# AC 2009-232: ENCOURAGING STUDENTS TO EAT FRENCH FRIES? LESSONS LEARNED FROM STUDENT SUSTAINABILITY PROJECTS

**Sharon deMonsabert, George Mason University**

Dr. deMonsabert is an Associate Professor of Civil, Environmental and Infrastructure Engineering. She has over 15 years of academic experience. She researches and teaches courses related to Sustainable Development, Environmental Systems and Engineering, and Technical Entrepreneurship. Dr. deMonsabert was recently appointed to the position of Fellow for Academic Curricula at George Mason University.

**Jeremy Jessup, George Mason University**

Mr. Jessup received his Bachelor of Science Degree in Civil and Infrastucture Engineering in 2008. He is currently a graduate student focused on environmental engineering. He received a grant to study the incorporation of biodiesel as a sustainable fuel alternative at GMU. He received the faculty appreciation award for academic excellence in 2008. He has accepted employment with the Federal Energy Regulatory Commission and will be working on hydropower projects.

**Lenna Storm, George Mason University**

Ms. Storm is the Susainability Coordinator at George Mason University. She is currently pursuing her MS degree in Environmental Science and Policy from GMU. Ms. Storm is researching the adoption of green roofs on college campuses. She is an active member of the Association for the Advancement of Sustainability in Higher Education.

# Encouraging Students to Eat French Fries?

## Lessons learned from student sustainability projects

**Abstract**

George Mason University (GMU) is one of approximately 500 universities that have endorsed the American College and University Presidents' Climate Commitment (ACUPCC) which promises to reduce carbon emissions. As a part of this challenge, GMU is undertaking many steps to decrease its footprint including the production and use of biodiesel. As a student engineering project, biodiesel generation on the Fairfax, VA campus was investigated. Biodiesel is an alternative fuel source that has environmental benefits; most notably vegetable-based biodiesel reduces unburned hydrocarbons by 67%, carbon monoxide by 48% and particulate matter by 47% as compared with petroleum-based diesel. These environmental benefits fueled student exploration of the possibility of producing biodiesel from waste cooking oil. The process to generate biodiesel results in a fuel price per gallon that is significantly lower than conventional diesel in the current market. This per gallon savings contributes to a short capital cost payback period for biodiesel installation. Student calculations showed annual savings in the range of $13,000 with an estimated payback of around two months. If the development of biodiesel on campus was purely an economic or environmental issue, the decision would be simple. Unfortunately, the production and use of biodiesel is accompanied by many obstacles that are often overlooked by students. Some of these obstacles are legitimate concerns while others represent simple misconceptions. Safety considerations from the handling of hazardous materials, Federal and State regulations, outsourcing alternatives for biodiesel processing equipment, personnel resource limitations, vehicle maintenance concerns, selecting and locating an appropriate facility to house the system, and numerous other concerns were encountered in the student project. These topics are often presented in the classroom but not fully appreciated by students until they face them as real obstacles to a successful project completion. This paper explores the learning opportunities presented by the GMU biodiesel project including an improved understanding of adoption barriers of innovative sustainable solutions and the difficulties in obtaining reliable engineering data for analysis of new technologies.

**What is Biodiesel?**

Biodiesel is an alternative to diesel made from renewable, biological sources, instead of petroleum[8]. The sources of biodiesel include vegetable oils, animal fats, and recycled cooking oil. The most common technique used to produce biodiesel is transesterification. Transesterification occurs when a fat or oil is purified and then reacted with alcohol in a presence of a catalyst. Methanol and ethanol are the two most common alcohols used for this process while potassium hydroxide and sodium hydroxide are commonly used as the catalyst[8]. This reaction results in glycerol and esters, the esters are called biodiesel[7]. Biodiesel is non-toxic and also renewable because the sources can be replenished through farming[8]. Biodiesel can be used straight or mixed with any concentration of petroleum based diesel fuel. A mix of 20 percent biodiesel and 80 percent petroleum can be used in all diesel-burning equipment without any changes, while higher blends of biodiesel can be used in most diesel engines made after 1994 with little to no alterations[2]. It must be noted that biodiesel is not the same thing as raw or straight vegetable oil which is another fuel alternative that can be used in converted diesel engines[10].

Biodiesel has several advantages when compared to conventional diesel. First, biodiesel is more environmentally friendly. Biodiesel has fewer emissions, is biodegradable, and is a renewable source of energy[8]. The use of biodiesel, pure or blended, reduces the emissions of carbon dioxide ($CO_2$), particulate matter (PM), carbon monoxide (CO), and sulfur dioxide ($SO_2$)[2]. $CO_2$ contributes to the greenhouse effect; PM has been directly related to negative health effects; CO is deadly in concentrated doses; and $SO_2$ contributes to the formation of acid rain. Biodiesel also decreases the emissions of polycyclic aromatic hydrocarbons (PAHs) which have been related to the development of certain types of cancer[8]. The significant decrease in most emissions when compared to conventional diesel can be seen in Table 1:

**Table 1:**

**AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA**

| Emission Type | B100 | B20 |
|---|---|---|
| **Regulated** | | |
| Total Unburned Hydrocarbons | -67% | -20% |
| Carbon Monoxide | -48% | -12% |
| Particulate Matter | -47% | -12% |
| Nox | +10% | +2% to -2% |
| **Non-Regulated** | | |
| Sulfates | -100% | -20%* |
| PAH (Polycyclic Aromatic Hydrocarbons)** | -80% | -13% |
| nPAH (nitrated PAH's)** | -90% | -50%*** |
| Ozone potential of speciated HC | -50% | -10% |

*** Estimated from B100 result**
**** Average reduction across all compounds measured**
***** 2-nitroflourine results were within test method variability**

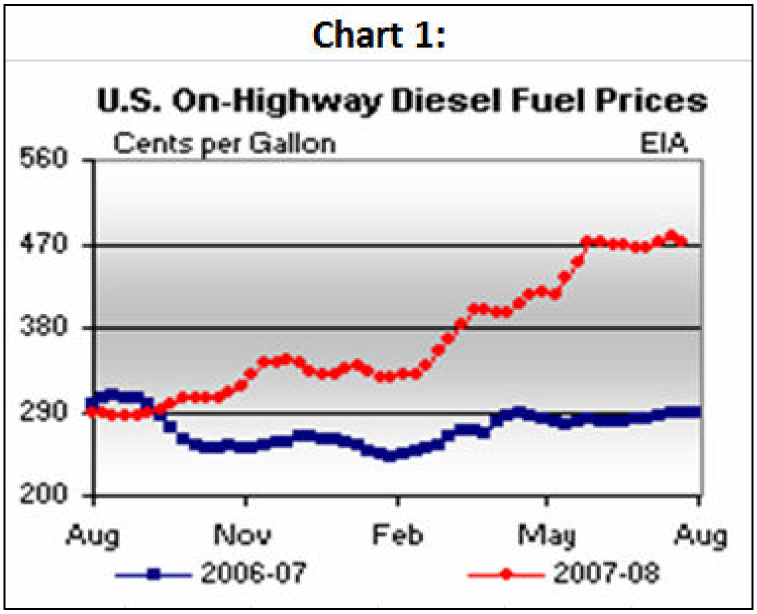
(National Biodiesel Board, 2008)

Biodiesel is also biodegradable which means it can decay as a result of natural agents such as bacteria[8]. According to the United States Environmental Protection Agency (EPA) biodiesel decomposes approximately four times faster than conventional diesel[2]. Secondly, biodiesel is safer than conventional diesel because it is non-toxic and less combustible. Biodiesel has a higher flashpoint which results in it burning at a higher temperature and lowers the chance of accidental combustion[8]. This makes biodiesel safer to store and transport[2]. Finally, biodiesel helps to lubricate the engine itself, which results in less wear on the engine than conventional diesel. Biodiesel acts as a solvent and loosens deposits from inside the engine which could eventually cause clogs, and pure biodiesel does not leave any deposits of its own. These factors lead to an increased engine life[8].

Although biodiesel does have many advantages it also has several disadvantages. First, the use of biodiesel has been shown to slightly increase the emissions of nitrogen oxides ($NO_x$), which is a key component in the formation of smog. The exact increase in $NO_x$ is still uncertain because of conflicting studies that have been conducted[8]. Another disadvantage of biodiesel has to do with its solvent like properties. Vehicles produced around or before 1992 may experience increased clogging with higher concentrations of biodiesel. This mainly occurs in the fuel filter and can be prevented by changing the fuel pump after switching to higher concentrated biodiesel. Older fuel systems may also have rubber components which can become degraded and may need to be replaced if biodiesel is used[8]. Finally, pure biodiesel has a higher “clouding” point than conventional diesel. This results in the biodiesel thickening at low temperatures and causes issues with storage and transportation in colder climates[2].

**Current Diesel Market**

The cost of diesel has experienced a recent rise, similar to the one experienced by gasoline. According to many experts, the large increase in prices is never going to return to what many Americans are accustomed to. Diesel is also currently running at an abnormal premium to gasoline in the United States. This trend is believed to be due to the large growth in global demand of diesel exported from the United States[9]. The reason for the increase in the global demand of diesel from the United States is thought to be due to the stricter standards instituted by the EPA. The EPA is requiring a cleaner form of fuel which is more costly to produce. The cleaner form of diesel is also more marketable to global markets because it now meets many of the tougher fuel specifications in Europe[9]. The increase in global demand has caused the cost of diesel to increase by 182.0 cents per gallon over the last year in the United States, to $4.72 per gallon on July 21, 2008[1]. The increase in diesel prices in the United States over the last two years can be seen in Chart 1.




(Energy Information Administration, 2008)

Trade sources are reporting that the trend of exporting cleaner diesel from the United States to Europe is only going to continue[9]. The Energy Information Administration predicts that national average retail diesel fuel prices will peak in the third quarter of 2008 at $4.75 per gallon (2008). They will eventually fall to $4.11 per gallon by the fourth quarter of 2009, still a major increase from the price of $2.89 per gallon from a year ago[1].

**Project Scope**

George Mason University (GMU) is one of approximately 500 universities that have endorsed the American College and University Presidents' Climate Commitment (ACUPCC) which promises to reduce carbon emissions. As a part of this challenge, GMU is investigating many steps to decrease its footprint including the production and use of biodiesel. In support of this initiative, a graduate project was developed; the goal of which was to perform a feasibility analysis to determine if switching from conventional diesel to biodiesel is technically and economically feasible for GMU. In order for this to be accomplished, several different aspects needed to be examined by the graduate student. First, the number of diesel vehicles and the amount of diesel that they utilize had to be determined. Once the usage was determined, numerous different biodiesel systems were sized and priced to determine the most cost effective option. Finally, the amount of waste cooking oil generated by GMU was calculated to determine if a sufficient amount of waste is produced by the University to support the demand of the diesel fleet. The goals of the project were focused on the environmental and economic feasibility. However, the lessons learned from the project encompassed a much broader scope.

**Learning Objectives**

The main learning objectives for this project focused around engineering applications and gaining field experience. The purpose was to apply the concepts, skills, and practices discussed in a classroom setting to a scenario that would commonly be experienced throughout a typical civil engineer's career. The four main learning objectives of this project were:

1. Gain real world engineering experience.
2. Implement educational knowledge in a professional setting
    a. Environmental systems analysis
    b. Engineering principles
3. Develop and expand skills necessary in a professional setting
    a. Team work
    b. Communication
    c. Leadership
4. Experience a complete project lifecycle

## Data Collection and Analysis

### *Fleet Analysis*

GMU currently has twelve diesel vehicles in their fleet. These vehicles are scattered between different departments and should have no problems with the switch to biodiesel because the oldest vehicle was produced in 1997. These vehicles traveled a combined 45,372 miles in 2007 and used nearly 4,012 gallons of diesel. This resulted in over $9,000 spent on diesel for fleet vehicles in 2007. Assuming at least the same amount of gallons of diesel is used in 2008; the amount of money spent on diesel for the University's fleet will increase due to the current state of the diesel market[5]. GMU's fleet diesel vehicles were paying $4.49 a gallon on September 4, 2008[14].

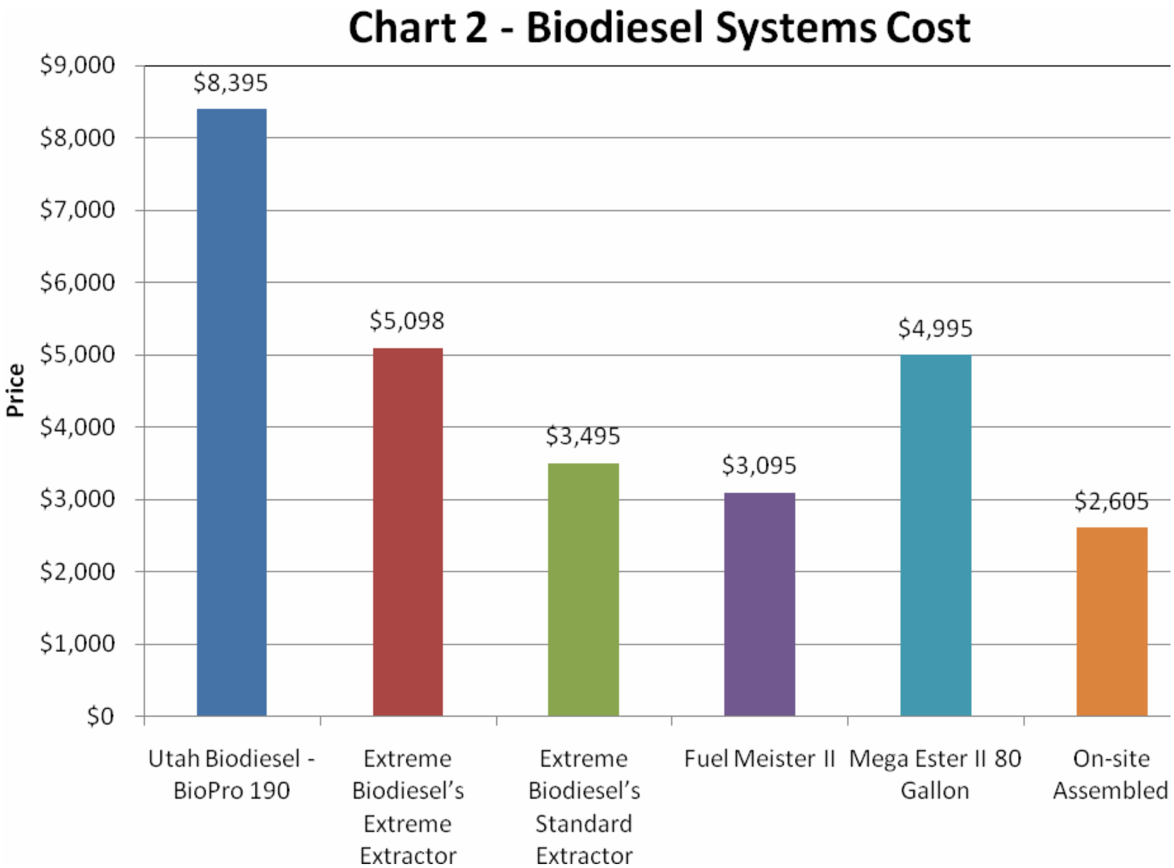
### *Biodiesel Systems and Costs*

The fleet demand of 4,012 gallons of diesel was used to size and price several systems. The systems were sized with the assumption that biodiesel would be produced approximately twice a week in approximately 40 gallon batches. The systems were priced two separate ways. First, a part by part price analysis was conducted for a system that would be assembled on-site. This analysis resulted in the total cost of the system being $2,605. The breakdown of the price analysis can be found in Table 2.

## Table 2 - Assembled On-Site

| Component Name | Source | Size | Quantity | Price ($)/Unit | Total Price ($) | Notes |
|---|---|---|---|---|---|---|
| Reaction Tank and $Na(CH_3O)$ Tank | http://www.b100supply.com/product_p/406%20cd.htm | 60gal and 15gal | 1 | 600 | 600 | |
| Pump | http://www.b100supply.com/product_p/201.htm | 110 Volt | 2 | 49.99 | 99.98 | |
| Collection Pump | http://www.b100supply.com/product_p/207.htm | 12 Volt | 1 | 179.99 | 179.99 | |
| Valve | Dax Startz | 3/4 in | 4 | 7 | 28 | |
| Piping | Dax Startz | 5 ft - 9 ft | 1 | 100 | 100 | |
| Pipe Fitting | Dax Startz | NA | 15 | 2.25 | 33.75 | |
| $Na(CH_3O)$ Pump | http://www.b100supply.com/product_p/214.htm | Hand Pump | 1 | 99.99 | 99.99 | |
| Drum Heater | http://www.fryer-to-fuel.com/store/product49.html | 1500 Watt | 1 | 157.99 | 157.99 | |
| Collection Heater | http://www.valleyvet.com/ct_detail.html?pgguid=2e87c5d7-7b6a-11d5-a192-00b0d0204ae5 | 120 Volt | 1 | 31.95 | 31.95 | |
| Methanol | http://www.aaa-chemicals.com/methanol.html | 55 gal | 1 | 329 | 329 | Includes Shipping, Quantity Lasts Approx. 2 Months |
| Sodium Hydroxide | http://www.aaa-chemicals.com/128-pounds-of-technical-grade-sodium-hydrox.html | 128 lbs | 1 | 219 | 219 | Includes Shipping, Quantity Lasts Approx. 3 Months |
| Collection Tank | http://www.biodieselwarehouse.com/xcart/product.php?productid=24&cat=5&page=1 | 50 gal | 1 | 125 | 125 | |
| Hoses | http://www.biodieselwarehouse.com/xcart/product.php?productid=135&cat=1&page=1 | 10 ft | 4 | 40 | 160 | |
| Camlock | http://www.b100supply.com/Camlock_p/133.htm | 3/4 in | 2 | 15 | 30 | |
| House Clamps | Dax Startz | NA | 8 | 1.29 | 10.32 | |
| Misc. Parts (switch, electrical wire, tape, etc.) | Dax Startz | NA | 1 | 300 | 300 | |
| Titration Kit | Dax Startz | NA | 1 | 50 | 50 | |
| Digital Scale | Dax Startz | NA | 1 | 30 | 30 | |
| Safety Equipment (goggles, MSDS Sheets, etc.) | Dax Startz | NA | 1 | 20 | 20 | |
| | | | | **Total Start-Up Price:** | 2604.97 | |

The part by part analysis included everything that would be needed to begin production of biodiesel. Analysis of several pre-assembled biodiesel processors was also conducted. Five different processers were analyzed from various different manufacturers. The most inexpensive of these five models is the Fuel Meister II which retails for $3,095. The prices for the five preassembled processors and the on-site assembled unit can be seen in Chart 2.




The pre-assembled options are priced only for the processor and other components such as pumps, collection tank(s), and chemicals will still need to be purchased. The different pre-assembled options along with the manufacturers' information can also be found in Table 3.

**Table 3 – Preassembled Systems**

| Name | Source | Price ($) |
|---|---|---|
| Utah Biodiesel - BioPro 190 | http://www.biodieselwarehouse.com/xcart/product.php?productid=40&cat=4&page=1 | 8395 |
| Extreme Biodiesel's Extreme Extractor | http://www.extremebiodiesel.com/extreme-extractor.aspx | 5098 |
| Extreme Biodiesel's Standard Extractor | http://www.extremebiodiesel.com/standard-extractor.aspx | 3495 |
| Fuel Meister II | http://www.fuelmeister.com/fuelmeister | 3095 |
| Mega Ester II 80 Gallon | http://www.evolutionbiodieselkits.com/mega-II-biodiesel-processor-specs.php | 4995 |
| | | |
| Note: These Units are only processors. Other equipment and supplies (pumps, collection tank(s), chemicals, etc.) are not included. | | |

The least expensive option for GMU would be to purchase components of the system separately and assemble the system on-site. If this option is chosen, the cost per gallon of biodiesel would be $1.24 per gallon[3]. This would result in a savings of $3.25 per gallon assuming the price paid for diesel on September 4, 2008. The system would be completely paid off in approximately 635 gallons or 58 days. Assuming a demand of 4,012 gallons, GMU would have saved approximately $13,000 by using biodiesel over conventional diesel. Even with the initial coast of the biodiesel system, a savings of just under $11,000 would occur. This savings does not consider the cost of a building, the cost of an operator, or additional chemicals. The cost calculations can be found in Table 4.

*Other Considerations*

Several additional aspects must be addressed when considering cost. Permits are often costly and timely to obtain, but no permits are required to produce or store biodiesel at this time[6]. Due to the relatively young concept of biodiesel, adequate research to support permits may still occur. In addition to no requirements for biodiesel permits, no permits are required for the storage and use of methanol and sodium hydroxide[6]. Once the system is in operation, additional inspection should be done to ensure all regulations and guidelines are being followed. In addition to permits, the cost associated with paying someone to operate the system must be considered. This was not analyzed in the cost calculations due to the uncertainty of the salary associated with such a position. This was also not analyzed because this position could be adopted into a current position which would result in no cost or only the difference in the raise acquired for the additional job responsibilities. The job responsibilities for this position would not require constant attention of the system, only periodic tasks and observance. Due to the chemicals involved in this process it is vital that the person responsible for this operation attends Hazards Communication Training through the Occupational Safety and Environmental Regulations Department[6].

**Table 4 - Cost Analysis**

| On-site Alternative | | |
|---|---|---|
| Diesel Demand (gal) | 4012 | |
| Initial Cost | $2,065 | |
| Price/gallon Produced | $1.24 | |
| Savings (assume $4.49/gal) | $3.25 | |
| Paid Off (gallons) | 635 | |
| Percent of Diesel Demand (%) | 16 | |
| Paid Off (days) | 58 | |
| | | |
| **Yearly Savings** | | |
| **Fuel Option** | **Price per Gallon** | **Yearly Cost** |
| Diesel | $4.49 | $18,013.88 |
| Biodiesel | $1.24 | $4,974.88 |
| | **Savings =** | **$13,039.00** |
| (note: Assuming 2007 Demand) | | |
| | | |
| **2007 Savings** | | |
| Estimated Yearly Savings | $13,039.00 | |
| Initial Cost of Unit | $2,065 | |
| **Savings =** | **$10,974.00** | |

The cost calculations do not consider several aspects that cannot be determined until the system is in operation. The system will need to be housed in a structure that is at least 12 ft by 16 ft[14]. This structure will need to be equipped with utility connections to electricity and water but will require no special ventilation. The change in electricity and water usage can also not be calculated until the system is in operation. Systems similar to the on-site assembled one have shown little to no change in utility usage in other locations[14].

*Waste Cooking Oil*

The amount of waste cooking oil produced by the Fairfax Campus of GMU was 25,725 lbs (3,321 gal) in 2007. This is an increase of nearly 5,000 lbs from 2006 and represents the general growth of waste cooking oil produced, which can be seen in Chart 3.


(Recycling and Waste Managment, 2003-2007)

The amount of biodiesel produced from used cooking oil is approximately a one to one ratio but depends mainly on the quality of the waste cooking oil. The cleaner the oil is the closer the outcome will be to a one to one ratio[11]. Assuming a one to one ration, GMU's Fairfax Campus currently does not produce enough waste cooking oil to meet the demand of the diesel vehicles in its fleet. However, the amount of waste cooking oil is expected to continually grow due to the construction of new dining facilities on campus and the increase in the number of students attending GMU. If the new facilities and increase students still do not produce enough waste cooking oil, additional sources must be determined. Several suggestions can be found in the *Areas to Grow* section below. GMU recently established a contract with FiltaFry that includes the transportation of waste cooking oil to a location on the Fairfax Campus, specified by the University, at no additional cost[13]. This eliminates concerns of purchasing a vehicle and hiring an employee to collect the waste cooking oil produced by GMU to meet fleet demand.

**Benefits for GMU**

The production and use of biodiesel by GMU offers several benefits beyond the generic environmental benefits of biodiesel. First, the production of biodiesel can be calculated in alternative fuel vehicle credits. The purer the blend of biodiesel the more credits that can be achieved[4]. Also, the production and use of biodiesel offers an excellent publicity opportunity. GMU has already taken many steps to become a more sustainable and environmentally cautious university. The production and use of biodiesel will offer a great centerpiece to the entire movement. Finally, the production and use of biodiesel on the campus of GMU will offer an excellent educational opportunity for many students.

**Areas to Grow**

The production and use of biodiesel on the Fairfax Campus of GMU is not only an economically feasible decision but also has many other benefits. The establishment of such a system is not limited to only the information mentioned in the previous sections of this report. There are several other areas that should be examined if this project comes to fruition. First, the amount of diesel used by off-road vehicles owned by GMU should be studied. Also, diesel vehicles not owned by GMU but operated for GMU, such as Reston Limousine, should be analyzed to evaluate the possibility of producing enough biodiesel to support these vehicles as well. The ultimate goal, if the production of biodiesel occurs on the campus of GMU, should be to supply all diesel vehicles owned by GMU and all diesel vehicles that operate for GMU. If this occurs, significantly more waste cooking oil will be needed. Other areas on the Fairfax Campus, such as the Patriot Center, should be utilized as a supplier of waste cooking oil. The amount produced by other campuses, such as Arlington and Prince William, should also be analyzed to determine if enough waste cooking oil is produced to support the increase in demand of biodiesel. If these options still fail to produce enough waste cooking oil, GMU should reach out into the neighboring community to obtain the amount needed.

**Community Feedback**

An informal survey was conducted on restaurants within close proximity of GMU's Fairfax Campus to gage the potential interest of the community. Google Maps was used to locate all the restaurants within approximately one mile of the Fairfax Campus. The search resulted in 39 restaurants within 1.3 miles of the Fairfax Campus. The majority of the restaurants are located in University Mall, across Braddock Road from the Fairfax Campus, or in Old Town Fairfax. Once the restaurants were located, each one was visited to determine the potential interest of the restaurant in allowing GMU to collect their waste cooking oil for no charge. The three possible outcomes of the survey are yes (Y) the restaurant is interested, no (N) the restaurant is not interested, or not applicable (NA). A restaurant received an NA if they do not use any cooking oil in their restaurant or if there was no person with the authority to accurately wage the potential interest available. The survey resulted in almost 73 percent of the restaurants applicable showing potential interest. A list of restaurants surveyed along with their address, distance from the Fairfax Campus, and interest is attached in Table 5. The main reason restaurants were not interested is due to the strict waste oil storage guidelines implemented by Fairfax City. Several of the restaurants are using a system developed by Restaurant Technology Inc. (RTI). This system is being used because it minimizes the amount of used cooking oil stored on-site as requested by Fairfax City. Several restaurant owners recommended contacting RTI to inquire about establishing a possible relationship with them, if more used cooking oil is necessary to meet current or future demands. This suggestion should be explored further if the need for a greater amount of used cooking oil is determined or once implementation of the project begins.

### Table 5 -Restaurants (within approx. 1 mile radius)

| Name | Location | Distance from GMU-Fairfax Campus (miles) | Interested? (Y/N/NA) |
|---|---|---|---|
| Brions Grille | University Mall | 0.3 | Y |
| Fat Tuesdays Raw Bar Inc | University Mall | 0.3 | Y |
| Elie's Deli | University Mall | 0.3 | NA |
| Domino's Pizza | University Mall | 0.3 | NA |
| Mc Donald's | University Mall | 0.3 | NA |
| Tong Thai Restaurant | University Mall | 0.3 | NA |
| University Mall Theatres | University Mall | 0.3 | NA |
| Saxby's | University Mall | 0.3 | NA |
| TCBY | University Mall | 0.3 | NA |
| Dunkin Donuts | University Mall | 0.3 | NA |
| Otani Japanese Steak and Seafood | University Mall | 0.3 | Y |
| Bernies Delicatessen & Gourmet Market | 4328 Chain Bridge Rd | 0.6 | NA |
| La Rue 123 | 4023 Chain Bridge Rd | 0.9 | NA |
| Red Hot and Blue | 4150 Chain Bridge Rd | 0.9 | Y |
| Hard Times Café | 4069 Chain Bridge Rd | 1.0 | N |
| Villa Mozart Restaurant | 4009 Chain Bridge Rd | 1.1 | Y |
| Bellisimo Restaurant LLC | 10403 Main St | 1.1 | NA |
| Subway Salads & Sandwiches | 10407 Main St | 1.1 | NA |
| Bombay Garden Fine Indian Cuisine | 4008 University Dr | 1.1 | Y |
| Best of Thai Restaurant | 4004 University Dr | 1.1 | N |
| Foster's Grille | 10427 North St | 1.1 | Y |
| Smoothe King | 10342 Main St | 1.1 | NA |
| Coyote Grille & Cantina | 10266 Main St | 1.2 | NA |
| Noodles & Co | 10296 Main St | 1.2 | NA |
| Auld Shebeen | 3971 Chain Bridge Rd | 1.2 | N |
| Firehouse Grill | 2988 University Dr | 1.2 | NA |
| Mamma Lucia's | 9650 Main St | 1.2 | NA |
| Quiznos | 10340 Main St | 1.2 | NA |
| Have A Bite Eatery | 10416 Main St | 1.2 | Y |
| Panera Bread | 3955 Chain Bridge Rd | 1.2 | NA |
| Potbelly Sandwich Works | 3955 Chain Bridge Rd | 1.2 | NA |
| Courtside Thai Cuisine | 3981 Chain Bridge Rd | 1.2 | NA |
| Sweet Life Café | 3950 Chain Bridge Rd | 1.2 | NA |
| Main St Bagel Deli | 10268 Main St | 1.2 | NA |
| Eastern Café | 10256 Main St | 1.2 | NA |
| Paisano's Pizza | 10330 Main St | 1.2 | NA |
| Starbucks | 10344 Main St | 1.2 | NA |
| Bridges Billiards & Grill | 10560 Main St | 1.2 | NA |
| Victoria's Cakery | 10430 Main St | 1.2 | NA |
| | | | |

## Analysis of Learning Objectives

The learning objectives focused on integrating education experience into a professional setting while enhancing the personal skills needed in a professional setting. The project successfully fulfilled the learning objectives established and offered several unique learning experiences that are further discussed in the Lessons Learned section. The project allowed for the student to be responsible for the development, execution, and completion of an engineering problem that could be presented in a professional setting. This is something that is often not capable of being performed in a classroom setting due to time restrictions. The majority of engineering projects can be time consuming and classes are normally restricted to a limited amount of time. This project allowed for the student to experience the complete lifecycle of the project, an invaluable experience for a smooth transition into the professional setting. In addition to providing the ability to experience an entire, full scope project, the student was also responsible for establishing the necessary contacts and organizing all interactions between all included parties. This responsibility is very similar to the responsibility experienced in a professional setting. By providing the student with control over the project, it required the student to take a leadership role and integrate many different people into the project. The project also offered an avenue for the application of educational principles in a professional setting. The student was responsible for identifying the problem, selecting possible alternatives to correct the problem, and recommending the best solution. The student was able to incorporate environmental systems analysis techniques covered in the academic program's curriculum, in addition to other engineering principles, to arrive at a recommendation. The success of the project in fulfilling the learning objectives has been validated by the student's seamless transitions into the professional setting since the completion of the project.

## Lessons Learned

As actual engineering problems take a greater role in engineering education, it is important to observe and record the learning potential offered by these exercises. The following paragraphs represent the lessons learned from the graduate student perspective. The uncontrolled nature of a "real" engineering problem provides an opportunity for students to gain knowledge beyond the specific objectives identified by the faculty in the development of the project course.

### *Student Lessons Learned*

The environmental and economic benefits of switching from conventional diesel to biodiesel at GMU are evident. All research shows that biodiesel decreases major pollutants associated with vehicles, except for the slight increase in $NO_x$. GMU will be able to benefit by receiving alternative fuel vehicle credits and by providing an excellent educational opportunity. The pay-back period of only the biodiesel system, if the on-site assembled unit is selected, is only a couple of months. The per gallon savings would be over $3.00, if not greater, with no clear signs of the increasing prices of diesel subsiding. All environmental and economic factors display that biodiesel is an excellent choice for GMU.

Although the science and engineering associated with biodiesel at GMU support its conception, other factors outside those an engineering student thought to encounter have delayed the implantation. The safety associated with the entire project has become a major concern for the administration at GMU. Many of the safety issues are due to the handling of the chemicals involved in the process, methanol and sodium hydroxide, and can be addressed through the proper education of employees. GMU already has a program in place that is mandatory for faculty and staff that handle chemicals. The safety concern regarding chemicals is not focused on only the faculty and staff that will potentially run the operations but the students that may be involved for educational opportunities. The administration is troubled by the possibility that a student may be involved with very dangerous chemicals, if not handled properly. While this is a legitimate concern, students handle chemicals in many of their classes and face the same possibly dangers associated with biodiesel anytime they fuel their own car. Adequate judgment in selecting students and an educational program similar to the one used for faculty and staff should be used before a student is allowed to participate in the educational opportunity that biodiesel offers.

In addition to safety, the adherence to state and federal regulations has provided additional issues for Biodiesel at GMU. Initially it was believed that the small size of the system considered in this student project and the use of the product only by GMU eliminates many of the regulatory concerns. The primary by-product associated with biodiesel, glycerol, will require obtaining water, wastewater, or solid waste permits. Glycerol alone is biodegradable and is often placed onto agriculture fields as a fertilizer. Glycerol alone does not require any permits but the glycerol resulting from the creation of biodiesel still contains a small amount of methanol. The existence of methanol provides an interesting dilemma of what to do with the waste. Large facilities that produce biodiesel for commercial use recapture the methanol from the glycerol to reuse in the production process. This process is time consuming and the amount of methanol regained would not be beneficial on a small scale operation. The methanol can be burnt out of the glycerol but this process, if allowed, would require air pollution permits. The existence of methanol would also require permits if the waste from the production of biodiesel was disposed of via storm sewers. The University would have to decide what option is best and incorporate the cost of permits or removal associated with that option into cost calculations.

The selection of the structure to house the biodiesel system and the location of that structure has provided another quandary for GMU. A structure simply to support the biodiesel system could only contain utility connections and a roof. This would eliminate any ventilation concerns and would be a relatively inexpensive option. However, Northern Virginia does experience low temperatures several months out of the year which would provide unfavorable working conditions and increase the likelihood of the waste oil and biodiesel solidifying. The factors that influence the type of structure to house the biodiesel system have very little to do with the system and more to do with the people involved. The structure could be fire proof, explosion proof, and spark proof to limit any of the possible dangers associated with safety aspects of the process. This type of structure can be purchased pre-manufactured but would be an extremely expensive option. The type of structure chosen needs to provide an environment suitable to work in, offer protection from the elements, and provide some safety aspects. Even if the ultimate structure is chosen and it cost around $40,000, the pay-back period of the biodiesel system will only be a little over three years. The University must decide what level of a structure they want and continue with the completion of the implementation of biodiesel.

Once a structure is chosen, the location of the structure must be determined. GMU is experiencing tremendous growth and future plans are in flux. One suggestion is to locate the system near the facilities management staff that will be charged with operating the system. Unfortunately, space near Facilities Management is extremely limited. The location must also be secluded or protected to prevent curious college students from encountering potentially dangerous chemicals or damaging the facility.

The most difficult obstacle that biodiesel must overcome is swaying the opposition. With any new technology, resistance due to a level of uncertainty should be expected. One of the major concerns associated with biodiesel surrounds vehicle maintenance. The University is worried that skeptics that will blame biodiesel for any unexpected maintenance problems. One solution might be a gradual implementation of the technology. As familiarity and comfort grow, more vehicles can be converted. The University environment encourages innovation. Uncertainty must be embraced before the benefits of biodiesel may be realized.

*Faculty Lessons Learned*

The goal of this graduate project was to strengthen engineering skills through a biodiesel feasibility study. Expectations were that students would gain a practical understanding of the economic and environmental benefits to be derived through the implementation of biodiesel as a fuel for the GMU fleet. Specifically the graduate student was to:

(1) Investigate the University fleet and fuel needs,
(2) Study the production of grease on and around campus,
(3) Perform and engineering analysis to determine the feasibility of converting the campus grease waste to biodiesel to fuel the fleet, and
(4) Perform an economic analysis to determine the cost effectiveness of the biodiesel implementation.

The learning objectives regarding the environmental engineering and economic analysis of the biodiesel conversion were fully accomplished. However, as articulated in "Student Lessons Learned", the project clearly taught the importance of support facilities, maintenance, environmental permitting, and communication with customers and support personnel. The factors outside of the engineering and science related to biodiesel proved to be a greater challenge in this project. In this age of sustainability education, students are quick to assume that the technical aspects of a "green" solution are of greatest importance. A "real" project can be invaluable to educating students in the practical limitations of an environmentally sound and economically viable solution. So often, students question why more is not done to incorporate solutions that solve environmental problems in a cost effective manner. Students fail to appreciate the other limitations. The adoption of actual engineering problems into a graduate curriculum provides an invaluable learning opportunity that is difficult to capture in the classroom.

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