Design of a Small-Scale Biodiesel Production System

Jeffrey Anderson
Jessica Caceres
Ali Khazaei
Jedidiah Shirey
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1.0 Context Analysis

Fredericksburg, VA is an independent city whose neighboring counties, Spotsylvania and Stafford, are our Area of Interest (AOI). These two counties are home to 592 farms ranging from 1 to 2,000+ acres. These farms have a total of 72,000 acres of farmland, of which over 34,000 acres are cropland. The average size of these farms is 115 acres and the median size is 47 acres. The area of interest is depicted by Figure 1. All data, unless otherwise noted, pertains to Spotsylvania and Stafford Counties of Virginia.

Figure 1: Map of Stafford and Spotsylvania Counties (VA) - (Google Maps)
Figure 2: Sizes of Farms - 2007

Figure 2 shows the size of farms in our AOI in 2007. This graph shows that 261 farms were in the 10-49 acre category in 2007, comprising 44.1% of all farms.

Value of sales, production expenses, and net income are three sets of data important in determining the market condition for farmers and is available in five year increments from the USDA Agricultural Census.

1.1 Problem Definition

1.1.1 Value of Sales

The USDA definition of farm is “any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold, during
the census year [1].” The value of sales is the amount of income generated from selling agricultural commodities. Essentially, it is the farms paycheck before expenses.

Figure 3: Number of Farms by Value of Sales

Figure 3 shows the spread of farms based on their respective value of sales. In this chart, the value of sales is broken down into twelve categories by the Agricultural Census. In 2007, 41.6% of farms had value of sales below $1,000, and 0.34% had value of sales greater than or equal to $500,000. “The USDA further defines farms by size: small farms are farms with $250,000 or less in sales of agricultural commodities [2].” In 2007, over 98% of the farms in our AOI were, by USDA definition, small farms. This project
is specifically interested in these farms. The solid black, vertical line in Figure 3 depicts the cut-off for small farm status and visually shows the small farm to large farm ratio.

1.1.2 Net Income

The income of operation (a.k.a. IFO) is the total profit realized by a business after all costs are deducted from all business related income to include total sales, government payments, and other farm related income [1].

Figure 4 shows the relationship between 1997, 2002 and 2007 regarding the total IFO (the sum of the IFO from all farms). As it is shown in the graph, the total income from operations (IFO) of the farms for the years 2002 and 2007 is negative and has increased 77% from $2.45 million to $4.33 million. The year 1997 was the last time these farms had a positive IFO.
This leads to our first gap: The gap between current negative net profit and the required positive net profit in order for a business to succeed.

![Net Cash Income from Operations Average per Farm](chart.png)

Figure 5 shows the average IFO per farm. This average, also a deficit in 2002 and 2007, had an increase of 58% between 2002 and 2007, from $4,634 to $7,320. Farmers are collectively and on average losing money. Any business sustaining losses such as these will not be sustainable in the long-run.

### 1.1.3 Production Expenses

Production expenses are a major factor in determining a farm’s success.
Figure 6 shows the production expenses for 2002 and 2007 by categories defined by the USDA Agricultural Census. Overall, production expenses have risen 84% from $7.6 million in 1997 to $18.1 million in 2007 (inflation adjusted percentage).

Of these categories, two are predominately affected by the price of crude oil: “fertilizers, lime and soil conditioners” and “gasoline, fuels and oils.” These two categories comprised 20.9% of total production expenses in 2007.
Figure 7 narrows in on the increase in oil price dependent expense categories. Between 1997 and 2007 the “fertilizers, lime, and soil conditioners” has increased by 122% while the prices of gasoline, fuels and oils has risen by 137%.

The increase in price of crude oil, which directly affects the price of petro-diesel, leads to the second gap in our project: The gap between current diesel prices and the price that farms can afford.
Figure 8: Diesel Prices Central Atlantic Region

Figure 8 shows the inflation-adjusted increase in the price of diesel in the Central Atlantic region of the United States—which includes Virginia (as defined by the United States Energy Information Administration). The horizontal line represents the price of diesel that is affordable to farmers. We chose the price of diesel in 1997 as the mark for farmer affordability because it was found that 1997 was the last time farmers in Spotsylvania and Stafford counties made a net profit as shown in Figure 7 and Figure 8. Thus, our second gap is the gap between current diesel prices and the rate affordable to farmers.

All the data presented thus far suggests an overall struggling farm operation in Spotsylvania and Stafford counties in Virginia. There is a need to return these farms to a profitable condition. Because diesel fuel prices are on the rise, and net income is in a deficit, an alternate source of energy is needed that can be purchased or produced at a cost below petro-diesel in order to decrease the gap between positive net profit and the current deficit, and to decrease the gap between the affordable price of fuel and the current price of petro-diesel.
1.2 Biodiesel Context

1.2.1 Biodiesel in the U.S.

Biodiesel is a biofuel made from living or recently living organisms such as vegetable oils, animal fats or algae. It can be used as an alternative source of fuel for any diesel engine trucks and cars without engine modification (with exception to the rubber fuel lines found in some pre-1991 vehicles. These fuel lines would need to be replaced). In contrast with petro-diesel, biodiesel is environmentally friendly. Data from the University of Minnesota shows that there is a 41% reduction in carbon emissions while data gathered by the US Department of Energy shows a 78% reduction in carbon emissions when compared to petro-diesel.

Nation-wide, biodiesel production hit 1.1 billion gallons in 2011 which is the current U.S. production record. To put that into perspective, the U.S. demand for diesel fuel rose to over 170 million gallons/day in 2011 (~62 billion gallons/year).
This 7200% increase in biodiesel production from 2002 to 2011 is due primarily to the government incentives provided for alternative fuel production. As shown in Figure 9, there was a steady increase in biodiesel production between 2002 and 2004. But in 2005, the number more than quadrupled. This is due to the Energy Policy Act (EPA) of 2005 which provided a $1/gallon blenders tax credit for biodiesel production. This tax credit expired in December 2008; however, in December 2010 it was reinstated through December 2011 (which explains the drop in production for 2009 and 2010).

Currently, there is no Federal biodiesel production tax credit, and another extension is not certain, but this does not seem to have affected U.S. production of biodiesel, as a significant increase is still shown in Figure 10 from the year 2010 to 2012.

Figure 10: U.S. Monthly Biodiesel Production 2010-2012
1.2.2 Biodiesel and the Government

The federal incentive of $1 per gallon of biodiesel produced or used in trade or business is currently expired. Nevertheless, farmers located in Fredericksburg, VA can apply for the current tax credits and grants offered in the state of Virginia.

The government offers a tax credit of $0.01 per gallon produced from vegetable oil and a tax credit of $0.05 per gallon produced from waste cooking oil or animal fat. The annual credit may not exceed $5,000 and the producer is eligible for this credit for the first three years of biodiesel production.

The government also offers grants for Virginia residents considering selling their biodiesel production. A grant of $0.125 per gallon of neat advanced biofuel (made from waste oil or animal fat) sold. And a grant of $0.10 per gallon of neat Non-advanced fuel (made from clean vegetable oil) sold. Each producer is only eligible for six calendar years. The grant credits expire on June 30th, 2017 [3].

1.3 Biodiesel Production

1.3.1 Production Life-Cycle Process

Figure 11: Biodiesel on a Farm Flowchart
The biodiesel process as it pertains to a farm is shown in Figure 11. This flow chart begins in the top left where a farmer must make a choice: produce biodiesel or not. This project pertains to those who choose to produce biodiesel. Then the farmer must choose the type of crop to be used as a feedstock for the biodiesel production process. This selection represents the alternatives for this project which will be discussed further in the alternatives section of this paper. Once the crop is selected, the process continues to the typical farm operations regarding crops: prepare land, plant crop, maintain crop (pesticides, fertilizers, etc), and finally harvest the crops. One the crops are harvested, they must be prepared to enter the oil extraction process by removing rocks and debris. The crop can then be put through an oil press used to mechanically extract or press the oil out of the crop. The oil press product is vegetable oil, and the byproduct is meal, a potential source of income. The vegetable oil is then cleaned through a process called degumming. Degumming is the process of removing gums in the oil that make the glycerin separation more difficult after the transesterification process (explained later). Once the oil is cleaned, a sample of the oil is titrated in order to determine the amount of catalyst to mix with the methanol as depicted in parallel with the titration process in Figure 11. Methoxide, the mixture of methanol and a catalyst, is mixed with the vegetable oil and a chemical process known as transesterification takes place. Transesterification is the chemical process of exchanging the organic group of an alcohol with the organic group of an ester (animal and vegetable fats/oils) in order to decrease the viscosity of the vegetable or fat oil [4]. This takes place in a biodiesel processor and is shown in more detail in Figure 12.
The product of the transesterification process is biodiesel, and the byproduct is glycerin, another potential source of income. The biodiesel is then washed, also performed in the biodiesel processor. A biodiesel standard is then verified as met as shown in Figure 11, and finally the biodiesel may be used or sold.
1.3.2 Transesterification Process

Chemical Design of Biodiesel

Figure 13 shows the chemical breakdown of the transesterification process. At the bottom of the figure, is petro-diesel’s chemical structure as a comparison to biodiesel’s chemical structure.
1.3.3 Safety Regulations

Biodiesel production is regulated by three government agencies and one international agency that regulate biodiesel production in the U.S. by providing standards and controls in order to help produce biodiesel in safely manner. The regulatory agencies are listed in Table 1. In order to create quality biodiesel and minimize accidents from occurring, it is of best practice to abide to the standards and regulations provided by these agencies.

*Table 1: Regulatory Agencies, Regulations and Mitigation Measures*

<table>
<thead>
<tr>
<th>Agencies</th>
<th>Regulations</th>
<th>Mitigation Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupational Safety and Health administration (OSHA).</td>
<td>Regulates employee safety and provides standards for workplace hazards. Request Material Safety Data Sheets (MSDS) for chemicals.</td>
<td>Methanol, Potassium Hydroxide and Sodium Hydroxide regulation. Large spill: Call fire department.</td>
</tr>
<tr>
<td>VA Department of Environmental Quality (DEQ).</td>
<td>Regulates waste product generation, (The Virginia Biodiesel Environmental Compliance Primer)</td>
<td>Glycerin: Contact waste solvent company. Give or sell. Use dry wash system.</td>
</tr>
</tbody>
</table>

The regulatory agency in the last row of Table 1 is not a government agency but rather an international agency. In order to legally sell biodiesel and prevent engine warranties from becoming void, all biodiesel produced must meet the requirements of The American Society for Testing and Materials (ASTM) specification D6751. ASTM is “a globally recognized leader in the development and delivery of international voluntary consensus standards [5].” The specification is available for purchase at astm.org.
OSHA’s mission is to assure the safety and health of America’s workers. Biodiesel producers have to always wear Personal Protection Equipment (PPE) at all times. Figure 14 shows the safety gear required by OSHA for biodiesel producers. A: Safety glasses or face shield. B: A respirator. C: An Apron. D: Chemical resistant gloves.

1.3.4 Advantages of Biodiesel

In addition to reducing costs, producing and using biodiesel in farm equipment has other benefits as well. Most notable is the reduced carbon dioxide emissions. “A US Department of Energy study showed that the production and use of biodiesel, compared to petroleum diesel, resulted in a 78.5% reduction in carbon dioxide emissions [6].” A few additional benefits of biodiesel are that biodiesel is biodegradable, it is a cleaning and lubricating agent which helps increase the life of diesel engines, and it has a potential net energy ratio (NER) greater than 4.5 [6].
1.3.5 Disadvantages of Biodiesel

There are two prominent disadvantages of biodiesel: (1) the potential of reducing the food supply in order to create fuel, and (2) biodiesel gels in cold weather. Disadvantage (1) is an area of ongoing concern. Disadvantage (2) is an inconvenience. Biodiesel, just like petrodiesel, gels in cold weather; however, biodiesel gels at warmer temperatures than petrodiesel. There are two measurements of concern, the cloud point (CP) and the pour point (PP). The CP is the temperature at which crystals start to form in the diesel turning the liquid into a solid. The PP is the temperature at which the diesel becomes a solid. Many factors decide the CP and PP of a biodiesel blend [7]. The CP values range from 21.2° F – 33.8° F, and the PP values range from 5° F – 28.4° F [7]. If operation in cold weather is necessary, biodiesel may be mixed with petrodiesel to reduce the CP and PP in ratios of 5% - 20% biodiesel to total mixed volume (B5 – B20).

1.3.6 Biodiesel and the Farm

Because the farms in the Fredericksburg, VA area are currently producing or capable of producing oil crops (corn, soybean, canola, etc), it will be determined if it is feasible for them to produce their own biodiesel to potentially reduce production costs of the farm. The methodology would be to grow crops for both food and fuel, sell the food crops, and produce biodiesel from the fuel crops. If this is economically feasible, it would create a self-sustaining farm while decreasing production costs.
2.0 Stakeholder Analysis

Table 2: List of Stakeholders

Table 2 lists all stakeholders involved in the production of biodiesel and their main objectives. The farmer is considered as the primary stakeholder, and the neighboring farmers, workers, food consumers and the government are considered the secondary stakeholders.

2.1 Farmer

Farmers located in the city of Fredericksburg, VA are considered the primary stakeholders for this project. The categories that significantly increased are the
agricultural materials such as fertilizers, lime, and soil conditioners as well as other sources of fuel, such as gasoline, diesel, and oils due to the increase in crude oil. Farms in the Fredericksburg, VA area are currently producing or they are capable of producing crops that can be pressed to produce vegetable oil such as corn, soybeans, canola, etc. It is of best interest for farmers to produce their own biodiesel to potentially reduce production costs of the farm and have a self-sustaining farm.

The farmer’s main objective is to make money by having reducing operating costs and producing a quality product to sell. This implies producing an alternative source of fuel that will cost less than the current price of petro-diesel in order to reduce operating costs and gain a profit if sold to neighboring farms. In order for the biodiesel to be sold, quality standards will have to be met which will help minimize the risk of vehicle machinery problems.

2.2 Neighboring Farmers

The population in Fredericksburg Virginia is approximately 25,691 people [8]. Figure 15 was formulated by gathering data from the USDA Agricultural Census. This graph shows that the number of part time farmers has increased 4.8% while the number of full time farmers has decreased 9.6%. This relationship of part time farmers increasing while full time farmers decrease, shows that farming will not be able to sustain families in the long-run because the net profit gained is currently negative. Due to this, there was a 2.8% decrease in the number of small farms in the Fredericksburg area.
The main objective of the neighboring farmers is to save money currently spent on petro diesel by purchasing biodiesel at a discounted rate from the primary stakeholder. Safety is also a primary concern for neighboring farmers; they do not want to be affected by hazardous spills which can cause land or water contamination, or be affected by odors that may be caused by its production.

2.3 Workers

Spotsylvania and Stafford counties offer farming employment to approximately 196 people [9]. Farmers that decide to produce their own biodiesel offer the opportunity for new jobs in Fredericksburg, VA. The workers’ objective is to earn a salary by helping with the production process of Biodiesel in a safe environment, for the primary stakeholder. Working in a safe environment minimizes risks involved in the production procedures. They have to be able to work in a safe environment to perform their job correctly. They will have to be provided with the right gear such as boots, gloves, face shield and goggles to be able to handle hazardous materials in a safe manner.
2.4 Food Consumers

One of the disadvantages of excess biodiesel production in the U.S. is possible food shortage in the future. Farmers planting more acres of crops to produce biodiesel will also be less likely to meet market demands in the long-run, so food crop demand will increase, causing the standard prices to rise greatly. A USDA projection shows that corn, wheat and soybeans will account for about 90% of acreage by 2017. Crop prices also affect the price of meat and dairy products because grain is used as feed in farms. The main objective for food consumers is to purchase crops at stable prices.

2.5 Government

The government’s objective is to promote non-polluting alternative fuels while also achieving energy independence. They are interested in increasing U.S. national energy security, improving air quality and public health and developing economic, academic, and research opportunities in the Commonwealth of Virginia. Government agencies, such as the Internal Revenue Service (IRS) and the Virginia Department of Taxation support this cause by creating incentives (tax fee reductions and tax incentives) and giving grants to people interested in producing their own alternative fuels such as biodiesel.

2.5.1 Regulatory Agencies

The government’s regulatory agencies also play a key role in the development of this project and the relationship with the primary stakeholder. The following agencies established a set of regulations and controls for the small and large production of Biodiesel. The Environmental Protection Agency (EPA) provides spill prevention controls as well as oil and hazardous material control, the Occupational Safety and Health Administration (OSHA) regulates employee safety and provides standards for workplace hazards, and the Virginia Department of Environmental Quality (DEQ) regulates waste
product production and controls air contamination. Following these regulations will minimize the risks of hazardous spills and accidents from occurring, and if they occur, the producers and workers will know how to take appropriate actions.

2.5.2 Stakeholder Relationship Diagram

Figure 16: Stakeholder Relationship Diagram

Figure 16 shows the interactions between the farmer who is our primary stakeholder and the secondary stakeholders. There are three reinforcement loops in this diagram, the cash flow loop, human resources loop and support loop. The reinforcement loops show a cause and effect process related to the objectives of each stakeholder and the process of achieving their goals. For instance, the support loop reinforcing the relationship between the government and the farmer will continue, as long as the government provides the tax credits and grants, and the farmer will continue with the
biodiesel production, supporting the goal of the government to produce alternative sources of fuel. The cash flow loop reinforcing the relationship between the neighboring farmers and the primary stakeholder will continue as long as the farmer produces a quality product to sell, and in return will receive a sale revenue, that will increase his profit. Lastly, the human resources loop will continue as long as the farmer keeps paying a salary to the worker, and in return he will get help in production. The regulatory agencies on the other hand, do not create reinforcement loops because the agencies give the farmer a set of regulations, but never impose on following them, it is of best practice to follow the standards and regulations, in order to minimize accidents from occurring and therefore minimize additional costs paid if those accidents occur.

2.6 Tension Influence Diagram

<table>
<thead>
<tr>
<th>Table 3: List of Stakeholders Tensions Due to Biodiesel Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Farmer and Worker</strong></td>
</tr>
<tr>
<td>Providing training and safety gear increases production cost.</td>
</tr>
<tr>
<td>Farmer is responsible for costs if accidents occur.</td>
</tr>
<tr>
<td>Workers handling products incorrectly can cause:</td>
</tr>
<tr>
<td>Injury, loss of life, property damage or environmental contamination.</td>
</tr>
<tr>
<td><strong>Between Farmer and Neighboring Farms</strong></td>
</tr>
<tr>
<td>Produce biodiesel minimizing risks and hazardous spills to avoid contamination to neighboring farms.</td>
</tr>
<tr>
<td>Produce biodiesel; profitable for farmer and affordable for neighboring farms.</td>
</tr>
<tr>
<td><strong>Between Farmer and Regulatory Agencies</strong></td>
</tr>
<tr>
<td>Creating a safe environment according to regulations increases production cost.</td>
</tr>
<tr>
<td>Follow ASTM standard D6751 to sell; increases production cost.</td>
</tr>
</tbody>
</table>

Table 3 shows the tensions between stakeholders due to biodiesel production. The tensions between the farmer and the workers, neighboring farms and regulatory agencies
as shown on table 3, are mainly caused by the increase in production costs which affects the farmer’s profitability.

**2.6.1 Tension Influence Diagram**

![Tension Influence Diagram](image)

*Figure 17: Tensions Influence Diagram*

Figure 17 shows an influence diagram developed by taking into account the tensions between the stakeholders, caused by the production of biodiesel. The color green means that the influence is beneficial; the color red means that it is not beneficial. The plus sign reinforces (keeps going up or down). If an increase in the source node occurs, an increase in the sink node also occurs. Similarly, a decrease in the source node causes a decrease in the sink node. The minus sign stabilizes (brings things to equilibrium). If an
increase in the source node occurs, a decrease in the sink node occurs. Similarly, a decrease in the source node causes an increase in the sink node.

Crop production, technology and cost of labor have a plus sign affecting the cost of production. The more we produce crops, the better the technology and more workers needed for production will cause an increase in production price. The more we abide to safety regulations, the higher the production price will be, but that it beneficial because it will help avoid accidents from occurring. Tax incentives and grants have a minus sign, the more the farmer takes advantage of the credits, the cost of production will decrease, which is beneficial for the farmer.

The cost of production will determine the quantity of biodiesel production. The higher the cost, the less the production quantity will be (- sign). As biodiesel production increases, the lower the selling price will be, which will possibly increase the demand for biodiesel, causing the farmer’s profit to rise (Reinforcement loop). Lastly, the higher the biodiesel production will be, the availability for raw materials (crop decreases), which will cause the price for crops to go up, resulting in higher food price.

The gaps and tensions described above help develop the problem and need statement for this project.

3.0 Problem and Need Statement

3.1 Problem Statement

Increasing fuel prices and lack of net profit threaten the long term sustainability of farms located in Fredericksburg, VA. Farmers rely heavily on petrochemical diesel, which has increased in price by nearly 230% since 1997, the last year that farmers in the Fredericksburg area of Virginia had a net profit.

3.2 Need Statement

Based on our problem statement, there is a need for a small-scale biodiesel production system for farms located in Fredericksburg, VA. The design of our biodiesel
production system will take into account the whole life-cycle process of biodiesel production, from crop planting to the final biodiesel yield. The small-scale biodiesel system provides a win-win for all of the major stakeholders. Farmers will save money on fuel costs by producing their own fuel. Because our design will include consideration for safety, workers will be able to work in a safe environment. Neighboring Farmers will have possible access to affordable biodiesel. The loss of food supplies will be minimized since our system will use the best crop alternative. This will allow the farmer to maximize his available farm land and the increase in food prices for consumers will be minimized. Finally, the government’s goal for energy independence will be furthered.

There is a need for a small-scale biodiesel production system for farms located in Fredericksburg. The design of the biodiesel production system will take into account the whole life-cycle process of biodiesel production, from crop planting to the final biodiesel yield. A win-win situation for all stakeholders will be achieved by helping farmers save money on fuel costs through biodiesel production while creating new product to sell, providing farmers with the proper information to minimize hazardous spills and safety risks, minimizing the impact on food supplies by recommending the optimal crop type, and furthering the government’s goal of energy independence.

4.0 Mission Requirements

We have determined three mission requirements for the design of our system:

1. The system shall be able to make biodiesel at a cost less than the retail cost of petro-diesel.
2. The system shall be able to make biodiesel with a Net Energy Ratio greater than 1.
3. The system shall be able to produce biodiesel that conforms to standard D6751.
Requirement 1 is important because if the production costs for biodiesel are greater than the cost of purchasing diesel, than the production of biodiesel will not be beneficial. Also, if the Net Energy Ratio is not greater than 1, than the farmer will be using more energy to create biodiesel than he will be receiving in return. This would negate the effectiveness of producing biodiesel. Finally, the biodiesel must be produced so that it conforms to Standard D6751 [10]. If the biodiesel does not conform to this standard, government incentives cannot be applied and additional income from the sale of biodiesel cannot be obtained. Thus, this standard must be followed.

5.0 Design Alternatives

As mentioned previously, the major alternative for this project is the crop selection alternatives. Since we are considering small scale farms, it is important that the best crop is chosen. Without the luxury of a large farm, the slightest difference in price or yield could mean the difference between making a profit and suffering loss. We must consider the most cost effective and most productive alternative. We will not exclude a “No change” option. If this process is determined to be financially infeasible, we will recommend that no changes be made in the purchasing of fuel for small scale farms.

<table>
<thead>
<tr>
<th>Crop</th>
<th>US gal/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm Oil</td>
<td>635</td>
</tr>
<tr>
<td>Rapeseed**</td>
<td>127</td>
</tr>
<tr>
<td>Peanut*</td>
<td>113</td>
</tr>
<tr>
<td>Sunflower**</td>
<td>102</td>
</tr>
<tr>
<td>Mustard Seed**</td>
<td>61</td>
</tr>
<tr>
<td>Soybean*</td>
<td>48</td>
</tr>
<tr>
<td>Hemp</td>
<td>39</td>
</tr>
<tr>
<td>Cotton**</td>
<td>35</td>
</tr>
<tr>
<td>Oats*</td>
<td>23</td>
</tr>
<tr>
<td>Corn*</td>
<td>18</td>
</tr>
</tbody>
</table>
Canola must be planted in rotation with crops other than soybeans [12]. Growing hemp is illegal in Virginia, so it is not a viable alternative. Palm oil can only be grown in tropical areas such as Asia, Africa, and South America [13]. Mustard seed and cotton are not currently grown in the Fredericksburg area, and since the infrastructure is not in place for these crops and their vegetable oil yield is not significantly greater than the existing crops, we removed them from consideration. Oats are not a significant crop in Virginia, and since the vegetable oil yield from oats is not significantly greater than corn (taking into consideration corn’s widespread usage throughout Virginia), we removed oats as a viable alternative as well.

This leaves us with five crop alternatives: canola, sunflower, peanuts, soybeans, and corn.

<table>
<thead>
<tr>
<th>Crop Alternative</th>
<th>Grown in VA</th>
<th>Growable in VA</th>
<th>Average Vegetable Oil Yield</th>
<th>2011 Crop Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola</td>
<td>No</td>
<td>Yes</td>
<td>127 (gal/acre)</td>
<td>0.243 ($/lb)</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Yes</td>
<td>Yes</td>
<td>102 (gal/acre)</td>
<td>0.304 ($/lb)</td>
</tr>
<tr>
<td>Peanut</td>
<td>Yes</td>
<td>Yes</td>
<td>113 (gal/acre)</td>
<td>0.239 ($/lb)</td>
</tr>
<tr>
<td>Soybean</td>
<td>Yes</td>
<td>Yes</td>
<td>48 (gal/acre)</td>
<td>0.22 ($/lb)</td>
</tr>
<tr>
<td>Corn</td>
<td>Yes</td>
<td>Yes</td>
<td>18 (gal/acre)</td>
<td>0.11 ($/lb)</td>
</tr>
</tbody>
</table>

*Table 4: Vegetable Oil Yield for Various Crops [11]*

* Grown in Fredericksburg area; ** Grown in Virginia

*Table 5: Crop Alternatives Available to Farms in Fredericksburg, Virginia*
Table 5 depicts the crop alternatives available to the farms in the Fredericksburg, VA area. Sunflower, peanut, soybean, and corn are currently grown in Virginia; however, canola is not widely grown.

![Vegetable Oil Yield Graph]

Figure 18: Vegetable Oil yield for Crop Alternatives [11]

Figure 18 shows the expected vegetable oil yield for our five crop alternatives: canola, peanuts, sunflowers, soybeans, and corn.

Another important consideration is planting season, since depending on the time of year there is the potential for overlap with existing crops that are planted, cutting into the farmer’s sale profit.
<table>
<thead>
<tr>
<th>Crop</th>
<th>Planting</th>
<th>Harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Apr 20 - May 20</td>
<td>Sep 5 - Oct 25</td>
</tr>
<tr>
<td>Soybean</td>
<td>May 20 - Jun 30</td>
<td>Oct 25 - Nov 25</td>
</tr>
<tr>
<td>Peanuts</td>
<td>May 5 - May 20</td>
<td>Oct 5 - Oct 25</td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>Oct 20 - Nov 15</td>
<td>Jun 20 - Jul 15</td>
</tr>
<tr>
<td>Canola</td>
<td>12-Oct</td>
<td>3-Jun</td>
</tr>
<tr>
<td>Sunflower</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

*Table 6: Planting and Harvesting Seasons [9]*

Any information as to the typical planting season for sunflower still has to be found, so this is one of the significant areas for further research.

### 5.1. Canola

Rapeseed, known as canola in North America, is a winter crop used primarily for vegetable oil. Ranking only behind soybean oil and palm oil, canola is the third largest source of vegetable oil in the world. Concerns over the high erucic acid content of rapeseed limited its use in the United States until it was genetically modified by Canadian researchers in the 1970s. They named the genetically modified version of rapeseed canola—Canadian oil low acid [14].

Canola generates the most vegetable oil per acre of all of our alternatives, producing 127 gallons per acre. However, canola is commonly grown in the North-Central United States (North Dakota produces 90% of the total amount in the United States), and is not a major crop in Virginia. Recent research at North Carolina State University [14] has suggested the possibility of substituting canola for winter wheat, a common crop in Virginia and North Carolina grown from October to July. Any farm that started
growing canola for biodiesel would have to ensure that it fit in with the existing crop schedule.

5.2 Peanuts

Peanuts have been grown in the United States primarily as a field crop since 1870. Peanuts are grown on 1,375,000 acres in the United States, and Virginia has over 10,000 acres of peanuts. Peanuts are grown primarily for use as a food substance such as peanut butter or oil. Peanut plants can grow to 6-24 inches in height and usually require between 100 and 150 days from planting to harvesting depending on the precise variety of the plant [y]. The standard vegetable oil yield from peanuts is 113 gallons per acre and the planting/harvesting season in Virginia lasts from April to November [9].

5.3 Sunflowers

Sunflowers were the third largest source of vegetable oil worldwide in 1985-1986 and are a significant source of vegetable oil. Sunflowers are also used for as a substitute for soybean meal as well as for swine and poultry feed. Currently, sunflowers in the United States are mostly grown in the northern Great Plains states such as North and South Dakota and Minnesota [12]. Sunflowers are highly durable and can flourish in temperature ranges from 64-91 degrees Fahrenheit. Recently, interest has increased in the use of sunflowers as a crop to convert to biodiesel [15]. Sunflowers have a high vegetable oil yield (102 gallons per acre) and are able to be grown in a variety of climates.

5.4 Soybeans
Soybeans are the world’s largest source of animal feed and the second largest source of vegetable oil. Soybeans make up 90% of the United States’ oilseed production [18]. In 2011, 570,000 acres of soybeans were planted in Virginia [16]. Although vegetable oil yield from soybeans (48 gallons per acre) is not as high as peanuts, sunflowers, or canola, the large presence in Virginia makes it a feasible alternative.

5.5 Corn

In 2011, 490,000 acres of corn were planted in Virginia [16]. Thus, although corn is not a good source of vegetable oil, producing only 18 gallons of oil per acre, the large amount of farms that grow corn make it a viable alternative as the farming infrastructure is already in place.

5.6 Vegetable Oil Extraction

For the oil extraction phase of this system, we have decided to utilize a 3 ton per day capacity oil press.

This press claims an oil press efficiency rate between 90 – 95% and costs $4,575.00. At this capacity, the approximate hourly extraction rate would be as shown in table 7.
<table>
<thead>
<tr>
<th>Crop</th>
<th>Gal of oil/ton</th>
<th>Gal/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola</td>
<td>110</td>
<td>13.8</td>
</tr>
<tr>
<td>Sunflowers</td>
<td>123</td>
<td>15.4</td>
</tr>
<tr>
<td>Peanuts</td>
<td>123</td>
<td>15.4</td>
</tr>
<tr>
<td>Soybean</td>
<td>46.5</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Table 7: Oil Extractable per Hour

5.7 Biodiesel Reactor

Biodiesel reactors come in varying shapes and sizes from “home-made” versions averaging $150-$225 in supplies, to 150 gallon capacity pre-manufactured systems costing over $8000. We have chosen a biodiesel processor with an 80 gallon per batch capacity with a dry-wash feature at a cost of $2,650.00.
This biodiesel processor cost also includes an instruction manual, a chemical safety kit, as well as a digital scale used for measure the catalyst in the methoxide blend.

6.0 Design Analysis Methodology

In order to determine the optimal alternative for each of the three areas, we will design and build two stochastic simulations: 1) Biodiesel Production Simulation and 2) Business Simulation. The Business Simulation will accept inputs that are outputs from the Biodiesel Production Simulation.

Figure 19: Stochastic Simulation Design

Monte Carlo simulation containing two parts: Biodiesel Production Simulation and Business Simulation. Biodiesel Production Simulation simulates the expected yield of biodiesel and other byproducts which are then inputs to the Business Simulation. The Business Simulation accounts for all of the variable costs associated with biodiesel production and calculate the NPV at the end of 15 years. These two simulations will
allow us to determine the amount of biodiesel produced with each alternative and the cost of each.

6.1 Simulation Assumptions

The following assumptions were made for the simulation:

1) The lifespan of the machinery is 15 years
2) The farm contains 75 acres of cropland
3) There is no salvage value for the machinery at the end of the system lifespan
4) Farmers own the proper equipment to plant and harvest crops
5) There exists unlimited demand for biodiesel, glycerin, and meal
6) After the first year of biodiesel production, all fuel needs will be supplied by the previous year’s biodiesel

6.2 Biodiesel Production Simulation

The purpose of the Biodiesel Production Simulation is to determine the amount of biodiesel produced by each crop alternative. In order to simulate the uncertain nature of biodiesel production, crop yield and vegetable oil press efficiency were used as random variable inputs.
Figure 20: Biodiesel Production Simulation Design of Experiment

Distributions for the crop yield are based on historical crop yields for the Fredericksburg area (Corn), the state of Virginia (Canola and Peanut), and the United States (Sunflower and Soybean). The outputs of the biodiesel simulation are expected biodiesel yield, expected glycerin yield, expected meal yield, and the net energy ratio. These values were calculated using (1), (2), and (3) below [7], [8]. Table 8 lists the variables used to calculate the yields.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Biodiesel Acreage</th>
<th>Crop Yield</th>
<th>Oil Percentage</th>
<th>Press Yield Percentage</th>
<th>Expected Biodiesel Yield</th>
<th>Feedstock Output</th>
<th>Glycerin Output</th>
<th>Biodiesel Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola</td>
<td>10</td>
<td>Beta</td>
<td>Normal</td>
<td>Lognormal</td>
<td>0.9885</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>10</td>
<td>Beta</td>
<td>Normal</td>
<td>Lognormal</td>
<td>0.9885</td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peanut</td>
<td>10</td>
<td>Triangular</td>
<td>Normal</td>
<td>Lognormal</td>
<td>0.9885</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td>10</td>
<td>Beta</td>
<td>Normal</td>
<td>Lognormal</td>
<td>0.9885</td>
<td>Beta</td>
<td>Beta</td>
<td>Beta</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td>10</td>
<td>Uniform</td>
<td>Normal</td>
<td>Lognormal</td>
<td>0.9885</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{y\text{pa}}$</td>
<td>Biodiesel Yield per Acre (gallons)</td>
</tr>
<tr>
<td>$C_{y\text{pa}}$</td>
<td>Crop Yield per Acre (lbs)</td>
</tr>
<tr>
<td>$O_C$</td>
<td>Oil Content by Weight (percentage)</td>
</tr>
<tr>
<td>$W_{\text{biodiesel}}$</td>
<td>Pounds per Gallon of Biodiesel (~7.6 lbs/gal)</td>
</tr>
<tr>
<td>$P_{\text{eff}}$</td>
<td>Oil Press Efficiency (percentage)</td>
</tr>
<tr>
<td>$M_{y\text{pa}}$</td>
<td>Meal Yield per Acre (lbs)</td>
</tr>
<tr>
<td>$G_{y\text{pa}}$</td>
<td>Glycerin Yield per Acre (gallons)</td>
</tr>
<tr>
<td>$G_{yr}$</td>
<td>Glycerin Yield Ratio (0.105)</td>
</tr>
<tr>
<td>$B_{yr}$</td>
<td>Biodiesel Yield Ratio (0.9885)</td>
</tr>
</tbody>
</table>
Three equations will be used for this simulation: one for biodiesel, one for glycerin, and one for meal.

\[ B_{ypra} = \frac{C_{ypra} \cdot O_c}{W_{biodiesel}} \cdot P_{eff} \cdot B_{yr} \]  

\[ M_{ypra} = C_{ypra} \cdot (1 - (O_c \cdot P_{eff})/10000) \]  

\[ G_{ypra} = \frac{C_{ypra} \cdot O_c}{W_{biodiesel}} \cdot P_{eff} \cdot G_{yr} \]

The biodiesel yield is dependent on the crop yield, the oil content of the crop, the oil press efficiency, and the biodiesel yield ratio. Glycerin yield is dependent on the biodiesel yield and the glycerin yield ratio. Finally, the meal yield is dependent on the crop yield, the oil content, and the press efficiency. The numbers in front of Equations 1 and 3 are unit conversion factors.

The factor with the largest impact on the yield amount is the crop yield and the oil content of the crop - both of which are random variables based on historical data from the USDA. The alternatives range from 4% oil content for corn to 43% oil content for sunflower. Meal yield is inversely proportional to the vegetable oil content of the crop; high oil content tends to produce lower meal yield. Meal and glycerin yield were calculated because these byproducts can be sold to offset the cost of biodiesel production. The yield equations were used to calculate the expected yields for each year that the simulation was run.

The random variables that were used are shown in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Canola</th>
<th>Corn</th>
<th>Peanut</th>
<th>Soybean</th>
<th>Sunflower</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop Yield</strong></td>
<td>Beta(1740, 2233)</td>
<td>Beta(2538, 7148)</td>
<td>TRIA(1350, 3070, 3800)</td>
<td>Beta(1412, 2646)</td>
<td>UNIF(967, 1510)</td>
</tr>
<tr>
<td><strong>Vegetable Oil Percentage</strong></td>
<td>Normal(.42, .0001)</td>
<td>Normal(.04, .0001)</td>
<td>Normal(.42, .0001)</td>
<td>Normal(.16, .0001)</td>
<td>Normal(.43, .0001)</td>
</tr>
<tr>
<td><strong>Oil Press Efficiency</strong></td>
<td>Lognormal(0.9, 0.92, 0.02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 9: Biodiesel Production Simulation Random Variables*
All distributions were fitted from historical data in Crystal Ball or Arena’s Input Analyzer using the Kolmogorov-Smirnov Test.

### 6.3 Business Simulation

The purpose of the business simulation is to determine the financial feasibility of producing biodiesel by calculating the NPV at the end of the system lifespan. The random variable inputs for the simulation include the outputs from the Biodiesel Production Simulation (biodiesel, glycerin, and meal yield) as well as planting and harvesting costs, opportunity cost, meal revenue, and glycerin revenue.

![Figure 21: Business Simulation Design of Experiment]

Opportunity cost represents the profit lost by not selling the crop as a food source. Other inputs are machinery costs, chemical costs, state biodiesel incentives, and the number of acres committed to biodiesel production. The output is the NPV for each crop alternative. Equation (4) was used to calculate the NPV for the lifespan of the system.

\[
I_0 + \sum_{t=1}^T F_t/(1 + k + p)^t
\]  

(4)
$I_0$ is the initial machinery investment, $F_t$ is the net cash flow in year $t$, $k$ is the discount factor, $p$ is the inflation rate per year, and $n$ is the number of years. Values for $p$ were obtained from the U.S. Bureau of Labor Statistics inflation forecast [9] and the duration of the simulation was determined to be 15 years based on the lifespan of the machinery. Equation (5) was used to calculate the net cash flow for each year [10], and Table 10 describes the variables (5).

$$F_t = (-F_c - PH_c - O_c + G_r + M_r + S_I) * B_A + B_P - M_c$$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_c$</td>
<td>Chemical expenses (dollars per acre)</td>
</tr>
<tr>
<td>$PH_c$</td>
<td>Crop costs (dollars per acre)</td>
</tr>
<tr>
<td>$O_c$</td>
<td>Opportunity cost (dollars per acre)</td>
</tr>
<tr>
<td>$G_r$</td>
<td>Glycerin revenue (dollars per acre)</td>
</tr>
<tr>
<td>$M_r$</td>
<td>Meal revenue (dollars per acre)</td>
</tr>
<tr>
<td>$B_P$</td>
<td>Biodiesel sales (dollars)</td>
</tr>
<tr>
<td>$B_A$</td>
<td>Biodiesel acreage on farm (acres)</td>
</tr>
<tr>
<td>$M_c$</td>
<td>Yearly maintenance costs (dollars)</td>
</tr>
<tr>
<td>$S_I$</td>
<td>State biodiesel incentives (dollars per acre)</td>
</tr>
</tbody>
</table>

The output of this simulation is the net present value of biodiesel production for each crop after 15 years. The random variables used had the following distributions:

<table>
<thead>
<tr>
<th></th>
<th>Canola</th>
<th>Corn</th>
<th>Peanut</th>
<th>Soybean</th>
<th>Sunflower</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop Price</strong></td>
<td>Gamma(1.7, .5, 6.3)</td>
<td>Weibull(2.1, 1.6, 1.5)</td>
<td>Norm(.25, .0016)</td>
<td>MinExtreme(9.7,1.8)</td>
<td>Weibull(2.1, 1.6, 1.5) [1]</td>
</tr>
<tr>
<td><strong>Meal Price</strong></td>
<td>Lognormal(203, 345, 130)</td>
<td>Norm(255, 653)</td>
<td>Norm(200, 400)</td>
<td>Gamma(128, 39,2)</td>
<td>Lognormal(33, 106, 39)</td>
</tr>
<tr>
<td><strong>Planting Costs</strong></td>
<td>205</td>
<td>Triangular(204, 207, 438)</td>
<td>Logistic(602, 48)</td>
<td>Triangular(83, 147, 246)</td>
<td>191</td>
</tr>
<tr>
<td><strong>Diesel Price</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Triangular(3.73,4.28,4.29)</td>
</tr>
</tbody>
</table>

*Table 11: Business Simulation Random Variables*
All distributions were fitted from historical data in Crystal Ball or Arena’s Input Analyzer using the Kolmogorov-Smirnov Test.

Historical data for Planting Costs for Canola and Sunflower are not available so a mean value was used instead of a random variable.

7.0 Results

7.1 Biodiesel Production Simulation

50,000 iterations of each simulation were run with the assumption that the farm had 75 acres of cropland. Nine simulation scenarios were run for biodiesel acreage of 10, 15, and 20 acres and discount rates of 2%, 5%, and 7%. Table 12 shows the results of the Biodiesel Production Simulation ranked from highest yield per acre to the lowest. These factors are not affected by the biodiesel acreage or the discount rate and remain constant for each simulation scenario.

<table>
<thead>
<tr>
<th>TABLE12 PRODUCTION SIMULATION OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Peanut</td>
</tr>
<tr>
<td>Sunflower</td>
</tr>
<tr>
<td>Canola</td>
</tr>
<tr>
<td>Soybean</td>
</tr>
<tr>
<td>Corn</td>
</tr>
</tbody>
</table>

Corn has the lowest biodiesel yield at 19 gallons per acre. Canola and Peanut have significantly higher biodiesel yields – about 5 and 7 times the Corn yield respectively.

As a result, Corn has a NER that is significantly lower than the other crops because the amount of biodiesel from corn is lower. The NER for Corn is lower than 1 and does not meet the requirement that biodiesel be produced with a NER greater than 1. Peanut and Canola have relatively high NER consistent with the higher biodiesel yield.
7.2 Business Simulation Results

Figure 22 shows the mean net present value results for each crop alternative for a discount rate of 2%.

![NPV at 10 Biodiesel Acres](image)

*Figure 22. Based on the average NPV results, Corn produces a positive return on investment (ROI) within 5 years and is the only alternative that produces a ROI. Corn has the lowest biodiesel yield but the highest meal yield which provides a significant contribution to profit.*

With 10 acres committed to biodiesel production, Corn is the only alternative with a positive average NPV. Based on the NPV distribution, Corn has an 80% chance of achieving a positive NPV. Canola has a 14% chance of achieving a positive NPV. Peanut, Soybean, and Sunflower all have a 0% chance of achieving a positive NPV.

Figure 23 shows the average NPV for the next scenario: 15 acres dedicated to biodiesel production.
Figure. 23. Based on the average NPV results, Corn and Canola achieve a positive ROI within 3 and 5 years respectively. No other crops achieve a positive ROI. Sunflower and Soybean are almost identical in average NPV in Figure. 23.

When increased to 15 acres, Canola has a 90% chance of achieving a positive NPV. Corn increases to an 86% chance. Peanut and Soybean have a 0% chance of a positive NPV. Sunflower has less than 1% chance of a positive NPV.

Figure. 24 shows the average NPV for the next scenario: 20 acres dedicated to biodiesel production.
Based on the average NPV results, Corn and Canola each achieve a positive ROI within 2 years. No other crops achieve a positive ROI.

As the number of acres increases, Canola becomes increasingly more profitable; at 20 acres producing biodiesel, there is a 99% chance of a positive NPV. Corn increases to an 88% chance of a positive NPV. Peanut and Soybean have 0% chance of a positive NPV. Sunflower increases to a 10% chance of a positive NPV.

As the number of acres committed to biodiesel increases, the mean NPV for Corn and Canola and the probability of a positive NPV increase significantly. Increased acreage has a minimal negative impact on Peanuts and Soybeans and a minimal positive impact on Sunflower. Scenarios with the higher discount rates of 5% and 7% mirror these results but with numbers of smaller magnitude.

### 7.3 Sensitivity Analysis

Sensitivity analysis was conducted for the price of diesel and the number of acres committed to biodiesel production. In order for Peanut to produce a positive NPV, diesel prices would have to increase to 13.00, 7.50, and 6.50 dollars per gallon for 10, 15, and 20 acres of biodiesel production respectively. Varying the number of biodiesel acres and diesel prices cannot result in a positive NPV for Soybeans. Peanut’s high biodiesel yield provides a positive NPV if enough is produced and sold at a high price, but Soybean’s biodiesel yield is not large enough to produce a positive NPV. Sunflower could attain a positive NPV if the number of biodiesel acres increased to 42 or if the price of diesel increased to 17.50 and 8.50 dollars per gallon for 15 and 20 biodiesel acres respectively.

### 8.0 Recommendations and Conclusion

#### 8.1 Value Hierarchy

In order to determine the best crop alternative to recommend to our sponsor, we have constructed a value hierarchy with input from our sponsor.
In order to determine the best crop alternative, three factors were analyzed in a value hierarchy: (1) Biodiesel yield in gallons per acre with a weight of 0.5, (2) Length of planting and harvesting season in days with a weight of 0.3, and (3) Hazard level associated with biodiesel production with a weight of 0.2. These factors and their weights were determined through discussion with the project sponsor. Maximizing the biodiesel yield per acre is essential to minimizing the number of biodiesel acres and in turn the impact on food supplies. The length of the planting and harvesting season measures the time until biodiesel can be produced – a shorter time is more desirable. The hazards associated with biodiesel production all stem from the chemicals and catalysts that are mixed with the vegetable oil. Thus, all of the crop alternatives have the same level of hazard.

### 8.2 Utility Function

The method of analysis includes evaluating the utility of each alternative in comparison to the NPV in order to determine the best crop alternative. It was assumed that each measure had a linear single dimensional value function. After calculating the relative value of each measure for each alternative, the value was multiplied by the weights from the value hierarchy to determine the utility. Figure 26 shows the utility for each crop
alternative plotted against the NPV for 20 acres committed to biodiesel production.

Figure 26. Utility vs Net Present Value

The three data points for each line represent the mean, 10%, and 90% NPV amount. The upper right part of the graph is the most desirable area as it has both a high utility and high NPV.

The results of the utility analysis show that Peanut has the highest utility but also the lowest NPV. Corn has the highest NPV but also the lowest utility and high NPV variability. Soybean and Sunflower both have moderate utility but a negative NPV. Canola has the middle utility but a positive NPV. Table 13 shows the alternatives ranked according to utility.
Peanut, Soybean, and Sunflower all have a negative NPV which makes them infeasible to implement. Corn has a positive NPV but the low biodiesel yield results in a low utility value. In order for Corn to become the best alternative the biodiesel yield would need to increase significantly. If the corn yield increased significantly, Corn could produce more biodiesel and become a more viable option. Canola’s long planting and harvesting season results in a low level of utility. The high biodiesel yield allows the farmer to sell the excess biodiesel for a profit.

Based on the analysis of the financial feasibility of producing biodiesel on small-scale farms in the Fredericksburg, Virginia area, farmers committing 20 acres to biodiesel production utilizing Canola can achieve a positive ROI within 2 years. When utilizing 20 acres of farmland, the Canola NPV distribution has a 99% probability of achieving a positive NPV at the end of 15 years at the 2% discount rate.

Although biodiesel production using Corn is profitable, it does not provide sufficient biodiesel for the average farm’s need and does not meet the minimum net energy ratio requirement. With the existing price for diesel, biodiesel yield per acre, and planting and harvesting expenses, biodiesel production using Peanut, Soybean, or Sunflower is not profitable.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Biodiesel Yield</th>
<th>NER</th>
<th>Season Length</th>
<th>Utility</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut</td>
<td>136</td>
<td>4.09</td>
<td>170</td>
<td>1</td>
<td>-46000</td>
</tr>
<tr>
<td>Sunflower</td>
<td>62</td>
<td>3.05</td>
<td>170</td>
<td>0.68</td>
<td>-24100</td>
</tr>
<tr>
<td>Canola</td>
<td>102</td>
<td>3.43</td>
<td>265</td>
<td>0.55</td>
<td>33700</td>
</tr>
<tr>
<td>Soybean</td>
<td>35</td>
<td>1.77</td>
<td>185</td>
<td>0.52</td>
<td>-35500</td>
</tr>
<tr>
<td>Corn</td>
<td>19</td>
<td>0.84</td>
<td>185</td>
<td>0.45</td>
<td>-40800</td>
</tr>
</tbody>
</table>

TABLE 13
RESULTS WITH UTILITY AND NPV
It is recommended that farmers in the Fredericksburg area of Virginia implement biodiesel production using Canola. Furthermore, by committing additional acres of land to biodiesel production farmers will be able to sell the unused biodiesel for a profit.

9.0 Project Management

9.1 Work Breakdown Structure

The Work Breakdown Structure for our project is a hierarchy of all of the categories we will be spending time on for the entire duration of the project.

![Work Breakdown Structure Diagram]

Figure 23: Work Breakdown Structure

The first step in solving this problem involves extensive research. We have to search for all the current methods of producing biodiesel then look for all the current
technologies which are available to produce biodiesel. Also, researching the operations of the farm is an important part of the project. Then, the government regulations which cover over all of the laws and state incentives must be researched. Finally, all the methods of disposal or reuse of waste materials and end products must be researched.

The next area is general analysis of the project. This includes analyzing the implementation and all the processes; analyzing the cost of the designed process to determine economic feasibility; and analyzing the safety rules.

The most important step of this project is simulationing the system. After gathering all the data and requirements, we need to design a simulation to test all the different ways of farming and producing biodiesel to see all the different scenarios and costs of different options that we have. For an example, which seeds we have to use in order to minimize the cost.

Throughout the project, we will be working on deliverables to submit. First, we will complete the Final Project Plan which includes context analysis, stakeholder analysis, problem and need statements, schedule, and budget. Second, we will submit the Proposal Final Report which covers everything in the Final Project Plan in greater depth and with the design alternatives, simulation design, and design of experiment. Also, this includes the Final Project Report due at the end of the year. Third, we will complete the conference paper, both the draft and final version, which is the same as the proposal final report but more succinct and in IEEE format. Finally, we will create the poster, both draft and final version, which contains the highlights of the important materials.

The final area on our WBS is management, which covers team meetings and project manager planning time.

9.2 Project Schedule

Based on the syllabus for this semester and next semester, we constructed our project schedule in Microsoft Project. Our project started the first week of September and will end at approximately the first week of May.
Figure 24: Project Schedule

In Figure 28 above, the name of each task is on the left, and the resources (i.e. team members) assigned to each task are listed on the right. The duration of each task is seen by comparing the length of the bar to the timeline at the top of the figure. The tasks marked with a “check” on the left side of the figure are those that we had already
completed at the date this picture was taken. The vertical green line marks the present date of the project from when this figure was compiled.

In our schedule, we have several tasks (management and research) that will continue the entire year and are performed by each member of the team. For our purposes, we determined that all team meetings will be charged under management. The remaining major tasks relate to deliverables, presentations, and simulation design/construction.

9.3 Project Risk
We have identified several areas of risk to completing our project on time. The risks and the steps we are taking to mitigate those risks are described in the table below.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail to submit SEIDS IEEE</td>
<td>Version 3 submitted for approval 3/27</td>
</tr>
<tr>
<td>Absent presenter at conference</td>
<td>All group member will become well-versed in all aspects of the project</td>
</tr>
</tbody>
</table>

Table 14: Risks and Mitigations

9.5 Budget and Earned Value
Using Microsoft Project, we assigned an approximate time required to complete each task for each resource assigned to it. Assuming a pay rate of $40 per hour for each team member, who is compatible with the rate for junior engineers, we determined the
cost of each task. Research accrues the highest cost since each team member will be doing research throughout the entire life of the project. Management also has a high cost, since we will have many team meetings during the project. The next most costly tasks are major deliverables such as the Proposal Final Report and large-scale tasks relating to simulation and the Design of Experiment. All told, the direct cost (labor cost) of the project is $129,640. When taking into account overhead and other costs, the total cost of the project goes up to $250,000, at a rate of approximately $84 per hour. This rate was determined using the standard George Mason University rate for researchers. According to this rate, the worker receives approximately 47% of the total amount charged to the customer.

Having established our overall project budget and schedule in Microsoft Project, we calculated earned value indicators based on our weekly timesheets (these values reflect the total project cost, including overhead).

![Earned Value](image)

*Figure 25: Earned Value*

Figure 29 depicts the Planned Value (formerly known as Budgeted Cost of Work Scheduled; BCWS), the Actual Cost (formerly known as the Actual Cost of Work Performed; ACWP), and Earned Value (formerly known as the Budgeted Cost of Work Performed; BCWP). The PV line indicates the estimated costs associated with the project at each month. AC is the actual time spent on the project, and EV is the work.
accomplished. As Figure 30 shows, although our total costs are well under budget, our actual accomplishments are much closer to the expected point.

Also, we determined our Cost Performance Index (CPI) and Schedule Performance Index (SPI).

![CPI and SPI](image)

*Figure 30: CPI vs. SPI*

As described previously, our costs are very low compared to the amount of work accomplished, so our CPI is fairly high at about 1.6. Our SPI is slightly behind at just over 9. However, the trend shows that it is increasing toward 1, showing that we are getting back on track.

**References**


