University of Pennsylvania School of Engineering and Applied Science
Department of Chemical and Biomolecular Engineering
220 South 33rd Street
Philadelphia, PA 19104

Dear Dr. Lee, Professor Vrana, and Mr. Tieri, April 18, 2017

Enclosed you will find a projected design for the coffee to biofuel and biomass pellet facility, specified in the problem statement provided by Mr. Stephen M. Tieri of DuPont. This plant is expected to produce 1.3 million liters/year of coffee biofuel and 2.56 million kg/year of biomass pellets. The spent coffee grounds for this process is sourced from 875 Starbucks and Dunkin Donuts coffee shops in New York City, take via trucks 3-4 times per week. These coffee grounds will not cost anything, as historically the shops give them to customers for free. Overall uptime is taken to be 90%. The spent coffee grounds undergo two separate processes to obtain the desired products. First, the oil is extracted in a decanter centrifuge, converted to free fatty acids and glycerol in a fat splitter and esterified in a bubble reactor to become biodiesel. Second, the solids are removed from the extractor, dried and pelletized to form the biomass pellets.

This report consists of a detailed process design and profitability analysis of the proposed plant. It includes material and energy calculations, equipment cost calculations, and profitability analyses that helped design the overall process of the plant.

Thorough sensitivity analyses were performed to determine plant feasibility based on gas prices, flow rate and a combination of both. Based on the current market value of gas and realistic expectations of coffee collection, total capital investment is $4,028,000 and a weighted average cost of capital of 15% is applied. The NPV of this project in 2017 is -$6.8 million. The IRR is negative and the third-year ROI is -22%. Therefore, given the current biodiesel market and coffee ground accessibility, pursuing this project is not recommended. However, when the biodiesel price is at its 90th percentile over the past 10 years and a capacity of five times as much coffee grounds per year is obtained, matching the total of Bio-Bean, the IRR is 17%, the NPV in 2017 is $0.9 million and third year ROI is 9.5%. If biodiesel price reaches $4 per gallon and the investing company has the ability to access coffee grounds from the equivalent of 4,375 coffee shops, this project may be feasible, just as long as the investing company does not have an alternative investment with a NPV higher than $0.9 million over the next 20 years.

Sincerely,

Chelsea Giller ______________________ Bhavish Malkani _____________________

Josh Parasar _______________________

Coffee to Biofuels

Chelsea Giller | Bhavish Malkani | Josh Parasar |

Project submitted to:	Dr. Daeyeon Lee
	Prof. Bruce Vrana
Project proposed by:	Mr. Stephen Tieri

Department of Chemical and Biomolecular Engineering School of Engineering and Applied Science University of Pennsylvania
April 18, 2016

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Section 1: Abstract

This project proposes a production plant that will utilize 9.58 million kg/year of spent coffee grounds in order to produce 1.03 million liters/year of coffee biofuel and 2.56 million kg/year of biomass pellets. This plant will be located in northern New Jersey, where the maximum amount of spent coffee grounds can be obtained every day from each of the five boroughs in New York City. Practically, trucks could obtain grounds from 875 Starbucks and Dunkin Donuts coffee shops, collected 3-4 times per week. Overall uptime is taken to be 90%. The biodiesel is formed by oil extraction, conversion to free fatty acids and glycerol in a fat splitter and esterification in a bubble reactor. The biomass pellets are formed by drying and pelletizing after removal from the extractor. Thorough sensitivity analyses were performed to determine plant feasibility based on gas prices, flow rate and a combination of both. Based on the current market value of gas and realistic expectations of coffee collection, total capital investment is $4,028,000 and a weighted average cost of capital of 15% is applied. The NPV of this project in 2017 is -$6.8 million. The IRR is negative and the third-year ROI is -22%. Therefore, given the current biodiesel market and coffee ground accessibility, pursuing this project is not recommended. However, when the biodiesel price is at its 90th percentile over the past 10 years and a capacity of five times as much coffee grounds per year is obtained, matching the total of Bio-Bean, the IRR is 17%, the NPV in 2017 is $0.9 million and third year ROI is 9.5%. If biodiesel price reaches $4 per gallon and the investing company has the ability to access coffee grounds from the equivalent of 4,375 coffee shops, this project may be feasible, just as long as the investing company does not have an alternative investment with a NPV higher than $0.9 million over the next 20 years.

Section 2: Introduction and Background Information

2.1 Introduction

Coffee is grown in over 80 countries worldwide and is the second largest commodity traded on the global market. Spent coffee grounds (SCG) are the byproduct of the coffee brewing process and are often discarded and sent to landfills, if not sold as gardening and composting agents. However, since SCG contain large percentages of organic compounds including fatty acids, lignin, cellulose, hemicellulose, and other polysaccharides, there is a lot of opportunity to exploit them as a feedstock for biofuel. In contrast with other feedstocks such as palm, corn and canola oil, coffee has the benefit of having high antioxidant character, making it stable for longer than these alternatives (Campos-Vega). Currently, Bio-Bean, a London-based startup, is exploring this endeavor. Founded in 2013, Bio-bean has committed to delivering a local renewable heat alternative through coffee-derived biofuels and biomass pellets. At this point, neither the biofuel nor the biomass pellet is on the market and they have not published a patent on their extraction process.

The project proposes a coffee production plant to produce biodiesel and biomass pellets from SCG from local coffee shops. SCG has between 15 and 21.5% oil, depending on the mode of extraction. This oil consists of approximately 46.1% palmitic acid, 32.9% linoleic acid, and the remaining 21% equal ratios of oleic acid, stearic acid, arachidic acid, and linolenic acid (Oliveira, 2006). This is comparable to other feedstocks. The remaining portion of the SCG is solid, which turns into the biomass pellets. Thus, this project is split into two production streams, one extracting and converting the oil to biodiesel, the other drying and pelleting the solids into biomass pellets.

The first part of this process is the extraction and solid separation. The SCG arrive in trucks at a moisture percentage of 66%. This wet cake is conveyed through an auger feeder into a hopper and fed into the decanter centrifuge for extraction and solid removal. The extraction solvent used is a 50:50 by mass mix of hexane and isopropanol (IPA) in order to obtain 21.5% oil from the SCG (AIDIC). The oil, solvent and water are then sent to a flash vessel where the oil and water is separated from the hexane and IPA at 85°C. The solvent gets recycled with a 0.7% purge stream to remove any impurities in the stream. The oil-water stream is decanted and sent to a fat splitter, where these reactants are turned into free fatty acids (FFA) and glycerol. Lastly, the FFA are sent through an esterification bubble reactor with a $SiO_2 \cdot HF$ (silicon dioxide coated with hydrofluoric acid molecules) catalyst and methanol in order to make the final biodiesel product. This stream is recycled back to the reactor to eventually get a 99.5% yield. On the other hand, the solids are dried using a rotary dryer with a nitrogen stream and pelletized into biomass pellets.

Based on market analysis and a high concentration of coffee shops, New York City is the target city for sourcing the most SCG. In order to build the plant in the most cost effective location, 1.55 acres of land (5 times the size of the facility) will be purchased in Bergen County, New Jersey, which is less than 25 miles outside the city. In examining the truck and employee requirement, it would be reasonable to collect SCG from 875 Starbucks and Dunkin Donuts shops in New York City, resulting in an input flow of 1215.3 kg/hour, operating at 90% up time (Observer). This eventually results in a biodiesel flow of 130 kg/hr and biomass pellet of 324.2 kg/hr.

2.2 Objective Time Chart

Project Name	Coffee To Biofuels
Project Advisors	Stephen M. Tieri, Dr. Daeyeon Lee, Professor Bruce Vrana
Project Leaders	Chelsea Giller, Bhavish Malkani, Josh Parasar
Specific Goals	Design a commercial coffee-to-biofuel plant to convert spent coffee grounds (SCG) to liquid biofuel and solid biomass pellets while evaluating its financial viability
Project Scope	*In-Scope* 1. Design manufacturing process for biofuel and biomass pellets from spent coffee grounds. 2. Determine plant location based on ease and volume of SCG transport. 3. Analyze profitability given reasonable estimates of coffee supply and fuel costs. 4. Obtain final product whose energy and cost is comparable to existing biofuels and alternative fuel sources. 5. Maintain process integrity by following good manufacturing practices, maximizing materials recycling and being environmentally friendly. *Out-of-Scope* 1. Utilize process for other waste products with significant oil content. 2. Increase the overall volume of biofuel in the world market.
Deliverables	Calculate and Create: 1. Mass and energy balances of the process 2. Equipment specifications, sizes and costs 3. Detailed flow sheet diagrams 4. Economics and profitability Assess: 1. Technical, manufacturing and economic feasibility 2. Sensitivity to certain factors, such as fuel price and flow rate 3. Practical likelihood of success in the fuel market
Timeline	Complete design and economic analysis by April 18, 2017.

Section 3: Market Landscape

3.1 Market Analysis

<u>Coffee Market</u>

In the United States, about 50% of Americans over the age of 18 drink coffee every day, resulting in 150 million coffee drinkers. And these coffee drinkers have about 3.2 cups of coffee per day. Both men and women drink coffee at almost equal rates, resulting in 400 million cups of coffee per day nationwide. Over time, the variety in type of coffee consumed has grown with the introduction of lattes, cappuccinos, and other specialty drinks. Even as the cost of coffee has risen, consumption has continued to rise. While countries such as Finland, Sweden, Switzerland, Germany, France, Italy and Brazil all rank higher than the United States in kg of coffee consumption per person, more cups of coffee are bought in the United States than anywhere in the world.

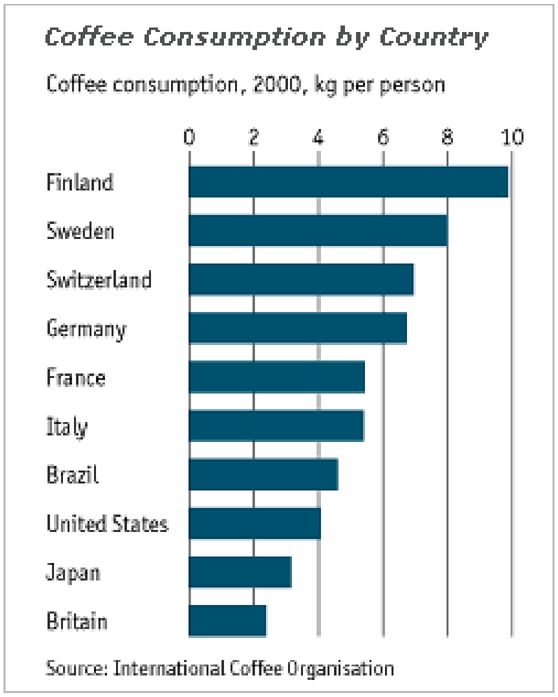


Figure 3.1: Coffee Consumption by Country in 2000. Source: http://www.e-importz.com/coffee-statistics.php

Within the United States, the cities with the most coffee shops per capita are Seattle, New York City and San Francisco. However, due to population size, New York City objectively has the most coffee shops. There are about 875 Starbucks and Dunkin Donuts locations alone.

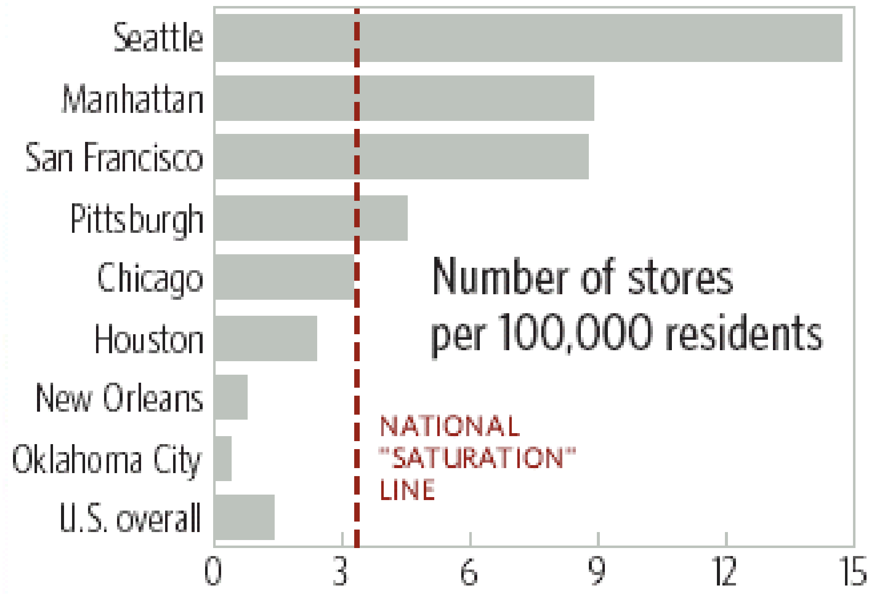


Figure 3.2: Coffee Shops Nationwide, Source: http://www.e-importz.com/coffee-statistics.php

Even though there is a lot of coffee being brewed in America, spent coffee grounds do not have a major use within our society. Currently, they act as compost for gardens. Many companies (such as Starbucks) often hand them out to customers for free to use as compost. They are even working to convert the grounds into laundry detergents, bioplastics and other products (Rolph). According to their recent recycling initiatives, the government and social pressure is pushing them to do whatever they can to limit the amount of grounds being sent to landfills.

Biodiesel Market

The first aspect that is important in understanding the future of biodiesel is to contextualize it in terms of fuel use in the United States. Currently, only about 5% of fuel use is biomass, which includes wood and liquid biofuels like ethanol and biodiesel. This statistic is not projected to increase much over the next couple of decades. In contrast, energy sources such as wind and solar are the fastest growing alternative energy sources ("Fossil Fuels"). Then, within the biomass sector, ethanol is produced and consumed at rates of about 10 times that of biodiesel. This is contrary to the reality that biodiesel's energy production:consumption ratio is higher than ethanol's and it emits significantly less greenhouse gases compared to conventional gasoline (Bullis). This contradiction is likely due to the difficulty in acquiring and converting the biofuel feedstock, along with potential ecological concerns with using crops (sugarcane and oil palms) for biofuel. However, there is a lot of opportunity to try new feedstocks and see if there would be fewer consequences (Today in Energy, eia).

For the past several years, the majority of U.S. biofuel production has been derived from Soybean, fluctuating between 40-50% of total feedstock. Oils such as canola, corn, and palm, as well as animal fats are used in small percentages. Still, according to Figure 3.3, there is a very small "other recycled feeds" category at less than 5%. Clearly, there is an openness and desire to recycle otherwise unusable byproducts for an environmental and economic purpose, leaving a lot of room for growth in this sector.

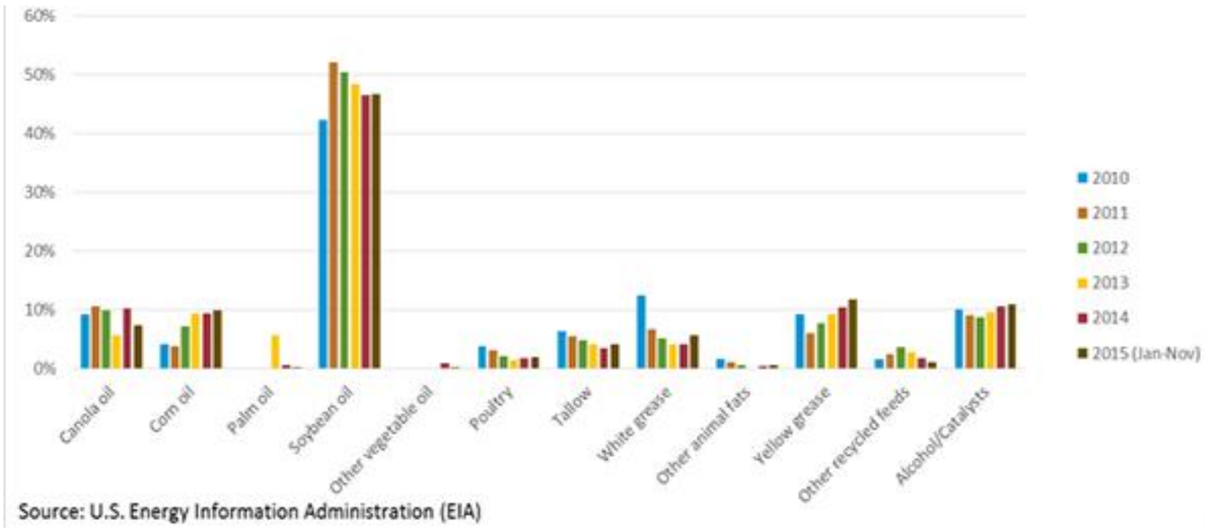


Figure 3.3: U.S. Feedstock Inputs Usage (%) in Biodiesel Production 2010-2015

In terms of scale, while there is a lot of coffee being produced, the volume to be converted to biodiesel is less substantial. There are approximately 20 g of dry spent coffee grounds in each cup of brewed coffee. So, assuming the 875 Starbucks and Dunkin Donuts locations in New York City, with 20 g per cup, 10 kilograms of waste per shop per day (Waste Management World) and 365 days per year, the flow of dry spent coffee grounds would be 3,194,000 kg/year. However, the grounds are supplied with 66% moisture, so the total wet spent coffee ground flow is 9,581,000 kg/year or 1,215 kg/hour at 90% up time. Based on the material and energy balances to follow, this would result in a biofuel production of 130 kg/hour and biomass pellet production of 324.2 kg/hour. With only small increases in coffee consumption annually, this flow would not be expected to increase dramatically without introducing more shops.

Regardless of scale, there is a lot of opportunity in both the biodiesel and biomass pellet markets if both products prove viable sources of energy. In terms of biodiesel, the U.S. market saw a 272% increase from 2010-2014, from 343 million gallons in 2010 to 1.278 billion gallons in 2014. In fact, production is expected to be at 4 billion gallons by 2022. However, it is important to clarify that the United States has been trending away from the exportation of biodiesel that it did from 2007-2012 and is now importing more than it exports (Agricultural Marketing Resource Center).

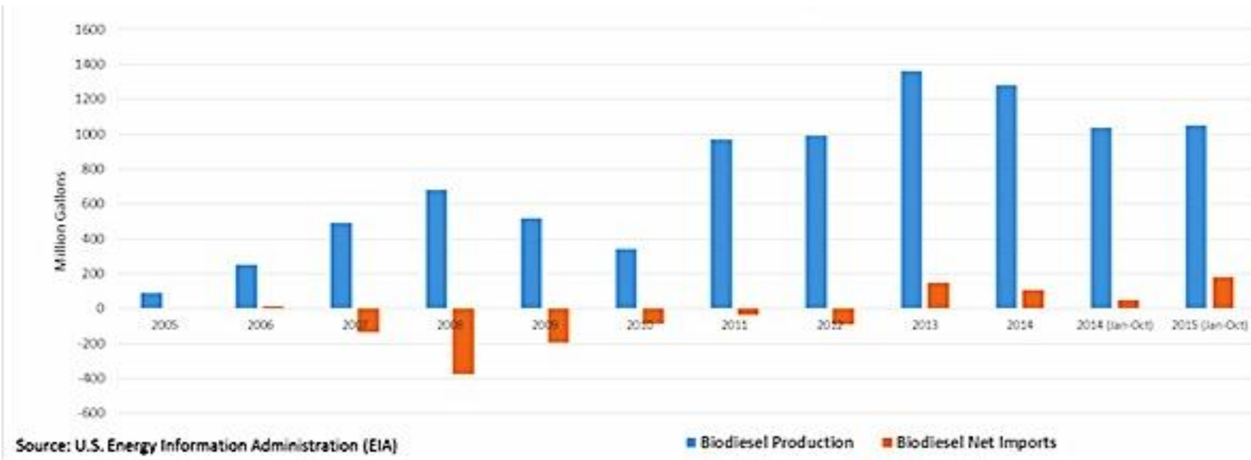


Figure 3.4: U.S. Biodiesel Production and Net Imports 2005-2015 (Million Gallons)

This is a result of the enactment of biodiesel tax credits into the economy. In order to capture these credits and other renewable energy credits, increasing homegrown biodiesel production is a potentially financially beneficial endeavor. In fact, in New York (where potential customers are located), the Refundable Clean Heating Fuel Tax Credit has created an incentive for residents to use biodiesel. According to this system, if 1-20% of your household heating oils is biofuel, you can receive a rebate of 1-20 cents per gallon through 2020 (U.S. Department of Energy). These sorts of incentives have had direct impacts on increased levels of production and the industry’s overall profits. That being said, there is still ongoing debate on the impact of having biodiesel tax credits apply to both local and international (largely Argentinian) fuel, as this could hurt US production (Energy.gov).

Biomass Pellet Market

Typically derived from woody plants, timber, sawdust, sugarcane, and grass, biomass pellets are often used as heating fuels in homes and factories. Production of biomass pellets is increasing rapidly as the demand for renewable energy sources in the power industry become more prominent. Additionally, government initiatives and strict environmental regulations are crucial drivers promoting the growth of the global biomass pellet market (Businesswire, Global Biomass Pellet Market). The global biomass pellet market was valued at about $7 billion in 2014, and it is expected to grow with a CAGR of 11.1% between 2015 and 2020. With 20 billion tons of pellets consumed in 2014, Europe accounted for the largest share of the global market. North America held the second highest share in terms of value and volume. This extreme growth was the result of low greenhouse gas emissions from the pellets, as well as increased government initiatives for renewable technologies ("Biomass Pellet Market"). In 2016 and 2017, biomass pellets are expected to be exported at rates of 21 billion annually, making it a top 10 U.S. export ("Biomass Wood Pellets"). All of these reasons point to the huge opportunity in selling the coffee biomass pellets produced in this plant.

3.2 Competitive Analysis

Currently, the main competitor in producing coffee biofuel is Bio-bean. At its current scale, it claims to be processing 50,000 tonnes of coffee per year, which accounts for one-tenth of the coffee consumed in the UK. Bio-bean gets the grounds from coffee shops, retailers, airports and coffee factories. However, this expressed flow seems unimaginably high, as it is 50 times higher than the flow rate based on 875 shops in New York.

Production levels:

In August 2016, Bio-bean ran a *Crowdfunder* campaign that raised £58,510 in 2 months for pre orders on their "Coffee Logs," which are biomass briquettes that can be used instead of dirty wood and coal. They claim that they "burn hotter and longer, ignite quickly, and are more sustainable, cost-effective." *Crowfunder* has pushed Bio-bean into the old charcoal market, hoping to sell briquettes to supermarkets, garden centres and gas stations. At this time, there does not appear to be coffee biofuel on the market (Crowdfunder).

As expressed in the market analysis section, the main competitors for coffee biodiesel are the huge variety of other biodiesel feedstock, as well as ethanol and faster growing renewable energy sources such as wind and solar. Amongst other biodiesel feedstocks, the oil content is at a comparable or higher percentage than coffee, with palm oil at 20%, soybean oil at 20% and rapeseed oil at 37-50%. However, using spent coffee grounds does not have the same ecological impact on rainforests as these alternatives. Additionally, spent coffee grounds should be stable for about a month before spoiling. This makes coffee more stable than its counterparts and has a higher antioxidant content. Lastly, in production, coffee has a much more pleasant smell than animal fats or some of the oils mentioned above. If the 16.34 billion points of coffee produced per year are converted, around 340 million gallons of biodiesel could be added to the world's supply (Journal of Agricultural and Food Chemistry).

The main competitors for coffee biomass pellets are wood pellets, which are easy to pelletize, have a high energy content and exist in much higher volumes than coffee. Still, the exploding market leaves room for more entrants with comparable energy content and low cost.

3.3 Customer Requirements

Our customers are people or oil companies that want to use oil in an eco-friendly way. Companies like UPS and Fed-Ex run their vehicles on up to 30% biodiesel and are hoping to continue to improve on their fuel efficiency and sustainability. There is also a large opportunity to find customers in the airline industry, as they are also looking to rely more on alternative energies. Given the scope of the biofuel market, huge profits are not expected, but there is an opportunity to prove that small flows of spent coffee grounds can be converted to viable biofuel and biomass pellets to be sold at rates comparable to existing competitors (Loiseau).

3.4 Preliminary Process Synthesis

Different decision pathways were evaluated in the design of this process. These decisions were made on the basis of obtaining the highest possible coffee flow, lowering energy costs, maximizing extraction percentages, minimizing the size and number of equipment. As the development of the process flow developed, the low potential profit margins and flow rate were the main drivers in picking the most efficient technology.

Sourcing the Spent Coffee Grounds

The first step for the process was figuring out the location and the sourcing for where the coffee grounds would come from. The question of location became essential in assuring a sustainable SCG flow rate to the facility. Based on the cities with the most coffee consumption and concentrated coffee shops, New York City became the best option. Number of trucks, employees, hourly rates and expected output were all considered in making this decision. Using the initial estimates from Bio-Bean and assuming the coffee consumption in New York City was similar to that of coffee consumption in London, the initial goal was to produce 40 million liters of biodiesel product a year. In order to produce that much diesel, there would need to be an equivalent of ~65,000 coffee shops from which the coffee can be sourced. Since it would be unreasonable to assume that every coffee shop in New York City would be willing to donate their coffee waste, the goal was changed to reflect the amount of biodiesel produced from targeting specifically Dunkin' Donuts and Starbucks shops in New York City. Starbucks currently gives its grounds away to patrons for free for use in their gardens, as it helps to reduce waste and can be utilized as a fertilizer. Dunkin' Donuts has started environmentally friendly initiatives as well, such as by starting a green building initiative in 2014 which helps franchisees open energy efficient restaurants. By partnering with these companies, a reasonable amount of coffee grounds can be sourced, and collection logistics can be set up between the corporation and the plant to make it as efficient as possible. Though the coffee grounds are being donated to us for free, there is a cost in the fuel, trucks, and workers who would be collecting the grounds from these partners. The costs were factored into our economic calculations to see whether this would be a sustainable method of sourcing spent coffee grounds

Extraction

The extraction process is the first phase of creating biodiesel. The first decision for this operation was to select an extraction solvent. Based on the initial prediction of having a low overall flow rate of SCGs, it became important to maximize the oil extracted from those grounds. Typically, coffee oil extraction utilized hexane as solvent, resulting in about 15% oil from grounds with 12% moisture. Many different options were considered, including heptane, ethanol, and isopropanol. It was seen through prior research that, when introducing isopropanol into the solvent mixture at a 50:50 ratio, the extraction percentage rose to 21.5% (AIDIC). This significant increase is due to the fact that there are polar and nonpolar triglycerides in the oil, so having both a polar and nonpolar solvent would help isolate all of that oil. A potential issue that arose was the separation of the solvents from the water due to an azeotrope between the three compounds. Using Aspen Plus v.9.0, a ternary residual curve diagram was created at the pressure of the flash vessel doing the separation. The molar fractions of each compound were calculated to be 25 mol% water, 31 mol% hexane, and 44 mol% isopropyl alcohol. Using the ternary diagram, it was seen that the mixture does not need to cross the azeotrope in order to get a split between the solvents and the water. There were concerns that the IPA would have trouble separating from the water due to their miscibility, but these were alleviated by conversations with the industrial consultants.

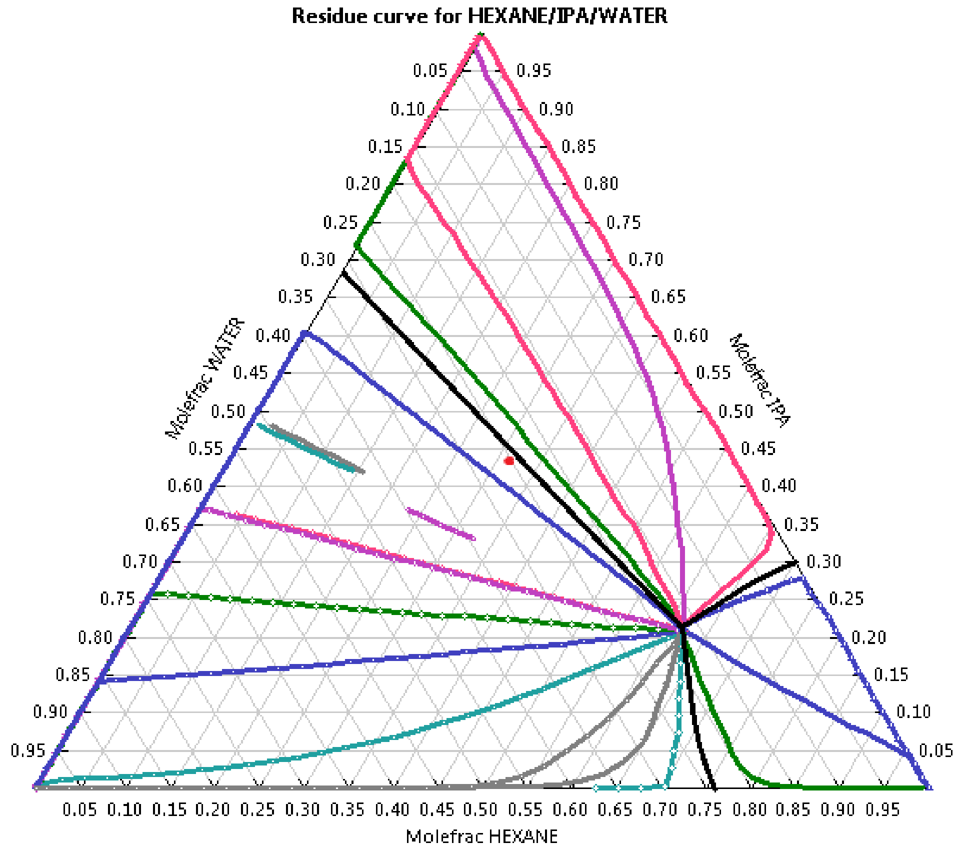


Figure 3.5: Ternary Diagram of Hexane/Water/ Isopropyl Alcohol. The black lines represent the azeotropic residual curves, and the red dot is the mole fraction of the water/solvent mix. This confirms that separation of hexane and IPA are able to be separated from water without the need for more specialized equipment.

Another important decision became whether or not the SCGs should be dried before entering the extraction vessel. Straight from coffee shops, the grounds are 66% moisture, which makes the mixture act like a wet cake. Drying the grounds would likely make for an easier transfer, smaller equipment due to less volumetric flow, and lower flash vessel energy costs, but calculations of the energy and time requirement of the initial drying step proved too costly. Additionally, the added water is beneficial in operating the fat splitter. With this excess of water, makeup and recycle streams are not necessary at any point of the process. For the extractor, it became important to use a decanter centrifuge to separate the solids and extract the oil in a singular piece of equipment.

Transesterification Versus Esterification

Another question that was considered was whether or not the oil was purified into triglycerides or not. Since the flow rates are fairly small compared to an average plant, it became costly to have to separate unwanted free fatty acids from the raw oil from the coffee grounds. It was decided that in order to maximize product production, the oil would go through a fat splitter to produce free fatty acids, and then be esterified into biodiesel. The fat splitter is a unit operation that breaks apart the triglyceride molecules into their constituent free fatty acids and glycerol. The reason for this is that it allows the total amount of free fatty acids to be converted into biodiesel, rather than just the triglycerides. Additionally, the fat splitter made it easy to use the extra water, produce sellable glycerol and set up an esterification reaction in a bubble reactor. Temperatures and pressures were selected to minimize the necessary pumps and heat exchangers. Based on the size of the facility and equipment, power will be supplied primarily as electricity.

Biomass Pelleting

Initially, there was some uncertainty into the viability of the coffee biomass pellets as sellable fuel. However, after researching the industry and seeing Bio-Bean's success in selling their briquettes, it became clear that there was real economic value in selling the pellets. Also, the plant has an overall positive energy output-input, so it would not be necessary for this plant to burn it as fuel instead of selling it.

3.5: Assembly of Database

The specific heats in gas and liquid phases, the boiling points, the molecular weight, and the prices for each of the compounds were found as the main thermophysical properties of the compounds used in this process. The property values for Hexane, Isopropanol, Water, Glycerol, and Methanol were found directly from or interpolated from data given by the PubChem Open Chemistry Database through the National Institute of Health. The specific heat value for the free fatty acids was estimated to be 2.3 kJ/(kg C) based off of other vegetable-based oils with similar component breakdowns. The price for Biodiesel was found from the United States Department of Energy as the current price for Biodiesel (B20) as of March 2017. This is shown below in Table 3.1.

Table 3.1: Thermodynamic and Thermophysical Properties and costs for various components

Component	$C_{p,l}$ (Kj/(Kg* C))	$C_{p,g}$ (Kj/(Kg* C))	Boiling Point (C)	Molecular Weight (g/mol)	Price	ΔH_{vap} (kJ/kg)	Density, Liquid (kg/m^3)	Density, Vapor (kg/m^3)
Water	4.18	N/A	100	18.02	$0.0015/gal	2257	1000	0.804
Hexane	2.26	1.88	68	86.2	$1.5/gal	335.3	655	3.64
Isopropanol	2.68	1.71	82.6	60.1	$1.5/gal	664	786	2.54
Glycerol	2.49	N/A	290	92.09	$0.01/kg	N/A	1260	12.85
Methanol	N/A	N/A	64.7	32.04	$0.442/kg	N/A	792	N/A
Linoleic Acid	2.3	N/A	230	280.45	N/A	N/A	880	N/A
Palmitic Acid			351	256.42	N/A	N/A		
Oleic Acid			360	282.46	N/A	N/A		
Linolenic Acid			231	278.43	N/A	N/A		
Biodiesel	N/A	N/A	N/A	N/A	$2.54/gal	N/A	880	N/A

Section 4: Process Descriptions, Flow Diagrams, and Material Balances

4.1: Overall Process

The overall process is described in 4 main parts: importing coffee grounds and extraction (red), pellet production (blue), free fatty acid creation (green), and esterification (yellow). The process starts with an input of coffee grounds to the plant. The coffee grounds are dropped off by collecting trucks, and are conveyed into an extraction unit, along with a 50/50 mix of isopropyl alcohol and hexane. The extraction separates the triglycerides and free fatty acids from the used coffee grounds. The coffee grounds then go to a dryer (E2) to remove any left over water and solvent, and are then sent to a pelletizer (E3) to be compressed into biomass pellets. The solvent-water-oil mix is sent to a flash vessel (E4) to recover the solvent. The flash vessel vaporizes the solvent, which is then condensed and pumped back to the extractor (E1). The remaining water-oil mix is sent to a decanter (E6) to be separated. The separated streams are heated and sent to the fat splitter (E7), which converts the triglycerides to free fatty acids, with a byproduct of glycerol and water as shown in Figure 4.0. The free fatty acids are then sent to a reactor(E8), in which they are reacted with methanol to form biodiesel. This stream is recycled (S19) in order to bring conversion to 99.5% biodiesel, which is then exported for sale.

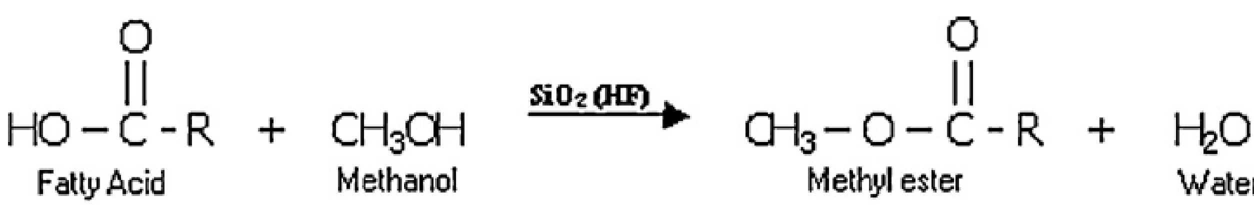


Figure 4.0: Chemical Equation for the Esterification of free fatty acids to methyl esters

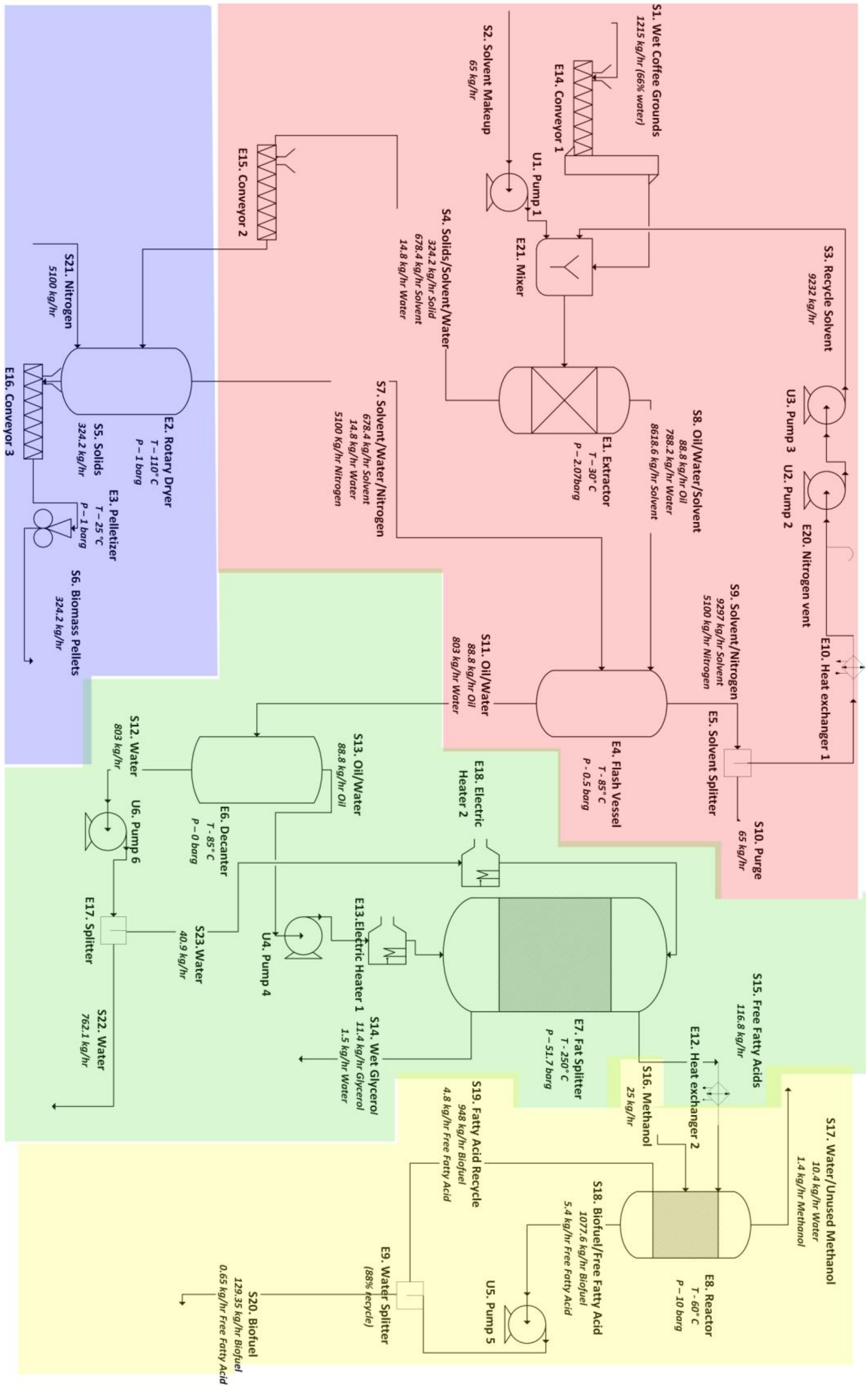


Figure 4.1: Overall Process Flow Diagram

4.2: Extraction Phase (Red Section)

Importing coffee grounds

The coffee grounds will be source from a total of 875 Starbucks and Dunkin' Donuts stores in New York City. There are a total of 8 trucks that will collect coffee grounds from 438 stores per day, meaning that coffee will be picked up from each store every alternating day. Each truck will collect approximately 20 kg of coffee grounds from each store. The trucks will deposit the coffee grounds directly into a 100 m^3 stainless steel tank, which will be connected to a conveyor system. This conveyor system is a bucket elevator system that will lift the coffee grounds from the storage tank into the extractor.

Extraction

The coffee grounds are inputted at a rate of 1215 kg/hr into a decanter centrifuge unit for the extraction process (S1). Entered along with the coffee grounds is a 9297 kg/hr mix of 50/50 mass ratio hexane/isopropanol (S2, S3), which is used to extract the coffee oils. The mixture is extracted over a residence time of 30 minutes in the mixing vessel (E21) and inputted into a decanter Centrifuge Extractor (E1) at a temperature of 30 °C and a pressure of 2.07 barg to be separated. The solids are sent to a pelletizer via a conveyor for biomass production (S4). The solvent-water-oil mixture is then piped out to a flash vessel for solvent recovery (S8). The solids have solvent absorbed in the grounds, so this gets evaporated from the grounds in the pelletizing step and sent to the flash vessel as a vapor (S7). The flash vessel operates at a temperature of 85 °C and 0.5 bar, gauge. The solvent-water-oil mix is inputted into the flash at 30 °C. The vessel will be electrically heated in order to make the mixture of the oils, eater and solvent get to 85 °C and phase separate. The solvents are evaporated (S9) and a purge is used to help remove any potential impurities from the gas stream (S10). This solvent will then be compressed, recycled, and sent back to the extraction unit for the next set of coffee grounds (S3).

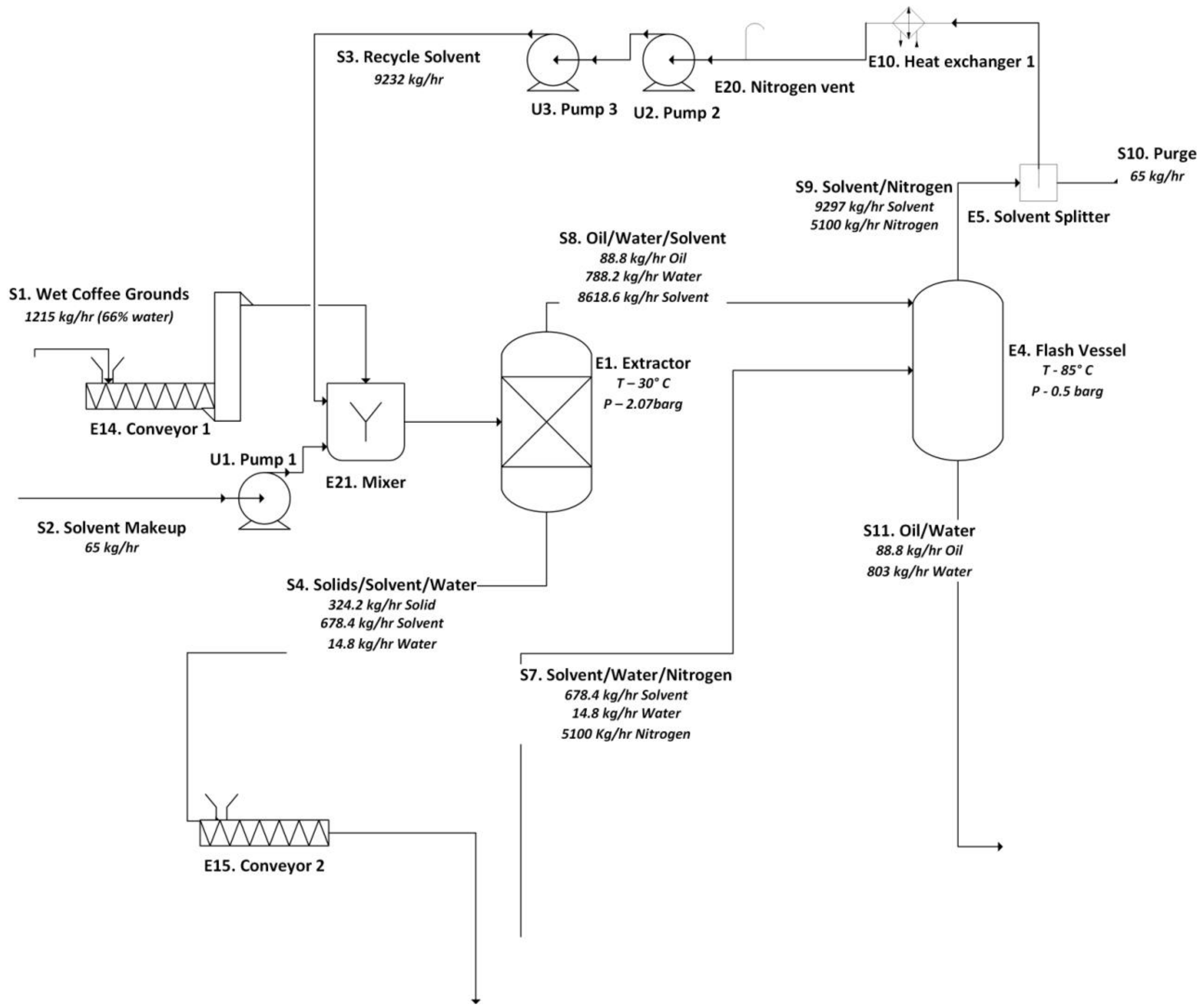


Figure 4.2: Process Flow Diagram for the Extraction Phase

Table 4.1: Mass Balance sheet for the Extraction Streams. These Streams correspond to the Streams in the overall Process flow Diagram (Figure 4.1) and the Extraction Phase Process Flow Diagram (Figure 4.2)

Stream ID	S1	S2	S3	S4	S7	S8	S9	S10	S11
Temperature (°C)	30	30	30	30	110	30	85	85	85
Pressure (barg)	0	2.07	2.07	0	1	2.07	0.5	0.5	0.5
Total Mass Flow (kg/hr)	1215	65	9232	1017.4	693.2	9495.6	9297	65	891.8
Component Flows									
Wet Coffee grounds	1215	0	0	0	0	0	0	0	0
Dried Coffee Grounds	0	0	0	0	0	0	0	0	0
Coffee Solids	0	0	0	324.2	0	0	0	0	0
Coffee Oil	0	0	0	0	0	88.8	0	0	88.8
Water	0	0	0	14.8	14.8	788.2	0	0	803
Hexane	0	32.5	4616	339.2	339.2	4309.3	4648.5	32.5	0
Isopropanol	0	32.5	4616	339.2	339.2	4309.3	4648.5	32.5	0
Nitrogen	0	0	0	0	5100	0	5100	0	0

4.3 Biomass Pelleting Phase (Blue Section)

The coffee grounds from the extractor (S4) are conveyed to a rotary dryer (E15) to remove any absorbed water or solvent. The wet cake solids are at approximately 66% moisture content of solvents and water. The drier will help reduce this amount down to about 5% for pelletizing. The rotary dryer is operated at a temperature of 110 °C and a pressure of 1 barg. Because the solvents are flammable, a stream of nitrogen (S21) is introduced as a carrier gas at 5100 kg/hr, and any water and solvent remaining is evaporated and sent to the flash vessel (S7) to be separated along with the other stream of solvent and oil. The solids are dried to reduce the moisture content to about 5%, so that they can be pelleted properly into the biomass pellets. The dry solids (S5) are sent to the pelletizer by a conveyor(E16). The pelletizer compresses the grounds into biomass pellets, which are then taken to be sold as a burning fuel source(S6). Sold biomass pellets will be transported monthly to a shipping location to be mailed to customers.

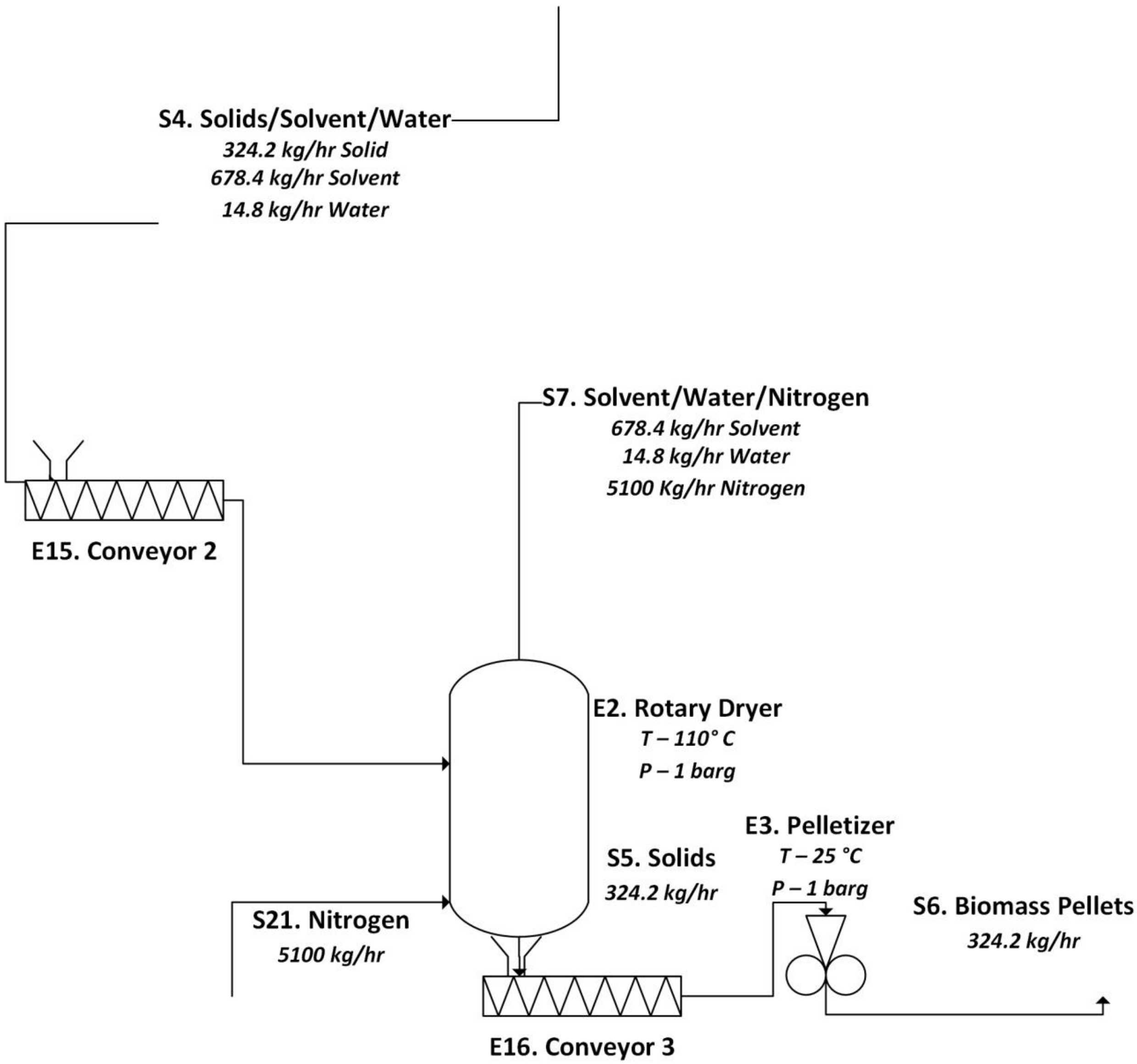


Figure 4.3: Process Flow Diagram for the Biomass Pelleting Phase

Table 4.2: Mass Balance Sheet for the Pelleting Phase. The streams in this table correspond to the streams in the overall Process Flow Diagram (Figure 4.1) and the Pelleting Process Flow Diagram (Figure 4.3)

Stream ID	S4	S5	S6	S7	S21
Temperature (°C)	30	110	25	110	30
Pressure (barg)	0	1	1	1	0
Total Mass Flow (kg/hr)	1017.4	324.2	324.2	693.2	5100
Component Flows					
Wet Coffee grounds	0	0	0	0	0
Dried Coffee Grounds	0	324.2	324.2	0	0
Coffee Solids	324.2	0	0	0	0
Coffee Oil	0	0	0	0	0
Water	14.8	0	0	14.8	0
Hexane	339.2	0	0	339.2	0
Nitrogen	0	0	0	5100	5100
Isopropanol	339.2	0	0	339.2	0

4.4 Free Fatty Acid Production (Green Section)

In order to optimize the production of biodiesel, the process converts the triglycerides in the coffee oil into free fatty acids, so that the free fatty acids already present in the oil can be utilized as well. The coffee oils, after being separated from the water, are heated to 250 °C and fed into the bottom of the fat splitter unit (S13). The water stream (S12) is pressurized and then split into two streams. One stream will be fed to the fat splitter (S23) at a rate of 45% the rate of the oils by mass, while the other splits off as a waste stream (S22) (Mills). The stream fed to the fat splitter is heated to 250 °C. A reaction occurs between the water and the triglycerides, converting them into free fatty acids with a by-product of glycerol. The free fatty acids created are then sent into the reactor to be converted into biodiesel (S15). The glycerol byproduct is removed along with excess water (S14), and will be sold to another company that will purify it for their own uses. The glycerol produced is approximately 88% by mass glycerol, and approximately 110,000 kg are produced annually. Using estimates from Alibaba, glycerol is priced at approximately $0.01/kg, so about $1000 will be made annually by selling this byproduct.

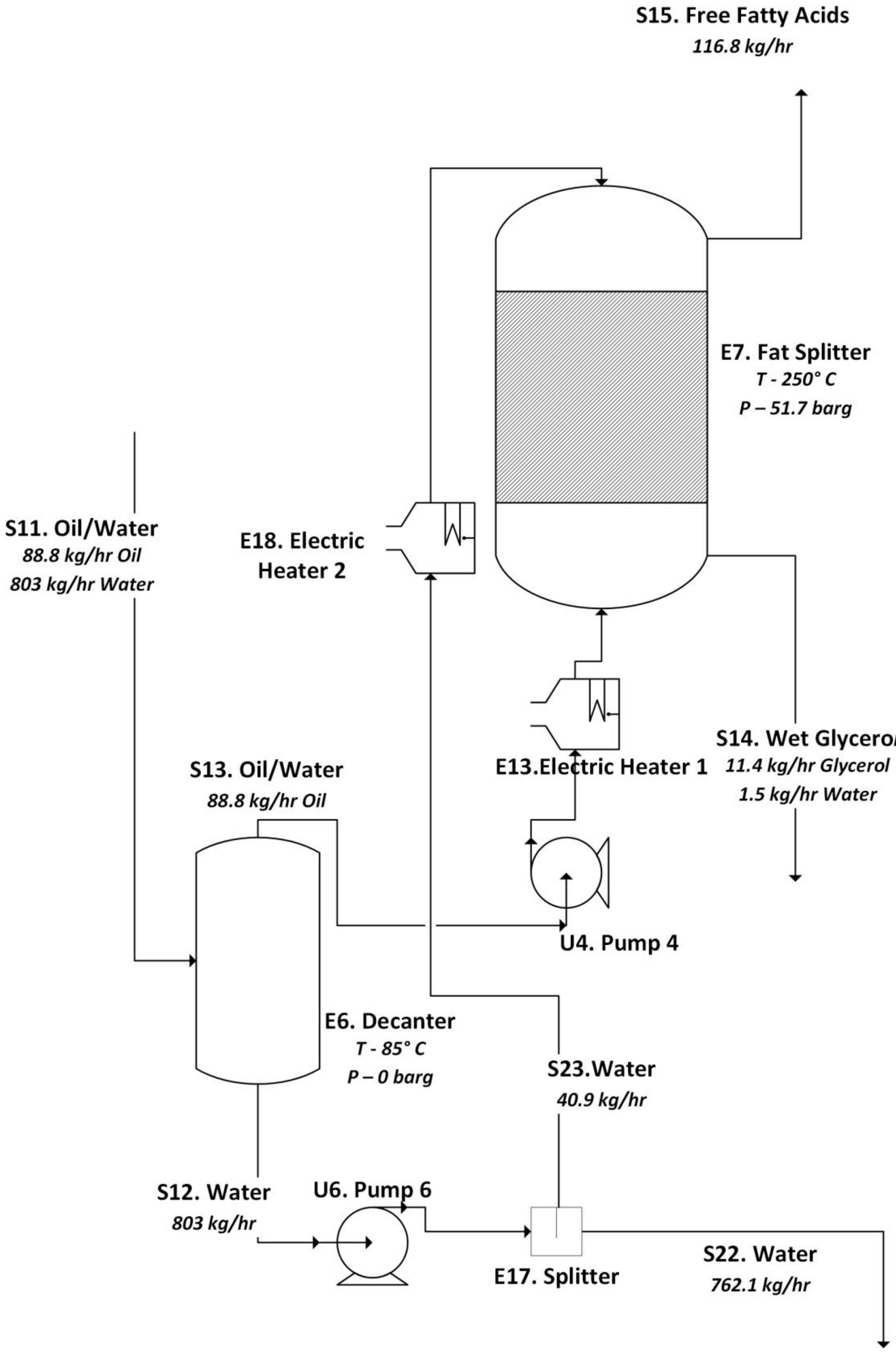


Figure 4.4: Process Flow Diagram for the Free Fatty Acid Production Phase

Table 4.3: Mass Balance Sheet for the Free Fatty Acid Production Phase. The streams in this table correspond to the streams in the overall Process Flow Diagram (Figure 41) and the streams in the Free Fatty Acid Production flow diagram (Figure 4.4).

Stream ID	S11	S12	S13	S14	S15	S22	S23
Temperature (°C)	85	85	250	250	250	85	250
Pressure (barg)	0.5	50	50	1	0	50	50
Total Mass Flow (kg/hr)	891.8	803	88.8	12.9	116.8	762.1	40.9
Component Flows							
Coffee Oil	88.8	0	88.8	0	0	0	0
Water	803	803	0	1.5	0	762.1	40.9
Free Fatty Acids	0	0	0	0	116.8	0	0
Glycerol	0	0	0	11.4	0	0	0

4.5: Biodiesel Production (Yellow Section)

The stream from the fat splitter is not composed almost entirely of free fatty acids, with a negligible amount of other compounds. The stream (S15) is cooled down via a cooling water heat exchanger to 60 °C. A stream of methanol is pumped through as well (S16), with the reactor being packed with a heterogeneous catalyst of $SiO_2 \cdot HF$ beads. The methanol - Free Fatty Acid reaction with that specific catalyst produces a theoretical conversion of 95%. At this point, the Biodiesel is not suitable for use since there is still a large quantity (>0.6%) of free fatty acids left in the product. Separating the free fatty acids would not be cost effective, so a recycle stream was implemented to increase the conversion percentage. The product goes to a recycle stream (S18, S19) of 88%, which brings that conversion rate up to 99.5% conversion of free fatty acids to biodiesel. The biodiesel is then collected as the final product (S20), and the unused methanol and water byproducts are released as waste (S17). Sold biodiesel will be transported monthly to a shipping location to be mailed to customers.

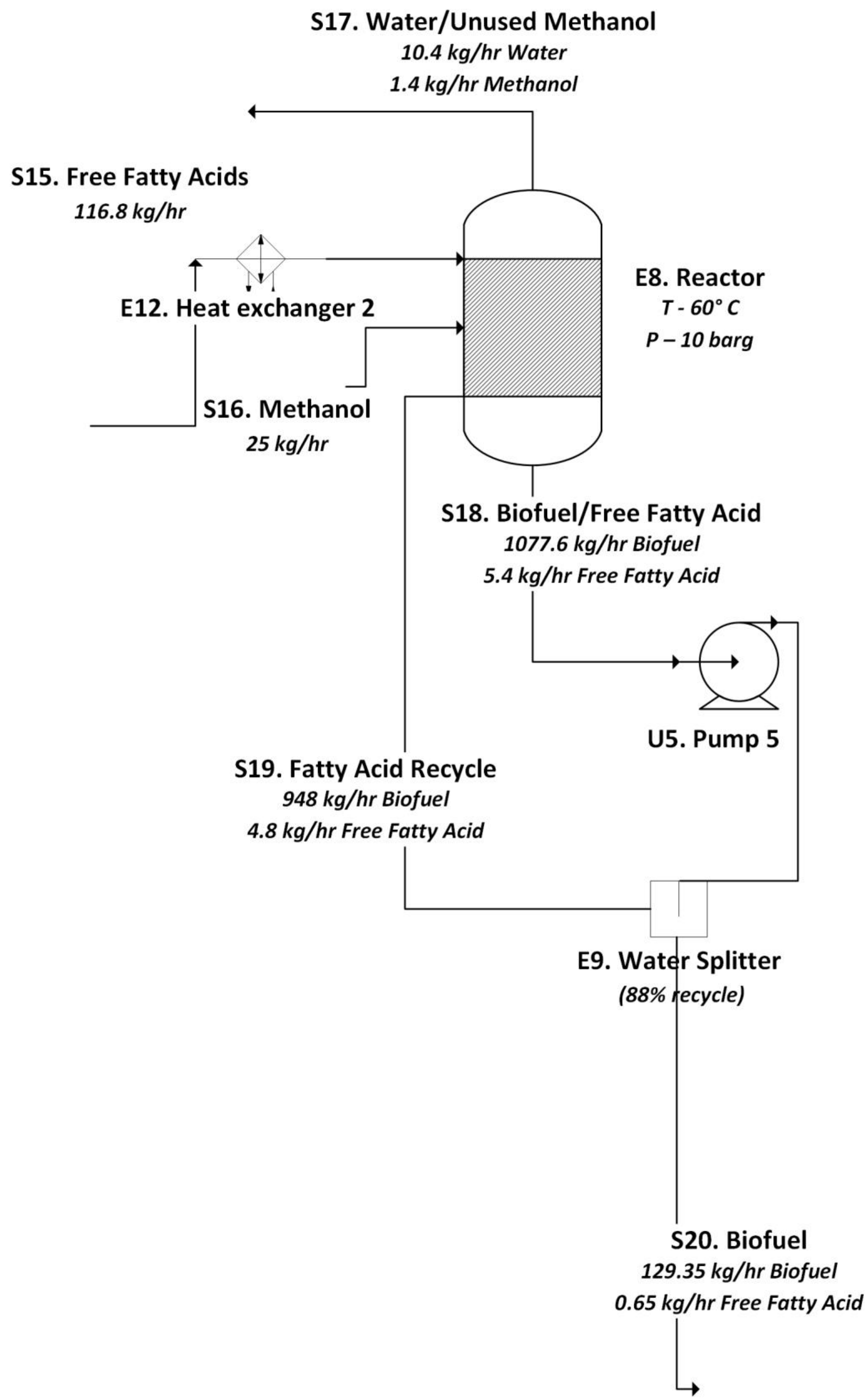


Figure 4.5: Biodiesel Production Process Flow Diagram

Table 4.4: Mass Balance Sheet for Biodiesel Production. The streams in this table correspond to the streams in the overall process flow diagram (Figure 4.1) and the Biodiesel production process flow diagram (Figure 4.5).

Stream ID	S15	S16	S17	S18	S19	S20
Temperature (°C)	60	60	60	60	60	60
Pressure (barg)	2.07	2.07	2.07	2.07	2.07	2.07
Total Mass Flow (kg/hr)	116.8	25	11.8	1083	952.8	130
Component Flows						
Water	0	0	10.4	0	0	0
Methanol	0	25	1.4	0	0	0
Free Fatty Acids	116.8	0	0	5.4	4.8	0.35
Biodiesel	0	0	0	1077.6	948	129.65

Section 5: Energy Balance and Utility Requirements

5.1 Energy Balances

The following energy balances utilize equations 5.1 and 5.2 in order to determine the energy associated with the temperature changes of various streams (Appendix A). All of these calculations were performed in Microsoft Excel due to the difficulty in implementing solids into ASPEN. Electricity provides the utility for the streams to the rotary dryer, flash and fat splitter. Cold water is the utility source for the stream to the reactor and chilled water is the utility source for the solvent recycle stream. These numbers are used to calculate total utility requirement.

Rotary Dryer (E2):
Inlet temperature = 30°C, Operates at 110°C, 1 bar, gauge

Material	Mass Flow (kg/hr)	Specific Heats (kJ/kg °C)	BP, °C	Hv (kJ/kg)	Energy (kJ/hr)
Solids	324.2	1.672	High	0	43,365
Water	14.8	4.18	100	2257	37,734
Hexane	339	2.26	68	365	152,937
IPA	339	2.68	82.6	732.2	296,176
				TOTAL (kJ/hr)	**530,212**
				TOTAL (kWh/yr)	**1,160,000**

Flash (E4):
Inlet temperature = 30°C, Operates at 85°C, 0.5 bar gauge

Material	Mass Flow (kg/hr)	Specific Heats (kJ/kg °C)	BP, °C	Hv (kJ/kg)	Energy (kJ/hr)
Water	817	4.18	100	0	187,812
Hexane	4648.5	2.26 (liquid)	68	335.3	1,958,785
		1.88 (gas)			148,566
IPA	4648.5	2.68	82.6	664	3,771,793
Oil	88.8	2	High	0	9,772
				TOTAL (kJ/hr)	**6,076,728**
				TOTAL (kWh/yr)	**13,300,000**

Fat Splitter (E7):
Inlet temp = 85°C, Operates at 250°C, 51.7 bar, gauge

Material	Mass flow (kg/hr)	Specific Heats (kJ/kgC)	Hv (kg/kJ)	BP	Energy (kJ/hr)
[Heater 1]					
Oil	88.8	2	--	300	29,317
				TOTAL (kJ/hr)	**29,317**
				TOTAL (kWh/yr)	**64,000**
[Heater 2]					
Water (liquid)	40.9	4.18	2257	100	94,796
Water (vapor)		2.1			12,872
				TOTAL (kJ/hr)	**107,668**
				TOTAL (kWh/yr)	**236,000**

Free Fatty Acid Reactor (Bubble Reactor)
Inlet temp = 250°C, Operates at 60°C, 10 bar, gauge

Material	Mass flow (kg/hr)	Specific Heats (kJ/kgC)	Hv (kg/kJ)	BP	Energy (kJ/hr)
Free Fatty Acids	116.8	2.3	--	300	51,042
				TOTAL (kJ/hr)	**51,042**
				TOTAL (kWh/yr)	**112,000**

Solvent Recycle
Flash Outlet temp = 85°C, Extractor Inlet Temp = 30°C

Material	Mass Flow (kg/hr)	Specific Heats (kJ/kgC)	BP, °C	Hv (kJ/kg)	Energy (kJ/hr)
Hexane	4,616	2.26 (liquid)	68	335.3	396,422
		1.88 (gas)			147,527
IPA	4,616	2.68 (liquid)	82.6	664	650,708
		1.71 (gas)			18,944
Nitrogen	5,100	1.1 (gas)	-195.8	--	308,550
				TOTAL (kJ/hr)	**6,100,000**
				TOTAL (GJ/yr)	**48,000**

5.2 Process Utilities

Tables 5.1 and 5.2 summarize the utility requirement for each equipment item. Cooling water was used in heat exchange E12, while chilled water was used in heat exchanger E10. The remaining equipment units used electricity as a utility source.

Table 5.1: Net Utility Requirements by Equipment Unit

Utility	**Equipment Unit**	**Quantity**
Chilled Water (GJ/year)	E10 – Heat Exchanger 1	48,000
Cooling Water (m^3/year)	E12 – Heat Exchanger 2	7,463
Electricity (kWh/year)	E1 – Extractor	292,000
	E2 –Rotary Dryer	59,100
	E3 – Pelletizer	185,000
	E4 – Flash Vessel	236,500
	E5 – Solvent Splitter	N/A
	E6 – Decanter	10,600
	E7 – Fat Splitter	39,400
	E8 – Reactor	20,500
	E9 – Water Splitter	N/A
	E13 – Electric Heater 1	64,200
	E14 – Conveyor 1	17,300
	E15 – Conveyor 2	8,700
	E16 – Conveyor 3	8,700
	E17 - Splitter	N/A
	E18 – Electric Heater 2	235,800
	U1 – Pump 1	800
	U2 – Pump 2	39,500
	U3 – Pump 3	39,500
	U4 – Pump 4	300
	U5 – Pump 5	4,700
	U6 – Pump 6	3,780

Table 5.2: Total Utility

Utility	**Unit**	**No. Equipment**	**Quantity**
Chilled Water	GJ/year	1	45,935
Cooling Water	m^3/hr	1	7,463
Electricity	kWh/year	18	1,266,380

Section 6: Equipment List & Unit Descriptions

6.1 Unit Descriptions

**** All cost calculations based on CE Index of 541.7 (2016 average). ****

Extractor (E1)

The process of extracting the oil from the spent coffee grounds (SCG) occurs in a solid-liquid decanter centrifuge at 30°C and 30 psig (2.07 bar). A higher than atmospheric pressure is implemented to have a downward pressure gradient to the flash vessel after extraction in order to eliminate the need for an extra pump. This 304 stainless steel decanter is explosion proof, using nitrogen gas. Separation takes place in a horizontal bowl with a screw conveyor. This conveyer moves the solids towards one end of the decanter (as it rotates in the same direction as the bowl) and out of the centrifuge from a solid discharge port. Then, the liquid phase is discharged out. Equal concentrations of hexane and isopropanol are used as solvent. The solvent: dry SCG ratio is 22.5:1. Using a basis of grounds with 12% moisture, 21.5% of the grounds by mass are extracted as oil, leaving 78.5% as solids. Based on a vessel of 8 m^3, weight of 3,510 kg and run time of 30 minutes, the total equipment cost is $50,000. With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is $160,000, which is a quoted cost based on a Zhejiang Lifeng Environmental Equipment Co., Ltd. Sludge Dewatering Decanter Centrifuge. This machine is typically used in dewatering of petrochemicals and textiles, but it is believed to work well in the extraction of oil from SCG solids. Utilities account for 292,000 kWh (Alibaba, Sludge Dewatering).

Rotary Dryer (E2)

The rotary dryer operates at a temperature of 110°C in and a pressure of 1 bar in order to assure evaporation of the solvent and excess water. This occurs as the machine rotates by gravitational forces, forcing the materials to the end of the cylinder. The wet solids in the cylinder body are heated and dried as 5,100 kg/hr nitrogen passes over them and are then discharged onto a belt conveyor. The calculation for this flow rate can be found in Appendix A. The solvents are separated from the solids before pelletizing. This is recycled 100%. The vessel has a capacity of 1-2 ton/hour and is typically used to dry coal and sand. The total equipment cost is $5,000, which is a quoted cost from Qingdao Tianjin. With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is $16,000. Utilities account for 59,100 kWh (Alibaba, High Output).

Pelletizer (E3)

The pelletizer serves to form the dried spent coffee grounds into briquettes to be used for household and industry heating. Operating at ambient pressure and temperature this type of machine is typically used for pellet of rice husk, palm fiber, wheat straw, cotton stalk, sawdust, wood chips, palm shell, sunflower, olive residue, bagasse and other biomass. A quote from Loudate Machinery estimated the vessel size at 3,000 L, operating capacity of 0.3 - 0.5 ton/day, motor speed of 470 rpm and utility requirement of 23.5 kW. The expected flow rate is 0.38 ton/hour. This results in a yearly sum of 185,000 kWh. The total equipment cost of this equipment is $30,000. With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is $96,000 (Alibaba, Pellet Machine Price).

Flash (E4)

The flash (one-stage) distillation column removes the solvent and nitrogen from the oil-water mixture to recycle and send the oil and water into the fat splitter (E7). Since the boiling point of hexane is 68 C and isopropanol is 82.6°C, the flash operates at 85°C and 0.5 bar gauge pressure. The nitrogen remains a gas and will be removed from the process via a vent after going through heat exchanger 1 (E10). In order to enhance the removal of liquid droplets in the vapor stream and reduce the overall residence time of this separation, the flash vessel will also have a mesh demister. This assumes perfect separation above solvent boiling points. With a run time of 1 hour, the distillation column should be 260,000 L in volume. Using Seider et al., diameter is 15.68 ft, length is 47.04 ft and material is stainless steel. The tray type is sieve tray and maximum allowable stress is 15,000 psi. The vapor density is 2.08 kg/m^3, liquid density is 988 kg/m^3, head velocity is 0.107 m/s, area is 17.93 m^2 and L/D is 3. The utility requirement of this unit is 236,500 kWh. The total equipment cost is $203,000 for the column and $27,000 for the tray. Equating this as a vertical pressure vessel (flash drum), the bare module factor is 4.16, resulting in a bare module cost of $957,000.

Solvent Splitter/Purge

The purpose of this basic splitter is to recycle the solvent at a rate of 99.3% and purge 0.7%. The recycle stream gets compressed and cooled after leaving the splitter. A makeup stream going into the extractor makes up for the loss of the purge. The utility requirement and overall purchase cost are both negligible for the splitter, as it is simply a 1 inch T-pipe directing the purge and recycle streams.

Decanter (E6)

This unit is a stainless steel horizontal tank that is used to split the oil and water, based on their respective densities at 85°C and 0 psig. Then, it sends the oil out of one end and the water out of the other. These two streams need to be heated and pumped separately before going to the fat splitter (E7) because they enter the column at opposite ends. Some of the water will divert before entering the fat splitter (E7), as only 45% the weight of oil is added as water. The expected residence time of this tank is 15 minutes and there is expected to be about 50% empty space in the tank to promote separation. Therefore, the tank size should be about 6,000 L. The electricity utility requirement is 10,600 kWh. The total equipment cost of this decanter is $10,000, which is based on a quote from Shandong Better Environmental Protection Technology Co., Ltd. With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is $32,000. This machine has been used in the chemical, food processing, and pharmaceutical industries as a centrifugal decanter for oil-water sludge separation (Alibaba, LW Serious).

Fat Splitter (E7)

This unit acts as a reactor-separator that converts the oil and water to free fatty acids, glycerol and water. This operates at 250°C and 51.7 bar gauge. The unit operates by sending the oil in the bottom channel and the oil countercurrent from the top. Chemically, the water dissolves in fat and then reacts sequentially to split the fat, from tri to diglyceride, di to monoglyceride and lastly from monoglyceride to fatty acid. This oil-water mixture has a conversion of 90% to fatty acids, with the remaining 10% being glycerine and water. The fatty acids leave out of one end and the glycerine/water mixture, known as “sweet water” leaves out the other end. “Sweet water” is approximately 88% crude glycerine. This product will be sold for $10/ton. The residence time of the fat splitter is 2 hours. Based on a pricing strategy of a SS304 steel tray column with no trays, pressure = 710.5 psig, diameter = 0.95 feet, length = 23.27 feet (volume about 500L), the total equipment cost is $28,000. With a bare module factor of 4.16, the bare module cost is $117,000. The total yearly utilities are 39,400 kWh.

Reactor (E8)

This unit is used to convert the free fatty acids to biodiesel and water. Operating at 60°C and 10 bar with a residence time of 2 hours, it functions as a typical packed bed bubble reactor. The reaction involved here is esterification, and appears as follows:

Fatty Acid + Methanol --(Solid Catalyst)→ Methyl Ester + Water

The solid catalyst is SiO_2-HF, which is inserted at the bottom of the reactor in order to avoid the catalyst dissolving into the solution and makes for easy reuse. The catalyst is unchanged after 30 esterification runs (Corro). Methanol is added at a 1:19.8 ratio to the free fatty acids. Based on the 1:1:1:1 stoichometric ratio, the first pass conversion of fatty acid + methanol to biodiesel and water is 95% by mass (Stacy). Of that 95%, 95% becomes biodiesel and 5% becomes water. The remaining 6% of free fatty acids comes out with the biodiesel and 6% of methanol bubbles out with the water. After leaving the bubble reactor, 88% of the product stream is recycled through a splitter and back to the inlet in order to obtain 99.5% overall conversion of FFA to biodiesel, which matches the industry standard. This occurs after about 8-9 cycles through the machine. Then, the product stream is removed at 60°C. The methanol and water that bubbles out the top of the reactor needs to be scrubbed or condensed and treated as a waste. Based on a quoted cost from Shanghai Chunran Mechanical Co., Ltd, the total purchase cost of this vessel is $5,000.

With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is $16,000. The total utility requirement is 20,500 kWh. The SS304 steel jacketed vessel is 2000 L in volume and is typically used in the pharmaceutical, chemical, petroleum and food industries (Alibaba, Export Oriented).

Conveyor 1 (E14, E21)

In this process, three conveyor systems will be used in order to transport the SCG to the extractor (E1), from the extractor to the rotary dryer (E2) and from the rotary dryer to the pelletizer (E3). The first conveyor is based on a carbon steel bucket elevator with 24 inch buckets and includes a spaced bucket centrifugal discharge type elevator with motor and drive. This is connected to a 12-inch rotary feed valve, running at a maximum of 2700 lb/hr solid feed rate. This rotary valve then connects to a slurry mixing tank, which will mix the grounds with the solvent before entering the extractor (E1). A diagram of this setup is shown in Figure 6.1 below. Based on information from our industry consultant Stephen Tieri and pricing from Icarus/Aspen Economic Evaluation for a 50 ft bucket elevator, the total equipment cost is expected to be $42,000. Additionally, the cost for the rotary feed valve is expected to be $9,000 in stainless steel, based on a 1st quarter 2015 basis. The 3000 L mixing tank is expected to cost $10,000. With a Lang factor of 3.6 for equipment with mixed fluids-solids, the bare module cost for these 3 pieces of equipment is 220,000 (“The Factorial Method of Cost Estimation”). The utility requirement is based on the specifications for the screw conveyors at 17,300 kWh.

Conveyors 2 and 3 (E15, E16)

The two other conveyors are carbon steel screw conveyors, which are used in the soybean industry to move soybean meal. Carbon steel is deemed appropriate given the low water quantity in the stream. Since the product of the extractor (E1) to the rotary dryer (E2) and pelletizer (E3) are mostly solids, a screw conveyor is appropriate. The other two conveyors have flow rates of 1.78 m^3 and 0.81 m^3, respectively, so they require the option with 2.2 m^3 capacity. These two conveyors cost $5,000 each and have utility requirements of 8,700 kWh. These quotes are based on the Jiangsu Yunxing Machinery Technology Co., Ltd. model (Alibaba, Manufacturer Supplier). With a Lang factor of 3.6 for equipment with mixed fluids-solids, each of these conveyors cost 18,000 ("The Factorial Method of Cost Estimation").

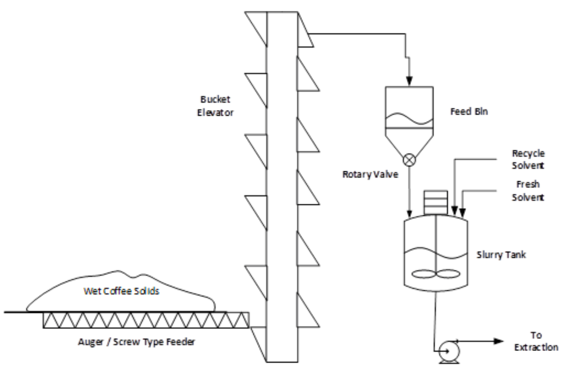


Figure 6.1: Bucket centrifugal discharge elevator with motor & drive, connected to rotary drive and slurry mixing tank.

Pumps (U1, U2, U3, U4, U5, U6)

There are 6 centrifugal pumps throughout this process, implemented to push the material forward where there is not a significant pressure drop. All of the purchase costs for the pumps were calculated using Seider et. al and were based on a bare module factor of 3.3, various pressure drops and SS304 Steel. The first pump (U1) is designed to pump the makeup solvent from the purge into the extractor. With a flow rate of 0.29 gal/min, pressure drop of 8.8 bar gauge, velocity of 0.146 m/s, inner diameter of 1 in, head of 397 feet, the total equipment cost of Pump 1 is $64,000 and bare module cost is $208,000. Based on 75% pump and motor efficiency of pumping water, the utility requirement is 800 kWh (Engineering Toolbox).

Pumps 2 and 3 (U2 and U3) exist in series in the solvent recycle stream in order to maintain the high level of flow in case of any breakdown in the plant. This stream has the highest flow in our process that requires a pump, so our consultants advised that we implement a backup pump. With a flow rate of 40.65 gal/min, velocity of 2.08 m/s, inner diameter of 1 in, pressure drop of 8.8 bar gauge, head of 398 feet, the total equipment costs of Pump 2 and 3 are $8,000 and bare module equipment costs are $26,000. The utility requirement is 39,500 kWh.

Pump 4 (U4) pumps the oil from the decanter (E6) to the heater (E13) before the fat splitter (E7). With a flow rate of 0.39 gal/min, velocity of 0.169 m/s, inner diameter of 1 in, pressure drop of 50 bar gauge, head of 1,902 feet, the total equipment cost of Pump 4 is $57,000 and bare module cost is $188,000. This shows that the smaller flow pumps end up costing more to get the desired pressure drop of 50 bar. The utility requirement is only 300 kWh.

Pump 6 (U6) pumps the water from the decanter (E6) to the heater (E18) before the fat splitter (E7). With a flow rate of 3.6 gal/min, velocity of 0.155 m/s, inner diameter of 1 in, pressure drop of 50 bar, head of 1,902 feet, the total equipment cost of Pump 6 is $20,000 and bare module cost is $66,000 Like with Pump 4, this shows that the smaller flow pumps end up costing more to get the desired pressure drop of 50 bar. The utility requirement is 3,780 kWh.

Pump 5 pumps the Biofuel/FFA through the splitter to the outlet and to the recycle stream back to the reactor. With a flow rate of 4.75 gal/min, velocity of 0.675 m/s, inner diameter of 1 in, pressure drop of 10 bar gauge, head of 380.4 feet, the total equipment cost of Pump 5 is $12,000 and bare module cost is $40,000. The utility requirement is 4,700 kWh.

Heat Exchangers (E10, E12)

There are 2 heat exchangers in this process. Both are modeled as continuous, stainless steel shell-in-tube exchangers. The means of heating and cooling the streams in each exchanger varies based on the state of the inlet and outlet streams, as well as their flow rates.

Heat Exchanger 1 (E10) condenses and cools the solvent recycle stream to 30°C before entering pumps 2 and 3 and back to the extractor (E1). There is also nitrogen in this stream, but it will not condense in the heat exchanger. Based on the large flow of 9,232 kg/hr and necessity of condensation, chilled water is used here. The chilled water comes into the exchanger at 5°C and exits at 20°C while the hot solvent comes in at 85°C and is cooled down to 30°C. Sizing and costing was performed using Seider et al. design data for a carbon steel tube and stainless steel shell. The baffle spacing is 22.2 inches, shell diameter is 37 inches, tube outer diameter is 0.75 inches, pitch is 1 inch, tube length is 16 feet, tubes per pass is 131, number of tubes is 786 with an area of 1,923 $feet^2$. These parameters produce a chilled water flow rate of 97,846 kg/hr, which is taken as a fixed cost, as it recirculates through the system and is not used up. Based on these calculations, the total equipment cost is $84,000. With a bare module factor of 3.17, the bare module cost is $266,000. Using the energy balance in section 5.1 for the solvent recycle, the utility requirement is 6,100,000 kJ/hr or 48,000 GJ/year.

Heat Exchanger 2 (E12) cools the free fatty acids before entering the reactor (E8) after leaving the fat splitter (E7). Based on the lower flow of 116.8 kg/hr and lack of phase change, simple cooling water is used here. The cooling water comes into the exchanger at 35°C and exits at 50°C while the hot FFA come in at 250°C and is cooled down to 60°C. Sizing and costing was performed using Seider et al. design data for stainless steel. The baffle spacing is 4.8 inches, shell diameter is 8 inches, tube outer diameter is 0.75 inches, pitch is 1 inch, tube length is 16 feet, tubes per pass is 4, number of tubes is 16 with an area of 39.1 feet^2. These parameters produce a cooling water flow rate of 814.1 kg/hr, which is taken as a fixed cost, as it recirculates through the system and is not used up. Based on these calculations, the total equipment cost is $46,000. With a bare module factor of 3.17, the bare module cost is $146,000. Using the flow rate of 814.1 kg/hr and a density of 860 kg/m^3, the total utility is 7,463 m^3/year.

<u>Heaters (E13, E18)</u>

There are 2 electric heaters in this process. They are both placed on streams being heated from the decanter (E6) to the fat splitter (E7). Since the streams have low flow rates, using steam to heat the oil and water would not be cost effective. Instead, an electric heater with an internal heating coil proved to be a better option. Both heaters are stainless steel 200 L vessels with a homogenizer speed of 3,000 rpm, mixer speed of 65 rpm and cost $10,000 from a quote by Guangzhou Guanyu Machinery Co., Ltd. (Alibaba, CE New Design). With a bare module factor of 3.2 for equipment not specified in Seider et. al, the bare module cost is 32,000.

Heater 1 (E13) heats the 88.8 kg/hr of oil from 85°C to 250°C, resulting in an electric utility of 64,200 kWh/year. After splitting off 776.1 kg/hr of water, heater 2 (E18) heats the remaining 40.9 kg/hr of water from 85°C to 250°C, resulting in an electric utility of 235,800 kWh/year. Both of these streams then enter the fat splitter (E7) from opposite ends.

6.2 Unit Specifications Sheets

Initial Feed Processing Equipment

Conveyor 1		
Identification:	Item	Bucket Elevator Rotary Feed and Mixing Tank
	Item No.	*E14, E21*
	No. Required	3
Function:	Transport the spent coffee grounds to the extractor	
Operation:	Continuous	
Type:	Conveyor	
Stream ID	*S1*	
	Inlet	Outlet
Temperature (°C)	25	
Pressure (bar, gauge)	0	
Flow rate (kg/hr)	1,215.3	
Flow rate (lb/hr)	2,679	
Spent Coffee Grounds (66% Moisture)	1215.3	
Design Data:	Capacity (lb/hour)	2700
	Elevator Height (ft)	50
	Bucket Size (in)	24
	Rotary Feed Size (in)	12
Total Purchase Cost:	$	61,000
Equipment Bare Module Cost:	$	195,000
Utilities Required/Year (kWh)	[2.2 kW]	17,300
Comments:	Elevator bucket connects to rotary valve and mixes with the solvent in the mixing tank before entering the extractor.	

Extractor			
Identification:	Item	Extractor	
	Item No.	*E1*	
	No. Required	1	
Function:	Separate solid coffee grounds from oil Extract oil from grounds using solvent		
Operation:	Continuous		
Type:	Solid-Liquid Decanter Centrifuge		
Stream ID	Inlet	Top Outlet	Bottom Outlet
	S1, S2, S3	*S8*	*S4*
Temperature (°C)	30	30	30
Pressure (bar, gauge)	1	2.07	2.07
Flow rate (kg/hr)	10,512	9,496	1,017
Water	746	788.2	14.8
Hexane	4,648	4,309.3	339.2
Isopropanol	4,648	4,309.3	339.2
Grounds with 12% Moisture	469.3 (56.3 water)		
Oil		88.8	
Solids			324.2
Design Data:	Run time (hour)	0.5	
	Length (mm)	3,805	
	Width (mm)	994	
	Height (mm)	2,130	
	Weight (kg)	3,510	
Total Purchase Cost:	$	50,000	
Equipment Bare Module Cost:	$	160,000	
Utilities Required/Year (kWh)	[1.87 kW]	292,000	
Comments:	Based on Zhejiang Lifeng Environmental Equipment Co., Ltd. Quote		

Pump 1		
Identification:	Item	Pump
	Item No.	*U1*
	No. Required	6
Function:	Pump makeup solvent into extractor	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S2*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	8.8	
Flow rate (kg/hr)	186	
Flow rate (gal/min)	0.29	
Solvent (Hexane and IPA) (kg/hr)	186	
Design Data:	Velocity (m/s)	0.146
	Inner diameter (in)	1
	Head (ft)	397
	Material	SS304 Steel
Total Purchase Cost:	$	64,000
Equipment Bare Module Cost:	$	208,000
Utilities Required/Year (kWh)	[0.1 kW]	800
Comments:	Assume 75% pump and motor efficiency, based on pumping water	

Heat Exchanger 1				
Identification:	Item		Heat Exchanger	
	Item No.		*E10*	
	No. Required		2	
Function:	Condenses and cools solvent recycle condensate to 30 degrees to enter the pumps to the extractor			
Operation:	Continuous			
Type:	Shell-in-tube heat exchanger			
Stream ID		*S3*		
	Cold Water		Hot Solvent	
	In	Out	In	Out
Temperature (°C)	5	20	85	30
Stream Flow rate (kg/hr)		9,232		
Solvent (Hexane and IPA) (kg/hr)		9,232		
Chilled Water Flow Rate (kg/hr)		97,846		
Design Data:	Baffle Spacing (in)		22.2	
	Shell diameter (in)		37	
	Tube outer diameter (in)		0.75	
	Pitch (in)		1	
	Tube length (ft)		16	
	Tubes/pass		131	
	No. Tubes		786	
	Heat Transfer Area (ft^2)		1923	
	Material		Carbon Steel Shell Stainless Steel Tube	
Total Purchase Cost:	$		84,000	
Equipment Bare Module Cost:	$		266,000	
Utilities Required/Year (GJ/year)	[6,100,000 kJ/hr]		48,000	
Comments:	Utilizes chilled water instead of cooling water			

Pump 2 (In Series with Pump 3)		
Identification:	Item	Pump
	Item No.	*U2, U3*
	No. Required	6
Function:	Pump recycle solvent into extractor	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S3*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	8.8	
Flow rate (kg/hr)	9,232	
Flow rate (gal/min)	40.65	
Solvent (Hexane and IPA) (kg/hr)	9,232	
Design Data:	Velocity (m/s)	2.08
	Inner diameter (in)	1
	Head (ft)	398
	Material	SS304 Steel
Total Purchase Cost:	$	8,000
Equipment Bare Module Cost:	$	26,000
Utilities Required/Year (kWh)	[5.08 kW]	39,500
Comments:	In series with pump 2 to maintain high flow in case of breakdown	

Pump 3 (In Series with Pump 2)		
Identification:	Item	Pump
	Item No.	*U2, U3*
	No. Required	6
Function:	Pump recycle solvent into extractor	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S3*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	8.8	
Flow rate (kg/hr)	9,232	
Flow rate (gal/min)	40.65	
Solvent (Hexane and IPA) (kg/hr)	9,232	
Design Data:	Velocity (m/s)	2.08
	Inner diameter (in)	1
	Head (ft)	398
	Material	SS304 Steel
Total Purchase Cost:	$	8,000
Equipment Bare Module Cost:	$	26,000
Utilities Required/Year (kWh)	[5.08 kW]	39,500
Comments:	In series with pump 2 to maintain high flow in case of breakdown	

Biomass Pellet Processing Equipment

Conveyor 2		
Identification:	Item	Screw Conveyor
	Item No.	*E15*
	No. Required	3
Function:	Transport the wet solids to the rotary dryer	
Operation:	Continuous	
Type:	Conveyor	
Stream ID	*S4*	
	Inlet	Outlet
Temperature (°C)	25	
Pressure (bar, gauge)	0	
Flow rate (kg/hr)	1,150	
Flow rate (m^3/hr)	1.78	
Solids	324.2	
Hexane	339	
Isopropanol	339	
Water	14.8	
Design Data:	Capacity (m^3/hr)	2.2
	Screw Diameter (mm)	100
	Pitch (mm)	100
	Speed (r/min)	140
Total Purchase Cost:	$	5,000
Equipment Bare Module Cost:	$	18,000
Utilities Required/Year (kWh)	[1.1 kW]	8,700
Comments:	Carbon steel chain conveyor, used for soybean meal	

Rotary Dryer			
Identification:	Item	Rotary Dryer	
	Item No.	*E2*	
	No. Required	1	
Function:	Separate solvent, nitrogen and water from solids to be pelletized		
Operation:	Continuous		
Type:	Rotary Dryer		
Stream ID	Inlet	Top Outlet	Bottom Outlet
	S4	*S7*	*S5*
Temperature (°C)	30	110	110
Pressure (bar, gauge)	1	1	1
Flow rate (kg/hr)	6,250	781.4	368.6
Solids	324.2		324.2
Hexane	339	339	
Isopropanol	339	339	
Water	14.8	14.8	
Nitrogen	5,100	5,100	
Design Data:	Capacity (ton/hour)	1-2	
	Weight (ton)	13.5	
	Gradient (%)	3-5	
	Specification (m)	1.2 x 10	
Total Purchase Cost:	$	5,000	
Equipment Bare Module Cost:	$	16,000	
Utilities Required/Year (kWh)	[7.5 kW]	59,100	
Comments:	Used for sand, coal drying		

Conveyor 3		
Identification:	Item	Elevator Conveyor
	Item No.	*E16*
	No. Required	3
Function:	Transport the wet solids to the rotary dryer	
Operation:	Continuous	
Type:	Screw Conveyor	
Stream ID	*S5*	
	Inlet	Outlet
Temperature (°C)	25	
Pressure (bar, gauge)	0	
Flow rate (kg/hr)	324.3	
Flow rate (m^3/hr)	0.81	
Solids	324.2	
Design Data:	Capacity (m^3/hour)	2.2
	Screw Diameter (mm)	100
	Pitch (mm)	100
	Speed (r/min)	140
Total Purchase Cost:	$	5,000
Equipment Bare Module Cost:	$	18,000
Utilities Required/Year (kWh)	[1.1 kW]	8,700
Comments:	Carbon steel chain conveyor, used for soybean meal	

Pelletizer		
Identification:	Item Item No. No. Required	Pelletizer *E3* 1
Function:	Form solid spent coffee ground product into briquettes	
Operation:	Continuous	
Type:	Feed Pellet Machine	
Stream ID	Inlet *S5*	Outlet *S6*
Temperature (°C)	25	
Pressure (bar, gauge)	1	
Flow rate (kg/hr)	324.2	
Flow rate (ton/hr.)	0.38	
Solids	324.2	
Design Data:	Capacity (ton/hour) Vessel Size (L) Speed of Motor (rpm)	0.3 – 0.5 3,000 470
Total Purchase Cost: Equipment Bare Module Cost:	$ $	30,000 96,000
Utilities Required/Year (kWh)	[23.5 kW]	185,000
Comments:	Cast iron and steel Typically used for pellet of rice husk, palm fiber, wheat straw, cotton stalk, sawdust, wood chips, palm shell, sunflower, olive residue, bagasse and other biomass.	

Biofuel Processing Equipment

Flash			
Identification:	Item	Flash	
	Item No.	*E4*	
	No. Required	1	
Function:	Flash off solvents and leave oil and water to get converted in fat splitter		
Operation:	Continuous		
Type:	One Stage Distillation Column		
Stream ID	Inlet	Solvent Outlet	Oil-Water Outlet
	S8, S7	*S9*	*S11*
Temperature (°C)	30	85	85
Pressure (bar, gauge)	0.5	0.5	0.5
Flow rate (kg/hr)	15,303	14,397	906
Hexane	4,648.5	4,648.5	
Isopropanol	4,648.5	4,648.5	
Oil	88.8		88.8
Water	817		817
Nitrogen	5,100	5,100	
Design Data:	Vapor Density (kg/m^3)	2.08	
	Liquid Density (kg/m^3)	988	
	Head Velocity (m/s)	0.107	
	Area (m^2)	17.93	
	L/D	3	
	Diameter (ft)	15.68	
	Vessel Size (L)	260,000	
Total Purchase Cost:	$	230,000	
Equipment Bare Module Cost:	$	957,000	
Utilities Required/Year (kWh)	[30 kW]	236,500	
Comments:	Assume perfect separation above solvent boiling points. Heat is provided with electricity.		

Solvent Splitter			
Identification:	Item	Splitter	
	Item No.	*E5*	
	No. Required	1	
Function:	Recycle 99.3% solvent, purge 0.7%		
Operation:	Continuous		
Type:	Splitter		
Stream ID	Inlet	Recycle Outlet	Purge Outlet
	S9	*S3*	*S10*
Temperature (°C)	85	85	85
Pressure (bar, gauge)	1	1	1
Flow rate (kg/hr)	9,297	9,232	185
Hexane	4,648.5	4,616	87.5
Isopropanol	4,648.5	4,616	87.5
Design Data:	Shape	Simple “T” pipe	
	Pipe Diameter (in)	1	
Total Purchase Cost:	$	Negligible	
Equipment Bare Module Cost:	$	Negligible	
Utilities Required/Year (kWh)		Negligible	
Comments:	Solvent is assumed to combine and split evenly		

Decanter			
Identification:	Item	Decanter	
	Item No.	*E6*	
	No. Required	1	
Function:	Split oil and water to enter two ends of the fat splitter		
Operation:	Continuous		
Type:	Horizontal Tank		
Stream ID	Inlet	Water Outlet	Oil Outlet
	S11	*S12*	*S13*
Temperature (°C)	85	85	85
Pressure (bar, gauge)	0	0	0
Flow rate (kg/hr)	905.8	776.1	129.7
Oil	88.8		88.8
Water	817	817	
Design Data:	Run time (minutes)	15-20	
	Vessel Size (L)	6,000	
Total Purchase Cost:	$	10,000	
Equipment Bare Module Cost:	$	32,000	
Utilities Required/Year (kWh)	[1.35 kW]	10,600	
Comments:	Oil and Water split evenly		

Pump 4 (Oil Pump)		
Identification:	Item	Pump
	Item No.	*U4*
	No. Required	6
Function:	Pump oil and water mixture from decanter to fat splitter	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S13*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	50	
Flow rate (kg/hr)	88.8	
Flow rate (gal/min)	0.39	
Oil	88.8	
Design Data:	Velocity (m/s)	0.169
	Inner diameter (in)	1
	Head (ft)	1,902
	Material	SS304 Steel
Total Purchase Cost:	$	57,000
Equipment Bare Module Cost:	$	188,000
Utilities Required/Year (kWh)	[0.038 kW]	300
Comments:		

Pump 6 (Water Pump)		
Identification:	Item	Pump
	Item No.	*U6*
	No. Required	6
Function:	Pump oil and water mixture from decanter to fat splitter	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S23*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	50	
Flow rate (kg/hr)	817	
Flow rate (gal/min)	3.6	
Water	817	
Design Data:	Velocity (m/s)	0.155
	Inner diameter (in)	1
	Head (ft)	1,902
	Material	SS304 Steel
Total Purchase Cost:	$	20,000
Equipment Bare Module Cost:	$	66,000
Utilities Required/Year (kWh)	[0.479 kW]	3,780
Comments:		

Water Splitter			
Identification:	Item	Splitter	
	Item No.	*E17*	
	No. Required	1	
Function:	Split off water not required for fat splitter.		
Operation:	Continuous		
Type:	Splitter		
Stream ID	Inlet	Outlet to Fat Splitter	Purge Outlet
	S12	*S23*	*S22*
Temperature (°C)	85	85	85
Pressure (bar, gauge)	1	1	1
Flow rate (kg/hr)	817	40.9	776.1
Water	817	40.9	776.1
Design Data:	Shape	Simple "T" pipe	
	Pipe Diameter (in)	1	
Total Purchase Cost:	$	Negligible	
Equipment Bare Module Cost:	$	Negligible	
Utilities Required/Year (kWh)		Negligible	
Comments:	Water to fat splitter based on 45% of mass of oil		

Heater 1		
Identification:	Item	Heater
	Item No.	*E13*
	No. Required	2
Function:	Heats oil to 250°C, to enter the fat splitter	
Operation:	Continuous	
Type:	Electric Heater	
Stream ID	*S13*	
	Inlet	Outlet
Temperature (°C)	85	250
Stream Flow rate (kg/hr)	88.8	
Oil	88.8	
Design Data:	Vessel Size (L)	200
	Homogenizer Speed (rpm)	3,000
	Mixer Speed (rpm)	65
	Material	Stainless Steel
Total Purchase Cost:	$	10,000
Equipment Bare Module Cost:	$	32,000
Utilities Required/Year (kWh)	[29,317 kJ/hr]	64,200
Comments:		

Heater 2		
Identification:	Item	Heater
	Item No.	*E18*
	No. Required	2
Function:	Heats water to 250 C to enter the fat splitter	
Operation:	Continuous	
Type:	Electric Heater	
Stream ID	*S23*	
	Inlet	Outlet
Temperature (°C)	85	250
Stream Flow rate (kg/hr)	40.9	
Water	40.9	
Design Data:	Vessel Size (L)	200
	Homogenizer Speed (rpm)	3,000
	Mixer Speed (rpm)	65
	Material	Stainless Steel
Total Purchase Cost:	$	10,000
Equipment Bare Module Cost:	$	32,000
Utilities Required/Year (kWh)	[107,668 kJ/hr]	235,800
Comments:		

Fat Splitter			
Identification:	Item	Fat Splitter	
	Item No.	*E7*	
	No. Required	1	
Function:	Convert Oil and Water to Free Fatty Acids, Glycerin and Water		
Operation:	Continuous		
Type:	Separation Reactor		
Stream ID	Inlet	FFA Outlet	Wet Glycerol Outlet
	S13	*S15*	*S14*
Temperature (°C)	85	250	250
Pressure (bar, gauge)	1	51.7	51.7
Flow rate (kg/hr)	127.7	116.8	12.9
Oil	88.8		
Water	40.9		1.5
Free Fatty Acids		116.8	
Glycerin			11.4
Design Data:	Residence time (hr)	2	
	No. Trays	0	
	Diameter (feet)	0.95	
	Length (feet)	23.27	
	Vessel Size (L)	500 L	
Total Purchase Cost:	$	28,000	
Equipment Bare Module Cost:	$	117,000	
Utilities Required/Year (kWh)	[5 kW]	39,400	
Comments:	Amount of inlet water equals 45% mass of oil. Conversion to FFA is 90% from oil and water mixture. Wet glycerol is 88% crude glycerin		

Heat Exchanger 2				
Identification:	Item		Heat Exchanger	
	Item No.		*E12*	
	No. Required		2	
Function:	Cools Free Fatty Acids to 60 C to enter reactor			
Operation:	Continuous			
Type:	Shell-in-tube heat exchanger			
Stream ID		*S15*		
	Cold Water		Hot Oil	
	In	Out	In	Out
Temperature (°C)	35	50	250	60
Stream Flow rate (kg/hr)		116.8		
Free Fatty Acids		116.8		
Cooling Water Flow Rate (kg/hr)		814.1		
Design Data:	Baffle Spacing (in)		4.8	
	Shell diameter (in)		8	
	Tube outer diameter (in)		0.75	
	Pitch (in)		1	
	Tube length (feet)		16	
	Tubes/pass		4	
	No. Tubes		16	
	Heat Transfer Area (ft^2)		39.1	
	Material		Stainless Steel	
Total Purchase Cost:	$		46,000	
Equipment Bare Module Cost:	$		146,000	
Utilities Required/Year (m^3/year)	[814.1 kg/hr]		7,463	
Comments:				

Reactor				
Identification:	Item		Reactor	
	Item No.		*E8*	
	No. Required		1	
Function:	Convert Free Fatty Acids to Biodiesel and Water			
Operation:	Continuous			
Type:	Jacket Bubble Reactor			
Stream ID	Inlet (One Pass) *S15, S16*	Inlet (Recycle) *S19*	Outlet (Recycle) *S18*	Outlet (Bubbled) *S17*
Temperature (°C)	60		60	60
Pressure (bar, gauge)	10		10	10
Flow rate (kg/hr)	141.8	953	1,083	10.4
Free Fatty Acid	116.8	4.8	5.4	
Methanol	25			1.4
Biodiesel		948.2	1078	
Water				9
One Time Addition (kg)				
SiO2*HF Catalyst	12.16			
Design Data:	Material		SS304 Steel	
	Body Diameter (mm)		1,400	
	Jacket Diameter (mm)		1,000	
	Height (mm)		1,820	
	Vessel Size (L)		2,000 L	
	Residence time (hr)		2	
Total Purchase Cost:	$		5,000	
Equipment Bare Module Cost:	$		16,000	
Utilities Required/Year (kWh)	[2.6 kW]		20,500	
Comments:	Jacket reactor used in pharmaceutical, chemical, petroleum and food industries. Assume 95% first pass mass conversion based on mole-stoichiometry, recycle ratio of 88%. Steady state is achieved after 8-9 cycles. Overall conversion is 99.5%.			

Pump 5		
Identification:	Item	Pump
	Item No.	*U5*
	No. Required	6
Function:	Pump Biofuel/FFA through splitter to recycle and outlet	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	*S18*	
Temperature (°C)	25	
Pressure Drop (bar, gauge)	10	
Flow rate (kg/hr)	1,083.4	
Flow rate (gal/min)	4.75	
Biofuel and FFA	1,083.4	
Design Data:	Velocity (m/s)	0.675
	Inner diameter (in)	1
	Head (ft)	380.4
	Material	SS304 Steel
Total Purchase Cost:	$	12,000
Equipment Bare Module Cost:	$	40,000
Utilities Required/Year (kWh)	[0.6 kW]	4,700
Comments:		

Biofuel/FFA Splitter			
Identification:	Item Item No. No. Required	Splitter *E9* 1	
Function:	Recycle Biofuel and FFA out of and back into reactor to get conversion to from 95% to 99.5% at steady state.		
Operation:	Continuous		
Type:	Splitter		
Stream ID	Inlet *S18*	Recycle Outlet *S19*	Product Outlet *S20*
Temperature (°C)	60	60	60
Pressure (bar, gauge)	1	1	1
Fl/ow rate (kg/hr)	1,083	953	130
Biofuel	1,077.6	948.2	129.4
Free Fatty Acids	5.4	4.8	0.6
Design Data:	Diameter (in)	1	
Total Purchase Cost:	$	Negligible	
Equipment Bare Module Cost:	$	Negligible	
Utilities Required/Year (kWh)		Negligible	
Comments:	Equipment is a simple pipe splitter directing 12% to the product outlet and 88% to the recycle to a pump back to the reactor. Product comes out cool at 60°C. All streams are 99.5% biofuel once steady state is achieved.		

Section 7: Equipment Cost Summary:

The total equipment costs of the project are detailed in this section. Variable costs, when considering revenue streams of the biomass pellets and wet glycerol bi-products, total $114,000. Fixed costs including operations, maintenance, and overhead total $1,712,000. The total permanent investment of the process is $3,896,000. The total capital investment is $4,028,000 using a weighted average cost of capital of 15%. Equipment costs are depreciated using the Modified Accelerated Cost Recovery System for tax purposes. This depreciation method affects the net present value (NPV) of the project. The equipment is also assumed to have a lifetime of 20 years when calculating the return on total investment (ROI) and the internal rate of return (IRR). Overall equipment utility costs total $396,000 per year. Raw material costs have two components due the recycling of solvent—an initial capital investment and an annual cost. The one-time cost of raw materials is $13,000, including both solvent and SiO_2 catalyst according to Alibaba, and the annual variable cost of solvent is $363,000. The cost of pipes totals $6,600 and is counted an initial capital investment. Factory utilities, not directly related to equipment usage, have a total cost of $600 per year. Land costs based on Zillow pricing quotes in northern New Jersey total $70,000 as a one-time fixed cost.

Section 8: Fixed-Capital Equipment Investment Summary

The total bare module cost is $2,680,000. These costs are laid out in table 8.1 below. All equipment costs described below are bare module costs. The largest components of the bare module cost are Flash E4 (36%), Heat Exchanger 1: E10 (10%), Conveyer E14 (8.2%), Pump U1 (7.8%), Pump U4 (7.0%), Extractor E1 (6.0%), Heat Exchanger 2: E12 (5.4%), Fat Splitter E7 (4.4%), and Pelletizer E3 (3.6%). The remaining 12% of the capital costs consist of Pumps U2, U3, U5, and U6; Electric Heaters E13 and E18; Reactor E8, Decanter E6, and Conveyers E15 and E16.

Table 8.1: Total bare module costs: C_P, bare module factor (F_{BM}), bare module cost (C_{BM}). The quantity for each unit listed is one unit.

Unit Name	C_P	F_{BM}	C_{BM}
Conveyer E14	$61,000	3.6	$220,000
Conveyer E15	$5,000	3.6	$18,000
Conveyer E16	$5,000	3.6	$18,000
Extractor E1	$50,000	3.2	$160,000
Pump 1 U1	$64,000	3.3	$208,000
Pump 2 U2	$8,000	3.3	$26,000
Pump 3 U3	$8,000	3.3	$26,000
Rotary Drier E2	$5,000	3.2	$16,000
Pelletizer E3	$30,000	3.2	$96,000
Flash E4	$230,000	4.16	$957,000
Decanter E6	$10,000	3.2	$32,000
Pump U4	$57,000	3.3	$188,000
Fat Splitter E7	$28,000	4.16	$117,000
Reactor E8	$5,000	3.2	$16,000
Pump U5	$12,000	3.3	$40,000
Pump U6	$20,000	3.3	$66,000
Heat Exchanger1: E10	$84,000	3.17	$266,000
Electric Heater 1: E13	$10,000	3.2	$32,000
Heat Exchanger2: E12	$46000	3.17	$146,000
Electric Heater 2: E18	$10,000	3.2	$32,000

Section 9: Operating Costs and Overall Revenues

This section details all the other costs of the project, not including the capital investment costs. Costs covered here include equipment utilities, raw materials, labor costs, non-equipment utility costs, and factory pipe costs. These costs are laid out in table 9.1 below. The method of calculating these costs is described here as well. Equipment utility costs are calculated by determining the kWh usage of each piece of equipment. This energy usage is then multiplied by the northern New Jersey average electricity price of 12 cents per kWh. Raw material costs are broken down into initial investment and annual cost. The initial investment is based on a price of $1.5/gallon of the hexane/isopropanol solvent mixture. The annual raw material cost contains the portion of nonrecycled solvent that need to be continuously added via a makeup stream as well as the cost of methanol, found to be $442/ metric ton according to the methanex cost index. Trucks used to collect the coffee grounds are a capital cost and employees, both drivers and factory workers, are labor costs. Gas and insurance costs are included as annual costs and are calculated based on quotes for the required truck size. Five trucks are purchased at $30,000 each. Each driver works every other day to collect coffee grounds and is paid $13.50 per hour based on the December 2017 NYC minimum wage. Each factory worker is paid an annual salary of $70,000 and five factory workers are employed. Total pipe cost was based on 1 inch inner diameter stainless steel pipes and 120 feet of total piping in the plant. Factory utilities include running water and electricity costs and are based on average utility costs in Bergen county, NJ.

Table 9.1: Manufacturing costs and Miscellaneous costs based on NYC utility costs

Operational process	**Fixed-Capital or Variable-Annual**	**Total Cost**
Equipment Utilities	Variable-Annual	$474,000
Raw Materials	Fixed-Capital	$13,000
Raw Materials	Variable-Annual	$363,000
Trucks	Fixed-Capital	$150,000
Trucks (gas and insurance)	Variable-Annual	$32,000
Labor cost (drivers and factory workers)	Variable-Annual	$579,000
Pipes	Fixed-Capital	$6,600
Non-Equipment Utilities	Variable-Annual	$600
Land	Fixed-Capital	$70,000

In addition to the non-equipment related costs of the process, the revenues are detailed in this section as well. As seen in Table 9.2 below, the revenues are comprised of sales of biodiesel, biomass pellets, and wet glycerol. The flow rates, prices, and revenues each are listed below. Biodiesel prices are based on market value according the US Alternative Fuels Data Center. Biomass pellets were based on the price of wood pellets, and reduced to ¾ the price of wood pellets since coffee ground biomass pellets contain ¾ of the useable energy of wood pellets with the same mass. Glycerol price is based on Alibaba pricing and its revenue is very small compared to that of the other products.

Table 9.2: Revenue Streams with flow rates and prices listed

Revenue Stream	Flow Rate (kg/hr)	Price ($/kg)	Revenue
Biodiesel	130	0.76	$782,000
Biomass Pellets	324.2	0.211	$587,000
Wet Glycerol	12.9	0.010	$1,000

Section 10: Other Important Considerations

10.1: Facility Location

The target location for the facility is northern part of New Jersey, a 20-minute drive from NYC, since this location provides access to many coffee shops (ideally every coffee shop in each of the five city boroughs) and will reduce the overall cost of transportation of the coffee grounds. The ground collectors will collect grounds from each of the 875 combined Starbucks and Dunkin Donuts in the city. They will go to each store every other day and spend an average of 15 minutes to collect the grounds from a store and then travel to the next store. The drawback of this location is that the land cost will be more expensive than average due to its convenient access to NYC. Land availability, based on data from Zillow, prices 1.55 acres of land (more than 5 times the required factory size) at $70,000 (Zillow). Utility costs were considered and the 12 cents per kWh used in the costing was on par with that of electricity throughout the US (ChooseEnergy).

10.2: Biofuel Quality

For the resulting biofuel to be marketable, the biofuel must be 99.5% pure. This purity was achieved by using the 88% recycle of the biofuel/free fatty acid mixture back into the reactor. If industrial grade biofuel quality were to change, requiring a higher level of purity than previously established, this process would have to use a larger recycle stream and will therefore have higher equipment flow rates and utility costs.

10.3: Waste Management

The waste products from the plant include two non-toxic water outputs, one in the liquid phase after oil/water decanting and the other coming off as vapor from the bubble reactor. There are also two toxic waste products, since 1.4 kg/hr of methanol comes out as vapor from the bubble reactor and 65 kg/hr of solvent is purged. This toxic waste products need to get scrubbed when escaping from the reactor so that they have no effect on the environment.

10.4: Renewable Energy Credits

Since this project has a positive net production of usable energy, profits earned by the plant are eligible for tax exemption through the US government's renewable energy program. Tax exemptions were not included in the economic analysis, but may have potential to improve the project's NPV slightly. These tax exemptions are not expected to be a game-changer unless certain economic conditions are met regarding the increase in the market value of the biodiesel and the increase in collection efficiency of the coffee grounds.

Section 11: Profitability Analysis

The profitability analysis is based on an investment by a large company with a weighted average cost of capital (WACC) assumed to be 15%. The metrics used to evaluate the potential investment are IRR, NPV, and third year ROI. The major revenue sources of the project are biodiesel and biomass pellets.

11.1: Baseline Analysis

The investment, at the current biodiesel price has a very small contribution margin of $32,000 per year. This margin is unable to recover the fixed and capital costs of the project in its 20-year lifetime and therefore the IRR was negative and the NPV of the project in 2017 is ($6.8 million). The ROI in year three of operation is -22%.

General Information Baseline Analysis	
Process Title:	**Coffee Grounds to Biofuel**
Product:	**Biofuel**
Plant Site Location:	**NYC**
Site Factor:	**1.00**
Operating Hours per Year:	**7884**
Operating Days Per Year:	**329**
Operating Factor:	**0.9000**

Product Information		
This Process will Yield		
	130	kg of Biofuel per hour
	3,120	kg of Biofuel per day
	1,024,920	kg of Biofuel per year
Price	**$0.76**	**/kg**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2017	Design		0.0%		
2018	Construction	100%	0.0%		
2019	Production	0%	45.0%	20.00%	$0.76
2020	Production	0%	67.5%	32.00%	$0.76
2021	Production	0%	90.0%	19.20%	$0.76
2022	Production		90.0%	11.52%	$0.76
2023	Production		90.0%	11.52%	$0.76
2024	Production		90.0%	5.76%	$0.76
2025	Production		90.0%		$0.76
2026	Production		90.0%		$0.76
2027	Production		90.0%		$0.76
2028	Production		90.0%		$0.76
2029	Production		90.0%		$0.76
2030	Production		90.0%		$0.76
2031	Production		90.0%		$0.76
2032	Production		90.0%		$0.76
2033	Production		90.0%		$0.76
2034	Production		90.0%		$0.76
2035	Production		90.0%		$0.76
2036	Production		90.0%		$0.76
2037	Production		90.0%		$0.76
2038	Production		90.0%		$0.76

Figure 11.1: Baseline General Information

Equipment Costs

Equipment Description		Bare Module Cost
conveyer	Process Machinery	$220,000
conveyer2	Process Machinery	$18,000
conveyer3	Process Machinery	$18,000
extractor	Process Machinery	$160,000
pump1	Process Machinery	$208,000
pump2	Process Machinery	$26,000
pump3	Process Machinery	$26,000
rotary drier	Process Machinery	$16,000
pelletizer	Process Machinery	$96,000
flash	Process Machinery	$957,000
oil/water decanter	Process Machinery	$32,000
pump4	Process Machinery	$188,000
fat splitter	Process Machinery	$117,000
reactor	Process Machinery	$16,000
pump5	Process Machinery	$40,000
pump6	Process Machinery	$66,000
heatX1- recycle solvent	Process Machinery	$266,000
heater1	Process Machinery	$32,000
heatX3	Process Machinery	$146,000
heater2	Process Machinery	$32,000
Total		***$2,680,000***

Figure 11.2: Baseline Equipment Costs

Raw Materials

	Raw Material:	Unit:	Required Ratio:	Cost of Raw Material:
1	solvent	kg	0.5 kg per kg of Biofuel	$0.535 per kg
2	methanol	kg	0.1923077 kg per kg of Biofuel	$0.44 per kg

Total Weighted Average: $0.353 per kg of Biofuel

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
1	biomass pellets	kg	2.4938462 kg per kg of Biofuel	$0.211 per kg
2	wet glycerol	kg	0.0992308 kg per kg of Biofuel	$0.010 per kg

Total Weighted Average: $0.528 per kg of Biofuel

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
3	Process Water	gal	0 gal per kg of Biofuel	$0.000E+00 per gal
4	Cooling Water	lb	1589.9594 lb per kg of Biofuel	$3.125E-05 per lb
5	Electricity	kWh	1.2355881 kWh per kg of Biofuel	$0.120 per kWh

Total Weighted Average: $0.198 per kg of Biofuel

Variable Costs

General Expenses:

Selling / Transfer Expenses:	**3.00% of Sales**
Direct Research:	**4.80% of Sales**
Allocated Research:	**0.50% of Sales**
Administrative Expense:	**2.00% of Sales**
Management Incentive Compensation:	**1.25% of Sales**

Working Capital

Accounts Receivable	a	**30**	**Days**
Cash Reserves (excluding Raw Materials)	a	**30**	**Days**
Accounts Payable	a	**30**	**Days**
Biofuel Inventory	a	**4**	**Days**
Raw Materials	a	**2**	**Days**

Figure 11.3: Baseline Raw Materials

Total Permanent Investment		
Cost of Site Preparations:	5.00%	of Total Bare Module Costs
Cost of Service Facilities:	5.00%	of Total Bare Module Costs
Allocated Costs for utility plants and related facilities:	$0	
Cost of Contingencies and Contractor Fees:	18.00%	of Direct Permanent Investment
Cost of Land:	2.00%	of Total Depreciable Capital
Cost of Royalties:	$0	
Cost of Plant Start-Up:	10.00%	of Total Depreciable Capital

Fixed Costs		
Operations		
Operators per Shift:	1	(assuming 5 shifts)
Direct Wages and Benefits:	$40	/operator hour
Direct Salaries and Benefits:	15%	of Direct Wages and Benefits
Operating Supplies and Services:	6%	of Direct Wages and Benefits
Technical Assistance to Manufacturing:	$60,000.00	per year, for each Operator per Shift
Control Laboratory:	$65,000.00	per year, for each Operator per Shift
Maintenance		
Wages and Benefits:	4.50%	of Total Depreciable Capital
Salaries and Benefits:	25%	of Maintenance Wages and Benefits
Materials and Services:	100%	of Maintenance Wages and Benefits
Maintenance Overhead:	5%	of Maintenance Wages and Benefits
Operating Overhead		
General Plant Overhead:	7.10%	of Maintenance and Operations Wages and Benefits
Mechanical Department Services:	2.40%	of Maintenance and Operations Wages and Benefits
Employee Relations Department:	5.90%	of Maintenance and Operations Wages and Benefits
Business Services:	7.40%	of Maintenance and Operations Wages and Benefits
Property Taxes and Insurance		
Property Taxes and Insurance:	2%	of Total Depreciable Capital
Straight Line Depreciation		
Direct Plant:	8.00%	of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities
Allocated Plant:	6.00%	of 1.18 times the Allocated Costs for Utility Plants and Related Facilities
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	$0	
Licensing Fees:	$0	
Miscellaneous:	$0	
Depletion Allowance		
Annual Depletion Allowance:	$0	

Figure 11.4: Baseline Investment Details

Variable Cost Summary			
Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	23,460
Direct Research:		$	37,537
Allocated Research:		$	3,910
Administrative Expense:		$	15,640
Management Incentive Compensation:		$	9,775
Total General Expenses		$	90,323
Raw Materials	$0.352500 per kg of Biofuel		$361,284
Byproducts	$0.527693 per kg of Biofuel		($540,843)
Utilities	$0.197957 per kg of Biofuel		$202,890
Total Variable Costs		**$**	**113,654**

Fixed Cost Summary		
Operations		
Direct Wages and Benefits	$	416,000
Direct Salaries and Benefits	$	62,400
Operating Supplies and Services	$	24,960
Technical Assistance to Manufacturing	$	300,000
Control Laboratory	$	325,000
Total Operations	**$**	**1,128,360**
Maintenance		
Wages and Benefits	$	156,539
Salaries and Benefits	$	39,135
Materials and Services	$	156,539
Maintenance Overhead	$	7,827
Total Maintenance	**$**	**360,039**
Operating Overhead		
General Plant Overhead:	$	47,859
Mechanical Department Services:	$	16,178
Employee Relations Department:	$	39,770
Business Services:	$	49,881
Total Operating Overhead	**$**	**153,689**
Property Taxes and Insurance		
Property Taxes and Insurance:	$	69,573
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	$	-
Licensing Fees:	$	-
Miscellaneous:	$	-
Total Other Annual Expenses	**$**	**-**
Total Fixed Costs	**$**	**1,711,661**

Figure 11.5: Baseline Variable and Fixed Costs

Investment Summary

Total Bare Module Costs:				
Fabricated Equipment	$	-		
Process Machinery	$	2,680,000		
Spares	$	-		
Storage	$	-		
Other Equipment	$	-		
Catalysts	$	-		
Computers, Software, Etc.	$	-		
Total Bare Module Costs:			$	2,680,000
Direct Permanent Investment				
Cost of Site Preparations:	$	134,000		
Cost of Service Facilities:	$	134,000		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			$	2,948,000
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	530,640		
Total Depreciable Capital			$	3,478,640
Total Permanent Investment				
Cost of Land:	$	69,573		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	347,864		
Total Permanent Investment - Unadjusted			$	3,896,077
Site Factor				1.00
Total Permanent Investment			$	3,896,077

Working Capital

		2018		2019		2020
Accounts Receivable	$	28,924	$	14,462	$	14,462
Cash Reserves	$	70,812	$	35,406	$	35,406
Accounts Payable	$	(20,867)	$	(10,433)	$	(10,433)
Biofuel Inventory	$	3,857	$	1,928	$	1,928
Raw Materials	$	891	$	445	$	445
Total	**$**	**83,617**	**$**	**41,808**	**$**	**41,808**
Present Value at 15%	*$*	*72,710*	*$*	*31,613*	*$*	*27,490*

Total Capital Investment	$	4,027,890

Figure 11.6: Baseline Investment Costs

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2017	0%		-	-	-	-	-	-	-	-	-	-	-	-
2018	0%		-	(3,896,100)	(83,600)	-	-	-	-	-	-	-	(3,979,700)	(3,460,600)
2019	45%	$0.76	351,900	-	(41,800)	(51,100)	(1,711,700)	(695,700)	-	(2,106,600)	779,500	(1,327,200)	(673,300)	(3,969,700)
2020	68%	$0.76	527,900	-	(41,800)	(76,700)	(1,711,700)	(1,113,200)	-	(2,373,700)	878,300	(1,495,400)	(424,100)	(4,248,500)
2021	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	(667,900)	-	(1,778,000)	657,900	(1,120,200)	(452,300)	(4,507,100)
2022	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	(400,700)	-	(1,510,900)	559,000	(951,900)	(551,100)	(4,781,100)
2023	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	(400,700)	-	(1,510,900)	559,000	(951,900)	(551,100)	(5,019,400)
2024	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	(200,400)	-	(1,310,500)	484,900	(825,600)	(625,200)	(5,254,400)
2025	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(5,483,000)
2026	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(5,681,800)
2027	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(5,854,700)
2028	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,005,100)
2029	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,135,800)
2030	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,249,400)
2031	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,348,300)
2032	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,434,200)
2033	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,509,000)
2034	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,574,000)
2035	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,630,500)
2036	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,679,600)
2037	90%	$0.76	703,800	-	-	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(699,400)	(6,722,400)
2038	90%	$0.76	703,800	-	167,200	(102,300)	(1,711,700)	-	-	(1,110,100)	410,800	(699,400)	(532,200)	(6,750,600)

Figure 11.7: Baseline Cash Flow Summary

Profitability Measures

The Internal Rate of Return (IRR) for this project is	Negative IRR
The Net Present Value (NPV) of this project in 2017 is	$ (6,750,600)

ROI Analysis (Third Production Year)

Annual Sales	**703,813**
Annual Costs	**(1,813,949)**
Depreciation	**(311,686)**
Income Tax	**526,075**
Net Earnings	**(895,749)**
Total Capital Investment	**4,063,310**
ROI	**-22.04%**

Figure 11.8: Baseline Profitability Measures

11.2: Sensitivity Analysis

Price of Biodiesel

The first sensitivity analysis was performed on the price of biodiesel. Biodiesel price was increased to it 90th percentile for the past ten years and profitability was reanalyzed. Costs were only increased slightly as the general expenses comprised of research and sales increased with the increase in revenue. The IRR remained negative and the NPV of the investment in 2017 is ($5.0 million). The ROI in year three of operation is -15%.

General Information Sensitivity 1	
Process Title:	**Coffee Grounds to Biofuel**
Product:	**Biofuel**
Plant Site Location:	**NYC**
Site Factor:	**1.00**
Operating Hours per Year:	**7884**
Operating Days Per Year:	**329**
Operating Factor:	**0.9000**

Product Information		
This Process will Yield		
	130	kg of Biofuel per hour
	3,120	kg of Biofuel per day
	1,024,920	kg of Biofuel per year
Price	**$1.21**	**/kg**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2017	Design		0.0%		
2018	Construction	100%	0.0%		
2019	Production	0%	100.0%	20.00%	$1.21
2020	Production	0%	100.0%	32.00%	$1.21
2021	Production	0%	100.0%	19.20%	$1.21
2022	Production		100.0%	11.52%	$1.21
2023	Production		100.0%	11.52%	$1.21
2024	Production		100.0%	5.76%	$1.21
2025	Production		100.0%		$1.21
2026	Production		100.0%		$1.21
2027	Production		100.0%		$1.21
2028	Production		100.0%		$1.21
2029	Production		100.0%		$1.21
2030	Production		100.0%		$1.21
2031	Production		100.0%		$1.21
2032	Production		100.0%		$1.21
2033	Production		100.0%		$1.21
2034	Production		100.0%		$1.21
2035	Production		100.0%		$1.21
2036	Production		100.0%		$1.21
2037	Production		100.0%		$1.21
2038	Production		100.0%		$1.21

Figure 11.9: Sensitivity 1: General Information

Equipment Costs

Equipment Description		Bare Module Cost
conveyer	Process Machinery	$220,000
conveyer2	Process Machinery	$18,000
conveyer3	Process Machinery	$18,000
extractor	Process Machinery	$160,000
pump1	Process Machinery	$208,000
pump2	Process Machinery	$26,000
pump3	Process Machinery	$26,000
rotary drier	Process Machinery	$16,000
pelletizer	Process Machinery	$96,000
flash	Process Machinery	$957,000
oil/water decanter	Process Machinery	$32,000
pump4	Process Machinery	$188,000
fat splitter	Process Machinery	$117,000
reactor	Process Machinery	$16,000
pump5	Process Machinery	$40,000
pump6	Process Machinery	$66,000
heatX1- recycle solvent	Process Machinery	$266,000
heater1	Process Machinery	$32,000
heatX3	Process Machinery	$146,000
heater2	Process Machinery	$32,000
Total		***$2,680,000***

Figure 11.10: Sensitivity 1 Equipment Costs

Raw Materials

	Raw Material:	Unit:	Required Ratio:	Cost of Raw Material:
1	solvent	kg	0.5 kg per kg of Biofuel	$0.535 per kg
2	methanol	kg	0.1923077 kg per kg of Biofuel	$0.44 per kg

Total Weighted Average: $0.353 per kg of Biofuel

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
1	biomass pellets	kg	2.4938462 kg per kg of Biofuel	$0.211 per kg
2	wet glycerol	kg	0.0992308 kg per kg of Biofuel	$0.010 per kg

Total Weighted Average: $0.528 per kg of Biofuel

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
3	Process Water	gal	0 gal per kg of Biofuel	$0.000E+00 per gal
4	Cooling Water	lb	1589.9594 lb per kg of Biofuel	$3.125E-05 per lb
5	Electricity	kWh	1.2355881 kWh per kg of Biofuel	$0.120 per kWh

Total Weighted Average: $0.198 per kg of Biofuel

Variable Costs

General Expenses:

Selling / Transfer Expenses:	**3.00% of Sales**
Direct Research:	**4.80% of Sales**
Allocated Research:	**0.50% of Sales**
Administrative Expense:	**2.00% of Sales**
Management Incentive Compensation:	**1.25% of Sales**

Working Capital

Accounts Receivable	a	**30**	**Days**
Cash Reserves (excluding Raw Materials)	a	**30**	**Days**
Accounts Payable	a	**30**	**Days**
Biofuel Inventory	a	**4**	**Days**
Raw Materials	a	**2**	**Days**

Figure 11.11: Sensitivity 1 Raw Materials

Total Permanent Investment		
Cost of Site Preparations:	**5.00%**	**of Total Bare Module Costs**
Cost of Service Facilities:	**5.00%**	**of Total Bare Module Costs**
Allocated Costs for utility plants and related facilities:	**$0**	
Cost of Contingencies and Contractor Fees:	**18.00%**	**of Direct Permanent Investment**
Cost of Land:	**2.00%**	**of Total Depreciable Capital**
Cost of Royalties:	**$0**	
Cost of Plant Start-Up:	**10.00%**	**of Total Depreciable Capital**

Fixed Costs		
Operations		
Operators per Shift:	**1**	**(assuming 5 shifts)**
Direct Wages and Benefits:	**$40**	**/operator hour**
Direct Salaries and Benefits:	**15%**	**of Direct Wages and Benefits**
Operating Supplies and Services:	**6%**	**of Direct Wages and Benefits**
Technical Assistance to Manufacturing:	**$60,000.00**	**per year, for each Operator per Shift**
Control Laboratory:	**$65,000.00**	**per year, for each Operator per Shift**
Maintenance		
Wages and Benefits:	**4.50%**	**of Total Depreciable Capital**
Salaries and Benefits:	**25%**	**of Maintenance Wages and Benefits**
Materials and Services:	**100%**	**of Maintenance Wages and Benefits**
Maintenance Overhead:	**5%**	**of Maintenance Wages and Benefits**
Operating Overhead		
General Plant Overhead:	**7.10%**	**of Maintenance and Operations Wages and Benefits**
Mechanical Department Services:	**2.40%**	**of Maintenance and Operations Wages and Benefits**
Employee Relations Department:	**5.90%**	**of Maintenance and Operations Wages and Benefits**
Business Services:	**7.40%**	**of Maintenance and Operations Wages and Benefits**
Property Taxes and Insurance		
Property Taxes and Insurance:	**2%**	**of Total Depreciable Capital**
Straight Line Depreciation		
Direct Plant:	8.00%	**of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Allocated Plant:	6.00%	**of 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	**$0**	
Licensing Fees:	**$0**	
Miscellaneous:	**$0**	
Depletion Allowance		
Annual Depletion Allowance:	**$0**	

Figure 11.12: Sensitivity 1 Investment Details

Variable Cost Summary			
Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	37,205
Direct Research:		$	59,527
Allocated Research:		$	6,201
Administrative Expense:		$	24,803
Management Incentive Compensation:		$	15,502
Total General Expenses		$	143,238
Raw Materials	$0.352500 per kg of Biofuel		$361,284
Byproducts	$0.527693 per kg of Biofuel		($540,843)
Utilities	$0.197957 per kg of Biofuel		$202,890
Total Variable Costs		$	166,569

Fixed Cost Summary		
Operations		
Direct Wages and Benefits	$	416,000
Direct Salaries and Benefits	$	62,400
Operating Supplies and Services	$	24,960
Technical Assistance to Manufacturing	$	300,000
Control Laboratory	$	325,000
Total Operations	**$**	**1,128,360**
Maintenance		
Wages and Benefits	$	156,539
Salaries and Benefits	$	39,135
Materials and Services	$	156,539
Maintenance Overhead	$	7,827
Total Maintenance	**$**	**360,039**
Operating Overhead		
General Plant Overhead:	$	47,859
Mechanical Department Services:	$	16,178
Employee Relations Department:	$	39,770
Business Services:	$	49,881
Total Operating Overhead	**$**	**153,689**
Property Taxes and Insurance		
Property Taxes and Insurance:	$	69,573
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	$	-
Licensing Fees:	$	-
Miscellaneous:	$	-
Total Other Annual Expenses	**$**	**-**
Total Fixed Costs	**$**	**1,711,661**

Figure 11.13: Sensitivity 1 Variable and Fixed Costs

Investment Summary

Total Bare Module Costs:				
	Fabricated Equipment	$ -		
	Process Machinery	$ 2,680,000		
	Spares	$ -		
	Storage	$ -		
	Other Equipment	$ -		
	Catalysts	$ -		
	Computers, Software, Etc.	$ -		
	Total Bare Module Costs:		$ 2,680,000	
Direct Permanent Investment				
	Cost of Site Preparations:	$ 134,000		
	Cost of Service Facilities:	$ 134,000		
	Allocated Costs for utility plants and related facilities:	$ -		
	Direct Permanent Investment		$ 2,948,000	
Total Depreciable Capital				
	Cost of Contingencies & Contractor Fees	$ 530,640		
	Total Depreciable Capital		$ 3,478,640	
Total Permanent Investment				
	Cost of Land:	$ 69,573		
	Cost of Royalties:	$ -		
	Cost of Plant Start-Up:	$ 347,864		
	Total Permanent Investment - Unadjusted		$ 3,896,077	
	Site Factor		1.00	
	Total Permanent Investment		$ 3,896,077	

Working Capital

	2018	2019	2020
Accounts Receivable	$ 101,930	$ -	$ -
Cash Reserves	$ 157,360	$ -	$ -
Accounts Payable	$ (46,370)	$ -	$ -
Biofuel Inventory	$ 13,591	$ -	$ -
Raw Materials	$ 1,980	$ -	$ -
Total	**$ 228,491**	**$ -**	**$ -**
Present Value at 15%	*$ 198,687*	*$ -*	*$ -*

Total Capital Investment $ 4,094,764

Figure 11.14: Sensitivity 1 Investment Costs

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2017	0%		-	-	-	-	-	-	-	-	-	-	-	-
2018	0%		-	(3,896,100)	(228,500)	-	-	-	-	-	-	-	(4,124,600)	(3,586,600)
2019	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(695,700)	-	(1,333,800)	493,500	(840,300)	(144,600)	(3,695,900)
2020	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(1,113,200)	-	(1,751,200)	648,000	(1,103,300)	9,900	(3,689,400)
2021	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(667,900)	-	(1,306,000)	483,200	(822,800)	(154,900)	(3,777,900)
2022	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(400,700)	-	(1,038,800)	384,400	(654,500)	(253,700)	(3,904,100)
2023	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(400,700)	-	(1,038,800)	384,400	(654,500)	(253,700)	(4,013,800)
2024	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	(200,400)	-	(838,400)	310,200	(528,200)	(327,900)	(4,137,000)
2025	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,268,400)
2026	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,382,700)
2027	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,482,100)
2028	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,568,500)
2029	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,643,600)
2030	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,708,900)
2031	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,765,800)
2032	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,815,200)
2033	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,858,100)
2034	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,895,500)
2035	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,928,000)
2036	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,956,200)
2037	100%	$1.21	1,240,200	-	-	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(402,000)	(4,980,800)
2038	100%	$1.21	1,240,200	-	228,500	(166,600)	(1,711,700)	-	-	(638,100)	236,100	(402,000)	(173,500)	(4,990,000)

Figure 11.15: Sensitivity 1 Cash Flow Summary

Profitability Measures

The Internal Rate of Return (IRR) for this project is Negative IRR

The Net Present Value (NPV) of this project in 2017 is $ (4,990,000)

ROI Analysis (Third Production Year)

Annual Sales	**1,240,153**
Annual Costs	**(1,878,230)**
Depreciation	**(311,686)**
Income Tax	**351,412**
Net Earnings	**(598,351)**
Total Capital Investment	**4,124,567**
ROI	**-14.51%**

Figure 11.16: Sensitivity 1 Profitability Measures

Price and Flow Rate Input with an Assumed Scaling Factor for Capital Costs

The second sensitivity analysis built on the first sensitivity. This analysis kept the price of biodiesel at its 10 year 90th percentile and increased the flow rate of biodiesel product by a factor of five to match the input flow rate of Bio-Bean. The increase in flow rate implies an improvement in the investment company's collecting of coffee grounds, since coffee ground availability was a limiting factor here. Since the coffee ground inputs is quintupled in this analysis, all variable costs will quintuple as they scale linearly with the input grounds. Capital costs are assumed to have scaled by a factor of 0.6 and therefore multiplied by 3 (5 times 0.6), in accordance with advice from industrial consultants, in this analysis. The IRR of the project was 17% and the NPV was $0.9 million. The NPV became positive after the fourteenth year of operation and the ROI of the third year of operation was 9.5%.

General Information Sensitivity 2	
Process Title:	**Coffee Grounds to Biofuel**
Product:	**Biofuel**
Plant Site Location:	**NYC**
Site Factor:	**1.00**
Operating Hours per Year:	**7884**
Operating Days Per Year:	**329**
Operating Factor:	**0.9000**

Product Information

This Process will Yield

	650	kg of Biofuel per hour
	15,600	kg of Biofuel per day
	5,124,600	kg of Biofuel per year
Price	**$1.21**	**/kg**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2017	Design		0.0%		
2018	Construction	100%	0.0%		
2019	Production	0%	100.0%	20.00%	$1.21
2020	Production	0%	100.0%	32.00%	$1.21
2021	Production	0%	100.0%	19.20%	$1.21
2022	Production		100.0%	11.52%	$1.21
2023	Production		100.0%	11.52%	$1.21
2024	Production		100.0%	5.76%	$1.21
2025	Production		100.0%		$1.21
2026	Production		100.0%		$1.21
2027	Production		100.0%		$1.21
2028	Production		100.0%		$1.21
2029	Production		100.0%		$1.21
2030	Production		100.0%		$1.21
2031	Production		100.0%		$1.21
2032	Production		100.0%		$1.21
2033	Production		100.0%		$1.21
2034	Production		100.0%		$1.21
2035	Production		100.0%		$1.21
2036	Production		100.0%		$1.21
2037	Production		100.0%		$1.21
2038	Production		100.0%		$1.21

Figure 11.17: Sensitivity 2: General Information

Equipment Costs

Equipment Description		Bare Module Cost
conveyer	Process Machinery	$660,000
conveyer2	Process Machinery	$54,000
conveyer3	Process Machinery	$54,000
extractor	Process Machinery	$480,000
pump1	Process Machinery	$624,000
pump2	Process Machinery	$78,000
pump3	Process Machinery	$78,000
rotary drier	Process Machinery	$48,000
pelletizer	Process Machinery	$288,000
flash	Process Machinery	$2,871,000
oil/water decanter	Process Machinery	$96,000
pump4	Process Machinery	$564,000
fat splitter	Process Machinery	$351,000
reactor	Process Machinery	$48,000
pump5	Process Machinery	$120,000
pump6	Process Machinery	$198,000
heatX1- recycle solvent	Process Machinery	$798,000
heater1	Process Machinery	$96,000
heatX3	Process Machinery	$438,000
heater2	Process Machinery	$96,000
Total		***$8,040,000***

Figure 11.18: Sensitivity 2: Equipment Costs

Raw Materials

	Raw Material:	Unit:	Required Ratio:	Cost of Raw Material:
1	solvent	kg	0.5 kg per kg of Biofuel	$0.535 per kg
2	methanol	kg	0.1923077 kg per kg of Biofuel	$0.44 per kg

Total Weighted Average: $0.353 per kg of Biofuel

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
1	biomass pellets	kg	2.4938462 kg per kg of Biofuel	$0.211 per kg
2	wet glycerol	kg	0.0992308 kg per kg of Biofuel	$0.010 per kg

Total Weighted Average: $0.528 per kg of Biofuel

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per kg of Biofuel	$0.000E+00 per lb
3	Process Water	gal	0 gal per kg of Biofuel	$0.000E+00 per gal
4	Cooling Water	lb	1589.9594 lb per kg of Biofuel	$3.125E-05 per lb
5	Electricity	kWh	1.2355881 kWh per kg of Biofuel	$0.120 per kWh

Total Weighted Average: $0.198 per kg of Biofuel

Variable Costs

General Expenses:

Selling / Transfer Expenses:	**3.00% of Sales**
Direct Research:	**4.80% of Sales**
Allocated Research:	**0.50% of Sales**
Administrative Expense:	**2.00% of Sales**
Management Incentive Compensation:	**1.25% of Sales**

Working Capital

Accounts Receivable	a	**30**	**Days**
Cash Reserves (excluding Raw Materials)	a	**30**	**Days**
Accounts Payable	a	**30**	**Days**
Biofuel Inventory	a	**4**	**Days**
Raw Materials	a	**2**	**Days**

Figure 11.19: Sensitivity 2: Raw Materials

Total Permanent Investment		
Cost of Site Preparations:	**5.00%**	**of Total Bare Module Costs**
Cost of Service Facilities:	**5.00%**	**of Total Bare Module Costs**
Allocated Costs for utility plants and related facilities:	**$0**	
Cost of Contingencies and Contractor Fees:	**18.00%**	**of Direct Permanent Investment**
Cost of Land:	**2.00%**	**of Total Depreciable Capital**
Cost of Royalties:	**$0**	
Cost of Plant Start-Up:	**10.00%**	**of Total Depreciable Capital**

Fixed Costs		
Operations		
Operators per Shift:	**1**	**(assuming 5 shifts)**
Direct Wages and Benefits:	**$40**	**/operator hour**
Direct Salaries and Benefits:	**15%**	**of Direct Wages and Benefits**
Operating Supplies and Services:	**6%**	**of Direct Wages and Benefits**
Technical Assistance to Manufacturing:	**$60,000.00**	**per year, for each Operator per Shift**
Control Laboratory:	**$65,000.00**	**per year, for each Operator per Shift**
Maintenance		
Wages and Benefits:	**4.50%**	**of Total Depreciable Capital**
Salaries and Benefits:	**25%**	**of Maintenance Wages and Benefits**
Materials and Services:	**100%**	**of Maintenance Wages and Benefits**
Maintenance Overhead:	**5%**	**of Maintenance Wages and Benefits**
Operating Overhead		
General Plant Overhead:	**7.10%**	**of Maintenance and Operations Wages and Benefits**
Mechanical Department Services:	**2.40%**	**of Maintenance and Operations Wages and Benefits**
Employee Relations Department:	**5.90%**	**of Maintenance and Operations Wages and Benefits**
Business Services:	**7.40%**	**of Maintenance and Operations Wages and Benefits**
Property Taxes and Insurance		
Property Taxes and Insurance:	**2%**	**of Total Depreciable Capital**
Straight Line Depreciation		
Direct Plant:	8.00%	**of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Allocated Plant:	6.00%	**of 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	**$0**	
Licensing Fees:	**$0**	
Miscellaneous:	**$0**	
Depletion Allowance		
Annual Depletion Allowance:	**$0**	

Figure 11.20: Sensitivity 2: Investment Details

Variable Cost Summary				
Variable Costs at 100% Capacity:				
General Expenses				
	Selling / Transfer Expenses:		$	186,023
	Direct Research:		$	297,637
	Allocated Research:		$	31,004
	Administrative Expense:		$	124,015
	Management Incentive Compensation:		$	77,510
Total General Expenses			$	716,188
Raw Materials		$0.352500 per kg of Biofuel		$1,806,422
Byproducts		$0.527693 per kg of Biofuel		($2,704,214)
Utilities		$0.197957 per kg of Biofuel		$1,014,449
Total Variable Costs			**$**	**832,846**

Fixed Cost Summary			
Operations			
	Direct Wages and Benefits	$	416,000
	Direct Salaries and Benefits	$	62,400
	Operating Supplies and Services	$	24,960
	Technical Assistance to Manufacturing	$	300,000
	Control Laboratory	$	325,000
	Total Operations	**$**	**1,128,360**
Maintenance			
	Wages and Benefits	$	469,616
	Salaries and Benefits	$	117,404
	Materials and Services	$	469,616
	Maintenance Overhead	$	23,481
	Total Maintenance	**$**	**1,080,118**
Operating Overhead			
	General Plant Overhead:	$	75,645
	Mechanical Department Services:	$	25,570
	Employee Relations Department:	$	62,860
	Business Services:	$	78,841
	Total Operating Overhead	**$**	**242,916**
Property Taxes and Insurance			
	Property Taxes and Insurance:	$	208,718
Other Annual Expenses			
	Rental Fees (Office and Laboratory Space):	$	-
	Licensing Fees:	$	-
	Miscellaneous:	$	-
	Total Other Annual Expenses	**$**	**-**
Total Fixed Costs		**$**	**2,660,112**

Figure 11.21: Sensitivity 2: Variable and Fixed costs

Investment Summary

Total Bare Module Costs:			
Fabricated Equipment	$	-	
Process Machinery	$	8,040,000	
Spares	$	-	
Storage	$	-	
Other Equipment	$	-	
Catalysts	$	-	
Computers, Software, Etc.	$	-	
Total Bare Module Costs:			**$ 8,040,000**
Direct Permanent Investment			
Cost of Site Preparations:	$	402,000	
Cost of Service Facilities:	$	402,000	
Allocated Costs for utility plants and related facilities:	$	-	
Direct Permanent Investment			**$ 8,844,000**
Total Depreciable Capital			
Cost of Contingencies & Contractor Fees	$	1,591,920	
Total Depreciable Capital			**$ 10,435,920**
Total Permanent Investment			
Cost of Land:	$	208,718	
Cost of Royalties:	$	-	
Cost of Plant Start-Up:	$	1,043,592	
Total Permanent Investment – Unadjusted			$ 11,688,230
Site Factor			1.00
Total Permanent Investment			**$ 11,688,230**

Working Capital

	2018	2019	2020
Accounts Receivable	$ 509,652	$ -	$ -
Cash Reserves	$ 302,019	$ -	$ -
Accounts Payable	$ (231,852)	$ -	$ -
Biofuel Inventory	$ 67,954	$ -	$ -
Raw Materials	$ 9,898	$ -	$ -
Total	**$ 657,670**	**$ -**	**$ -**
Present Value at 15%	*$ 571,887*	*$ -*	*$ -*

Total Capital Investment	**$ 12,260,117**

Figure 11.22: Sensitivity 2: Investment Costs

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2017	0%		-	-	-	-	-	-	-	-	-	-	-	-
2018	0%		-	(11,688,200)	(657,700)	-	-	-	-	-	-	-	(12,345,900)	(10,735,600)
2019	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(2,087,200)	-	620,600	(229,600)	391,000	2,478,200	(8,861,700)
2020	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(3,339,500)	-	(631,700)	233,700	(398,000)	2,941,500	(6,927,600)
2021	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(2,003,700)	-	704,100	(260,500)	443,600	2,447,300	(5,528,400)
2022	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(1,202,200)	-	1,505,600	(557,100)	948,500	2,150,700	(4,459,100)
2023	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(1,202,200)	-	1,505,600	(557,100)	948,500	2,150,700	(3,529,200)
2024	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	(601,100)	-	2,106,700	(779,500)	1,327,200	1,928,300	(2,804,300)
2025	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(2,246,600)
2026	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(1,761,700)
2027	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(1,340,000)
2028	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(973,400)
2029	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(654,500)
2030	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(377,200)
2031	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	(136,200)
2032	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	73,500
2033	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	255,800
2034	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	414,300
2035	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	552,200
2036	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	672,000
2037	100%	$1.21	6,200,800	-	-	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	1,705,900	776,300
2038	100%	$1.21	6,200,800	-	657,700	(832,800)	(2,660,100)	-	-	2,707,800	(1,001,900)	1,705,900	2,363,600	901,800

Figure 11.23: Sensitivity 2: Cash Flow Summary

Profitability Measures

The Internal Rate of Return (IRR) for this project is 16.70%

The Net Present Value (NPV) of this project in 2017 is $ 901,800

ROI Analysis (Third Production Year)

Annual Sales	6,200,766
Annual Costs	(3,492,958
Depreciation	(935,058
Income Tax	(655,917
Net Earnings	1,116,83
Total Capital Investment	12,345,90
ROI	9.5%

Figure 11.24: Sensitivity 2: Profitability Measures

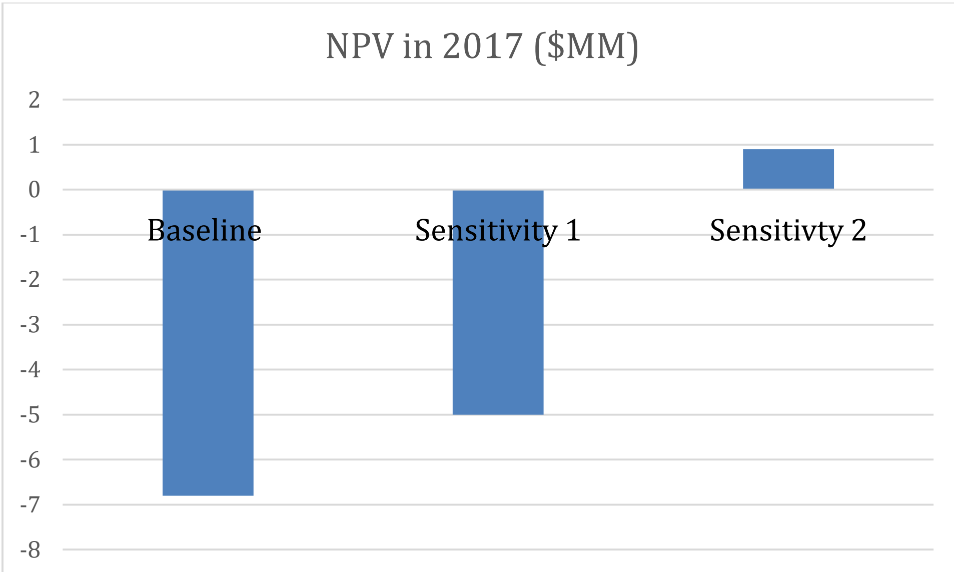


Figure 11.25: 2017 NPV Analysis

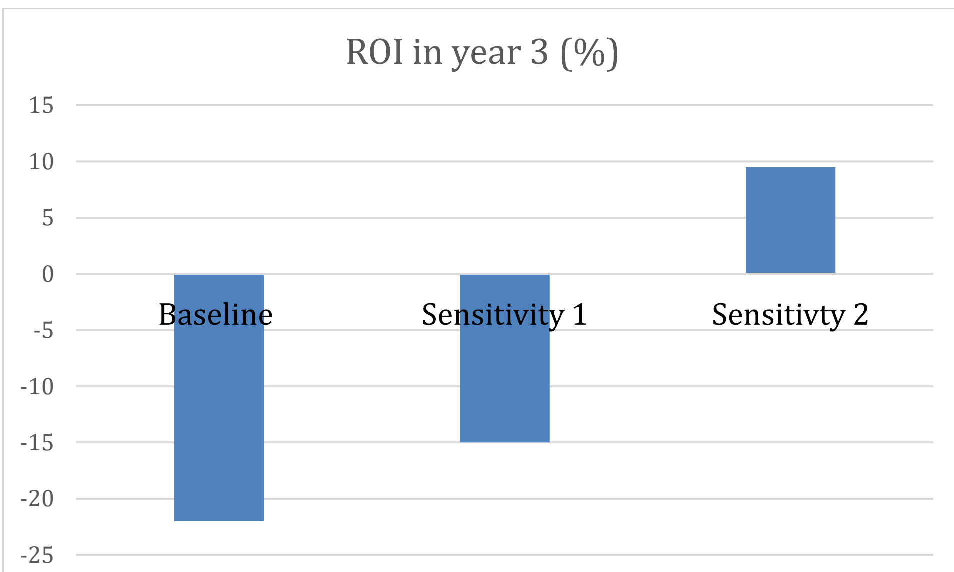


Figure 11.26: Third year ROI Analysis

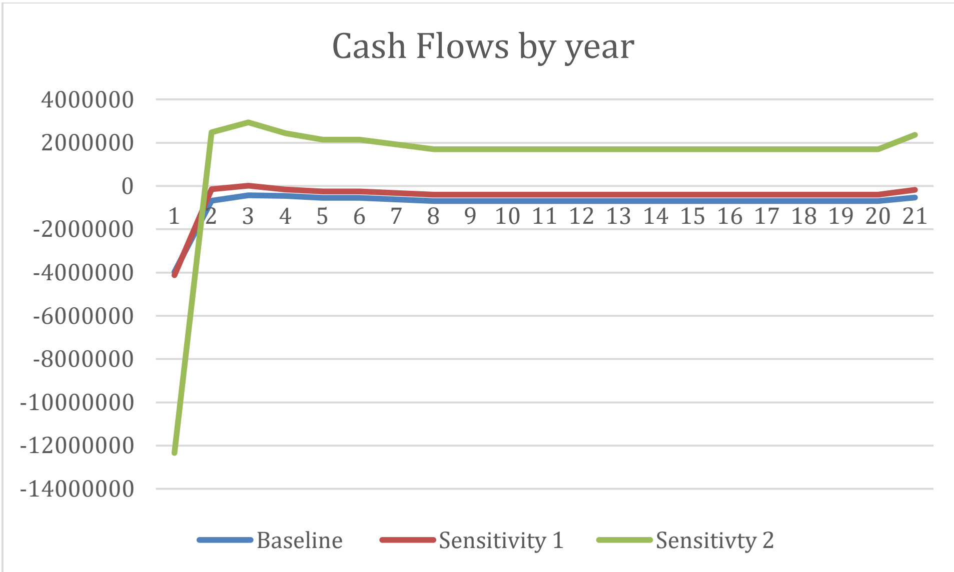


Figure 11.27: Cash Flow Analysis

Section 12: Conclusions and Recommendations

The coffee grounds to biodiesel investment has limited potential at current gas prices, since the sum of the variable costs of labor and raw materials is only slightly below the annual revenue from biodiesel and biomass pellets. However, the investment can be profitable sometime in the future, since biodiesel, like many other commodities, has a high volatility in price. In addition to the price of biodiesel, the viability of this investment is linked to the amount of coffee grounds available for collection. The baseline analysis based coffee ground collection on gathering all the waste from the 875 Starbucks and Dunkin Donuts in NYC. This goal must be expanded to more coffee shops and other coffee retailers like McDonalds, institutions in the area that consume large amounts of coffee such as universities, and a larger overall radius of collection. If five times as much coffee is collected and this project matches the capacity of Bio-Bean in the UK, the investment has much greater potential. Variable costs of labor and raw materials will likely scale linearly with the increase in coffee ground collection, and capital costs of the process scale are assumed to scale by a factor of 0.6. Based on the results from the second sensitivity analysis, if the price of biodiesel reaches its 90th percentile of the past ten years ($4/gal) and the investment company can hire a labor force to collect coffee grounds from the equivalent of 4,375 coffee shops, the project should have a positive NPV of $0.9 million given the assumed weighted average cost of capital of 15%. In addition to a positive NPV, the IRR and third year ROI of the project should be 17% and 9.5%, respectively. Even at this high biodiesel price and great increase in scale, the project's profitability is not off the charts. Therefore, the recommendation is to not pursue the coffee ground to biofuel process unless the previously stated sensitivity conditions are met and the investing company has no alternative investment with a higher NPV over the 20-year period.

Section 13: Acknowledgements

We would like to thank Dr. Daeyeon Lee and Professor Bruce Vrana for their help and guidance in completing this project. We would also like to thank our project author, Mr. Stephen Tieri, for providing us with immense support throughout every step of this process. We would also like to thank Mr. Leonard A. Fabiano, Dr. Ivan Baldychev of DuPoint, Dr. E. Robert Becker of Environex, Dr. Richard Bockrath of DuPont, Mr. Adam A. Brostow of Air Products and Chemicals, Mr. Brian K. Downey of Sanford C. Bernstein & Co., Dr. P.C. Gopalratnam, Dr. Michael Grady, Mr. David M. Kolesar of Dow Chemical, Dr. Robert Luo of Glaxo-Smith-Kline, Mr. Donald Maynard of Synovision Solutions LLC, Dr. Shaibal Roy, Mr. Gary Sawyer of CDI Corporation, Mr. Edward H. Steve, and Dr. Matthew Targett of LP Amina for all of their guidance during weekly design meetings. Each of these consultants contributed to our project's progress with their advice on innovative technologies and plant operation. Finally, we would like to thank Dr. Warren Seider and Dr. Marilyn Huff for sharing their knowledge on equipment design and costing.

Section 14: Appendices

Appendix A: Sample Calculations

<u>Energy Balances</u>:

$$Q_{Overall} = Q_{calorimetry} + Q_{latent\ heat} \quad (5.1)$$
$$Q_{Overall} = \left(m_{material} * \Delta T_{(Operational-Initial)} * c_{material}\right) + (m_{material} * H_{vaporization}) \quad (5.2)$$

[Q and m are in terms of flow rates]

Pump sizing:

$Q \div \rho \div A = v$

Q = [kg/s]
ρ = [kg/m^3]
A = [m^2]
v = [m/s]

$Head = \Delta P \div (g * \rho) + v^2 \div (2 * g)$

Head = [m]
ΔP = [Pa]
g = [m/s^2]
v = [m/s])

Example Calculation for pump 1:
Q = 0.29 gal/min = 0.018 kg/s
ρ = 742 kg/m^3
$A = \frac{\pi D^2}{4}$
A = 0.00166 m^2
v = 0.0146 m/s
Head = $8800000 \div (9.8 * 742) + 0.0146^2 \div (2 * 9.8) =$ 121m = 397 ft

Flash sizing:

k = 1.07 m/s
$V_{perm} = k * ((\rho_l - \rho_g) \div \rho_l)^{0.5}$
V = [m/s]
$\rho_l = [\frac{kg}{m^3}]$
$V_{perm} = \dot{V} \div A$

$\dot{V} = [\text{m3/s}]$
A = [m^2]
$A = \frac{\pi D^2}{4}$
D = [m]
L [m] = 3 * D

Flash Drum calculation:

$V_{perm} = 1.07 * (\frac{(988-2.88)}{988})^{0.5}$ = 0.1069 m/s
A = $\dot{V} \div V_{perm}$ = 1.92/ 0.1069 = 17.95 m^2
$A = \pi D^2/4$
D = 4.78 m = 15.68 ft
L = 3*D = 47.05 ft

Heat Exchanger E10 Calculation

In order to condense the solvents, the total energy required was calculated using the specific heats and the enthalpy of vaporizations for both Hexane and isopropanol.

Total energy to cool hexane from 85 °C to 30 °C.

1) Cooling to T_{boil}

Using $\dot{q} = \dot{m} * C_{p,g} * \boldsymbol{\Delta}T$,

T_{boil} = 68 °C

$\dot{m} = 4616 \frac{kg}{hr}$

$C_{p,g} = 1.88 \frac{kJ}{kg * K}$

$4616 \frac{kg}{hr} * 1.88 \frac{kJ}{kg*K} * (85 - 68)\ K = 147{,}527.36 \frac{kJ}{hr}$

2) Condensing

Using $\dot{q} = \dot{m}\boldsymbol{\Delta}H_{vap}$

$\Delta H_{vap} = 335.3 \frac{kJ}{kg}$

$4616 \frac{kg}{hr} * 335.3 \frac{kJ}{kg} = 1{,}547{,}744.8 \frac{kJ}{hr}$

3) Cooling to 30 °C

Using $\dot{q} = \dot{m} * C_{p,l} * \boldsymbol{\Delta}T$,

$\dot{m} = 4616 \frac{kg}{hr}$

$C_{p,l} = 2.26 \frac{kJ}{kg * K}$

$4616 \frac{kg}{hr} * 2.26 \frac{kJ}{kg*K} * (68 - 30)\ K = 396{,}422.08 \frac{kJ}{hr}$

Total energy to cool isopropanol from 85 °C to 30 °C.

1) Cooling to T_{boil}

Using $\dot{q} = \dot{m} * C_{p,g} * \boldsymbol{\Delta}T$,

T_{boil} = 82.6 °C

$\dot{m} = 4616 \frac{kg}{hr}$

$C_{p,g} = 1.71 \frac{kJ}{kg * K}$

$4616 \frac{kg}{hr} * 1.71 \frac{kJ}{kg*K} * (85 - 82.6)\ K = 18{,}944.064 \frac{kJ}{hr}$

2) Condensing

Using $\dot{q} = \dot{m}\boldsymbol{\Delta}H_{vap}$

$\Delta H_{vap} = 664 \frac{kJ}{kg}$

$4616 \frac{kg}{hr} * 664 \frac{kJ}{kg} = 3{,}065{,}024 \frac{kJ}{hr}$

3) Cooling to 30 °C

Using $\dot{q} = \dot{m} * C_{p,l} * \boldsymbol{\Delta}T$,

$\dot{m} = 4616 \frac{kg}{hr}$

$C_{p,l} = 2.68 \frac{kJ}{kg * K}$

$4616 \frac{kg}{hr} * 2.68 \frac{kJ}{kg*K} * (82.6 - 30)\ K = 396{,}422.08 \frac{kJ}{hr}$

Energy for Nitrogen Cooling

$\dot{q} = \dot{m} * C_{p,nitrogen} * \boldsymbol{\Delta}T$

$\dot{q} = 308550$

Total energy: $6{,}134{,}921 \frac{kJ}{hr}$

<u>Water flow required</u>

Assuming water is chilled and is going from 5 °C to 20 °C, to maintain a ΔT_{min} of 10 °C:

$\dot{q} = \dot{m} * C_{p,l} * \boldsymbol{\Delta}T$, with $C_{p,l} = 4.18 \frac{kJ}{kg*K}$, ΔT = 15 °C, and q = $6{,}134{,}921 \frac{kJ}{hr}$

$\dot{m} = 97{,}846 \frac{kg}{hr}$

Using *Product and Process Design* by Seider et al. an overall Heat Transfer Coefficient was assumed from Table 12.5 to be about $150 \frac{BTU}{°F*ft^2*hr}$ or $851 \frac{W}{m^2 * °C}$

using $q = U * A * \boldsymbol{\Delta}T_{lm} * F_t$

q=$6{,}134{,}921 \frac{kJ}{hr}$

U = $851 \frac{W}{m^2 * °C}$

$\boldsymbol{\Delta}T_{lm}$ = 41.9 °C

F_t was estimated using the graphs in *Product and Process Design* for a 2-4 shell and tube heat exchanger.

Calculating the R and S values as listed in Product and Process Design,

R = 3.7

S= 0.1875

Giving an F_t value of 0.994.

using $q = U * A * \boldsymbol{\Delta}T_{lm} * F_t$, $851 \frac{W}{m^2 * °C} * A * 41.9\ °C * 0.994 = 6{,}134{,}921 \frac{kJ}{hr}$

A = 173.2 m^2, or 1865 ft^2

Choosing a flow of $u = 0.7 \frac{m}{s}$, and density = $1000 \frac{kg}{m^3}$, and $\dot{m} = 97{,}846 \frac{kg}{hr}$

finding the inner tube cross sectional area needed for this flow with $Ai = \frac{\dot{m}}{density*u}$

$Ai = \dot{m} = \frac{97846 \frac{kg}{hr}}{1000 \frac{kg}{m^3} * u = 0.7 \frac{m}{s} * 3600 \frac{s}{hr}} = 0.038828\ m^2$ or 0.417937 ft^2

number of tubes per pass was calculated using $\frac{4*Ai}{\pi*Di} = \frac{No.\ of tubes}{pass}$

$$\frac{4 * 0.417937 ft^2}{\pi * 0.584\ in * \frac{144 in}{ft}} = \frac{No.\ of tubes}{pass} = 131$$

Assuming 16 ft tube..

the Heat transfer area = $\pi * Di * L = \pi * 0.584 in * \frac{16 ft}{12 \frac{in}{ft}} = 2.4462\ ft^2$

No. of Tube passes $= \frac{A}{\frac{heat\,transfer\,area}{tube} * \frac{tubes}{pass}} = \frac{1865\,ft^2}{2.4462 ft^2 * 125} = 6$

Assuming the tubes are 3/4 in OD on a 1 in. square pitch,

Total tubes = $\frac{tubes}{pass} * no.of\ passes = 131 * 6 = 786$

Using the Table 12.6 in *Product and Process Design*, the shell diameter would be 37 in.

finding minimum and maximum baffle spacing.

minimum was assumed to be 1/5 of the max shell diameter, and maximum was assumed to be the entire diameter.

B_{min} = 7.4 in

B_{max} = 37 in

choosing a baffle spacing in between, B = 22.2 in

Heat Exchanger E12 Calculation

In order to cool, the total energy required was calculated using the specific heats of the free fatty acids. An average specific heat was estimated due to the number of different compounds in coffee oil. A number was estimated based on average specific heats of other vegetable oils with similar composition.

Total energy to cool free fatty acids from 250 °C to 60 °C.

Using $\dot{q} = \dot{m} * C_{p,l} * \boldsymbol{\Delta}T$,

$\dot{m} = 116.8 \frac{kg}{hr}$

$C_{p,l} = 2.3 \frac{kJ}{kg * K}$

$4616 \frac{kg}{hr} * 2.26 \frac{kJ}{kg*K} * (250 - 60)\ K = 51042 \frac{kJ}{hr}$

Total energy: $51{,}042 \frac{kJ}{hr}$

Water flow required

Assuming water is cooling water and is going from 35 °C to 50 °C, to maintain a ΔT_{min} of 10 °C:

$\dot{q} = \dot{m} * C_{p,l} * \boldsymbol{\Delta}T$, with $C_{p,l} = 4.18 \frac{kJ}{kg*K}$, ΔT = 15 °C, and q = $51{,}042 \frac{kJ}{hr}$

$\dot{m} = 814.1 \frac{kg}{hr}$

Using *Product and Process Design* by Seider et al. an overall Heat Transfer Coefficient was assumed from Table 12.5 to be about $32.5 \frac{BTU}{°F*ft^2*hr}$ or $184.4 \frac{W}{m^2 * °C}$

using $q = U * A * \boldsymbol{\Delta}T_{lm} * F_t$

q=$51{,}042 \frac{kJ}{hr}$

U = $184.4 \frac{W}{m^2 * °C}$

$\boldsymbol{\Delta}T_{lm}$ = 84.2 °C

F_t was estimated using the graphs in *Product and Process Design* for a 2-4 shell and tube heat exchanger.

Calculating the R and S values as listed in Product and Process Design,

R = 12.7

S= 0.07

Giving an F_t value of 0.97.

using $q = U * A * \boldsymbol{\Delta}T_{lm} * F_t$, $184.4 \frac{W}{m^2 * °C} * A * 84.2°C * 0.97 = 51{,}042 \frac{kJ}{hr}$

A = 3.4m^2, or 36.5 ft^2

Choosing a flow of $u = 0.2 \frac{m}{s}$, and density = $1000 \frac{kg}{m^3}$, and $\dot{m} = 814.1 \frac{kg}{hr}$

finding the inner tube cross sectional area needed for this flow with $Ai = \frac{\dot{m}}{density*u}$

Ai=$\frac{814.1\frac{kg}{hr}}{1000\frac{kg}{m^3}*0.2\frac{m}{s}*3600\frac{s}{hr}} = 0.001131\ m^2$ or 0.01217 ft^2

number of tubes per pass was calculated using $\frac{4*Ai}{\pi*Di} = \frac{No.\ of tubes}{pass}$

$$\frac{4 * 0.01217\text{ft}^2}{\pi * 0.584\ in * \frac{144 in}{ft}} = \frac{No.\ of tubes}{pass} = 4$$

Assuming 16 ft tube..

the Heat transfer area = $\pi * Di * L = \pi * 0.584 in * \frac{16 ft}{12\frac{in}{ft}} = 2.4462\ ft^2$

No. of Tube passes =$\frac{A}{\frac{heat\ transfer\ area}{tube} * \frac{tubes}{pass}} = \frac{36.5\ ft^2}{2.4462 ft^2 * 4} = 4$

Assuming the tubes are 3/4 in OD on a 1 in. square pitch,

Total tubes = $\frac{tubes}{pass} * no. of\ passes = 4 * 4 = 16$

Using the Table 12.6 in *Product and Process Design*, the shell diameter would be 8 in.

finding minimum and maximum baffle spacing.

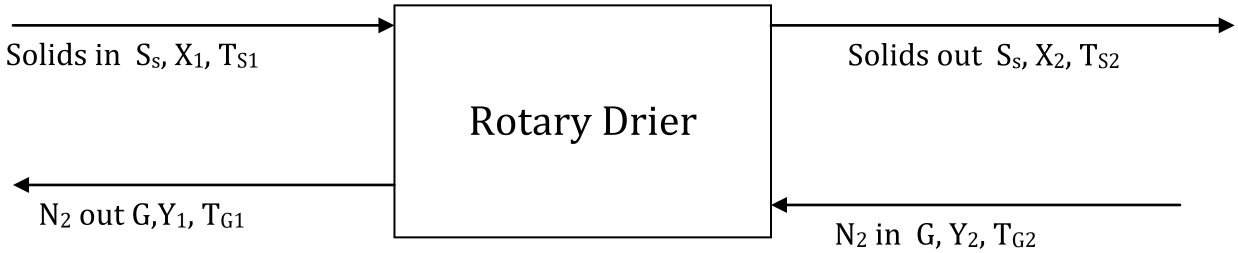
minimum was assumed to be 1/5 of the max shell diameter, and maximum was assumed to be the entire diameter.

B_{min} = 1.6 in

B_{max} = 8 in

choosing a baffle spacing in between, B = 4.8 in

Carrier Gas Flow Rate Calculation



Variables

$X_1 = 2.14 \frac{kg\ moisture}{kg\ solid}$

$X_2 = 0.05 \frac{kg\ moisture}{kg\ solid}$, so the final grounds have ~ 5% moisture

$T_{S1} = 30$ °C

$T_{S2} = 110$ °C

$T_{G2} = 120$ °C

$T_{G1} = 36.5$ °C

$Y_2 = 0$

$Y_1 = ?$

G = ?

latent heat on the moisture = $\lambda_o = 605.7 \frac{kJ}{kg}$

$C_{p,solid} = 1.672 \frac{kJ}{kg*K}$

$C_{p.moisture} = 2.5 \frac{kJ}{kg*K}$

$C_{p,\ Nitrogen} = 1.1 \frac{kJ}{kg*K}$

Doing a Material Balance on the moisture content:

$G*Y_2 + S_S*X_1 = S_S * X_2 + G*Y_1$

$G\ (\ 0\ ) + (324.2\ kg)(2.14) = (324.2\ kg)(0.05) + GY_1$

$679 = GY_1$

Energy Balance on the system

$G*H_{G2} + S_S*H_{S1} = G*H_{G1} + S_S*H_{S2}$

Where the enthalpies for the gas, H_{Gi}, are given by the equation

$H_{Gi} = (C_{p,\ Nitrogen}+C_{p,moisture}*Y_i)*(T_{Gi} - T_o) + Y_i*\lambda_o$

so for each H value:

$H_{G2} = (1.1 + 2.5*(0))*(120 - 0) + 0*605.7 = 132 \frac{kJ}{kg}$

$H_{G1} = (1.1 + 2.5*Y_1)*(36.5 - 0) + Y_1*605.7 = 40.15 \frac{kJ}{kg} + 697*Y_1 \frac{kJ}{kg}$

The enthalpies for the solid are given by:

$H_{Si} = C_{P,solid}\ (T_{Si} - T_o) + X_i*C_{p,moisture}\ (T_{Si} - T_o)$

so

$H_{S1} = (1.672)\ (30 - 0) + (2.14)(2.5)\ (30 - T_o) = 210.66 \frac{kJ}{kg}$

$H_{S2} = 1.672\ (110-0) + (0.05)(2.5)\ (110 - 0) = 197 \frac{kJ}{kg}$

plugging into the energy balance:
$121*G + 324.2*(210.66) = G*(40.15+697*Y_1) + 324.2*197$
$121*G + 68296 = 40.15*G +697*G*Y_1 + 63867$
Then substituting in $678 = G*Y_1$ which was derived from the material balance:
$121*G + 68296 = 40.15*G +697*678 + 63867$

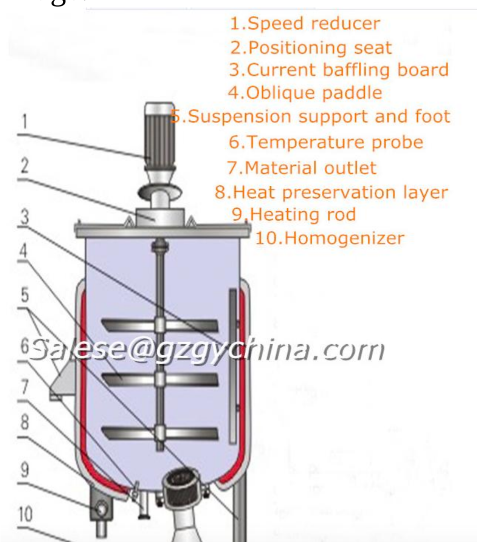
G ≈ 5100 kg/hr

Appendix B: Equipment Images, Quotes and Specifications

The following images, quoted prices and specifications are based on Alibaba.com research. They are all cited in Section 17: Resources.

Heaters-

"CE New design chemical machinery equipment, cosmetics production equipment"
Cost: $10,000
Image:



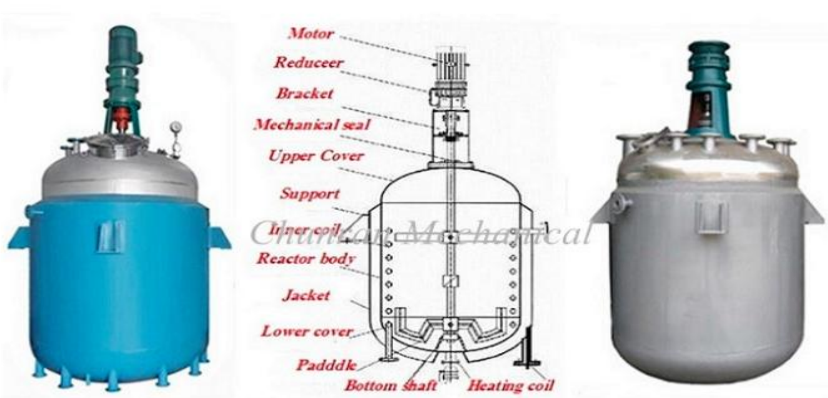
Specifications:

Item	Model	Capacity	Mixer power	Mixer speed	Homogenizer power	Homogenizer speed	The method of the heat
		L	kw	rpm	kw	rpm	
1	GYM200	200	1.5	0~65	3	3000	Steam or the electric
2	GYM500	500	2.2	0~65	4	3000	
3	GYM1000	1000	2.2-4	0~65	7.5	3000	
4	GYM1500	1500	4-5.5	0~65	11	3000	
5	GYM2000	2000	5.5	0~53	11	3000	
6	GYM3000	3000	7.5	0~53	15	1500	
7	GYM5000	5000	11	0~53	22	1500	

Bubble Esterification Reactor-

"Export oriented bubble column reactor with ISO certified seal"
Cost: $5,000
Specifications and Image:

Model & Specification	PR500	PR1000	PR2000	PR3000	PR5000
Volume L	500	1000	2000	3000	5000
Max pressure	12 Bar	12 Bar	12 Bar	12 Bar	12 Bar
Body diameter mm	900	1200	1400	1600	1900
Jacket diameter mm	1000	1300	1500	1700	2000
Height mm	1820	2200	2360	2380	3100
Power kwh	0.75	1.8	2.6	3.5	5.0
Mixing Speed r/min	60-200	60-200	60-200	60-200	60-200



Rotary Dryer-

"High output drying equipment/rotary drier with reasonable structure"

Cost: $5,000

Image:

Specifications:

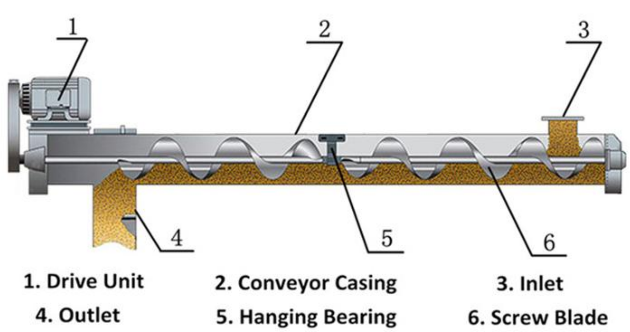
Specification (m)	Capacity (T/H)	Main motor		reduction box		Weight (T)
		Power(KW)	model	model	Speed ratio	
1 × 10M	0.5-1	5.5	Y132M2-6	ZL400-2	25	10.5
1.2×10m	1-2	7.5	Y160M-6	ZL500-1	25	13.5
1.5×12m	2-5	11	Y160L-6	JZQ500-3	25	18.9
1.5×15m	4-6	15	Y180L-6	JZQ500-3	25	21
1.8×12m	5-8	18.5	Y200L1-6	ZQ50-162	16.46	22.83
2.2×12m	6-10	18.5	Y200L1-6	JZQ650-3	31.5	37.6
2.2×14m	7-12	18.5	Y200L1-6	JZQ650-3	31.5	40
2.2×16m	9-14	30	Y225M-6	JZQ750-3	31.5	45
2.4×14m	10-16	30	Y250M-6	JZQ750-3	31.5	51
2.4×18m	12-18	37	Y250M-6	ZL85-13-1	27.16	54
2.4×20m	14-22	37	Y250N-6	ZL85-13-1	27.16	54.14
3×20m	16-25	55	Y250M-4	ZL100-16-1	41.52	78
Φ3×25m	32-36	75	YR280M-4	ZL100-16-1	41.52	104.9

Screw Conveyor

"Manufacturer Supplier Soybean meal chain conveyor"

Cost: $5,000

Image:



Specifications:

Model	LS100	LS200	LS315	LS400	LS500	LS630	LS800	LS1000	LS1250
screw diameter（mm）	100	200	315	400	500	630	800	1000	1250
pitch（mm）	100	200	315	355	400	450	500	560	630
speed（r/min）	140	90	75	75	60	60	45	35	30
capacity(m^3/h)	2.2	11	36.4	66.1	93.1	160	223	304	458
power（kw）	1.1	2.2	3.2	5.1	6.1	8.6	12	16	24.4

Extractor:
"Sludge dewatering horizontal decanter centrifuge machine MDS313"
Cost: $50,000
Image:

Specifications:

Model	Screw Shaft Specification (mm)	Sludge Cake Outlet Distance (mm)	Machine Specification (mm)			Net Wetight(kg)	Running Weight (kg)	Power (kW)
			Length	Width	Height			
MDS 101	Φ100x1	215	1861	736	1072	205	315	0.24
MDS 131	Φ130x1	250	1861	736	1072	205	315	0.24
MDS 132	Φ130x2	250	1929	912	982	275	450	0.36
MDS 201	Φ200x1	350	2580	833	1375	520	720	0.3
MDS 202	Φ200x2	350	2650	1055	1375	720	1000	0.66
MDS 311	Φ310x1	495	3436	941	1671	910	1320	0.74
MDS 312	Φ310x2	495	3643	1260	1822	1350	2090	1.11
MDS 313	Φ310x3	495	3981	1050	1671	1820	2820	1.86
MDS 411	Φ410x1	585	3805	994	2130	1610	1900	1.87
MDS 412	Φ410x2	585	4365	1550	2155	2300	3250	3.75
MDS 413	Φ410x3	585	4565	2100	2156	3350	4850	6
MDS 414	Φ410x4	585	4660	2650	2190	4500	6100	8.2

Pelletizer
"Pellet Machine"
Cost: $30,000
Image:

Specifications:

Kelly Lee   Luoyang Luodate Machinery Equipment Co., Ltd.

Hi Chelsea Giller

Good day,

Regarding this pellet machine:

1. The host frame and driven wheel of the main spindle use HT150 cast iron casting mold, solid and durable.
2. The high yield, low noise, convenient operation and maintenance.
3. The VVVF (electromagnetic speed) feeding, is equipped with overload protection device, a magnetic plate iron removing device.
4.Ring die aperture diameter 6-12 mm,capacity is 0.3-0.5 T/H;
5. Main motor power is 22kw, speed 470 rpm. Feeder power is 0.75kw, Forced feeding device of power is 0.75kw,
6. The ring die material is special alloy steel, consists of 12 elements,abrasion resistant and long service life.
7. Can be used for pellet of rice husk, palm fiber,wheat straw, cotton stalk, sawdust, wood chips, palm shell, sunflower, olive residue, bagasse and other biomass.

Best Regards
Kelly

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