of three components means that they will have a combined effect on the final product. It would be more accurate to analyze all three components at once. We did this by looking at the average energy density per dollar (J/g/$) in a gallon of fuel of different recipes. The recipes we analyzed were ones that had enough data to be examined and were easily converted to 100 g batches so not every recipe is included. To calculate these values, we took a recipe and scaled it to 100 g if it was not already. Then, we calculated the price for 100 g of biodiesel, then increased the cost to match the price of a gallon of biodiesel. Finally, we took the average energy density of those recipes and divided them by the cost of a gallon of that fuel. Figure 23 illustrates our results. The biodiesel recipe that we analyzed with the highest results was a canola oil, KOH, and ethanol recipe (n=1) with 751.13 J/g/$/gal. The lowest was an olive oil, KOH, and methanol recipe (n=3) that had a ratio of 190.19 J/g/$/gal. These values are significantly lower than the energy density to cost ratio for industrial grade biodiesel, which had one of 10800 J/g/$/gal. The highest ratio shown on the graph was the average gasoline with 19298.25 J/g/$/gal.

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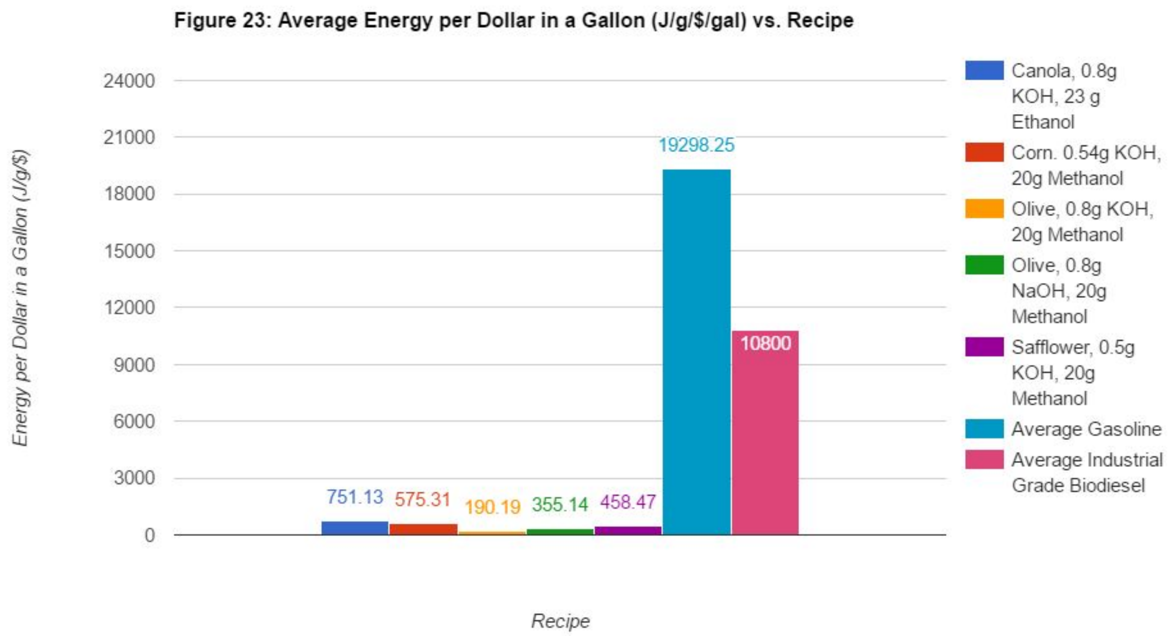

Based on this, we concluded that we were unable to create a biodiesel recipe which could compete with the energy to cost ratio of gasoline or even average industrial grade biodiesel. In addition, our overall hypothesis seems to be supported because our predicted recipe had the highest energy density to dollar ratio. However, these calculations have multiple weakness and are not conclusive. The amount of biodiesels analyzed for each recipe was extremely limited, at most 3 batches. A lack of data prevents us from finding consistent results that we are confident would support a claim. The pricing for the ingredients used in our calculations is subject to vary depending on the retailer, so they are not applicable to the majority of biodiesels outside of our experiment. We used prices from the specific brands we used to synthesize biodiesel. The average energy densities calculated from our database have large amounts of standard error (see Figure 23's description), meaning those averages may not represent the data as a whole too accurately (see results section for specific error values). Some had a standard error of 0 J/g/$/gal not due to the average being a strong representation, but because there was only one batch that was analyzed. Furthermore, the energy density to cost ratio for industrial grade biodiesel was calculated using pricing from biodiesel in Iowa ($4.20/gal) so that might not be an accurate representation of biodiesel from other regions. Cheaper biodiesels do exist that cost $2 to $3 per gallon but those values were not used. All these inaccuracies mean that the results we found for this specific ratio need more data before any strong conclusions can be made.

Errors in Experimental Design

In addition to data gaps in our analysis, there were errors in our experimental design. During the biodiesel synthesis process, there were large amounts of inconsistencies. One aspect of our lab that was not properly monitored was the temperature of the lab itself. There was no recording of the temperature of the room nor any attempts made to maintain the temperature for every day of

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biodiesel synthesis or calorimetry. Transesterification and the process of creating biodiesel as a whole is an endothermic reaction because energy is added through heating to cause the reaction to occur. Inconsistencies in the temperature of the environment can affect the amount of biodiesel yielded and the amount of glycerol that separates from the biodiesel. Even with heating, the ambient temperature would need to maintain a certain temperature to facilitate the transesterification process to continue after the biodiesel is taken off the hot plate. The temperature also changes as the days get closer to summer. There has been a difference in temperature since the beginning of March, where we started synthesis, and the end of the month, where we finished synthesizing. On the 1st of March, the average temperature was 11.67ºC while on March 31st, the average was 16.94ºC [40]. The outside temperature can heat up the air inside the lab, which would still result in a temperature change. However, environmental temperature is an uncontrollable variable. Another flaw in the experiment stems from a lack of cleaning supplies. At the start of synthesis and for a majority of the time, we lacked soap or isopropyl alcohol to clean the our glassware. As a result, we relied on only water to clean them but oils do not properly wash off with only water so some of our glassware was used in multiple experiments with residue from previous experiments. This led to cross contamination between batches. Similarly, we ran out of pipettes mid-way through the experimental process so we started cleaning and reusing pipettes. However, we could only wash pipettes to a certain extent and it was inevitable that there would still be substances from previous experiments left inside. For the calorimetry experiments, there were inconsistencies between experiments, both in our own and for the entire research team. Candle wick lengths varied by groups as well as the height that the calorimeter was above the flame. As the wick burned down, there was no time to use a ruler to readjust the calorimeter height. We estimated for a new height and we have no information on how other groups readjusted, if at all. Different groups also burned their biodiesel for different amount of time. Perhaps the greatest error in our experimental design was the lack of unity and communication between groups. Groups used different measurements for their biodiesel batches and followed varying experimental processes. When attempting to analyze data for a specific claim (the impact of oil on energy density and cost in our case), it is standard for one variable to be independent, one to be dependent, and all other variables to stay consistent. In our situation, there were so many inconsistencies that we could not compare enough recipes that changed the oil type while keeping lye and alcohol consistent. This is why, as mentioned in the discussion above, some of our findings lacked enough data to be conclusive. Inconsistencies in recipe measurements were especially impactful on our price ratio calculations, where we had to use a single amount of lye or alcohol for the calculations that failed to encompass the entire data set. If all of the recipes used the same amount of lye or alcohol, then our calculations would be more accurate. More consistency would have allowed for more usable data and thus, more accurate conclusions. The timing of when we collected our data was when not everyone has their data in the database, which alters our analysis, results, and conclusions.

Future Work

We would need to make many new changes for future work about biodiesel. The first and most important addition would be consistency among the various groups. We propose holding regular group meetings so that everyone can have the same goals in mind. To continue on the work done here, we want to continue exploring how different biodiesel components impact the energy density and cost of the biodiesel. In order to do this, we would require consistency across all

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groups to use recipes with the same measurements but with different ingredients. For example, to see how oil type affects the biodiesel's energy density, 10 batches of biodiesel for each oil type would be made, with the amount and type of lye and alcohol staying consistent. A similar process would follow for testing lyes and alcohols. Before starting our experiments, we would ensure we had the proper cleaning supplies on hand to prevent cross contamination, along with enough supplies for the experiments. For calorimetry, all the groups would be instructed to use the same wick length, burn their biodiesels for the same amount of time, and maintain the calorimeter 2 cm above the flame's tip. We would also buy gasoline and industrial biodiesel ourselves and perform calorimetry on them as well. For the calculations, we would also record the price for the materials we used in our biodiesel in addition to checking if those calculations are correctly done. While it is true that we could take our future research in different directions and pursue other questions, we felt as though the work done for this hypothesis was incomplete with too many errors. We would rather redo this research study with less errors. After all the work done here, we would go into our repeat of this study with a new hypothesis that safflower oil, NaOH, and ethanol would produce the most energy dense biodiesel. In addition, we still wonder if we can make a biodiesel with the energy to cost ratio (J/g/$/gal) that competes with that of gasoline. New calculations for this question would be made in combination with the new data that we would collect.

Our research into biodiesel is only a piece of the inquiry on this renewable energy source. There are still many improvements and investigations that need to be made to it before it can become a practical replacement for petroleum diesel. Currently, petroleum diesel provides more energy than current biodiesel while also costing less. If the affordability of biodiesel and energy content of biodiesel does not increase, the public will not see it as a new method to run their technology, especially transportation. Money is a valuable possession for people and the majority of them will only pay for biodiesel when they see its monetary worth. With the depletion of the world's fossil fuels reservations and a growing number of fossil fuel burning technology, humanity needs a renewable fuel to meet the demands if it were to survive and advance. Furthermore, it is inevitable that more technology will be created, increasing the demand for energy sources. While it is expected for scientists to discover a revolutionary new form of energy, that is predicted to be far in the future. Until that happens, advancements in biodiesel need to be made so it can serve as a practical temporary fuel source for the world. It is imperative scientists continue to research this topic.

References:

[1] "World Energy Council Report Confirms Global Abundance of Energy Resources and Exposes Myth of Peak Oil." Worldenergy.org. World Energy Council, n.d. Web. 03 Apr. 2017.
[2] "Fossil Fuels." IER. Institute for Energy Research, n.d. Web. 03 Apr. 2017.
[3] Fool, Matt DiLallo The Motley. "The World Has 53.3 Years of Oil Left." USA Today. Gannett Satellite Information Network, 28 June 2014. Web. 03 Apr. 2017.
[4] "IEO2014: World Liquid Fuels Consumption to Rise 38% by 2040." OGJ. Oil & Gas Journal, 09 Sept. 2014. Web. 02 Apr. 2017.
[5] "Carbon Dioxide, Methane Rise Sharply in 2007." NOAA. NOAA - National Oceanic and Atmospheric Administration - Carbon Dioxide, Methane Rise Sharply in 2007, 23 Apr. 2008. Web. 03 Apr. 2017.

[1]*Department of Chemistry, Summit Public School: Shasta, Daly City, CA 94015, USA*

[6] "1958-present CO2 Data." NOAA. National Oceanic and Atmospheric Administration, 06 Mar. 2017. Web. 02 Apr. 2017.
[7] "Global Surface Temperature | NASA Global Climate Change." NASA. NASA, 23 Feb. 2017. Web. 03 Apr. 2017.
[8] Huang, Daming, Haining Zhou, and Lin Lin. "Biodiesel: An Alternative to Conventional Fuel." Biodiesel: An Alternative to Conventional Fuel (2012): 1-12. ScienceDirect. Web. 2 Apr. 2017.
[9] "What's So Different about Biodiesel Fuel?" Penn State Extension. Penn State, n.d. Web. 03 Apr. 2017.
[10] Lee, Seung Bum, Kyong Ho Han, Jae Dong Lee, and In Kwon Hong. "Optimum Process and Energy Density Analysis of Canola Oil Biodiesel Synthesis." ResearchGate. ResearchGate, Nov. 2010. Web. 2 Apr. 2017.
[11] Tech, Rick Da. "Biodiesel Feedstock Oils." Make Biodiesel. Make Biodiesel, n.d. Web. 03 Apr. 2017.
[12] "Typical Fatty–Acid Compositions of Some Common Fats." Typical Fatty–Acid Compositions of Some Common Fats (n.d.): 1-2. Web.pdx.edu. Portland State University. Web. 2 Apr. 2017.
[13] "Vegetable Oils – Comparison, Cost, and Nutrition – Spend Smart. Eat Smart." Iowa State University. Iowa State University, 19 Aug. 2013. Web. 03 Apr. 2017.
[14] Tech, Rick Da. "Catalysts for Biodiesel." Make Biodiesel. Make Biodiesel, n.d. Web. 03 Apr. 2017.
[15] "Breaking Away from Potassium Hydroxide." Biofuels International. Biofuels International, 01 Nov. 2008. Web. 2 Apr. 2017.
[16] "Sodium Hydroxide (NaOH) vs. Potassium Hydroxide (KOH)." Utah Biodiesel Supply Blog. Utah Biodiesel Supply, 25 Apr. 2011. Web. 03 Apr. 2017.
[17] "Alternative Fuels Data Center – Fuel Properties Comparison." (n.d.): 1-4. Alternative Fuels Data Center. US Department of Energy, 29 Oct. 2014. Web. 2 Apr. 2017.
[18] Hossain, A.B.M.S., and M.A. Mazen. "Effects of Catalyst Types and Concentrations on Biodiesel Production from Waste Soybean Oil Biomass as Renewable Energy and Environmental Recycling Process." Australian Journal of Crop Science (2007): 3-5. AJCS. Australian Journal of Crop Science. Web. 2 Apr. 2017.
[19] "AAA Gas Prices." AAA Gas Prices. American Automobile Association, n.d. Web. 03 Apr. 2017.
[20] Campbell, Hank. "Energy Density: Why Gasoline Is Here To Stay." Science 2.0. Science 2.0, 26 Aug. 2014. Web. 03 Apr. 2017.
[21] Blair, Graydon. "Biodiesel Tutorial Videos." Utah Biodiesel Supply. Utah Biodiesel Supply, n.d. Web. 03 Apr. 2017.
[22] "Biodiesel Made from Ethanol." Green Trust. Green Trust, n.d. Web. 03 Apr. 2017.
[23] "What Is Biodiesel." Esru.strath.ac. University of Strathclyde Glasgow, n.d. Web. 03 Apr. 2017.
[24] "POTASSIUM HYDROXIDE." National Center for Biotechnology Information. PubChem Compound Database. U.S. National Library of Medicine, n.d. Web. 03 Apr. 2017.
[25] "Potassium Hydroxide." Chemical Book. Chemical Book, 2016. Web. 03 Apr. 2017.
[26] "Glycerol." National Center for Biotechnology Information. PubChem Compound Database. U.S. National Library of Medicine, n.d. Web. 03 Apr. 2017.

[1]*Department of Chemistry, Summit Public School: Shasta, Daly City, CA 94015, USA*

[27] "How Does Soap Work?" Chagrin Valley Soap. Chagrin Valley Soap, n.d. Web. 03 Apr. 2017.
[28] "Waste Glycerol." Official Biodiesel. Official Biodiesel, 26 Nov. 16. Web. 03 Apr. 2017.
[29] "What to Do with Your Glycerin Layer." Springboard Biodiesel, LLC. Springboard Biodiesel, LLC., 18 Oct. 2016. Web. 03 Apr. 2017.
[30] Wen, Zhiyou, Christopher Bachmann, Robert Grisso, Jactone Arogo, and David Vaughan. "Making Your Own Biodiesel." (n.d.): 4-8. MIT Department of Biology. Massachusetts Institute of Technology. Web. 2 Apr. 2017.
[31] Perlman, Howard. "Why Is Water the "universal Solvent"?" The USGS Water Science School. United States Geological Survey, 02 Dec. 2016. Web. 03 Apr. 2017.
[32] "Water Washing Biodiesel 101." Utah Biodiesel Supply Blog. Utah Biodiesel Supply, 07 Sept. 2011. Web. 03 Apr. 2017.
[33] Elvidge, Suzanne. "Why Oil and Water Don't Mix." Science Project Ideas. Science Project Ideas Corporation, 24 Jan. 2017. Web. 03 Apr. 2017.
[34] Bennink, Curt. "Water in Diesel Fuel Can Wreak Havoc in Engines." ForConstructionPros.com. For Construction Pros, 22 Mar. 2012. Web. 03 Apr. 2017.
[35] Goodrum, J.W. "Volatility and Boiling Points of Biodiesel from Vegetable Oils and Tallow." ScienceDirect. ScienceDirect, Mar. 2002. Web. 03 Apr. 2017.
[36] "BBC - Measuring Energy Transfers." BBC News. BBC, n.d. Web. 03 Apr. 2017.
[37] Carriquiry, Miguel, and Bruce A. Babcock. "A Billion Gallons of Biodiesel: Who Benefits?" Center for Agricultural and Rural Development. Iowa State University, Winter 2008. Web. 03 Apr. 2017.
[38] "TOP-NOTCH TECHNOLOGY IN PRODUCTION OF OILS AND FATS." ChemPro. ChemPro, n.d. Web. 2 Apr. 2017.
[39] "What Is the Structure of Ethanol? - What Is the Structure of Methanol? - Structural Formula." Gcsescience.com. GCSE Science, 2015. Web. 03 Apr. 2017.
[40] "Temperature in Daly City During March 2017." AccuWeather. AccuWeather, Mar. 2017. Web. 03 Apr. 2017.
[41] "Straight Vegetable Oil Vs Biodiesel." *Springboard Biodiesel, LLC.* Springboard Biodiesel, LLC., 27 June 2014. Web. 05 Apr. 2017.

Acknowledgements:
There are many people that made this research study possible and allowed us to solve issues that emerged along the way. First and foremost, we would like to thank Mr. Davey for paying for all the lab equipment and supplies that made it possible to perform our experiments. We also thank him for giving us advice when we needed it and staying with us to help us understand what was happening with our ethanol biodiesels. Our peers also deserve recognition for helping us answer our questions, pushing our thinking, and providing new ideas for us to utilize. These notable peers are Andrew Yee, Jasjeet Jhally, Brian Lam, Nicolas Radoc, Ethan Edelhart, Zachary Hui, Eric Hom, Jonathan Ho, Fiona Gleeson, and Lance Kyi. Finally, we thank our entire 11th grade for allowing us to analyze their data and collect more information than we could have by ourselves.

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