1. Introduction & Background:

As one of world's largest agricultural commodities, coffee is simultaneously a significant contributor to waste and has the potential to be an abundant renewable fuel source as biodiesel. The waste product created after the coffee brewing process is referred to as 'spent coffee grounds', or 'SCG'. Biodiesel is a type of fuel that is made from the vegetable oils or animal fats, and produces less pollutants than conventional petroleum diesel. Traditionally, biodiesel is created by combining plant oils or animal fats with ethanol or methanol to produce ethyl esters or methyl esters respectively. Various alcohols can react with oils to create esters. Biodiesel typically consists of entirely all esters or a mixture consisting of approximately 20% esters and about 80% conventional petroleum. For the purposes of this proposal, we are assuming that Rutgers will utilize this biodiesel as a mixture, rather than as 'neat' biodiesel which would consist of 100% esters. Neat biodiesel consists of a large cetane number and is oxygen rich. The cetane number indicates that the combustion speed of the fuel, a higher cetane number indicates that the combustion speed will be faster. Fast combustion speeds are ideal in a culinary setting, such as the dining hall. Biodiesel derived from vegetable oil typically consists of a cetane number between 46 and 52. Although the production of biodiesel is about 2.5 percent less efficient than the production of petroleum diesel, biodiesel produces at least three times as much energy for an equivalent amount of petroleum fuel. SCG consists of approximately 9.3% to 17% of lipids. After these lipids are extracted, they are transesterified, a process that enables the exchange of organic group R" of an ester with the organic group R' of alcohol through the use of a catalyst. This transesterification process forms fatty acid methyl esters, also known by the acronym 'FAME'. We have elected to model our design proposal around the soxhlet extraction method, the primary method used for lipid extraction from SCG's. As coffee grounds are one of the largest contributors to the organic waste in the dining halls, and can produce such clean and powerful fuel, it is an ideal candidate for use to power the dining halls' various stoves and ovens.

Our proposal is to utilize an existing technique for extracting the oil, lipids, from spent coffee grounds, SCG, to produce biodiesel that can be utilized on site. Specifically, we are proposing for this process to be used for the dining halls on campus. The advantages would not only include a reduction in the energy costs required for operation, but it also would also include a decrease in the amount of fuel used for waste removal. Moreover, this alternative fuels source is especially beneficial for use in the dining halls as it is biodegradable and is non-toxic, unlike petroleum gas. This proposal includes an economic breakdown of exactly how much money will be saved, a step by step guide to implementing this into the dining halls, and the a design of the device to synthesize the fuel from the coffee grains.

2. Economic Analysis & Relevant Equations

According to our research, Rutgers dining halls use 22,460 lb of coffee per year. Once the grounds have been spent, approximately 15% of the weight of it is lipids, meaning around 3300 lbs of oil. Using an estimated oil molecular weight of 858 g/mol, there are 1781 moles of oil. This oil is converted into biodiesel at a 1:3 molar ratio. So theoretically 5343 moles of biodiesel are produced. Converting to pounds, around 3380 lb of biodiesel are produced. This is also around 460 gallons. This amount of biodiesel contains 57966 MJ of energy or 16.1 MW. This is quite a bit of energy given that Busch and Livingston Campuses combined consume around 12

MW. Using the cost of coffee at Applebee's at \$0.26 per ounce as an approximation, the cost of the coffee was around \$93,002.37. According to the Energy Institute of America, the cost of energy is \$0.10/kW. This means that the coffee derived biodiesel would produce energy that is worth \$1669.74

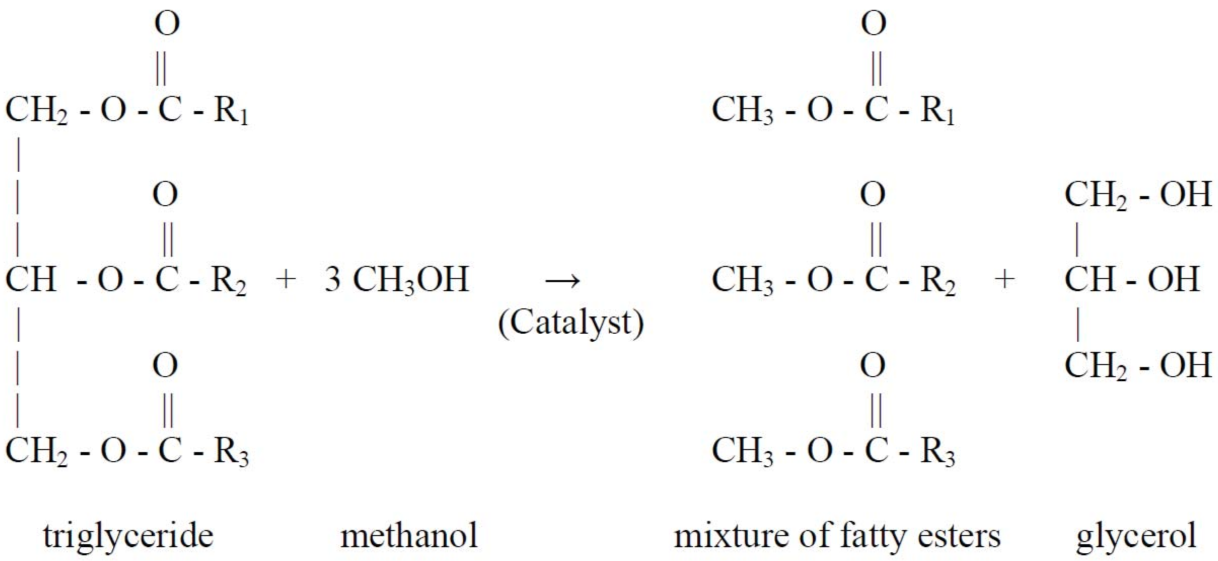


Figure 1. Main Conversion Reaction from coffee oil to biodiesel (fatty esters)

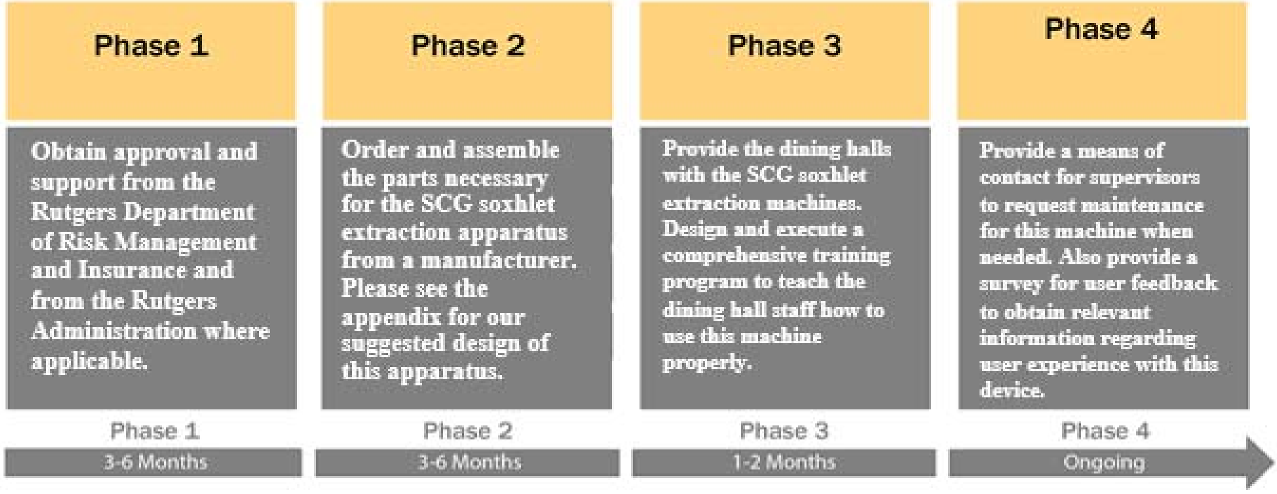
For every mole of oil extracted from the SCG, stoichiometrically, 3 moles of biodiesel can be made.

Costs

Solvent for lipid extraction is cyclohexane, which costs \$0.26 per gallon. As the cyclohexane would be recycled during after extraction, it is estimated that around 1100 gallons are needed coming to \$286. The total volume of methanol needed is 36 gallons, costing about \$54 at \$1.50 per gallon. Assuming the extractors' manufacturing cost is similar to the retail cost, each would cost around \$200. In this plan, each dining hall would have an extractor so an initial \$800 total.

So the total initial cost of the capital is $800 with yearly operating cost of material of around $340 saving around $1669 yearly, producing a net savings of $1329.

3. Implementation Timeline



Phase 1	Phase 2	Phase 3	Phase 4
Obtain approval and support from the Rutgers Department of Risk Management and Insurance and from the Rutgers Administration where applicable.	Order and assemble the parts necessary for the SCG soxhlet extraction apparatus from a manufacturer. Please see the appendix for our suggested design of this apparatus.	Provide the dining halls with the SCG soxhlet extraction machines. Design and execute a comprehensive training program to teach the dining hall staff how to use this machine properly.	Provide a means of contact for supervisors to request maintenance for this machine when needed. Also provide a survey for user feedback to obtain relevant information regarding user experience with this device.
Phase 1 3-6 Months	Phase 2 3-6 Months	Phase 3 1-2 Months	Phase 4 Ongoing

Phase 1:

Phase 1 may require approximately three to six months for completion. In phase 1, approval and financial support must be obtained by the Rutgers administration. As this proposal directly affects the affairs of the Rutgers Dining Services, we recommend correspondence with the office of the executive director of Rutgers Dining Services, Joe Charette. Furthermore, approval from from the Rutgers Department of Risk Management and Insurance, the Rutgers Environmental Health and Safety Department, and from any other applicable Rutgers Administration Officials is recommended.

Phase 2:

Phase 2 may require approximately three to six months for completion. In phase 2, the SCG soxhlet extraction apparatus -described further in the following section- will need to be manufactured. Using the design we have provided as supplementary material in the appendix, the required parts for the apparatus must be ordered and assembled by a manufacturer. Manufacturing this device is recommended as it is likely to provide more durability. However, this step may be substituted by utilizing either the Makerspace or the machine shop to assemble a similar apparatus by hand, as the apparatus is fairly simple and consists of only one moving electric part.

Phase 3:

Phase 3 may require approximately one to two months for completion. For phase 3, SCG soxhlet extraction machines will be distributed to the dining halls. Accompanying each machine will be a user manual as well as a training program to provide a comprehensive demonstration for how to properly and safely use these machines. The steps for utilizing these machines will include the following instructions:

- Step 1: Dry the spent grains (via convection by either the sun or in an oven)
- Step 2: Place the dried grains into the top portion of the machine. This is where it will be exposed to the solvent and heat, and the oils will pass through the semipermeable membrane into the bottom half of the machine.
- Step 3: Add the alcohol catalyst to the lipids for the spin process on the bottom half of the machine after step 2 is complete. This transforms the lipids into what we know as biodiesel.

- Step 4: Dispense biodiesel from the funnel at the bottom of the machine into a proper container for use. Dispose of the remaining spent grains from the top half of the machine.

Phase 4:

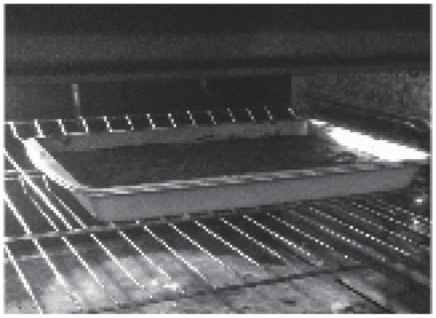
Phase 4 is included for purposes of machine maintenance and obtaining user feedback. As with all equipment, the dining hall supervisors should be provided a contact that is qualified to provide troubleshooting and maintenance to the machines in the event that an issue with the machines occurs. A survey for user feedback can be created using free services such as ‘surveymonkey.com’ or with ‘google forms’ to obtain relevant information regarding the user experience with the device. It can contain questions including but not limited to the following:

1. What-if any- is the most difficult part of using this machine?
2. What adjustments would make this device easier for you to use?

4. Proposal Implementation Suggestions

A. Coffee Fuel Machine Overview

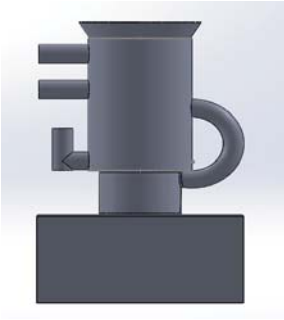
Step 1- Dry the grains



As stated previously, the first step in creation of this coffee biofuel is to dry out the SCG- spent coffee grains. The process of drying out SCG’s can be achieved by exposing them to any form of heat. Note that it is not necessary to expunge energy specifically for this purpose. SGC’s could be left outside and exposed to natural sunlight to dry out. However, in colder months it is highly recommended to place SCG’s either inside of, on top of, or beneath ovens that are already being utilized. This method would take advantage of the excess heat that is already being exhausted, and thus does contribute to any increase in energy demand.

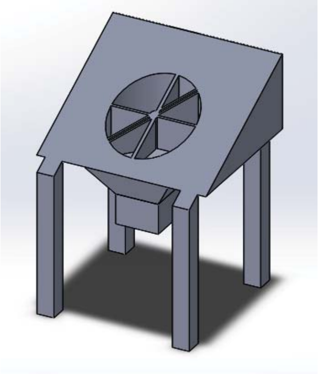
Step 2- Lipid Extraction with solvent

After successfully drying out the SCG's, commence the lipid extraction process by placing the dried SCG's into the top inlet of the machine. Here, the SCG's will be exposed to the alcohol solvent and additional heat. The oils that are extracted will pass through the semipermeable membrane into the lower portion of the machine.



Step 3- Cyclonic chamber and catalyst

The purpose of the lower portion of this device is to expose the lipids to the catalyst. It consists of a motor with fins that operate at approximately 500 rpm's- which is lower than a that of a standard washing machine which ranges at about 800 rpm's. In this case, the catalyst is an alcohol that must be manually added to the process. This is the phase of the process where the transesterification occurs, resulting in the formation of fatty acid methyl esters and glycerol. The finished product is the desired biodiesel containing a relatively high cetane number.

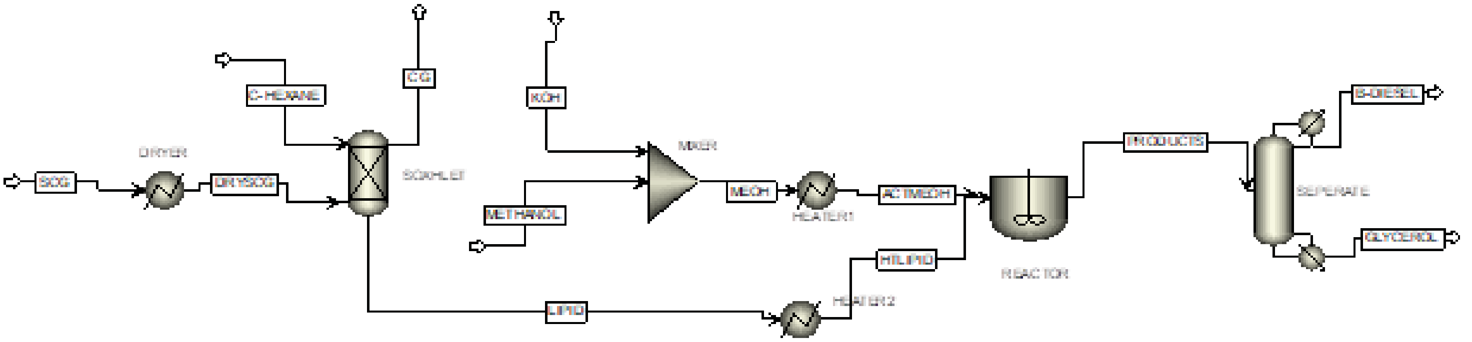


Step 4- Dispense funnel

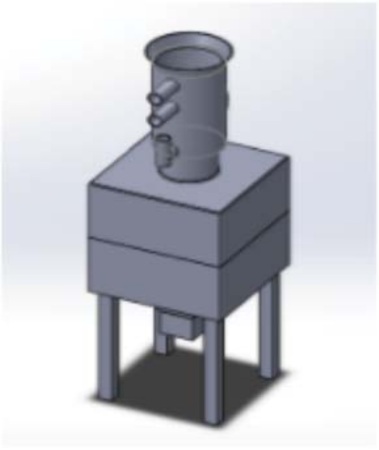
The biodiesel may be dispensed through the funnel at the bottom of the machine into an OSHA approved plastic gas can after the glycerol layer has been separated. Please note that there exist inexpensive plastic gas cans that may meet EPA requirements, but conflict with DOT and OSHA standard requirements. After the fuel has been successfully dispensed, if it is not being put to immediate use it must be stored in accordance with Rutgers Environmental Health and Safety requirements. Just as with gasoline, the biodiesel that is created must be placed in a cool location away from exposure to open flames and heat. Dispose of the remaining spent grains from the top half of the machine. After properly storing or using the fuel, clean the machine by emptying the remaining SCG's from the top half of the apparatus into the appropriate receptacle.

A. Machine Models and Design

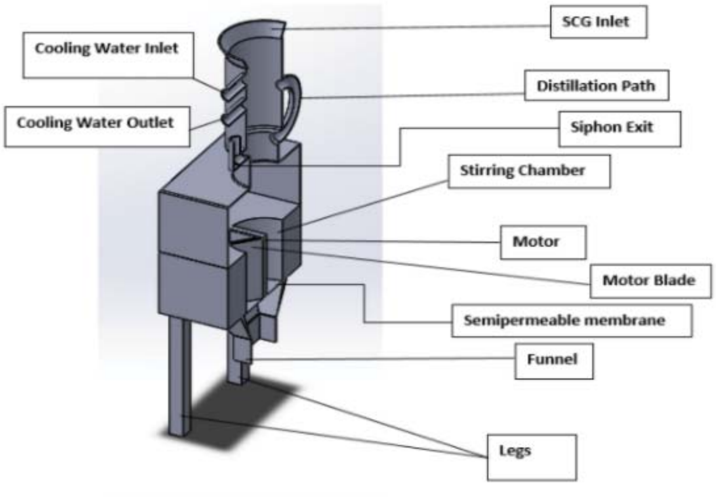
a. ASPEN Model



b. CAD Model of Entire Machine

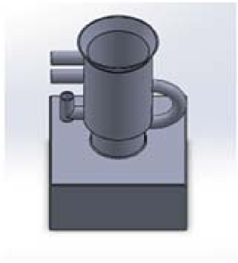


(Entire Machine- Full View)

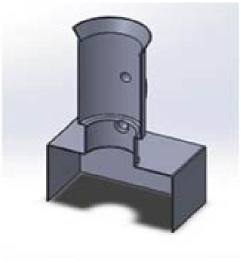


(Entire Machine- Sectioned View)

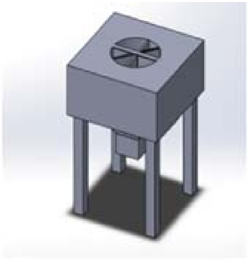
c. CAD Model of Individual Components



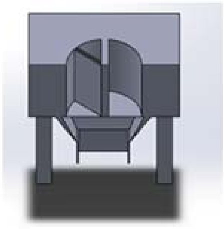
(Machine Top -Full View)



(Machine Top -Sectioned View)



(Machine Bottom- Full View)



(Machine Bottom- Sectioned View)

B. Applications

Dining Hall Kitchens

We highly recommend utilizing this device to produce biodiesel from SCG's within the Rutgers dining hall kitchens due to the fuels renewable abundance, low cost to produce, low toxicity, and high cetane number resulting in fast and effective combustion. It is ideal in this colunary setting since the fuel source is derived from an abundant waste product from the dining halls, the spent coffee grains. Using the fuel onsite will save on losses in energy caused by transporting the fuel to other locations.

Backup Generators for academic/ residential buildings

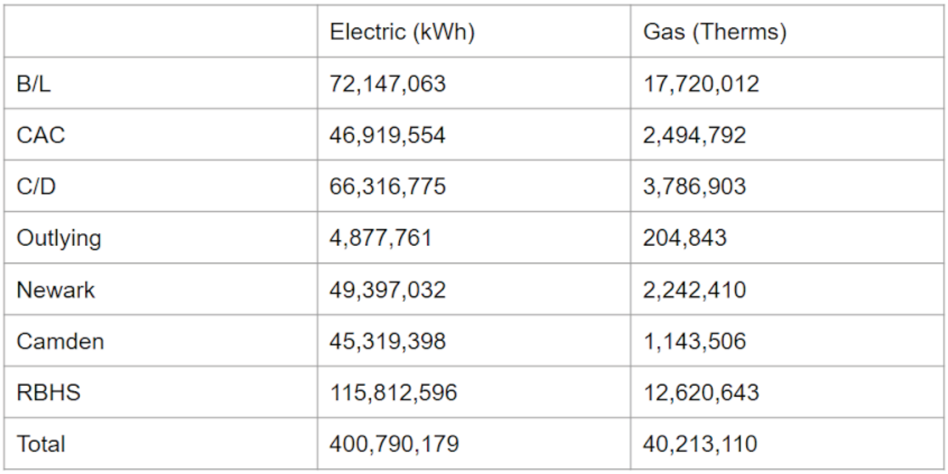
Backup generators typically operate on diesel fuel or natural gas. This biodiesel is a suitable alternative, and may be combined with conventional diesel to increase its yield, especially in the case of an emergency. Our proposal may also be applied and utilized as a backup fuel source for the Universities emergency generators throughout campus.

On Campus Power Plant

The cogeneration power plant on Busch campus is expected to undergo major facility renovations within the next few years. In its current condition, the busch power plant is capable of utilizing multiple fuel sources including diesel fuels. Since some of the waste heat is used directly for heating purposes in facilities and dorms, excess waste heat may be utilized for a bottoming cycle to recover some of the power and increase the facility's efficiency. The exit temperature of gas turbines are approximately 1000 °F. However, steam engine cycles have very low exit temperatures, allowing them to use this excess heat for a combined cycle. Utilizing some of this excess heat after a rankine cycle in conjunction with the coffee fuel biodiesel, the exit temperature of the rankine cycle could be raised once more, allowing for additional steam engine cycles to be operated in series with one another. Furthermore, this biofuel may be utilized to aid in the startup process when the facility deems it necessary to operate multiple turbines. Rutgers collects and monitors fuel data from ‘ICETEC’ to determine whether or not it's more economic to operate turbines or purchase electricity from PSEG. This biodiesel could serve as a resource for a third option, to be combined with conventional diesel, as its production and use is cost effective. Moreover, combining this biofuel with diesel would raise combustion temperatures, thus increasing the efficiency of the turbines.

Appendix A.1

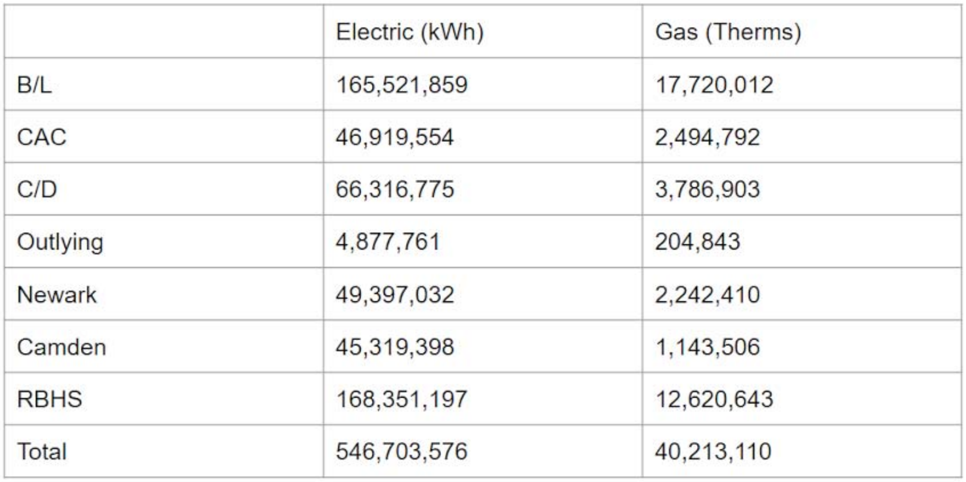
Purchased Utilities for 2013-14



	Electric (kWh)	Gas (Therms)
B/L	72,147,063	17,720,012
CAC	46,919,554	2,494,792
C/D	66,316,775	3,786,903
Outlying	4,877,761	204,843
Newark	49,397,032	2,242,410
Camden	45,319,398	1,143,506
RBHS	115,812,596	12,620,643
Total	400,790,179	40,213,110

Appendix A.2

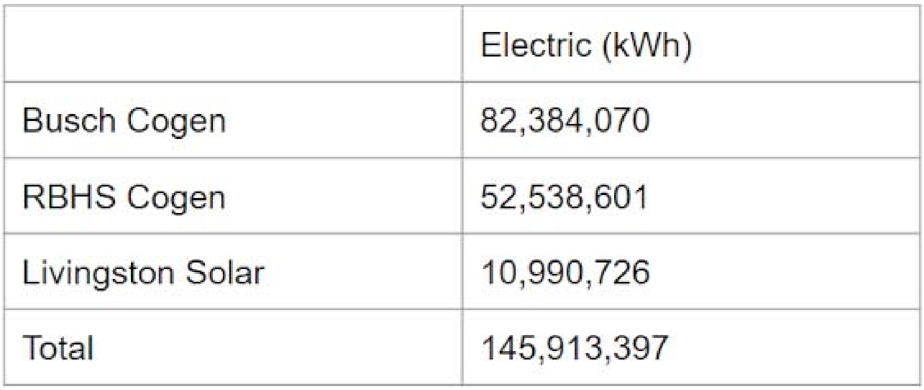
Total Utilities for 2013-14



	Electric (kWh)	Gas (Therms)
B/L	165,521,859	17,720,012
CAC	46,919,554	2,494,792
C/D	66,316,775	3,786,903
Outlying	4,877,761	204,843
Newark	49,397,032	2,242,410
Camden	45,319,398	1,143,506
RBHS	168,351,197	12,620,643
Total	546,703,576	40,213,110

Appendix A.3

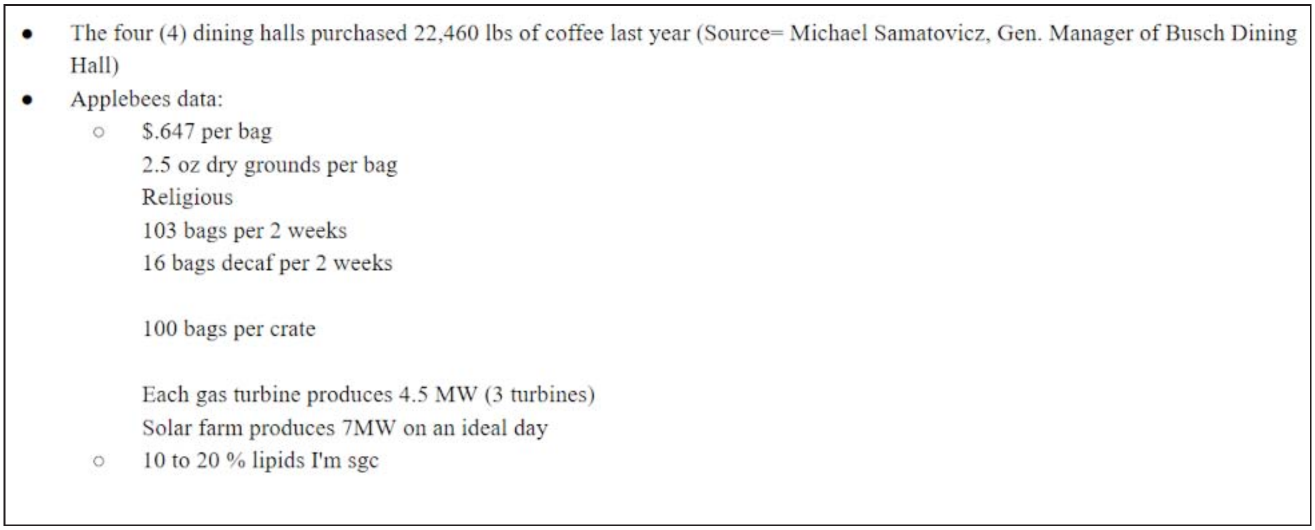
Produced Electricity for 2013-14



	Electric (kWh)
Busch Cogen	82,384,070
RBHS Cogen	52,538,601
Livingston Solar	10,990,726
Total	145,913,397

Appendix B.1

Coffee Data



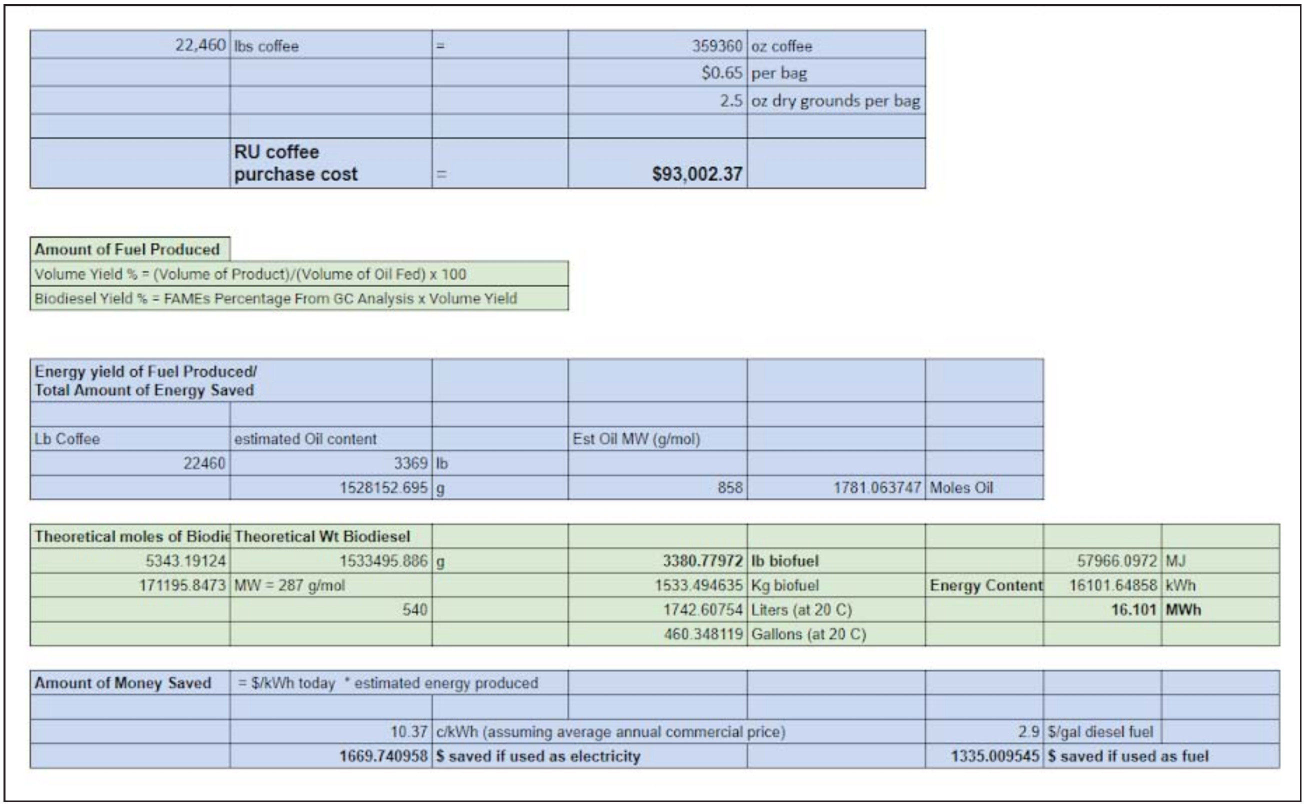
- The four (4) dining halls purchased 22,460 lbs of coffee last year (Source= Michael Samatovicz, Gen. Manager of Busch Dining Hall)
- Applebees data:
  - $.647 per bag
    2.5 oz dry grounds per bag
    Religious
    103 bags per 2 weeks
    16 bags decaf per 2 weeks

    100 bags per crate

    Each gas turbine produces 4.5 MW (3 turbines)
    Solar farm produces 7MW on an ideal day
  - 10 to 20 % lipids I'm sgc

Appendix B.2

Excel Calculations



22,460	lbs coffee	=	359360	oz coffee
			$0.65	per bag
			2.5	oz dry grounds per bag
	RU coffee purchase cost	=	**$93,002.37**	

Amount of Fuel Produced
Volume Yield % = (Volume of Product)/(Volume of Oil Fed) x 100
Biodiesel Yield % = FAMEs Percentage From GC Analysis x Volume Yield

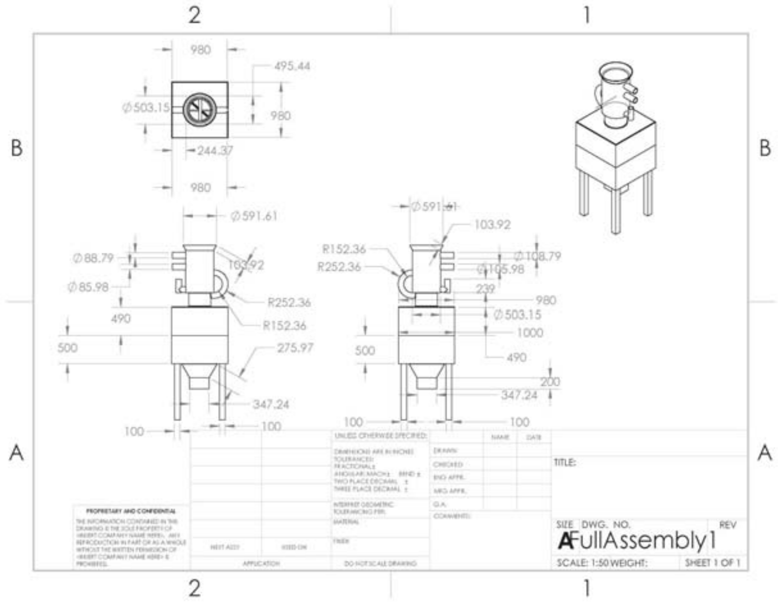
Energy yield of Fuel Produced/ Total Amount of Energy Saved					
Lb Coffee	estimated Oil content		Est Oil MW (g/mol)		
22460	3369	lb			
	1528152.695	g	858	1781.063747	Moles Oil

Theoretical moles of Biodie	**Theoretical Wt Biodiesel**						
5343.19124	1533495.886	g	**3380.77972**	**lb biofuel**		57966.0972	MJ
171195.8473	MW = 287 g/mol		1533.494635	Kg biofuel	**Energy Content**	16101.64858	kWh
	540		1742.60754	Liters (at 20 C)		**16.101**	**MWh**
			460.348119	Gallons (at 20 C)			

Amount of Money Saved	= $/kWh today * estimated energy produced						
	10.37	c/kWh (assuming average annual commercial price)			2.9	$/gal diesel fuel	
	1669.740958	**$ saved if used as electricity**			**1335.009545**	**$ saved if used as fuel**	

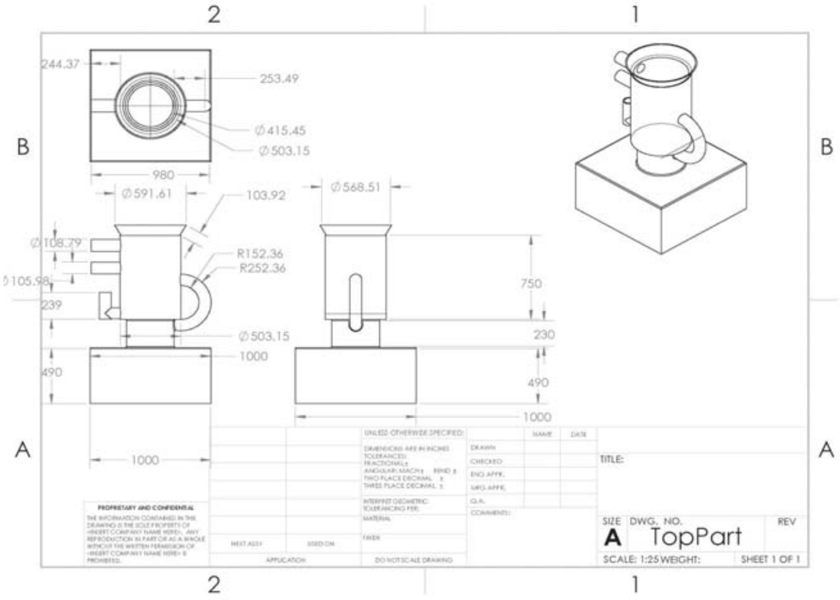
Appendix C.1

Full Assembly



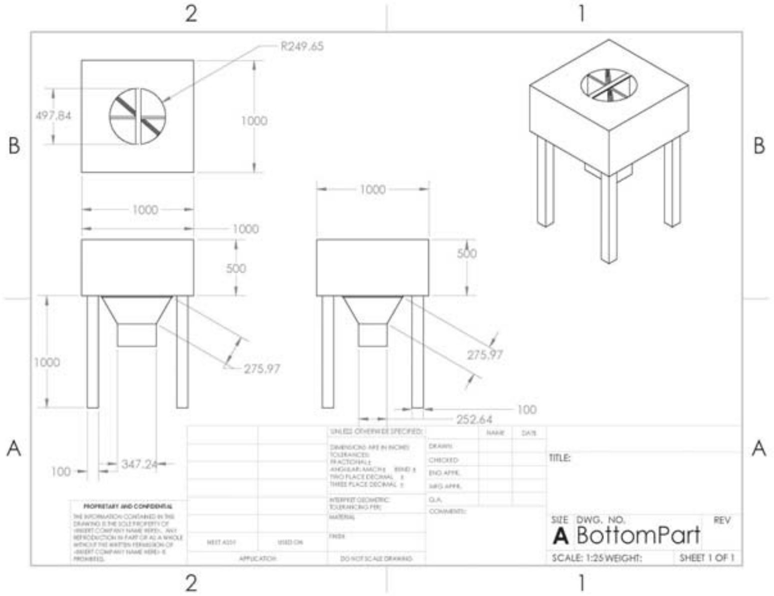
Appendix C.2

Top Apparatus



Appendix C.3

Bottom Apparatus



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